## 2.4. Electricity Development Plan

### 2.4.1. Electricity Development Plan Stipulated in ESSP

The power demand forecast for 2017/18 are laid down in the last draft of ESSP (as of October 2014), and if the electrification rate does reach 48% targeted in the Ambitious Scenario, it is assumed that demand will be 470MW. If a reserve factor of 20% is then added to this figure, the necessary capacity of power generation facilities becomes 563MW.

Expected potential of indigenous resources for generation in Rwanda is as follows:

- Hydropower 400 MW :250 MW of domestic and 150MW of regional
- Methane 350 MW: development following the pilot project at Lake Kivu
- Peat 700MW

Furthermore, ESSP considers the possibility of delays in power source development due to technological and funding problems, and sets out to achieve generation capacity of 593MW in 2017/18. Planned energy composition is to make use of hydro, methane and peat, which are domestic resources.

With regard to the potential of geothermal power development, the earlier ESSP draft (as of June 2013) estimated the capacity achieved with geothermal energy to be 700 MW (Kalisimbi with 320MW, Gisenyi with 200MW, Kinigi with 200MW and Bugarama with 20MW). Unfortunately however, the current ESSP (October 2014) has taken a position that the ongoing scientific research must be further implemented in order to determine the resource amount, based on the test drilling result at Kalisimbi and the evaluation of the geothermal potential provided by the JICA study team.

As for diesel power generation, ESSP had planned no facility investment or introduction as of June 2013, with an assumption that diesel power generation will be totally discontinued in the future. However, the current ESSP switched course and took a realistic stance by planning more plants since there is a delay in development of other power sources (peat, methane and hydro) that were planned at that time, and there is a need to supply power to Kigali’s special economic zone in the near future. Table 2-4.1 shows the latest power source development plan up to fiscal 2017 included in ESSP.

Table 2-4.1 Power development plan given in ESSP

| | Project | Capacity | Total Capacity |
|---|---|---|---|
| 2013/14 | Installed capacity | | 119.6 |
| 2014/15 | | 70.5 | 190.1 |
| Hydro | Mushishito HPP (RukararaV) | 2 | |
| Hydro | Nyabarongo I | 28 | |
| Thermal | Rental | 4 | |
| Solar | Rwamagana Solar | 8.5 | |
| Methane | Kivu Watt I Methane | 25 | |
| Peat | Gishoma Peat | 15 | |
| Hydro | Mukungwa I | -12 | |
| 2015/16 | | 75 | 265.1 |
| Hydro | Mushishito HPP (RukararaV) | 3 | |
| Hydro | Mukungwa I | 12 | |
| Hydro | Micro Hydro (IPPS) | 10 | |
| Solar | Rwinkwavu solar | 10 | |
| Import | Interconnection (Ethiopia-Kenya-Uganda-Rwanda) | 40 | |
| 2016/17 | | 137 | 402.1 |
| Hydro | Micro Hydro (IPPS) | 6 | |
| Hydro | Micro Hydro (REFIT) | 5 | |
| Thermal | KSEZ HFO | 40 | |
| Peat | Hakan Peat | 80 | |
| Solar | Nyagatare | 10 | |
| Thermal | Rental | -24 | |
| Import | Interconnection (Ethiopia-Kenya-Uganda-Rwanda) | 20 | |
| 2017/18 | | 191 | 593.1 |
| Hydro | Ntaruka B HPP | 5 | |
| Hydro | Micro Hydro (IPPS) | 4 | |
| Hydro | Micro Hydro (REFIT) | 10 | |
| Thermal | KSEZ HFO | 10 | |
| Thermal | Additional HFO Unit | 10 | |
| Solar + Bioenergy | Solar + Bioenergy (REFIT) | 12 | |
| Methane | Additional PPA | 50 | |
| Peat | Akanyaru Peat | 50 | |
| Import | Interconnection (Ethiopia-Kenya-Uganda-Rwanda) | 40 | |
| **Total Generation/Import Capacity End EDPR II** | | | **593.1** |

Source: ESSP（Oct, 2014）

However, in most cases of generation resources above mentioned are yet to be fully proven. Therefore, the project preparations for generation need feasibility studies including the survey for energy resource potential are recommended in the ESSP. This preparation cost until 2017/2018 is expected as approx. US$141m and which will be funded by government/development partners.

Table 2-4.2 Expected Investment Cost

| Generation (to deliver 591MW) | $289.4 | $318.6 | $524.2 | $510.5 | $1,642.8 |
|---|---|---|---|---|---|
| *Project Preparation (all Public/DP)* | *$56.3* | *$28.4* | *$56.0* | *$0.6* | *$141.3* |
| *Peat* | $1.0 | $0.5 | $0.0 | $0.0 | $1.5 |
| *Hydro* | $7.0 | $0.0 | $0.0 | $0.0 | $7.0 |
| *Geothermal* | $38.6 | $22.7 | $55.2 | $0.0 | $116.5 |
| *Methane* | $0.6 | $0.0 | $0.0 | $0.0 | $0.6 |
| *Solar* | $0.5 | $0.0 | $0.0 | $0.0 | $0.5 |
| *Other sector studies* | $8.7 | $5.2 | $0.8 | $0.6 | $15.2 |
| *Generation* | *$233.1* | *$290.2* | *$468.3* | *$509.9* | *$1,501.5* |
| *Public/Dev Partner* | $96.4 | $114.0 | $78.7 | $143.9 | $433.0 |
| *Private* | $136.6 | $176.2 | $389.6 | $366.0 | $1,068.4 |
| *Peat* | $71.5 | $116.4 | $152.9 | $103.1 | $443.8 |
| *Hydro (Domestic)* | $69.9 | $26.6 | $46.3 | $24.8 | $167.6 |
| *Hydro (Regional)* | $19.5 | $39.1 | $62.4 | $85.7 | $206.8 |
| *Geothermal* | $0.0 | $0.0 | $0.0 | $0.0 | $0.0 |
| *Methane* | $0.0 | $54.0 | $176.0 | $255.0 | $485.0 |
| *Thermal* | $24.2 | $54.0 | $5.7 | $11.3 | $95.2 |
| *Solar* | $48.0 | $0.1 | $25.0 | $30.0 | $103.1 |

Source: ESSP Final Draft（Oct, 2014）

**(1)** Private sector engagement plan

In ESSP, it is not recommended and even then no reasonable for government to undertake all of the power development project without private sector participation. The expected scope of private sector utilization for the development is engineering, construction, funding and initial consultations and implementation support for O&M. Now, specific approach to attract the private sector is being considered. This private sector participation approach below will be reviewed and updated in the future, because this was drafted on the timing before the REG establishment.

**a. Formalized Process**

Government will establish a formal process to ensure that all energy projects, and clarify the specific procurement step that needs related ministries' approval (Fig. 2-4.1).

| Step procurement process | Responsible entity | Approvals required |
|---|---|---|
| 1. Decision to bring to market as a PPP | EWSA | MINECOFIN / MININFRA |
| 2. Preparation bidding documents | EWSA | None |
| 3. Tendering | EWSA | MININFRA |
| 4. Selection preferred bidder | EWSA | MININFRA/RDB |
| 5. Final negotiation contracts | EWSA | RDB / Attorney General |
| 6. Signing contracts | EWSA | MINECOFIN / MININFRA / RDB / RURA / Attorney General |

Source: ESSP

Fig. 2-4.1 Proposed competitive process and responsibilities

**b. Competitive and transparent projects procurement**

In order to maximize the Value-for-Money project, the Government will promote using competitive and transparent procurement

**c. Fund establishment for attracting the private sector**

At the initial stage of the project development as feasibility study, due to the lack of energy resources proven, development risk is particularly high. In order to provide financing for this stage of FS and Pre-FS, to support the private investment until it has been proven generating resources, Energy Development Fund scheme is expected to be established.

(This risk reduction fund scheme is being considered by KfW and EU along to the African Union's coordinating)

**d. Competitive selection processes**

The preparatory works necessary to allow competitive process to find partners to enter into an EPC contract with, in accordance with the projects (Hydro, Peat, Methane and Geothermal) undertaken during EDPRS 2, will be conducted in the short-run 2013/2014.

**e. Strengthening Investment management capabilities in EWSA**

EWSA recently established an internal investment unit to assume responsibility for the entire procurement process of energy projects with a private sector participation.

In addition to the investment unit, a firm of transaction advisors is contracted with government, provides financial, technical and legal expertise to assist in project packaging, development and negotiations with the private sector.

**f. Operational efficiencies and financial sustainability of the utility**

In order that EWSA's organizational structure may be improved as the independent utility, specific efforts for enhancement of operational efficiencies and increase of credit worthiness are conducted. Particularly, organizational reform, reduction of subsidies to the electricity tariff (over 40 %) arisen from indigenous energy resources promotion, loss-reduction of transmission and distribution, improvement of preventive maintenance measures, supply chain efficiencies for maintenance parts procurement and storage

**(2)** Projects of new transmission lines construction and reinforcement

Further, corresponding to future forecasts on increased power demand, ESSP lays down plans for projects to construct new transmission lines and reinforce existing ones as below.

Table 2-4.3 Transmission line development plans given in ESSP

| | Project | Category | Length [km] for Line | Commis-sioning |
|---|---|---|---|---|
| 1 | 110kV line Gishoma-Bugarama* | Line | 11 km | 2014 |
| 2 | Kilinda - Nyaborongo1 110kV line* | Line | 25 km | 2014 |
| 3 | Rukarara - Kilinda 110kV* | Line | 29.5 km | 2015 |
| 4 | 220kV line Shango-Rilima | Line | 53 km | 2015 |
| 5 | Construction of 220/110/30kV Rilima substation | Substation | | 2015 |
| 6 | Construction of Nyabihu Substation | Substation | | 2015 |
| 7 | Extension of Bugarama Substation | Substation | | 2015 |
| 8 | Construction of 110/30kV Ntendezi substation | Substation | | 2015 |
| 9 | Construction of 30 kV transmission line Rulindo-Byumba-Gatuna and Byumba-Ngarama | Line | 41km + 22km | 2015 |
| 10 | 110kV line Mukungwa - Nyabihu | Line | 23.5 km | 2015 |
| 11 | Rehabilitation of 110/30kV Gifurwe substation | Substation | | 2015 |
| 12 | Nyabugogo Substation (Kigali Reinforcement) | Substation | | 2015 |
| 13 | Jabana - Mont Kigali 110kV line (Kigali Ring) | Line | 14 km | 2015 |
| 14 | 110kV line Mont Kigali - Gahanga (Kigali Ring) | Line | 8 km | 2015 |
| 15 | Mirama(Uganda) - Shango* | Line | 92 km | 2015 |
| 16 | Shango - Rubavu - 220kV line* | Line | 106.5 km | 2015 |
| 17 | Shango 220/110kV Substation* | Substation | | 2015 |
| 18 | Shango - Birembo 110kV double circuit* | Line | 9 km | 2015 |
| 19 | Kigoma-Butare-Burundi 220kV* | Line | 64 km | 2016 |
| 20 | Construction of 220kV Transmission line Butare – Mamba | Line | 23 km | 2016 |
| 21 | Construction of 110/30kV Rulindo substation | Substation | | 2016 |
| 22 | Construction of 220/30kV Gabiro substation | Substation | | 2016 |
| 23 | Construction of 220/110/30kV Ruhengeri substation | Substation | | 2016 |
| 24 | Rilima 220/110/30kV Substation | Substation | | 2016 |
| 25 | Kabarondo - Kirehe 110kV line | Line | 32 km | 2016 |
| 26 | Kirehe substation | Substation | | 2016 |
| 27 | Gahanga Substation (Kigali Ring) | Substation | | 2016 |
| 28 | 220kV Transmission line Bwishyura-Kilinda-Kigoma-Rwabusoro-Rilima | Line | 100 km | 2016 |
| 29 | Construction of 110kV Transmission line Musha – Ngarama – Rulindo | Line | 92 km | 2016 |
| 30 | Construction of 110/30kV Ngarama substation | Substation | | 2016 |
| 31 | Rubavu - Bwishyura 220kV line* | Line | 54 km | 2016 |
| 32 | Rubavu 220/30kV Substation* | Substation | | 2016 |
| 33 | Bwishyura 220/110/30kV Substation* | Substation | | 2016 |
| 34 | 110kV Line Rukarara - Huye - Butare | Line | 42 km | 2016 |
| 35 | Huye Substation | Substation | | 2016 |
| 36 | Ndera Substation (Kigali Ring) | Substation | | 2017 |
| 37 | 110kV line Gahanga - Ndera (Kigali Ring) | Line | 15.5 km | 2017 |
| 38 | 110kV line Ndera - Gasogi (Kigali Ring) | Line | 6.52km | 2017 |
| 39 | Nyaborongo I - Nyabihu 110kV line | Line | 43 km | 2017 |
| 40 | Nyaborongo I 110/30kV 10MVA substation | Substation | | 2017 |
| 41 | 110kV transmission line NyabarongoII HPP – Rulindo substation | Line | 13 km | 2017 |
| 42 | 220kV line Rilima-Rusumo falls | Line | 70 km | 2017 |
| 43 | Kirehe - Nyamugari 110kV line | Line | 17 km | 2018 |
| 44 | Nyamugari substation | Substation | | 2018 |
| 45 | Upgrade Jabana - Kabarondo line | Line | 57 km | 2018 |

***Note: Projects with * are ongoing projects***

Source: ESSP Final Draft（Oct, 2014）

### 2.4.2. Potential of New Power Source Development

#### (1) Peat

1) Development of peat power in Rwanda

While the reserve of peat in Rwanda is estimated to be 155 million tons, only few amount has been exploited. The government has been promoting the utilization of peat, such as in ESSP (2013), which positions peat as a power generation source for intermediate load. Since peat was already utilized in 1970's globally, such as in Europe, there are little technical risks with the proven technology.

Currently, EWSA is constructing a pilot plant to utilize the peat reserved in Gishoma area, in southwest part of Rwanda. JICA study team collected information about peat utilization at EWSA headquarters and visited to Gishoma area during the 1st work in Rwanda. (Refer to Photo 2-1.1 and Photo 2-1.2.)

Photo 2-4.1 Power plant construction area

Photo 2-4.2 Peat field

2) Concerns of peat development

Following points should be considered for the utilization of peat as a principal power generation source:

- While ESSP recognizes peat as peak power source and methane as middle power source, the positioning of these sources in electricity master plan should be reconsidered carefully in accordance with the characteristics, such as estimated reserve, costs, facilities, operability, and grid connection.
- The moisture of the peat to be delivered to the power plant in Gishoma is managed by peat supplier. However, since the drying process at peat field is sunbaking, the moisture would become extremely high for combustion in rainy season. Thus, it will be necessary to control peat moisture at power plant with drying facilities for constant power generation all year round.
- The estimated reserve amount of the peat in the vicinity of the Gishoma peat plant is 500 thousand tons, which is only for 4-5 years of the operation of the plant. Therefore, after the depletion of the peat in Gishoma, it will be necessary to take measures such as fuel conversion, alternative peat supply, or plant relocation, in order to continue power

generation. Since each alternative will take several years for planning and implementation, it is necessary to choose most appropriate option soon. Additionally, electricity master plan needs to be updated in accordance with the option.

- In Rwanda, in 1992, Peat Master Plan was conducted, and that study indicated the estimated reserves of 155 million tons of dry peat spread over the country. Whereas, according to the update study on the Peat Master Plan done in 2012, due to the restricted conditions such as high ash and environmental regulations (i.e. Ramsar Area), production potential dry matter were reduced to 12.5 million tons as 8% of original, and which would be only equivalent to 60TWh estimated power production. In simply conversion to a generating capacity, this potential quantity will supply fuel a 230MW plant for 25years, if country can use full potential of reserves. Furthermore, this update report proposed that an additional hydrological survey for needed area (Akanyaru South).
- In order to peat development promotion, scientific survey for potential production and social environment survey through the country.

| | | Scientifically defined peat reserves in 1992 survey | | | | | Current usability assessment based on 2012 update study | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Area (ha) | Thickness (m) | Ash content (%) | Reserves (Mm3) | Reserves dry matter (1000 t) | Estimated % of reserves | Production potential, dry matter (1000 t) | Estimated production potential, TWh | Remarks |
| 1 | Nyabarongo -Akagera | 26 740 | 2-4 | 9-20 | 800 | 40 000 | 0 % | 0 | 0 | high ash content, non drainable |
| 2 | Rucahabi (Akanyaru North) | 460 | 2-4/6 | 7-13.6 | 20 | 994 | 25 % | 250 | 1,3 | peat production method to be confirmed |
| 3 | Akanyaru North (Others) | 5 120 | 2-6 | 10-20 | 200 | 10 000 | 5 % | 500 | 2,5 | high ash content , thin peat layer |
| 4 | Busoro (Akanyaru South)* | 800 | 1-5 | 6-15 | 32 | 1 000 | | 3 800 | 19,0 | hydrological surveys needed |
| 5 | Rw amko (Akanyaru South) | 130 | 1->20 | 6-8 | 14 | 675 | 30 % | 200 | 1,0 | peat production method to be confirmed |
| 6 | Akanyaru South (Others) | 7 070 | 2->20 | 6-15/20 | 920 | 69 000 | 10 % | 6 900 | 34,5 | peat production method to be confirmed, thick clay layer in southern part |
| 7 | Cyabaralika | 23 | 1-5 | 5.3-17.8 | 0,4 | 150 | 70 % | 110 | 0,6 | high ash content |
| 8 | Kiguhu | 49 | 1-4 | 8.5-14.4 | 2 | 240 | 70 % | 170 | 0,9 | high ash content |
| 9 | Rugezi | 6 500 | 1->11 | 2-15 | 650 | 32 000 | 0 % | 0 | 0,0 | RAMSAR area (protected) |
| 10 | Gishoma* | 410 | 1-5 | 6.3-13.6 | 8 | 463 | | 490 | 2,7 | part of the area under production |
| 11 | Gihitasi* | 80 | 1-2 | 14.4 | 0,6 | 40 | | 40 | 0,2 | thin peat layer |
| 12 | Mashya* | 30 | 1-5 | 2.7 | 0,8 | 60 | | 60 | 0,3 | small size big |
| 13 | Kamiranzovu | 820 | 1 | 6,0 | 8 | 500 | 0 % | 0 | 0,0 | Nyungw e natural forest (protected) |
| | **Total** | **48 200** | | | **2 700** | **155 000** | **8 %** | **12 500** | **60** | |
| 14 | 2012 update: Bahimba/Rulindo | 89 | 4 | 12,0 | 3 | n.a | 40 % | n.a | | limited OGMR investigations |
| 15 | 2012 update:Nyirabirande | 206 | 2.5-4 | 10,8 | 7 | n.a | 30 % | n.a | | limited OGMR investigations |
| | *updated data | | | | | | | | | |

Source: Peat Master Plan Update (February, 2013)

Fig. 2-4.2 Update of estimated peat production potential

- JICA study team interviewed to EWSA on the prospect of peat production during the 2nd work. Busoro north and south area along to the Akanyaru river are expected to be the largest peat potential land in Rwanda, with some private peat power projects follows the Gishoma pilot project. However, there, the related peat bog is located in wetland near a river, and with the effect of rainy seasons, the time period as well as the area for peat harvest are limited. Thus, compared to peat obtained near the EWSA pilot plant that is under construction in Gishoma, that obtained in Busoro is more problematic with higher moisture content. Peat with high moisture content might require drying with the use of electricity or other heat sources, in addition to natural drying, which could impact the sending-end efficiency of the power plants and cost increase.

- Turkish private company Hakan proceed with the 80MW (two 40 MW units) peat project in South Akanyaru (Mamba, Gisagara district), that will cost an estimated $260 million, and COD target is 2017. Further, private Indian company Punj Lloyd has an approx. $371 million project with the maximum of 100MW (two 50 MW units) in North Akanyaru (Ruwabusuro, Bugesera District). Both projects shares the same concern for low cost and stable peat production.
- According to EWSA, since neighboring country Burundi has peat reserves, the procurement of peat from remote locations both within and outside of the country will likely be examined. The costs for purchasing and transporting peat should be considered as future project costs.
- Several issues and concerns, which have not been identified during the research for the cases of other countries and desktop planning, will be realized after the commencement of pilot plant. Since such problem finding is irreplaceable role of pilot plant, the findings should be adequately applied to the planning of larger peat power plants, peat utilization programs, and forthcoming electricity master plans.

Specific information of the pilot plant is indispensable to consider above-mentioned issues, but the information such as facility specifications, system configuration, and plot plan is not provided during 1st and 2nd work in Rwanda. The cost of the peat has not been provided, either, since EWSA is negotiating peat price with supplier. However, fuel price, which account for majority of thermal power generation cost, is crucial for the Project to establish optimal power development plan with cost minimization method. Therefore, further information about pilot plant and peat price must be provided upon 3rd work in Rwanda.

3) Impact on social environment caused by peat development

The potential peat land in Rwanda is close to the living area of the residents and has long been tied to their lives through farming and other uses. Peat is used widely as fuel for cooking, cottage industries, etc. Thus, the effect of peat power development on social environment must be thoroughly studied, especially from the standpoints of agriculture and living.

Without the consensus of local residents or that in terms of environment, the project itself could be derailed, creating a long-lasting impact on future development. In Southeast Asia including Thailand and Indonesia, coal-fired thermal power projects were switched to gas-fired thermal power project and some projects fell apart due to lack of consensus by the residents. There are issues still affecting coal-fired thermal power development in those nations.

The main reasons that residents oppose coal-fired thermal power are the expropriation of land for ash disposal yards and other facilities that require large areas, climate change including that due to CO2 and SOx, and impacts on the living environment. Additional concerns in the case of peat include the restriction on the everyday use of peat as fuel and adverse effects on agriculture.

The social environment survey for consensus of the peat projects must be carefully conducted since peat is a domestic energy resource of great value. .

**(2) Methane**

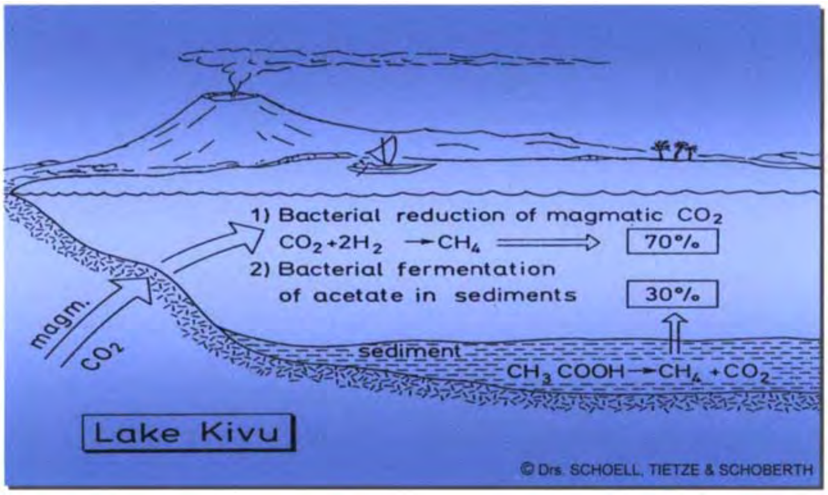
Rwanda is actively promoting the development of methane dissolved in Lake Kivu, as one of the indigenous energy resources. Lake Kivu stretches over the eastern part of Democratic Republic of the Congo and western Rwanda. It was created through volcanic activity along part of the African Great Rift Valley and spews out a large amount of methane along with $CO_2$ and $SO_2$ from its bed.

The JICA study team observed, during the 2$^{nd}$ work, the KP1 project that started operation in 2009 as a pilot plant, and the KivuWatt project that aims to commence operation in 2015 as an IPP project promoted by an American private company, in order to study the methane development situation in Lake Kivu and examine its benefits and issues.

1) History of methane development

In Lake Kivu, the existence of methane was confirmed in research using the stratified sampling method in the 1930s and full-scale exploration started in the 1970s. Since Lake Kivu is located over Rwanda and Congo, the countries initially planned to tackle methane development jointly, and signed a memorandum in 1975 and established a joint development company in 1990 (SOCIGAS). However, the company was later dissolved and the two countries currently accept that each country is to develop methane within its own respective territory. Further in 2007, they concluded a memorandum with additional items regarding the framework for methane development and environmental monitoring for Lake Kivu.

Currently, following the KP1 project (2009), Kivu Watt Ltd. is constructing a 25MW, methane gas power plant as an IPP project sponsored by a US-based private power company ContourGlobal. Kivu Watt Ltd. concluded a power purchase agreement with the Rwanda government in 2009, and is working to develop 25MW during Phase 1 (2015 - ) and 75MW during Phase 2 (2017 - ), to make a total output of 100MW.




Source: Figure (K. Tietze, 1974-75) in LAKE KIVU METHANE PROJECT – FEASIBILITY STUDY (2003)

Fig. 2-4.3 Simplified model of forming methane in Lake Kivu

There are some 1000 studies on the methane found in Lake Kivu, which is said to contain 65 billion cubic meters of methane. It is theorized that about 70% of this methane was created by methanogenic bacteria at the bottom of the lake, which convert carbon dioxide and biogenous sediment from volcanic gas into methane, and the remaining 30% was volcanic gas. Approximately 125 to 250 million cubic meters of methane are said to be generated annually in the lake from carbon dioxide, which is a precursor of methane and still spews out from the lake bed.

According to studies by EWSA, Lake Kivu has enough methane reserves to fuel a max. 700MW of power generation. KP1 engineers believe that 100 years of power generation would not exhaust the methane in the lake.

2) KP1 project

- Started operation in Oct. 2009, as a government-funded, methane gas power pilot plant.
- All generated output is sold to EWSA.
- Dissolved methane is extracted and refined at a floating plant 1.5km off the lake shore where the power plant is located. (floating plant is anchored with about 120 tons of concrete at its four corners)
- The installed capacity of the power plant is 3.6MW. Three 1.2MW, 16-cylinder gas engines are installed; however, with limited methane fuel, only two gas engines are used at any one time, generating 2.4MW. In the actual operation, three engines are rotated with one being inspected while the other two are in service, in order to enhance availability.
- The power plant and methane extraction plant are run and tended by operators 24 hours a day.
- An output increase to 5MW is planned for 2014, which is equivalent to the current max. capacity of the methane extraction plant.

- The sending and receiving voltage of the power plant is 30kV. To power the floating methane extraction plant, electricity is sent via a 1.5km-long cable (bound to the methane gas pipeline), after a voltage reduction from 30kV to 6.6kV (650kVA) at the power plant, and used at 400V (630kVA).
- For the gas engines used for power generation, a radiator-type cooling system has been adopted, and the cooling water is cooled outside with forced air-cooling to be recirculated and reused. No cooling water is taken from and no thermal effluent is discharged into the lake.
- In May 2008 before the operation of KP1 commenced, British diesel generator lease company AGGRECO installed a 1MW power plant in an area adjacent to KP1; however the project ended shortly afterwards.
- Dissolved methane extraction method could be refered in the following description related to KivuWatt, since it will apply the same principle

Photo 2-4.3 Methane plant

Photo 2-4.4 Engine for methane gas power generation

Photo 2-4.5 Gas pipes

Source: Photo 2-4.3 Web Site of Lake Kivu Organization, 2-4.4 and 2-4.5 taken by the JICA study team

3) KivuWatt project

KivuWatt is the first IPP project in Rwanda to be project-financed and is being sponsored by a US-based private power company ContourGlobal*. The plant is to start operation mid over 2015 (as of January 2015).

During the JICA study team’s site visit in June 2014, the power plant was expected to start in January 2015, two month after the completion of methane extract plant construction in November 2014. However, due to some problem of construction, the plan of commissioning was delyed.

* ContourGlobal is an American power company which was established by the investment fund, Reservoir Capital Group in 2005 with its headquarters in New York. It owns and operates power generation assets equivalent to 3,718MW in 18 countries of Africa, South America and Europe (capacity of plants under construction amounts to 573MW). With its 1,600 employees, the company maintains a high growth rate with various power source mixes including renewable energies in its “quad-generation” or four business fields (power generation, thermal energy, cold energy and supply of cold energy for drinks using $CO_2$) in

both developed and developing nations.

**[Power generation facilities]**

- An internal combustion power plant using general-purpose gas engines with a total output of 25MW (8.5MW×3). EPC is Wartsila* from Finland and the gas engines are supplied by the AVK Group from UK.

  * Wartsila, a Finland-based company, is involved in the sale of marine vessels and internal-combustion power generation equipment, as well as construction projects in 70 countries, with its employees of 18,000. It has business bases in Tokyo, Kobe and Toyama (plant) and offers products and services in Japan.

- Methane gas will be supplied at a pressure of 9 bar, which will be lowered to 3.5 bar and used for power generation by the engines, each of which is fitted with 20 cylinders with a diameter of 34cm. Radiators with three cooling fans will be used for cooling outside the power plant building (one per generator) and no water will be taken from or discharged into Lake Kivu, because cooling water will be recirculated.
- The same models of power generation equipment to be used in KivuWatt are popular in other internal combustion power plants that use natural gas in Africa including Tanzania and Kenya. The generation facilities of KivuWatt are for general purposes, and reportedly there is accumulated O&M know-how for power generation. If the use of methane gas becomes difficult, the generators could be converted to accommodate natural gas use; however conversion to use HFO (diesel fuel) is harder. The need for fuel gasification would create issues in terms of work necessary for facility installation and economy (power sale price is fixed by PPA and HFO is expensive).
- For use at the plant, grid power will be received from Kibuye SS at 11kV and used after reducing voltage to 400V. After the commissioning, transmission to the SS is planned via 11kV×2 circuits. Transmission lines are installed. Power via the lines is currently used for generator temperature control, etc. Ten staff members including the manager will be involved in the plant operation, in five groups and three 8-hour shifts.
- Regular inspection will be done with prudence every 50 hours immediately after the commissioning, then every 500 hours, 1,000 hours and 2,000 hours. Major inspections will be done every 24,000 hours.
- The target availability is 98% for the first year of commissioning and 99% for the following years.

**[Methane extraction facility]**

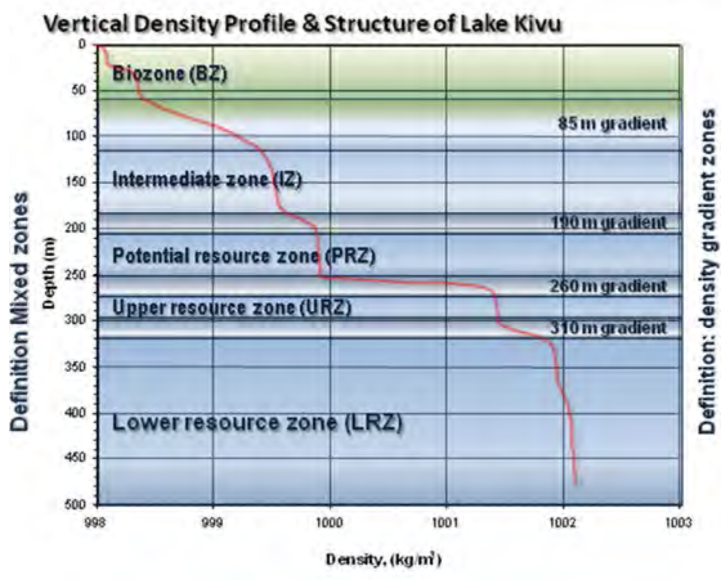
- Currently, the methane extraction plant is being assembled at the lake shore. After its completion, it will be taken to a point 13km off the shore of Lake Kivu and anchored to supply gas to the power plant via gas pipeline. Though, the start of gas provision was expected in

November 2014 (as of June 2014), due to some troubles including the cut of anchor ropes to fix the extraction plant, it has not been removed from the shore of the lake.

- There will be no grid power supplied to the methane extraction plant since it will have gas engines with 3.6MW (1.2MW×3units) and generate power using the extracted gas for its own use. Diesel generators will be installed as an emergency power source.
- 2 gas compressors (to supply compressed gas when starting the separator), 3 gas engines, 4 scrubbers (removal facility for $CO_2$ and $H_2S$), control room, etc. are on the barge plant. A separator for underwater methane extraction is being fabricated on the lake shore.

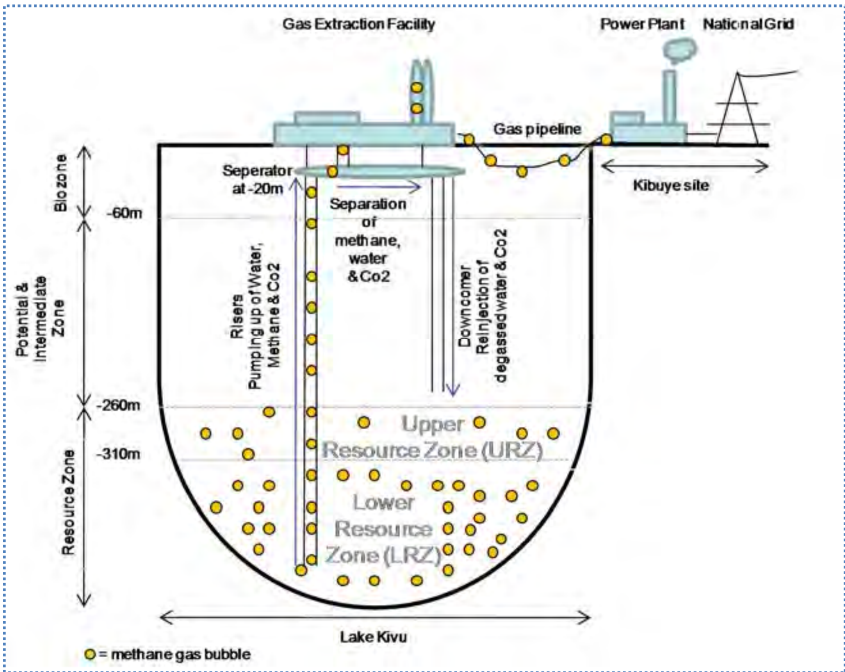
**[Extraction of dissolved methane]**

- Water containing methane will be taken at a depth of 350m to 380m and separated into gas and water through decompression in the underwater separator, which process creates upward flow to collect water (upon startup, the upward flow will be created from above water using compressed air).
- $CO_2$ and $H_2S$ will be further removed from the gas by adding water to the scrubber, and the resultant gas will be sent to the dryer and then to the power plant onshore, to be used as fuel via the gas pipeline.
- Through scrubber treatment, the methane gas will be concentrated from 68% to 85% which is the fuel specification for gas power plants.
- Water containing $CO_2$ and $H_2S$ which will be removed by the scrubber will be returned to Lake Kivu at a depth of 60m or more. This is to avoid impacts on the ecosystem since the depth of 50m is the limit of habitation for living organisms such as fish (it is believed that no living organisms can survive in deeper waters due to high concentration of methane, etc.)
- The methane extraction plant will be operated based on five groups (of three staff) and three 8-hour shifts. The plant will be controlled by collaborating with the power plant via wireless communication.
- It is assumed that it will take four hours to restart the methane extraction plant once it has stopped.




Source: Management Prescription Report for the Development of Lake Kivu Gas Report 2009

Fig. 2-4.4 Vertical Density Profile & Structure of Kivu Lake




Source: AfDB

Fig. 2-4.5 Overview of KivuWatt methane extraction

**[Future prospect for the project]**

- No novel generation technologies are to be applied as general-purpose gas engines will be used. However, it will be the first time anywhere in the world that large-scale methane gas extraction and commercial power generation at a lake are to be carried out, and how well the power plant will operate is unknown. If the commercial power generation is successful, the project is scheduled to move on to 75MW Phase 2, with potential for further expansion.

- Since the project is expensive with a project cost of about US127.58 million for 25MW (USD 5.1 million /MW), the key for the next phase is to lower the EPC cost (per AfDB data and based on the assets as of 2010, IRR of the project would be over 9%).
- The standards for construction and safety management are those used in Europe. There are European instructors and migrants from Kenya, Uganda, India and Philippines working for the project. There are some 500 construction workers including Rwandans (visually estimated when workers were going to lunch); thus some economic benefits for the area are expected based on the years that the construction work will take (as of June, 2014).
- In February, 2012, ContourGlobal was awarded the 2011 Africa Power Deal of the Year by Euro money's Project Finance magazine for its KivuWatt project, as the 1st Project Finance deal in Rwanda. KivuWatt is receiving a lot of expectation for its stable achievement of the operation as a driving force for private projects in Rwanda.

Photo 2-4.6 Methane extraction plant assembly site

Source: JICA study team

Photo 2-4.7 Engine for methane gas power generation

Photo 2-4.8 Control room for Generator

Photo 2-4.9 New installed transmission line for KivuWatt PS (11kV)

4) Potential future concerns

Development and use of methane as a power source is important in terms of securing future domestic energy resources in Rwanda. Concerning use of methane around Lake Kivu, since there are many unknown and uncertain factors, it is necessary to conduct detailed monitoring and examine countermeasures in the event of unforeseen situations.

- Adverse effects on the ecosystem or Lake Kivu environment due to large-scale methane extraction and utilization.
- Changes in environment and resultant changes in the properties of water containing methane and $CO_2$ due to inflow of sediment, sewage, etc. into Lake Kivu. Effects (decrease or increase) on and risks associated with continuous methane generation
- Effects on methane and $CO_2$ reserves due to unexpected changes in natural environment (continuity of power generation projects)

### (3) Geothermal

1) Status of geothermal power in Rwanda's power source development plans

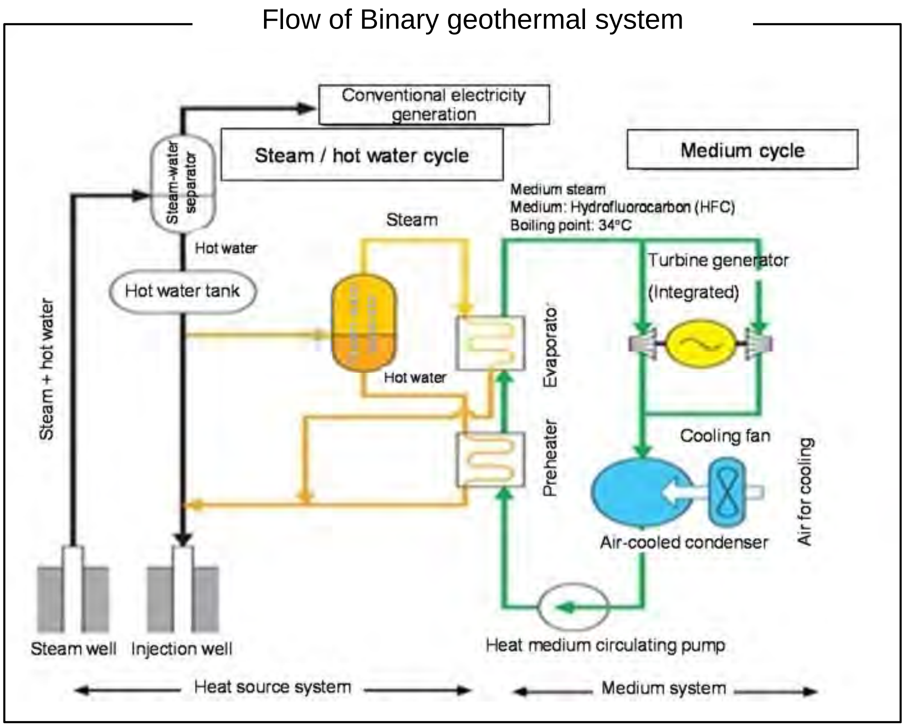
In the geothermal development plan described later (see Chapter 3), the volume of geothermal resources in Rwanda was estimated based on the volumetric method using the Monte Carlo approach. Moreover, Kinigi in the northwest of Rwanda, and Bugarama in the southwest were selected as areas with relatively high priority based on low resistivity structure. Since there are many uncertain factors concerning the assessment of geothermal resources and it will be necessary to conduct detailed and specialized site survey and analysis from now on, it is difficult to incorporate concrete geothermal power development projects into the current power source development plans of Rwanda.

However, in light of the results of geothermal development surveys implemented so far in Rwanda, human resources development including the training programs conducted by JICA and other donors will be continued. Also, emphasizing the policy of examining the future feasibility of geothermal development (ESSP), trial estimation of the costs of geothermal power station construction and operation will be conducted in this study report in spite of the numerous uncertain factors that exist.

Concerning the power generation method, based on the assumption that geothermal fluid of around 200℃ is stored in strata at deep levels, estimation will be conducted based on the adoption of binary power generation technology, which can be effectively utilized with relatively low-temperature geothermal fluid.

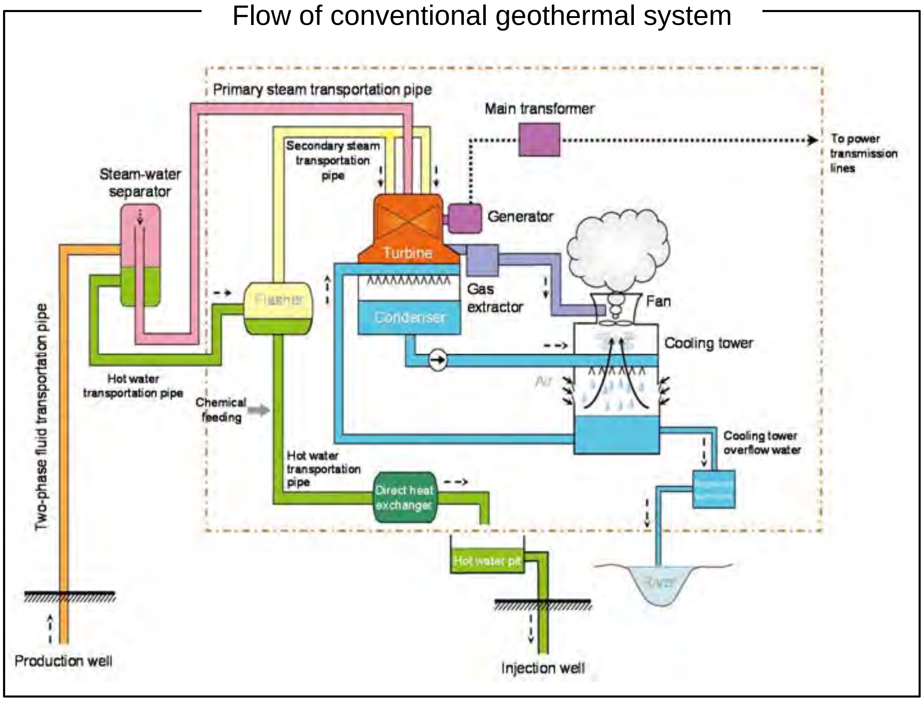
2) Outline of geothermal binary power generation

In conventional geothermal power generation, power is generated by sending high-temperature steam extracted in a steam separator to a turbine, however, in the case of binary power generation, even if an ample quantity of high-temperature steam cannot be obtained, the separated hot water is depressurized and separated into steam and hot water, that are used to heat and boil a secondary media (alternative hydrofluorocarbon or ammonia, etc.) having a low boiling point, and thereby generate power in a turbine. Figure 2-4.6 shows the image of the geothermal binary power generation system, while Figure 2-4.7 shows an image of the conventional geothermal power generation system for reference purposes.




Source: JICA study team

Fig. 2-4.6 Image of the Geothermal Binary System



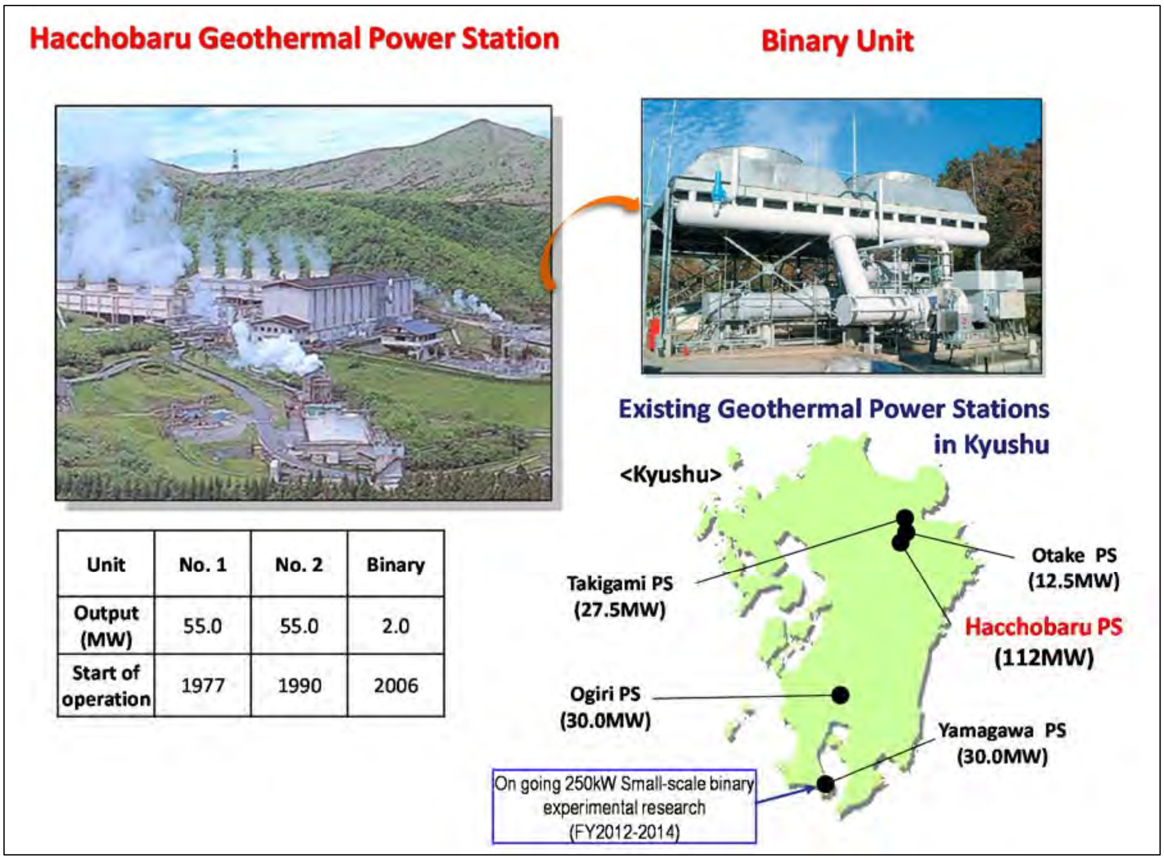

Source: JICA study team

Fig. 2-4.7 Image of the Conventional Geothermal System

In geothermal binary power generation, due to the use of secondary media and installation of additional equipment in line with this, the plant investment and operating costs are higher than compared to conventional geothermal generation. However, because geothermal binary power generation realizes effective utilization of unused energy, like conventional geothermal generation it is attracting worldwide attention as an alternative to thermal power, which uses expensive imported fossil fuels, as a means of boosting dependence on domestic energy, enhancing energy security, and securing an energy source that doesn't emit $CO_2$ and is kind to the global environment.

In Japan, in light of the experience following the Great East Japan Earthquake of 2011, when power supply was cut over a large part of eastern Japan, and following introduction of the FIT geared to renewable energy including geothermal in 2012, there has been active development of geothermal power stations including small-scale facilities in recent years, and demonstration experiments on compact binary power generation technology have also been implemented. Particularly in the Kyushu region of Japan, there are abundant geothermal resources and 40% of Japan's geothermal power stations (in terms of plant capacity) are in operation. Figure 2-4.2 shows photographs of Hacchobaru Geothermal Power Station (110MW = conventional geothermal generating units x 2), which was opened by Kyushu Electric Power Co. in 1977, and the first geothermal binary plant (2M) to be introduced to Japan in 2006. The same figure also shows the outputs and locations of other geothermal power stations owned by Kyushu Electric Power Co.

Concerning estimation of the costs of constructing and operating geothermal power stations in Kinigi in the northwest of Rwanda and Bugarama in the southwest, experience and knowledge of developing and operating geothermal power stations in Japan and overseas will be utilized. In the absence of specific and detailed development conditions and information, the methodology will be simple, however, the costs of constructing and operating binary power generation power stations will be estimated.




Source: Prepared by JICA study team

Fig. 2-4.8 Outline of Hacchobaru Geothermal Power Station and Locations of Other Geothermal Power Stations (Kyushu Electric Power Co., Inc.)

3) Trial calculation of construction and operation cost for geothermal power stations

Based on the amount of geothermal resources estimated during the study of the geothermal development plans (see Chapter 3), the trial calculation of construction and operation cost was carried out by assuming that one 20MW-class geothermal power station will be built in Kinigi in northwest Rwanda and one 5MW-class power station in Bugarama in southwest Rwanda, which were selected as the relatively high priority regions for development.

**i) Kinigi Power Station**

The result of the trial calculation for the construction of 20MW-class Kinigi Geothermal Power Station (installation of 4 units with approximately 5MW each) is explained. The particulars assumed for the trial calculation are given in Table 2-4.6 and Table 2-4.7. The premise for the conditions in the table is that the calculation is to address the period of full-fledged construction work to build the power station (about 5 years) and that for the operation (30 years), with a total of 35 years. In other words, the assumption is made that all the preliminary studies such as the geothermal resource estimation and test drilling to narrow down the site of the power station construction are complete, and the time for such preparatory work and related costs are not included in the calculation as a rule.

This trial calculation of the power station construction and operation cost is merely to understand the approximate cost since the facility and equipment specifications or operation methods, etc. required for the power station could not be determined unless the preliminary work listed above has been conducted.

Therefore, the premises for the trial calculation were kept simple, and the level of the economic impact from cost increases or other fluctuations caused by the change in the precondition is explained with the responsiveness analysis as necessary.

Five production wells and three reinjection wells are assumed to be excavated for the construction of the power station, and they are assumed to be in service for 30 years, the same duration as the operation of the power station. Regarding the aging and other degradation such as well drying up and a drop in steam extraction efficiency, the responsiveness to the shortening of the wells' estimated life (use period) is explained.

As for the procurement of the fund for construction, the trial calculation was done assuming the use of a yen loan as the base case, since Rwanda became eligible for yen loan last year and can obtain a loan with a low interest rate and favorable terms from JICA depending of the conditions. In the case of a yen loan, the terms include the loan period of 40 years, interest rate of 0.01% and grace period of up to 10 years, making it most appropriate for the first attempt at constructing a geothermal power station. A geothermal power generation project runs a risk of development ending in failure, especially when studying the resource amount at the beginning of the project, and has a higher capital cost compared to the construction of thermal power plants that utilize gas or diesel. It is difficult for the private sector to get directly involved in such projects in countries that are still developing the geothermal technology. Especially in a country like Rwanda where the market rate of interest is 17% or higher, the hurdle gets even higher when inviting the private sector to participate in geothermal development.

It is hard for REG to raise funds for the development of geothermal energy, since the company is not financially sound as evidenced in the diesel subsidies that company currently receives.

- **Notes regarding the trial calculation**

  The points that require attention regarding the trial calculation are explained below:

  ① **Loan to cover the entire construction cost**

  - The trial calculation is done assuming that REG or the Rwanda government borrows funds to build the power station. In the case of an IPP project, the construction might be financed through a special-purpose company (SPP) to which the private sector contributes funds. However, as stated earlier, the first geothermal projects in Rwanda will be led by the government, considering the risks associated with subterranean resources and financing (in the case of ODA, the Rwanda government must request assistance from Japan).

② **Interest during the construction period**

- The interest incurred during the construction period will be added to the loan amount since there will be no income during this period. The interest for the first three years of the operation (grace period) will also be capitalized.

③ **EPC consultant cost during the construction period**

- 5% of the construction cost, not cumulative but as a general level even though it is somewhat conservative

④ **Calculation method for the levelized cost of electricity**

- It is calculated simply by adding up the total construction cost and total cost incurred during the operation period including the interest capitalized during the construction period, then dividing the figure by the total generated energy (in 30 years).

$$\text{Levelized cost of electricity} = \frac{\text{Generation Cost Total (US\$)}}{\text{Generation of plant life time (kWh)}}$$

⑤ **Assumed income for the calculation of Internal Rate of Return (IRR)**

- The annual income is calculated by multiplying the generated energy by the average electric unit price (20.6 cent/kWh) of Rwanda.
- It must be noted that the current electric unit price is not set to reflect all the power supply costs such as those for power generation, transmission & distribution and administration. In other words, one cannot use the electric unit price to justify REG's internal trading (power wholesale) price. However, if the generated energy is sold, REG as a whole receives the income based on the unit price.

- **Trial calculation result**

The explanation is given on the trial calculation of the levelized cost of electricity as well as the construction and operation cost of Kinigi (20MW) Geothermal Power Station.

Table 2-4.4 Calculation result of Kinigi's levelized cost of electricity

| Items | Unit | Value | |
|---|---|---|---|
| Plant Availability | % | 97% | |
| Debt | MMUS$ | 130.232 | |
| Loan principal payment period | year | 27 | |
| Loan interest rate | % | 0.01% | |
| Tax | % | 30% | |
| Generation cost total | MMUS$ | 184.47 | 100% |
| Construction cost | MMUS$ | 124.03 | 67.24% |
| EPC Consultant fee | MMUS$ | 6.2 | 3.36% |
| Interest during construction period | MMUS$ | 0.0527 | 0.03% |
| O&M, Major Inspection | MMUS$ | 48 | 26.02% |
| (per year) | MMUS$ | 1.6 | - |
| Labour cost for O&M | MMUS$ | 6 | 3.25% |
| (per year) | MMUS$ | 0.2 | - |
| Loan interest | MMUS$ | 0.1824 | 0.1% |
| Generation of plant life time | GWh | 5,112 | |
| Levelized cost of electriciy | US cent /kWh | 3.609 | |
| Projejct IRR | % | 16.2% | |

Source: JICA study team

The calculation is done based on the assumptions in the table above and also assuming as seen above that Kinigi Power Station was constructed and stably operated as a base load power source at a high availability of 97% without well drying up or plant performance decline. The result was the levelized cost of electricity of 3.609 US cent/kWh and IRR of 16.2% with the yen loan of about 130 million US$ at the interest rate of 0.01%. The result of the responsiveness analysis for some of the cost increasing factors is given as reference.

① Well drying up and aging deterioration

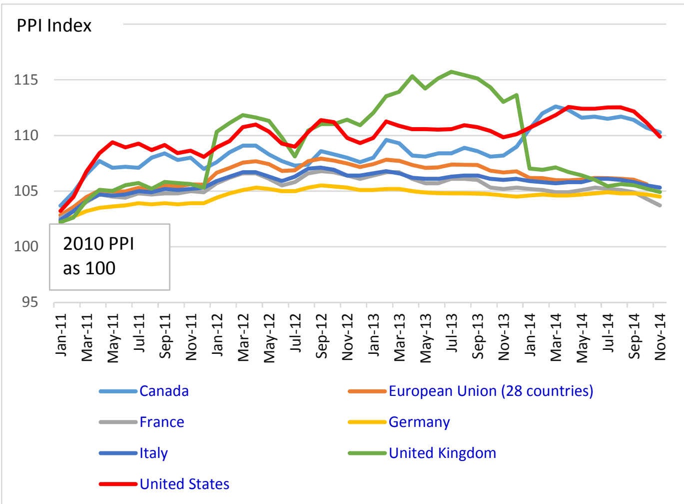
| Years of production | 30 | 15 | 12 | 8 | 6 | 3 |
|---|---|---|---|---|---|---|
| Levelized cost of electricity (US cent/kWh) | 3. 61 | 4. 60 | 5. 09 | 6. 33 | 7. 56 | 12. 50 |
| IRR (%) | 16. 2 | 12. 2 | 10. 8 | 8. 30 | 6. 5 | 2. 7 |

- The base case for Kinigi is calculated by assuming that all five production wells and three reinjection wells can be operated without a decline in steam production (heat, pressure and flow rate) or in the power generation facility performance over the 30 years of operation. If the wells' life is 8 years on average, the levelized cost of electricity will almost double at 6.33 US cent/kWh.

② Increase in the construction cost, e.g. steel stock

| Construction cost(Index) | 100 | 105 | 110 | 115 | 120 | 125 |
|---|---|---|---|---|---|---|
| Levelized cost of electricity (US cent/kWh) | 3.61 | 3.736 | 3.864 | 3.991 | 4.119 | 4.274 |
| IRR (%) | 16.2 | 15.5 | 14.9 | 14.4 | 13.8 | 13.3 |

- The lead time for the geothermal power plant construction and start of operation is long. For example, if a preliminary study and test drilling is done and sufficient time and fund is spent to evaluate the amount of resources and to narrow down the development site, it can take more than 10 years before the start of operation.
- With a longer lead time, the construction cost could increase for a geothermal power plant that requires much of the materials to be procured from the developed countries. For example, the product price index for the USA has gone up 10 points in the past four years. Therefore, by assuming the construction cost in the base case to be 100, the impact from the increase in such cost by 5 to 25 points was calculated.
- The result revealed that the increase in the construction cost by about 25 points would raise the levelized cost of electricity by about 20% to 4.27 US cent/kWh and lower the IRR by about 20% to 13.3%.




Source: JICA study team based on OECD data

Fig. 2-4.9 Producer price index (PPI) of the major developed countries

③ Increase in the loan interest rate

| Interest rate (%) | 0.01% | 2.6% | 5.1% | 8.5% | 13.6% | 17.0% |
|---|---|---|---|---|---|---|
| Levelized cost of electricity (US cent/kWh) | 3.61 | 4.885 | 6.402 | 8.839 | 13.531 | 17.471 |

- Generally in geothermal power generation, the ratio of marginal cost to the levelized cost of electricity is small while the ratio of the construction cost to such levelized cost of electricity is great. Thus, the increase in the fundraising cost (interest rate) greatly affects the rise in the construction cost (interest during construction) and operation cost, and in turn lowers the profitability of geothermal power generation.

- **Evaluation of construction and operation cost of Kinigi Geothermal Power Station**
  - If the construction and operation of the power station are possible based on the assumptions made for the base case, the levelized cost of electricity is low at 3.6 US cents/kWh and the IRR is 16.2%, making the project promising in terms of profitability.
  - However, drying up of the wells, increase in construction cost or financing cost (interest rate) affects the profitability significantly as indicated by the result of the responsiveness analysis. Therefore, one cannot judge whether the power station should be developed or its profitability without conducting detailed and sufficient evaluation of the subterranean resources.
  - Geothermal power generation has great uncertainty especially at the time of introduction and has a long lead time. For such an endeavor, it is essential to establish technology for developing and evaluating subterranean resources such as that for survey and excavation as well as techniques for the operation and maintenance of the power plants and wells. Thus, active participation by regular private companies or overseas investors with little technology or knowledge cannot be expected. In this light, it is desirable to consider the utilization of donors' support for fundraising and technical ability during the study phase in addition to procuring funds for the construction of the power station.

**ii) Bugarama Geothermal Power Statio**

The trial calculation result for the construction of 5MW-class Bugarama Geothermal Power Station (installation of one power generation unit with about 5MW) is explained. The assumptions used for the trial calculation are shown in Table 2-4.8 and Table 2-4.9. There will be a total of three wells (two production wells and one reinjection well). As with the case of Kinigi, the purpose of the calculation is to understand the approximate cost since the facility and equipment specifications and operation method required for the power station cannot be decided without preliminary study, and without such information, the construction and operation cost for the power station cannot be determined. Therefore, the preconditions for the trial calculation for the Bugarama Geothermal Power Station such as cost, interest rate for loan and time period are the same as the Kinigi Power station, except for the number of wells and the construction cost for power generation facilities, as a rule.

- **Trial calculation result**
  - The calculation result of the construction and operation cost as well as the levelized cost of electricity for the Bugarama (5MW) Geothermal Power Station is explained.

Table 2-4.5 Calculation result of Bugarama's levelized cost of electricity

| Items | Unit | Value | |
|---|---|---|---|
| Plant Availability | % | 97% | |
| Debt | MMUS$ | 41.591 | |
| Loan principal payment period | year | 27 | |
| Loan interest rate | % | 0.01% | |
| Tax | % | 30% | |
| Generation cost total | MMUS$ | 65.67 | 100% |
| Construction cost | MMUS$ | 39.61 | 60.32% |
| EPC Consultant fee | MMUS$ | 1.98 | 3.02% |
| Interest during construction period | MMUS$ | 0.0168 | 0.03% |
| O&M, Major Inspection | MMUS$ | 18 | 27.41% |
| (per year) | MMUS$ | 0.6 | - |
| Labour cost for O&M | MMUS$ | 6 | 9.14% |
| (per year) | MMUS$ | 0.2 | - |
| Loan interest | MMUS$ | 0.0583 | 0.09% |
| Generation of plant life time | GWh | 1,278 | |
| Levelized cost of electriciy | US cent /kWh | 5.138 | |
| Projejct IRR | % | 12.6% | |

Source: JICA study team

- **Evaluation of the construction and operation cost for Bugarama Geothermal Power Station**
  - If the power station construction and operation are possible based on the assumptions in the base case, the levelized cost of electricity is low at 5.138 cents and IRR is 12.6%, making the endeavor promising in terms of profitability.
  - Based on the composition of the power generation cost, the levelized cost of electricity is somewhat higher since its installed capacity is one-quarter of that of Kinigi, unable to take advantage of the economies of scale. However, the differences are small overall. As for the power station operators, a certain number of the operators are necessary. Since it is a fixed expense, the ratio of personnel expenses is greater compared to that of Kinigi.
  - As with the case of Kinigi, whether the power station should be developed or its profitability cannot be judged without detailed and sufficient evaluation of the subterranean resources.

**iii) Cost calculation tables for geothermal power stations' construction and operation**

These following tables show the assumption and the trial cost calculation for geothermal power stations' construction and operation, as a reference.

Table 2-4.6 Particulars for Calculation of Kinigi Geothermal Power Station Construction and Operating Costs (1/2)

| Item | Contents | Remarks |
|---|---|---|
| Location | A site approximately 20km southwest of Mukungwa power station is envisaged. | |
| Plant Capacuty | 20.00 MW | 4 units with output of around 5MW are envisaged |
| Operating period | 30 years | The possibility of extending the operating period is reserved. (Extension based on renewal, improvement, or rehabilitation of primary components is possible). |
| Construction cost ($ million) | 124.03 | |
| - Well excavation | 48.00 | Excavation of 8 wells is envisaged (5 production wells and 3 reinjection well) |
| - Construction of steam production equipment | 14.00 | Steam piping and monitoring and control equipment |
| - Power station construction | 59.00 | Estimated in reference to construction costs of power stations in third countries in recent years |
| - Construction of transmission and transformation facilities | 3.03 | Including power generation equipment, major transformers, and transmission line switching equipment |
| EPC consultant cost | 6.20 | Estimated as 5% of the construction cost |
| Construction period | Around 5 years | Including the design, procurement, well excavation, steam equipment, and transmission and transformer equipment construction period |
| Fundraising | ODA loan | |
| Scheme | Yen loan (LDC/untied) | Yen-based loan, yen-based repayment conditions (For convenience, costs are estimated in US dollars). |
| Interest | 0.01% | Fixed interest |
| Borrowing period | 35 years (upto 40 years) | Total construction and operating period is envisaged. |
| Grace period | 8 years (upto 10 years) | Repayment over the construction period (5 years) and first 3 years of operation |
| Procurement rate | 100% | The ratio of fundraising provided by yen loan will be determined by the actual needs in Rwanda and negotiations, etc. with the Japanese side. For convenience, 100% is provisionally envisaged. |

Source: JICA study team

Table 2-4.7 Particulars for Calculation of Kinigi Geothermal Power Station Construction and Operating Costs (2/2)

| Item | Contents | Remarks |
|---|---|---|
| Operation and maintenance cost | $1.6 million (annual average)<br>- Repair, maintenance, spare parts, materials, etc. | Trial estimation based on reference to similar power stations in third countries in recent years. The following preconditions were adopted:<br>- Periodic inspections of each unit once every 2 years (inspection and repair of steam pipes including scale removal, etc. is envisaged as 4 years, but equalization to 2 years is assumed here for convenience).<br>- Special repairs will be implemented after 15 years of operation. (Turbine rotor, computer, generator rotor, stator coil rewinding, etc.) |
| | $0.2 million (annual average)<br>- Labour cost | 20 staff regularly work on O&M (4 teams work on 3 shifts a day. The number of personnel on each team is 5). Labour cost are estimated due to the EWSA's budget in 2013. |
| Plant Availability | 97% | Plant availability =<br>Operating time/annual days (365) x 24 hours<br>(Planned stoppage days based on periodic inspection (14 days/2 years) and planned stoppage days due to breakdown (3 days/1 year) are considered as provisional values). |
| Annual energy production (average) | 170,400,000 kWh | Annual energy production =<br>Output x Plant availability x Annual days x 24 hours |
| Steam procurement price | N/A (provisional value = 0) | Concerning steam procurement, estimation is conducted assuming that REG wells will be used and the cost of surveying and digging wells is excluded from the power station construction and operating cost). |
| Tax rate | 30% | Statutory tax rate in Rwanda |

Source: JICA study team

Table 2-4.8 Particulars for Calculation of Bugarama Geothermal Power Station Construction and Operating Costs (1/2)

| Item | Contents | Remarks |
|---|---|---|
| Location | A site no more than 10km east or south of Bugarama is envisaged. | |
| Output (MW) | 5.00 MW | 1 unit with output of around 5MW is envisaged |
| Operating period | 30 years | The possibility of extending the operating period is reserved. (Extension based on renewal, improvement, or rehabilitation of primary components is possible). |
| Construction cost ($ million) | 39.61 | |
| - Well excavation | 18 | Excavation of 3 wells is envisaged (2 production well and 1 reinjection well) |
| - Construction of steam production equipment | 5 | Steam piping and monitoring and control equipment |
| - Power station construction | 16 | Estimated in reference to construction costs of power stations in third countries in recent years |
| - Construction of transmission and transformation facilities | 0.61 | Including power generation equipment, major transformers, and transmission line switching equipment |
| EPC consultant cost | 1.98 | Estimated as 5% of the construction cost |
| Construction period | Around 5 years | Including the design, procurement, well excavation, steam equipment, and transmission and transformer equipment construction period |
| Funding | ODA loan | |
| Scheme | Yen loan (LDC/untied) | Yen-based loan, yen-based repayment conditions (For convenience, costs are estimated in US dollars). |
| Interest | 0.01% | Fixed interest |
| Borrowing period | 35 years (upto 40 years) | Total construction and operating period is envisaged. |
| Grace period | 8 years (upto 10 years) | Repayment over the construction period (5 years) and first 3 years of operation |
| Procurement rate | 100% | The ratio of fundraising provided by yen loan will be determined by the actual needs in Rwanda and negotiations, etc. with the Japanese side. For convenience, 100% is provisionally envisaged. |

Source: JICA study team

Table 2-4.9 Particulars for Calculation of Bugarama Geothermal Power Station Construction and Operating Costs (2/2)

| Item | Contents | Remarks |
| --- | --- | --- |
| Operation and maintenance cost | $0.6 million (annual average)<br>- Repair, maintenance, spare parts, materials, etc. | Trial estimation based on reference to similar power stations in third countries in recent years. The following preconditions were adopted:<br>- Periodic inspections of each unit once every 2 years (inspection and repair of steam pipes including scale removal, etc. is envisaged as 4 years, but equalization to 2 years is assumed here for convenience).<br>- Special repairs will be implemented after 15 years of operation. (Turbine rotor, computer, generator rotor, stator coil rewinding, etc.) |
| | $0.2 million (annual average)<br>- Labour cost | 20 staff regularly work on O&M (4 teams work on 3 shifts a day. The number of personnel on each team is 5). Labour cost are estimated due to the EWSA's budget in 2013. |
| Operating rate (Plant availability) | 97% | Plant availability =<br>Operating time/annual days (365) x 24 hours<br>(Planned stoppage days based on periodic inspection (14 days/2 years) and planned stoppage days due to breakdown (3 days/1 year) are considered as provisional values). |
| Annual energy production (average) | 42,600,000 kWh | Annual energy production =<br>Output x Plant availability x Annual days x 24 hours |
| Steam procurement price | N/A (provisional value = 0) | Concerning steam procurement, estimation is conducted assuming that REG wells will be used and the cost of surveying and digging wells is excluded from the power station construction and operating cost). |
| Tax rate | 30% | Statutory tax rate in Rwanda |

Source: JICA study team

## Table 2-4.10 Cost Table of Kinigi Geothermal Power Station for Construction and Operating

| Fiscal year | | | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Phase | | | Construction period | | | | | Operation period | | | | | | | | | | | | | |
| Year | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| | Plant Capacity | MW | - | - | - | - | - | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| | Plant Availability | % | - | - | - | - | - | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% |
| | Annual Generation | MWh | - | - | - | - | - | 167,040 | 173,760 | 167,040 | 173,760 | 167,040 | 173,760 | 167,040 | 173,760 | 167,040 | 173,760 | 167,040 | 173,760 | 167,040 | 173,760 |
| Revenue | | MMUS$ | | | | | | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 |
| | Electricty Sales | MMUS$ | | | | | | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 |
| | Unit for Sales | UScent /kWh | | | | | | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 |
| Cost / Expense | | MMUS$ | 1.240 | 1.240 | 42.584 | 42.584 | 42.584 | 7.509 | 8.174 | 7.509 | 8.174 | 7.509 | 8.174 | 7.509 | 8.174 | 7.509 | 8.174 | 7.509 | 8.174 | 7.509 | 8.174 |
| | EPC Consultant Fee | | 1.240 | 1.240 | 1.240 | 1.240 | 1.240 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Construction | | 0.000 | 0.000 | 41.343 | 41.343 | 41.343 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | O&M, Major Inspection | | - | - | - | - | - | 1.108 | 1.772 | 1.108 | 1.772 | 1.108 | 1.772 | 1.108 | 1.772 | 1.108 | 1.772 | 1.108 | 1.772 | 1.108 | 1.772 |
| | labour cost for O&M | | - | - | - | - | - | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 |
| | Depreciation (20 years) | | | | | | | 6.202 | 6.202 | 6.202 | 6.202 | 6.202 | 6.202 | 6.202 | 6.202 | 6.202 | 6.202 | 6.202 | 6.202 | 6.202 | 6.202 |
| Interest for Loan | | MMUS$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.013 | 0.013 | 0.012 | 0.012 | 0.011 | 0.011 | 0.010 | 0.010 | 0.009 | 0.009 | 0.008 |
| Profit before taxation | | MMUS$ | - | - | - | - | - | 26.901 | 27.621 | 26.901 | 27.608 | 26.889 | 27.609 | 26.889 | 27.610 | 26.890 | 27.611 | 26.891 | 27.612 | 26.892 | 27.613 |
| Corporate tax | | MMUS$ | - | - | - | - | - | 8.070 | 8.286 | 8.070 | 8.282 | 8.067 | 8.283 | 8.067 | 8.283 | 8.067 | 8.283 | 8.067 | 8.283 | 8.068 | 8.284 |
| Net profit | | MMUS$ | - | - | - | - | - | 18.831 | 19.335 | 18.831 | 19.325 | 18.822 | 19.326 | 18.823 | 19.327 | 18.823 | 19.327 | 18.824 | 19.328 | 18.825 | 19.329 |
| FCF(Depriciation carried back) | | MMUS$ | (1.240) | (1.240) | (42.584) | (42.584) | (42.584) | 25.032 | 25.536 | 25.032 | 25.527 | 25.023 | 25.528 | 25.024 | 25.528 | 25.025 | 25.529 | 25.025 | 25.530 | 25.026 | 25.530 |
| Debt/Equity | | MMUS$ | 1.240 | 2.481 | 45.065 | 87.653 | 130.245 | 149.089 | 168.436 | 187.280 | 201.780 | 215.777 | 230.278 | 244.275 | 258.776 | 272.774 | 287.276 | 301.275 | 315.778 | 329.777 | 344.281 |
| Debt | Loan Disbursement | | 1.240 | 1.240 | 42.584 | 42.584 | 42.584 | | | | | | | | | | | | | | |
| | Loan repayment | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 |
| | Outstanding balance | | 1.240 | 2.481 | 45.065 | 87.653 | 130.245 | 130.258 | 130.271 | 130.284 | 125.459 | 120.634 | 115.808 | 110.983 | 106.158 | 101.332 | 96.507 | 91.681 | 86.856 | 82.031 | 77.205 |
| Equity | Capital | | | | | | | | | | | | | | | | | | | | |
| | Revenue reserves | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 18.831 | 19.335 | 18.831 | 19.325 | 18.822 | 19.326 | 18.823 | 19.327 | 18.823 | 19.327 | 18.824 | 19.328 | 18.825 | 19.329 |
| | Shareholders' interests | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 18.831 | 38.165 | 56.996 | 76.321 | 95.143 | 114.469 | 133.292 | 152.619 | 171.442 | 190.770 | 209.594 | 228.922 | 247.746 | 267.075 |

| Fiscal year | | | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 | Averaged in 30 years | Total in 30 years |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Phase | | | Operation period | | | | | | | | | | | | | | | | | |
| Year | | | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | | |
| | Plant Capacity | MW | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | - |
| | Plant Availability | % | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 97% | - |
| | Annual Generation | MWh | 167,040 | 173,760 | 167,040 | 173,760 | 167,040 | 173,760 | 167,040 | 173,760 | 167,040 | 173,760 | 167,040 | 173,760 | 167,040 | 173,760 | 167,040 | 173,760 | 170,400.000 | 5,112,000.000 |
| Revenue | | MMUS$ | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 35.102 | 1,053.072 |
| | Electricty Sales | MMUS$ | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 34.410 | 35.795 | 35.102 | 1,053.072 |
| | Unit for Sales | UScent /kWh | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | - |
| Cost / Expense | | MMUS$ | 7.509 | 12.974 | 7.509 | 8.174 | 7.509 | 8.174 | 1.308 | 1.972 | 1.308 | 1.972 | 1.308 | 1.972 | 1.308 | 1.972 | 1.308 | 1.972 | 5.934 | 178.030 |
| | EPC Consultant Fee | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.000 | 0.000 |
| | Construction | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.000 | 0.000 |
| | O&M, Major Inspection | | 1.108 | 6.572 | 1.108 | 1.772 | 1.108 | 1.772 | 1.108 | 1.772 | 1.108 | 1.772 | 1.108 | 1.772 | 1.108 | 1.772 | 1.108 | 1.772 | 1.600 | 48.000 |
| | labour cost for O&M | | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 6.000 |
| | Depreciation (20 years) | | 6.202 | 6.202 | 6.202 | 6.202 | 6.202 | 6.202 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 4.134 | 124.030 |
| Interest for Loan | | MMUS$ | 0.008 | 0.007 | 0.007 | 0.006 | 0.006 | 0.005 | 0.005 | 0.004 | 0.004 | 0.003 | 0.003 | 0.002 | 0.002 | 0.001 | 0.001 | 0.000 | 0.006 | 0.182 |
| Profit before taxation | | MMUS$ | 26.893 | 22.814 | 26.894 | 27.614 | 26.895 | 27.615 | 33.098 | 33.818 | 33.099 | 33.819 | 33.100 | 33.820 | 33.101 | 33.821 | 33.102 | 33.822 | 29.162 | 874.860 |
| Corporate tax | | MMUS$ | 8.068 | 6.844 | 8.068 | 8.284 | 8.069 | 8.285 | 9.929 | 10.145 | 9.930 | 10.146 | 9.930 | 10.146 | 9.930 | 10.146 | 9.930 | 10.147 | 8.749 | 262.458 |
| Net profit | | MMUS$ | 18.825 | 15.969 | 18.826 | 19.330 | 18.827 | 19.331 | 23.168 | 23.673 | 23.169 | 23.673 | 23.170 | 23.674 | 23.170 | 23.675 | 23.171 | 23.675 | 20.413 | 612.402 |
| FCF (Depriciation carried back) | | MMUS$ | 25.027 | 22.171 | 25.028 | 25.532 | 25.028 | 25.532 | 23.168 | 23.673 | 23.169 | 23.673 | 23.170 | 23.674 | 23.170 | 23.675 | 23.171 | 23.675 | 24.548 | 736.432 |
| Debt/Equity | | MMUS$ | 358.281 | 369.425 | 383.425 | 397.930 | 411.931 | 426.437 | 444.780 | 463.627 | 481.971 | 500.819 | 519.163 | 538.012 | 556.357 | 575.206 | 593.552 | 612.402 | - | - |
| Debt | Loan Disbursement | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | | |
| | Loan repayment | | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | 4.825 | | |
| | Outstanding balance | | 72.380 | 67.555 | 62.729 | 57.904 | 53.079 | 48.253 | 43.428 | 38.603 | 33.777 | 28.952 | 24.127 | 19.301 | 14.476 | 9.651 | 4.825 | (0.000) | | |
| Equity | Capital | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | | |
| | Revenue reserves | | 18.825 | 15.969 | 18.826 | 19.330 | 18.827 | 19.331 | 23.168 | 23.673 | 23.169 | 23.673 | 23.170 | 23.674 | 23.170 | 23.675 | 23.171 | 23.675 | | |
| | Shareholders' interests | | 285.900 | 301.870 | 320.696 | 340.026 | 358.853 | 378.183 | 401.352 | 425.024 | 448.194 | 471.867 | 495.036 | 518.710 | 541.881 | 565.555 | 588.726 | 612.402 | | |

Source: JICA study team

Table 2-4.11 Cost Table of Bugarama Geothermal Power Station for Construction and Operating

| | Fiscal year | | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Phase | | Construction period | | | | | Operation period | | | | | | | | | | | | | |
| | Year | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| | Plant Capacity | MW | - | - | - | - | - | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | Plant Availability | % | - | - | - | - | - | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% |
| | Annual Generation | MWh | - | - | - | - | - | 41,760 | 43,440 | 41,760 | 43,440 | 41,760 | 43,440 | 41,760 | 43,440 | 41,760 | 43,440 | 41,760 | 43,440 | 41,760 | 43,440 |
| Revenue | | MMUS$ | | | | | | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 |
| | Electricty Sales | MMUS$ | | | | | | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 |
| | Unit for Sales | UScent /kWh | | | | | | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 |
| Cost / Expense | | MMUS$ | 0.396 | 0.396 | 13.599 | 13.599 | 13.599 | 2.596 | 2.845 | 2.596 | 2.845 | 2.596 | 2.845 | 2.596 | 2.845 | 2.596 | 2.845 | 2.596 | 2.845 | 2.596 | 2.845 |
| | EPC Consultant Fee | | 0.396 | 0.396 | 0.396 | 0.396 | 0.396 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Construction | | 0.000 | 0.000 | 13.203 | 13.203 | 13.203 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | O&M, Major Inspection | | - | - | - | - | - | 0.415 | 0.665 | 0.415 | 0.665 | 0.415 | 0.665 | 0.415 | 0.665 | 0.415 | 0.665 | 0.415 | 0.665 | 0.415 | 0.665 |
| | labour cost for O&M | | - | - | - | - | - | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 |
| | Depreciation (20 years) | | | | | | | 1.981 | 1.981 | 1.981 | 1.981 | 1.981 | 1.981 | 1.981 | 1.981 | 1.981 | 1.981 | 1.981 | 1.981 | 1.981 | 1.981 |
| Interest for Loan | | MMUS$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 |
| Profit before taxation | | MMUS$ | - | - | - | - | - | 6.007 | 6.104 | 6.007 | 6.099 | 6.003 | 6.100 | 6.003 | 6.100 | 6.003 | 6.100 | 6.004 | 6.101 | 6.004 | 6.101 |
| Corporate tax | | MMUS$ | - | - | - | - | - | 1.802 | 1.831 | 1.802 | 1.830 | 1.801 | 1.830 | 1.801 | 1.830 | 1.801 | 1.830 | 1.801 | 1.830 | 1.801 | 1.830 |
| Net profit | | MMUS$ | - | - | - | - | - | 4.205 | 4.272 | 4.205 | 4.270 | 4.202 | 4.270 | 4.202 | 4.270 | 4.202 | 4.270 | 4.203 | 4.270 | 4.203 | 4.271 |
| FCF (Depriciation carried back) | | MMUS$ | (0.396) | (0.396) | (13.599) | (13.599) | (13.599) | 6.185 | 6.253 | 6.185 | 6.250 | 6.182 | 6.250 | 6.183 | 6.250 | 6.183 | 6.251 | 6.183 | 6.251 | 6.183 | 6.251 |
| Debt/Equity | | MMUS$ | 0.396 | 0.792 | 14.392 | 27.993 | 41.595 | 45.804 | 50.080 | 54.289 | 57.018 | 59.679 | 62.407 | 65.068 | 67.797 | 70.459 | 73.188 | 75.849 | 78.579 | 81.240 | 83.970 |
| Debt | Loan Disbursement | | 0.396 | 0.396 | 13.599 | 13.599 | 13.599 | | | | | | | | | | | | | | |
| Debt | Loan repayment | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 |
| Debt | Outstanding balance | | 0.396 | 0.792 | 14.392 | 27.993 | 41.595 | 41.599 | 41.603 | 41.607 | 40.066 | 38.525 | 36.984 | 35.443 | 33.902 | 32.361 | 30.820 | 29.279 | 27.738 | 26.197 | 24.656 |
| Equity | Capital | | | | | | | | | | | | | | | | | | | | |
| Equity | Revenue reserves | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 4.205 | 4.272 | 4.205 | 4.270 | 4.202 | 4.270 | 4.202 | 4.270 | 4.202 | 4.270 | 4.203 | 4.270 | 4.203 | 4.271 |
| Equity | Shareholders' interests | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 4.205 | 8.477 | 12.682 | 16.951 | 21.153 | 25.423 | 29.625 | 33.895 | 38.097 | 42.368 | 46.570 | 50.841 | 55.043 | 59.314 |

| | Fiscal year | | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 | Averaged in 30 years | Total in 30 years |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Phase | | Operation period | | | | | | | | | | | | | | | | | |
| | Year | | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | | |
| | Plant Capacity | MW | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | - |
| | Plant Availability | % | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 95% | 99% | 97% | - |
| | Annual Generation | MWh | 41,760 | 43,440 | 41,760 | 43,440 | 41,760 | 43,440 | 41,760 | 43,440 | 41,760 | 43,440 | 41,760 | 43,440 | 41,760 | 43,440 | 41,760 | 43,440 | 42,600.000 | 1,278,000.000 |
| Revenue | | MMUS$ | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.776 | 263.268 |
| | Electricty Sales | MMUS$ | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.603 | 8.949 | 8.776 | 263.268 |
| | Unit for Sales | UScent /kWh | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | 20.600 | - |
| Cost / Expense | | MMUS$ | 2.596 | 4.645 | 2.596 | 2.845 | 2.596 | 2.845 | 0.615 | 0.865 | 0.615 | 0.865 | 0.615 | 0.865 | 0.615 | 0.865 | 0.615 | 0.865 | 2.120 | 63.610 |
| | EPC Consultant Fee | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.000 | 0.000 |
| | Construction | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 0.000 | 0.000 |
| | O&M, Major Inspection | | 0.415 | 2.465 | 0.415 | 0.665 | 0.415 | 0.665 | 0.415 | 0.665 | 0.415 | 0.665 | 0.415 | 0.665 | 0.415 | 0.665 | 0.415 | 0.665 | 0.600 | 18.000 |
| | labour cost for O&M | | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 0.200 | 6.000 |
| | Depreciation (20 years) | | 1.981 | 1.981 | 1.981 | 1.981 | 1.981 | 1.981 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.320 | 39.610 |
| Interest for Loan | | MMUS$ | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.002 | 0.058 |
| Profit before taxation | | MMUS$ | 6.004 | 4.301 | 6.005 | 6.102 | 6.005 | 6.102 | 7.986 | 8.083 | 7.986 | 8.083 | 7.986 | 8.083 | 7.987 | 8.084 | 7.987 | 8.084 | 6.653 | 199.600 |
| Corporate tax | | MMUS$ | 1.801 | 1.290 | 1.801 | 1.830 | 1.801 | 1.831 | 2.396 | 2.425 | 2.396 | 2.425 | 2.396 | 2.425 | 2.396 | 2.425 | 2.396 | 2.425 | 1.996 | 59.880 |
| Net profit | | MMUS$ | 4.203 | 3.011 | 4.203 | 4.271 | 4.203 | 4.271 | 5.590 | 5.658 | 5.590 | 5.658 | 5.590 | 5.658 | 5.591 | 5.658 | 5.591 | 5.659 | 4.657 | 139.720 |
| FCF (Depriciation carried back) | | MMUS$ | 6.183 | 4.991 | 6.184 | 6.252 | 6.184 | 6.252 | 5.590 | 5.658 | 5.590 | 5.658 | 5.590 | 5.658 | 5.591 | 5.658 | 5.591 | 5.659 | 5.978 | 179.330 |
| Debt/Equity | | MMUS$ | 86.632 | 88.102 | 90.764 | 93.494 | 96.156 | 98.887 | 102.936 | 107.052 | 111.102 | 115.219 | 119.268 | 123.385 | 127.435 | 131.552 | 135.602 | 139.720 | - | - |
| Debt | Loan Disbursement | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | | |
| Debt | Loan repayment | | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | 1.541 | | |
| Debt | Outstanding balance | | 23.115 | 21.574 | 20.033 | 18.492 | 16.951 | 15.410 | 13.869 | 12.328 | 10.787 | 9.246 | 7.705 | 6.164 | 4.623 | 3.082 | 1.541 | 0.000 | | |
| Equity | Capital | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | | |
| Equity | Revenue reserves | | 4.203 | 3.011 | 4.203 | 4.271 | 4.203 | 4.271 | 5.590 | 5.658 | 5.590 | 5.658 | 5.590 | 5.658 | 5.591 | 5.658 | 5.591 | 5.659 | | |
| Equity | Shareholders' interests | | 63.517 | 66.528 | 70.731 | 75.002 | 79.205 | 83.477 | 89.067 | 94.724 | 100.315 | 105.973 | 111.563 | 117.221 | 122.812 | 128.470 | 134.061 | 139.720 | | |

Source: JICA study team

### 2.4.3. Electric Power Development Plan

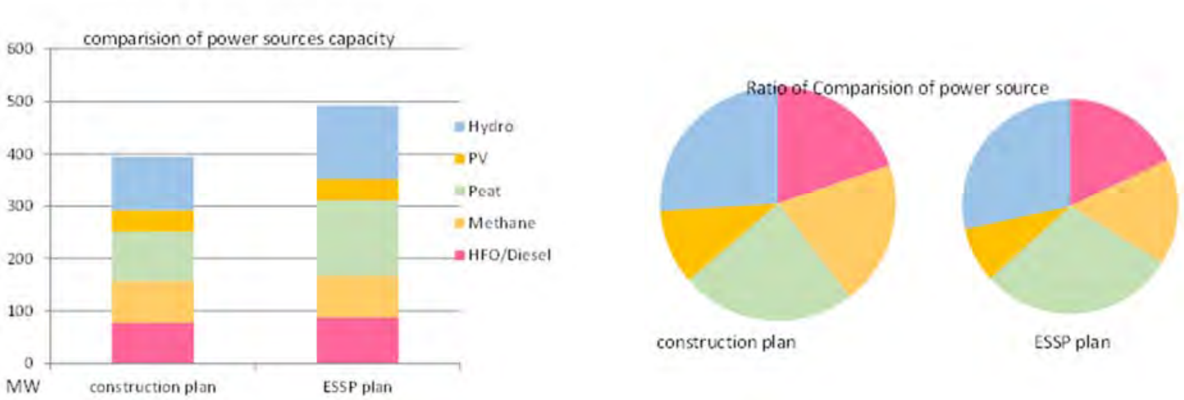
#### (1) Power plant development plan

Table 2-4.12 below shows Rwanda's power plant construction plan for the immediate future (for fiscal 2014-2017) which the JICA study team acquired from REG during the 3rd work (November 2014). Compared to the draft of ESSP compiled by the government in October 2014, REG's construction plan indicates that about 20% (97MW) will be postponed or delayed. Both plans were obtained around the same time, and it is easy to see the gap between the government's expectation for power source development and the actual speed of development. The facility composition does not include the amount of newly imported electricity via the interconnector, so the actual power supply facility capacity is likely to be more.

Table 2-4.12 Power plant construction plan in Rwanda

| Year | Installed capacity(MW) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Heavy/ Diesel oil | Methane | Peat | Geothermal | Solar | Hydro | Total |
| 2013 | 47.8 | 3.6 | - | - | 0.25 | 66.8 | 118.45 |
| 2014 | 4 | - | - | - | 8.5 | 28 | 158.95 |
| 2015 | - | 25 | 15 | - | 10 | - | 208.95 |
| 2016 | 16 | - | - | - | 10 | 3 | 237.95 |
| 2017 | 10 | 50 | 80 | - | 12 | 5 | 394.95 |
| Total | 77.8 | 78.6 | 95 | 0 | 40.75 | 102.8 | 394.95 |
| ESSP Plan | 87.8 | 78.6 | 145 | 0 | 40.25 | 139.8 | 491.95 |
| Difference | -10.0 | 0.0 | -50.0 | 0.0 | 0.0 | -37.0 | -97.0 |

Source: EWSA-EPU



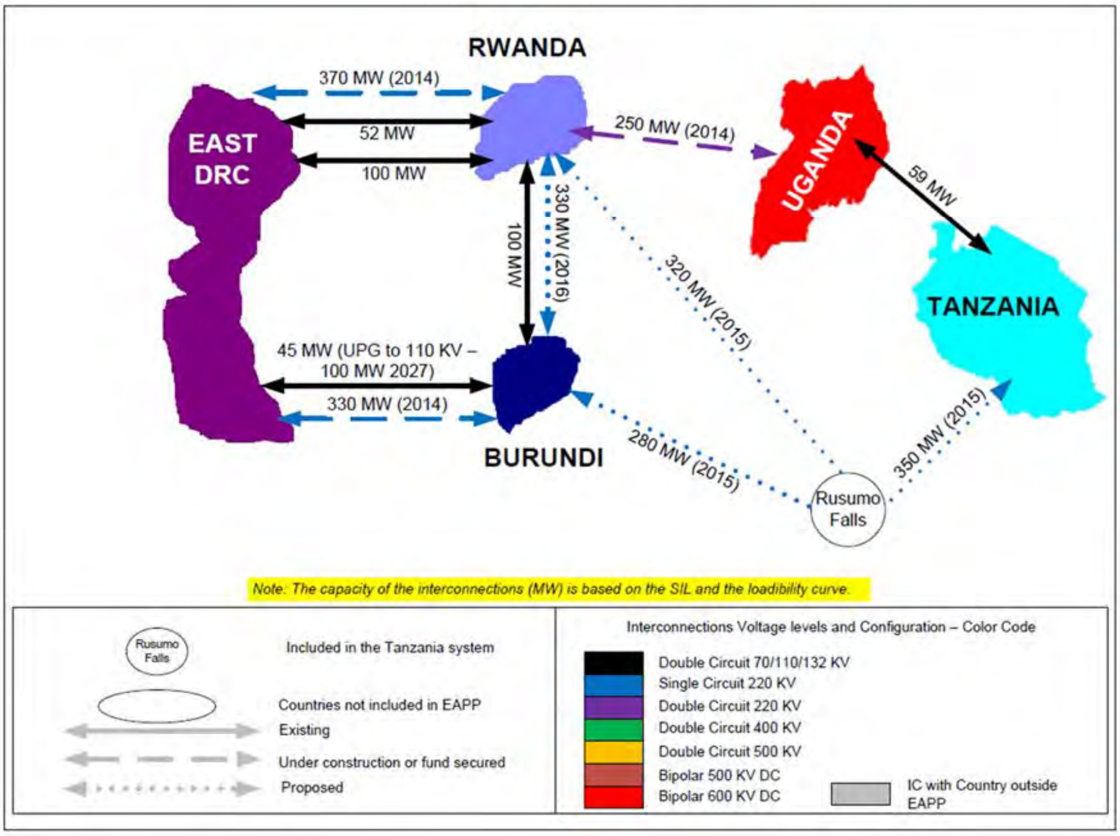

Source: ESSP and EWSA-EPU

Fig. 2-4.10 Comparison of power source capacity and Ratio of composition of power source

### (2) Power system development plan

Concerning the electric power system development plan, there are many plans for new construction of 220kV transmission lines whose voltage is not used in Rwanda at this time, reinforcement of 110kV lines, and extensions to substations. 220kV line construction plan is stated in the Regional Power System Plan and Grid Code Study, which also covers Rwanda, and under which power grid integration with expanded international interconnection lines is planned for the east African region. According to this plan, from the year 2018 onwards, the status of interconnection lines between Rwanda and other countries is shown in Fig.2-4.11.

**Figure 5-8 Burundi, Eastern DRC and Rwanda transmission interconnections for the year 2018 onwards**




Source: Regional Power System Master Plan and Grid Code Study, May 2011

Fig. 2-4.11 transmission interconnections network in Rwanda

Construction plans for transmission lines, substations and power plants are shown in Table 2-4.13.

Table 2-4.13 Transmission line construction plan in Rwanda

| | Projects to be financed | Length | Cost estimation in USD | Commis-sioning |
|---|---|---|---|---|
| 1 | 110kV line Gishoma-Bugarama | 11 | 1,320,000 | 2014 |
| 2 | Bugarama Substation | | 8,335,250 | 2014 |
| 3 | Construction of 110kV line Bugarama-Ntendezi | 23 | 2,760,000 | 2014 |
| 4 | Construction of 110/30kV Ntendezi substation | | 6,730,500 | 2014 |
| 5 | Kilinda - Nyaborongo1 110kV line | 24.6 | 2,952,000 | 2014 |
| 6 | Rukarara - Kilinda 110kV | 29.3 | 3,516,000 | 2014 |
| 7 | Rehabilitation of 110/30kV Rulindo substation | | 6,500,000 | 2014 |
| 8 | 220kV line Shango-Rilima | 53 | 12,720,000 | 2015 |
| 9 | Rilima 220/110/30kV Substation | | 8,323,550 | 2015 |
| 10 | Construction of 220/110/30kV Rilima substation | | 8,830,300 | 2015 |
| 11 | Construction of Nyabihu Substation | | 4,453,500 | 2015 |
| 12 | 110kV line Mukungwa - Nyabihu | 23.3 | 2,796,000 | 2015 |
| 13 | Rehabilitation of 110/30kV Gifurwe substation | | 6,500,000 | 2015 |
| 14 | Nyabugogo Substation (Kigali Reinforcement) | | 7,256,700 | 2015 |
| 15 | Jabana - Mont Kigali 110kV line (Kigali Ring) | 13.7 | 1,644,000 | 2015 |
| 16 | 110kV line Mont Kigali - Gahanga (Kigali Ring) | 7.9 | 948,000 | 2015 |
| 17 | 110kV line Gahanga - Ndera (Kigali Ring) | 15.1 | - | 2015 |
| 18 | 110kV line Ndera - Gasogi (Kigali Ring) | 6.52 | 782,400 | 2015 |
| 19 | Ndera Substation (Kigali Ring) | | 6,320,000 | 2015 |
| 20 | Mirama(Uganda) to Shango | 92 | 22,080,000 | 2015 |
| 21 | Shango - Rubavu - 220kV line | 106.2 | 25,488,000 | 2015 |
| 22 | Shango 220/110kV Substation | | 10,302,000 | 2015 |
| 23 | Shango - Birembo 110kV double circuit | 8.6 | 1,651,200 | 2015 |
| 24 | Kigoma-Butare-Burundi 220kV | 64 | 15,360,000 | 2015 |
| 25 | Construction of 220kV Transmission line Butare – Mamba | 20 | 4,800,000 | 2015 |
| 26 | Kabarondo - Kirehe 110kV line | 32 | 4,140,500 | 2016 |
| 27 | Kirehe substation | | 4,435,500 | 2016 |
| 28 | Gahanga Substation (Kigali Ring) | | 4,535,500 | 2016 |
| 29 | 220kV Transmission line Bwishyura-Kilinda-Kigoma-Rwabusoro-Rilima | 99.9 | 8,830,300 | 2016 |
| 30 | Construction of 110kV Transmission line Musha – Ngarama – Rulindo | 92 | 22,080,000 | 2016 |
| 31 | Construction of 110/30kV Ngarama substation | | 5,591,750 | 2016 |
| 32 | Rubavu - Bwishyura 220kV line | 53.7 | 12,888,000 | 2016 |
| 33 | Rubavu 220/30kV Substation | | 6,409,550 | 2016 |
| 34 | Bwishyura 220/110/30kV Substation | | 8,830,300 | 2016 |
| 35 | 110kV Line Rukarara - Huye - Butare | 41.7 | 5,004,000 | 2016 |
| 36 | Huye Substation | | 5,047,500 | 2016 |
| 37 | Nyaborongo 1 - Nyabihu 110kV line | 42.8 | 5,136,000 | 2017 |
| 38 | Nyaborongo 1 110/30kV 10MVA substation | | 4,375,500 | 2017 |
| 39 | 110kV transmission line NyabarongoII HPP – Rulindo substation | 12.8 | 3,072,000 | 2017 |
| 40 | 220kV Transmission line Karisimbi Geothermal Plant – Rubavu | 21 | 5,040,000 | 2017 |
| 41 | 220kV line Rilima-Rusumo falls | 66.9 | 16,056,000 | 2017 |
| 42 | Kirehe - Nyamugari 110kV line | 17 | 2,040,000 | 2018 |
| 43 | Nyamugari substation | | 5,407,950 | 2018 |
| 44 | Upgrade Jabana - Kabarondo line | 56.9 | 5,803,800 | 2018 |
| | On-going projects | | 307,093,550 | |

Source: EWSA-ETU

### 2.4.4. Economic Analysis and Evaluation

Based on the information provided by EWSA and REG between 1st and the 3rd work in Rewanda, the costs for facility investments associated with power source and electricity network development are added up as in Fig. 2-4.12 and Table 2-4.14 show. The total amount is 2,555 MUSD.

With regard to the cost of power source development are the figures provided by REG. The cost of network development has been accumulated based on the exsisting cost data of the projects provided by EWSA and REG, and has been estimated due to the cost of similar cases in Rwanda by the JICA study team. The power source development cost includes the cost of small-hydro which is more than 0.5MW.

As figure 2-4.12 indicates, the facility investments towards power source and system development are concentrated in the next three years (during 2015 to 2017). This is because of the projects that are going forward promptly to ease the current power shortage and to meet the power demand forecasted for the future in Rwanda. However, it is desirable to ensure that these facility investments would not become a huge economic burden to Rwanda in the future. To this end, the detailed analysis of fund procurement and power supply and demand status must be conducted for the projects for which the construction has not commenced, and those projects prioritized by reviewing the time of the construction. For the projects that can be postponed to after the next fiscal year, the change of the timing for implementation must be considered.

About 4.3% of the facility investment amount in this period goes to reinforcing substations by overcoming the deficiency in transformer capacity and installing capacitors to maintain the voltage level based on the system analysis result of this study.

Regarding the cost after 2018, the next reviews are planned for 2023 and 2028. There are plants that are slated to start operation between 2019 and 2023 even though the exact time is undetermined. The costs for these plants are leveled out and listed for the years between 2019 and 2023. The same rule was applied to years between 2024 and 2028.

The period to which the latest ESSP is applicable is until 2018; thus the facility investment plan for 2018 and after will have to be examined at the proper time based on the increase in power demand in the future.

With the reinforcement of the transmission line system, more electricity could be imported; however, a power supply that relies on large imported power can be unstable depending on the various reasons on the exporter side and it is not strongly recommended when taking into consideration the nation’s energy security. Under the current situation, the power source development will be promoted to make up for the deficiency in meeting the power demand, by developing power supply facilities in the fields where the development is possible. However, it is important to ensure a stable power supply even when the available output from different power sources fluctuates, as is the case of hydroelectric power between the dry season and rainy season, and photovoltaic power between daytime and nighttime. Therefore, it is recommended for the future to establish the ratio of different power sources such as thermal, hydro, imported and renewable power to the total installed capacity.

In order to ensure a stable power supply from thermal power generation plants, it is necessary to secure ample labor not only during the construction stage but also for daily equipment inspection and periodical repair work. The construction of new power plants in a country not only increases the power supply but also creates jobs for the local residents over an extended period of time. Considering the contributions that the power plants make to Rwanda’s economic growth, it is recommended that facility investments in the country continue at appropriate timing.

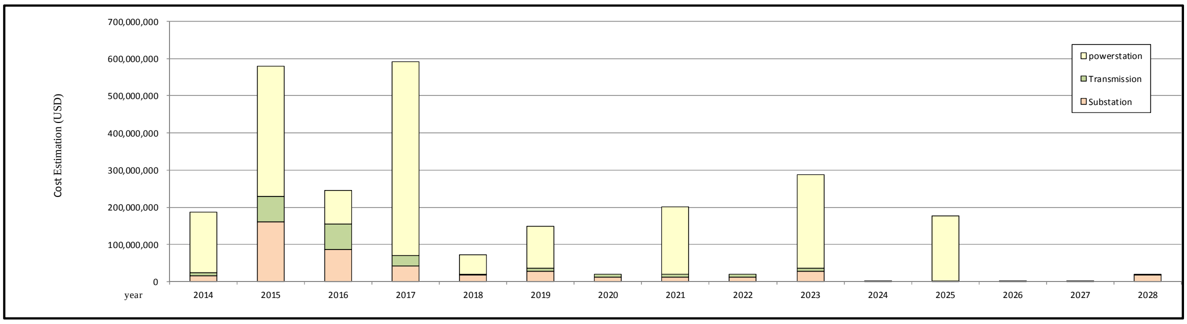



Fig. 2-4.12 Cost Estimation of Power Souse and Power System Development

Table 2-4.14 Cost Estimation of Power Souse and Power System Development

| Year | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Estimate Cost | 186,968,000 | 579,917,171 | 244,529,162 | 591,023,824 | 73,232,500 | 149,200,053 | 20,090,100 | 200,982,119 | 20,090,100 | 286,980,100 | 1,532,000 | 177,118,854 | 1,532,000 | 1,532,000 | 20,042,000 |
| Power Station | 162,800,000 | 351,456,971 | 88,943,662 | 519,787,324 | 52,350,000 | 112,769,953 | 0 | 180,892,019 | 0 | 251,000,000 | 0 | 175,586,854 | 0 | 0 | 0 |
| Nyabarongo 1 | 110,000,000 | | | | | | | | | | | | | | |
| Rental Aggreko | 40,800,000 | | | | | | | | | | | | | | |
| S/M-Hydro | 12,000,000 | | | | | | | | | | | | | | |
| Kivu Watt | | 191,549,296 | | | | | | | | | | | | | |
| Gishoma | | 42,367,675 | | | | | | | | | | | | | |
| Import | | 117,540,000 | | | | | | | | | | | | | |
| Rukarara 5 | | | 15,000,000 | | | | | | | | | | | | |
| KESZ HFO | | | 73,943,662 | | | | | | | | | | | | |
| Ntaruka B | | | | N/A | | | | | | | | | | | |
| KESZ HFO | | | | N/A | | | | | | | | | | | |
| Simbion | | | | 239,436,620 | | | | | | | | | | | |
| Mamba | | | | 216,450,704 | | | | | | | | | | | |
| S/M-Hydro | | | | 63,900,000 | | | | | | | | | | | |
| Rwabusoro | | | | | N/A | | | | | | | | | | |
| S/M-Hydro | | | | | 52,350,000 | | | | | | | | | | |
| Rusumo | | | | | | 112,769,953 | | | | | | | | | |
| Simbion | | | | | | | N/A | | | | | | | | |
| Ruzizi 3 | | | | | | | | 180,892,019 | | | | | | | |
| Nyabarongo 2 | | | | | | | | | | 60,000,000 | | | | | |
| Kivu Watt Phase 2 | | | | | | | | | | 191,000,000 | | | | | |
| Ruzizi 4 | | | | | | | | | | | | 175,586,854 | | | |
| Sub Station | 16,380,000 | 161,370,000 | 86,810,000 | 42,210,000 | 18,750,000 | 27,980,000 | 11,640,000 | 11,640,000 | 11,640,000 | 27,530,000 | 504,000 | 504,000 | 504,000 | 504,000 | 19,014,000 |
| Bugarama | 6,840,000 | | | | | | | | | | | | | | |
| Kibuye | 450,000 | | | | | | | | | | | | | | |
| Ntendezi | 5,540,000 | | | | | | | | | | | | | | |
| Rukarara | 3,550,000 | | | | | | | | | | | | | | |
| Butare | | 22,280,000 | | | | | | | | | | | | | |
| Gasogi | | 3,700,000 | 280,000 | | | | | | | | | | | | |
| Gifurwe | | 4,730,000 | | | 340,000 | | | | | 1,400,000 | | | | | 1,060,000 |
| Gishoma | | 7,500,000 | | | | | | | | 590,000 | | | | | |
| Jabana 1 | | 2,520,000 | | | | | | | | 2,520,000 | | | | | 630,000 |
| Mt.Kigali | | 5,940,000 | 630,000 | | | | | | | | | | | | |
| Musha | | 3,670,000 | 630,000 | | | | | | | 2,680,000 | | | | | 680,000 |
| Ndera | | 8,690,000 | | 590,000 | | | | | | | | | | | 1,180,000 |
| Nyabihu | | 5,360,000 | | | | | | | | | | | | | |
| Nyabugogo | | 9,740,000 | | | | | | | | | | | | | 1,180,000 |
| Rilima | | 28,760,000 | | | | | | | | | | | | | |
| Rulindo | | 2,210,000 | 630,000 | 630,000 | | | | | | 590,000 | | | | | 1,030,000 |
| Shango | | 49,520,000 | | | | | | | | 750,000 | | | | | 6,000,000 |
| Mukungwa | | 5,100,000 | | | | | | | | 2,880,000 | | | | | 3,330,000 |
| Kigoma | | 970,000 | 13,980,000 | 90,000 | | | | | | 1,620,000 | | | | | |
| Rwinkwabu | | 680,000 | | | | | | | | 2,520,000 | | | | | |
| Bwinshura | | | 8,170,000 | | | | | | | | | | | | |
| Gahanga | | | 8,960,000 | | | | | | | | | | | | |
| Huye | | | 6,710,000 | | | | | | | | | | | | |
| Kirehe | | | 6,080,000 | 340,000 | | | | | | | | | | | |
| Ngarama | | | 5,990,000 | | | | | | | 340,000 | | | | | 340,000 |
| Rubabu | | | 8,170,000 | | | | | | | | | | | | |
| Ruwabusoro | | | 12,670,000 | | | | | | | | | | | | |
| Kabarondo | | | 630,000 | | | | | | | | | | | | 1,620,000 |
| Kilinda | | | 13,280,000 | | | | | | | | | | | | 1,460,000 |
| Mamba | | | | 8,980,000 | | | | | | | | | | | |
| Nyabarongo 1 | | | | 5,540,000 | | | | | | | | | | | |
| Nyabarongo 2 | | | | 6,260,000 | | | | | | | | | | | |
| Simbion | | | | 19,780,000 | | | | | | | | | | | |
| Nyabugari | | | | | 18,410,000 | | | | | | | | | | |
| Rusumo | | | | | | 16,340,000 | | | | | | | | | |
| (Estimate Cost) | | | | | | 11,640,000 | 11,640,000 | 11,640,000 | 11,640,000 | 11,640,000 | | | | | |
| Air Port | | | | | | | | | | 13,460,000 | | | | | |
| Birembo | | | | | | | 58,200,000 / 5 = 11,640,000 | | | 4,410,000 | | | | | |
| Kamanyora | | | | | | | | | | 27,950,000 | | | | | |
| Ntaruka | | | | | | | | | | 1,890,000 | | | | | |
| Rubona | | | | | | | | | | 10,490,000 | | | | | |
| | | | | | | | | | | | 504,000 | 504,000 | 504,000 | 504,000 | 504,000 |
| Karongi | | | | | | | | | | | | | | | 1,260,000 |
| Kibogora | | | | | | | | | | | | 2,520,000 / 5 = 11,628,000 | | | 1,260,000 |
| Transmission Line | 7,788,000 | 67,090,200 | 68,775,500 | 29,026,500 | 2,132,500 | 8,450,100 | 8,450,100 | 8,450,100 | 8,450,100 | 8,450,100 | 1,028,000 | 1,028,000 | 1,028,000 | 1,028,000 | 1,028,000 |
| 220KV | | 54,447,000 | 46,179,500 | 22,354,500 | 92,500 | 6,311,700 | 6,311,700 | 6,311,700 | 6,311,700 | 6,311,700 | 740,000 | 740,000 | 740,000 | 740,000 | 740,000 |
| | | | | | | | 31,558,500 / 5 = 6,311,700 | | | 31,558,500 | | 3,700,000 / 5 = 740,000 | | | 3,700,000 |
| 110KV | 7,788,000 | 12,643,200 | 22,596,000 | 6,672,000 | 2,040,000 | 2,138,400 | 2,138,400 | 2,138,400 | 2,138,400 | 2,138,400 | 288,000 | 288,000 | 288,000 | 288,000 | 288,000 |
| | | | | | | | 10,692,000 / 5 = 2,625,600 | | | 10,692,000 | | 1,440,000 / 5 = 288,000 | | | 1,440,000 |

## 2.5. Power System Analysis

Power generation and system require a large amount of fund and long construction period. Any change in major specifications after the start of the project affecting extension of work period and cost increase would give huge social impacts. Therefore, it is necessary to carry out system impact analysis and verification technically to ensure appropriate system configuration and specification of facilities to be designed in the development planning.

### 2.5.1. Power System Analysis Method

It is necessary to establish criteria for maintaining the system reliability before system analysis being conducted. The criteria were set as described below:

- The installed capacity of the generators including imported power must be greater than power demand.
- The facilities must not be overloaded (however, temporary overload is allowed during N-1 fault)
- Bus voltage does not deviate outside the rated voltage ±5%.
- During a three-phase short-circuit fault on a bus, circuit breakers connected to the bus must interrupt the fault current.

The guidelines for meeting the above criteria are considered:

- Constructing new power plants
- Selection of equipment specifications
- Installing phase-modifying capacitors
- Consideration of transmission line route and specification

### 2.5.2. Power Demand Estimation and Power Development Plan

The estimation of power demand was addressed earlier, and since the demand distribution after the commissioning of new substations falls under the operation of the distribution division, it is excluded in this Master Plan. Therefore this time, big consumers were connected to nearest substations and general demands were divided equally among areas (central/north/south/east/west).

The power development plan established new power sources within the capacity of power sources considered developable, for the year when the development was judged necessary, based on “Power Supply and Demand Scenario” which is the difference between the capacity of power plants already owned and estimated power demand.

Concerning the prospects for development of geothermal power stations by the JICA study team, there are two promising locations, specifically a 5MW facility in Bugarama and a 20MW facility in Kinigi.

Since power supplied using renewable energies such as photovoltaic power cannot be controlled to respond to change in power demand, such power was not included in the total power generation capacity for the purpose of system analysis. Thus the power generation capacity excluding photovoltaic power and estimated power demand is shown in Fig. 2-5.1 and Table. 2-5.1

The future power demand and generation capacity were estimated and shown in Fig. 2-5.2 and Fig. 2-5.3 as distribution maps for Rwanda.

It is necessary to find out whether the estimated power demand used for “Power Supply and Demand Scenario” takes into consideration transmission line power loss, operation power factor, reserve margin, etc. “Power Supply and Demand Scenario” here shown in pink was obtained by allowing a tolerance of 20% for operation power factor and reserve margin. In this case, transmission power loss is included in the estimated power demand.

The fig. of “Power Supply and Demand Scenario” shows that after the commissioning of Mamba Peat Plant (80MW) and Methane Plant (50MW) in Lake Kivu in 2017, the reliability of Rwanda’s power supply would improve drastically; thus thorough attention must be paid to the construction schedule and actual power generation output of these plants.

Looking at the future expected demand and supply, power supply stability in Rwanda will be greatly improved when Mamba Peat Plant (80MW) and Simbion Methane Plant (50MW) on Lake Kivu start operation in 2017. It will be necessary to display ample care regarding the construction schedule of these plants and the actual generation output.

Moreover, looking at the situation according to each power source, there is a high degree of dependence on hydropower, and since output of around 50~70% is possible even in the dry season, it should be possible to achieve stable power supply throughout the year when the abovementioned two plants and imports are also taken into account.

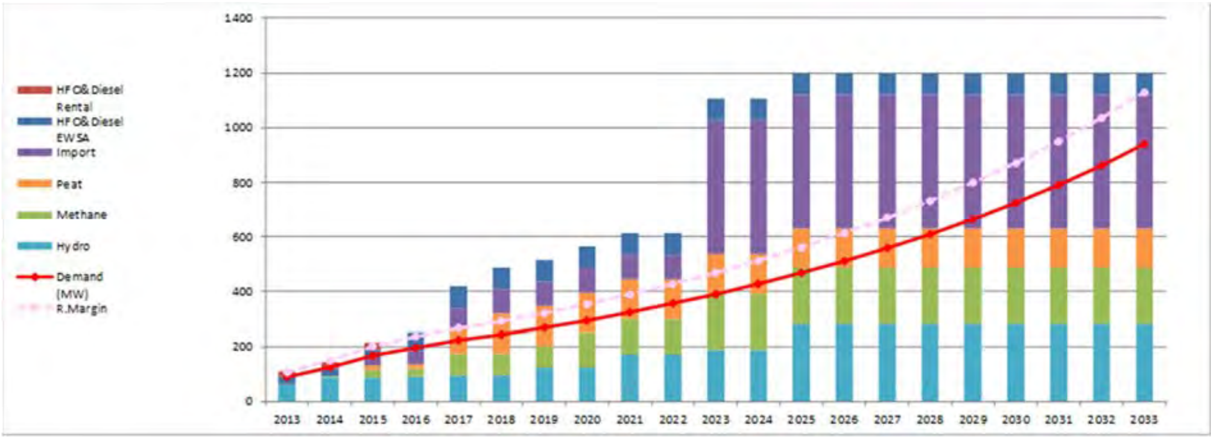



Fig. 2-5.1 Power Supply and Demand Scenario

Table 2-5.1 Power plant construction plan in Rwanda

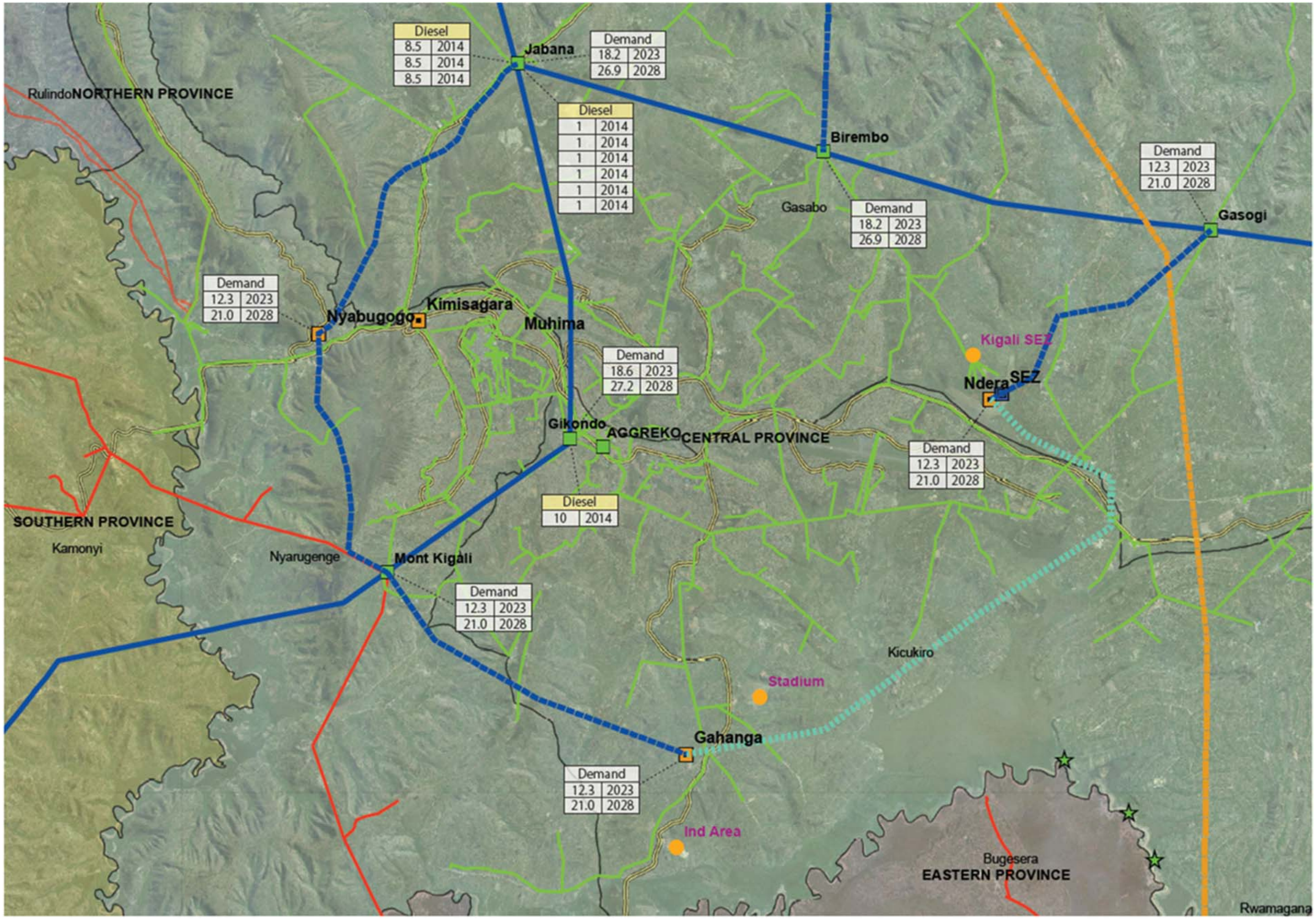
| | | | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Demand (MW) | | | 87.9 | 124.5 | 167.1 | 196.3 | 222.4 | 243.0 | 267.7 | 294.7 | 324.1 | 355.8 | 390.2 | 427.4 | 467.7 | 511.4 | 558.7 | 610.0 | 665.7 | 726.1 | 791.7 | 863.0 | 940.4 |
| R.Rargin(%) | | 20 | 106 | 149 | 201 | 236 | 267 | 292 | 321 | 354 | 389 | 427 | 468 | 513 | 561 | 614 | 670 | 732 | 799 | 871 | 950 | 1036 | 1128 |
| Year | | | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
| Type | Hydro | Existing(44.63) +Ruzizi I , II (15.5) | 60.13 | 28 | | 3 | 5 | | 27 | | 48 | | 17 | | 95 | | | | | | | | |
| | | | 60.13 | 88.13 | 88.13 | 91.13 | 96.13 | 96.13 | 123.1 | 123.1 | 171.1 | 171.1 | 188.1 | 188.1 | 283.1 | 283.1 | 283.1 | 283.1 | 283.1 | 283.1 | 283.1 | 283.1 | 283.1 |
| | HFO&Diesel EWSA | | 27.8 | | | 40 | 10 | | | | | | | | | | | | | | | | |
| | | | 27.8 | 27.8 | 27.8 | 67.8 | 77.8 | 77.8 | 77.8 | 77.8 | 77.8 | 77.8 | 77.8 | 77.8 | 77.8 | 77.8 | 77.8 | 77.8 | 77.8 | 77.8 | 77.8 | 77.8 | 77.8 |
| | HFO&Diesel Rental | | 20 | 4 | | −24 | | | | | | | | | | | | | | | | | |
| | | | 20 | 24 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Methane | | 3.6 | | 25 | | 50 | | | 50 | | | 75 | | | | | | | | | | |
| | | | 3.6 | 3.6 | 28.6 | 28.6 | 78.6 | 78.6 | 78.6 | 128.6 | 128.6 | 128.6 | 203.6 | 203.6 | 203.6 | 203.6 | 203.6 | 203.6 | 203.6 | 203.6 | 203.6 | 203.6 | 203.6 |
| | Peat | | | | 15 | | 80 | 50 | | | | | | | | | | | | | | | |
| | | Black Number: Planned Install Capacity<br>Red Number: Total Installed Capacity | 0 | 0 | 15 | 15 | 95 | 145 | 145 | 145 | 145 | 145 | 145 | 145 | 145 | 145 | 145 | 145 | 145 | 145 | 145 | 145 | 145 |
| | Import | | | | 30 | 20 | 20 | 20 | | | | | 400 | | | | | | | | | | |
| | | | 0 | 0 | 30 | 50 | 70 | 90 | 90 | 90 | 90 | 90 | 490 | 490 | 490 | 490 | 490 | 490 | 490 | 490 | 490 | 490 | 490 |

| 年 | 種類 | Owner | 名前 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2014 | Hydro | REG | Nyabarongo 1 | 28 | | | | | | | | | | | | | | | | | | | |
| | Diesel | Rental | Rental Aggreko | 4 | | | | | | | | | | | | | | | | | | | |
| 2015 | Methane | IPP | Kivu Watt | | 25 | | | | | | | | | | | | | | | | | | |
| | Peat | REG | Gishoma | | 15 | | | | | | | | | | | | | | | | | | |
| | Import | Import | Import(from Kenya) | | 30 | | | | | | | | | | | | | | | | | | |
| 2016 | Hydro | IPP | Rukarara 5 | | | 3 | | | | | | | | | | | | | | | | | |
| | Diesel | REG | KSEZ HFO | | | 40 | | | | | | | | | | | | | | | | | |
| | Diesel | Rental | Rental Aggreko | | | −24 | | | | | | | | | | | | | | | | | |
| | Import | Import | Import(from Kenya) | | | 20 | | | | | | | | | | | | | | | | | |
| 2017 | Hydro | IPP | Ntaruka B | | | | 5 | | | | | | | | | | | | | | | | |
| | Diesel | REG | KSEZ HFO | | | | 10 | | | | | | | | | | | | | | | | |
| | Methane | IPP | Simbion | | | | 50 | | | | | | | | | | | | | | | | |
| | Peat | IPP | Mamba | | | | 80 | | | | | | | | | | | | | | | | |
| | Import | Import | Import(from Kenya) | | | | 20 | | | | | | | | | | | | | | | | |
| 2018 | Peat | IPP | Rwabusoro | | | | | 50 | | | | | | | | | | | | | | | |
| | Import | Import | Import(from Kenya) | | | | | 20 | | | | | | | | | | | | | | | |
| 2019～ | Hydro | IPP | Rusumo | | | | | | 27 | | | | | | | | | | | | | | |
| | Methane | IPP | Simbion | | | | | | | 50 | | | | | | | | | | | | | |
| | Hydro | IPP | Ruzizi 3 | | | | | | | | 48 | | | | | | | | | | | | |
| | Hydro | IPP | Nyabarongo 2 | | | | | | | | | | 17 | | | | | | | | | | |
| | Methane | IPP | Kivu Watt Phase2 | | | | | | | | | | 75 | | | | | | | | | | |
| | Import | Import | Import(from Kenya) | | | | | | | | | | 400 | | | | | | | | | | |
| | Hydro | IPP | Ruzizi 4 | | | | | | | | | | | | 95 | | | | | | | | |

Source: “Energy investment in Rwanda” edited by JICA study team


Source: GIS map from EWSA-GIS unit edited by JICA study team

Fig. 2-5.2 Rwanda




Source: GIS map from EWSA-GIS unit edited by JICA study team

Fig. 2-5.3 Kigali city

### 2.5.3. Simulation

In implementing the simulation, in this master plan, because transmission lines and power station substations are targeted, system analysis on the distribution system (up to 30KV) was implemented upon sorting out conditions as follows.

#### (1) Setting of collective load

Power is distributed to each area through a number of distribution feeder circuit breakers connected to the 30KV bus line of each substation. Therefore, the load of distribution feeders connected to each substation were collectively connected as bus load in the manner shown in Figure. 2-5.4.

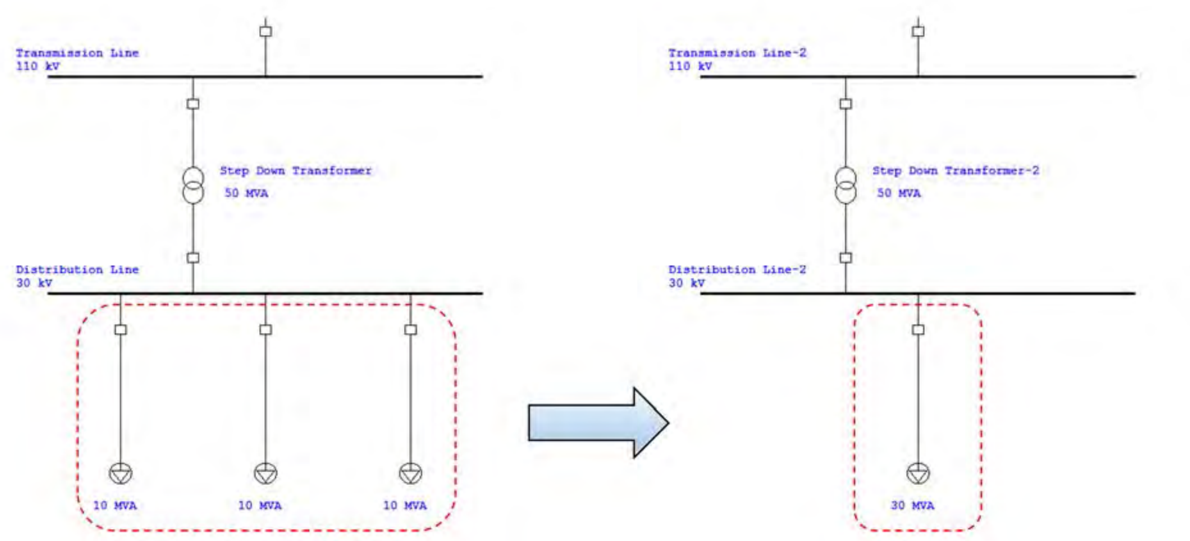



Fig. 2-5.4 Distribution Line Load Simulation

#### (2) Western Loop System (Mukungwa/Ntaruka~Kibuye/Karongi)

A feature of transmission and distribution systems in Rwanda is that the 30KV distribution system in the western zone is looped with the 110KV transmission system.

Conventionally, loop operation is conducted on transmission systems in order to increase reliability in consideration of line interruptions caused by failures and so on, but it is usual for distribution lines in distribution systems to be extended in a radial manner.

Accordingly, loop operation has been stopped here as shown in Figure … Here, when the total projected demand of Camp Belge S/S, Gihira HPP, Gisenyi HPP and Mukungwa HPP in the above zone exceeds the plant capacity of Gihira HPP, Gisenyi HPP, Keya HPP and Mukungwa HPP, the differential is added to Mukungwa S/S.

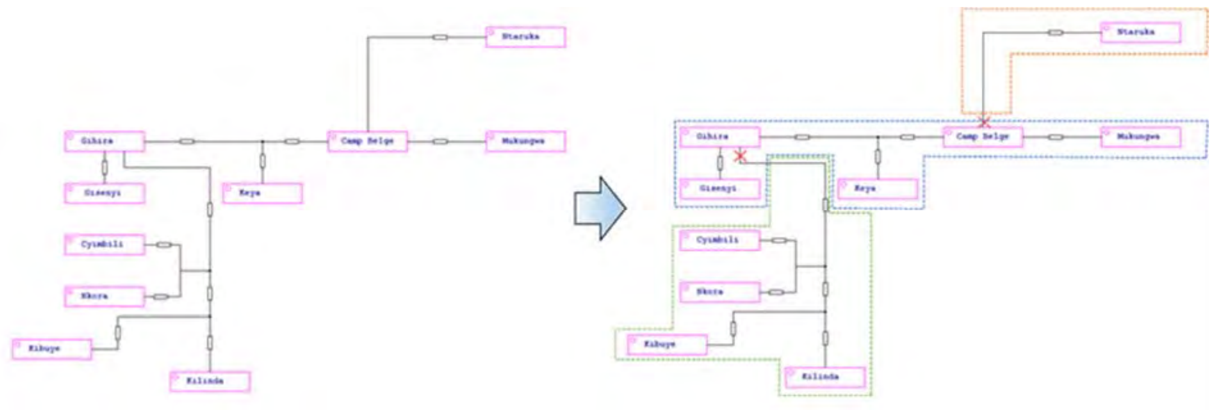



Fig. 2-5.5 Loop-off in the Western Distribution System

Moreover, because demand in Cyimbili area is minimal, there is no additional demand at Kilinda S/S like that assumed at Mukungwa S/S.

Concerning the apportionment of demand, as was mentioned previously, the results of equally apportioning the load of general consumers are as shown in the table. Wet and Dry exist for Mukungwa HPP because, following the end of loop operation in 2018, the output of Keya HPP, Gihira HPP and Gisenyi HPPs is deducted and added to the load of Mukungwa HPP.

Table 2-5.2 Demand Share of Each Substation

| | Substation | 2014 | 2015 | 2016 | 2017 | 2018 | 2023 | 2028 |
|---|---|---|---|---|---|---|---|---|
| Central | Birembo | 16.9 | 8.9 | 9.9 | 11.9 | 14.0 | 18.2 | 26.9 |
| | Gasogi | 1.4 | 7.5 | 7.0 | 7.5 | 8.1 | 12.3 | 21.0 |
| | Gikondo | 31.8 | 12.3 | 13.2 | 13.8 | 14.4 | 18.6 | 27.2 |
| | Jabana 1 | 10.5 | 13.4 | 12.9 | 13.4 | 14.0 | 18.2 | 26.9 |
| | Mt.Kigali | 12.7 | 18.5 | 23.9 | 30.4 | 31.0 | 12.3 | 21.0 |
| | Ndera | | 7.5 | 7.0 | 7.5 | 8.1 | 12.3 | 21.0 |
| | Rilima | | 7.5 | 7.0 | 7.5 | 8.1 | 12.3 | 21.0 |
| | Nyabugogo | | 7.5 | 7.0 | 7.5 | 8.1 | 12.3 | 21.0 |
| | Shango | | 7.5 | 7.0 | 7.5 | 8.1 | 12.3 | 21.0 |
| | Gahanga | | | 7.0 | 7.5 | 8.1 | 12.3 | 21.0 |
| | AirPort | | | | | | 35.2 | 43.8 |
| | Rubona | | | | | | 12.3 | 21.0 |
| North | Camp Belge | 4.5 | 2.5 | 4.4 | 4.5 | 4.9 | 8.1 | 12.8 |
| | Gihira | 0.6 | 2.5 | 2.9 | 3.1 | 3.5 | 6.7 | 11.3 |
| | Gisenyi | 0.8 | 2.5 | 2.9 | 3.1 | 3.5 | 6.7 | 11.3 |
| | Mukungwa | 1.9 | 2.5 | 2.9 | 3.1 | 3.5 | 6.7 | 11.3 |
| | Total Mukungwa Area | 7.8 | 10.0 | 13.1 | 13.7 | 15.4 | 28.2 | 46.6 |
| | Mukungwa -Dry | | | | | 12.8 | 25.6 | 44.0 |
| | Mukungwa -Wet | | | | | 10.2 | 23.0 | 41.4 |
| | Ntaruka | 0.9 | 2.5 | 2.9 | 3.1 | 3.5 | 6.7 | 11.3 |
| | Rulindo | 4.4 | 2.5 | 2.9 | 3.1 | 3.5 | 6.7 | 11.3 |
| | Gifurwe | | 2.5 | 2.9 | 3.1 | 3.5 | 6.7 | 11.3 |
| | Nyabarongo 2 | | | | 3.1 | 3.5 | 6.7 | 11.3 |
| South | Kigoma | 9.8 | 6.5 | 4.7 | 4.6 | 5.1 | 8.6 | 13.6 |
| | Butare | | 6.5 | 3.2 | 3.1 | 3.7 | 7.2 | 12.1 |
| | Huye | | | 3.2 | 3.1 | 3.7 | 7.2 | 12.1 |
| | Rukarara | | | 3.2 | 3.1 | 3.7 | 7.2 | 12.1 |
| | Rwabusoro | | | 3.2 | 3.1 | 3.7 | 7.2 | 12.1 |
| | Mamba | | | | 3.1 | 3.7 | 7.2 | 12.1 |
| East | Kabarondo | 4.4 | 5.7 | 2.9 | 3.5 | 3.4 | 6.7 | 11.4 |
| | Musha | 4.2 | 17.2 | 16.1 | 18.2 | 19.6 | 22.9 | 27.6 |
| | Rwinkwavu | 0.3 | 0.4 | 2.9 | 3.5 | 3.4 | 6.7 | 11.4 |
| | Kirehe | | | 2.9 | 3.5 | 3.4 | 6.7 | 11.4 |
| | Ngarama | | | 2.9 | 3.5 | 3.4 | 6.7 | 11.4 |
| | Nyabugari | | | | | 3.4 | 6.7 | 11.4 |
| West | Karongi | 1.4 | 1.5 | 1.3 | 1.3 | 1.5 | 3.0 | 5.1 |
| | Kibogora | 1.4 | 1.5 | 1.3 | 1.3 | 1.5 | 3.0 | 5.1 |
| | Kilinda | 1.4 | 1.5 | 1.3 | 1.3 | 1.5 | 3.0 | 5.1 |
| | Mururu 1 | 1.4 | 1.4 | 2.8 | 2.8 | 3.0 | 4.4 | 6.6 |
| | Bugarama | 12.4 | 12.5 | 16.0 | 16.1 | 16.3 | 17.7 | 19.8 |
| | Ntendezi | 1.4 | 1.5 | 1.3 | 1.3 | 1.5 | 3.0 | 5.1 |
| | Nyabihu | | 1.5 | 1.3 | 1.3 | 1.5 | 3.0 | 5.1 |
| | Rubavu | | | 1.3 | 1.3 | 1.5 | 3.0 | 5.1 |
| | Bwishura | | | 1.3 | 1.3 | 1.5 | 3.0 | 5.1 |
| | Nyabarongo 1 | | | | 1.3 | 1.5 | 3.0 | 5.1 |

### (3) Load Flow Analysis

Based on the survey findings, Figure 2-5.6 shows the inter-regional connections in Rwanda in 2028 that is the final year of this study. Power flow results for each year are shown based on the figure.


| No. | 接続 | 220KV S/S | | 110KV S/S | |
|---|---|---|---|---|---|
| 1 | I-C | (Uganda) | Shango | | |
| 2 | C-E | Rilima | Rusumo | Gasogi | Musha |
| | | | | Rubona | Musha |
| 3 | C-N | | | Jabana 1 | Rulindo |
| 4 | C-W | Shango | Rubabu | | |
| 5 | C-S | Rilima | Rwabusoro | Mt.Kigali | Kigoma |
| 6 | N-E | | | Rulindo | Ngarama |
| 7 | N-W | | | Mukungwa | Nyabihu |
| 8 | W-S | Kilinda | Kigoma | Kilinda | Kigoma |
| | | | | Kilinda | Rukarara |

I : IMPORT
C : CENTRAL ZONE
N : NORTHERN ZONE
E : EASTERN ZONE
W : WEATER ZONE
S : SOUTHERN ZONE

: 220KV
: 110KV
: Import (220KV)

Fig. 2-5.6 Inter-regional Connections in 2028

In the current facilities, it is absolutely necessary to install modulating capacitors in order to keep the bus voltage within standard levels. Concerning the areas where bus voltage cannot be maintained, modulating capacitors are connected to the 30KV bus line to maintain the bus voltage.

In cases where the power source capacity exceeds demand, as a rule plant operations are suspended in order from those with the highest operating costs (Diesel→HFO→Peat→Import→Gas), however, in cases where it is difficult to sustain the bus voltage, this order is reversed and priority is given to maintaining the bus voltage.

In the analysis work here, the typical data used in ETAP was used in the capability curve for generators where future construction is planned, however, through examining the capability curve necessary for generators from the analysis results, whereas the modulating capacitors and reduction of equipment costs based on reducing the number of modulating capacitors can only be adjusted in terms of capacity for each bank, generators can be finely adjusted, thereby allowing bus voltage to be enhanced.

Since the results here were obtained based on currently available information, in the event where sufficient plant capacity is created to make a contribution to the economy of Rwanda, it may be possible to bind PPAs and sell power to neighboring countries in the future. At this time, since it is forecast that the actual power flows will differ from the results of power flow analysis here, it must be remembered that it will be necessary to review the equipment configuration to ensure that no impact is imparted on the system stability of Rwanda.


<2014-WET>

| No. | | 220KV S/S | | 110KV S/S | |
|---|---|---|---|---|---|
| 1 | **I-C** | (Uganda) | Shango | | |
| | | - | | | |
| 2 | C-E | Rilima | Rusumo | **Gasogi** | **Musha** |
| | | - | | **→8.7MW→** | |
| | | | | Rubona | Musha |
| | | | | - | |
| 3 | C-N | | | **Jabana 1** | **Rufindo** |
| | | | | **←23.3MW←** | |
| 4 | C-W | Shango | Rubabu | | |
| | | - | | | |
| 5 | C-S | Rilima | Rwabusoro | **Mt.Kigali** | **Kigoma** |
| | | - | | **←17.0MW←** | |
| 6 | N-E | | | Rulindo | Ngarama |
| | | | | - | |
| 7 | N-W | | | Mukungwa | Nyabihu |
| | | | | - | |
| 8 | W-S | Kilinda | Kigoma | **Kilinda** | **Kigoma** |
| | | - | | **→26.6MW→** | |
| | | | | **Kilinda** | **Rukarara** |
| | | | | - | |

Fig. 2-5.7 Load Flow System in 2014 (Wet Season)

Nyabarongo1 (28MW) is scheduled to start operation in 2014. Power will be supplied to the capital region via Kilinda S/S, however, power source equipment with capacity equivalent to 7MVA will be required at Gikondo S/S in order to maintain voltage. The load flow will not differ greatly from the present situation and will generally be supplied from east to west.


<2014-DRY>

| No. | Area | 220KV S/S | | 110KV S/S | |
|---|---|---|---|---|---|
| 1 | **I-C** | (Uganda) | Shango | | |
| | | - | | | |
| 2 | C-E | Rilima | Rusumo | **Gasogi** | **Musha** |
| | | - | | **→8.9MW→** | |
| | | | | Rubona | Musha |
| | | | | - | |
| 3 | C-N | | | **Jabana 1** | **Rulindo** |
| | | | | **←21.1MW←** | |
| 4 | C-W | Shango | Rubabu | | |
| | | - | | | |
| 5 | C-S | Rilima | Rwabusoro | **Mt.Kigali** | **Kigoma** |
| | | - | | **→5.2MW→** | |
| 6 | N-E | | | Rulindo | Ngarama |
| | | | | - | |
| 7 | N-W | | | Mukungwa | Nyabihu |
| | | | | - | |
| 8 | W-S | Kilinda | Kigoma | **Kilinda** | **Kigoma** |
| | | - | | **→4.3MW→** | |
| | | | | **Kilinda** | **Rukarara** |
| | | | | | |

Fig. 2-5.8 Load Flow System in 2014 (Dry Season)

In the dry season, as is also the case in the wet season, the bus voltage cannot be maintained, however, when the output of HPPs excluding Ntaruka HPP and Mukungwa HPP is calculated as 50%, power source equipment with capacity equivalent to 25MVA will be required at Gikondo S/S in order to maintain voltage.


<2015-WET>

| No. | Area | 220KV S/S | | 110KV S/S | |
|---|---|---|---|---|---|
| 1 | I-C | (Uganda) | Shango | | |
| | | →5.0MW→ | | | |
| 2 | C-E | Rilima | Rusumo | Gasogi | Musha |
| | | - | | →22.3MW→ | |
| | | | | Rubona | Musha |
| | | | | - | |
| 3 | C-N | | | Jabana 1 | Rulindo |
| | | | | ←20.7MW← | |
| 4 | C-W | Shango | Rubabu | | |
| | | - | | | |
| 5 | C-S | Rilima | Rwabusoro | MtKigali | Kigoma |
| | | - | | ←49.4MW← | |
| 6 | N-E | | | Rulindo | Ngarama |
| | | | | - | |
| 7 | N-W | | | Mukungwa | Nyabihu |
| | | | | →1.5MW→ | |
| 8 | W-S | Kilinda | Kigoma | Kilinda | Kigoma |
| | | - | | →63.7MW→ | |
| | | | | Kilinda | Rukarara |
| | | | | ←3.0MW← | |

Fig. 2-5.9 Load Flow System in 2015 (Wet Season)

By 2015, because the methane gas plants of Kivu Watt (25MW) and peat plant of Gishoma (15MW) will be connected to the grid and imports will be started, it will be possible to maintain voltage, and it will no longer be necessary to connected power sources to Gikondo S/S like in 2014.


<2015-DRY>

| No. | Area | 220KV S/S | | 110KV S/S | |
|---|---|---|---|---|---|
| 1 | I-C | (Uganda) | Shango | | |
| | | →31.1MW→ | | | |
| 2 | C-E | Rilima | Rusumo | Gasogi | Musha |
| | | - | | →22.3MW→ | |
| | | | | Rubona | Musha |
| | | | | - | |
| 3 | C-N | | | Jabana 1 | Rulindo |
| | | | | ←11.6MW← | |
| 4 | C-W | Shango | Rubabu | | |
| | | - | | | |
| 5 | C-S | Rilima | Rwabusoro | MtKigali | Kigoma |
| | | - | | ←26.6MW← | |
| 6 | N-E | | | Rulindo | Ngarama |
| | | | | - | |
| 7 | N-W | | | Mukungwa | Nyabihu |
| | | | | →1.5MW→ | |
| 8 | W-S | Kilinda | Kigoma | Kilinda | Kigoma |
| | | - | | →40.0MW→ | |
| | | | | Kilinda | Rukarara |
| | | | | ←1.5MW← | |

Fig. 2-5.10 Load Flow System in 2015 (Dry Season)

In the Wet season, it will be necessary to import more power to compensate for lower output from HPPs.

Currently 30MW is scheduled, however, according to the results of system analysis, it will be possible to maintain voltage if an equivalent amount is imported.


<2016-WET>

| No. | Area | 220KV S/S | | 110KV S/S | |
|---|---|---|---|---|---|
| 1 | I-C | (Uganda) | Shango | | |
| | | →10.7MW→ | | | |
| 2 | C-E | Rilima | Rusumo | Gasogi | Musha |
| | | - | | →23.3MW→ | |
| | | | | Rubona | Musha |
| | | | | - | |
| 3 | C-N | | | Jabana 1 | Rulindo |
| | | | | ←3.2MW← | |
| 4 | C-W | Shango | Rubabu | | |
| | | ←4.5MW← | | | |
| 5 | C-S | Rilima | Rwabusoro | Mt.Kigali | Kigoma |
| | | ←15.9MW← | | ←19.7MW← | |
| 6 | N-E | | | Rulindo | Ngarama |
| | | | | →3.6MW→ | |
| 7 | N-W | | | Mukungwa | Nyabihu |
| | | | | →1.3MW→ | |
| 8 | W-S | Kilinda | Kigoma | Kilinda | Kigoma |
| | | →14.8MW→ | | →26.7MW→ | |
| | | | | Kilinda | Rukarara |
| | | | | →8.8MW→ | |

Fig. 2-5.11 Load Flow System in 2016 (Wet Season)

By 2016, 220KV will be transmitted from the western zone. It is anticipated that this will mitigate transmission losses and create allowance in the power supply.


<2016-DRY>

| No. | Area | 220KV S/S | | 110KV S/S | |
|---|---|---|---|---|---|
| 1 | I-C | (Uganda) | Shango | | |
| | | →36.2MW→ | | | |
| 2 | C-E | Rilima | Rusumo | Gasogi | Musha |
| | | - | | →23.9MW→ | |
| | | | | Rubona | Musha |
| | | | | - | |
| 3 | C-N | | | Jabana 1 | Rulindo |
| | | | | ←2.0MW← | |
| 4 | C-W | Shango | Rubabu | | |
| | | →0.2MW→ | | | |
| 5 | C-S | Rilima | Rwabusoro | Mt.Kigali | Kigoma |
| | | ←1.7MW← | | ←15.0MW← | |
| 6 | N-E | | | Rulindo | Ngarama |
| | | | | →3.0MW→ | |
| 7 | N-W | | | Mukungwa | Nyabihu |
| | | | | →1.3MW→ | |
| 8 | W-S | Kilinda | Kigoma | Kilinda | Kigoma |
| | | →7.0MW→ | | →17.6MW→ | |
| | | | | Kilinda | Rukarara |
| | | | | →8.0MW→ | |

Fig. 2-5.12 Load Flow System in 2016 (Dry Season)

In the dry season, as in 2015, it is thought that imports will be relied on. However, because the currently planned 30MW will fall short by around 6MW, it will be necessary to combine imports with temporary power sources in order to maintain voltage.


<2017-WET>

| No. | Area | 220KV S/S | | 110KV S/S | |
|---|---|---|---|---|---|
| 1 | I-C | (Uganda) | Shango | | |
| | | →25.7MW→ | | | |
| 2 | C-E | Rilima | Rusumo | Gasogi | Musha |
| | | - | | →19.8MW→ | |
| | | | | Rubona | Musha |
| | | | | - | |
| 3 | C-N | | | Jabana 1 | Rulindo |
| | | | | ←9.1MW← | |
| 4 | C-W | Shango | Rubabu | | |
| | | ←11.2MW← | | | |
| 5 | C-S | Rilima | Rwabusoro | Mt.Kigali | Kigoma |
| | | ←38.6MW← | | ←49.6MW← | |
| 6 | N-E | | | Rulindo | Ngarama |
| | | | | →11.4MW→ | |
| 7 | N-W | | | Mukungwa | Nyabihu |
| | | | | ←17.0MW← | |
| 8 | W-S | Kilinda | Kigoma | Kilinda | Kigoma |
| | | →20.8MW→ | | →22.3MW→ | |
| | | | | Kilinda | Rukarara |
| | | | | ←19.7MW← | |

Fig. 2-5.13 Load Flow System in 2017 (Wet Season)

In 2017, power source facilities will be greatly strengthened with the start of supply from Mamba peat plant (80MW) and Simbion methane plant (50MW). Accordingly, it will be possible to suspend operation of diesel generators and thereby reduce fuel costs. However, if Simbion TPP is operated, since power will become excessive and will need to be exported, it is assumed that operation will be suspended in this case.


<2017-DRY>

| No. | Area | 220KV S/S | | 110KV S/S | |
|---|---|---|---|---|---|
| 1 | I-C | (Uganda) | Shango | | |
| | | →3.5MW→ | | | |
| 2 | C-E | Rilima | Rusumo | Gasogi | Musha |
| | | - | | →21.2MW→ | |
| | | | | Rubona | Musha |
| | | | | - | |
| 3 | C-N | | | Jabana 1 | Rulindo |
| | | | | ←5.6MW← | |
| 4 | C-W | Shango | Rubabu | | |
| | | ←33.7MW← | | | |
| 5 | C-S | Rilima | Rwabusoro | Mt.Kigali | Kigoma |
| | | ←45.5MW← | | ←47.3MW← | |
| 6 | N-E | | | Rulindo | Ngarama |
| | | | | →10.3MW→ | |
| 7 | N-W | | | Mukungwa | Nyabihu |
| | | | | ←13.6MW← | |
| 8 | W-S | Kilinda | Kigoma | Kilinda | Kigoma |
| | | →35.3MW→ | | →16.3MW→ | |
| | | | | Kilinda | Rukarara |
| | | | | ←20.0MW← | |

Fig. 2-5.14 Load Flow System in 2017 (Dry Season)

In the dry season, because hydropower supply will decline, it will be necessary to operate Simbion TPP, which will be suspended during the Wet season, in order to maintain voltage. Through operating Simbion TPP, the quantity of supply from the west will increase, allowing imports to be reduced.


<2018-WET>

| No. | Area | 220KV S/S | | 110KV S/S | |
|---|---|---|---|---|---|
| 1 | I-C | (Uganda) | Shango | | |
| | | ←4.5MW← | | | |
| 2 | C-E | Rilima | Rusumo | Gasogi | Musha |
| | | →17.2MW→ | | →10.7MW→ | |
| | | | | Rubona | Musha |
| | | | | - | |
| 3 | C-N | | | Jabana 1 | Rulindo |
| | | | | ←9.1MW← | |
| 4 | C-W | Shango | Rubabu | | |
| | | ←15.1MW← | | | |
| 5 | C-S | Rilima | Rwabusoro | Mt.Kigali | Kigoma |
| | | ←79.7MW← | | ←50.3MW← | |
| 6 | N-E | | | Rulindo | Ngarama |
| | | | | →7.8MW→ | |
| 7 | N-W | | | Mukungwa | Nyabihu |
| | | | | ←17.7MW← | |
| 8 | W-S | Kilinda | Kigoma | Kilinda | Kigoma |
| | | →15.0MW→ | | →22.2MW→ | |
| | | | | Kilinda | Rukarara |
| | | | | ←18.6MW← | |

Fig. 2-5.15 Load Flow System in 2018 (Wet Season)

In 2018, power sources will be bolstered with the start of operation of Rwabsoro TPP (50MW), however, because exports are not scheduled, in the analysis, Simbion TPP and Rwabsoro TPP are both suspended. If either one of these is operated, it is expected that exports will be around 5MW.


<2018-DRY>

| No. | Area | 220KV S/S | | 110KV S/S | |
|---|---|---|---|---|---|
| 1 | I-C | (Uganda) | Shango | | |
| | | →23.5MW→ | | | |
| 2 | C-E | Rilima | Rusumo | Gasogi | Musha |
| | | →18.3MW→ | | →10.9MW→ | |
| | | | | Rubona | Musha |
| | | | | | |
| 3 | C-N | | | Jabana 1 | Rulindo |
| | | | | ←5.3MW← | |
| 4 | C-W | Shango | Rubabu | | |
| | | ←31.1MW← | | | |
| 5 | C-S | Rilima | Rwabusoro | Mt.Kigali | Kigoma |
| | | ←44.2MW← | | ←47.2MW← | |
| 6 | N-E | | | Rulindo | Ngarama |
| | | | | →6.3MW→ | |
| 7 | N-W | | | Mukungwa | Nyabihu |
| | | | | ←14.6MW← | |
| 8 | W-S | Kilinda | Kigoma | Kilinda | Kigoma |
| | | →36.2MW→ | | →16.3MW→ | |
| | | | | Kilinda | Rukarara |
| | | | | ←18.7MW← | |

Fig. 2-5.16 Load Flow System in 2018 (Dry Season)

In the dry season, it will be necessary to operate Simbion TPP or Rwabsoro TPP, which will be suspended during the Wet season, in order to compensate for the shortage of hydropower. Operation of Simbion TPP has been assumed in consideration of operating costs, however, there wouldn't be a problem in system terms if Rwabsoro TPP were operated.


<2023-WET>

| No. | Area | 220KV S/S | | 110KV S/S | |
|---|---|---|---|---|---|
| 1 | I-C | (Uganda) | Shango | | |
| | | →11.9MW→ | | | |
| 2 | C-E | Rilima | Rusumo | Gasogi | Musha |
| | | →1.3MW→ | | →13.9MW→ | |
| | | | | Rubona | Musha |
| | | | | →1.4MW→ | |
| 3 | C-N | | | Jabana 1 | Rulindo |
| | | | | ←0.9MW← | |
| 4 | C-W | Shango | Rubabu | | |
| | | ←46.7MW← | | | |
| 5 | C-S | Rilima | Rwabusoro | Mt.Kigali | Kigoma |
| | | ←111.8MW← | | ←35.6MW← | |
| 6 | N-E | | | Rulindo | Ngarama |
| | | | | →9.0MW→ | |
| 7 | N-W | | | Mukungwa | Nyabihu |
| | | | | ←18.4MW← | |
| 8 | W-S | Kilinda | Kigoma | Kilinda | Kigoma |
| | | →33.2MW→ | | →14.9MW→ | |
| | | | | Kilinda | Rukarara |
| | | | | →6.0MW→ | |

Fig. 2-5.17 Load Flow System in 2023 (Wet Season)

Between 2018 and 2023, operation will be started at Rusumo (27MW: 2019), Simbion Phase 2 (50MW: 2020), Rusizi 3 (48MW: 2021), Nyabarongo 2 (17MW: 2023), and Kivu Watt Phase 2 (75MW), and moreover it is scheduled for imports to increase to 400MW, although the exact timing is unclear. This will thus become the maturation period for power source development. Around this time, the best mix must be derived from the operating performance, etc. of each power station, and review must be conducted to ensure that appropriate system operation is carried out. In this case, Kivu Watt Phase 2 is suspended to allow for adjustment of the quantity of imports.


<2023-DRY>

| No. | Area | 220KV S/S | | 110KV S/S | |
|---|---|---|---|---|---|
| 1 | I-C | (Uganda) | Shango | | |
| | | ←0.1MW← | | | |
| 2 | C-E | Rilima | Rusumo | Gasogi | Musha |
| | | →17.1MW→ | | →15.1MW→ | |
| | | | | Rubona | Musha |
| | | | | →2.3MW→ | |
| 3 | C-N | | | Jabana 1 | Rulindo |
| | | | | →7.9MW→ | |
| 4 | C-W | Shango | Rubabu | | |
| | | ←65.9MW← | | | |
| 5 | C-S | Rilima | Rwabusoro | Mt.Kigali | Kigoma |
| | | ←131.2MW← | | ←36.9MW← | |
| 6 | N-E | | | Rulindo | Ngarama |
| | | | | →6.2MW→ | |
| 7 | N-W | | | Mukungwa | Nyabihu |
| | | | | ←18.5MW← | |
| 8 | W-S | Kilinda | Kigoma | Kilinda | Kigoma |
| | | →58.8MW→ | | →13.8MW→ | |
| | | | | Kilinda | Rukarara |
| | | | | →6.1MW→ | |

Fig. 2-5.18 Load Flow System in 2023 (Dry Season)

In the dry season, results show that domestic demand and supply will become balanced through operating Kivu Watt Phase 2.


<2028-WET>

| No. | 接続 | 220KV S/S | | 110KV S/S | |
|---|---|---|---|---|---|
| 1 | I-C | (Uganda) | Shango | | |
| | | →13.5MW→ | | | |
| 2 | C-E | Rilima | Rusumo | Gasogi | Musha |
| | | →21.5MW→ | | →19.6MW→ | |
| | | | | Rubona | Musha |
| | | | | →5.4MW→ | |
| 3 | C-N | | | Jabana 1 | Rulindo |
| | | | | →20.4MW→ | |
| 4 | C-W | Shango | Rubabu | | |
| | | ←129.9MW← | | | |
| 5 | C-S | Rilima | Rwabusoro | Mt.Kigali | Kigoma |
| | | ←171.9MW← | | ←54.2MW← | |
| 6 | N-E | | | Rulindo | Ngarama |
| | | | | →9.1MW→ | |
| 7 | N-W | | | Mukungwa | Nyabihu |
| | | | | ←32.8MW← | |
| 8 | W-S | Kilinda | Kigoma | Kilinda | Kigoma |
| | | →134.0MW→ | | →18.1MW→ | |
| | | | | Kilinda | Rukarara |
| | | | | →10.4MW→ | |

Fig. 2-5.19 Load Flow System in 2028 (Wet Season)

After 2023, the only newly developed power source will be Rusizi 4 (90MW), and there will be no problem regarding energy security because balance will be secured between demand and the capacity of domestic power sources.

However, because it is forecast that imports will be more costly than domestic power sources and the maintenance cycles for each power station will overlap, it is supposed that facilities will need to be operated with even more consideration given to economy.


<2028-DRY>

| No. | Area | 220KV S/S | | 110KV S/S | |
|---|---|---|---|---|---|
| 1 | I-C | (Uganda) | Shango | | |
| | | →131.3MW→ | | | |
| 2 | C-E | Rilima | Rusumo | Gasogi | Musha |
| | | →36.0MW→ | | →22.4MW→ | |
| | | | | Rubona | Musha |
| | | | | →5.7MW→ | |
| 3 | C-N | | | Jabana 1 | Rulindo |
| | | | | →31.6MW→ | |
| 4 | C-W | Shango | Rubabu | | |
| | | ←94.0MW← | | | |
| 5 | C-S | Rilima | Rwabusoro | Mt.Kigali | Kigoma |
| | | ←124.9MW← | | ←48.2MW← | |
| 6 | N-E | | | Rulindo | Ngarama |
| | | | | →6.4MW→ | |
| 7 | N-W | | | Mukungwa | Nyabihu |
| | | | | ←29.5MW← | |
| 8 | W-S | Kilinda | Kigoma | Kilinda | Kigoma |
| | | →96.9MW→ | | →8.8MW→ | |
| | | | | Kilinda | Rukarara |
| | | | | →7.5MW→ | |

Fig. 2-5.20 Power Flow System in 2028 (Dry Season)

In the dry season, although the capacity of power sources means that imports will need to be relied on, because the lead time until then is long, growth in demand will be appropriately monitored, and it is deemed that there will be enough time to fully review power source development plans.

**(4) Transmission Line Systems**

Table 2-5.3 Study of reinforced Transmission Line

| Year | Transmission Line | | Current(A/Phase) | | |
|---|---|---|---|---|---|
| | From | To | Before | After | Countermeasure |
| 2015 | Kivu Watt TPP | Kibuye S/S | 650 | 325 | Single→Double Conductors/Phase |
| 2023~ | Shango S/S | Birembo S/S | 500 | 250 | |
| | Birembo S/S | Jabana S/S | 600 | 300 | Single→Double /Circuit |

Table 2-5.3 is the locations where system analysis indicates that over-capacity will occur on transmission lines between substations. Since there is a risk that the heat of current flows will cause fusing on transmission lines when transmission is continued in the over capacity state, it is necessary to take appropriate measures.

In 2015, Kivu Watt TPP (25MW) will start operation, however, because power between Kivu Watt S/S and Kibuye S/S is supplied at 11KV, the flowing current will be larger than in the case of high voltage transmission. As a result of system analysis, since a total of roughly 1,300A will flow when operation is at 25MW, care will be required concerning the specifications and quantity of conductors. Since the single wire double circuit transmissions assumed at the time of survey will not provide enough capacity, it may be necessary to adopt twin wires per phase in some cases.

Similarly, from 2023 onwards, because the current flowing from Shango S/S to Birembo S/S will exceed 1,000A, it will be necessary to adopt twin wires transmission.

Also, because the current flowing from Birembo S/S to Jabana S/S (currently connected by single circuit transmission) is more than 600A, it is recommended that double circuit transmission be adopted.

When comparing single wire double circuit transmissions with twin wires single circuit transmission, the current flowing per wire is the same, however, when failure occurs, whereas power is interrupted on the twin wire single circuit transmission line, power interruptions can be averted on the single wire double circuit transmissions line because transmission is continued on the unaffected line. Therefore, in consideration of system stability, loop operation based on double circuit transmissions is normally adopted.

It is also possible to reduce the amount of power flow through changing the load flow operation, however, because conditions are subject to change depending on local power consumption and generator operating conditions, it is necessary for operators to acquire advanced skills. Therefore, it is recommended that changes to load flow be considered as a backup measure after first reviewing equipment measures while fully bearing costs in mind.

## (5) Transformer

Table 2-5.4 Study of Transformer Capacity

(1) Data form Demand Forecast
(2) Change to MVA (P.F=0.9)
(3) Included Reserve Margin(20%) [Red:Over Load]
(4) Installe Transfomer [Red:Refurbishment, Bule: Aditional]
(5) Total Installed Capcity

| Year | 2014 | 2015 | 2016 | 2017 | 2018 | 2023 | 2028 |
|---|---|---|---|---|---|---|---|
| Birembo | | | | | | | |
| (1) | 16.9 | 8.9 | 9.9 | 11.9 | 14.0 | 18.2 | 26.9 |
| (2) | 18.8 | 9.9 | 11.0 | 13.2 | 15.6 | 20.2 | 29.9 |
| (3) | 22.5 | 11.9 | 13.2 | 15.9 | 18.7 | 24.3 | 35.9 |
| (4) | | | | | | 20.0 | |
| (5) | **20.0** | 20.0 | 20.0 | 20.0 | 20.0 | **40.0** | 40.0 |
| Gasogi | | | | | | | |
| (1) | 1.4 | 7.5 | 7.0 | 7.5 | 8.1 | 12.3 | 21.0 |
| (2) | 1.6 | 8.3 | 7.8 | 8.3 | 9.0 | 13.7 | 23.3 |
| (3) | 1.9 | 10.0 | 9.3 | 10.0 | 10.8 | 16.4 | 28.0 |
| (4) | | 30.0 | | | | | |
| (5) | **2.5** | **30.0** | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 |
| Gikondo | | | | | | | |
| (1) | 31.8 | 12.3 | 13.2 | 13.8 | 14.4 | 18.6 | 27.2 |
| (2) | 35.3 | 13.7 | 14.7 | 15.3 | 16.0 | 20.7 | 30.2 |
| (3) | 44.2 | 17.1 | 18.3 | 19.2 | 20.0 | 25.8 | 37.8 |
| (4) | | | | | | | |
| (5) | **45.0** | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 |
| Jabana 1 | | | | | | | |
| (1) | 10.5 | 13.4 | 12.9 | 13.4 | 14.0 | 18.2 | 26.9 |
| (2) | 11.7 | 14.9 | 14.3 | 14.9 | 15.6 | 20.2 | 29.9 |
| (3) | 14.6 | 18.6 | 17.9 | 18.6 | 19.4 | 25.3 | 37.4 |
| (4) | | 20.0 | | | | 20.0 | |
| (5) | **12.0** | **20.0** | 20.0 | 20.0 | 20.0 | **40.0** | 40.0 |
| Mt.Kigali | | | | | | | |
| (1) | 12.7 | 18.5 | 23.9 | 30.4 | 31.0 | 12.3 | 21.0 |
| (2) | 14.1 | 20.6 | 26.6 | 33.8 | 34.4 | 13.7 | 23.3 |
| (3) | 17.6 | 25.7 | 33.2 | 42.2 | 43.1 | 17.1 | 29.2 |
| (4) | | 50.0 | | | | | |
| (5) | **10.0** | **50.0** | 50.0 | 50.0 | 50.0 | 50.0 | 50.0 |
| Mukungwa(110/30KV) | | | | | | | |
| (1) | 1.9 | 2.5 | 2.9 | 3.1 | 0.8 | 13.6 | 32.0 |
| (2) | 2.1 | 2.8 | 3.2 | 3.4 | 0.9 | 3.1 | 23.6 |
| (3) | 2.6 | 3.5 | 4.0 | 4.3 | 1.1 | 3.9 | 29.4 |
| (4) | | | | | | | 30.0 |
| (5) | **15.0** | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | **30.0** |
| Mukungwa(6.6/30KV) | | | | | | | |
| (1) | 1.9 | 2.5 | 2.9 | 3.1 | 12.8 | 25.6 | 44.0 |
| (2) | 2.1 | 2.8 | 3.2 | 3.4 | 14.2 | 28.4 | 48.9 |
| (3) | 2.6 | 3.5 | 4.0 | 4.3 | 17.8 | 35.6 | 61.1 |
| (4) | | 30.0 | | | | 30.0 | 30.0 |
| (5) | **3.0** | **30.0** | 30.0 | 30.0 | 30.0 | **60.0** | **90.0** |

Remarks:
Mukungwa S/S
(110/30kV)
Under the assumption that loop-off starts in 2018 due to balance between demand and supply of Mukungwa area, figure of deducting 12MW of Mukungwa power plant from total demand is applied.

(6.6/30KV)
It wouldn't meet the required installed capacity considering R.Margin in 2028, however it is excluded from calculation of development cost because it is less than rating capacity.

| Year | 2014 | 2015 | 2016 | 2017 | 2018 | 2023 | 2028 |
|---|---|---|---|---|---|---|---|
| Rulindo | | | | | | | |
| (1) | 4.4 | 2.5 | 2.9 | 3.1 | 3.5 | 6.7 | 11.3 |
| (2) | 4.9 | 2.8 | 3.2 | 3.4 | 3.9 | 7.4 | 12.6 |
| (3) | 6.1 | 3.5 | 4.0 | 4.3 | 4.9 | 9.3 | 15.7 |
| (4) | | 10.0 | | | | | 10.0 |
| (5) | **3.0** | **10.0** | 10.0 | 10.0 | 10.0 | 10.0 | **20.0** |
| Kigoma | | | | | | | |
| (1) | 9.8 | 6.5 | 4.7 | 4.6 | 5.1 | 8.6 | 13.6 |
| (2) | 10.9 | 7.2 | 5.2 | 5.1 | 5.7 | 9.6 | 15.1 |
| (3) | 13.6 | 9.0 | 6.5 | 6.4 | 7.1 | 11.9 | 18.9 |
| (4) | | | | | | 10.0 | |
| (5) | **10.0** | 10.0 | 10.0 | 10.0 | 10.0 | **20.0** | 20.0 |
| Kabarondo | | | | | | | |
| (1) | 4.4 | 5.7 | 2.9 | 3.5 | 3.4 | 6.7 | 11.4 |
| (2) | 4.9 | 6.3 | 3.2 | 3.9 | 3.8 | 7.4 | 12.7 |
| (3) | 6.1 | 7.9 | 4.0 | 4.9 | 4.7 | 9.3 | 15.8 |
| (4) | | | | | | | 10.0 |
| (5) | **10.0** | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | **20.0** |
| Musha | | | | | | | |
| (1) | 4.2 | 17.2 | 16.1 | 18.2 | 19.6 | 22.9 | 27.6 |
| (2) | 4.7 | 19.1 | 17.9 | 20.2 | 21.8 | 25.4 | 30.7 |
| (3) | 5.8 | 23.9 | 22.4 | 25.3 | 27.2 | 31.8 | 38.3 |
| (4) | | 10.0*2 | | | | 10.0 | |
| (5) | **10.0** | **30.0** | 30.0 | 30.0 | 30.0 | **40.0** | 40.0 |
| Rwinkwabu | | | | | | | |
| (1) | 0.3 | 0.4 | 2.9 | 3.5 | 3.4 | 6.7 | 11.4 |
| (2) | 0.3 | 0.4 | 3.2 | 3.9 | 3.8 | 7.4 | 12.7 |
| (3) | 0.4 | 0.6 | 4.0 | 4.9 | 4.7 | 9.3 | 15.8 |
| (4) | | | | | | 20.0 | |
| (5) | **6.0** | 6.0 | 6.0 | 6.0 | 6.0 | **20.0** | 20.0 |
| Karongi | | | | | | | |
| (1) | 1.4 | 1.5 | 1.3 | 1.3 | 1.5 | 3.0 | 5.1 |
| (2) | 1.6 | 1.7 | 1.4 | 1.4 | 1.7 | 3.3 | 5.7 |
| (3) | 1.9 | 2.1 | 1.8 | 1.8 | 2.1 | 4.2 | 7.1 |
| (4) | | | | | | | 6.0 |
| (5) | **6.0** | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | **12.0** |
| Kibogora | | | | | | | |
| (1) | 1.4 | 1.5 | 1.3 | 1.3 | 1.5 | 3.0 | 5.1 |
| (2) | 1.6 | 1.7 | 1.4 | 1.4 | 1.7 | 3.3 | 5.7 |
| (3) | 1.9 | 2.1 | 1.8 | 1.8 | 2.1 | 4.2 | 7.1 |
| (4) | | | | | | | 6.0 |
| (5) | **6.0** | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | **12.0** |
| Kilinda | | | | | | | |
| (1) | 1.4 | 1.5 | 1.3 | 1.3 | 1.5 | 3.0 | 5.1 |
| (2) | 1.6 | 1.7 | 1.4 | 1.4 | 1.7 | 3.3 | 5.7 |
| (3) | 1.9 | 2.1 | 1.8 | 1.8 | 2.1 | 4.2 | 7.1 |
| (4) | | | | | | | 6.0 |
| (5) | **6.0** | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | **12.0** |

Table 2-5.4 is the locations where system analysis indicates that over-capacity will occur in substation transformers. Transformer capacity is set based on projected demand in the final year of 2028, and it is assumed that the used capacity of transformers at that time will not exceed 80% of the rated capacity at that time. Transformers can be reinforced through carrying out additional installations or upgrading, however, because such measures require additional land acquisition and long-term power interruptions, it is necessary to display ample care when setting capacity.

Transformer losses are broadly divided into load loss and no-load loss, and because a uniform loss is constantly generated in the charged state (no-load loss), it is better in terms of stable power supply and impedance reduction to adopt multiple small- and medium-capacity transformers rather than a single large-capacity transformer.

Accordingly, at Birembo S/S, rather than installing one transformer with capacity of 40MVA, it has been decided to install 2 transformers with capacity of 20MVA.

Concerning other substations, similarly the changes shown in Table 2-5.4 are recommended.

Since power losses become especially large when large-capacity transformers are installed in circumstances where there is insufficient power, care is needed.

**(6) Short Circuit**

Table 2-5.5 Study of Circuit Breaker Capacity

(KA)

| Year | P/S | Short-Circuit | Rated Current |
|---|---|---|---|
| 2017 | Simbion | 35.2 | 31.5 |

Concerning parts where the short-circuit capacity exceeds the interruption capacity of circuit breakers, because there is risk that fault points at times of three phase short circuits cannot be removed, leading to prolonging of faults and damage of equipment, it is recommended that circuit breakers be renewed.

**(7) Bus Voltage**

Bus voltage drop is confirmed in some terminal substations as a result of conducting system analysis based on modeling of the projected demand and power stations planned for construction.

These are cases of voltage dropping below the standard scope due to unique transmission losses caused by impedance on transmission lines. This phenomenon is conspicuously seen at substations connected to power receiving equipment and large-scale consumers when conducting long distance transmission.

Since active power can be increased through restoring voltage drop caused by transmission line losses and improving the power factor of generators by installing capacitors on distribution bus lines and supplying reactive power, it is recommended that capacitors be installed at appropriate locations.

As a result of examining the installation of capacitors, the capacitors required for maintaining the voltage standard are as shown in Table.2-5.6.

Since the capacity per bank of capacitors is set, it has been assumed that small quantities of inactive power that exceed the capacity per bank can be supplied from nearby power stations and these are indicated in red.

Table 2-5.6 Study of Capacitor Capacity

(MVar)

| S/S | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | | 2023 | | 2028 | | Recommendation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Bank Capacity | No. of Bank |
| Gifurwe | | | | | 2 | | 1 | | 1 | 5 | 5 | 10+3 | 10 | | 5 | 2 |
| Gihira | | | | 1 | 1 | | 1 | | | | | | | | | |
| Gishoma | | | | | | | | | | | 10 | | | | 5 | 2 |
| Kigoma | 5 | | 5 | | | | | | | | | | | | 5 | 1 |
| Kirehe | | | | | 1 | 1 | 5 | | | | | | | | 5 | 1 |
| Mt.Kigali | | | | | | | 5 | | 5+2 | 10 | | | 15 | | 5 | 3 |
| Mukungwa | | | | | | | | | | | | 10 | 30 | | 10 | 3 |
| Musha | | 5 | | | | | | 5 | 5 | | 10 | | 20 | | 5 | 4 |
| Ndera | | | | | | | | 5 | 5 | 10 | | | 30 | 20 | 5 | 6 |
| Ngarama | | | | | | | | | | | 5 | | 10 | | 5 | 2 |
| Nyabugogo | | | | | | | | | | | | | 20 | | 10 | 2 |
| Rubona | | | | | | | | | | | 10 | | 20 | | 10 | 2 |
| Rulindo | | | | | | | | | | | 10 | | 10 | | 10 | 1 |
| Rwinkwabu | 5 | | 10 | | | | 5 | 5 | | | 5 | | 10 | | 5 | 2 |
| Shango | | | 6 | | | | | | | | 10 | | 90 | 60 | 10 | 10 |

In Japan, when large scale customers are connected, installation of capacitors is sometimes discussed with operators. In Rwanda, too, it is recommended that guidelines be formulated concerning the new connection of receiving facilities such as tea plants and so on in future.

Here, improvement was sought through installing modulating capacitors to modulate the bus line voltage.

Figure. 2-5.21 and Figure. 2-5.22 show the power flow diagrams before and after improvement (outlines of these flow diagrams are shown in Figure. 2-5.23 and Figure. 2-5.24).

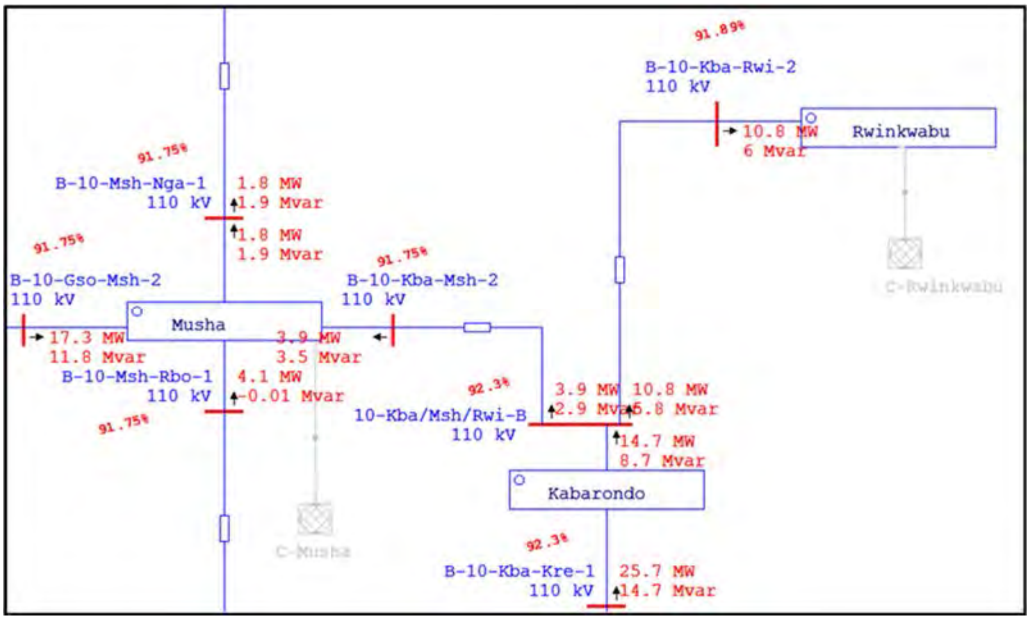



Fig. 2-5.21 Load flow of before the improvement

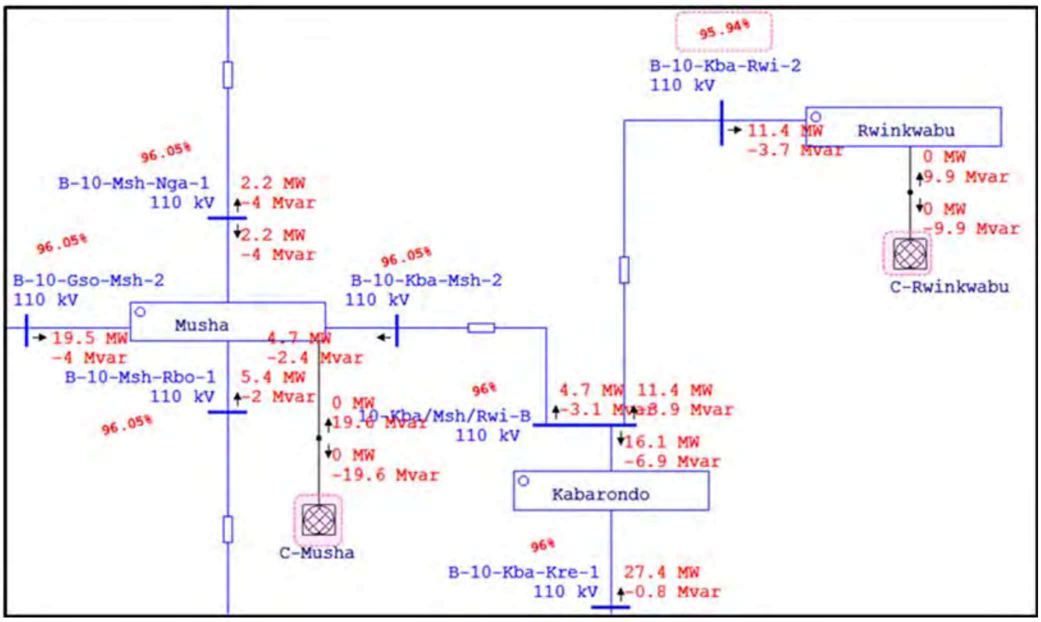



Fig. 2-5.22 Load flow of after the improvement

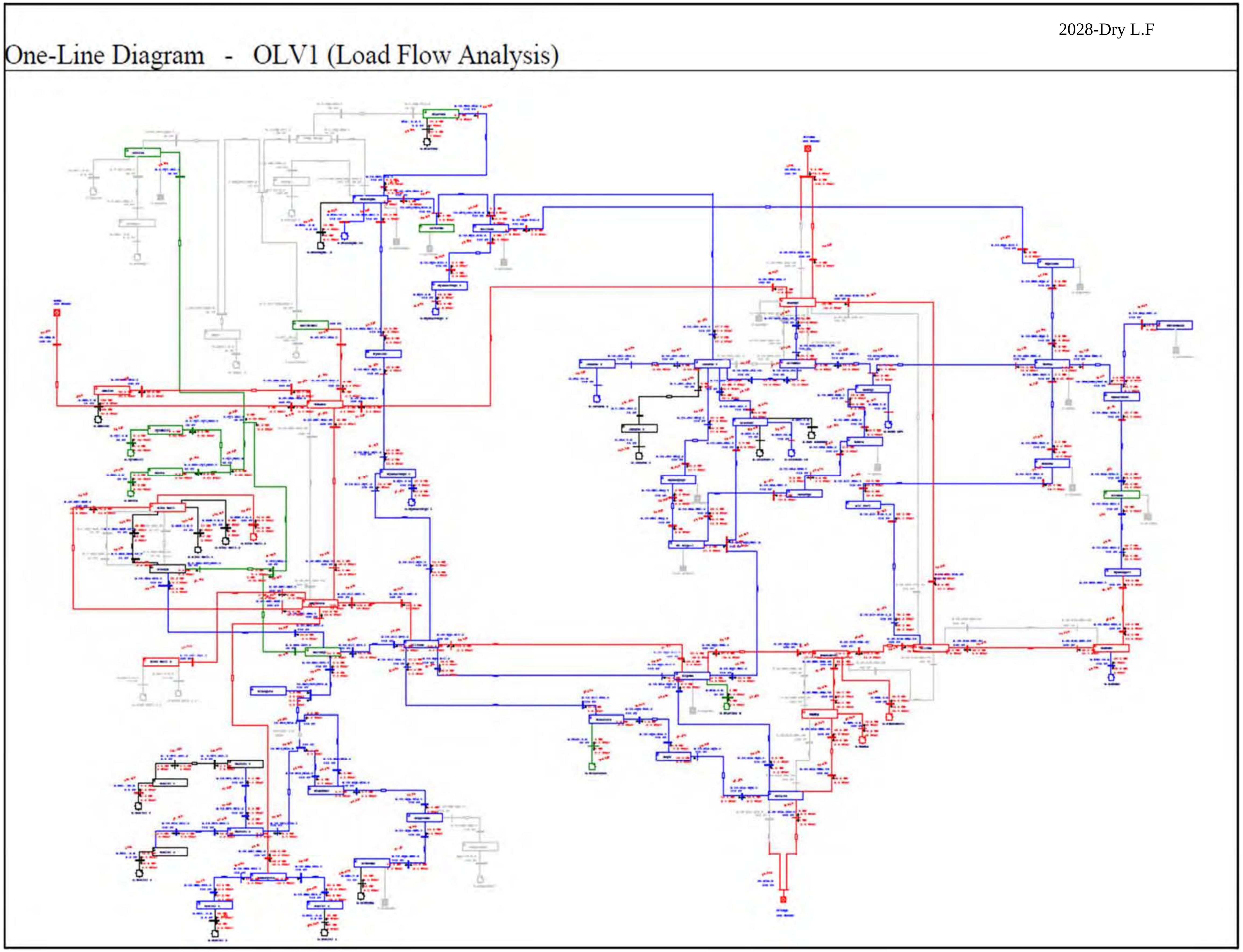



Fig. 2-5.23 Result of Load Flow Analysis by ETAP (before the improvement)

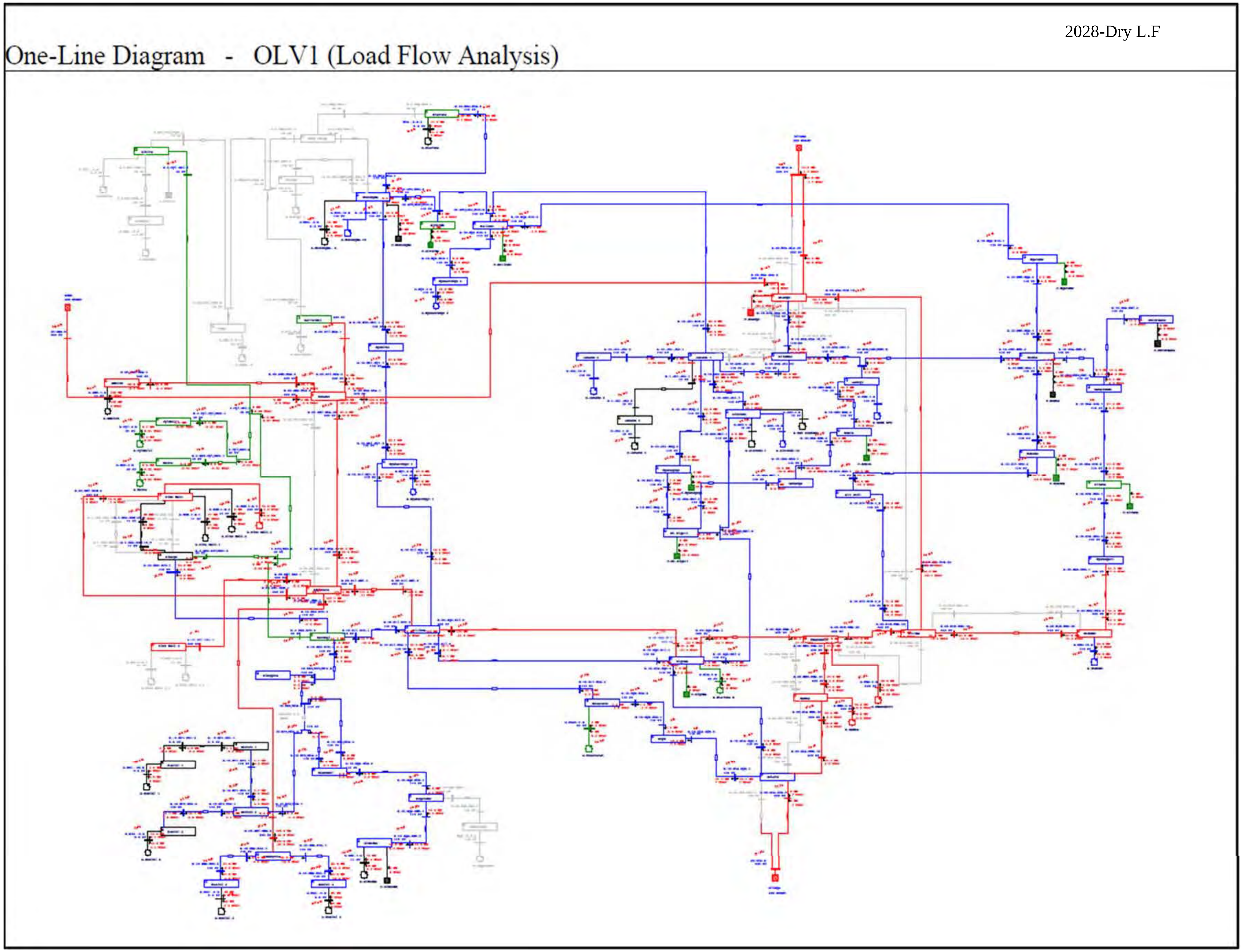



Fig. 2-5.24 Result of Load Flow Analysis by ETAP (after the improvement)

### 2.5.4. Aprropriate timing and cost of Facility Renewal

If the existing facilities are used continuously above their rated capacities to meet the increased power demand in the future, it can lead to equipment burnout or fire due to overcurrent. In such events, it might not be possible to continue the operation of the damaged facilities. Thus, any part of a facility that is in need of enhancement must be replaced at a proper time.

The system analyses based on the demand estimated in the study revealed areas that require new facility construction or renewal of the existing facility. The time and cost for such work are listed in Table 2-5.7 and 2-5.8.

Upon planning a renewal work, it is necessary to determine the proper time by understanding in advance the demand increase for the area as well as the schedule for the equipment procurement and work itself. Care must also be taken so that no substation or other facility will suffer overload during the transmission system operation due to the suspension of the operation of the facility where the work is being conducted.

# Table 2-5.7 Cost Estimation of Substation Development (1/6)

(USD)

Substation

| Items | Cost | | | |
|---|---|---|---|---|
| **Air Port** | Total | | | **13,460,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 12,490,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 100 | MVA | 90,000 | 9,000,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 270,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Cost | | | |
|---|---|---|---|---|
| **Birembo** | Total | | | **4,410,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 0 |
| AC/DC Supply | | set | 200,000 | 0 |
| SCADA System including 48V DC supply | | set | 500,000 | 0 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 4,320,000 |
| Civil Work and Building | | | | 500,000 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 500,000 |
| Bay | 3 | Bay | 100,000 | 300,000 |
| Transformer | 1 | Tr. | 200,000 | 200,000 |
| Feeder Bay | 3 | set | 350,000 | 1,050,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | 4 | Bay | 180,000 | 720,000 |
| Transformer | 20 | MVA | 90,000 | 1,800,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 90,000 |
| Feeder Bay | | Bay | 90,000 | 0 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Cost | | | |
|---|---|---|---|---|
| **Bugarama** | Total | | | **6,840,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 5,870,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | | set | 350,000 | 0 |
| Transformer Bay | | set | 250,000 | 0 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | 4 | Bay | 180,000 | 720,000 |
| Transformer | 35 | MVA | 90,000 | 3,150,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 270,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Cost | | | |
|---|---|---|---|---|
| **Butare** | Total | | | **22,280,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 14,940,000 |
| Civil Work and Building | | | | 3,500,000 |
| New | 1 | set | 3,500,000 | 3,500,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | 1 | set | 520,000 | 520,000 |
| Transformer Bay | 1 | set | 500,000 | 500,000 |
| Bus Coupler | 1 | set | 520,000 | 520,000 |
| Control and Protection | 5 | Bay | 180,000 | 900,000 |
| Transformer | 100 | MVA | 90,000 | 9,000,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 6,370,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 4 | Bay | 180,000 | 720,000 |
| Transformer | 30 | MVA | 90,000 | 2,700,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 270,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Cost | | | |
|---|---|---|---|---|
| **Bwinshura** | Total | | | **8,170,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 7,200,000 |
| Civil Work and Building | | | | 3,500,000 |
| New | 1 | set | 3,500,000 | 3,500,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | 1 | set | 520,000 | 520,000 |
| Transformer Bay | 1 | set | 500,000 | 500,000 |
| Bus Coupler | 1 | set | 520,000 | 520,000 |
| Control and Protection | 7 | Bay | 180,000 | 1,260,000 |
| Transformer | 10 | MVA | 90,000 | 900,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | | set | 350,000 | 0 |
| Transformer Bay | | set | 250,000 | 0 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 270,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Cost | | | |
|---|---|---|---|---|
| **Gahanga** | Total | | | **8,960,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 7,990,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 50 | MVA | 90,000 | 4,500,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 270,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Cost | | | |
|---|---|---|---|---|
| **Gasogi** | Total | | | **3,980,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 0 |
| AC/DC Supply | | set | 200,000 | 0 |
| SCADA System including 48V DC supply | | set | 500,000 | 0 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 3,890,000 |
| Civil Work and Building | | | | 400,000 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 400,000 |
| Bay | 2 | Bay | 100,000 | 200,000 |
| Transformer | 1 | Tr. | 200,000 | 200,000 |
| Feeder Bay | | set | 350,000 | 0 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 30 | MVA | 90,000 | 2,700,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 90,000 |
| Feeder Bay | | Bay | 90,000 | 0 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Cost | | | |
|---|---|---|---|---|
| **Gifurwe** | Total | | | **7,530,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 5,790,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 3 | set | 250,000 | 750,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 4 | Bay | 180,000 | 720,000 |
| Transformer | 18 | MVA | 90,000 | 1,620,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 1,040,000 |
| Feeder Bay | 2 | Bay | 90,000 | 180,000 |
| Transformer Bay | 3 | Bay | 90,000 | 270,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | 10 | MVA | 50,000 | 500,000 |

## Table 2-5.7 Cost Estimation of Substation Development (2/6)

(USD)

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Gishoma** | | Total | | **8,090,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 6,440,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 2 | set | 250,000 | 500,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 30 | MVA | 90,000 | 2,700,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 950,000 |
| Feeder Bay | 2 | Bay | 90,000 | 180,000 |
| Transformer Bay | 2 | Bay | 90,000 | 180,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | 10 | MVA | 50,000 | 500,000 |

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Huye** | | Total | | **6,710,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 5,740,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 25 | MVA | 90,000 | 2,250,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 270,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Jabana 1** | | Total | | **5,670,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 0 |
| AC/DC Supply | | set | 200,000 | 0 |
| SCADA System including 48V DC supply | | set | 500,000 | 0 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 5,490,000 |
| Civil Work and Building | | | | 500,000 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 500,000 |
| Bay | 1 | Bay | 100,000 | 100,000 |
| Transformer | 2 | Tr. | 200,000 | 400,000 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 2 | set | 250,000 | 500,000 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 40 | MVA | 90,000 | 3,600,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 180,000 |
| Feeder Bay | | Bay | 90,000 | 0 |
| Transformer Bay | 2 | Bay | 90,000 | 180,000 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Kabarondo** | | Total | | **2,250,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 0 |
| AC/DC Supply | | set | 200,000 | 0 |
| SCADA System including 48V DC supply | | set | 500,000 | 0 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 2,160,000 |
| Civil Work and Building | | | | 300,000 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 300,000 |
| Bay | 1 | Bay | 100,000 | 100,000 |
| Transformer | 1 | Tr. | 200,000 | 200,000 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | 2 | Bay | 180,000 | 360,000 |
| Transformer | 10 | MVA | 90,000 | 900,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 90,000 |
| Feeder Bay | | Bay | 90,000 | 0 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Kamanyora** | | Total | | **27,950,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 23,580,000 |
| Civil Work and Building | | | | 3,500,000 |
| New | 1 | set | 3,500,000 | 3,500,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | 1 | set | 520,000 | 520,000 |
| Transformer Bay | 1 | set | 500,000 | 500,000 |
| Bus Coupler | 1 | set | 520,000 | 520,000 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 200 | MVA | 90,000 | 18,000,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 3,670,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 4 | Bay | 180,000 | 720,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 0 |
| Feeder Bay | | Bay | 90,000 | 0 |
| Transformer Bay | | Bay | 90,000 | 0 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Karongi** | | Total | | **1,260,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 0 |
| AC/DC Supply | | set | 200,000 | 0 |
| SCADA System including 48V DC supply | | set | 500,000 | 0 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 1,170,000 |
| Civil Work and Building | | | | 200,000 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 200,000 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | 1 | Tr. | 200,000 | 200,000 |
| Feeder Bay | | set | 350,000 | 0 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | 1 | Bay | 180,000 | 180,000 |
| Transformer | 6 | MVA | 90,000 | 540,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 90,000 |
| Feeder Bay | | Bay | 90,000 | 0 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Kibogora** | | Total | | **1,260,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 0 |
| AC/DC Supply | | set | 200,000 | 0 |
| SCADA System including 48V DC supply | | set | 500,000 | 0 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 1,170,000 |
| Civil Work and Building | | | | 200,000 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 200,000 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | 1 | Tr. | 200,000 | 200,000 |
| Feeder Bay | | set | 350,000 | 0 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | 1 | Bay | 180,000 | 180,000 |
| Transformer | 6 | MVA | 90,000 | 540,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 90,000 |
| Feeder Bay | | Bay | 90,000 | 0 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Kibuye** | | Total | | **450,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 0 |
| AC/DC Supply | | set | 200,000 | 0 |
| SCADA System including 48V DC supply | | set | 500,000 | 0 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | | set | 350,000 | 0 |
| Transformer Bay | | set | 250,000 | 0 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 450,000 |
| Feeder Bay | | Bay | 90,000 | 0 |
| Transformer Bay | 2 | Bay | 90,000 | 180,000 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | 3 | MVA | 90,000 | 270,000 |
| Capacitor | | MVA | 50,000 | 0 |

# Table 2-5.7 Cost Estimation of Substation Development (3/6)

(USD)

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Kigoma** | | Total | | **16,660,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 12,850,000 |
| Civil Work and Building | | | | 3,500,000 |
| New | 1 | set | 3,500,000 | 3,500,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | 2 | set | 520,000 | 1,040,000 |
| Transformer Bay | 1 | set | 500,000 | 500,000 |
| Bus Coupler | 1 | set | 520,000 | 520,000 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 75 | MVA | 90,000 | 6,750,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 2,590,000 |
| Civil Work and Building | | | | 300,000 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 300,000 |
| Bay | 1 | Bay | 100,000 | 100,000 |
| Transformer | 1 | Tr. | 200,000 | 200,000 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 2 | set | 250,000 | 500,000 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 10 | MVA | 90,000 | 900,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 520,000 |
| Feeder Bay | 2 | Bay | 90,000 | 180,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | 5 | MVA | 50,000 | 250,000 |

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Kilinda** | | Total | | **14,740,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 0 |
| AC/DC Supply | | set | 200,000 | 0 |
| SCADA System including 48V DC supply | | set | 500,000 | 0 |
| 220KV | | | M.Total | 12,850,000 |
| Civil Work and Building | | | | 3,500,000 |
| New | 1 | set | 3,500,000 | 3,500,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | 2 | set | 520,000 | 1,040,000 |
| Transformer Bay | 1 | set | 500,000 | 500,000 |
| Bus Coupler | 1 | set | 520,000 | 520,000 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 75 | MVA | 90,000 | 6,750,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 1,800,000 |
| Civil Work and Building | | | | 400,000 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 400,000 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | 2 | Tr. | 200,000 | 400,000 |
| Feeder Bay | | set | 350,000 | 0 |
| Transformer Bay | 2 | set | 250,000 | 500,000 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | 2 | Bay | 180,000 | 360,000 |
| Transformer | 6 | MVA | 90,000 | 540,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 90,000 |
| Feeder Bay | | Bay | 90,000 | 0 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Kirehe** | | Total | | **6,420,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 5,110,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 2 | Bay | 180,000 | 360,000 |
| Transformer | 20 | MVA | 90,000 | 1,800,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 610,000 |
| Feeder Bay | 2 | Bay | 90,000 | 180,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | 5 | MVA | 50,000 | 250,000 |

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Mamba** | | Total | | **8,980,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 7,920,000 |
| Civil Work and Building | | | | 3,500,000 |
| New | 1 | set | 3,500,000 | 3,500,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | 1 | set | 520,000 | 520,000 |
| Transformer Bay | 1 | set | 500,000 | 500,000 |
| Bus Coupler | 1 | set | 520,000 | 520,000 |
| Control and Protection | 6 | Bay | 180,000 | 1,080,000 |
| Transformer | 20 | MVA | 90,000 | 1,800,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | | set | 350,000 | 0 |
| Transformer Bay | | set | 250,000 | 0 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 360,000 |
| Feeder Bay | 2 | Bay | 90,000 | 180,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Mt.Kigali** | | Total | | **6,570,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 0 |
| AC/DC Supply | | set | 200,000 | 0 |
| SCADA System including 48V DC supply | | set | 500,000 | 0 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 6,390,000 |
| Civil Work and Building | | | | 400,000 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 400,000 |
| Bay | 2 | Bay | 100,000 | 200,000 |
| Transformer | 1 | Tr. | 200,000 | 200,000 |
| Feeder Bay | 2 | set | 350,000 | 700,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 50 | MVA | 90,000 | 4,500,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 180,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Mukungwa** | | Total | | **11,310,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 0 |
| AC/DC Supply | | set | 200,000 | 0 |
| SCADA System including 48V DC supply | | set | 500,000 | 0 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 3,960,000 |
| Civil Work and Building | | | | 300,000 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 300,000 |
| Bay | 1 | Bay | 100,000 | 100,000 |
| Transformer | 1 | Tr. | 200,000 | 200,000 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | 2 | Bay | 180,000 | 360,000 |
| Transformer | 30 | MVA | 90,000 | 2,700,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 7,350,000 |
| Feeder Bay | | Bay | 90,000 | 0 |
| Transformer Bay | 5 | Bay | 90,000 | 450,000 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | 60 | MVA | 90,000 | 5,400,000 |
| Capacitor | 30 | MVA | 50,000 | 1,500,000 |

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Musha** | | Total | | **7,660,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 0 |
| AC/DC Supply | | set | 200,000 | 0 |
| SCADA System including 48V DC supply | | set | 500,000 | 0 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 6,030,000 |
| Civil Work and Building | | | | 800,000 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 800,000 |
| Bay | 2 | Bay | 100,000 | 200,000 |
| Transformer | 3 | Tr. | 200,000 | 600,000 |
| Feeder Bay | 2 | set | 350,000 | 700,000 |
| Transformer Bay | 3 | set | 250,000 | 750,000 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | 6 | Bay | 180,000 | 1,080,000 |
| Transformer | 30 | MVA | 90,000 | 2,700,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 1,630,000 |
| Feeder Bay | 4 | Bay | 90,000 | 360,000 |
| Transformer Bay | 3 | Bay | 90,000 | 270,000 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | 20 | MVA | 50,000 | 1,000,000 |

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Ndera** | | Total | | **10,460,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 7,810,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 2 | Bay | 180,000 | 360,000 |
| Transformer | 50 | MVA | 90,000 | 4,500,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 1,950,000 |
| Feeder Bay | 3 | Bay | 90,000 | 270,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | 30 | MVA | 50,000 | 1,500,000 |

# Table 2-5.7 Cost Estimation of Substation Development (4/6)

(USD)

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Ngarama** | Total | | | **6,670,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 5,110,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 2 | Bay | 180,000 | 360,000 |
| Transformer | 20 | MVA | 90,000 | 1,800,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 860,000 |
| Feeder Bay | 2 | Bay | 90,000 | 180,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | 10 | MVA | 50,000 | 500,000 |

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Ntaruka** | Total | | | **1,890,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 0 |
| AC/DC Supply | | set | 200,000 | 0 |
| SCADA System including 48V DC supply | | set | 500,000 | 0 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | | set | 350,000 | 0 |
| Transformer Bay | | set | 250,000 | 0 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 1,890,000 |
| Feeder Bay | | Bay | 90,000 | 0 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | 20 | MVA | 90,000 | 1,800,000 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Ntendezi** | Total | | | **5,540,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 4,570,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 4 | Bay | 180,000 | 720,000 |
| Transformer | 10 | MVA | 90,000 | 900,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 270,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Nyabarongo 1** | Total | | | **5,540,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 4,570,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 4 | Bay | 180,000 | 720,000 |
| Transformer | 10 | MVA | 90,000 | 900,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 270,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Nyabarongo 2** | Total | | | **6,260,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 5,290,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 20 | MVA | 90,000 | 1,800,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 270,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Nyabihu** | Total | | | **5,360,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 4,390,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 10 | MVA | 90,000 | 900,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 270,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Nyabugari** | Total | | | **18,410,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 12,150,000 |
| Civil Work and Building | | | | 3,500,000 |
| New | 1 | set | 3,500,000 | 3,500,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | 1 | set | 520,000 | 520,000 |
| Transformer Bay | 1 | set | 500,000 | 500,000 |
| Bus Coupler | 1 | set | 520,000 | 520,000 |
| Control and Protection | 2 | Bay | 180,000 | 360,000 |
| Transformer | 75 | MVA | 90,000 | 6,750,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 5,290,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 20 | MVA | 90,000 | 1,800,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 270,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

Substation

| Items | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Nyabugogo** | Total | | | **10,920,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 8,770,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 2 | set | 350,000 | 700,000 |
| Transformer Bay | 2 | set | 250,000 | 500,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 4 | Bay | 180,000 | 720,000 |
| Transformer | 50 | MVA | 90,000 | 4,500,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 1,450,000 |
| Feeder Bay | 2 | Bay | 90,000 | 180,000 |
| Transformer Bay | 2 | Bay | 90,000 | 180,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | 20 | MVA | 50,000 | 1,000,000 |

# Table 2-5.7 Cost Estimation of Substation Development (5/6)

(USD)

| Items (Substation) | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Rilima** | | Total | | **28,760,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 19,800,000 |
| Civil Work and Building | | | | 3,500,000 |
| New | 1 | set | 3,500,000 | 3,500,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | 1 | set | 520,000 | 520,000 |
| Transformer Bay | 1 | set | 500,000 | 500,000 |
| Bus Coupler | 1 | set | 520,000 | 520,000 |
| Control and Protection | 7 | Bay | 180,000 | 1,260,000 |
| Transformer | 150 | MVA | 90,000 | 13,500,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 7,990,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 50 | MVA | 90,000 | 4,500,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 270,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

| Items (Substation) | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Rubabu** | | Total | | **8,170,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 7,200,000 |
| Civil Work and Building | | | | 3,500,000 |
| New | 1 | set | 3,500,000 | 3,500,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | 1 | set | 520,000 | 520,000 |
| Transformer Bay | 1 | set | 500,000 | 500,000 |
| Bus Coupler | 1 | set | 520,000 | 520,000 |
| Control and Protection | 7 | Bay | 180,000 | 1,260,000 |
| Transformer | 10 | MVA | 90,000 | 900,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | | set | 350,000 | 0 |
| Transformer Bay | | set | 250,000 | 0 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 270,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

| Items (Substation) | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Rubona** | | Total | | **10,490,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 8,340,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 2 | set | 350,000 | 700,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 3 | Bay | 180,000 | 540,000 |
| Transformer | 50 | MVA | 90,000 | 4,500,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 1,450,000 |
| Feeder Bay | 3 | Bay | 90,000 | 270,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | 20 | MVA | 50,000 | 1,000,000 |

| Items (Substation) | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Rukarara** | | Total | | **3,550,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 0 |
| AC/DC Supply | | set | 200,000 | 0 |
| SCADA System including 48V DC supply | | set | 500,000 | 0 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 3,460,000 |
| Civil Work and Building | | | | 400,000 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 400,000 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | 2 | Tr. | 200,000 | 400,000 |
| Feeder Bay | | set | 350,000 | 0 |
| Transformer Bay | | set | 250,000 | 0 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | 2 | Bay | 180,000 | 360,000 |
| Transformer | 30 | MVA | 90,000 | 2,700,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 90,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | | Bay | 90,000 | 0 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

| Items (Substation) | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Rulindo** | | Total | | **5,090,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 0 |
| AC/DC Supply | | set | 200,000 | 0 |
| SCADA System including 48V DC supply | | set | 500,000 | 0 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 4,320,000 |
| Civil Work and Building | | | | 600,000 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 600,000 |
| Bay | 2 | Bay | 100,000 | 200,000 |
| Transformer | 2 | Tr. | 200,000 | 400,000 |
| Feeder Bay | 2 | set | 350,000 | 700,000 |
| Transformer Bay | 2 | set | 250,000 | 500,000 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | 4 | Bay | 180,000 | 720,000 |
| Transformer | 20 | MVA | 90,000 | 1,800,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 770,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 2 | Bay | 90,000 | 180,000 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | 10 | MVA | 50,000 | 500,000 |

| Items (Substation) | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Rusumo** | | Total | | **16,340,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 12,510,000 |
| Civil Work and Building | | | | 3,500,000 |
| New | 1 | set | 3,500,000 | 3,500,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | 1 | set | 520,000 | 520,000 |
| Transformer Bay | 1 | set | 500,000 | 500,000 |
| Bus Coupler | 1 | set | 520,000 | 520,000 |
| Control and Protection | 4 | Bay | 180,000 | 720,000 |
| Transformer | 75 | MVA | 90,000 | 6,750,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 3,130,000 |
| Civil Work and Building | | | | 2,000,000 |
| New | 1 | set | 2,000,000 | 2,000,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | 1 | set | 350,000 | 350,000 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | 1 | set | 350,000 | 350,000 |
| Control and Protection | 1 | Bay | 180,000 | 180,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 0 |
| Feeder Bay | | Bay | 90,000 | 0 |
| Transformer Bay | | Bay | 90,000 | 0 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

| Items (Substation) | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Ruwabusoro** | | Total | | **12,670,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 700,000 |
| AC/DC Supply | 1 | set | 200,000 | 200,000 |
| SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| 220KV | | | M.Total | 11,700,000 |
| Civil Work and Building | | | | 3,500,000 |
| New | 1 | set | 3,500,000 | 3,500,000 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | 1 | set | 520,000 | 520,000 |
| Transformer Bay | 1 | set | 500,000 | 500,000 |
| Bus Coupler | 1 | set | 520,000 | 520,000 |
| Control and Protection | 7 | Bay | 180,000 | 1,260,000 |
| Transformer | 60 | MVA | 90,000 | 5,400,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | | Tr. | 200,000 | 0 |
| Feeder Bay | | set | 350,000 | 0 |
| Transformer Bay | | set | 250,000 | 0 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 270,000 |
| Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |

| Items (Substation) | Qty. | Unit | Unit Price | S.Total |
|---|---|---|---|---|
| **Rwinkwabu** | | Total | | **3,200,000** |
| Equipment | Qty. | Unit | Unit Price | S.Total |
| 220/110KV | | | M.Total | 0 |
| AC/DC Supply | | set | 200,000 | 0 |
| SCADA System including 48V DC supply | | set | 500,000 | 0 |
| 220KV | | | M.Total | 0 |
| Civil Work and Building | | | | 0 |
| New | | set | 3,500,000 | 0 |
| Expantion | | | | 0 |
| Bay | | Bay | 150,000 | 0 |
| Transformer | | Tr. | 400,000 | 0 |
| Feeder Bay | | set | 520,000 | 0 |
| Transformer Bay | | set | 500,000 | 0 |
| Bus Coupler | | set | 520,000 | 0 |
| Control and Protection | | Bay | 180,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | | MVA | 50,000 | 0 |
| 110KV | | | M.Total | 2,430,000 |
| Civil Work and Building | | | | 200,000 |
| New | | set | 2,000,000 | 0 |
| Expantion | | | | 200,000 |
| Bay | | Bay | 100,000 | 0 |
| Transformer | 1 | Tr. | 200,000 | 200,000 |
| Feeder Bay | | set | 350,000 | 0 |
| Transformer Bay | 1 | set | 250,000 | 250,000 |
| Bus Coupler | | set | 350,000 | 0 |
| Control and Protection | 1 | Bay | 180,000 | 180,000 |
| Transformer | 20 | MVA | 90,000 | 1,800,000 |
| Capacitor | | MVA | 50,000 | 0 |
| 30(15)KV | | | M.Total | 770,000 |
| Feeder Bay | 2 | Bay | 90,000 | 180,000 |
| Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| Bus Coupler | | Bay | 90,000 | 0 |
| Transformer | | MVA | 90,000 | 0 |
| Capacitor | 10 | MVA | 50,000 | 500,000 |

# Table 2-5.7 Cost Estimation of Substation Development (6/6)

(USD)

| Items | | Cost | | | |
|---|---|---|---|---|---|
| Substation | Shango | Total | | | 56,270,000 |
| | Equipment | Qty. | Unit | Unit Price | S.Total |
| | 220/110KV | | | M.Total | 700,000 |
| | AC/DC Supply | 1 | set | 200,000 | 200,000 |
| | SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| | 220KV | | | M.Total | 46,000,000 |
| | Civil Work and Building | | | | 3,500,000 |
| | New | 1 | set | 3,500,000 | 3,500,000 |
| | Expantion | | | | 0 |
| | Bay | | Bay | 150,000 | 0 |
| | Transformer | | Tr. | 400,000 | 0 |
| | Feeder Bay | 14 | set | 520,000 | 7,280,000 |
| | Transformer Bay | 1 | set | 500,000 | 500,000 |
| | Bus Coupler | 1 | set | 520,000 | 520,000 |
| | Control and Protection | 15 | Bay | 180,000 | 2,700,000 |
| | Transformer | 300 | MVA | 90,000 | 27,000,000 |
| | Capacitor | 90 | MVA | 50,000 | 4,500,000 |
| | 110KV | | | M.Total | 9,300,000 |
| | Civil Work and Building | | | | 2,000,000 |
| | New | 1 | set | 2,000,000 | 2,000,000 |
| | Expantion | | | | 0 |
| | Bay | | Bay | 100,000 | 0 |
| | Transformer | | Tr. | 200,000 | 0 |
| | Feeder Bay | 3 | set | 350,000 | 1,050,000 |
| | Transformer Bay | 2 | set | 250,000 | 500,000 |
| | Bus Coupler | 1 | set | 350,000 | 350,000 |
| | Control and Protection | 5 | Bay | 180,000 | 900,000 |
| | Transformer | 50 | MVA | 90,000 | 4,500,000 |
| | Capacitor | | MVA | 50,000 | 0 |
| | 30(15)KV | | | M.Total | 270,000 |
| | Feeder Bay | 1 | Bay | 90,000 | 90,000 |
| | Transformer Bay | 1 | Bay | 90,000 | 90,000 |
| | Bus Coupler | 1 | Bay | 90,000 | 90,000 |
| | Transformer | | MVA | 90,000 | 0 |
| | Capacitor | | MVA | 50,000 | 0 |

| Items | | Cost | | | |
|---|---|---|---|---|---|
| Substation | Simbion | Total | | | 19,780,000 |
| | Equipment | Qty. | Unit | Unit Price | S.Total |
| | 220/110KV | | | M.Total | 700,000 |
| | AC/DC Supply | 1 | set | 200,000 | 200,000 |
| | SCADA System including 48V DC supply | 1 | set | 500,000 | 500,000 |
| | 220KV | | | M.Total | 19,080,000 |
| | Civil Work and Building | | | | 3,500,000 |
| | New | 1 | set | 3,500,000 | 3,500,000 |
| | Expantion | | | | 0 |
| | Bay | | Bay | 150,000 | 0 |
| | Transformer | | Tr. | 400,000 | 0 |
| | Feeder Bay | 1 | set | 520,000 | 520,000 |
| | Transformer Bay | 1 | set | 500,000 | 500,000 |
| | Bus Coupler | 1 | set | 520,000 | 520,000 |
| | Control and Protection | 3 | Bay | 180,000 | 540,000 |
| | Transformer | 150 | MVA | 90,000 | 13,500,000 |
| | Capacitor | | MVA | 50,000 | 0 |
| | 110KV | | | M.Total | 0 |
| | Civil Work and Building | | | | 0 |
| | New | | set | 2,000,000 | 0 |
| | Expantion | | | | 0 |
| | Bay | | Bay | 100,000 | 0 |
| | Transformer | | Tr. | 200,000 | 0 |
| | Feeder Bay | | set | 350,000 | 0 |
| | Transformer Bay | | set | 250,000 | 0 |
| | Bus Coupler | | set | 350,000 | 0 |
| | Control and Protection | | Bay | 180,000 | 0 |
| | Transformer | | MVA | 90,000 | 0 |
| | Capacitor | | MVA | 50,000 | 0 |
| | 30(15)KV | | | M.Total | 0 |
| | Feeder Bay | | Bay | 90,000 | 0 |
| | Transformer Bay | | Bay | 90,000 | 0 |
| | Bus Coupler | | Bay | 90,000 | 0 |
| | Transformer | | MVA | 90,000 | 0 |
| | Capacitor | | MVA | 50,000 | 0 |

# Table 2-5.8 Cost Estimation of Transmission Line Development

(USD)

| Section | Type | Unit Price | Length | Unit | Total |
|---|---|---|---|---|---|
| 220KV | **Total** | | | | **154,502,500** |
| 2015 | | | | M.Total | 54,447,000 |
| Mirama | Single | 185,000 | 0.0 | km | 22,080,000 |
| - Shango | Double | 240,000 | 92.0 | | |
| Rubabu | Single | 185,000 | 106.2 | km | 19,647,000 |
| - Shango | Double | 240,000 | 0.0 | | |
| Shango | Single | 185,000 | 0.0 | km | 12,720,000 |
| - Rilima | Double | 240,000 | 53.0 | | |
| 2016 | | | | M.Total | 42,350,000 |
| Bwinshura | Single | 185,000 | 0.0 | km | 12,888,000 |
| - Rubabu | Double | 240,000 | 53.7 | | |
| Bwinshura | Single | 185,000 | 0.0 | km | 12,888,000 |
| - Rubabu | Double | 240,000 | 53.7 | | |
| Bwinshura | Single | 185,000 | 3.7 | km | 684,500 |
| - Kivu Watt | Double | 240,000 | 0.0 | | |
| Kigoma | Single | 185,000 | 13.9 | km | 2,571,500 |
| - Rwabusoro | Double | 240,000 | 0.0 | | |
| Bwinshura | Single | 185,000 | 42.8 | km | 7,918,000 |
| - Kilinda | Double | 240,000 | 0.0 | | |
| Rilima | Single | 185,000 | 0.0 | km | 5,400,000 |
| - Rwabusoro | Double | 240,000 | 22.5 | | |
| 2017 | | | | M.Total | 22,354,500 |
| Butare | Single | 185,000 | 0.0 | km | 4,800,000 |
| - Mamba | Double | 240,000 | 20.0 | | |
| Rilima | Single | 185,000 | 0.0 | km | 16,056,000 |
| - Rusumo | Double | 240,000 | 66.9 | | |
| Rubabu | Single | 185,000 | 8.1 | km | 1,498,500 |
| - Simbion | Double | 240,000 | 0.0 | | |
| 2018 | | | | M.Total | 92,500 |
| Nyabugari | Single | 185,000 | 0.5 | km | 92,500 |
| - Rusumo | Double | 240,000 | 0.0 | | |
| 2023 | | | | M.Total | 31,558,500 |
| Bwinshura | Single | 185,000 | 92.1 | km | 17,038,500 |
| - Kamanyora | Double | 240,000 | 0.0 | | |
| Butare | Single | 185,000 | 0.0 | km | 5,472,000 |
| - Gitega | Double | 240,000 | 22.8 | | |
| Mamba | Single | 185,000 | 0.0 | km | 9,048,000 |
| - Rwabusoro | Double | 240,000 | 37.7 | | |
| 2028 | | | | M.Total | 3,700,000 |
| Kinigi | Single | 185,000 | 20.0 | km | 3,700,000 |
| - Mukungwa | Double | 240,000 | 0.0 | | |

| Section | Type | Unit Price | Length | Unit | S.Total |
|---|---|---|---|---|---|
| 110KV | **Total** | | | | **74,659,200** |
| 2014 | | | | M.Total | 7,788,000 |
| Bugarama | Single | 120,000 | 11.0 | km | 1,320,000 |
| - Gishoma | Double | 192,000 | 0.0 | | |
| Klinda | Single | 120,000 | 24.6 | km | 2,952,000 |
| - Nyabarongo 1 | Double | 192,000 | 0.0 | | |
| Klinda | Single | 120,000 | 29.3 | km | 3,516,000 |
| - Rukarara | Double | 192,000 | 0.0 | | |
| 2015 | | | | M.Total | 14,671,200 |
| Birembo | Single | 120,000 | 0.0 | km | 1,651,200 |
| - Shango | Double | 192,000 | 8.6 | | |
| Butare | Single | 120,000 | 41.2 | km | 4,944,000 |
| - Kigoma | Double | 192,000 | 0.0 | | |
| Gasogi | Single | 120,000 | 6.5 | km | 780,000 |
| - Ndera | Double | 192,000 | 0.0 | | |
| Jabana 1 | Single | 120,000 | 7.8 | km | 936,000 |
| - Nyabugogo | Double | 192,000 | 0.0 | | |
| Mt.Kigali | Single | 120,000 | 6.4 | km | 768,000 |
| - Nyabugogo | Double | 192,000 | 0.0 | | |
| Mukungwa | Single | 120,000 | 23.3 | km | 2,796,000 |
| - Nyabihu | Double | 192,000 | 0.0 | | |
| Mukungwa | Single | 120,000 | 23.3 | km | 2,796,000 |
| - Nyabihu | Double | 192,000 | 0.0 | | |
| 2016 | | | | M.Total | 30,360,000 |
| Butare | Single | 120,000 | 19.7 | km | 2,364,000 |
| - Huye | Double | 192,000 | 0.0 | | |
| Gahanga | Single | 120,000 | 7.9 | km | 948,000 |
| - Mt.Kigali | Double | 192,000 | 0.0 | | |
| Gahanga | Single | 120,000 | 15.1 | km | 1,812,000 |
| - Ndera | Double | 192,000 | 0.0 | | |
| Huye | Single | 120,000 | 22.0 | km | 2,640,000 |
| - Rukarara | Double | 192,000 | 0.0 | | |
| Kabarondo | Single | 120,000 | 32.0 | km | 3,840,000 |
| - Kirehe | Double | 192,000 | 0.0 | | |
| Kigoma | Single | 120,000 | 20.7 | km | 2,484,000 |
| - Kilinda | Double | 192,000 | 0.0 | | |
| Musha | Single | 120,000 | 47.6 | km | 5,712,000 |
| - Ngarama | Double | 192,000 | 0.0 | | |
| Ngarama | Single | 120,000 | 44.0 | km | 5,280,000 |
| - Rilima | Double | 192,000 | 0.0 | | |
| Ngarama | Single | 120,000 | 44.0 | km | 5,280,000 |
| - Rilima | Double | 192,000 | 0.0 | | |
| 2017 | | | | M.Total | 6,672,000 |
| Nyabarongo 1 | Single | 120,000 | 42.8 | km | 5,136,000 |
| - Nyabihu | Double | 192,000 | 0.0 | | |
| Nyabarongo | Single | 120,000 | 12.8 | km | 1,536,000 |
| - Rilima | Double | 192,000 | 0.0 | | |
| 2018 | | | | M.Total | 2,040,000 |
| Kirehe | Single | 120,000 | 17.0 | km | 2,040,000 |
| - Nyabugari | Double | 192,000 | 0.0 | | |
| 2023 | | | | M.Total | 13,128,000 |
| Air Port | Single | 120,000 | 30.6 | km | 3,672,000 |
| - Rubona | Double | 192,000 | 0.0 | | |
| Air Port | Single | 120,000 | 15.2 | km | 1,824,000 |
| - Rilima | Double | 192,000 | 0.0 | | |
| Kamanyora | Single | 120,000 | 11.0 | km | 1,320,000 |
| - Ruzizi 3 | Double | 192,000 | 0.0 | | |
| Kamanyora | Single | 120,000 | 22.0 | km | 2,640,000 |
| - Ruzizi 4 | Double | 192,000 | 0.0 | | |
| Musha | Single | 120,000 | 10.3 | km | 1,236,000 |
| - Rubona | Double | 192,000 | 0.0 | | |
| Musha | Single | 120,000 | 10.3 | km | 1,236,000 |
| - Rubona | Double | 192,000 | 0.0 | | |
| Bugarama | Single | 120,000 | 10.0 | km | 1,200,000 |
| - Bugarama 2 | Double | 192,000 | 0.0 | | |

## 2.6. Power Development by Least-Cost-Development Method

### 2.6.1. Concept of Least-Cost-Development

The production and consumption of electricity, different from other goods, occur at the same time. Therefore, it is necessary to adjust the output of power stations or start and stop the facilities to meet ever-changing demand.

On the other hand, in terms of power generation cost structure, hydraulic power stations compared with diesel power stations for example, usually have higher capital costs per output (kW) and lower marginal operation cost per electric energy output (kWh). Thus, hydraulic power stations are more beneficial than diesel power stations at higher utilization factor and vice versa. Consequently, if hydraulic power stations operate continuously (Base Load Operation) while diesel power stations operate when demand is high (Peak Load Operation), the aggregate generation cost can be lower than the generation cost with singular power generation source (Best Mix).

As above, combining diversified power generation sources with various cost behavior in response to utilization factor to seek lowest aggregate generation cost while meeting the fluctuating demand, is "Least-Cost-Development."

During 4$^{th}$ work in Rwanda, a technology transfer workshop will take place for REG staff to instruct the methodologies of Least-Cost-Development, similar to the instruction of demand forecast, so that REG will be able to update electricity development master plan with own cost data in the future.

### 2.6.2. Steps for Simulation

(1) Estimate the fixed and variable costs of each power generation source in order to evaluate the variations of annual costs in response to utilization factor.

(2) Draw the generation duration curve of horizon year with reserve margin based on the demand forecast carried out in this project.

(3) Seek the portfolio of power generation sources that is expected to provide lowest generation cost, based on "Least-Cost-Development" concept, with the information in (1) and (2) as above.

(4) Confirm the consistency with the existing power sources and ongoing installation. Adjust step (3) if discrepancies are found.

(5) Perform power system analysis to find transmission and transformation facilities to be upgraded (see the section of Power System Analysis for detail), if a combination of generation sources with lowest cost and satisfying the conditions, is found.

(6) Determine the priorities and the development schedule of the power stations to be installed until the horizon year, in compliance with the concept of "Least-Cost-Development."

### 2.6.3. Preparing Load Duration Curve

Load Duration Curve is drawn with a set of load data during a certain period (e.g., a year), sorted by the magnitude of the load regardless of chronological order. Such curve is used to find most economical power generation portfolio composed of multiple power sources with various generation cost and cost structure (i.e., the ratio of fixed and variable costs). For this masterplan study, a template that is formed by Monte-Carlo method with the statistical properties of 2013 load data is magnified so that the maximum load is equal to the forecasted demand of the corresponding year as calculated in the previous section of this report. The procedure is as follows:

#### (1) Organizing 2013 Load Data

At first, the hourly load data of 2013 were grouped under the days of the week since the electricity demand of Rwanda does not have seasonal variation. However, the data of holidays are collected separately and there are eight groups, Holiday in addition to the seven groups from Monday to Sunday.

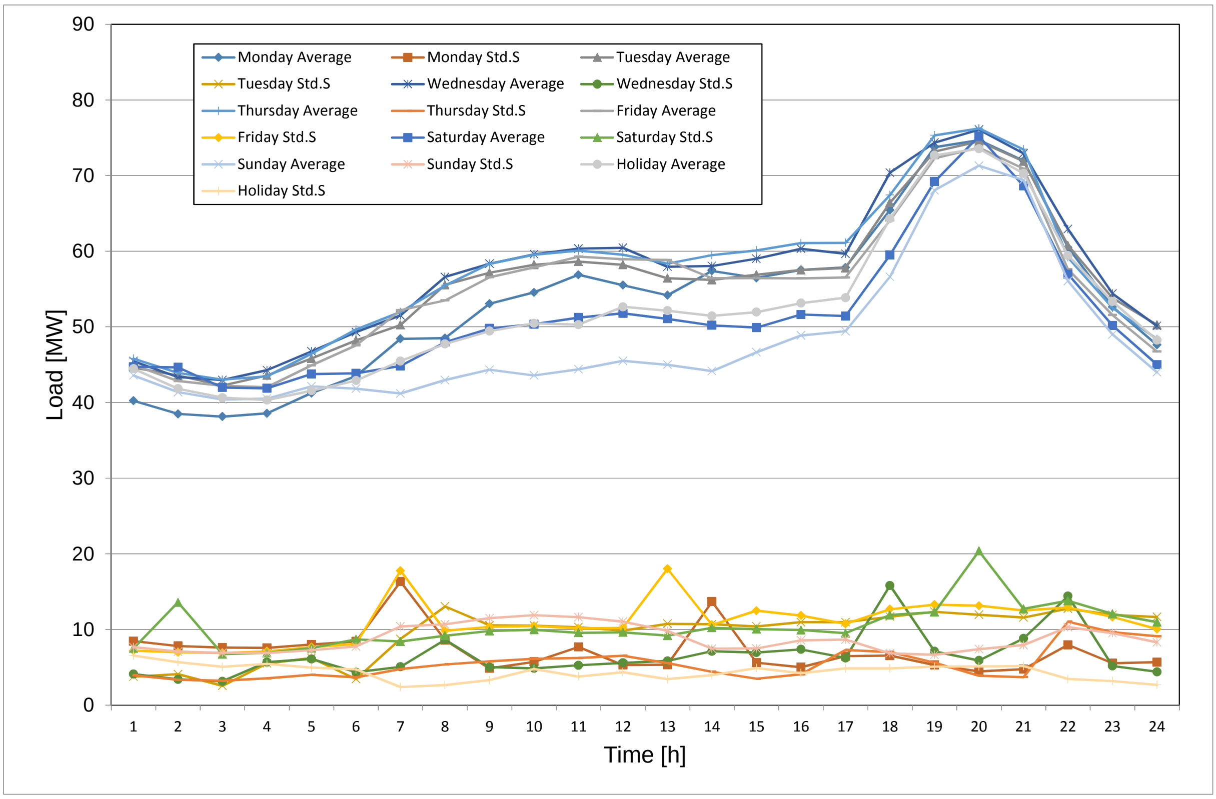



Fig. 2-6.1 Population Means and Standard Deviation Hourly Load (incl. abnormal values)

Some load data are 0[MW] representing missing values. Therefore, if the values are summarized with authentic data, the demand will be underestimated. Thus, null data are manually removed before statistical analysis. Then, Smirnoff-Grubbs test is performed on each cluster of data, which may contain "abnormal values," even null data have been already removed, assuming normal distribution. As the result, sequences of remarkably low data, probably due to load shedding, are also removed as well as accidental outliers.

Table 2-6.1 Elimination of Abnormal Values (Red: Too High, Blue: Too Low, Yellow: Missing)

| | Time[h] | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/7 | Monday | 39.21 | 36.59 | 37.41 | 38.01 | 41.34 | 43.16 | 46.64 | 49.03 | 49.44 | 50.76 | 51.81 | 51.42 | 54.4 | 57.66 | 58.7 | 57.39 | 59.12 | 69.04 | 78.36 | 78.44 | 61.24 | 50.84 | 48.43 | 46.72 |
| 1/14 | Monday | 35.53 | 40.38 | 39.94 | 39.38 | 44.01 | 45.6 | 47.3 | 51.43 | 52.38 | 48.01 | 51.75 | 59.85 | 50.93 | 56.9 | 57.72 | 58.31 | 86.83 | 57.87 | 75.76 | 72.31 | 69.88 | 59.89 | 55.36 | 51.69 |
| 1/21 | Monday | 41.33 | 40.24 | 40.79 | 41.53 | 45.88 | 46.65 | 44.05 | 45.48 | 45.93 | 47.68 | 48.34 | 49.22 | 47.09 | 45.36 | 48.24 | 51.03 | 50.66 | 44.15 | 57.22 | 68.78 | 65.31 | 52.8 | 53.2 | 48.06 |
| 1/28 | Monday | 39.45 | 37.61 | 36.26 | 37.42 | 42.21 | 44.88 | 43.5 | 45.17 | 49.56 | 56.02 | 58.66 | 57.15 | 47.04 | 47.51 | 47.56 | 47.71 | 47.66 | 52.64 | 62.42 | 62.78 | 57.98 | 51.5 | 46.42 | 43.18 |
| 2/4 | Monday | 40.62 | 39.63 | 40.46 | 40.71 | 43.4 | 43.85 | 45.06 | 47.37 | 47.4 | 49.31 | 48.05 | 50.6 | 47 | 45.64 | 49.32 | 51.8 | 49.93 | 54.23 | 67.41 | 72.69 | 71.07 | 66.64 | 60.4 | 50.56 |
| 2/11 | Monday | 42.69 | 41.95 | 41.83 | 41.27 | 45.79 | 49.18 | 47.75 | 49.34 | 54.24 | 57.7 | 57.58 | 57.09 | 51.93 | 142.28 | 58.59 | 57.89 | 52.8 | 64.39 | 73.23 | 71.9 | 71.39 | 55.61 | 44.99 | 40.42 |
| 2/18 | Monday | 42.8 | 40.32 | 40.04 | 40.29 | 42.92 | 49.39 | 51.13 | 48.76 | 57.28 | 60.68 | 61.02 | 60.24 | 56.88 | 59.78 | 61.08 | 63.45 | 61.27 | 66.55 | 74.34 | 73.44 | 69.8 | 42.88 | 40.15 | 34.77 |
| 2/25 | Monday | 37.18 | 36.77 | 34.54 | 34.8 | 36.13 | 42.63 | 44.18 | 45 | 50.55 | 49.61 | 52.32 | 54.25 | 54.53 | 53.54 | 55.63 | 59.45 | 56.04 | 62.91 | 74.14 | 80.54 | 70.01 | 56.78 | 51.6 | 48.83 |
| 3/4 | Monday | 41.52 | 38.52 | 37.86 | 38.54 | 42.47 | 47.4 | 134.76 | 55.42 | 56.36 | 57.75 | 56.02 | 55.36 | 57.38 | 57.8 | 58.27 | 60.04 | 61.05 | 58.68 | 66.42 | 75.91 | 74.41 | 58.33 | 53.12 | 48.07 |
| 3/11 | Monday | 37.16 | 34.61 | 33.95 | 34.62 | 38.84 | 39.18 | 41.56 | 46.2 | 49.02 | 46.79 | 51.15 | 53.14 | 50.91 | 56.64 | 55.15 | 55.67 | 54.13 | 62.58 | 71.95 | 67.25 | 68.15 | 66.04 | 60.05 | 46.58 |
| 3/18 | Monday | 31.6 | 31.1 | 31.9 | 31.1 | 31.9 | 33.3 | 35.4 | 37.11 | 48.84 | 47.24 | 53.63 | 56.3 | 50.34 | 50.89 | 53.36 | 56.16 | 53.45 | 65.66 | 67.24 | 69.95 | 67.98 | 43.49 | 37.76 | 33.96 |
| 3/25 | Monday | 36.72 | 31.38 | 32.19 | 33.18 | 34.87 | 38.68 | 45.32 | 47.64 | 49.14 | 51.57 | 53.35 | 52.28 | 51.77 | 52.9 | 50.78 | 55.23 | 55.31 | 62.26 | 63.38 | 63.06 | 61.93 | 53.76 | 46.21 | 41.06 |
| 4/1 | Monday | 52.23 | 46.26 | 43.79 | 41.7 | 41.01 | 43.41 | 41.76 | 46.51 | 44.68 | 45.86 | 47.04 | 46.05 | 46.17 | 47.3 | 45.28 | 44.55 | 46.55 | 56.33 | 66.95 | 70.02 | 68.03 | 58.86 | 51.82 | 43.98 |
| 4/8 | Monday | 44.4 | 44.02 | 42.78 | 44.67 | 48.85 | 48.3 | 52.42 | 51.63 | 57.68 | 59.24 | 59.43 | 56.56 | 57.14 | 58.34 | 58.39 | 59.34 | 59.81 | 66.67 | 78.96 | 81.86 | 77.5 | 64.3 | 52.72 | 48.12 |
| 4/15 | Monday | 44.98 | 44.49 | 44.17 | 44.42 | 48.63 | 50.49 | 56.19 | 54.92 | 53.03 | 56.64 | 57.9 | 57.84 | 60.65 | 59.48 | 60.49 | 62.64 | 62.04 | 62.83 | 69.9 | 78.65 | 77.29 | 56.6 | 49.31 | 46.73 |
| 4/22 | Monday | 45.66 | 44.51 | 44.65 | 44.9 | 50.6 | 52.69 | 52.92 | 54.24 | 54.1 | 51.94 | 52.93 | 50.96 | 50.79 | 53.53 | 53.2 | 54 | 51.15 | 60.66 | 69.16 | 69.09 | 64.08 | 61.1 | 56.22 | 49.4 |
| 4/29 | Monday | 41.22 | 37.94 | 39.7 | 39.29 | 39.95 | 46.07 | 47.56 | 49.02 | 54.52 | 49.13 | 56.68 | 58.96 | 56.33 | 54.91 | 58.22 | 58.44 | 55.4 | 67.96 | 74.35 | 78.39 | 76.28 | 55.16 | 48.08 | 47.64 |
| 5/6 | Monday | 39.69 | 39.92 | 37.87 | 38.5 | 40.41 | 44.5 | 49.22 | 54.98 | 56.86 | 60.22 | 60.51 | 60.54 | 60.63 | 58.32 | 58.45 | 59.73 | 62.11 | 73.86 | 79.29 | 76.55 | 72.69 | 55.6 | 50.3 | 45.17 |
| 5/13 | Monday | 32.73 | 31.95 | 31.87 | 32.5 | 38.1 | 40.55 | 41.96 | 45.83 | 51.82 | 54.14 | 55.61 | 54.91 | 52.58 | 61.02 | 60.62 | 61.2 | 62.75 | 66.89 | 77.13 | 79.23 | 75.06 | 59.98 | 51.58 | 44.38 |
| 5/20 | Monday | 36.51 | 35.53 | 35.7 | 37.1 | 41.75 | 43.21 | 42.97 | 38.84 | 50.9 | 57.33 | 56.81 | 59.64 | 54.12 | 57.91 | 62.05 | 55.89 | 61.94 | 74.95 | 81.12 | 77.7 | 74.84 | 55.65 | 46.1 | 33.29 |
| 5/27 | Monday | 38.83 | 37.79 | 35.97 | 38.01 | 43.98 | 46.65 | 45.52 | 55.91 | 59.41 | 58.61 | 57.33 | 57.45 | 56.13 | 55.63 | 58.95 | 60.07 | 58.67 | 59.72 | 74.85 | 80.39 | 79.42 | 89.7 | 57.13 | 52.47 |
| 6/3 | Monday | 40.54 | 38.58 | 37.32 | 39.36 | 43.76 | 44.81 | 45.57 | 47.02 | 54.12 | 56.06 | 57.94 | 54.12 | 57.49 | 55 | 59.22 | 60.02 | 56.77 | 67.28 | 78.69 | 77.29 | 69.92 | 68.68 | 54.71 | 49.87 |
| 6/10 | Monday | 40.24 | 37.88 | 36.94 | 36.3 | 37.72 | 42.29 | 45.93 | 50.27 | 53.54 | 53.99 | 84.52 | 50.71 | 52.09 | 56.51 | 51.31 | 57.15 | 57.91 | 62.94 | 74.31 | 74.48 | 72.93 | 58.72 | 46.67 | 46.07 |
| 6/17 | Monday | 41.09 | 39.26 | 39.33 | 40.19 | 43.17 | 45.45 | 43.08 | 55.85 | 55.35 | 58.59 | 59.01 | 57.23 | 56.18 | 58.36 | 55.31 | 57.75 | 52.6 | 71.68 | 75.45 | 75.57 | 75.86 | 60.77 | 54.01 | 50.48 |
| 6/24 | Monday | 40.28 | 39.05 | 39 | 42.14 | 45.31 | 51.15 | 42.6 | 43.86 | 47.33 | 48.29 | 49.48 | 46.22 | 47.71 | 61.62 | 63.26 | 63.14 | 61.62 | 72.34 | 77.74 | 77.87 | 77.42 | 54.97 | 48.24 | 41.82 |
| 7/8 | Monday | 40.36 | 38.63 | 38.67 | 39.99 | 42.06 | 44.18 | 44.02 | 48.91 | 54.19 | 56.84 | 58.77 | 58.63 | 56.87 | 57.65 | 61.02 | 60.65 | 59.39 | 67.58 | 79.05 | 79.3 | 76.4 | 57.82 | 57.24 | 51.09 |
| 7/15 | Monday | 41.66 | 41.08 | 40.51 | 42.43 | 42.74 | 46.8 | 49.7 | 57.37 | 57.76 | 59.43 | 60.59 | 60.36 | 58.3 | 60.75 | 60.22 | 60.37 | 60.15 | 71.19 | 77.8 | 77.19 | 73.81 | 55.09 | 52.27 | 50.38 |
| 7/22 | Monday | 45.94 | 43.05 | 42.28 | 41.6 | 43.04 | 46.97 | 49.32 | 47.06 | 56.29 | 59.69 | 61.82 | 59.96 | 65.6 | 61.62 | 63.08 | 59.45 | 59.29 | 72.47 | 79.9 | 79.64 | 73.83 | 60.98 | 52.63 | 48.85 |
| 7/29 | Monday | 44.25 | 41.56 | 40.95 | 41.68 | 43.81 | 39.4 | 48.75 | 54.82 | 59.14 | 61.88 | 60.85 | 59.94 | 60.34 | 60.73 | 59.37 | 62.9 | 64.8 | 72.89 | 76.59 | 75.74 | 75.99 | 71.35 | 62.69 | 54.54 |
| 8/5 | Monday | 44.94 | 42.38 | 40.58 | 40.91 | 41.28 | 44.82 | 50.07 | 52.01 | 60.83 | 59.59 | 61.75 | 62.54 | 61.62 | 59.31 | 68.5 | 61.95 | 56.52 | 66.37 | 76.39 | 76.62 | 77.6 | 67.59 | 52.61 | 50.07 |
| 8/12 | Monday | 46.45 | 39.15 | 42.44 | 42.77 | 45.19 | 47.55 | 51.11 | 52.28 | 57.61 | 61.73 | 59.8 | 58.71 | 56.79 | 58.73 | 60.69 | 61.23 | 62.54 | 66.14 | 68.9 | 74.22 | 70.36 | 65.05 | 53.2 | 37.44 |
| 8/19 | Monday | 41.8 | 42.33 | 41 | 41.26 | 43.68 | 46.57 | 50.29 | 53.29 | 58.71 | 61.19 | 61.77 | 59.51 | 57.66 | 59.38 | 61.48 | 61.16 | 60.69 | 73.74 | 76.39 | 76.35 | 74.02 | 65.5 | 53.95 | 48.59 |
| 8/26 | Monday | 45.03 | 40.21 | 39.59 | 31.22 | 43.69 | 45.33 | 43.51 | 52.7 | 56.03 | 56.28 | 55.75 | 56.29 | 54.15 | 58.54 | 54.45 | 56.28 | 58.72 | 57.86 | 64.16 | 66.65 | 65.38 | 57.51 | 51.1 | 47.93 |
| 9/2 | Monday | 44.03 | 41.83 | 41.27 | 41.51 | 41.9 | 47.97 | 47.88 | 49.42 | 53.55 | 54.32 | 55.64 | 54.54 | 54.99 | 55.11 | 58.95 | 59.97 | 61.77 | 68.44 | 75.89 | 76.95 | 72.83 | 49.26 | 45.33 | 43.81 |
| 9/9 | Monday | 45.1 | 41.1 | 41.4 | 43.19 | 42.58 | 47.86 | 51.29 | 52.8 | 56.25 | 59.94 | 61.37 | 60.21 | 58.6 | 60.53 | 59.48 | 63.98 | 62.94 | 67.51 | 72.03 | 74.95 | 73.34 | 57.93 | 51.98 | 50.83 |
| 9/16 | Monday | 43.98 | 42.42 | 41.31 | 41.89 | 43.09 | 41.44 | 42.09 | 40.19 | 48.05 | 46.51 | 47.96 | 50.14 | 49.37 | 49.54 | 48.97 | 53.01 | 54.5 | 67.81 | 75.87 | 76.58 | 75.11 | 66.04 | 61.88 | 57.55 |
| 9/23 | Monday | 42.14 | 41.73 | 41.5 | 42.73 | 46.11 | 47.88 | 50.49 | 51.46 | 57.57 | 59.9 | 61.09 | 61.36 | 58.03 | 62.11 | 59.56 | 58.48 | 63.46 | 71.03 | 77.54 | 76.58 | 74.93 | 62.75 | 54.02 | 47.51 |
| 9/30 | Monday | 43.8 | 40.75 | 40.18 | 41.3 | 46.17 | 46.24 | 46.73 | 48.36 | 51.98 | 54.18 | 54.03 | 47.15 | 50.34 | 48.39 | 49.16 | 62.36 | 57.95 | 67.53 | 70.92 | 71.15 | 67.27 | 70.15 | 60.39 | 48.34 |
| 10/7 | Monday | 44.41 | 41.6 | 40.51 | 40.67 | 40.37 | 45.71 | 48.19 | 53.16 | 53.9 | 58.41 | 57.69 | 60.22 | 57.32 | 59.41 | 59.62 | 60.15 | 60.87 | 75.95 | 75.97 | 75.69 | 76 | 62.06 | 55.11 | 52.59 |
| 10/14 | Monday | 46.74 | 43.82 | 43.74 | 42.33 | 45.98 | 46.2 | 47.11 | 50.88 | 53.13 | 49.31 | 49.66 | 49.27 | 48.52 | 50.1 | 50.31 | 49.33 | 51.42 | 68.5 | 76.52 | 71.14 | 71.06 | 58.76 | 52.72 | 48.85 |
| 10/21 | Monday | 46.63 | 45.13 | 45.29 | 45.81 | 46.13 | 48.57 | 89.75 | 50.73 | 51.65 | 53.92 | 50.86 | 54.1 | 56.17 | 53.51 | 52.13 | 51.92 | 52.41 | 63.58 | 73.93 | 72.06 | 69.03 | 58.07 | 52.72 | 48.8 |
| 10/28 | Monday | 45.42 | 43.96 | 43.74 | 47.71 | 46.03 | 45.52 | 47.55 | 43.71 | 43.25 | 43.7 | 51.47 | 46.35 | 39.06 | 46.09 | 46.36 | 55.26 | 58.23 | 68.29 | 76.35 | 72.71 | 72.05 | 60 | 52.27 | 51.63 |
| 12/2 | Monday | 10.7 | 11.72 | 13.12 | 16.66 | 16.69 | 17.5 | 47.5 | 53.25 | 58.7 | 59.47 | 59.79 | 57.12 | 55.77 | 57.81 | 62.41 | 58.1 | 57.99 | 70.56 | 72.11 | 71.66 | 71.78 | 63.7 | 57.87 | 45.5 |
| 12/9 | Monday | 42.53 | 40.15 | 39.17 | 40.19 | 43.44 | 41.94 | 44.7 | 44.72 | 36.49 | 37.37 | 36.3 | 39.07 | 41.65 | 42.69 | 41.54 | 39.24 | 45.16 | 54.99 | 72.66 | 76.54 | 73.31 | 71.47 | 49.92 | 62.69 |
| 12/16 | Monday | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 58.49 | 61.99 | 64.04 | 63.52 | 60.5 | 61.61 | 60.26 | 60.39 | 51.22 | 58.82 | 76.42 | 76.48 | 75.28 | 66.14 | 56.34 | 50.3 |
| 12/23 | Monday | 36.69 | 38.81 | 37.77 | 38.04 | 41.11 | 40.08 | 45.81 | 49.38 | 50.78 | 55.6 | 80.98 | 58.37 | 55.64 | 61.51 | 60.09 | 59.54 | 60.9 | 67.36 | 81.53 | 81.64 | 79.08 | 72.63 | 65.87 | 57.04 |
| 12/30 | Monday | 44.07 | 41.88 | 41.47 | 39.14 | 40.17 | 43 | 45.47 | 56.97 | 55.61 | 59.55 | 62.76 | 63.57 | 60.61 | 47.84 | 57.18 | 59.99 | 60.45 | 71.8 | 78.93 | 76.19 | 72.81 | 64.98 | 57.11 | 49.9 |

## (2) Calculating Average and Standard Deviation

Regarding the load data, after the elimination of missing and abnormal values as above, as a set of samples by each day of the week and each hour, population means and population standard deviations are calculated.

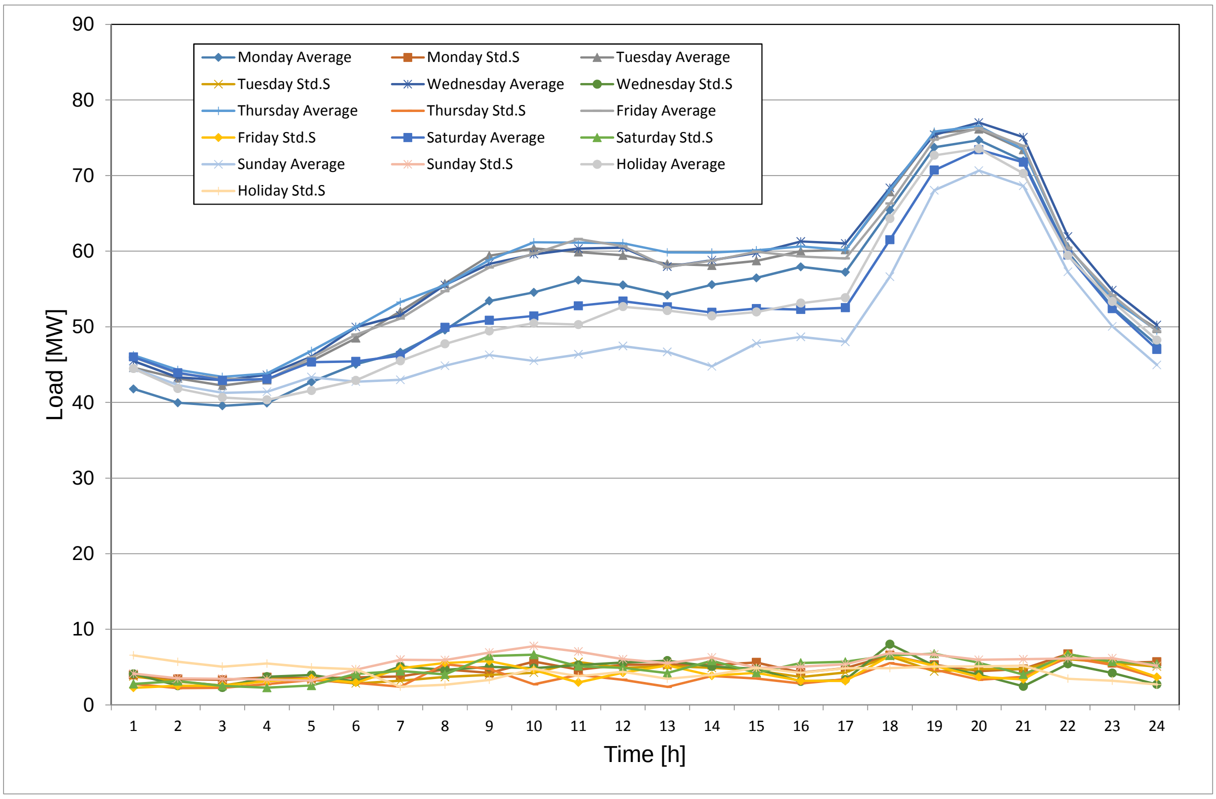



Fig. 2-6.2 Population Means and Standard Deviation Hourly Load (without abnormal values)

**(3) Preparing Annual Load Duration Curve**

Assuming that the hourly demand of each day of the week follow normal distribution, 8760 hourly load data for a year are generated by Monte-Carlo method with the population means and the population standard deviation estimated as above. In order to form a model load duration curve (the template), 131,072 (17th power of 2) sets of year-round load data are generated as noted above, each set is sorted by the magnitude of load, then the data having the same ranking in each set are averaged. Then, the template is magnified so that the maximum load is equal to the peak load of the relevant year, from 2014 to 2033, as forecasted in the previous section, and will be used for power development planning as described later.

Reserve margin is determined so that supply hindrance does not occur even when the largest two unit in the grid stop concurrently. Specifically in 2013, the aggregated peak output at power supply is estimated as 110MW, for the peak demand 87.9MW in consideration of 20% transmission loss. The largest units are three 10MW unit at Jabana 2 and the total capacity of the two units is 20MW, equivalent to 18% of the peak output at supply side. Assuming that larger generation unit will installed in parallel with the expansion of grid capacity, the reserve margin is set to 20% for the following studies in this report.

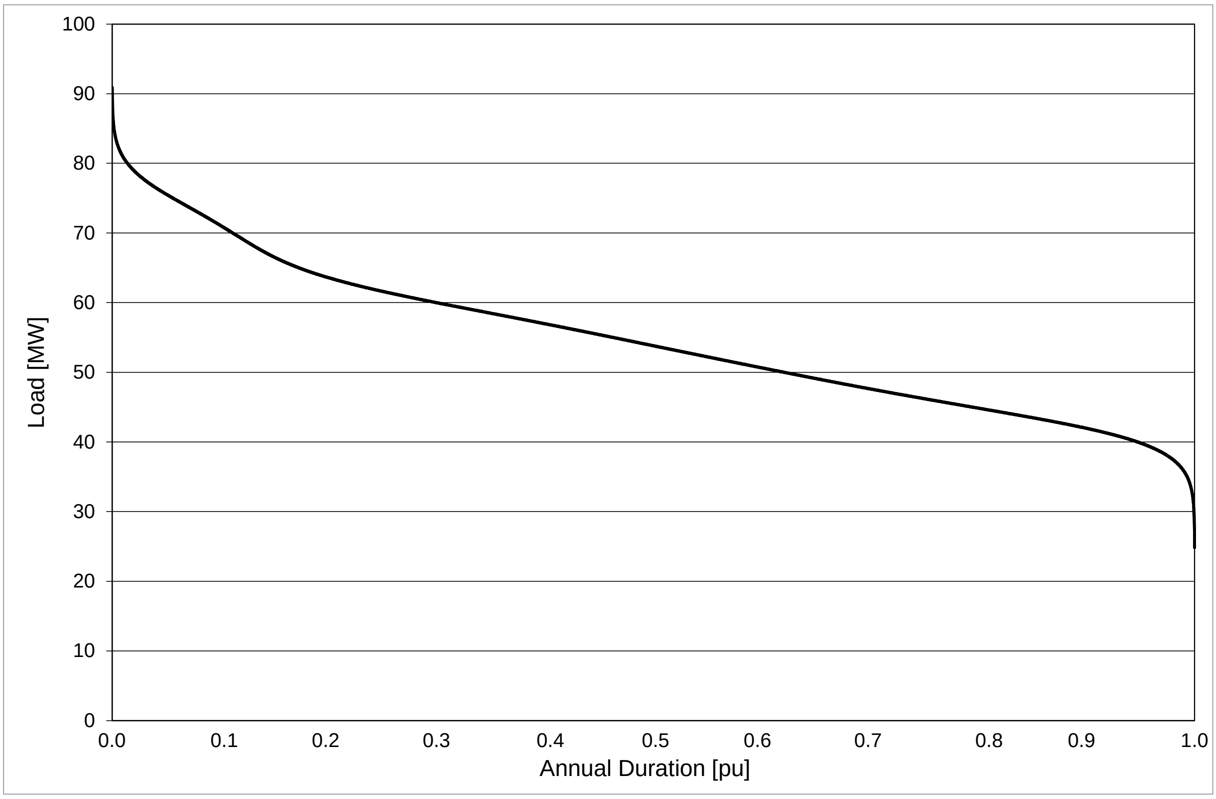
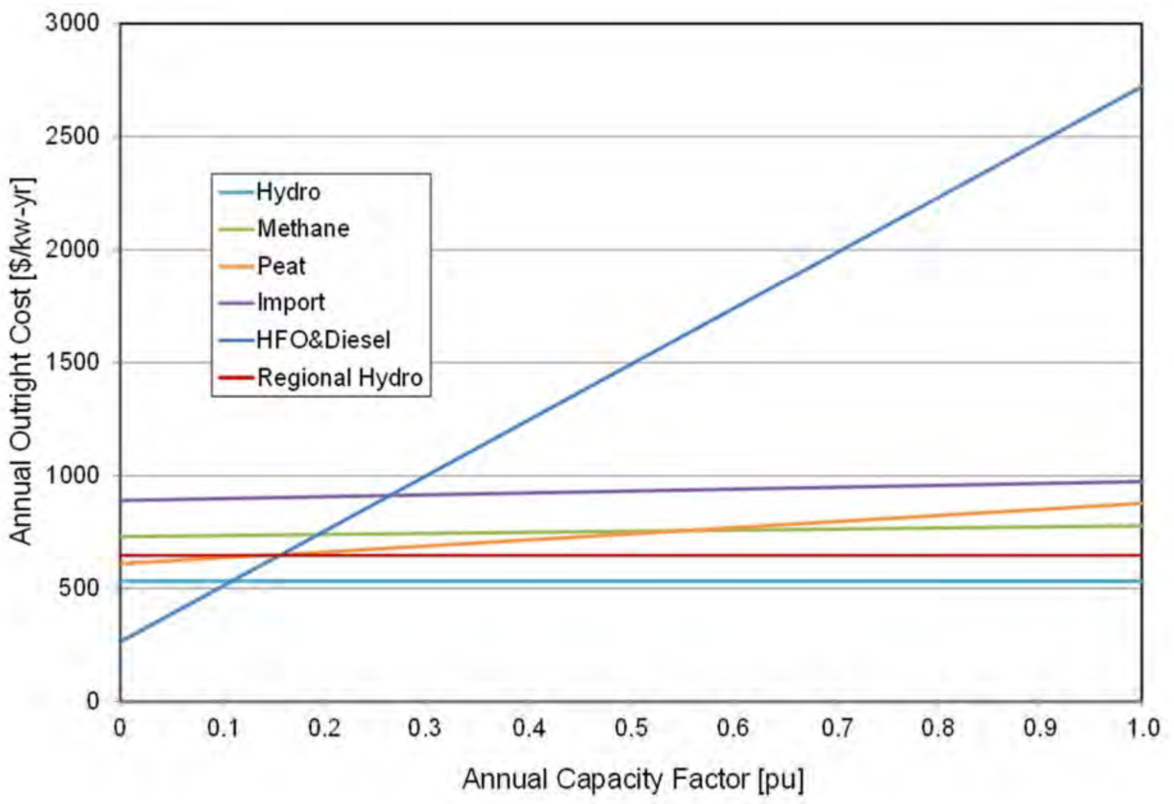



Fig. 2-6.3 Template of Annual Load Duration Curve (Based on 2013 Load)

### 2.6.4. Generation Costs by Energy Sources

The JICA study team tried to collect cost information by electrical sources for Least Cost Power Development Planning, from the documentations of REG and interview of REG staff. However, much of the data is not intended for disclosure and especially some data, for example the contract price with IPP, is limited to particular sections and the staffs in charge. In addition, the disclosure of the information regarding the generation cost of REG, may seriously affect the bargaining power of REG in negotiation with IPP, and for electricity trading/importing. Therefore, averaged costs by energy sources are used for the instruction of procedure.




Source：JICA study team, based on the information collected during the field surveys.

Fig. 2-6.4 Generation Costs by Energy Sources for Generation Planning

### 2.6.5. Power Generation Development Plan

#### (1) Formulation of the Problem

Least Cost Development can be reduced to the following optimization problem.

Suppose that there are n power stations and that the capacity, annual fixed cost, and the marginal generation cost of the i-th (1 ≤i≤n) power station are Pi[kW], FCi[$/kW/year], and MCi[$/kWh], respectively. The annual cost of the i-th power station is TCi[$/year], given by the following equation.

$$\mathrm{TC_i} = P_i * FC_i + a_i * h * P_i * MC_i$$

Where, ai[pu] is the annual load factor of the i-th power station and h is the number of hours in one year (constant: 8760[h/year]). Thus, total generation cost of the n power stations is (TC[$/year]) as follows.

$$TC = \sum_{i=1}^{n} TC_i = \sum_{i=1}^{n} (P_i * FC_i + a_i * h * P_i * MC_i)$$

Minimization of TC under given Pi (i = 1..n) is achived by the load dispatching to minimize the generation cost (economical load dispatching: ELD). In such case, the output of the power station with the lowest marginal generation cost is increased up to the capacity of the power station when the aggregate load of the power system is increasing. Conversely, the output of the power station with the highest marginal generation cost is decreased down to zero when the aggregate load is decreasing. Schematically, the loads are stacked from down to up in an order from those of less marginal generation cost, as in the figure to illustrate the relationship between duration curve and load.

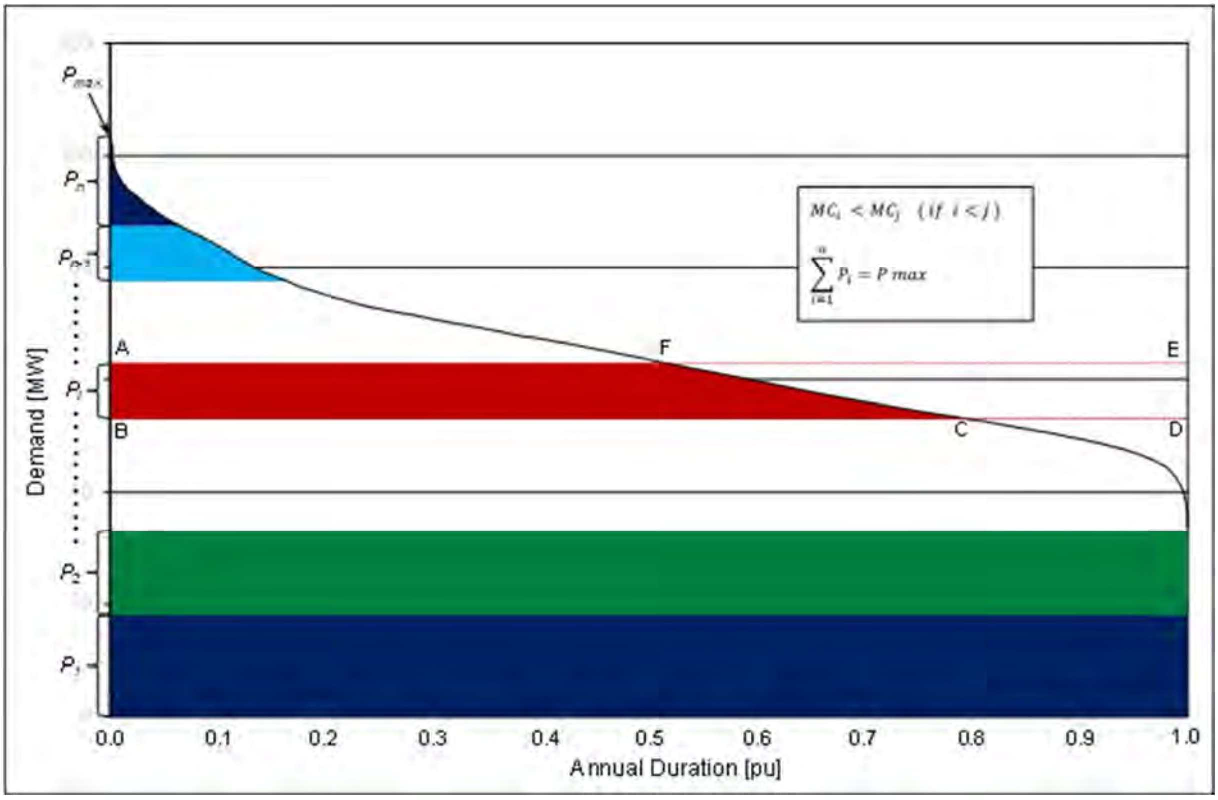



Fig. 2-6.5 Least Cost Power Development Illustrated with Load Duration Curve

In the figure, ai is defined as the proportion of the area surrounded by outline ABCF to the rectangle ABDE.

Now Least Cost Development is equivalent to determine the optimal combination of Pi, with the constraint of $\sum_{i=1}^{n} Pi$ = Pmax (maximum load) to minimize TC that is minimized by ELD under the given combination of Pi. (i = 1..n). In practical, such problem can be solved with the add-in optimizer of the commonplace spreadsheet software (e.g., LibreOffice/Openoffice, MS-Excel) for personal computers.

### (2) Study with No Constraints

For the study without constraints, a portfolio of power generation sources providing minmum generation cost with the assumption as follows.

- All power stations will be newly installed; there is no existing power stations.
- Each power generation source is inexhaustible.
- No operational constraints of power plants (e.g., minimum load).

For this case, the portfolio of generation sources to minimize generating cost, is composed of 77[%]hydro for base load and 23[%] diesel for peak load, with average generating cost at around 9[¢/kWh].

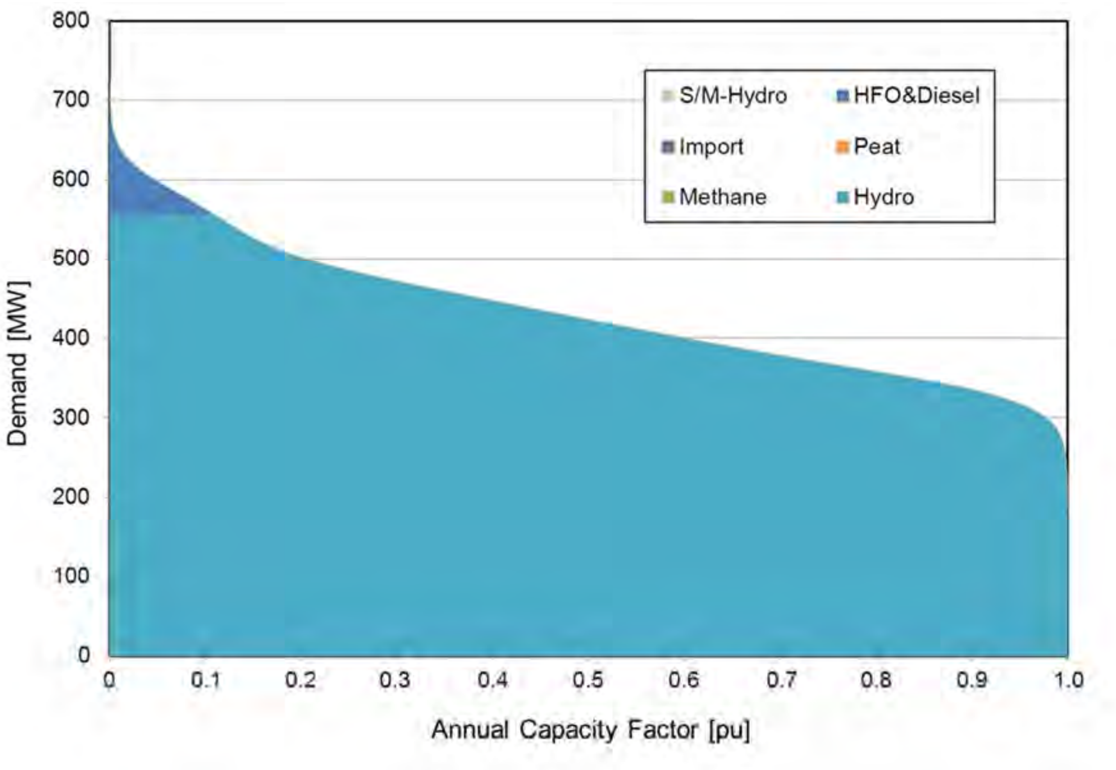



Fig. 2-6.6 Illustration of Least Cost Development Study with No Constraints

This study, though a number-crunchng in unrealistic world, is a benchmark to evaluate the generation cost with real-world conditions and assess the impact of constraints to generation cost.

### (3) Study with Constraints

For the study of least cost development in real world, it is necessary to consider constraints with exsiting and planned power stations, and operational restrictions and each power source. Existing and planned power stations are as follows.

## Table 2-6.2 Existing and Planned Power Stations Categorized by Power Source

| Year | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Grand Total** | **150.17** | **220.17** | **259.17** | **424.17** | **494.17** | **521.17** | **571.17** | **619.17** | **619.17** | **1111.2** | **1111.2** | **1206.2** | **1206.2** | **1206.2** | **1206.2** | **1206.2** | **1206.2** | **1206.2** | **1206.2** | **1206.2** |
| Existing Total | **118.17** | **118.17** | **98.17** | **98.17** | **98.17** | **98.17** | **98.17** | **98.17** | **98.17** | **98.17** | **98.17** | **98.17** | **98.17** | **98.17** | **98.17** | **98.17** | **98.17** | **98.17** | **98.17** | **98.17** |
| Existing domestic hydro | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** | **51.27** |
| Gisenyi | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Ntaruka | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 | 11.25 |
| Mukungwa 1 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Gihira | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 |
| Murunda (IPP) | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Rukarara (IPP) | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| Rugezi | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 |
| Keya | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 |
| Nkora | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 |
| Cyimbili | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Mazimeru (IPP) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Nshili 1 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Musarara (IPP) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Mukungwa 2 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| Existing regional hydro | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** | **15.5** |
| Ruzizi 1 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 |
| Ruzizi 2 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Existing diesel | **27.8** | **27.8** | **7.8** | **7.8** | **7.8** | **7.8** | **7.8** | **7.8** | **7.8** | **7.8** | **7.8** | **7.8** | **7.8** | **7.8** | **7.8** | **7.8** | **7.8** | **7.8** | **7.8** | **7.8** |
| Jabana 1 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 |
| Aggreko Gikondo (Rental) | 10 | 10 | | | | | | | | | | | | | | | | | | |
| Aggreko Mukungwa (Rental) | 10 | 10 | | | | | | | | | | | | | | | | | | |
| Existing HFO | **20** | **20** | **20** | **20** | **20** | **20** | **20** | **20** | **20** | **20** | **20** | **20** | **20** | **20** | **20** | **20** | **20** | **20** | **20** | **20** |
| Jabana 2 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Existing Methane | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** | **3.6** |
| KP1 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 |
| Planned Total | **32** | **102** | **161** | **326** | **396** | **423** | **473** | **521** | **521** | **1013** | **1013** | **1108** | **1108** | **1108** | **1108** | **1108** | **1108** | **1108** | **1108** | **1108** |
| Solar PV | | | | | | | | | | | | | | | | | | | | |
| Gas (methane) | **0** | **25** | **25** | **75** | **75** | **75** | **125** | **125** | **125** | **200** | **200** | **200** | **200** | **200** | **200** | **200** | **200** | **200** | **200** | **200** |
| Kivu Watt (IPP) | | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| Simbion (IPP) | | | | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| Simbion (IPP) | | | | | | | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| Kivu Watt Phase 2 (IPP) | | | | | | | | | | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 |
| Peat | **0** | **15** | **15** | **95** | **145** | **145** | **145** | **145** | **145** | **145** | **145** | **145** | **145** | **145** | **145** | **145** | **145** | **145** | **145** | **145** |
| Gishoma | | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Mamba (IPP) | | | | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| Rwabusoro (IPP) | | | | | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| New domestic hydro | **28** | **28** | **31** | **36** | **36** | **36** | **36** | **36** | **36** | **53** | **53** | **53** | **53** | **53** | **53** | **53** | **53** | **53** | **53** | **53** |
| Nyabarongo 1 (IPP) | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| Rukarara 5 (IPP) | | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Ntaruka B (IPP) | | | | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Nyabarongo 2 (IPP) | | | | | | | | | | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| New regional hydro | **0** | **0** | **0** | **0** | **0** | **27** | **27** | **75** | **75** | **75** | **75** | **170** | **170** | **170** | **170** | **170** | **170** | **170** | **170** | **170** |
| Rusumo (IPP) | | | | | | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
| Ruzizi 3 (IPP) | | | | | | | | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 |
| Ruzizi 4 (IPP) | | | | | | | | | | | | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 |
| Import | **0** | **30** | **50** | **70** | **90** | **90** | **90** | **90** | **90** | **490** | **490** | **490** | **490** | **490** | **490** | **490** | **490** | **490** | **490** | **490** |
| From Kenya | | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| From Kenya | | | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| From Kenya | | | | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| From Kenya | | | | | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| From Kenya | | | | | | | | | | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 |
| New Diesel | **4** | **4** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| Rental Aggreco | 4 | 4 | | | | | | | | | | | | | | | | | | |
| New HFO | **0** | **0** | **40** | **50** | **50** | **50** | **50** | **50** | **50** | **50** | **50** | **50** | **50** | **50** | **50** | **50** | **50** | **50** | **50** | **50** |
| KSEZ HFO | | | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| KSEZ HFO | | | | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |

The notable restrictions regarding existing and planned power stations are as follows.

a． **Ntaruka Hydro (Existing)**

The power station operates only four (4) hours a day in peak period, by order of parliament. Thus, it is assumed that the power station operates from 18 o'clock through 21 o'clock. Also an assumption that the power station can operate for 355 days out of a year is made, in consideration of maintenance and drought.

b． **Solar Power (Existing and Planned)**

Solar power stations are capable of generating only with the presense of sunshine and the output is roughly in proportion to insolation intensity. For this study, two major factors, solar altitude (definite) and weather (stochastic), affecting insolation intensity, are used to estimate the output of solar power stations. Besides, it should be noted that the fluctuation of the output of solar power, affected by changeable weather, may instabilize power network. Thus, further analysis is necessary to determine the appropriate amount of solar power to be installed, in consideration of the demand-supply balance and the transient characteristics of the network as well as the load following capabilities of other power stations.

For the study of least cost development in consideration of above-mentioned constraints, a least cost development plan is studied power sources without the power sources listed above, with the load duration curve and daily demand curve excluding the power sources as above. A case study for year

2028 is as follows.

Duration curve as of 2028 excluding the contribution from Ntarka Hydro and solar power is as follows.

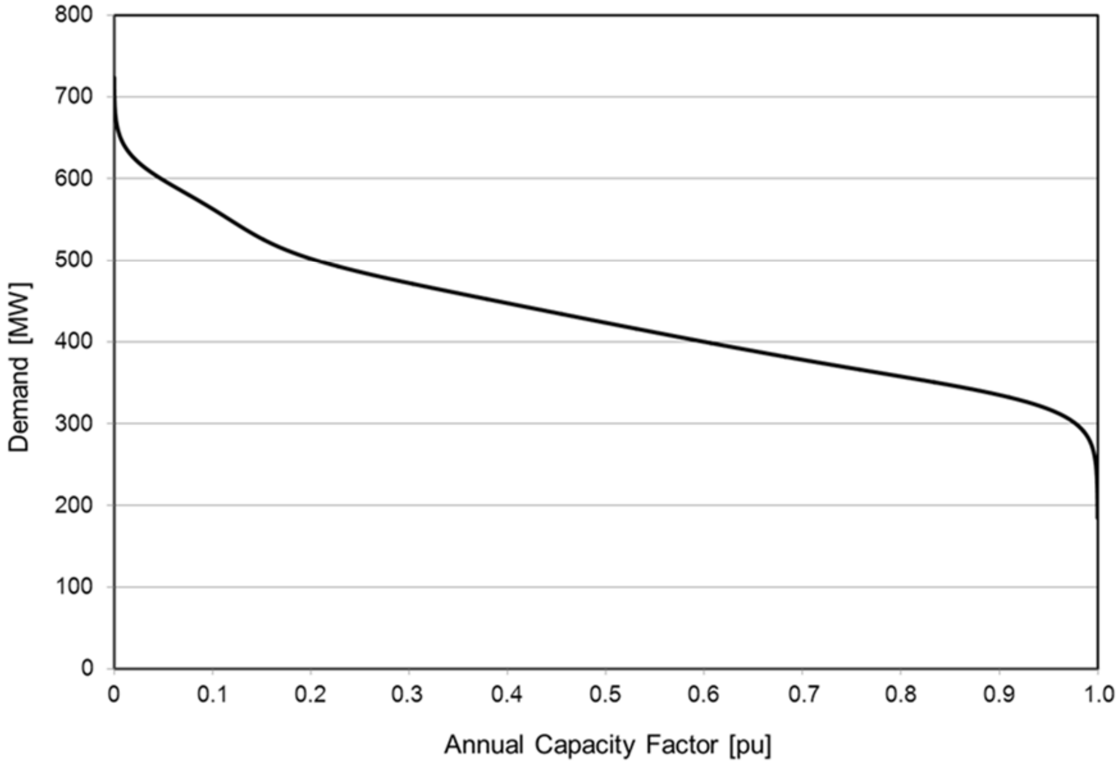



Fig. 2-6.7 Annual Load Duration Curve (forecasted for 2028)

Then, least cost power development plan is sought with the average cost of each type of power source under the restriction of the maximum amount of each type of power source, i.e., the total capacities of existing and planned (including both committed and not committed) power projects. The result is illustrated in the following figure.

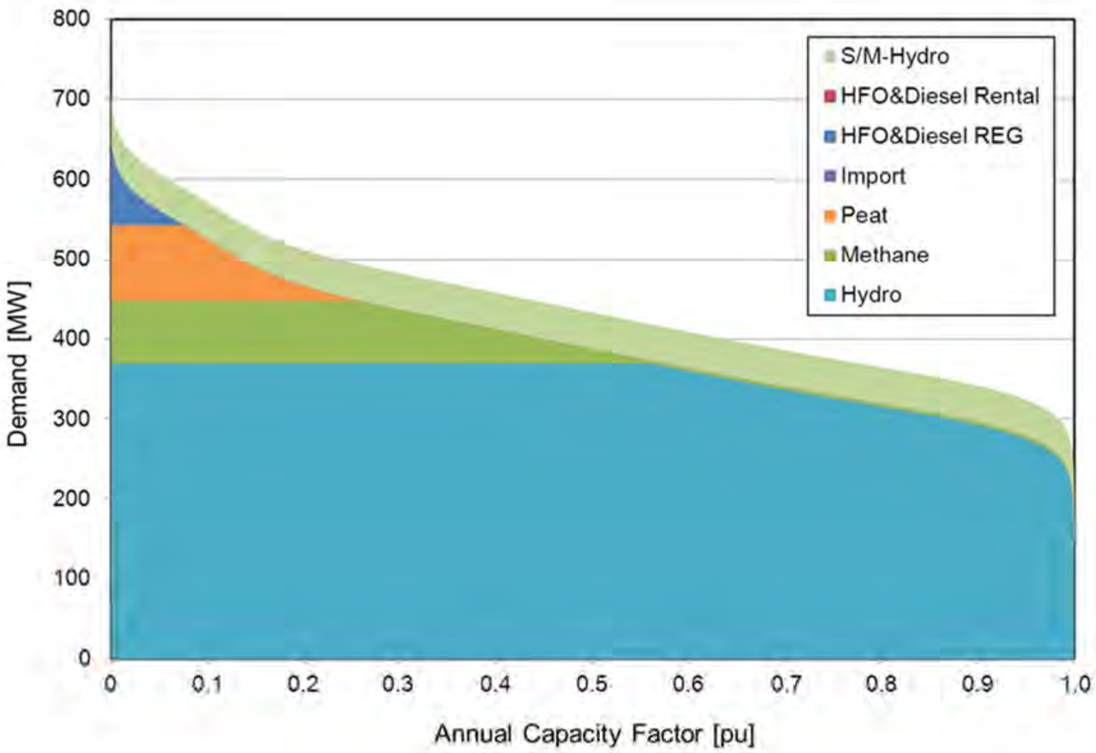



Fig. 2-6.8 in Least Cost Power Development considering Restrictions (forecasted for 2028)

**(4) Remarks on Energy Security**

Rwanda, with scare domestic energy resources, has no choice to import almost all energy resources to correspond to future demand growth. Thus, not only costs but energy security must be seriously considered to determine the composition of power generation sources. Of course it is necessary to utilize domestic resources such as methane, peat, geothermal, and solar. In addition, careful attention is to be paid to variety, form, and origines of the energy to be imported.

Importing electric and multinational hydro development backed by abundant hydraulic power of surrounding countries, is an important alternative for Rwanda. On the other hand, domestic electricity demand-supply balance will be tigheten promptly once power import stops. Thus, it is recommended that electricity import should be limited to a degree that will not give serious impact on the electricity demand during weekday daytime upon import stoppage. In other words, import should be limited to the amount business activities may not be affected seriously even in import restriction (up to 20 % of peak demand based on current daily load pattern). Diesel generation will become primary back-up when power import stops. Thus, it is necessary to install diesel generators a certain degree and to secure enough amount of fuel reserve in consideration of the lead time for emergency import of fuel. Diesel generators exclusively for emergency backup must have lower equipment cost but the efficiencies may not be so high. It is an idea to save REG's diesel generators planned to retire in future, if any, as emergency reserve. Another solution is diversification of origin countries. Currently the power will be imported exclusively from Kenya among the lineup of future electric supply. However, the risk of depending upon electricity import will be diversified if the origin is diversified to other countries such as Ethiopia and Tanzania as well via EAPP network. Such diversification will also strengthen the bargaining power of Rwanda in cross-boarder electricity trading. Otherwise, it will reduce the risk of regional drought or flood to receive electricity by hydraulic power from different river system, even from a single country.

It must be noted that the electric power demand style will change drastically due to the transformation of industrial structure or improvement in the standard of living. Thus, it is necessary to analyze and forecast electric power demand structure to reevaluate the appropriate level of import dependency of electricity from time to time.

Utilization of renewable energies enhances energy security. However, it is essential to understand the characteristic of renewable energy as a power source (e.g., predictability, controllability, and disturbance to grid) thoroughly and to estimate the appropriate amount to be introduced without grid instability and to take necessary countermeasures before full-fledged implementation. Especially, small/micro hydros and photovoltaics with small output (tens of kW) are usually connected to the peripheral part of distribution network. Therefore, meticulous countermeasures for each project in consideration of advers current, including voltage stabilization, reactive power management, and circuit protection upgrade.

### 2.6.6. Study based on Existing Power Sources and Development Plan

During the 4th work in Rwanda, JICA study team obtained detailed data including the latest power source development plan, actual cost of the existing power plants, and estimated cost for each power source planned for development. While carrying out tasks during the 5th work in Japan, the possible prioritization of projects was considered based on the least cost development concept. Among the obtained data, there are data and confidential information that are not meant for disclosure; therefore, only the policy, procedure and result of the study are given in this report.

Table 2-6.3 shows the comparison of the existing and planned power sources (including both committed and not committed) of Rwanda at this point in time and the peak demand between 2016 and 2033 based on the demand forecasted by JICA study team.

## Table 2-6.3 Existing and planned power source facilities and peak demand

Existing as of 2013

| Year | Type | Owner | Name | Status | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | Hydro(a) | - | - | Existing | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 |
| | HFO&Diesel EWSA | - | - | Existing | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 |
| | Methane | - | - | Existing | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 |
| | S/M-Hydro | - | - | Existing | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

Planned as of 2013

| Year | Type | Owner | Name | Status | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2014 | Hydro | REG | Nyabarongo 1 | Committed | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| | S/M-Hydro | - | - | Committed | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 2015 | Methane | IPP | Kivu Watt | Committed | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| | Import | Import | Import(from Kenya) | Committed | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| 2016 | Hydro | IPP | Rukarara 5 | Committed | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | Diesel | REG | KSEZ HFO | Not Committed | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| | Peat | REG | Gishoma | Committed | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 |
| | Import | Import | Import(from Kenya) | Not Committed | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 2017 | Diesel | REG | KSEZ HFO | Not Committed | | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | Peat | IPP | Mamba | Committed | | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| | Import | Import | Import(from Kenya) | Not Committed | | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| | S/M-Hydro | - | - | Committed | | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 |
| 2018 | Methane | IPP | Simbion | Committed | | | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| | Import | Import | Import(from Kenya) | Not Committed | | | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| | S/M-Hydro | - | - | Committed | | | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 |
| 2019 | Hydro | IPP | Rusumo | Committed | | | | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
| | Methane | IPP | Kivu Watt Phase2 | Not Committed | | | | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 | 75 |
| | Import | Import | Import(from Kenya) | Not Committed | | | | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| 2021 | Hydro | IPP | Ruzizi 3 | Committed | | | | | | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 |
| 2023 | Hydro | IPP | Nyabarongo 2 | Not Committed | | | | | | | | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| | Import | Import | Import(from Kenya) | Not Committed | | | | | | | | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 |
| 2025 | Hydro | IPP | Ruzizi 4 | Not Committed | | | | | | | | | | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 |

Non-Identified Projects

| Year | Type | Owner | Name | Status | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2018 | Diesel or HFO | IPP | - | Not Committed | | | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 |
| 2021 | Methane | IPP | - | Not Committed | | | | | | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| | Peat | IPP | - | Not Committed | | | | | | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 |
| 2023 | Hydro | IPP | - | Not Committed | | | | | | | | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |

| Category | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Existing (1) | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 |
| Committed (2) | 104.5 | 195.8 | 263.3 | 290.3 | 290.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 |
| Sub Total (3)=(1)+(2) | 186.78 | 278.08 | 345.58 | 372.58 | 372.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 |
| Not Committed (4) | 50 | 80 | 1100 | 1195 | 1195 | 1430 | 1430 | 1872 | 1872 | 1967 | 1967 | 1967 | 1967 | 1967 | 1967 | 1967 | 1967 | 1967 |
| Total (5)=(3)+(4) | 236.78 | 358.08 | 1445.6 | 1567.6 | 1567.6 | 1850.6 | 1850.6 | 2292.6 | 2292.6 | 2387.6 | 2387.6 | 2387.6 | 2387.6 | 2387.6 | 2387.6 | 2387.6 | 2387.6 | 2387.6 |
| | | | | | | | | | | | | | | | | | | |
| Peak Demand (6) | 196.3 | 222.4 | 243 | 267.7 | 294.7 | 324.1 | 355.8 | 390.2 | 427.4 | 467.7 | 511.4 | 558.7 | 610 | 665.7 | 726.1 | 791.7 | 863 | 940.4 |
| w/margin (7)=(6)x1.2 | 235.56 | 266.88 | 291.6 | 321.24 | 353.64 | 388.92 | 426.96 | 468.24 | 512.88 | 561.24 | 613.68 | 670.44 | 732 | 798.84 | 871.32 | 950.04 | 1035.6 | 1128.5 |
| Top Load (8)(b) | 228.66 | 259.65 | 284.2 | 313.67 | 345.93 | 381.08 | 419.01 | 460.19 | 504.74 | 553.02 | 605.39 | 662.09 | 723.6 | 790.39 | 862.82 | 941.5 | 1027 | 1119.9 |
| | | | | | | | | | | | | | | | | | | |
| Top Load to be Covered by "Not Committed" (9)=(8)-(3) | 41.88 | -18.43 | -61.38 | -58.91 | -26.65 | -39.5 | -1.572 | 39.609 | 84.161 | 132.44 | 184.81 | 241.51 | 303.02 | 369.81 | 442.24 | 520.92 | 606.45 | 699.29 |

Notes:
(a) Excluding Ntarka (3.75MW x 3)
(b) Top of Duration Curve: Peak demand in consideration of peak shaving by Ntarka (3.75MW x 3)

As the table indicates, a power supply shortage of 41.88MW is expected for 2016 based on the existing and committed power sources. However, between 2017 and 2022, there is enough power supply to cover the demand based on the existing and committed power sources. Of these power sources, Mamba for 2017 is a peat power plant and Simbion for 2018 is a methane power plant. Any delay in the start of operation could be a risk factor; however, if they are put into service as planned, there is no need for the power sources not committed between 2017 and 2022.

As for 41.9MW that the existing and committed power sources cannot supply in 2016, it can be covered mostly by the power source KSEZ HFO (40MW), which is not committed. However, if Mamba and Simbion plants could start operation as planned, it might be a good idea to cover the gap in 2016 with rental diesel power generation plants as bridging. REG might benefit from this scenario since it could ease the burden of up-front investment and prevent having idle facilities by postponing the commissioning of KSEZ HFO by six years to 2023 or later. On the other hand, since the existing and committed power sources cannot supply sufficient power to keep up with the increase in demand in and after 2023, it will be necessary to select the power sources to be put into service among not committed ones.

**(1) Selection of Horizon Year**

In order to select the power sources to be put into service, an examination is done for the power source composition that will be optimal (most economical) for the specific point in the future (horizon year), and then unnecessary power sources will be eliminated by going back in time year by year. This is a procedure that is commonly followed for the preparation of the power source plan which requires long-term consistency. It is more desirable to have the later base year from the viewpoint of the consistency in long-term planning, the securing ample lead time for construction and the degree of freedom in selection. On the other hand, it might be difficult to consider the optimal power source composition for such later horizon year since the conditions such as social structure, energy situation and technological trend might change drastically by then, increasing the uncertainty in demand forecast and cost evaluation. Given these circumstances, JICA study team selected 2028, 15 years from now, to be the horizon year for the purpose of examining the power source composition for 2023 and after.

**(2) Optimal power source composition for the base year (2028)**

JICA study team calculated the installed capacity of the power plants that would minimize the total cost, based on the demand forecast carried out in this study (= peak load) and hourly load data in 2013. It was done by using the load duration curve (excluding the contributions from Ntarka hydropower and photovoltaic power) for 2028 that was created with the Monte Carlo simulation, and assuming that each plant is operated according to the concept of Economic Load Dispatching (as the load increases, plants with the smallest marginal cost will be put into operation first). As for peat power operation, it is necessary to impose restriction on the minimum operational output (lower limit) to maintain the boiler combustion, and here, the restriction on the output is that the output should not go below 50% of the installed capacity.

Based on these assumptions, the optimization calculation was carried out. It revealed that the cost would be smallest if Nyabarongo 2 hydro with 17MW, IPP hydro for 2023 with 25MW, Ruzizi 4 hydro with 1.4MW, methane for 2021 with 92.0MW and diesel for 2018 with 167.6MW were introduced among the power sources not committed. JICA study team assumed for the optimization calculation that the installed capacity to be introduced could be any figure above zero (fractional figure) up to the planned installed capacity. However, the hydro or methane projects can have no intermediate solution and have to be either adopted or not. On the other hand, diesel can have an intermediate solution since the installed capacity can be adjusted with the number of units. Therefore, a decision could be made to introduce Nyabarongo 2 hydro and IPP hydro for 2023, while a selection had to be made regarding the project to be introduced between Ruzizi 4 hydro (95MW) and methane power for 2021 (150MW). Here, JICA study team adopted a plan to adopt Ruzizi 4 and cover the balance with diesel power plants. It was a decision reached by comprehensively considering various factors including: since Ruzizi 4 hydro is a joint project with the neighboring countries, any change to the plan due to the expediency of Rwanda seems difficult, and if the project is forced to be delayed, there might be a penalty based on the Take-or-Pay principle; the specific plan for the development of methane power plan to be introduced in

2021 has not been decided; and it is necessary to secure a certain number of diesel power plants that have shorter lead time to the start of operation and have an excellent ability to balance power supply with demand, in order to handle fluctuating factors such as risks associated with methane harvest, change in power demand and network disturbances caused by renewable energy plants.

The power sources to be introduced by the base year (2028) are Nyabarongo 2 hydro (17MW), IPP hydro for 2023 (25MW), Ruzizi 4 hydro (95MW) and diesel (166.1MW). Figure 2-6-9 shows the ratio of power sources against the load duration curve. As for diesel, the installed capacity required might be less than what it was in the past depending on the operation of other power sources; thus, the cost reduction must be achieved by optimally combining IPP plants, REG' own plants and rental plants. On this matter, a separate examination will be required with thorough consideration of the specific contents of the contracts concluded with IPPs and rental companies.

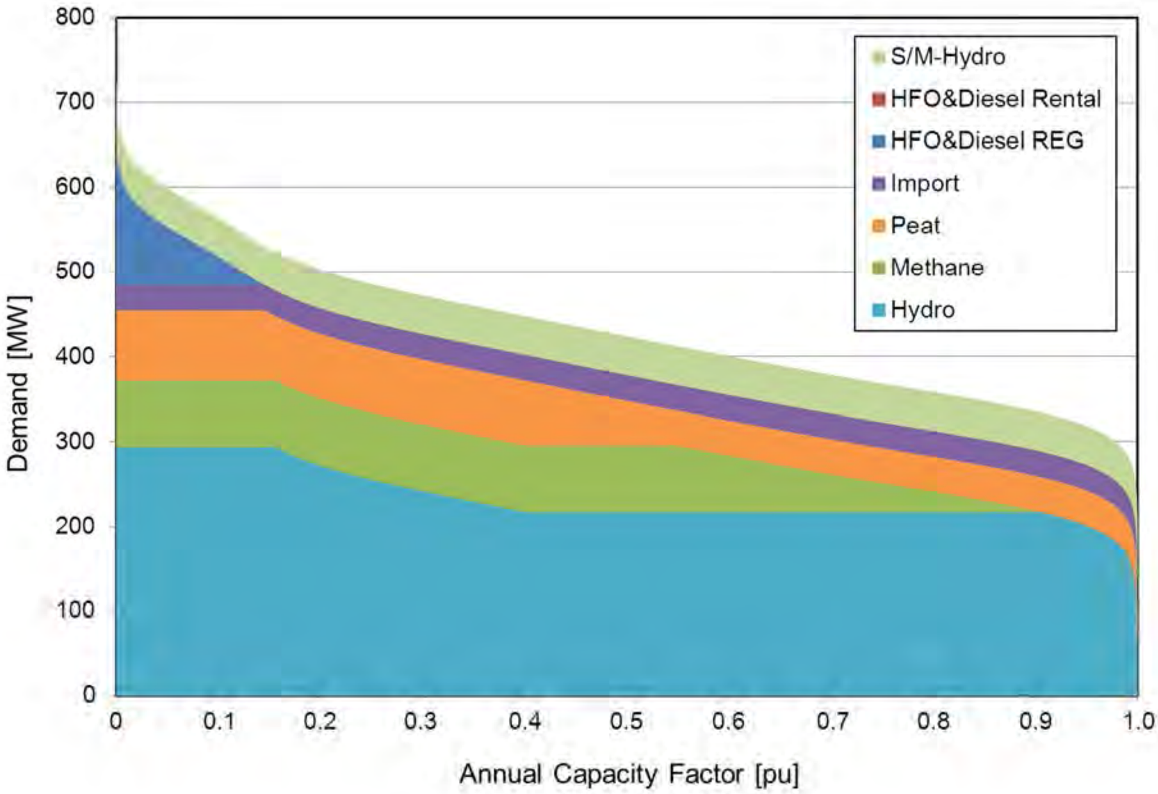



Fig. 2-6.9 Ratio of power sources based on the least cost development concept (2028)

### (3) Optimal Power Source Composition before Horizon Year (2023 – 2027)

The optimal power source composition for the years prior to the horizon year 2028 (2023 – 2027) is explained below. By following the process stated above, the examination was done for each year by going back from the base year. For power sources that could not be divided such as hydropower and methane, either adoption or no-adoption was selected similar to the study for year 2028, and diesel power was assumed to be necessary to cover any gap between power supply and demand caused by power sources that cannot be divided, since it is easy to adjust the installed capacity of the diesel power plants. The result is shown below.

2027: since there is a larger supply margin compared to 2028, it turned out that the potential power sources to be reduced are IPP's hydropower for 2023 (25MW) and Ruzizi 4 (95MW). They are almost equivalent in terms of cost, so the JICA study team kept Ruzizi 4 which was the result of multilateral development for the reason given above, and removed the domestic IPP's hydropower plant (start of operation 2023 according to REG's plan). In this case, the installed capacity of diesel power will be 129.5MW.

2026: IPP hydro Nyabarongo 2 (17MW, start of operation 2023 according to REG's plan) was removed from the 2027 power source composition.

2025: with the same power source composition as 2026, the power supply is balanced with the use of diesel (in actuality, diesel power plants will be added in 2026).

2024: Ruzizi 4 was removed. The power plant will start operation in 2025, same as the time for the start of operation indicated in REG's plan.

2023: With the same power source composition as 2026, the power supply is balanced with the use of diesel (in actuality, diesel power plants will be added in 2024).

**(4) Power Source Composition for 2016 – 2022**

As explained earlier, the existing and committed power sources can supply enough power during this period that there is no need to put the power sources not committed into service. Therefore, it is recommended to postpone the start of operation for the excess portion of the committed power sources whose work schedule can be changed, in order to reduce the up-front investment. Since the power supply is expected to be tight in and after 2023, it might be a good idea to carry out work that requires the power plants to be shut down for a prolonged period of time, since there will be an excess power supply during this period. Such work might include the structure inspection and various tests on aging hydropower plants, rehabilitation, expansion and improvement of facilities such as transmission and transformation facilities, as well as preparation for such work.

**(5) Power source composition in and after 2029**

The power source composition for years following the base year 2028 (from 2029 to 2033) is explained below. An examination was carried out for each year starting from 2028.

- 2029: the methane IPP (150MW) planned for 2021 will have to be put into service; however, if all of the 150MW are supplied at once, much of the diesel plants will become excessive. Therefore, measures must be taken such as bringing in 75MW in 2029 and 2030, respectively, depending on the situation, or taking advantage of the excess power to conduct work on other facilities that requires them to be shut down for an extended period.

- 2030: the methane IPP (150MW) planned for 2021 will be put to service (if half was already put to operation in the previous year, then the remaining half will be put to service)

- 2031: diesel plants are added depending on the increase in power demand.

- 2032: Kivu Watt2 (75MW) planned for 2019 is put to service. The timing is later than the methane IPP planned for 2021 because of a difference in cost. However, the difference is so small that the cost must be closely examined to determine the order to be put to service.

- 2032: diesel plants are added depending on the increase in demand.

Table 2-6-4 shows the revised version of the power source plan that was examined based on the least cost development method, using the same format of the current power source development plan (Table 2-6-3) (the differences between the two tables is shown in yellow). The power source composition for the years is shown in Figure 2-6-10.

## Table 2-6-4 Power source plan examined based on the least cost development method

Existing as of 2013

| Year | Type | Owner | Name | Status | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | Hydro[a] | - | - | Existing | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 |
| | HFO&Diesel EWSA | - | - | Existing | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 |
| | Methane | - | - | Existing | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 |
| | S/M-Hydro | - | - | Existing | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

Planned as of 2013

| Year | Type | Owner | Name | Status | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2014 | Hydro | REG | Nyabarongo 1 | Committed | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| | S/M-Hydro | - | - | Committed | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 2015 | Methane | IPP | Kivu Watt | Committed | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| | Import | Import | Import(from Kenya) | Committed | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| 2016 | Hydro | IPP | Rukarara 5 | Committed | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | Diesel | REG | KSEZ HFO[c] | Not Committed | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Peat | REG | Gishoma | Committed | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 |
| | Import | Import | Import(from Kenya) | Not Committed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2017 | Diesel | REG | KSEZ HFO[c] | Not Committed | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Peat | IPP | Mamba | Committed | | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| | Import | Import | Import(from Kenya) | Not Committed | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | S/M-Hydro | - | - | Committed | | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 |
| 2018 | Methane | IPP | Simbion | Committed | | | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| | Import | Import | Import(from Kenya) | Not Committed | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | S/M-Hydro | - | - | Committed | | | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 |
| 2019 | Hydro | IPP | Rusumo | Committed | | | | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
| | Methane | IPP | Kivu Watt Phase2 | Not Committed | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 75 | 75 |
| | Import | Import | Import(from Kenya) | Not Committed | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2021 | Hydro | IPP | Ruzizi 3 | Committed | | | | | | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 |
| 2023 | Hydro | IPP | Nyabarongo 2 | Not Committed | | | | | | | | 0 | 0 | 0 | 0 | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| | Import | Import | Import(from Kenya) | Not Committed | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2025 | Hydro | IPP | Ruzizi 4 | Not Committed | | | | | | | | | | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 |

Non-Identified Projects

| Year | Type | Owner | Name | Status | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2018 | Diesel or HFO[c] | IPP | - | Not Committed | | | 0 | 0 | 0 | 0 | 0 | 39.609 | 84.161 | 37.443 | 89.814 | 129.51 | 166.06 | 157.81 | 155.24 | 233.92 | 244.45 | 337.29 |
| 2021 | Methane | IPP | - | Not Committed | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 75 | 150 | 150 | 150 | 150 |
| | Peat | IPP | - | Not Committed | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2023 | Hydro | IPP | - | Not Committed | | | | | | | | 0 | 0 | 0 | 0 | 0 | 25 | 25 | 25 | 25 | 25 | 25 |

| Category | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Existing (1) | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 |
| Committed (2) | 104.5 | 195.8 | 263.3 | 290.3 | 290.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 |
| Sub Total (3)=(1)+(2) | 186.78 | 278.08 | 345.58 | 372.58 | 372.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 |
| Not Committed (4) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 39.609 | 84.161 | 132.44 | 184.81 | 241.51 | 303.06 | 369.81 | 442.24 | 520.92 | 606.45 | 699.29 |
| Total (5)=(3)+(4) | 186.78 | 278.08 | 345.58 | 372.58 | 372.58 | 420.58 | 420.58 | 460.19 | 504.74 | 553.02 | 605.39 | 662.09 | 723.64 | 790.39 | 862.82 | 941.5 | 1027 | 1119.9 |
| | | | | | | | | | | | | | | | | | | |
| Peak Demand (6) | 196.3 | 222.4 | 243 | 267.7 | 294.7 | 324.1 | 355.8 | 390.2 | 427.4 | 467.7 | 511.4 | 558.7 | 610 | 665.7 | 726.1 | 791.7 | 863 | 940.4 |
| w/margin (7)=(6)x1.2 | 235.56 | 266.88 | 291.6 | 321.24 | 353.64 | 388.92 | 426.96 | 468.24 | 512.88 | 561.24 | 613.68 | 670.44 | 732 | 798.84 | 871.32 | 950.04 | 1035.6 | 1128.5 |
| Top Load (8)[b] | 228.66 | 259.65 | 284.2 | 313.67 | 345.93 | 381.08 | 419.01 | 460.19 | 504.74 | 553.02 | 605.39 | 662.09 | 723.6 | 790.39 | 862.82 | 941.5 | 1027 | 1119.9 |
| | | | | | | | | | | | | | | | | | | |
| Top Load to be Covered by "Not Committed" (9)=(8)-(3) | 41.88 | -18.43 | -61.38 | -58.91 | -26.65 | -39.5 | -1.572 | 39.609 | 84.161 | 132.44 | 184.81 | 241.51 | 303.02 | 369.81 | 442.24 | 520.92 | 606.45 | 699.29 |

Notes:

(a) Excluding Ntarka (3.75MW x 3)

(b) Top of Duration Curve: Peak demand in consideration of peak shaving by Ntarka (3.75MW x 3)

(c) Capacities of Diesel generation are listed in "Non-Identified Projects" altogether; the optimal allocation to IPP, REG's own, and rental should be considered separately (see main text of the report).

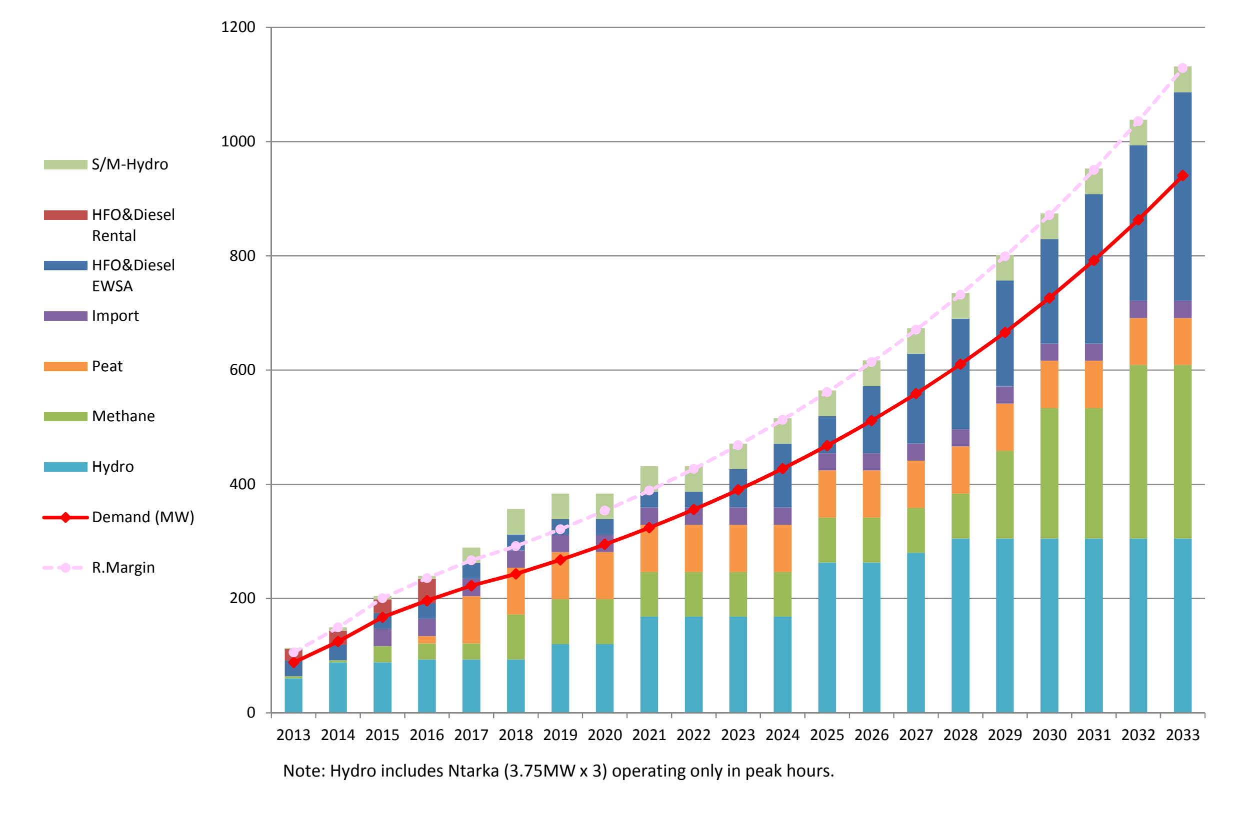



Fig. 2-6-10 Power source composition based on the least cost development method

### (6) Handling of imported electricity

Based on this examination, the import of electricity planned for 2016 – 2019 (10MW - 20MW annually) and that planned for 2023 (400MW) are not necessary. The reason was that there are other power source options and the imported electricity will be more expensive than those options. To put it the other way around, the import of electricity might come up as an option if the power purchase price goes down through negotiation with the partner country or if the cost for other options goes up, or if other options became unavailable, making the power supply shortage likely. Supply and demand for electricity occur simultaneously leaving no room for delay. Therefore, it is necessary to collect the latest information on the alternative energy sources not limited to imported electricity and to periodically update the master plan and the supporting data in order to keep up with the ever-changing situation. Also, the power flow in the grid can be very different for using electricity supplied from the domestic power source and for introducing imported electricity. Attention must be given to capabilities of the transmission and transformation facilities by review ing the network assuming the import of electricity and anticipating necessary reinforcement and improvement of facilities, in order to ensure that the transmission line and substation have sufficient capacity and that the network voltage will be maintained.

### 2.6.7. Examination of Risk Senarios

The peat and methane power plants are planned to be put to service in or after 2017 to become the core power sources of Rwanda. However, there are many areas that can become a bottleneck in the supply chain starting from the fuel all the way to power generation.

First of all, power generation with the use of peat as fuel has been practiced in Ireland and other areas, and there are no major technological concerns. However, in the peat reserve area in the Akanyaru River region where the development is planned for the future, marshes and farmland are mixed. Adequate consideration must be given for the environment and harmonious coexistence with the community in order to utilize methane. There are uncertainties about the reserve amount, whether the long-term continuous power generation is possible or not, and the possibility of procuring alternative fuel. On the other hand, gas engine power generation using methane is a mature technology; however, methane gas mining from the bed of Lake Kivu is unprecedented in the world with technological and economical uncertainties. The gas extraction from the lake bed involves disaster prevention, which could restrict the construction and operation of the power plant.

Various external factors are deeply involved with a power generation project especially if the expansion of the related transmission and transformation facilities is included, and it is necessary to consider a possible delay due to natural environment or social impacts. The JICA study team examined the impacts on the plan and the countermeasures based on the risk scenarios that were envisioned under this policy.

#### (1) Two-year delay in peat power development

The JICA study team examined the scenario that the introduction of the committed peat power plants Gishoma (12.5MW, introduction planned for 2016) and Mamba (70MW, introduction planned for 2017) is delayed by two years. In this scenario, the impact on the supply is the decrease of 12.5MW in 2016, 82.5MW in 2017 and 70MW in 2018.

The shortage will have to be covered with diesel power plants since they can be introduced in a short time with a short lead time. The planned (not committed) diesel plants include KSEZ HFO that is planned for introduction in 2016 and 2017 (40MW and 10MW) and IPP diesel plant whose introduction is planned for 2018. However, if peat power plants are introduced, no new power sources will be needed until 2022. In this case, it might be best to cover any temporary power shortage by using the rental diesel power plants (extension of Aggreco contract or new contract), in order to avoid increase in the fixed cost that will be brought on by accelerating introduction of facilities.

As for the peat power plant (85MW, planned introduction 2021 but not committed), its introduction was judged to be unnecessary in the optimal power source composition and the impact from its delay does not have to be taken into consideration. The power source composition for the years is shown in Table 2-6.5 (the highlighted with orange represents the deviations from Table 2-6.4).

Table 2-6.5 Power Source Plan in Consideration of 2 Year Delay in Peat

Existing as of 2013

| Year | Type | Owner | Name | Status | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | Hydro[(a)] | - | - | Existing | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 |
| | HFO&Diesel EWSA | - | - | Existing | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 |
| | Methane | - | - | Existing | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 |
| | S/M-Hydro | - | - | Existing | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

Planned as of 2013

| Year | Type | Owner | Name | Status | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2014 | Hydro | REG | Nyabarongo 1 | Committed | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| | S/M-Hydro | - | - | Committed | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 2015 | Methane | IPP | Kivu Watt | Committed | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| | Import | Import | Import(from Kenya) | Committed | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| 2016 | Hydro | IPP | Rukarara 5 | Committed | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | Diesel | REG | KSEZ HFO[(c)] | Not Committed | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Peat | REG | Gishoma | Committed | | | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 |
| | Import | Import | Import(from Kenya) | Not Committed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2017 | Diesel | REG | KSEZ HFO[(c)] | Not Committed | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Peat | IPP | Mamba | Committed | | | | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| | Import | Import | Import(from Kenya) | Not Committed | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | S/M-Hydro | - | - | Committed | | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 |
| 2018 | Methane | IPP | Simbion | Committed | | | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| | Import | Import | Import(from Kenya) | Not Committed | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | S/M-Hydro | - | - | Committed | | | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 |
| 2019 | Hydro | IPP | Rusumo | Committed | | | | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
| | Methane | IPP | Kivu Watt Phase2 | Not Committed | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 75 | 75 |
| | Import | Import | Import(from Kenya) | Not Committed | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2021 | Hydro | IPP | Ruzizi 3 | Committed | | | | | | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 |
| 2023 | Hydro | IPP | Nyabarongo 2 | Not Committed | | | | | | | | 0 | 0 | 0 | 0 | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| | Import | Import | Import(from Kenya) | Not Committed | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2025 | Hydro | IPP | Ruzizi 4 | Not Committed | | | | | | | | | | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 |

Non-Identified Projects

| Year | Type | Owner | Name | Status | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2018 | Diesel or HFO[(c)] | IPP | - | Not Committed | 54.38 | 64.068 | 0 | 0 | 0 | 0 | 0 | 39.609 | 84.161 | 37.443 | 89.814 | 129.51 | 166.06 | 157.81 | 155.24 | 233.92 | 244.45 | 337.29 |
| 2021 | Methane | IPP | - | Not Committed | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 75 | 150 | 150 | 150 | 150 |
| | Peat | IPP | - | Not Committed | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2023 | Hydro | IPP | - | Not Committed | | | | | | | | 0 | 0 | 0 | 0 | 0 | 25 | 25 | 25 | 25 | 25 | 25 |

| Category | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Existing (1) | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 |
| Committed (2) | 92 | 113.3 | 193.3 | 290.3 | 290.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 |
| Sub Total (3)=(1)+(2) | 174.28 | 195.58 | 275.58 | 372.58 | 372.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 |
| Not Committed (4) | 54.38 | 64.068 | 0 | 0 | 0 | 0 | 0 | 39.609 | 84.161 | 132.44 | 184.81 | 241.51 | 303.06 | 369.81 | 442.24 | 520.92 | 606.45 | 699.29 |
| Total (5)=(3)+(4) | 228.66 | 259.65 | 275.58 | 372.58 | 372.58 | 420.58 | 420.58 | 460.19 | 504.74 | 553.02 | 605.39 | 662.09 | 723.64 | 790.39 | 862.82 | 941.5 | 1027 | 1119.9 |
| | | | | | | | | | | | | | | | | | | |
| Peak Demand (6) | 196.3 | 222.4 | 243 | 267.7 | 294.7 | 324.1 | 355.8 | 390.2 | 427.4 | 467.7 | 511.4 | 558.7 | 610 | 665.7 | 726.1 | 791.7 | 863 | 940.4 |
| w/margin (7)=(6)x1.2 | 235.56 | 266.88 | 291.6 | 321.24 | 353.64 | 388.92 | 426.96 | 468.24 | 512.88 | 561.24 | 613.68 | 670.44 | 732 | 798.84 | 871.32 | 950.04 | 1035.6 | 1128.5 |
| Top Load (8)[(b)] | 228.66 | 259.65 | 284.2 | 313.67 | 345.93 | 381.08 | 419.01 | 460.19 | 504.74 | 553.02 | 605.39 | 662.09 | 723.6 | 790.39 | 862.82 | 941.5 | 1027 | 1119.9 |
| | | | | | | | | | | | | | | | | | | |
| Top Load to be Covered by "Not Committed" (9)=(8)-(3) | 54.38 | 64.068 | 8.6192 | -58.91 | -26.65 | -39.5 | -1.572 | 39.609 | 84.161 | 132.44 | 184.81 | 241.51 | 303.02 | 369.81 | 442.24 | 520.92 | 606.45 | 699.29 |

Notes:
(a) Excluding Ntarka (3.75MW x 3)
(b) Top of Duration Curve: Peak demand in consideration of peak shaving by Ntarka (3.75MW x 3)
(c) Capacities of Diesel generation are listed in "Non-Identified Projects" altogether; the optimal allocation to IPP, REG's own, and rental should be considered separately (see main text of the report).

## (2) Two-Year Delay in Methane Power Development

The JICA study team examined the scenario that the introduction of both Kivu Watt (25MW, introduction planned for 2015) and Simbion (50MW, introduction planned for 2017) is delayed by two years. In this scenario, the impact on the supply is the decrease of 25MW in 2016 and 2017, and 50MW in 2018 and 2019, respectively.

In this scenario, measures will be needed to address the supply shortage of 2016, but not that of 2017 – 2019 since the amount of shortage falls within the margin. Therefore, it might be best to deal with the supply shortage of 2016 temporarily with the use of rental diesel power plants equivalent to 66.88MW (extension of Aggreco contract or new contract).

As for the peat power plant (85MW, planned introduction 2021 but not committed), its introduction was judged unnecessary in the optimum power source composition and the impact from its delay does not have to be taken into consideration. The least cost power development plan, in accordance with this scenario, is shown in Table 2-6.6 (the highlighted with orange represents the deviations from Table 2-6.4).

Table 2-6.6 Power Source Plan in Consideration of 2 Year Delay in Methanet

Existing as of 2013

| Year | Type | Owner | Name | Status | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | Hydro[a] | - | - | Existing | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 |
| | HFO&Diesel EWSA | - | - | Existing | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 |
| | Methane | - | - | Existing | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 |
| | S/M-Hydro | - | - | Existing | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

Planned as of 2013

| Year | Type | Owner | Name | Status | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2014 | Hydro | REG | Nyabarongo 1 | Committed | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| | S/M-Hydro | - | - | Committed | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 2015 | Methane | IPP | Kivu Watt | Committed | | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| | Import | Import | Import(from Kenya) | Committed | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| 2016 | Hydro | IPP | Rukarara 5 | Committed | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | Diesel | REG | KSEZ HFO[c] | Not Committed | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Peat | REG | Gishoma | Committed | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 |
| | Import | Import | Import(from Kenya) | Not Committed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2017 | Diesel | REG | KSEZ HFO[c] | Not Committed | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Peat | IPP | Mamba | Committed | | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| | Import | Import | Import(from Kenya) | Not Committed | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | S/M-Hydro | - | - | Committed | | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 |
| 2018 | Methane | IPP | Simbion | Committed | | | | | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| | Import | Import | Import(from Kenya) | Not Committed | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | S/M-Hydro | - | - | Committed | | | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 |
| 2019 | Hydro | IPP | Rusumo | Committed | | | | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
| | Methane | IPP | Kivu Watt Phase2 | Not Committed | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 75 | 75 |
| | Import | Import | Import(from Kenya) | Not Committed | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2021 | Hydro | IPP | Ruzizi 3 | Committed | | | | | | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 |
| 2023 | Hydro | IPP | Nyabarongo 2 | Not Committed | | | | | | | | 0 | 0 | 0 | 0 | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| | Import | Import | Import(from Kenya) | Not Committed | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2025 | Hydro | IPP | Ruzizi 4 | Not Committed | | | | | | | | | | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 |

Non-Identified Projects

| Year | Type | Owner | Name | Status | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2018 | Diesel or HFO[c] | IPP | - | Not Committed | 66.88 | | 0 | 0 | 0 | 0 | 0 | 39.609 | 84.161 | 37.443 | 89.814 | 129.51 | 166.06 | 157.81 | 155.24 | 233.92 | 244.45 | 337.29 |
| 2021 | Methane | IPP | - | Not Committed | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 75 | 150 | 150 | 150 | 150 |
| | Peat | IPP | - | Not Committed | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2023 | Hydro | IPP | - | Not Committed | | | | | | | | 0 | 0 | 0 | 0 | 0 | 25 | 25 | 25 | 25 | 25 | 25 |

| Category | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Existing (1) | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 |
| Committed (2) | 79.5 | 195.8 | 213.3 | 240.3 | 290.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 |
| Sub Total (3)=(1)+(2) | 161.78 | 278.08 | 295.58 | 322.58 | 372.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 |
| Not Committed (4) | 66.88 | 0 | 0 | 0 | 0 | 0 | 0 | 39.609 | 84.161 | 132.44 | 184.81 | 241.51 | 303.06 | 369.81 | 442.24 | 520.92 | 606.45 | 699.29 |
| Total (5)=(3)+(4) | 228.66 | 278.08 | 295.58 | 322.58 | 372.58 | 420.58 | 420.58 | 460.19 | 504.74 | 553.02 | 605.39 | 662.09 | 723.64 | 790.39 | 862.82 | 941.5 | 1027 | 1119.9 |
| | | | | | | | | | | | | | | | | | | |
| Peak Demand (6) | 196.3 | 222.4 | 243 | 267.7 | 294.7 | 324.1 | 355.8 | 390.2 | 427.4 | 467.7 | 511.4 | 558.7 | 610 | 665.7 | 726.1 | 791.7 | 863 | 940.4 |
| w/margin (7)=(6)x1.2 | 235.56 | 266.88 | 291.6 | 321.24 | 353.64 | 388.92 | 426.96 | 468.24 | 512.88 | 561.24 | 613.68 | 670.44 | 732 | 798.84 | 871.32 | 950.04 | 1035.6 | 1128.5 |
| Top Load (8)[b] | 228.66 | 259.65 | 284.2 | 313.67 | 345.93 | 381.08 | 419.01 | 460.19 | 504.74 | 553.02 | 605.39 | 662.09 | 723.6 | 790.39 | 862.82 | 941.5 | 1027 | 1119.9 |
| | | | | | | | | | | | | | | | | | | |
| Top Load to be Covered by "Not Committed" (9)=(8)-(3) | 66.88 | -18.43 | -11.38 | -8.906 | -26.65 | -39.5 | -1.572 | 39.609 | 84.161 | 132.44 | 184.81 | 241.51 | 303.02 | 369.81 | 442.24 | 520.92 | 606.45 | 699.29 |

Notes:
(a) Excluding Ntarka (3.75MW x 3)
(b) Top of Duration Curve: Peak demand in consideration of peak shaving by Ntarka (3.75MW x 3)
(c) Capacities of Diesel generation are listed in "Non-Identified Projects" altogether; the optimal allocation to IPP, REG's own, and rental should be considered separately (see main text of the report).

## (3) One -Year Delay in Overall Power Development

The JICA study team examined the scenario that all committed power sources that are planned to start operation in the future are delayed by one year. The impact on supply capability is as follows.

From 2016 through 2019, the capabilities decrease by 17.5MW, 91.3MW, 67.5MW, and 27MW, respectively. There will be no substantial deficiency in 2019 since the original supply will exceed demand by 58.9MW. In 2021, the reduction of supply capability will be 48MW but only 8.5MW will be realized. In 2025, the reduction of supply will be 95MW and as the result, the shortage on aggregate will be 133.44MW, including the originally forecasted deficiency.

The shortfall from 2016 through 2018 would be covered with the installation of diesel power facilities due to short lead time and rental facilities would be appropriate since the shortfall is temporary. For 2011, since the deficiency is not significant, it will be adequate to bring forward a part of the diesel facilities originally to be installed in 2023. For 2025, 50MW of diesel power generation will be necessary and two options should be compared: moving forward a portion of the diesel generators originally planned in 2027, or installing rental diesel generators for one year. The power source composition for the years is shown in Table 2-6.7 (the highlighted with orange represents the deviations from Table 2-6.4).

Table 2-6.7 Power Source Plan in Consideration of 1 Year Delay in Oveall Power Development

Existing as of 2013

| Year | Type | Owner | Name | Status | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | Hydro[(a)] | - | - | Existing | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 | 48.88 |
| | HFO&Diesel EWSA | - | - | Existing | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 |
| | Methane | - | - | Existing | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 |
| | S/M-Hydro | - | - | Existing | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

Planned as of 2013

| Year | Type | Owner | Name | Status | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2014 | Hydro | REG | Nyabarongo 1 | Committed | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| | S/M-Hydro | - | - | Committed | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 2015 | Methane | IPP | Kivu Watt | Committed | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| | Import | Import | Import(from Kenya) | Committed | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| 2016 | Hydro | IPP | Rukarara 5 | Committed | | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | Diesel | REG | KSEZ HFO[(c)] | Not Committed | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Peat | REG | Gishoma | Committed | | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 |
| | Import | Import | Import(from Kenya) | Not Committed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2017 | Diesel | REG | KSEZ HFO[(c)] | Not Committed | | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | Peat | IPP | Mamba | Committed | | | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| | Import | Import | Import(from Kenya) | Not Committed | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | S/M-Hydro | - | - | Committed | | | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 | 21.3 |
| 2018 | Methane | IPP | Simbion | Committed | | | | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| | Import | Import | Import(from Kenya) | Not Committed | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | S/M-Hydro | - | - | Committed | | | | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 |
| 2019 | Hydro | IPP | Rusumo | Committed | | | | | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
| | Methane | IPP | Kivu Watt Phase2 | Not Committed | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 75 | 75 |
| | Import | Import | Import(from Kenya) | Not Committed | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2021 | Hydro | IPP | Ruzizi 3 | Committed | | | | | | | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 |
| 2023 | Hydro | IPP | Nyabarongo 2 | Not Committed | | | | | | | | 0 | 0 | 0 | 0 | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| | Import | Import | Import(from Kenya) | Not Committed | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2025 | Hydro | IPP | Ruzizi 4 | Not Committed | | | | | | | | | | | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 95 |

Non-Identified Projects

| Year | Type | Owner | Name | Status | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2018 | Diesel or HFO[(c)] | IPP | - | Not Committed | 59.38 | 72.868 | 6.1192 | 0 | 0 | 8.4999 | 0 | 39.609 | 84.161 | 132.44 | 89.814 | 129.51 | 166.06 | 157.81 | 155.24 | 233.92 | 244.45 | 337.29 |
| 2021 | Methane | IPP | - | Not Committed | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 75 | 150 | 150 | 150 | 150 |
| | Peat | IPP | - | Not Committed | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2023 | Hydro | IPP | - | Not Committed | | | | | | | | 0 | 0 | 0 | 0 | 0 | 25 | 25 | 25 | 25 | 25 | 25 |

| Category | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Existing (1) | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 | 82.28 |
| Committed (2) | 87 | 104.5 | 195.8 | 263.3 | 290.3 | 290.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 | 338.3 |
| Sub Total (3)=(1)+(2) | 169.28 | 186.78 | 278.08 | 345.58 | 372.58 | 372.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 | 420.58 |
| Not Committed (4) | 59.38 | 72.868 | 6.1192 | 0 | 0 | 8.4999 | 0 | 39.609 | 84.161 | 132.44 | 184.81 | 241.51 | 303.06 | 369.81 | 442.24 | 520.92 | 606.45 | 699.29 |
| Total (5)=(3)+(4) | 228.66 | 259.65 | 284.2 | 345.58 | 372.58 | 381.08 | 420.58 | 460.19 | 504.74 | 553.02 | 605.39 | 662.09 | 723.64 | 790.39 | 862.82 | 941.5 | 1027 | 1119.9 |
| | | | | | | | | | | | | | | | | | | |
| Peak Demand (6) | 196.3 | 222.4 | 243 | 267.7 | 294.7 | 324.1 | 355.8 | 390.2 | 427.4 | 467.7 | 511.4 | 558.7 | 610 | 665.7 | 726.1 | 791.7 | 863 | 940.4 |
| w/margin (7)=(6)x1.2 | 235.56 | 266.88 | 291.6 | 321.24 | 353.64 | 388.92 | 426.96 | 468.24 | 512.88 | 561.24 | 613.68 | 670.44 | 732 | 798.84 | 871.32 | 950.04 | 1035.6 | 1128.5 |
| Top Load (8)[(b)] | 228.66 | 259.65 | 284.2 | 313.67 | 345.93 | 381.08 | 419.01 | 460.19 | 504.74 | 553.02 | 605.39 | 662.09 | 723.6 | 790.39 | 862.82 | 941.5 | 1027 | 1119.9 |
| | | | | | | | | | | | | | | | | | | |
| Top Load to be Covered by "Not Committed" (9)=(8)-(3) | 59.38 | 72.868 | 6.1192 | -31.91 | -26.65 | 8.4999 | -1.572 | 39.609 | 84.161 | 132.44 | 184.81 | 241.51 | 303.02 | 369.81 | 442.24 | 520.92 | 606.45 | 699.29 |

Notes:
(a) Excluding Ntarka (3.75MW x 3)
(b) Top of Duration Curve: Peak demand in consideration of peak shaving by Ntarka (3.75MW x 3)
(c) Capacities of Diesel generation are listed in "Non-Identified Projects" altogether; the optimal allocation to IPP, REG's own, and rental should be considered separately (see main text of the report).

### (4) Other Form of Risks and Countermeasures

Above-mentioned studies are for delayed startup. Since the demand-supply balance will be restored to orginal plan after the delayed project starts operation, the impact will be temporary. On the other hand, the impact will be permanent if a project is cancelled. The entire least cost development plan should be restructed in such cases.

In addition, risk exists at demand side as well as supply side. If the demand keep advancing compared to the forecast, supply-demand condition becomes tight to be in danger of outage. If the demand stagnates, there is a risk that the utilization of power generation facilities worsen to drive up generation costs. In this study the effect to generation costs if the demand falls short of the forecast (as low as the Low Case of Figure 2-3.20) is evaluated. The result follows.

## 2.6.8. Estimation of Generation Cost

The estimated average generation costs from 2016 through 2033, on the condition that the installation of generation facilities is carried out along the least cost development plan suggested in this report, are as in Fig. 2-6.11. The chart shows that the generation cost, after leveling off with some fluctuations until 2027, is thought to decline to dip from 10 US cent/kWh after 2030. This chart also includes the trends of the generation costs along above-mentioned risk scenarios. If the construction schedule of power statins delays, the generation costs will stay lower. It is because the supply capability will exceed the demand and the delays of construction is favorable to the generation cost in the situation of oversupply. However, this figure shows that the generation costs rise significantly if oversupply and sluggish demand come together.

The "generation costs" in this section includes cost of power generation but not the costs for transmission, distribution, billing, or administration. It should be noted that the costs as is cannot be used for the basis of electricity tariff.

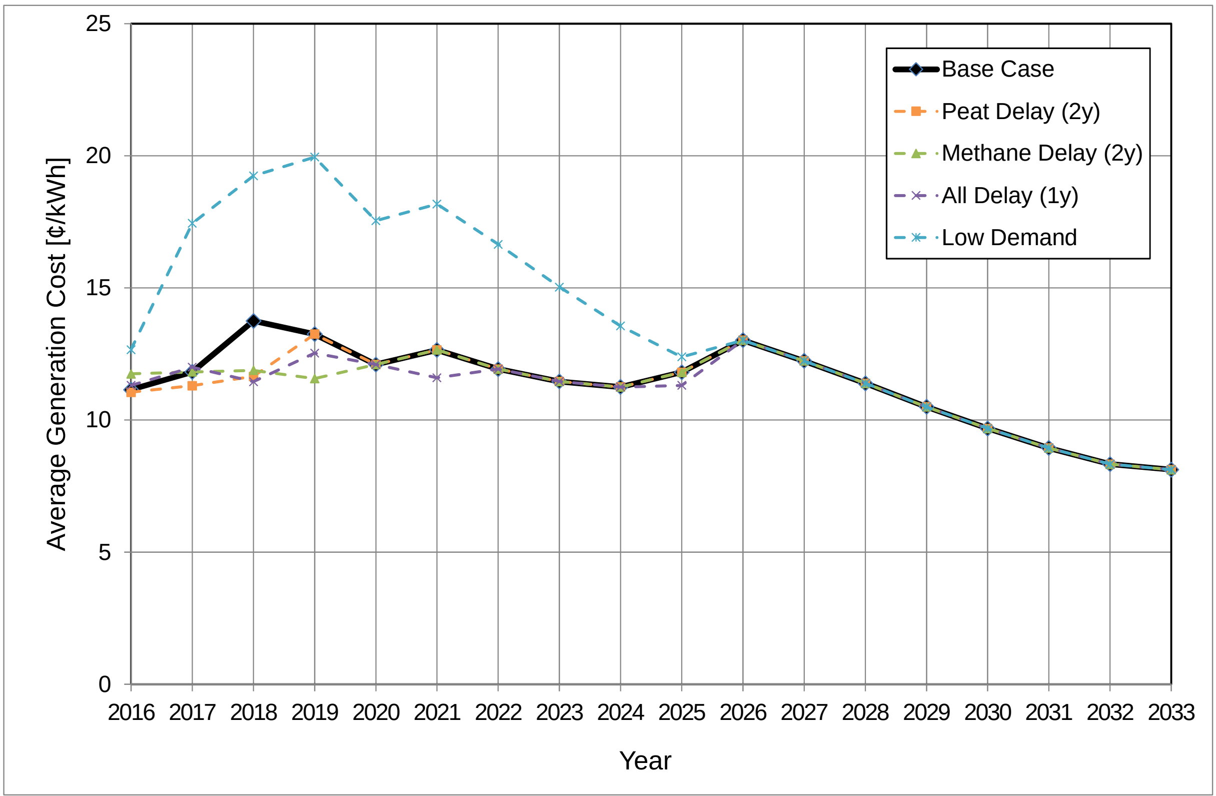



Fig. 2-6.11 Estimated Generation Costs (2016 - 2033)

## 2.7. Power Information Database

The JICA study team will attach almost all documentation and data collected for the formulation of the master plan to the study report, and deliver it to the counterpart, REG. Concerning the specific methods for delivery, items obtained as electronic files will be delivered in their original form; items obtained as hardcopy will be delivered converted into electronic form, such as PDF format; and more than 500 items of documentation all converted into electronic form will be delivered in general-purpose software (MS-ACCESS) file format. The database file name is "Power Information Database", referred to below as "POWER DB".

In addition, network facility information collected and organized to carry out an analysis of the network (PSI: Power System Information) will be delivered in general-purpose spreadsheet software (MS-EXCEL) file format. The features of POWER DB and PSI will be explained.

### 2.7.1. POWER DB

The concept of POWER DB is to provide easy operability and fast access to information, as well as low cost and ease of maintenance. Expensive and complicated databases are difficult for the general user to master, and future database updates and improvements are not simple. For these reasons considerable time and expense is necessary when such a database is introduced into an organization, and for its use to permeate the organization. "ACCESS" is inexpensive and all REG staff members have it installed in their PCs as standard, therefore it is likely that they will be able to use the database in a short amount of time, update information on it themselves, and continue to use it.

According to ESSP (draft), there is a plan to construct an "Energy Management Information System (MIS)," a power business integrated support system, within the REG intranet. Because this MIS monitors and evaluates energy sector performance, such as the degree to which EDPRS II has been attained, strong government level participation such as from MININFRA and MINECOFIN is being received, and REG is planning to build the system. In other words, this MIS system targets high-level business management through IT, and after this new company REG's organization, systems, and authority have been streamlined, its expenditure and allowances will be structured. As a result, a large, national-level MIS system, that can demonstrate these effects, will be created.

In contrast, the objective of the POWER DB to be provided by the JICA study team is not business management, but use as a more working-level tool to allow administrators to easily share and use information, rather like a business-use library. Because the objective of this study is to formulate a master plan, the POWER DB brings together in one place useful information collected in detail from REG departments, donors and sources such as the internet and other publicly available information, which covers Rwanda's generation, transmission-transformation, distribution and sale of power, international interconnection, related development planning and FS reports, and other useful information.

Information posted to the POWER DB is searchable by categories such as national/regional and field, and even file content is searchable instantaneously.

During the third on-site survey, the JICA study team conducted a workshop for REG Planning staff on how to use the POWER DB. During the workshop, after the operation manual had also been explained, it was confirmed that staff were eager to make use of the POWER DB.

Photo 2-7.1 Database workshop conducted during third on-site survey

**(1) POWER DB Basic Functions**

Use of the POWER DB gives consideration to both information sharing and security, and is limited to users whose User ID and Password have already been registered. An administrator (ADMIN) has a superior level of authority in POWER DB use, and is able for example, to make changes to User ID registrations, and to data file paths that make up the POWER DB.

After logging in, users who have obtained User IDs basically use two functions, that is, posting of data (input, update/deletion) and search.

Items to be input when data is posted include: title, national/regional, field, creator, date of issue, type of data, storage location, location of related internet information (URL, etc.) and remarks; however, for POWER DB usability it is the drag and drop function that should be emphasized. Using this function data such as electronic files created with MS-WORD, MS-EXCEL and other software, data in PDF format, and photographs stored in any PC screen folder can easily be linked and thereby posted to the POWER DB by drag and drop operation. And at the same time, text data held in such files is automatically posted to the POWER DB itself for search purposes.

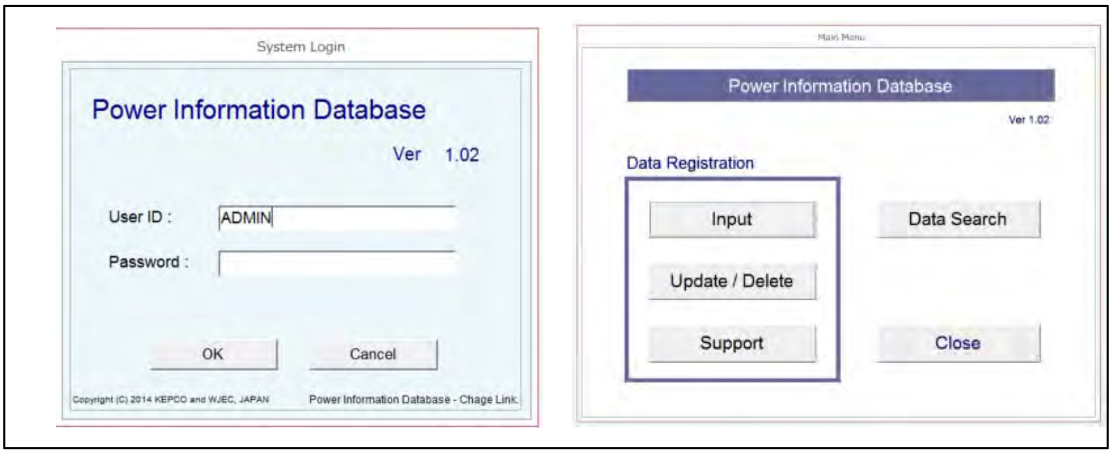



Fig. 2-7.1 POWER DB login screen and first screen after login

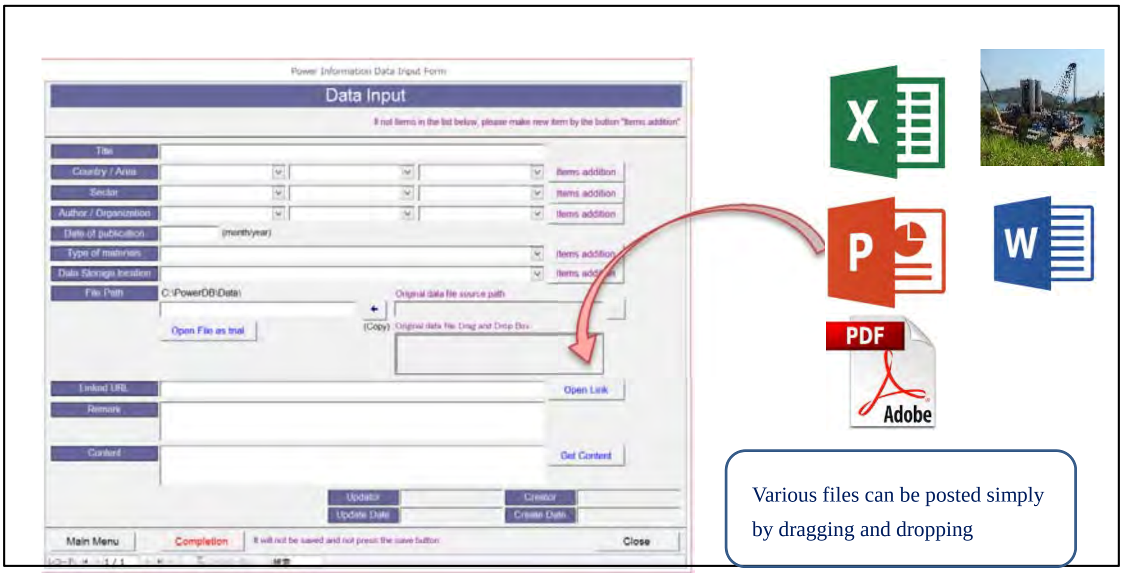



Fig. 2-7.2 POWER DB data input screen

The search function enables flexible search using multiple/refined (AND/OR) conditions for items input when data was posted (for example: title, national/regional, field, creator, issue and key words from data posted).

After search results have been confirmed, target data files can be read immediately, and search results can be listed.

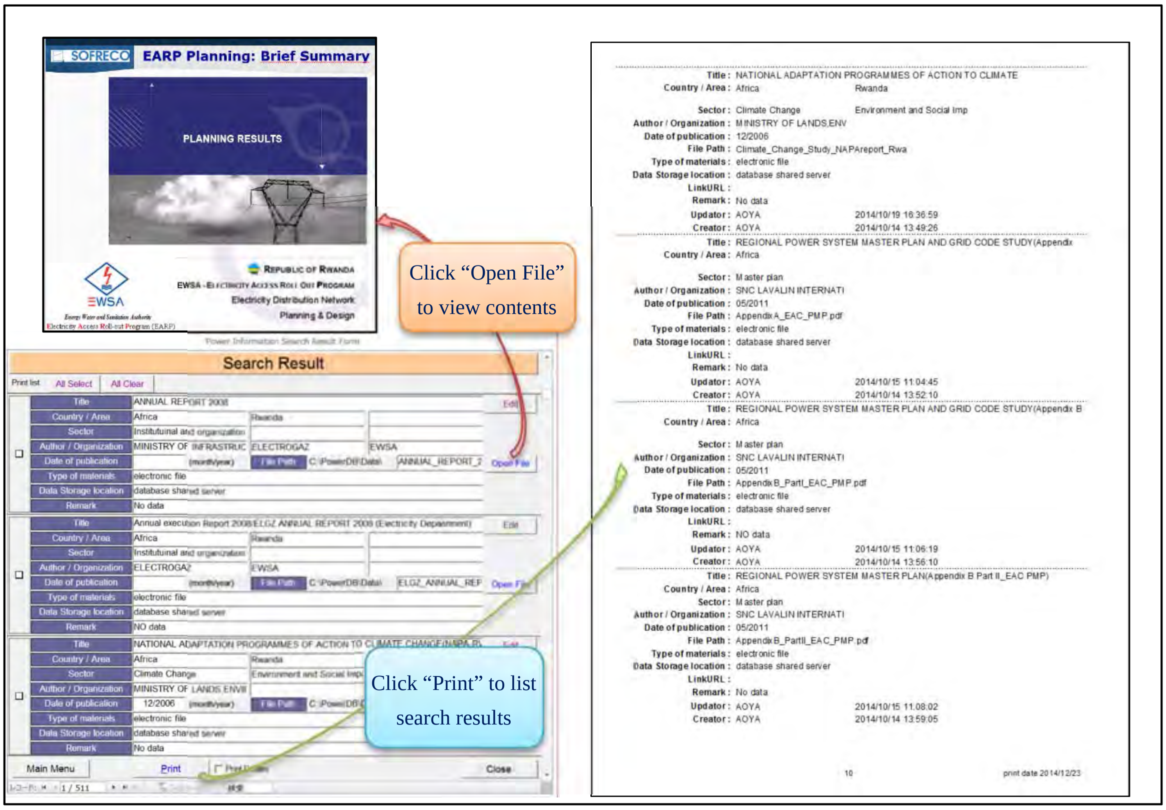



Fig. 2-7.3 POWER DB search result image

### (2) Points to consider in practical use of POWER DB

As mentioned above POWER DB uses "ACCESS", Microsoft's general-purpose database software, which is distributed worldwide, and concerning the environment in which it will actually be used, it is assumed by the JICA study team that REG staff members will use and store data on PC's and shared servers located in each workplace. Therefore, in relation to the database and its content to be delivered, the JICA study team can in no way compensate for any losses arising from unlikely events such as leakage of information, cyber-attack, fraudulent use from either inside or outside the organization, or from an information management accident. For this reason, concerning information management and security, it is necessary for REG as an organization to act appropriately under the directions of its personnel responsible for information management.

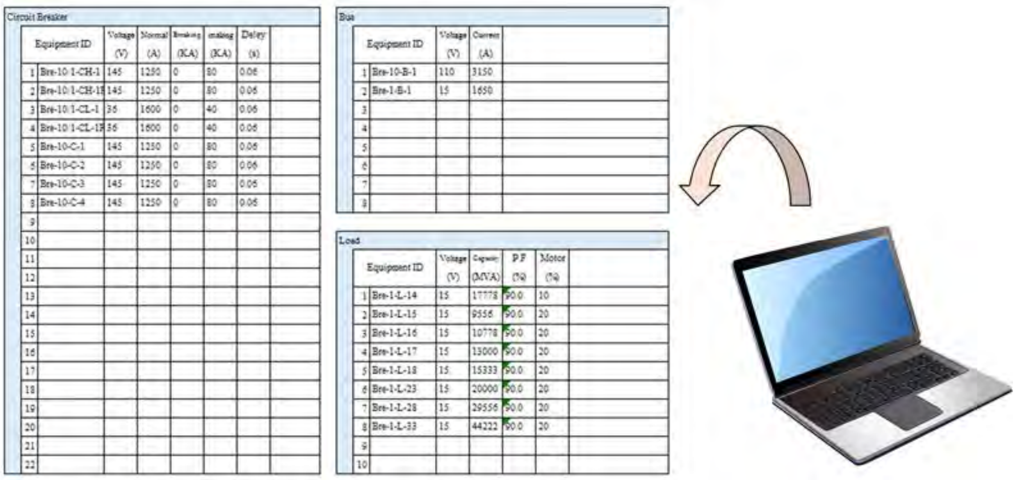
In addition, because information such as data and documentation formed into the database to be delivered has been collected with the objective of formulating a master plan, generally speaking it contains much non-public information. Concerning authority for use, the REG organization in charge of business planning acting under the directions of those personnel, after reviewing the data posted, must study how to share and use it, so that it can contribute to quick and smooth operation.

### 2.7.2. PSI DB

PSI DB has a concept similar to that of POWER DB, but uses MS-EXCEL with an aim to integrally manage the equipment and specifications of the transmission and substation facilities subject to system analysis. (Even though how the facility management system will be established and operated within REG in unknown,) It is important to manage and control data in a unified manner and define a locus of responsibility when a company engaged in infrastructure work plans a new power source development or equipment renewal while controlling and operating facilities on a permanent basis.

Rwanda is a member of the Eastern Africa Power Pool (EAPP) that works to bring a stable power supply to East Africa, and the country plans to develop large-scale power sources and systems in the future. In the light of the situation, it is advisable to introduce the unified data management at an early stage to ensure both the work reliability and efficiency improvement. At Kyushu Electric Power, the facility ledger is used for this purpose. Kyushu Electric Power's headquarters manages the facility ledger in a unified manner and shares the information with the sections in charge.

The system analysis software ETAP that was used in the creation of the master plan is owned by Rwanda, and this DB uses ETAP's output function and places emphasis on versatility and convenience. Since the facility specifications stored in ETAP and PSI DB can be made to coincide with each other, the latest facility specifications can be confirmed easily at all times. Without a risk of confusion due to differences in perception among individuals, the DB should be able to contribute to the proper facility management. Hopefully, REG starts using the DB from the point of facility planning to examine the validity of the specifications and improvement plans themselves.



Circuit Breaker

| | Equipment ID | Voltage (V) | Normal (A) | Breaking (KA) | making (KA) | Delay (s) | |
|---|---|---|---|---|---|---|---|
| 1 | Bre-10/1-CH-1 | 145 | 1250 | 0 | 80 | 0.06 | |
| 2 | Bre-10/1-CH-1F | 145 | 1250 | 0 | 80 | 0.06 | |
| 3 | Bre-10/1-CL-1 | 36 | 1600 | 0 | 40 | 0.06 | |
| 4 | Bre-10/1-CL-1F | 36 | 1600 | 0 | 40 | 0.06 | |
| 5 | Bre-10-C-1 | 145 | 1250 | 0 | 80 | 0.06 | |
| 6 | Bre-10-C-2 | 145 | 1250 | 0 | 80 | 0.06 | |
| 7 | Bre-10-C-3 | 145 | 1250 | 0 | 80 | 0.06 | |
| 8 | Bre-10-C-4 | 145 | 1250 | 0 | 80 | 0.06 | |
| 9 | | | | | | | |
| 10 | | | | | | | |
| 11 | | | | | | | |
| 12 | | | | | | | |
| 13 | | | | | | | |
| 14 | | | | | | | |
| 15 | | | | | | | |
| 16 | | | | | | | |
| 17 | | | | | | | |
| 18 | | | | | | | |
| 19 | | | | | | | |
| 20 | | | | | | | |
| 21 | | | | | | | |
| 22 | | | | | | | |

Bus

| | Equipment ID | Voltage (V) | Current (A) | |
|---|---|---|---|---|
| 1 | Bre-10-B-1 | 110 | 3150 | |
| 2 | Bre-1-B-1 | 15 | 1650 | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |

Load

| | Equipment ID | Voltage (V) | Capacity (MVA) | P.F (%) | Motor (%) | |
|---|---|---|---|---|---|---|
| 1 | Bre-1-L-14 | 15 | 17778 | 90.0 | 10 | |
| 2 | Bre-1-L-15 | 15 | 9556 | 90.0 | 20 | |
| 3 | Bre-1-L-16 | 15 | 10778 | 90.0 | 20 | |
| 4 | Bre-1-L-17 | 15 | 13000 | 90.0 | 20 | |
| 5 | Bre-1-L-18 | 15 | 15333 | 90.0 | 20 | |
| 6 | Bre-1-L-23 | 15 | 20000 | 90.0 | 20 | |
| 7 | Bre-1-L-28 | 15 | 29556 | 90.0 | 20 | |
| 8 | Bre-1-L-33 | 15 | 44222 | 90.0 | 20 | |
| 9 | | | | | | |
| 10 | | | | | | |

Fig. 2-7.4 Example of PSI DB output

### (1) PSI DB's basic performance

The easy facility data management was realized by grouping the transformers, circuit breakers, buses and loads that are associated with one substation and necessary for the system analysis in one sheet. The transmission line data are also tied to the associated substation, for the better understanding of the substation facility status.

By storing data entered into ETAP in the nominated folder, a necessary datasheet for the substation is created automatically, and data such as the equipment ID, rated capacity and service voltage are listed. However, as letters and numbers are insufficient to describe the configuration of the substation, a one-line diagram is shown in the sheet along with the equipment IDs and specifications as seen in Fig 2-7.5, so that the configuration is visually understandable.

In this stage, the data acquired in the study is entered, and it must be noted that the plan might be changed depending on the situation in the future. The datasheet has a maintenance mode, and can accommodate changes in the facility configuration due to facility renewals or additions from new constructions, making the datasheet permanently usable. The unified data management is essential in facility management, and the stored data must reflect the actual and current state of the facility. Also, it is critical to ensure easy operability and continued usability considering REG's continued facility operation and change of staff in charge; thus care had been taken to address those points.

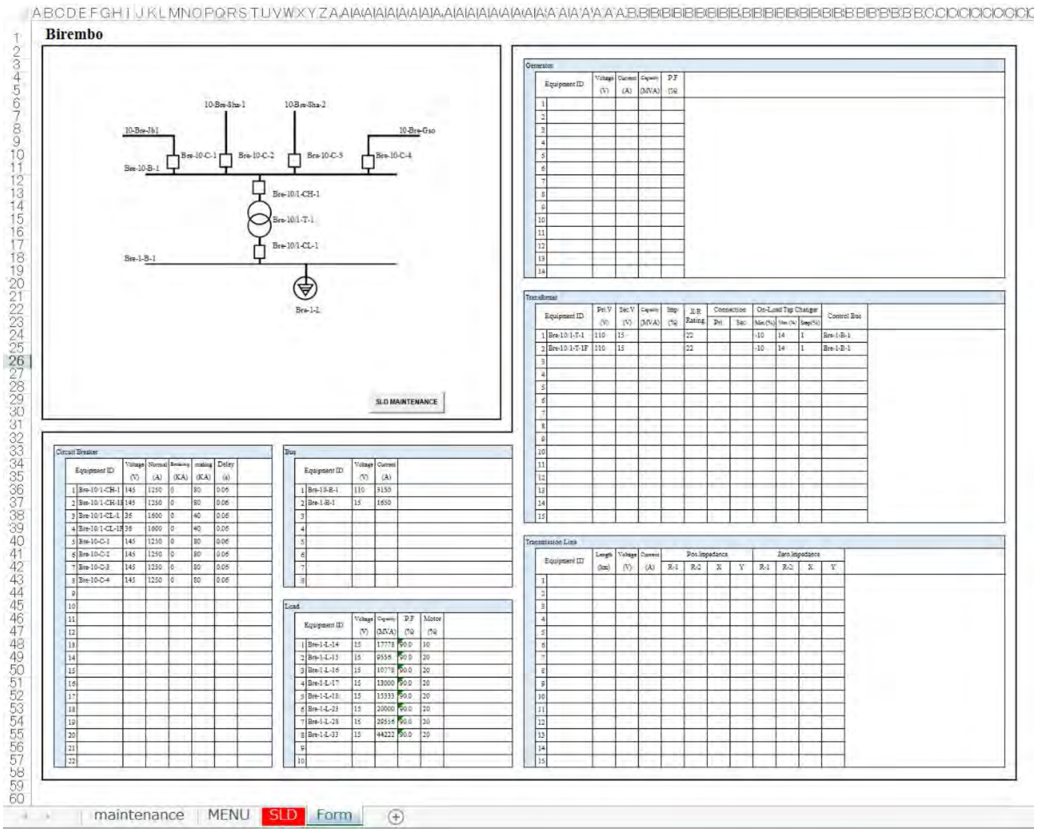



Fig. 2-7.5 PSI DB data sheet

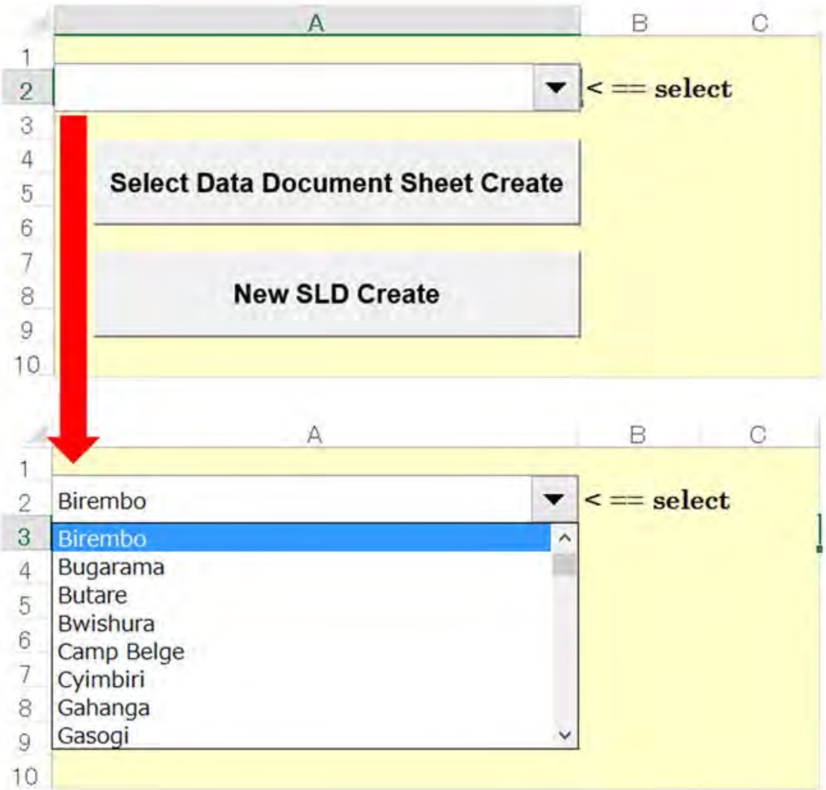



Fig. 2-7.6 PSI DB output operation

**(2) Points to remember when using PSI DB**

Upon creation of the database, the maximum simplification was considered; however, REG staff still need to input data into ETAP. Therefore, the minimum work must be done with an understanding of the necessity for the unified data management and system analysis.

Also, it must be noted that although the data can be rewritten in EXCEL, the data will not be reflected on ETAP. Based on the functions of ETAP, data could be imported from a CSV file. However, it is not recommended since an inquiry must be made to OTI, the creator of ETAP, each time and data discrepancy could occur due to forgotten Import.

REG staff must create the one-line diagram for a new construction, but the figures used are the same as the existing ones and the diagram can be created by copying and placing the figures. It can be done as long as the staff is capable of usual computer operation since no special skill is needed. Although the amount of work required might differ based on the facility configuration, the diagram can be created in five minutes for a simple configuration and ten minutes for a more complicated one, assuming that there is a referential diagram. The creation of the diagram is strongly recommended since it is important in helping the staff understand the configuration of the substation and the placement of the equipment.

It is also possible to customize the datasheet to suit the need of the REG staff, such as creating a column where necessary data not outputted by ETAP (e.g. manufacturer) can be entered directly by the staff. It must be reminded to keep a copy of the database in case of data corruption.

## 2.8. Workshop of practical method for power development planning

In this study, JICA study team made efforts to establish firmly the basic idea and know-how of the power development planning (PDP) in mind of REG's staff. Especially, the study team conducted workshops including demonstration of the practical tools with REG in Rwanda.

For example, with regard to the demand forecast, the study team explained all the information about concept, calculation method, steps for coordination, assumption and etc. to REG and MININFRA with plenty of time in 2nd, 3rd and 4th work in Rwanda. And finally, the study team provided not only the simulation result but also the organized spread sheet made by MS-EXCEL as a complementary.

In addition, regarding the Least Cost Power Development Plan (LCDPD) which was one of the prime concerns to REG and MININFRA, same as the demand forecast, with a formulated spread sheet on MS-EXCEL, details were explained in the workshop presentation to them.

Furthermore, workshop of the power flow analysis with the simulation software "ETAP" was held to mainly the network engineers for 3days, and in terms of the information arrangement and share, workshop for the document database "Power DB" and the power facility database "PSI" was carried out.

During 4th work in Rwanda, the study team carried out the Electric Power Development seminar to

REG, MININFRA and related governmental organization. This was a 1 day session, in order to broaden the achievement and knowledge through this study to promised staff in various sectors of government in Rwanda. Regarding the matters of general understanding, demand forecast, power flow analysis and LCPDP were explained there, and the issues of the organization and risk management were also explained with the cases in Japan that has no energy sufficiency same as Rwanda.

As an impressive matter during the series of technology transfer activities above, huge amount of the question and proposal for improvement were provided by REG and MINFRA, from the standpoint of the person in charge of updating for the future.

The study team believe that REG should proactively install practical methods to promote their improvement, and accordingly, REG would be able to procure a problem-solving skills.

These below are the outlook of the workshop and seminar during this study.

- Demand Forecast Workshop

  Date : June 18, 2014 (2nd work) November 6, 2014 (3rd work)

  Attendees : Total 4 (June) from REG EPU, MININFRA and etc., Total 8 (November)

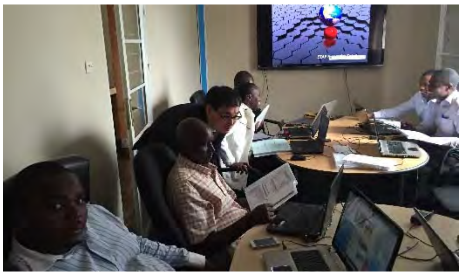
[June18, 2014]

[November 6, 2014]

- Power Flow Analysis Workshop

  Date : February 4-6, 2015 (4th work)

  Attendees : Total 10 from REG Transmission, Distribution and etc.



- Least Cost Power Development Plan Workshop

  Date : February 4-6, 2015（4th work）

  Attendees : Total 11 from REG EPU, MININFRA and etc.

- Database Workshop

  Date : February 10, 2015（4th work）

  Attendees : Total 9 from REG EPU and ICT, MININFRA etc.

[PSI DB]

- Electricity Power Development Seminar

  Date : February 9, 2015（4th work）

  Attendees : Total 14 from MINECOFIN、MINAGRI、NIRDA 、REG、MININFRA etc.

  - Project Overview
  - Overview of Electricity Development Master Plan
  - Demand Forecast
  - Least Cost Power Development Plan
  - Network development and power flow analysis
  - Policy, Organization and Management (including reference cases of Japan and Kyushu)

[Project Overview]

[Policy, Organization and Management]

## 2.9. Recommendations

### 2.9.1. Power Demand Forecast

#### (1) Need for annual appropriate update

It is recommended that the following points be studied and implemented.

- Review demand forecasts once every year, and when carrying out a review verify the causes of any differences between demand forecasted the previous year and actual demand
- Basic actual supply and demand data necessary for demand forecasts is to be collected by section responsible for demand forecasting once a year from related sections, and together with past data managed statistically
- Concerning future large-scale customers, collect detailed information including that on peak time periods, peak demand and load factor
- In the current demand forecast, multiple scenarios were not formulated for some prior conditions (e.g. rate of increase in specific consumption for Normal Customer, GDP Elasticity for Medium Customer, etc.). For future forecasts, where conditions are expected to change significantly, and it is thought that forecasting results will be sensitive to such prior conditions, formulate multiple scenarios

### 2.9.2. Power source development

#### (1) Notes regarding the connection of peat power plants to the network

Thermal power plants that are developed by the private sector and utilize peat are included in the power development plan for the future. It must be remembered how peat power generation facilities differ from the conventional hydro, diesel or methane power generation facilities.

Currently, the frequency in Rwanda is below the reference value at all times since the capacity of the power supply facilities is less than the power demand. This trend is expected to continue unless there is progress in power source development. The relation between frequency and generator rotation speed is as expressed with the formula below, and the drop in frequency leads to the drop in the rotation speed.

$$RPM = \frac{120 * f}{P}$$

RPM = generator rotation speed f= frequency P= generator pole number

The steam turbine used in peat power generation has its own resonant frequency based on its characteristics, and when the rotation speed drops, vibration might occur depending on the resonant frequency band. Generally, a protective device is installed for large rotational equipment in order to prevent vibration-caused damage. Once the protective device is triggered, the protected equipment is shut down automatically. Since the steam turbine for peat power generation is no exception, the JICA study team assumes that the protective device will be installed for equipment protection.

Also, if the electric feed-water pump is used to supply water to the boiler, the drop in the rotation speed might cause the ability to supply water to the boiler to go down, which might lead to the boiler tube burnout or drop in water supply flow rate, and in turn trigger the protective device. When this happens, it might cause the automatic shutdown of the plant.

The automatic shutdown of large thermal power plants due to frequency drop on the network side could cause further drop in frequency and even a large-scale power outage. Depending on the contents of the PPAs, the businesses might impose a penalty for reasons of unstable network and frequency; therefore, it is important for those responsible to understand that adequate care must be taken to maintain proper frequency.

**(2) Note regarding the introduction of renewal energy such as small-scale hydro and photovoltaic power**

Currently in Rwanda, planning and construction of small-scale hydroelectric and photovoltaic power plants are underway led mainly by IPPs, thanks to the developmental support by foreign donors and encouragement by FIT. The introduction of renewable energy plants such as these is significant since these energy sources are $CO_2$ free and the domestic energy resources are put to utilization effectively. However, it is necessary for REG, the entity responsible for the network operation, to always recognize the amount of electricity from renewable energy plants that can be introduced in the immediate future and measures to ensure network stability as well as associated costs. For example, generally speaking, if the reverse power flow (bank reverse power flow) occurs in the bank of the distribution substation to which small-scale hydro or photovoltaic power plants are connected, trouble could occur in the voltage control or protective coordination of the distribution system. Therefore, the network operator will have to take measures to prevent the reverse power flow in the back. Needless to say, it is unavoidable for the government or REG to bear the cost of such measures, and a decision must be made as to how to cover such cost, whether using taxes, or paid by IPPs or by a wide range of customers.

The power produced with renewable energy is still being purchased at a relatively high price under the governmental policy. There is a risk that cost associated with renewable energy utilization goes up, and as seen in the bitter experiences of many developed countries, this issue could become a national problem for Rwanda sooner or later. Especially considering the network development status, where the loss factor is still high and modernization is required, the policy for introducing renewable energy plants must be established with thorough deliberation of the matter from the technological and financial viewpoints. Japan has many remote islands and positions diesel as one of the key power sources just like Rwanda. When Japan examines the maximization of the amount of electricity from the introduction of renewable energy plants such as photovoltaic plants, it does so in a comprehensive manner taking into consideration the fuel cell introduction, network measures and cooperative operation of diesel power plants. In Rwanda where the land area is small and there are many intermountain regions, the areas where renewable power plants can be located might be limited due to its riverine systems and topographical features. That combined with the issue of power demand balance in surrounding areas, there could be a concentration of power sources in certain areas. Given these situations, REG must carry out detailed technological investigation on connections and necessary measures from the standpoint of stable network operation.

It is probably reasonable to recognize the installation of the meter to all feeders at the distribution substations described below as one of the basic conditions to be satisfied to promote the introduction of renewable energy.

**(3) Need for updating the hydropower master plan**

The study of Rwanda's hydropower development potential has not been carried out since "Hydro Power Atlas" which was a hydropower development feasibility study reported in 2008. According to the report, there are 333 sites that have been confirmed suitable for small-scale or micro hydropower plants in Rwanda. Currently, more and more small-scale or micro hydropower plants are being developed based on this FS.

On the other hand, there are cases of hydropower facilities constructed in recent years that have not performed as well as initially estimated. Also, as stated earlier, it is necessary to evaluate the potential sites for small-scale and micro hydropower plants that are to be connected to the distribution line, with thorough consideration of the balance among demand areas and the network development status. Looking back the electricity policies of Rwanda in recent years, the excessive expectation for the electricity development potential seems to have led the policy making, whether they were for peat or geothermal power generation. The JICA study team recommends that Rwanda considers the necessity of updating the hydropower master plan in order to effectively utilize hydropower continuously into the future as Rwanda's core power source that uses an indigenous energy resource.

**(4) Need for comprehensive review of hydropower rehabilitation and modernization**

It is likely that measures are required to ensure soundness of the hydropower facilities through rehabilitation and to enhance power generation efficiency for the majority of REG's hydropower plants since they are old. There are many large-capacity facilities, and thus the further drop in the supply capability is expected during work implementation. However, the adequate supply system is not in place to procure equipment components, due to change of suppliers, etc. If a plant is shut down due to a facility trouble, the drop in the power supply capability could last a long time.

Also, there is a concern that power demand and supply capability might start fluctuating drastically in a short duration of time within a day in Rwanda as experienced by the developed countries, due to the introduction of renewable energy plants and lifestyle change in the people living in cities. The hydroelectric power plants have a high ability to coordinate power supply and demand, and for this reason, not only the rehabilitation of the hydro plants but also the modernization of communication and control devices will be required to promote timely cooperation with the load dispatching center.

It is imperative that REG consider the rehabilitation and modernization as its important tasks, prioritize the measures through close collaboration with the network operation sector, plan appropriate renewal work to minimize the drop in the supply capability, and work to avoid unexpected supply deficiency as well as enhance supply capability flexibly and comprehensively.

### 2.9.3. Electricity Network development

**(1) Voltage fluctuation and impact on the network including the distribution line**

The network analysis was conducted during this study assuming that the transmission bus voltage was within the reference value (rated bus voltage ±5%). Therefore, if the operation continues with the bus voltage deviating from the reference value, there could be a problem with the analysis result as well as with the stable operation of actual facilities. It must be recognized that the deviation of bus voltage from the reference value could greatly affect not only the transmission network but also the distribution line operation and facility design.

**(2) Need for meter on each feeder and understanding supply and demand situation**

In Rwanda, not all feeders are equipped with an electricity meter at the substation; therefore, the network analysis for this study was done to analyze the balance between power supply and demand based on the data and information that are currently obtainable. The result revealed that the electricity from the power supply facilities that are currently planned for development and that imported would be able to meet the demand for the immediate future. However, it is desirable to install the meter on the feeders of all substations and to manage the trend of power demand and facility tolerance on the daily basis in order to improve the analytical precision for power supply and demand balance.

The precise management of the facility and power supply and demand situation offers benefits not only in the technological aspect but also with respect to productivity and economy such as the facility investment, and maintenance and management efficiency. Therefore, the JICA study team recommends that REG, the operator of the network, to take initiative and plan and implement such an undertaking. It must also be noted that it will offer basic information for estimating power demand.

**(3) Need for following and analyzing the trend of power demand**

In the effort to estimate power demand, the network analysis was carried out by assuming that the general customer loads connected to a new substation are distributed evenly throughout the area. This was because of the issue related to the meter on the feeders described above, as well as the limitation on the obtainable data and information. Depending on the future urban development and plans to attract factories, the load distribution could be different from assumed distribution and the reality could be that a large amount of load moves unevenly between the feeders and substations.

Thus, if the estimated power demand per substation could change significantly, the network analysis must be carried out as appropriate, and the facility plan and the operation method must be reviewed.

**(4) Need of Installation of capacitors**

In this study, bus voltage drop is confirmed in some terminal substations as a result of conducting system analysis based on modeling of the projected demand and power stations planned for construction.

These are cases of voltage dropping below the standard scope due to unique transmission losses caused by impedance on transmission lines. This phenomenon is conspicuously seen at substations connected to power receiving equipment and large-scale consumers when conducting long distance transmission.

Since active power can be increased through restoring voltage drop caused by transmission line losses and improving the power factor of generators by installing capacitors on distribution bus lines and supplying reactive power, it is recommended that capacitors be installed at appropriate locations.

JICA study team has calculated the capacity of the installing capacitors. Since the capacity of capacitors per bank is set, it has been assumed that small quantities of inactive power that exceed the capacity per bank can be supplied from nearby power stations. In Japan, when large scale customers are connected, installations of capacitors are sometimes discussed with operators. In Rwanda, too, it is recommended that guidelines be formulated concerning the new connection of receiving facilities such as tea plants and so on in future.

**(5) Management of new facility construction or renewal**

If the existing facilities are used continuously above their rated capacities to meet the increased power demand in the future, it can lead to equipment burnout or fire due to overcurrent. In such events, it might not be possible to continue the operation of the damaged facilities. Thus, any part of a facility that is in need of enhancement must be replaced at a proper time.

Based on the power flow analysis in this study, revealed areas that require new facility construction or renewal of the existing facility with the timing and cost for such work.

Upon planning a renewal work, it is necessary to determine the proper time by understanding in advance the demand increase for the area as well as the schedule for the equipment procurement and work itself. Care must also be taken so that no substation or other facility will suffer overload during the transmission system operation due to the suspension of the operation of the facility where the work is being conducted.

### 2.9.4. Electricity development using the least cost development plan method

#### (1) Updating power development plan

Power development plan should be updated once a year in accordance with the demand forecast as a precondition. In addition, when material change such as the delay of construction schedule, long unscheduled outage of exsisting power station, significant impact on costs (e.g.,balooning oil price) occured, power development plan should be updated to carry out necessary action immediatly.

#### (2) Updating hydraulic power master plan

The utilization of older hydro is better compared to newer ones but it is too hasty to compare only by numbers. The potential of the river of older hydro may be underestimated. Now, different from the periods when old hydros were installed, elaborate hydrological analysis is available thanks to the detailed information such as local climate, satellite images, and GIS. In addition, technologies for numerical analysis and simulation as well as the advancement of the performance of personal computer hardware and software.

For example, when the utilization of upstream hydro is high and that of downstream is low in a same water system, it would be possible to improve the utilization of downstream hydro drasticaly sacrificing the output of upstream hydro a little. In consideration of such cases, it is worthy to seek the possibilities to improve overall output of a water system, not the hydros individually. As mentioned before, JICA study team suggests updating hydraulic power master plan.

#### (3) Integrating construction and O&M

The electric utility division of EWSA/REG is being separated into EUCL, in charge of O&M, and EDCL, in charge of expansion. Although the separation has merits such as clarity of powers and functions and expedition of decision, some concerns exist. For example, since trade-off exists between construction cost and O&M costs, comprehensive viewpoint, not from construction or O&M individually, is essential to optimize generation costs as whole. Therefore, construction staffs in EDCL should be familiar with O&M while managing staffs in EUCL should be familiar with construction.

Therefore, JICA study team suggests that even after the separation of EDCL and EUCL, information sharing and personal exchanges should take place perennially between the two organizations. Electric supply will be sufficient for demand between 2017 and 2022 and technology inheritance within EDCL should take place during this period. In addition, it will be effective if the staffs of EDCL are dispatched to power stations in operation for the OJT of O&M. Oppositely, it will be also effective if the staffs of EUCL are dispatched to power station construction sites for OJT when expansion projects are active.

#### (4) Systematic refurbishment in consideration of demand/supply balance

As mentioned previously in this report, demand-supply situation will be relaxed between 2017 through 2022. Under favor of the period, it is recommended to perform extensive works with long shutdown of power plant such as the inspection and repair of structures hydro power plant, intensive rehabilitation and renovation. Also it is expected to similar period will occur, for example, after the large power sorce joins the line. It is also recommended to predict such situations in power development plan and to planify massive works in long-term schedule.

In order to perform such activity smoothly, EUCL and EDCL should continue close communication.

**(5) Minimizing reserve margin**

In the situation that power shortage is the pressing issue, higher forecasted demand and higher reserve margin tend to be set as target in order to avoid the risk of demand tightness. However, the lower the reserve margin it is better because reserve margin implies overinvestment and idle facilities. For power utility as an asset-based industry, the existence of redundant assets brings about higher generation costs.

The measures to reduce unnecessary reserve margin are, (a) more accurate demand forecast and (b) operation of electric power facilities meeting the specifications and expectation. (a) is as previously noted, and (b) actualizes only if the perfect coordination from planning, construction, operation, and maintenance of each component of power system is achieved. Such purpose will become a reality only if every staff concerned understands the association with relevant tasks as well as the intimacy with own duties. In this context, systematic collaboration between EUCL and EDCL is inevitable.

**(6) References for further study**

The concept of Least Cost Power Development is an application of minimization of production cost as in the theory of microeconomics. Refer to Chapter 22 of "Economics" by Samuelson & Nordhaus, for example.

* Samuelson, Paul A., and Nordhaus, William D., Economics, New York: McGraw-Hill, since 1948.

Refer to following books for the theoretical framework of Least Cost Power Development.

* Marsh, W.D. Marsh, Economics of Electric Utility Power Generation: Oxford Engineering Science Series, New York: Oxford University Press, 1980.
* Stoll, Harry G., et al., Least-Cost Electric Utility Planning, New York: John Wiley & Sons, 1989.

### 2.9.5. Policy, organization and business management

**(1) Issues related to organizational change**

REG was newly and legally established on August 12, 2014 after the repeal of the former EWSA law. As of November 2014, the CEO of REG appointed by the government and the Managing Directors (MD) of EUCL and EDCL were the only workers that have entered into a formal employment agreement with REG. All others in the director position and their subordinates had not entered into a formal employment agreement. The stance of the organizational change until July 2015 is moving forward while thinking. However, the organization is at the base of all work and duties, and the sense of responsibility and loyalty to the organization could affect the quality and efficiency of work greatly.

The former EWSA was split up over three years, and the JICA study team had an impression that the sufficient evaluation of the organizational and financial issues and performance was not carried out during the split up which led to this hasty organizational change. Their plan is to discontinue the subsidies in the next three years and turn the new companies into highly profitable entities. However, they are planning to establish an evaluation system only one year after the organizational change, without clearly explaining the tasks or segregation of duties, and to made decisions on employment and salary based on the evaluation result. The JICA study team believes that it is critical for REG and the government to take caution to ensure that there is no arbitrariness in the establishment of the evaluation rules.

The JICA study team was told that the draft for this organizational change was drawn based on the suggestion from the outside consultants. However, it is questionable whether the companies that were benchmarked as a model and the size of the market that these companies target matched Rwanda's electricity situation. The JICA study team believes that it is quite possible for the organizations to be improved or reintegrated as an electric business sector as REG continues its operation.

**(2) Issues related to a rapid shift to power source development led by the private sector**

The JICA study team believes that Rwanda should not rush into the discussion of the promotion scheme for the power source development that use geothermal energy and is led by the private sector until sufficient developmental potential has been confirmed. There are many uncertainties related to the subterranean resource development that it is hard for the private sector to take risks that exist at the beginning of the development. Therefore, the government and REG should lead the way for the time being and take steps to confirm the amount of resources by collaborating with donors from Japan and other countries. It would not be too late to discuss specific schemes such as the legal system for bringing in the private sector and setting up the funds once the development is in sight. For this purpose, it is effective and less risky financially and politically to train geothermal specialists through technological transfer like that taken place during the examination of the geothermal development plans in this work or training programs in Japan like the one that some of the staff had already gone through.

It appears also that REG started thinking about turning over many of its hydropower plants to the private sector. In the operation and maintenance of hydropower plants, there are many things that can be expected of the private sector such as technological capability, fund procurement or knowhow of market competition. On the other hand, it must be noted that a hasty judgment of the use of the private sector can produce many problems. Examples of such problems are:

・Stalled facility investment and repair in pursuit of profit
  → Issues related to power generation capability and quality maintenance

・Hindrance to comprehensive power source operation due to too many IPPs

→ Risks of reduced ability to coordinate power supply and demand

・Increase in O&M cost due to dispersed owners

→ Risks of power supply cost increase

In Europe, the liberalization and privatization of the power sector have been pushed since the 1990s; however, the electricity tariff didn't necessarily go down. There were cases where the necessary facility investment or repair was postponed, and facility maintenance such as the measures for ageing facilities was not implemented.

There is no objection to entrusting foreign capital companies or IPPs with power generation projects for which the country lacks specific technology and knowhow such as methane and peat power generation. However, Especially in Rwanda that still suffers a low electrification rate and requires the expansion of its entire power supply system including the networks along with power sources, the JICA study team believes that REG should think hard before deciding to transfer hydropower to the private sector, from the viewpoint of energy security and the efficient and sound facility development, since hydropower has been operated and maintained for many years as one of the key power sources of the nation.

The methane and peat power plants that are planned to be newly introduced will adopt the "Take or Pay" principle in the PPAs as a rule. If REG transfer hydropower plants which should be operated as base load plants to the private sector, the power sources that belong to REG will be middle-load or peak-load power sources among those in service. It means that REG's power sources will be mainly those that are used to balance or back up the power supply and REG would be forced to take on power generation with a low load factor and high cost. This is not a scenario that is likely to help REG improve its profitability. The JICA study team believes that there is very little merit from inviting the private sector into Rwanda's electric power sector at this point in time, and therefore, the electricity development should be led by the government and REG for the time being.

**(3) Project management and cost-consciousness**

Based on the fact that the hydropower plants constructed by EWSA in and after 2011 are experiencing many troubles and have not achieved the forecasted capacity, the JICA study team believes that the development of new power sources must go through fundamental review, including the entire process of the project management and system, starting with design, procurement of equipment and facility, to contracting and management of work.

The reasons for the lack of project management ability might include the suspension of new constructions by EWSA for 15 years between 1984 and 2010, and during which time, the engineering technology was not passed down. On the other hand, there are many cases of electricity development in Rwanda where the initial work schedules were not met, in addition to the projects of EWSA. For example, Rwanda's first commercial methane power plant Kivu Watt (25MW) was initially planned to start operation in January 2015; however, it was expected to be delayed by about six months when the confirmation was made at the time of the 4th work (February 2015). Also, for EWSA's Gishoma peat power plant, the operation was planned to start in 2014, but was delayed to the middle of 2015 or later.

The JICA study team would like to emphasize that the ability to manage projects is an important factor for REG to ensure profitability and to work to become a sustainable project company. For example, a delay in the start of a power plant operation brings on disadvantages below, including cost increase.

- Increase in loan interest during the construction period and related cost due to deferred loan payment
- Increase in the construction and management expenses (labor cost, lease expense for offices and equipment and expenses for management by contract)
- Increase in unplanned expenses due to procurement of alternative power sources
- Adverse impact on revenue and expenditure due to the prolonged revenue recognition period
- Decrease in evaluation by the capital market due to disrepute → future increase in the fund procurement cost

The project management ability and cost-consciousness are common factors associated not only with construction work, but also with overall business management, including the conventional power facility operation, maintenance and procurement activities. Regarding the low cost-consciousness, the effect of low crisis awareness cannot be denied, which was the result of the fact that EWSA has been covering the diesel rental cost with the government subsidy and receiving various gratuitous financial aid for many years. However, the biggest reason might be EWSA's failure to achieve independent business attitude in the past three years.

The JICA study team hopes that the newly-emerged REG tackles managerial reform so that the project management and cost-awareness will sink in the minds of all staff of REG, from the top management to those working on site.

The JICA study team recommends REG to study and take advantage of the balanced scorecard (BSC), which is one of the world-famous business management methods proposed by Drs. Kaplan and Norton in the United States in the 1990s and has been adopted by Japanese power companies. The concept of BSC is the examination of the issues and solutions of the corporate activities from the four perspectives (Financial, Business Process, Learning & Growth and Customer Perspectives) and that the consequences of all activities lead to a financial result and repeated sustainable growth.

Unlike conventional business management methods which tend to be biased towards financial matters and lead to sectionalism within the company, BSC helps all the employees to understand the missions and issues of the organization. It is suitable to power companies since power companies place emphasis on work processes and keeping harmonious relationships with the regional society. Figure 2-9.1 below shows part of the materials used by the JICA study team during the seminar that was held on February 9, 2015 for REG and related ministries and agencies of Rwanda.

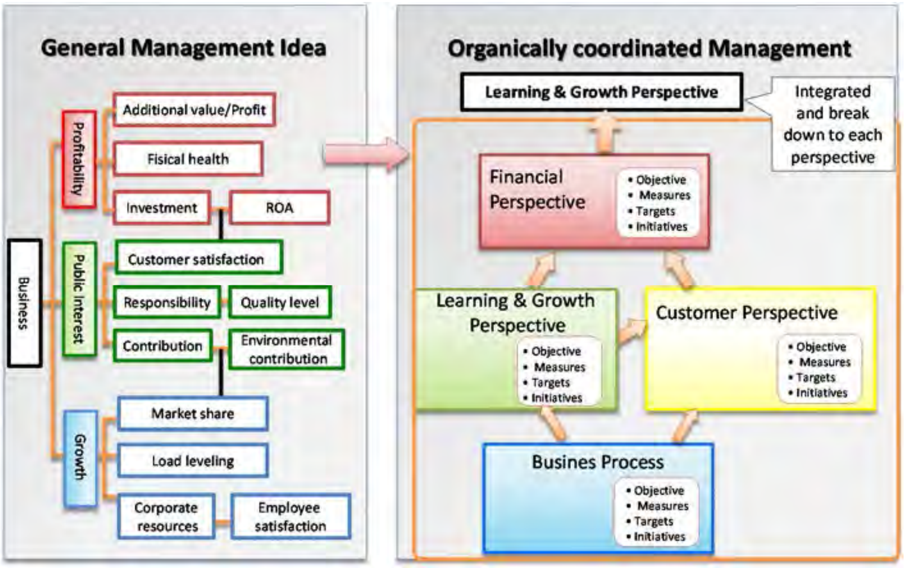



Fig. 2-9.1 Scheme of the balanced scorecard

### (4) Need for the financial management task force

IRR and capital cost were not adopted in EWSA's financial management. However, they are among the most common and important indexes that are used to estimate profit gained from facility investment for new power source development, large-scale renewal and other work. These indexes are essential when making decisions regarding the launch of a project, as well as the continuation of and withdrawal from a project once it was launched, and the restructuring of power generation assets (portfolio). The JICA study team recommends that REG adopt and use these indexes as soon as possible as the basic tools for financing and project management.

Even if IRR is obtained through trial calculation, it cannot be used unless the company's capital cost is understood. The capital cost is the cost for a project company like REG to procure fund from the capital market. If IRR does not exceed the capital cost as the hurdle rate, the company value will eventually diminish and no reinvestment or prosperity will be brought on, no matter how long the project lasts or how much revenue the project brings in. In order to incorporate the concepts of IRR and capital cost into the financial management, it is necessary to "calculate the existing investment cost and O&M cost for the power generation, transmission and distribution sections, respectively" as explained earlier, and to understand the accurate fund procurement cost, which EWSA's current financial management method cannot accommodate.

EWSA plans to have EDCL, a subsidiary responsible for facility development, to manage each project after the restructuring to create a new REG. However, before IRR and capital cost can be calculated, it is necessary to understand the details of the financial activities of REG as a whole including the utility subsidiary EUCL, by using separate accounting and reallocating common expenses by subsidiary and section. EDCL and EUCL are practically one unit in REG's power supply chain. If the reasonable internal transaction prices cannot be set between the two companies, it will be impossible to recognize the income (sales from EUCL) when EDCL is to calculate IRR, for example. On the other hand, when EUCL calculates the electric bill and collects it from the consumers, it will be impossible to know the cause of the deficit in the electricity business and take necessary countermeasures.

The JICA study team recommends the creation of a financial management task force to grasp REG's financial situation quickly. It should be one group within REG and have access to both subsidiaries. By precisely understanding the financial activities of REG as a whole by using separate accounting and reallocating common expenses by subsidiary and section, the electricity tariff can be calculated to reflect the power supply cost. On the other hand, without this process, the relationship between the cost and the tariff will be unclear and the calculation of reality-based tariff menu would be difficult.

According to RURA, the government plans to have the new electricity tariff system to be introduced July 2015. The JICA study team believes that REG should calculate the power supply cost for the power generation, transmission and distribution sections respectively, and allocate the broken down cost to different contract types, depending on the customers' receiving voltage and power consumption. The group sincerely hopes that the early introduction of the tariff system does not become the goal itself.

It appears that RURA plans to review the reasonableness of REG's costs quarterly once the new tariff system is introduced, which seems too frequent. The review might become an excess and unnecessary burden to REG and RURA, and there might be a risk of the review becoming a mere facade if it takes place too often. If the review is a limited investigation and approval as is the case of Japan where the variable factors associated with fossil fuel are reflected quarterly, then the quarterly review might be effective.

### 2.9.6. Electricity development database

#### (1) Issues related to organizing and sharing information

While collecting information for the study, an issue was highlighted that information was not organized and shared adequately. Generally speaking, the planning unit of an electric power company is responsible for forecasting power demand and developing power plants and should have all necessary information, already organized and shared as necessary. In the case of EWSA, however, the situation was different. The electronic data were buried in the PCs of the respective employees and there was no library that housed books and various reports such as FSs in their office. When asked about the information management, an employee of the planning unit of EWSA responded by indicating an issue that "since information is in the PCs of respective employees, if the employee in concern is on a business trip or having a day off, other staff are not able to refer to the information and sometimes have to stop the work."

To address the situation, the JICA study team created a database that is actually being used in Japanese offices, by using Microsoft software ACCESS which is simple and versatile. The JICA study team then organized electronic files and paper files in the PDF form that were gathered for this study and presented the database to EWSA with a view to enhance information literacy of REG for the future.

This database can be used by each employee in his or her PC or used by multiple employees if the master file is stored in the server on the network or shared PCs. As a support for REG to facilitate smooth introduction, the JICA study team held workshops during the 3rd and 4th works and helped the staff in charge of information management understand how to use the database. This database is useful in many situations such as managing information related to the business clients, IPP businesses or PPAs.

The first bottleneck when introducing information management or database is brought on by the influence of the outside recommendations or over-acquisitiveness of the user. It often leads to a too large system, high cost, prolonged introduction period, and complicated maintenance.

The JICA study team believes that REG must recognize the information organization and sharing as its basic task, implement what it can promptly without overextending itself, and promote speedy and efficient work execution. In terms of information management, it is important to take into consideration the convenience of use as well as the establishment of security measures and rules for using the data, such as ensuring that only those who need to know have access to such information.

**(2) Use of database for facility management**

For a continuous and stable power supply, it is important to ensure the appropriate facility management on site and the development of the environment where facility information is collected and effectively utilized in order to support the work at site. During the inspection of EWSA's power facilities and interviews of the staff on site, the JICA study team had an impression that the level of knowledge and skill of the individuals is high. However, regarding the integrated organization and sharing of facility information, the lack of companywide infrastructure was a concern, since there was no ledger with readily available information.

With an enormous amount of facility data to be managed, it is impossible to store all the data at once in an integrated manner, but an improvement can be made as the first step toward the facility information management by combining and using the information management tools that were presented by the JICA study team in this study. For example, with the use of Power DB explained earlier, the periodical records and data can be managed including the specifications and inspection record of equipment and facilities, record of faults and countermeasures, and power generation amount. On the other hand, the material for studying the latest facility composition and estimated cost based on the network analysis can be created and managed with PSI.

By taking these measures, the detailed information including the aging degradation could be managed with Power DB, and the latest facility information required for network analysis could be viewed using PSI, making it possible to search and use the necessary information in a timely manner. It will also be possible to share the latest facility information companywide across sections, which will help a wide range of work including the efficient facility operation and prioritization of facility maintenance, management and renewal with thorough economic consideration. The JICA study team hopes that REG considers the effective utilization of Power DB and PSI and move forward with efficient facility operation, maintenance and management.

# 3. Study of Geothermal Development Plan

## 3.1. Situation of Geothermal Development

### 3.1.1. Framework of Geothermal Development in Rwanda

MININFRA is the authority having jurisdiction over geothermal development policy in Rwanda. The energy division of MININFRA includes some senior engineers and legal officials who handle geothermal energy policy and develop geothermal law. In addition, geothermal development work including survey, analysis and well drilling is handled by the Geothermal Unit, in the Energy Development Corporation Limited (EDCL), Rwanda Energy Group(REG). The chief of the Geothermal Development Unit of EDCL stated that the following 8 staff were working there, as of February 2016 .(3 of EDCL staffs are in Japan for their master's course.)

| | |
|---|---|
| Manager | ：1 staff member |
| Geochemists | ：2 staff members |
| Geophysicists | ：2 staff members |
| Reservoir engineers | ：1 staff member |
| Drilling engineers | ：1 staff members |
| Direct Use | ：1 staff member |

Some staff were trained in geothermal technology in Iceland, New Zealand, Kenya or Japan, but we cannot say they are well-trained in the full range of geothermal technology and know-how because most of them have no personal survey experience.

### 3.1.2. Present Status of the Support by Development Partners

Support for geothermal development survey by other donors as of January, 2014 was as follows.

(1) **EU**

1) Geothermal resource survey in Gisenyi-Karisimbi

A geothermal resource survey in Gisenyi-Karisimbi in the northwestern part of Rwanda is planned. This survey includes surface survey (geological, geochemical, TEM and magnetic surveys) and slim hole drilling. The project is named "The study in support of Developing Geothermal Resources in Rubavu - Karisimbi"

2) Geothermal resource survey in Bugarama

A geothermal resource survey for Rwanda, Burundi and DRC is now ongoing. In this survey, surface survey (geological, geochemical, magnetic and TEM surveys), thermal gradients wells and integrated analysis of the geothermal resource (elaborating a geothermal conceptual model) are planned. Furthermore, a deep exploratory well drilling is planned at one field in one of these three countries. The consultant for this survey is determined as Reykjavik Geothermal (RG). The project is named "Regional Project for Geothermal Exploration in Rwanda, Burundi and DRC"

3) Legal and policy framework for geothermal development by EUEI-PDF

The object of this survey is the formulation of policy and implementation guidelines for the promotion of privatization of the geothermal sector in Rwanda. This survey will be conducted for one year from January 2014 and will examine funding of geothermal development (including private sector funding) as well as strategy and an action plan for geothermal development, and will propose a new legal and policy framework for the promotion of geothermal development.

4) Support from in-house experts

Three in-house experts were employed to support work on geothermal policy, strategy and geothermal management law.

(2) **UNEP**

1) Geothermal resource survey in Kinigi-Karisimbi and donation of measurement equipment

A proposal for geothermal resource survey is planned in Kinigi-Karisimbi in northwestern Rwanda was submitted to UNEP. This proposal included surface survey (geological, geochemical, gravity, magnetic and MT surveys) and an integrated analysis of the geothermal resource (elaborating a geothermal conceptual model).A gravimeter and a magnetic meter were to be donated as part of this project. The name of the project is "Funding for a Stepwise Exploration, Appraisal and Monitoring of Geothermal Resources in Karisimbi-Kinigi Field" A technical Evaluation of the Proposal was conducted under the ARGEO Programme and unfortunately the proposal was rejected. UNEP is open to support another field for geoscientific surveys.

(3) **BTC**

1) A preparatory survey for a geothermal well drilling rig and a study of "detailed staffing requirements and institutional arrangements" were in discussion but not implemented.

2) Support for geothermal resource survey

Exploratory well drilling in Kinigi was supported considering the outcome of the Karisimbi drilling, and a supplementary survey for the implemented surface survey will be conducted if necessary. The support was withheld after results of the Karisimbi drilling.

3) Support for establishment of a Geothermal Energy Advisory Committee (GEAC)

Because one of the problems facing geothermal development in Rwanda is lack of expertise, the establishment of a GEAC was supported within EWSA(now EDCL), and 6 experts were to be hired and funded by BTC with expertise in the following areas: (1) power plant design, (2) geothermal risk analysis and funding planning, (3) drilling, (4) reservoir modeling and management, (5) environmental and social considerations, (6) geothermal survey and development planning policy. The GEAC was not established.

(4) **ICEIDA**

ICEIDA conducted technical training for EWSA(now EDCL) staff from June 25 to June 29, 2013. Additionnal on job training was provided during drilling in Karisimbi. This program comprised training in surface survey, drilling, logging and well testing.

(5) **WB**

WB has not provided much support for geothermal in Rwanda so far. However, the WB has purchased well testing equipment for the Karisimbi project. Basically, they wish to support low-cost power plant facilities, but they may support the geothermal sector if the geothermal resource is confirmed and the Rwandan government requests their support.

(6) **KfW**

The Geothermal Risk Mitigation Fund (GRMF) is a fund set up by KfW and AU sponsors to finance surface survey and exploratory well drilling in fields with unknown resources at the early stage of the development. At present, it's funded by KfW and EU, but DFID and the Northern Europe fund are interested in providing support. Rift valley countries can apply for funding, and Rwanda is also included. Up to 80% of surface survey and up to 40% of exploratory well drilling is fundable. EDCL has applied to the GRMF fund for support for exploratory well drilling in the Kinigi filed. This application was approved in December 2015.

(7) **AfDB**

If the geothermal potential is confirmed in the master plan project conducted by JICA and is also feasible, AfDB intends to support geothermal development in Rwanda.

### 3.1.3. Present Status of Geothermal Resource Development

(1) **History and results of previous survey**

Many organizations have surveyed geothermal resources in Rwanda with a view to development. From those results, Karisimbi, Kinigi, and Gisenyi in the northwestern area and Bugarama in the southwestern area have been selected as promising geothermal areas (Fig.3-1.1). Information about the previous survey results and geothermal resource potential in Rwanda is as follows.

The geothermal exploration of Rwanda was initiated in 1982 by BRGM (French Bureau of Geology and Mines). They conducted geochemical surveys at Mashyuza (Bugarama), Gisenyi, Kibuye, Ntaresi and Musanze, identifying Gisenyi and Bugarama as potential sites for geothermal development with estimated reservoir temperatures of over 100ºC. Later, Chevron studied reservoir temperatures using geothermometry of the hot springs in Bugarama and Gisenyi in 2006.

In 2008, BGR (Germany Institute for Geosciences and Natural Resources) collaborated with KenGen (Kenya Electricity Generating Company), ISOR (Icelandic Geo Survey) and ITER (Institute for Technology and Renewable Energies) to conduct geochemical, geophysical and soil gas surveys in Gisenyi, Karisimbi and Kinigi. They concluded (1) a geothermal system with a temperature over

200$^{o}$C is located south of Karisimbi volcano, (2) the temperature of the geothermal system near Lake Karago is 150 to 200$^{o}$C and (3) the depth of heat source in Karisimbi is about 5 km.

In 2009, KenGen conducted additional surface surveys (geophysical and geochemical) and an environmental impact assessment south of Karisimbi volcano. In a workshop held in Kigali in February 2010, a geothermal conceptual model based on those results and drilling targets for three wells were discussed. Also in this year, it was reported that the geothermal resource potential of the whole of Rwanda was estimated to be 120MWe (±50MWe) from the averaging of the results based on the counting of volcanoes, natural heat flux, soil $CO_2$ flux and a Monte Carlo assessment and 50 MWe can be considered as a reasonable initial target for geothermal generation in Rwanda in say the next 5-6 years (United Nations University Geothermal Training Program Report 2009 Number 25). In 2010, KenGen conducted geophysical (MT and TEM), geochemical (soil gas: $CO_2$, mercury and Radon) and hydrogeological survey. They concluded that the geothermal system is possibly distributed to the regions around the southern slopes and trends to the southeast through the town of Mukamira toward Lake Karago. Therefore it was recommended that the exploration wells should be drilled directionally ranging between 2,000 and 3,000 m in depth to intersect as many structures as possible.

In 2011, MININFRA re-evaluated the geothermal resource potential of Rwanda as over 700 MWe in total and 300 MWe in the northeastern area (Table 3.1-1). However, these values were calculated by just simply multiplying the number of production wells per unit area (10 wells per km$^2$ was assumed for all areas) by the output from one production well (4 MWe per well was assumed for all areas), where the promising geothermal areas were determined from the geophysical survey. Therefore the actual geothermal reservoir conditions are not reflected in this calculation. When information on underground structure and geothermal fluid properties is obtained by drilling and production testing, a re-evaluation of the geothermal resource potential will be necessary.

From 2011 to 2012, IESE (Institute of Earth Science and Engineering) conducted geological, geochemical, and geophysical (MT, TEM and CSAMT) survey, as part of a microseismic and heat flow study with boreholes at Kinigi, Gisenyi and Karisimbi. As a result, a geothermal conceptual model regarding geological structure and geothermal fluid flow was elaborated, and targets for three vertical exploratory wells were proposed to confirm the reservoir.

In April 2012, the first validation workshop was held to verify previous survey results and enable the elaboration of a geothermal conceptual model of the area around Karisimbi and the targeting of three exploratory wells. However, the geophysical analytical results were thought to be insufficient. In January 2013, another validation workshop was held by UniServices, GDC (Geothermal Development Company), RG (Reykjavik Geothermal), KenGen and EWSA (now EDCL) to verify the re-analyzed results. They can be summarized as follows: (1) the resistivity model around Karisimbi volcano consists of a high resistivity layer (recent volcanic), a low resistivity layer (may be the clay cap) due to hydrothermal alteration of low temperature clays and a higher resistivity layer (reservoir) due to a higher degree of hydrothermal alteration, (2) there is a deeper low resistivity layer (heat source) which becomes shallower toward Karisimbi volcano and dips sharply to the south, (3) drilling targets were confirmed: future drilling should be directional toward Karisimbi volcano targeting the NW and NE trending interpreted fractures and go to a depth of 3,000m.

Drilling for the first geothermal exploratory well in Karisimbi, KW-01 (Karisimbi Well No.1) started on 18th July, 2013, and finished on 23rd October, when it reached 3,015m depth. Following this drilling, the second exploratory well (KW-02) was drilled in Karisimbi.

(2) **Status of geothermal exploration and development and plan**

There are no operating geothermal power plants in Rwanda, and each geothermal field is in the survey stage of geothermal resource development. The drilling of two geothermal exploratory wells in Karisimbi has been completed in March 2014, but no geothermal reservoir suitable for power generation has been discovered. The Rwanda government and international agencies have surveyed geothermal resources for development in Rwanda. From those results, Karisimbi, Kinigi, Gisenyi in the northwestern area and Bugarama in the southwestern area have been selected as promising geothermal areas. Many kinds of surveys have been conducted in these four areas.

The status of geothermal exploration and development was summarized in Tables 3-1.2 and 3-1.3 based on verbal information provided by geothermal organizations operating in Rwanda and existing reports and papers. Furthermore Table 3-1.4 shows the status of geothermal exploration and development as of February, 2016.

Regional surface surveys have been finished in areas except Mufunnba Cone in Gisenyi and Bize in Bugarama. As for the geopysical exploration, MT/CSMT survey has already been conducted in Karisimbi, Kinigi and Gisenyi in the northwestern area. In 2015, JICA conducted re-analysis of these data. Although aerial gravity and magnetic survey was conducted for the entire Rwanda field, the four promising areas were not included in these surveys. Therefore gravity survey by JICA was conducted in Bugarama and Kinigi fields in 2014 and 2015 respectively. Geothermal exploratory wells were drilled only in Karisimbi, but no geothermal reservoir suitable for power generation has been discovered.


Source: JICA study team

Fig. 3-1.1 Location map of geothermal areas in Rwanda

Table 3-1.1 List of geothermal areas and their potential resources in Rwanda

| Geothermal Prospect | Karisimbi | Gisenyi | Kinigi | Bugarama | Other areas | **Total** |
|---|---|---|---|---|---|---|
| Approximate Resource Area ($km^2$) | 25 | 30 | 25 | 50 | 20 | **150** |
| Estimated Development Resource area ($km^2$) | 8 | 5 | 4 | 2 | 2 | |
| Number of wells per $km^2$ | 10 | 10 | 10 | 10 | 10 | |
| Average well Productivity (MWe) | 4 | 4 | 3 | 3 | 2 | |
| Resource potential (MWe) | 320 | 200 | 120 | 60 | 40 | **740** |
| Targeted Generation by 2017 | 160 | 150 | | | | **310** |

Source: from MININFRA (2011)

Table 3-1.2 Status of Geothermal Exploration and Development Plans as of Jan. 2014

| Field Name | Surface Study (conducted) | | | | | | | Surface Study (planned) | | | | | Slim hole drilling | Integrated Analysis (Construction of geothermal concepual model) | Exploratory Well | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Preliminary Study | | Detailed Study (～10$km^2$) | | Geophysical Study | | | Geological Study | Geochemical Study | Geophysical Study | | | | | Deep well drilling | Well test | |
| | Geological Study | Geochemical Study | Geological Study | Geochemical Study | Gravity | Magnetic | MT/CSMT | | | Gravity | Magnetic | MT/CSMT | | | | | |
| Karisimbi | Done | Done | Done | Done | None | None | Done | - | - | Partly covered by the study in Kinigi and Giseni | - | - | None | | KW-01 (3,015m) KW-02 (on-going) | KW-01: not productive | |
| Kinigi | Done | Done | Done | Done | None | None | Done | Planned by UNEP (April-June2014?) | Planned by UNEP (April-June2014?) | Planned by UNEP (April-June2014?) | Planned by UNEP (April-June2014?) | Planned by UNEP (April-June2014?) | - | Planned by UNEP (July 2014?) | - | - | |
| Gisenyi | Done | Done | Done | Done | None | None | Done | Planned by EU (March-May2014?) | Planned by EU (March-May2014?) | Planned by EU (March-May2014?) | Planned by EU (March-May2014?) | - | Planned by EU (March-May2014?) | | - | - | schedule: 2months delay |
| Bugarama | Done | Done | None | None | None | None | None | Planned by EU (Feb.-April2014) | Planned by EU (Feb.-April2014) | - | Planned by EU (May-Aug.2014) | TEM, Dec. 2013 to June 2014 | Planned by EU (March-Nov.2014?) | Planned by EU (Nov.-Dec.2014) | Planned by EU (Jan. -Oct.2015) | - | Preliminary survey of geology and geochemistry started. |
| Others | Done | Done | - | - | - | - | - | - | - | - | - | - | - | | - | - | |

Source: Modified from EWSA data

# Table 3-1.3 Status of Geothermal Exploration and Development Plans as of Feb. 2015

| Prospect | Area | Surface Study (conducted) | | | | | | | | | Surface Study (planned) | | | | | Slim hole drilling | Integrated Analysis (Construction of geothermal concepual model) | Exploratory Well | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Preliminary Study | | Detailed Study (～ 10km$^2$) | | Geophysical Study | | | | Integrated Analysis (Construction of preliminary geothermal concepual model) | Geological Study | Geochemical Study | Geophysical Study | | | | | Deep well drilling | Well test | |
| | | Geological Study | Geochemical Study | Geological Study | Geochemical Study | Gravity | Magnetic | MT/CSMT | Data Re-analysis | | | | Gravity | Magnetic | MT/CSMT/TEM | | | | | |
| Karisimbi | Karisimbi | Done | Done | Done | Done | None | None | Done | Done by ISOR (MT etc.) (2014) Done (MT) by JICA (2015) | Done before exoloratory well drilling | - | - | - | - | - | None | - | KW-01 KW-02 | KW-01 and KW-02: not productive | |
| | Karago | Done | Done | Done, supplemental study is desireble | Done, supplemental study is desireble | None | None | Partly covered | Partly covered | Done by JICA (2015) | - | - | - | - | - | - | - | - | - | Plan to apply UNEP ? |
| Kinigi | Kinigi | Done | Done | Done, supplemental study is desireble | Done, supplemental study is desireble | None | None | Done | Done by ISOR (MT etc.) (2014) Done (MT) by JICA (2015) | Done by JICA (2015) | - | - | - | - | - | - | - | Planned 3 slim holes (max. 2,500m depth) Application for Grant of 40% to be re-submitted to African Union Commission in May 2015, result will be shown by September 2015: GRMF | - | |
| Gisenyi | Gisenyi | Done | Done | Done, supplemental study is desireble | Done, supplemental study is desireble | None | None | Done | Done by ISOR (MT etc.) (2014) Done (MT) by JICA (2015) | Done by JICA (2015) | Start of Procurement procedure (Jan.2015), financed by EU (6 months) | Start of Procurement procedure (Jan.2015), financed by EU (6 months) | - | Start of Procurement procedure (Jan.2015), financed by EU (6 months) | TEM: Start of Procurement procedure (Jan.2015), financed by EU (6 months) | - | Start of Procurement procedure (Jan.2015), financed by EU (6 months) | - | - | |
| | Iriba | Done | Done | Done, supplemental study is desireble | Done, supplemental study is desireble | None | None | None | None | Done by JICA (2015) | - | - | - | - | - | - | | | | |
| | Muhumba Cone | Done | Done | None | None | None | None | None | Done by ISOR (MT etc.) (2014) Done (MT) by JICA (2015) | None | Start of Procurement procedure (Jan.2015), financed by EU (6 months) | Start of Procurement procedure (Jan.2015), financed by EU (6 months) | - | Start of Procurement procedure (Jan.2015), financed by EU (6 months) | TEM: Start of Procurement procedure (Jan.2015), financed by EU (6 months) | - | - | - | - | This area is included by study area of Gisenyi by EU |
| Bugarama | Mashyza | Done | Done | Done by EU (2014), by JICA (2015), supplemental study is desireble | Done by EU (2014), by JICA (2015), supplemental study is desireble | Done by JICA (2015) | Done by EU (2014) | TEM: Done by EU (2014) | None | Done by JICA (2015) | - | - | - | - | - | Planned by EU (2015): 300m depths (3 -5 holes) | Planned by EU (2015) | One well in one selected country: Planned by EU (2016) | - | - |
| | Bize | Partly done | Partly done | None | None | None | None | None | None | None | - | - | - | - | - | - | - | - | - | - |

Source: Modified from EDCL data

# Table 3-1.4 Status of Geothermal Exploration and Development Plans as of Feb. 2016

**Progress of Geothermal Resource Study and Future Plan of the Study in Rwanda (as of February, 2016)**

| Prospect | Area | Surface Study (conducted) | | | | | | | | | Surface Study (planned) | | | | | Slim hole drilling | Integrated Analysis (Construction of geothermal concepual model) | Exploratory Well | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Preliminary Study | | Detailed Study (～ 10km$^2$) | | Geophysical Study | | | | Integrated Analysis (Construction of preliminary geothermal concepual model) | Geological Study | Geochemical Study | Geophysical Study | | | | | Deep well drilling | Well test | |
| | | Geological Study | Geochemical Study | Geological Study | Geochemical Study | Gravity | Magnetic | MT/CSMT | Data Re-analysis | | | | Gravity | Magnetic | MT/CSMT/TEM | | | | | |
| Karisimbi | Karisimbi | Done | Done | Done | Done | None | None | Done | Done by ISOR (MT etc.) (2014) Done (MT) by JICA (2015) | Done before exoloratory well drilling | - | - | - | - | - | None | - | KW-01 KW-02 | KW-01 and KW-02: not productive | |
| | Karago | Done | Done | Done, supplemental study is desireble | Done, supplemental study is desireble | None | None | Partly covered | Partly covered | Done by JICA (2015) | - | - | - | - | - | - | - | - | - | |
| Kinigi | Kinigi | Done | Done | Done, supplemental study is desireble | Done, supplemental study is desireble | Done by JICA (2016) | None | Done | Done by ISOR (MT etc.) (2014) Done (MT) by JICA (2015) | Done by JICA (2015) | - | - | - | - | - | - | JICA (2015) | GRMF: Application for drilling of 3 slim holes (max. 2, 500m depth) was approved in December 2015 (Grant of 40%). | - | |
| Gisenyi | Gisenyi | Done | Done | Done, supplemental study is desireble | Done, supplemental study is desireble | None | None | Done | Done by ISOR (MT etc.) (2014) Done (MT) by JICA (2015) | Done by JICA (2015) | Study started in December, 2015 (survey period: 6 months). | Study started in December, 2015 (survey period: 6 months). | - | Study started in December, 2015 (survey period: 6 months). | Study started in December, 2015 (survey period: 6 months). | - | Study started in December, 2015 (survey period: 6 months). | - | - | |
| | Iriba | Done | Done | Done, supplemental study is desireble | Done, supplemental study is desireble | None | None | None | None | Done by JICA (2015) | - | - | - | - | - | - | | | | |
| | Muhumba Cone | Done | Done | None | None | None | None | None | Done by ISOR (MT etc.) (2014) Done (MT) by JICA (2015) | None | Study started in December, 2015 (survey period: 6 months). | Study started in December, 2015 (survey period: 6 months). | - | Study started in December, 2015 (survey period: 6 months). | Study started in December, 2015 (survey period: 6 months). | - | Study started in December, 2015 (survey period: 6 months). | - | - | A part of this area is included by study area of Gisenyi by EU |
| Bugarama | Mashyza | Done | Done | Done by EU (2014), by JICA (2015), supplemental study is desireble | Done by EU (2014), by JICA (2015), supplemental study is desireble | Done by JICA (2015) | Done by EU (2014) | TEM: Done by EU (2014) | None | Done by JICA (2015) | - | - | - | - | - | EU: Additional three-five thermal gradient holes will be drilled at depths between 100-300m. | Planned by EU (2016) after drillings | One well in one selected country: Planned by EU (2016) | - | - |
| | Bize | Partly done | Partly done | None | None | None | None | None | None | None | - | - | - | - | - | - | - | - | - | - |

Source: Modified from EDCL data

### 3.1.4. Exploratory Well Drilling of KW-01 in Karisimbi Field

#### (1) **Evaluation of KW-01**

1) Outline of the exploratory well KW-01

The outline of the exploratory well KW-01 is summarized as follows. An integrated columnar section is shown in Fig. 3.1-2.

| | |
|---|---|
| Drilling Period | July 18, 2013 - October 23, 2013 |
| Drilling Depth (TDL) | 3,015 m |
| Elevation of Well Head | 2,675 m a.s.l |
| Direction/Deviation | Plan: Vertical |
| Production zone | From 1,299m to 3,015m (open hole: 8-1/2”) |
| Lithology | 0-(960m): Volcanic materials<br>(960m)-3,015m: Proterozoic granitic formation |
| Measured Maximum Temperature ($^{o}$C) | 74 $^{o}$C @ 2,950m (October 30, 2013)<br>(Values are read from a graph provided by EWSA) |
| Loggings and Testings | - Temperature and pressure logging<br>- Air lift test<br>- Injection and fall off tests (0.61L/s/bar) |

Source: JICA study team

2) Azimuth and Inclination of KW-01

Some deviation surveys were conducted during the drilling. Data from the deviation survey are shown in Table 3-1.5.

As shown in Table 3-1.5, the well was deviated below the depth of 1,801m, though the well was planned as a vertical well. At the bottom of the well (3,003.5m), the value of the inclination was measured as 11.21 degrees. This indicates that the inclination increases with depth. Although total deviation (from well head to the bottom) was reported as 580 m in the EWSA report, this seems doubtful because of the shortage of deviation survey data.

Table 3-1.5 Well KW-01 Measured Inclination and Azimuth

| Depth (m) | Inclination (Degree) | Azimuth (Degree) |
|---|---|---|
| 340 | 1.38 | 28.90 |
| 790 | 0.47 | 73.84 |
| 1331 | 4.99 | 270.78 |
| 1399 | 4.67 | 144.96 |
| 1504 | 5.04 | 336.83 |
| 1657 | 4.30 | 338.89 |
| 1801 | 3.72 | 145.17 |
| 2211 | 7.87 | 345.51 |
| 3003.5 | 11.21 | 229.17 |

Source: EWSA data

3) Well Geology

Cutting samples were not obtained at depths between 3 - 56m, 76 - 322.5m and 328 - 1,302m due to total lost circulation (samples were partly taken by junk-sub). In the production zone (open hole zone), cutting samples were taken continuously. Well geology confirmed in KW-01 is as follows.

Surface to 334m: Volcanic materials
960m to 3,015 m: Granite
(The lithological boundary was not determined due to lack of cuttings)

Secondary minerals are one indicator of temperature condition. Chlorite, which usually indicates a temperature condition higher than 150°C, is recognized from a depth of around 2,500 m. The presence of chlorite suggests that there is a possibility that the subsurface temperature below 2,500 m may reach 150°C. Except for chlorite, there is little presence of secondary minerals in KW-01. The reason for that is unclear, but the following reasons can be considered.

- ✓ Geothermal activity around KW-01 (geothermal activity is not so active).
- ✓ Geological condition
- ✓ Recognition of secondary minerals

To determine the reason, detailed petrological analysis such as X-ray diffraction analysis is required (according to the EWSA report, petrological analysis of cuttings from KW-01 will be conducted in Iceland).

(2) **Well testing**

Some temperature logging was conducted during drilling. However, the aim of temperature logging was for the examination of casing cementing, not to evaluate subsurface temperature. Therefore, it is difficult to evaluate the temperature of KW-01 from the temperature logging data (Figs. 3-1.3, 3-1.4 and

3-1.5).

Usually, in order to measure the heat recovery, temperature logging is conducted several times (at 24 hours, 48 hours, and 72 hours, for example) after stopping the pumping. However, only one temperature logging was conducted at KW-01, after drilling to a depth of 3,015m. This logging was conducted in the drill pipe and the sonde was stopped in the pipe during the logging. Therefore the fluid in the pipeline might have moved together with sonde, and the temperature logging data obtained under such conditions is not appropriate for evaluating subsurface temperature around the well (temperature logging in the drill pipe is not common). At present, data which indicates the possibility of high temperatures around KW-01 has not been obtained.

(3) **Air lift**

The airlift pipe was set at a depth of 1,253 m in KW-01. It seems that during the airlift test of KW-01 not all of water in the borehole could be replaced by fluid coming from the formation (Fig. 3-1.6). Although the temperature above 1,900m was changed by airlifting, the deeper part of borehole (below 1,900m) seems not to have changed in KW-01 (Fig. 3-1.7). This indicates that relatively low temperature fluid probably comes into the borehole at a depth of 1,950m from the formation. This is only one of several possibilities, because data from greater depths is limited. It is difficult to evaluate the subsurface temperature using such limited data.

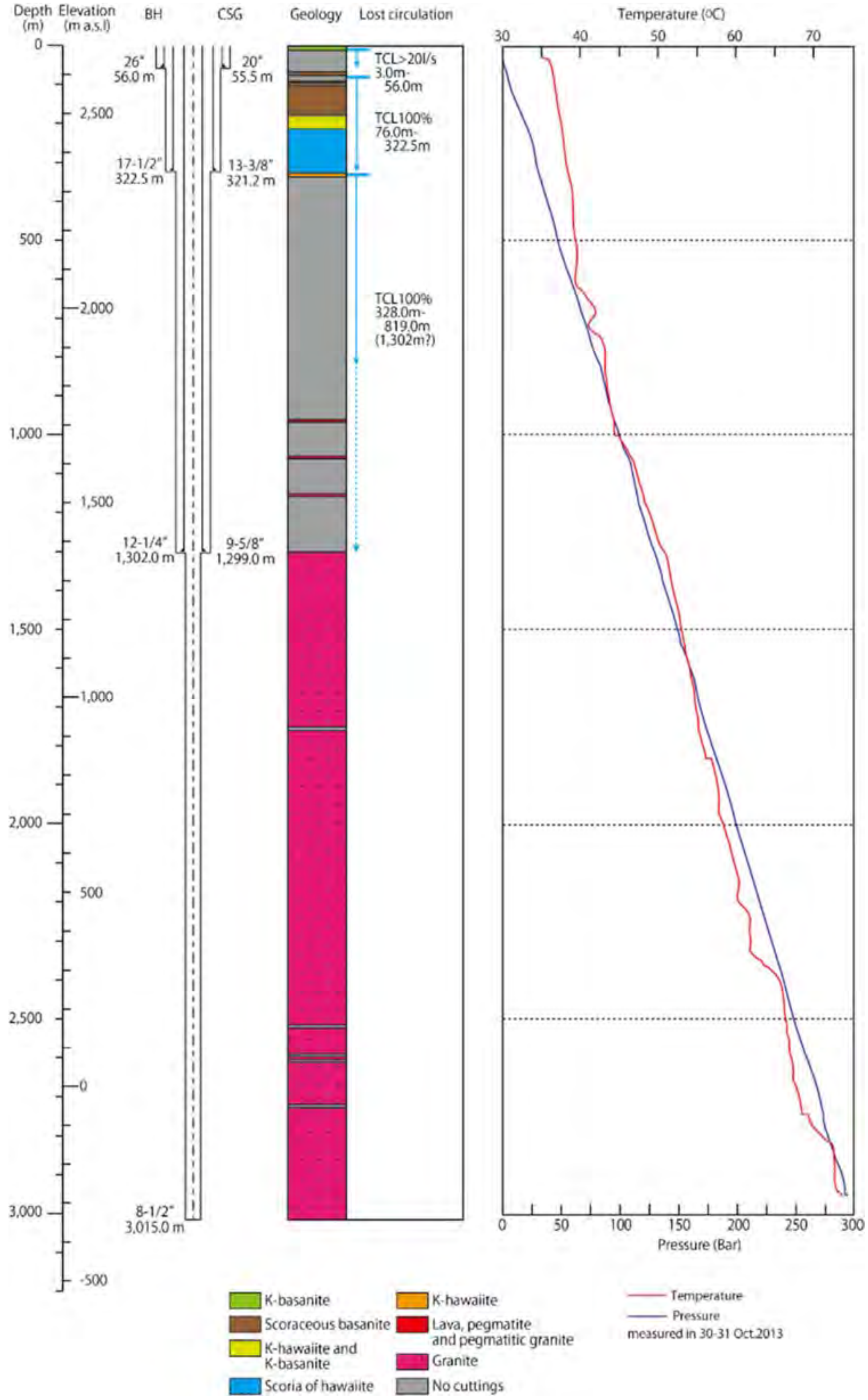
(4) **Permeability of KW-01**

Though a highly permeable zone was identified at shallower depths, such as 328m, the presence of highly permeable structures which play a role in geothermal fluid flow (reservoir structures) has not been confirmed at depth in the production zone of KW-01. Hydrothermal alteration, which indicates high temperature conditions, has not been identified at KW-01.

The Injectivity index of KW-01 was determined to be 0.63 l/s/bar from the results of injection testing (Fig. 3-1.8). This analyzed value for KW-01 is relatively small compared with that of other geothermal wells (productive wells). In addition, the well pressure change after the air lift supports a possibility of low permeability around KW-01. The well pressure after the air lift did not recover quickly to reservoir pressure (Fig. 3-1.9). This phenomena is assumed to be due to the fact that the amount of fluid supplied from the formation was smaller than the amount of swabbing water in the borehole, due to low permeability of the KW-01.

(5) **Evaluation of KW-01**

Though a highly permeable zone was identified at shallower depths, such as 328m, the presence of highly permeable structures which play a role in geothermal fluid flow (reservoir structures) has not been confirmed at depth in the production zone of KW-01. Judging from data and information provided, the subsurface temperature around this exploratory well seems to be insufficient to produce geothermal fluid. The presence of a geothermal reservoir which is suitable for power generation has not been confirmed by the drilling of KW-01.




Source: Modified EWSA data

Fig. 3-1.2 Well KW-01 Geologic Column and PT Profile

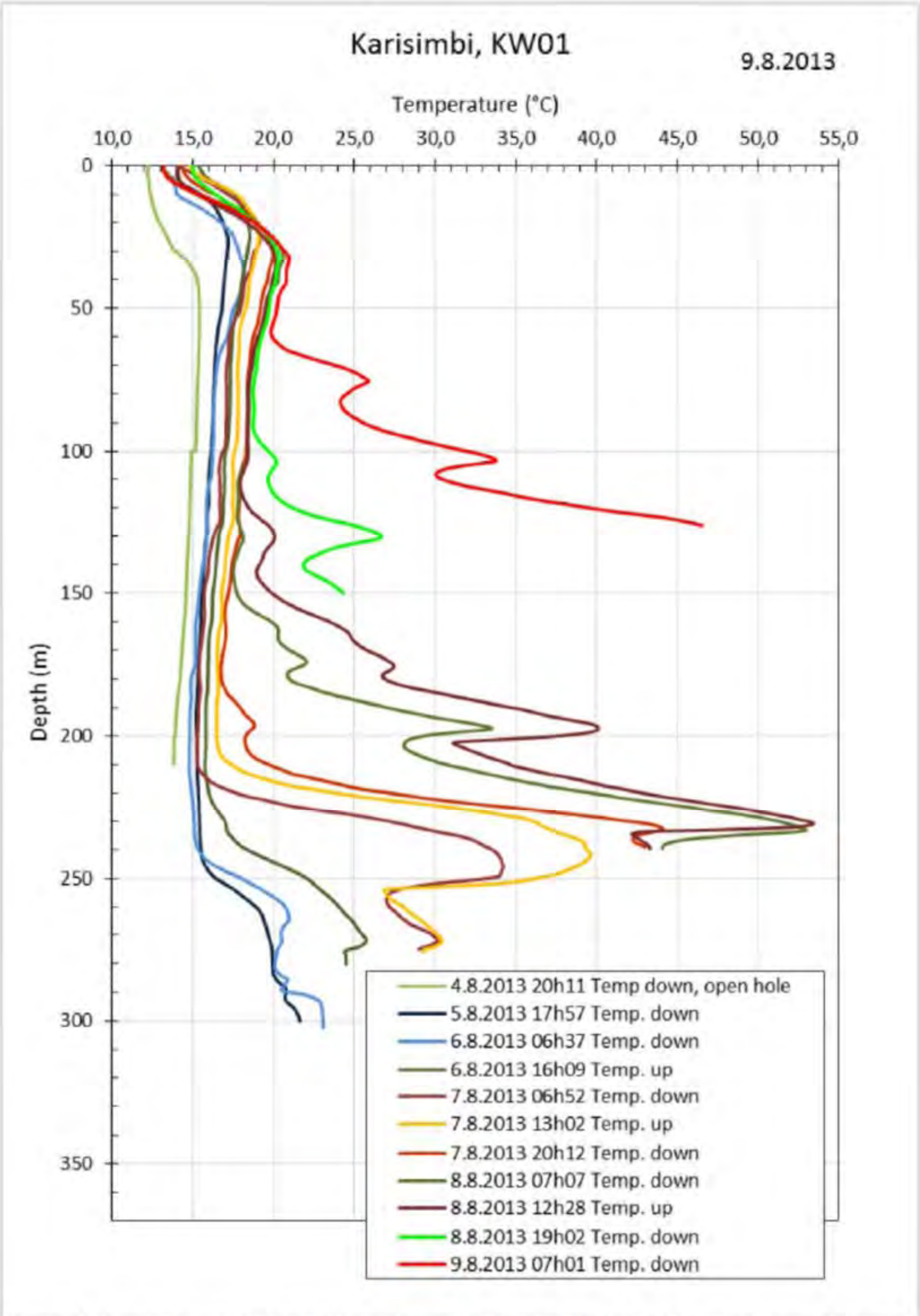
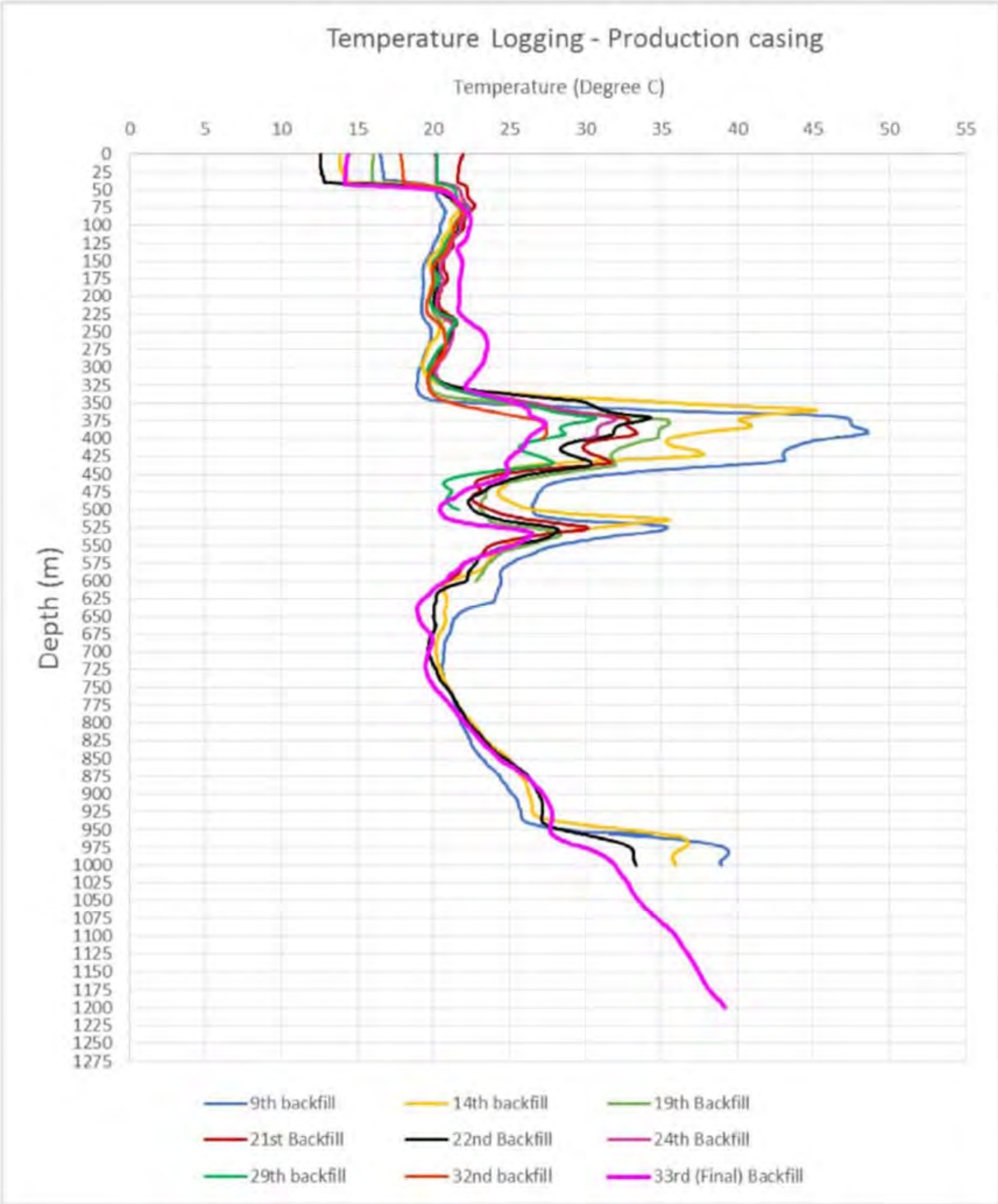



**Figure 2**. *Temperature logs in 13 ⅜" anchor casing to monitor level of cement in annulus.*

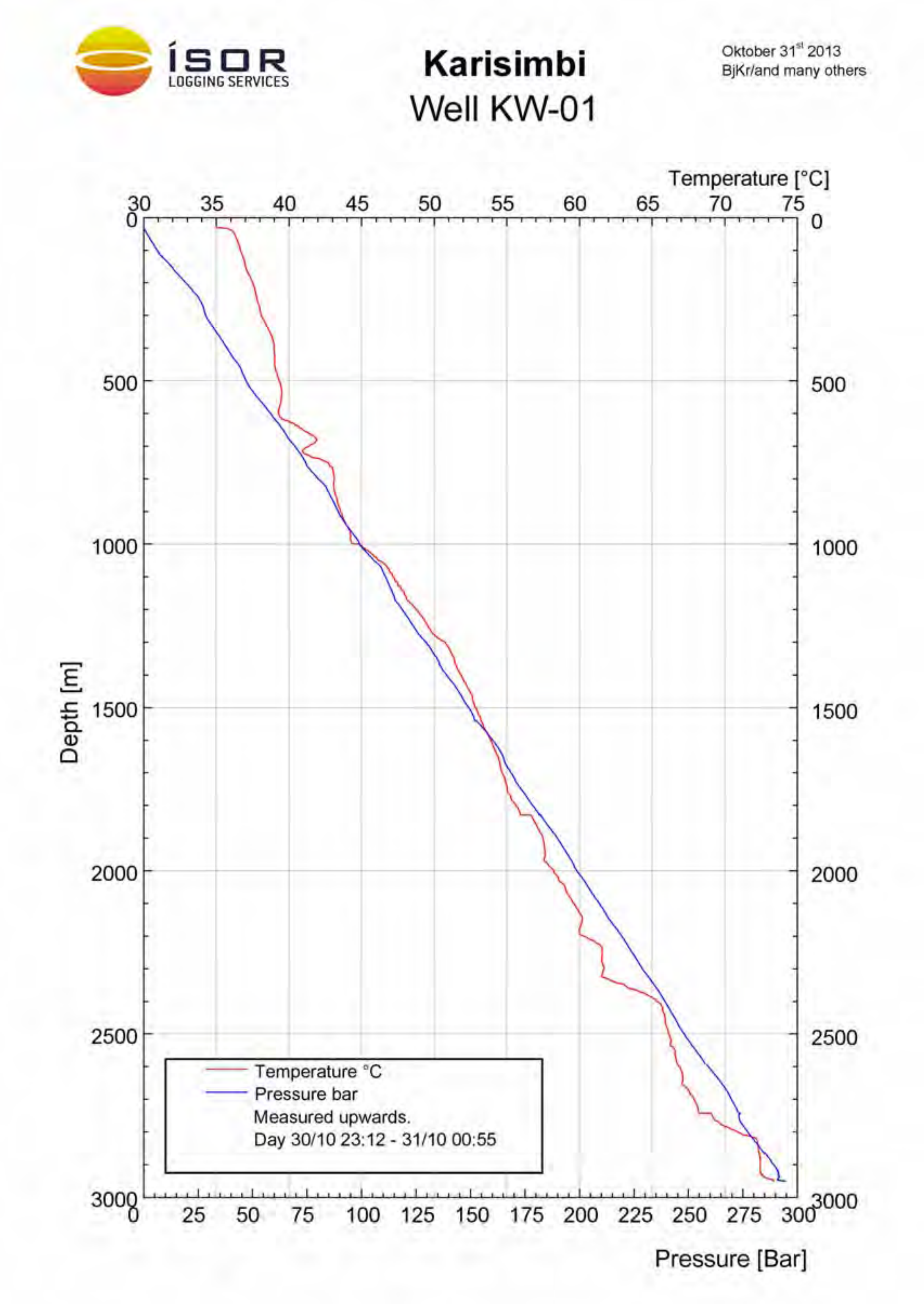
Source: EWSA data

Fig. 3-1.3 Well KW-01 Temperature Logging of 13-3/8" Casing



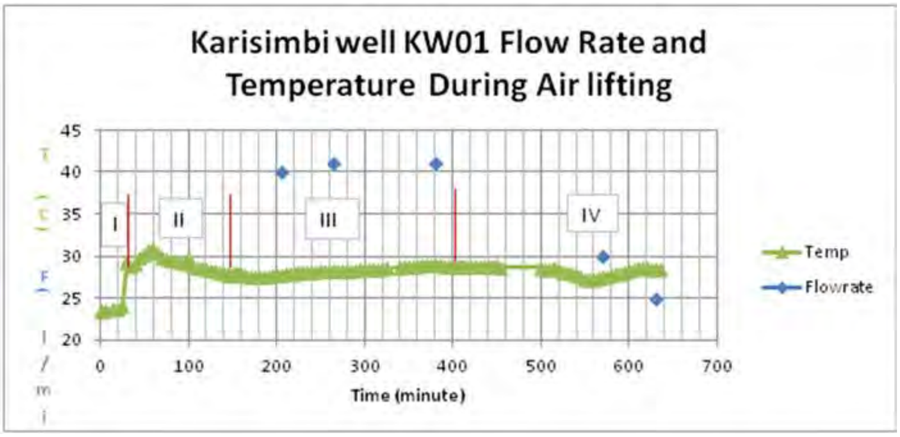

Source: EWSA data

Fig. 3-1.4 Well KW-01 Temperature Logging of Production Casing



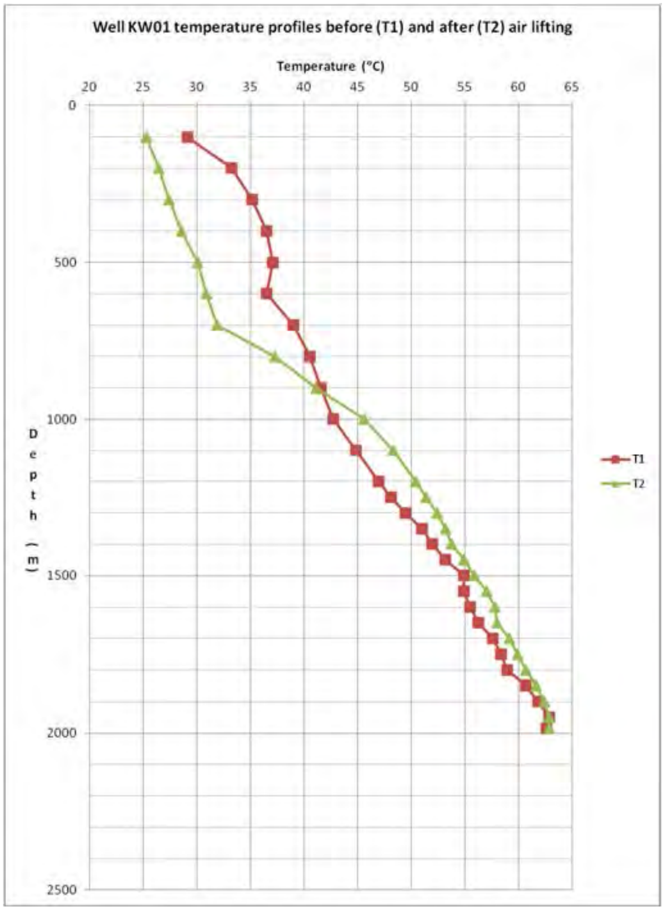

Source: EWSA data

Fig. 3-1.5 Well KW-01 Temperature and Pressure Profile



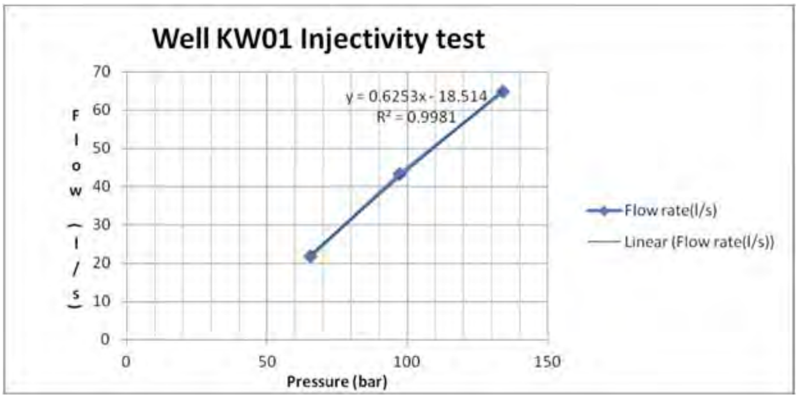

Source: EWSA data

Fig. 3-1.6 Well KW-01 Flow Rate and Temperature during Air Lifting



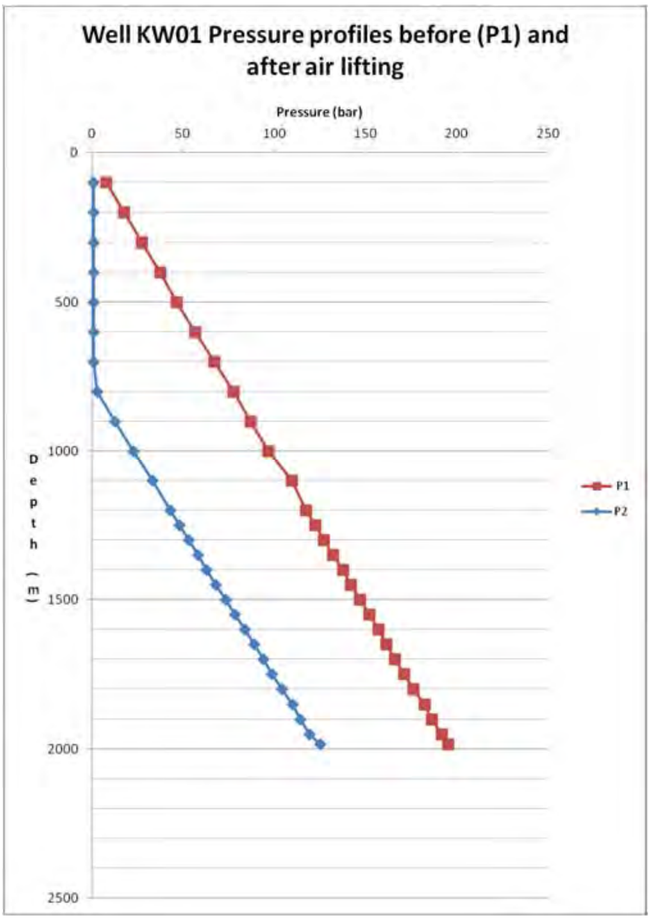

Source: EWSA data

Fig. 3-1.7 Well KW-01 Temperature Profile Before and After Air Lifting




Source: EWSA data

Fig. 3-1.8 Well KW-01 Injectivity Test




Source: EWSA data

Fig. 3-1.9 Well KW-01Pressure Profiles Before and After Air Lifting

### 3.1.5. Exploratory Well Drilling of KW-02 in Karisimbi Field

(1) **Outline of exploratory well KW-02**

Exploratory well (KW-02) was drilled from December 14 2013 to March 22 2014 at a site 1.8 km away from the KW-01 drilling site. This exploratory well was planned to be drilled to a depth of 3,500 m to confirm the geothermal structure which had not been found by the drilling of exploratory well KW-01 due to drilling troubles. However the drilling of KW-02 was terminated at a depth of 1,378 meters because the geological conditions of this well were the same as those for KW-01 and the temperature of the drilling fluid was lower.

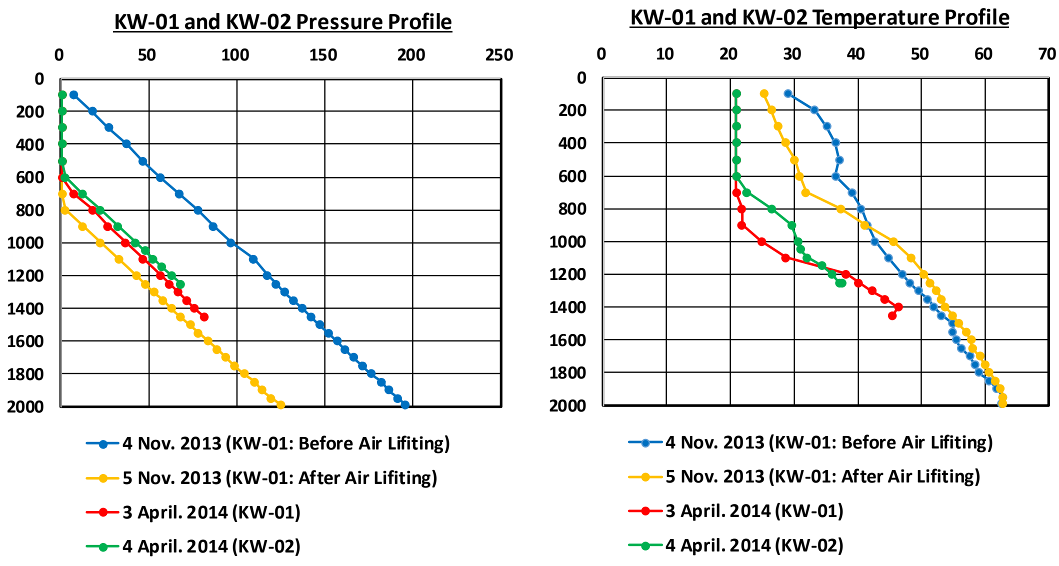
Temperature and pressure logging, an injection test, and a fall-off test were executed as completion tests of KW-02. Since the injectivity index was 0.4 1 L/s/bar and maximum temperature was 37.4$^{o}$C at 1,256 m (ST=13days), the reservoir conditions around KW-02 were concluded to be unsuitable for generation.

(2) **Comparing the logging results of KW-01 and KW-02**

The temperature and pressure measurements up to a depth of 1,450m were conducted using the KUSTER logging tool on April 3, 2014. The results showed that the temperature and pressure at a depth of 1,452m were 45.4$^{o}$C and 81.5 bars respectively. The temperature and pressure logging results of KW-01 before and after the air lift and on April 3, 2014 are shown in Fig.3-1.10.

The shallower temperature distribution of KW-01 in April 2014 was lower than that in November 2013. However, the temperature distributions at greater depths in April 2014 and November 2014 seemed not to be very different. In addition the temperature distributions of KW-01 and KW-02 in April 2014 are very similar to each other. Accordingly, temperature recovery in deeper zones (up to 2,000m) is considered not to be expected in either well.

On the other hand, the pressure distribution of KW-01 in April 2014, which was higher than that measured after the air lift, is almost the same as the pressure distribution of KW-02. As explained above, the temperature and pressure distributions of KW-01 and KW-02 show a very similar trend, though the wells are separated by 1.8km. Therefore it is considered that KW-01 and KW-02 were drilled in the same hydraulic and temperature structures.




Source: EWSA data

Fig. 3-1.10 Temperature and pressure logging results of KW-01 and KW-02

## 3.2. Geothermal Resource Assessment

### 3.2.1. Selection of Objective Fields for Detailed Geoscientific Survey

#### (1) Collection and review of existing data

1) Available existing data

Geothermal resource studies have been conducted in Rwanda in cooperation with donors. The main resource studies conducted to date are as follows.

- Chevron (2006)：Preliminary Assessment of Rwanda's Geothermal Energy Development Potential
- UWERA RUTAGARAMA (2009)：Assessing Generating Capacity of Rwanda Geothermal Fields from Green Field Data Only
- BGR (2009)：Geothermal Potential Assessment in the Virunga Geothermal Prospect, Northern Rwanda
- Stephen A. Onacha (2010)：Rwanda Geothermal Resources Exploration and Development for 2011-2017
- Uwera Rutagarama and Theoneste Uhorakeye (2010): Geothermal Development in Rwanda: An Alternative to the Energy Crisis
- Stephen A. Onacha (2011)：Rwanda Geothermal Resources Potential
- MININFRA (2011)：Rwanda Geothermal Resources Potential

- IESE (2011) : Geothermal Prospects in Rwanda
- IESE (2012) : Geoscientific Surveys of the Rwandan Karisimbi, Gisenyi and Kinigi Geothermal Prospects (Final Report)
- EWSA (2013) : Data and Final Report, Validation Workshop

In addition to reviewing these reports, the study team has collected the following data and information.

- Digital topographic data
- Satellite imagery data
- Exploratory well data for Karisimbi
- Geochemical data for hot spring and cold spring water
- Published papers and reports related to geothermal resource study

2) Review of collected data and information

i) Regional tectonic setting

Rwanda is part of the western arm of the East African Rift System, the Western Rift, also called the Albertine Rift. The Western Rift is bordered by some of the highest mountains in Africa, including the Virunga Mountains, Mitumba Mountains, and Ruwenzori Range. It contains the Rift Valley lakes, which include some of the deepest lakes in the world (up to 1.470 m for Lake Tanganyika). Lake Victoria, the second largest area freshwater lake in the world, is considered part of the Rift Valley system although it actually lies between the two branches. All of the African Great Lakes were formed as the result of the rifting, and most lie within the rift valley (Fig. 3-2.1).


Source: Rutagarama and Uhorakeye, 2010

Fig. 3-2.1 Regional topography in East Africa

The geology of Rwanda consists of granite, migmatites, gneisses and micaschists of the

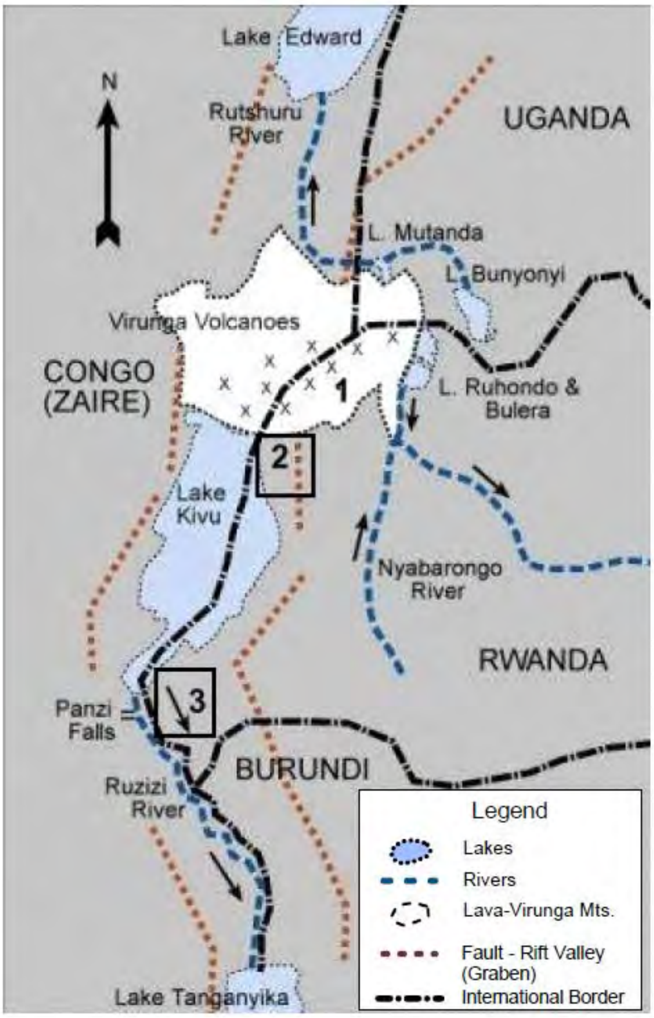
Paleoproterozoic Ruzizian basement overlain by the Mesoproterozoic Kibaran Belt. The Kibaran, composed of folded and metamorphosed sediments, mainly schists and quartzites intruded by granites, covers most of Rwanda. Cenozoic to Recent volcanic rocks occur in the northwest and southwest.

Except for the area located inside the Ubendian insular shelf and both NW and SW tertiary/quaternary lava fields, the major geological formations of Rwanda are mid-Proterozoic (Burundian). They have been folded during the Kibaran–Burundian orogeny. Laterite and thick alluvium directly overlie the Precambrian rocks. Those Precambrian rocks include a granitic/gneissic basement complex of Paleo-Proterozoic period which is intruded by subsequent granites, pegmatites, metabasics, migmatites and a deformed sequence of meta sediments, which is essentially mid-Proterozoic in age.

ii) Geothermal fields in Rwanda

Rwanda hosts two prospective fields with geothermal potential: the Volcanoes National Park and the faults associated with the Western Branch of the East African Rift near Lake Kivu (Rutagarama, 2009). Following preliminary reconnaissance studies (Demange et al., 1982), three important zones presenting a geothermal potential for electricity production were selected (Fig. 3-2.2):

1) The northwest zone which comprises the Virunga volcanic complex
2) The hot springs of Gisenyi which are located in the northern part of Lake Kivu
3) The southwest zone which comprises the Bugarama field along the southern part of Lake Kivu

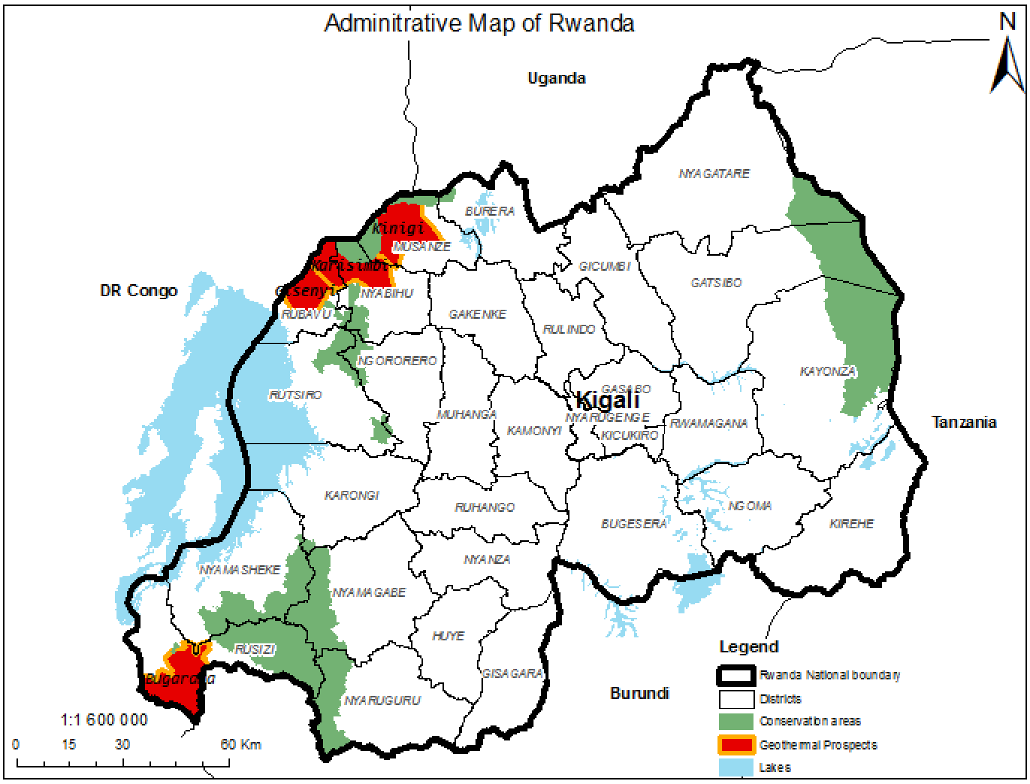



Source : Rutagarama, 2009

Fig. 3-2.2 Location of Geothermal Fields in Rwanda

After Demange et al. (1982), EWSA re-defined the main geothermal fields in Rwanda as 4 prospect fields: Karisimbi, Kinigi, Gisenyi and Bugarama (Fig. 3-2.3).

The Virunga volcanic complex is made up of eight stratovolcanoes, five of which (Muhabura, Gahinga, Sabinyo, Bisoke, and Karisimbi) are on the Rwanda side, while two actives ones, Nyiragongo and Nyamulagira, are in Congo. These five are commonly defined as the National Volcanoes Field. After some geoscientific surveys for geothermal exploration, EWSA defined four prospect fields for geothermal development in Rwanda: 1) Karisimbi, 2) Kinigi, 3) Gisenyi, and 4) Bugarama, as shown in Fig. 3-2.3.

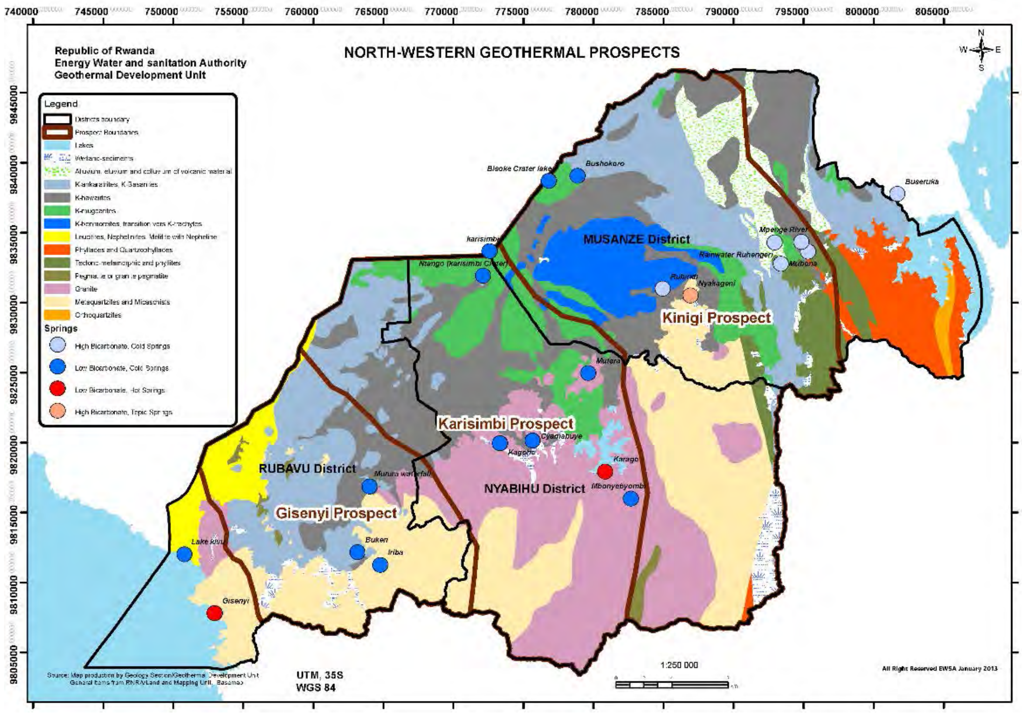



Source: EWSA data

Fig. 3-2.3 Geothermal Prospects in Rwanda

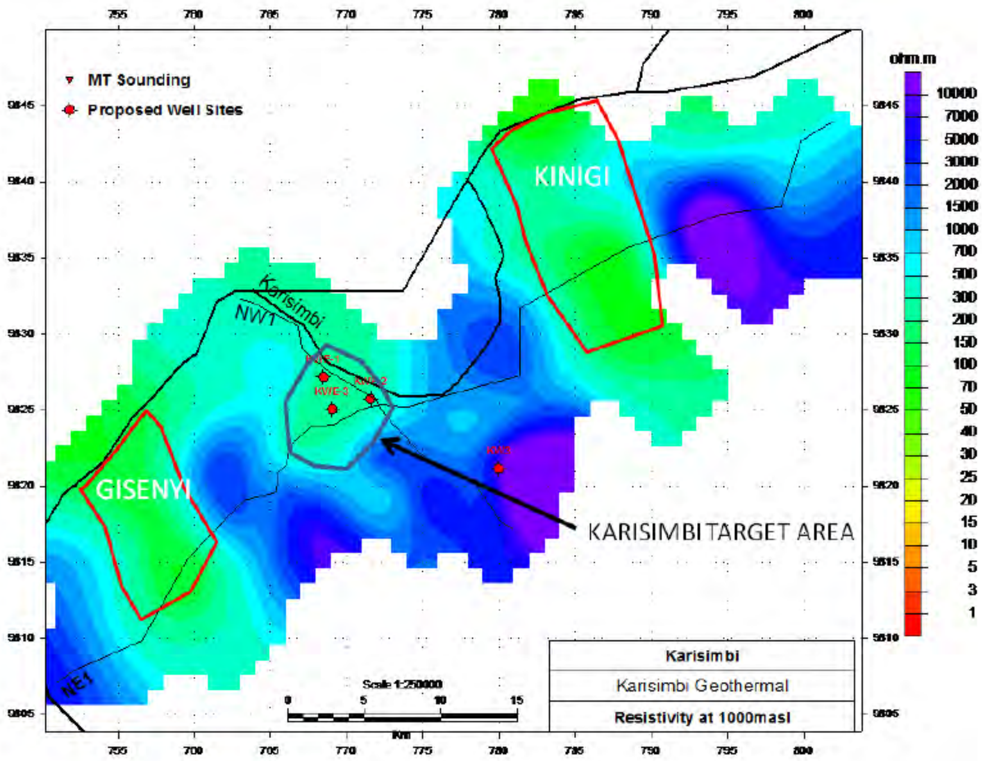
Figures 3-2.4 and 3-2.5 show the location of hot and cold springs and the resistivity structures in northwestern Rwanda, respectively.

Not all the fields of the four (4) prospects in Rwanda have been delineated, but the fields of the three (3) prospects in northwestern Rwanda are roughly defined based on resistivity structures. Relatively high resistivity areas at depth characterize the three (3) prospects in northwestern Rwanda.




Source: EWSA data

Fig. 3-2.4 Geothermal Prospects in northwestern Rwanda




Source: MININFRA, 2011

Fig. 3-2.5 Resistivity Structures in northwestern Rwanda

iii) Geothermal resource potential in Rwanda

The geothermal resource potential was estimated as more than 700 MWe in MININFRA (2011) (Table 3-1.1). Most of the resources are located in the northwestern part of Rwanda. The potential estimated in MININFRA (2011) was deduced based on following premises:

- well productivity of a single well is equivalent to 4 MWe.
- 10 wells can be drilled in 1 km$^2$.
- resource areas were delineated from geophysical data

However, the reliability of the potential estimated in MININFRA (2011) is not so high because the estimation failed to consider subsurface conditions. In general, resource potential estimation takes into consideration the subsurface condition in each field. Therefore, it is necessary to update the value of the resource potential in Rwanda by reviewing geoscientific data which will be acquired by donors in each field and through construction of a geothermal conceptual model. It is desirable to consider the results of exploratory well drilling in Karisimbi for potential evaluation.

iv) Main geothermal fields in Rwanda

Karisimbi Field

Geothermal resource study has been conducted in northwestern Rwanda. A geothermal conceptual model based on KenGen (2010), Namugize (2011), IESE (2012), and Namugize et al. (2013) can be summarized as follows.

Karisimbi geothermal field is located in the Virunga Volcanoes Range (VVR) where there are some late quaternary volcanoes. Some of the volcanoes are active at present (Fig. 3-2.6). Judging from the presence of late quaternary volcanoes in and around Karisimbi field, the heat source is assumed to be related to volcanic activity in VVR. Karisimbi geothermal field consists of pre-Cambrian metamorphic rocks. Neogene volcanic rocks and volcanic products cover the basement. Karisimbi field is located in a normal fault zone related with the Great Rift Valley. Some NE-SW and NW-SE trending faults were detected by KenGen (2010) and EWSA (2013).

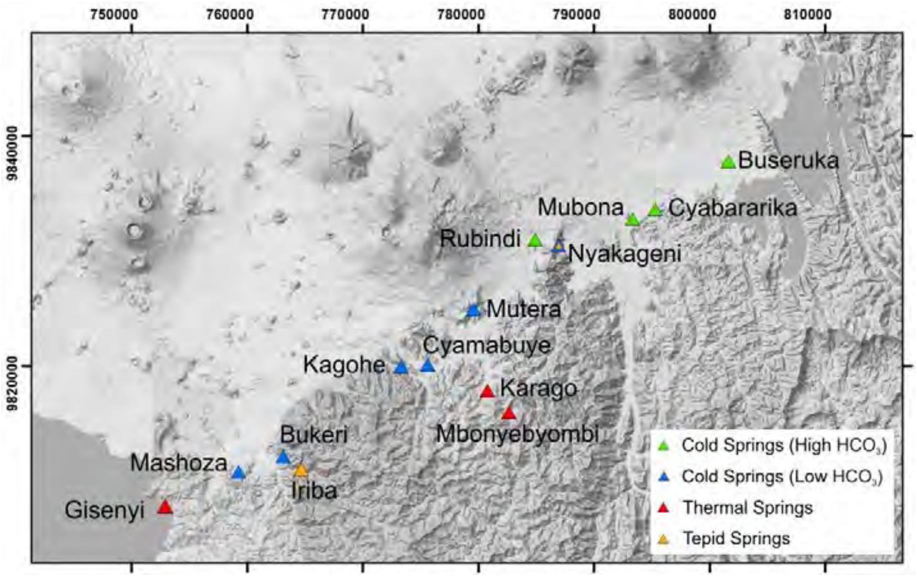
No geothermal manifestations such as fumaroles or alteration have been reported in the Rwandan part of this area. However, a couple of hot springs are located to the south outside of the volcanic field, with the highest temperature of 64°C recorded at Karago. There is no obvious hydrothermal alteration or hydrothermal deposition at the Karago springs, but we measured temperatures there at depths at about 50 cm of up to 72° (IESE, 2011) (Figs. 3-2.7 and 3-2.8). Cold springs occur in northwestern Rwanda. They contain $CO_2$ gas which is assumed to be derived from lower crust or mantle.

The spring water in and around Karisimbi originates in meteoric water. Infiltrated meteoric water at depth is heated up by a heat source related to volcanic activity. Hot fluids are assumed to have up-flowed through a permeable zone related to faults (Fig. 3-2.9). Based on geochemical data for the spring water, the temperature of the hot fluid was estimated as 90-110°C (IESE, 2012). There is no geochemical data indicating the possible existence of a high-temperature geothermal reservoir because there are no hot springs originating from high temperature fluid at depths in and around the field.

Some geophysical surveys, such as MT and TEM, have been conducted in the Karisimbi field. However, each institute/surveyor differs in their methods of data processing and data interpretation. Therefore, a consensus interpretation of geophysical data and an agreed geothermal conceptual model have not been reached for Karisimbi field.

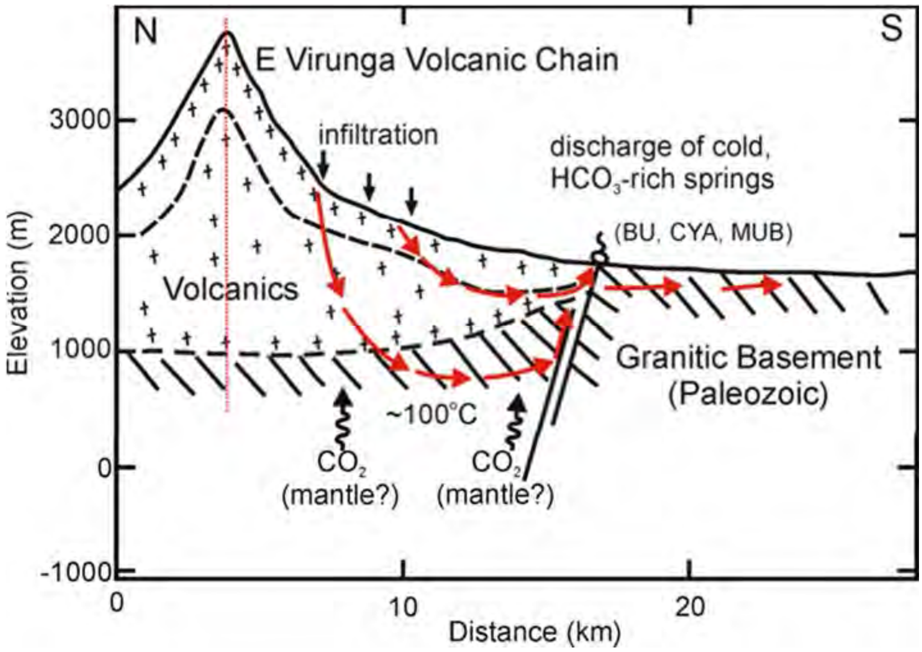

Source: KenGen, 2010

Fig. 3-2.6 Volcanoes in Virunga volcanic range



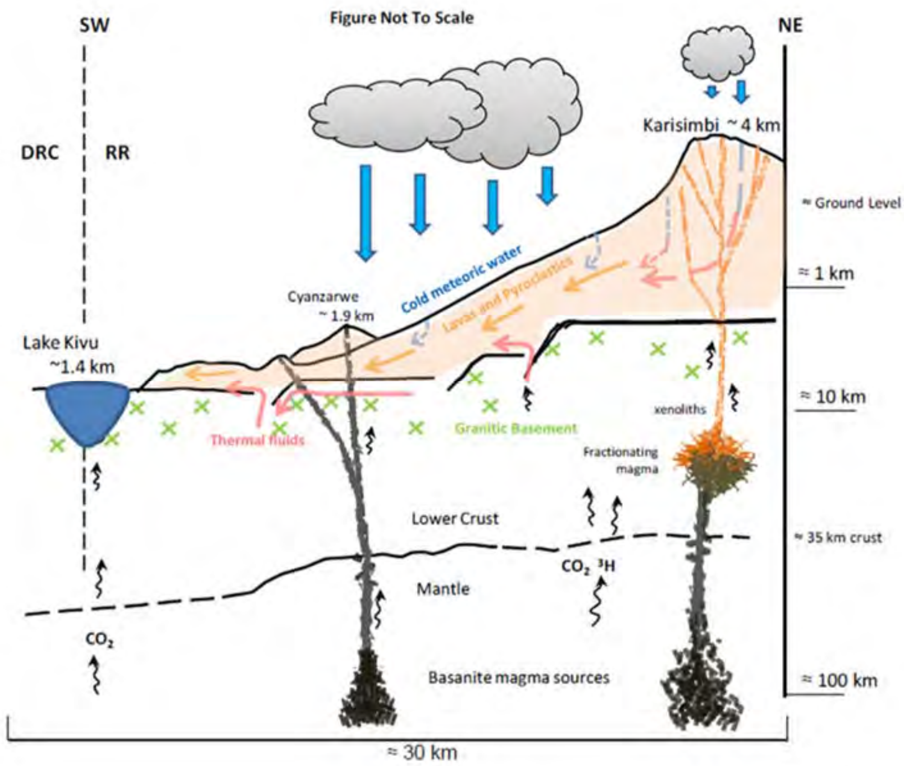

Source: IESE, 2012

Fig. 3-2.7 Location of hot springs and cold springs in northwestern Rwanda




Source: IESE, 2012

Fig. 3-2.8 Fluid flow model for Karago hot spring area




Source: IESE, 2012

Fig. 3-2.9 Geothermal conceptual model for Karisimbi

Kinigi Field

Kinigi geothermal prospect is located in a NW-SE fracture zone between the Visoke and Sabinyo Volcanoes. The topography of the Kinigi geothermal prospect is dominated by valleys, volcanic cones and volcanoes with elevations ranging from 2,000 to over 4,000 m above sea level.

The surface geology of the Kinigi field is characterized by lavas derived from Sabinyo volcano and only minor flows from Visoke. However, lavas from Karisimbi also cover its southwest margin. The Kinigi field also contains lahars and debris flows (boulder deposits) evidently mostly derived from Sabinyo but these are thin. Two boreholes drilled to 51 and 60 m in depth near Nyange primary school and at Buhunge encountered fractured volcanic rocks, probably lavas, ash and soil but did not reach the basement. (IESE, 2012)

The tectonic features are characterized by NW-SE, N-S and NE-SW trending faults. The NW-SE and N-S accidents are older and likely associated with pre-rift, Mesoproterozoic basement structures. The NE-SW faults are the youngest generation of fractures and are buried below the young volcanic rocks. Remote sensing-based geological investigations (Jolie et al., 2009) have confirmed the presence of the geological structures within the Kinigi field.

At present, the only known active geothermal manifestations in the Kinigi field are saline waters and travertines: the Rubindi 1 and 2, Cyabararika 1 and 2, Buseruka 1 and 2 and Nyakageni saline springs. The travertines commonly extend along the NS oriented Mpenge river, Kigombe river, Mugara river and around Buseruka river near the shore of lake Ruhondo. No hot springs, fumaroles, mud pools or hot grounds were found. The surface temperatures of waters are in the range of 16°C (Mpenge) – 23.5°C (Burera).

Gisenyi Field

The Gisenyi field consists of a hot spring with several small vents located along the eastern shore of Lake Kivu several kilometers south of the town of Gisenyi and near the local brewery. The hot spring, which issues from a brecciated and silicified quartzite, produces Na-$HCO_3$ waters with temperatures between 70 and 75°C. The geochemistry of the waters in Gisenyi suggests the presence of a geothermal system of moderate reservoir temperature ranging from 150 to 210°C, as calculated from chemical geothermometers (Newell et al., 2006; BGR, 2009, Rutagarama, 2009)

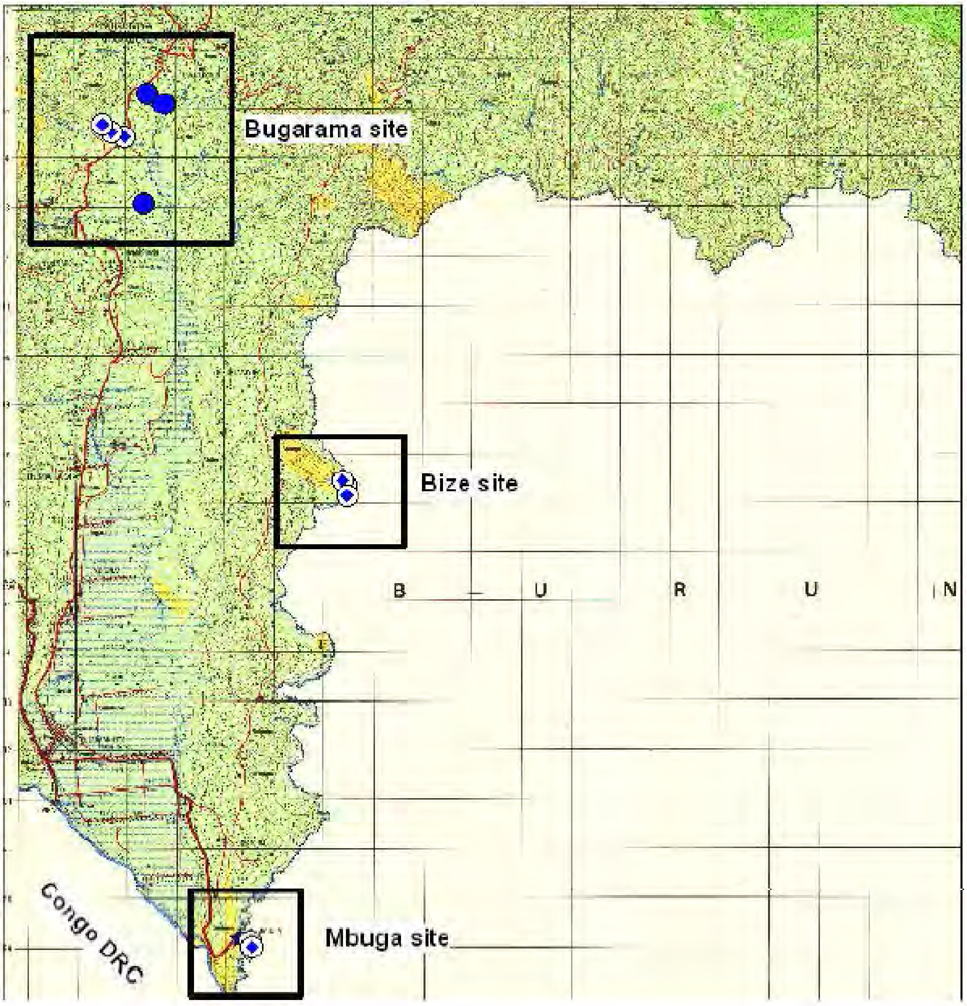
The most likely geologic model for this field is that the reservoir waters are rising vertically along a normal fault near the eastern boundary of the East African Rift. The fluids could be mixing along their flow path from the reservoir with low temperature ground water or water from Lake Kivu. The reservoir waters may also be degassing during their ascent, as suggested by the relatively small amount of gas being vented from the hot springs.

An alternative and less likely model is that the hot springs represent a distal outflow of fluids from a high temperature reservoir associated with the Virunga Volcanoes to the north. These volcanoes lie in the Democratic Republic of Congo. This alternative model should be examined through additional geologic fieldwork (Chevron, 2006).

Bugarama Field

The geothermal prospect in the southwest field is controlled by the faulting of the western branch of the East Africa rift system. The Bugarama field (Fig. 3-2.10) is located in the Rubyiro River valley, approximately 13 km southeast of the town of Cyangugu. This valley appears to be a graben, which is a block of down-dropped rock bounded by normal faults. The manifestations are hot and warm springs and travertine deposits, currently being mined as feedstock for a nearby cement factory. The hot springs flow out along the western edge of the graben as dilute Na-$HCO_3$ water with temperatures up to 50°C. The hot springs form a large pool on top of the travertine deposit. Flow rates are estimated to be greater than 50 l/s, and the influx is accompanied by a large quantity of gas. The higher temperature vents along the shores of the pool are depositing reddish brown iron oxide. The geochemistry of the waters in Bugarama suggests the presence of a low-temperature geothermal system with a resource temperature between 100 and 130°C (Newell et al., 2006). The geologist from the cement factory noted that travertine deposits also occur in Burundi to the south and that they may occur along the same geologic structure (Chevron, 2006).

Tertiary volcanics, primarily basaltic lavas, are noted both south and west of the hot spring area. Although the age of these lavas is unknown, they appear to be too old to indicate that a viable magmatic heat source underlies the geothermal system (Chevron, 2006). Despite the presence of basalt in the Bugarama graben, their occurrence does not indicate to me that magma is a possible heat source; rather the thermal fluids flow within interconnected joints in granites, quartzites, phyllites and other Proterozoic rocks belonging the Cyangugu Complex.(IESE, 2011).




Source: Rutagarama, 2009

Fig. 3-2.10 Location of Bugarama Field

### (2) **Confirmation of geothermal prospects by satellite imagery data analysis**

In this project, base maps which cover the whole territory of Rwanda have been created from satellite imagery data and topographic data (digital elevation model: hereafter referred to as “DEM”) obtained by earth observation satellites, and information regarding geography, geology, infrastructure and so on, has been extracted from these data. In addition, the extraction of information regarding geothermal manifestations (alteration minerals, thermal anomalies) in geothermal prospects in Rwanda has been conducted using satellite imagery data with high spatial resolution and high spectral resolution.

1) Data used

The data used for this project are as follows. With regard to satellite imagery data, Landsat-7/ETM+, Landsat-8/OLI/TIRS and Terra/ASTER data were utilized for processing and analysis. On some images from these optical sensors, clouds have been observed at high altitude, since the study area has high precipitation. Therefore some processing and analysis was conducted using satellite imagery data from ALOS/PALSAR, a synthetic aperture radar (SAR) satellite unaffected by cloud cover. ASTER/GDEM data acquired and generated from Terra/ASTER’s stereoscopic data was utilized as DEM data,.

【Optical Satellite Imagery Data】
Landsat-7/ETM+ data
Landsat-8/OLI/TIRS data
Terra/ASTER data
ALOS/PRISM data

【SAR Satellite Imagery Data】
ALOS/PALSAR data

【DEM Data】
ASTER/GDEM data

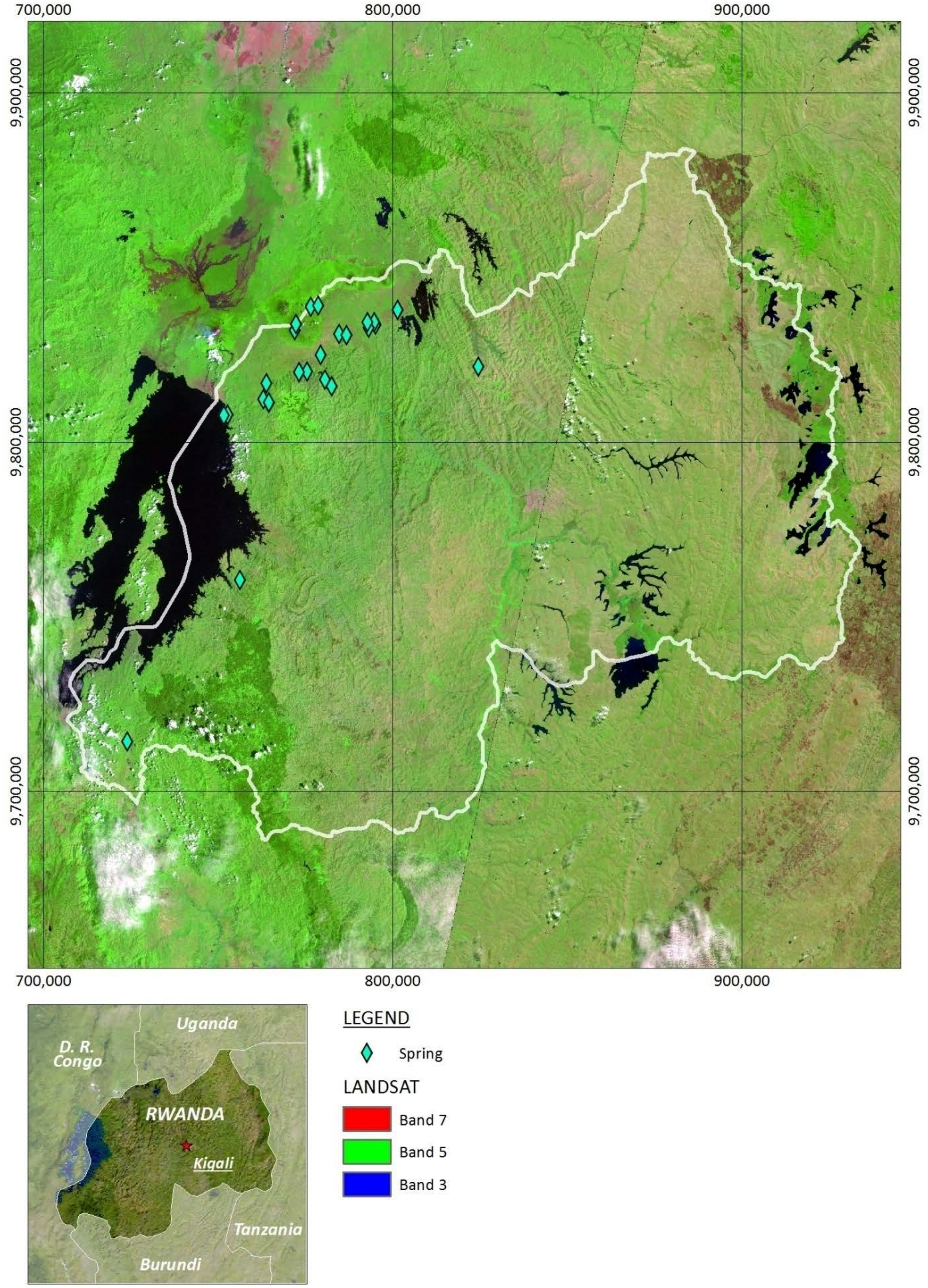
2) Base map developing

The false color images of Landsat-7/ETM+ and Landsat-8/OLI/TIRS data (Fig. 3-2.11) and the color shaded images of ASTER/GDEM data (Fig. 3-2.12) were generated as base maps covering the whole territory of Rwanda. Reconnaissance terrain analysis using ASTER/GDEM data was also conducted to review geographical and geological features in Rwanda. Landsat-7/ETM+ data is satellite imagery data obtained by the optical sensor Enhanced Thematic Mapper Plus (ETM+) mounted on the earth observation satellite Landsat-7 of the National Aeronautics and Space Administration (NASA), and has eight (8) observation wavebands in the spectral region from visible, near infrared, short wave infrared, to thermal infrared. Similarly, Landsat-8 data is obtained by the optical sensor Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), and has eleven (11) observation wavebands from visible to thermal infrared. ASTER/GDEM is DEM data generated from Terra/ASTER’s stereo vision. Both types of data can be downloaded free of charge from the website of the United States Geological Survey

(USGS) and Japan Space Systems (J-spacesystems).

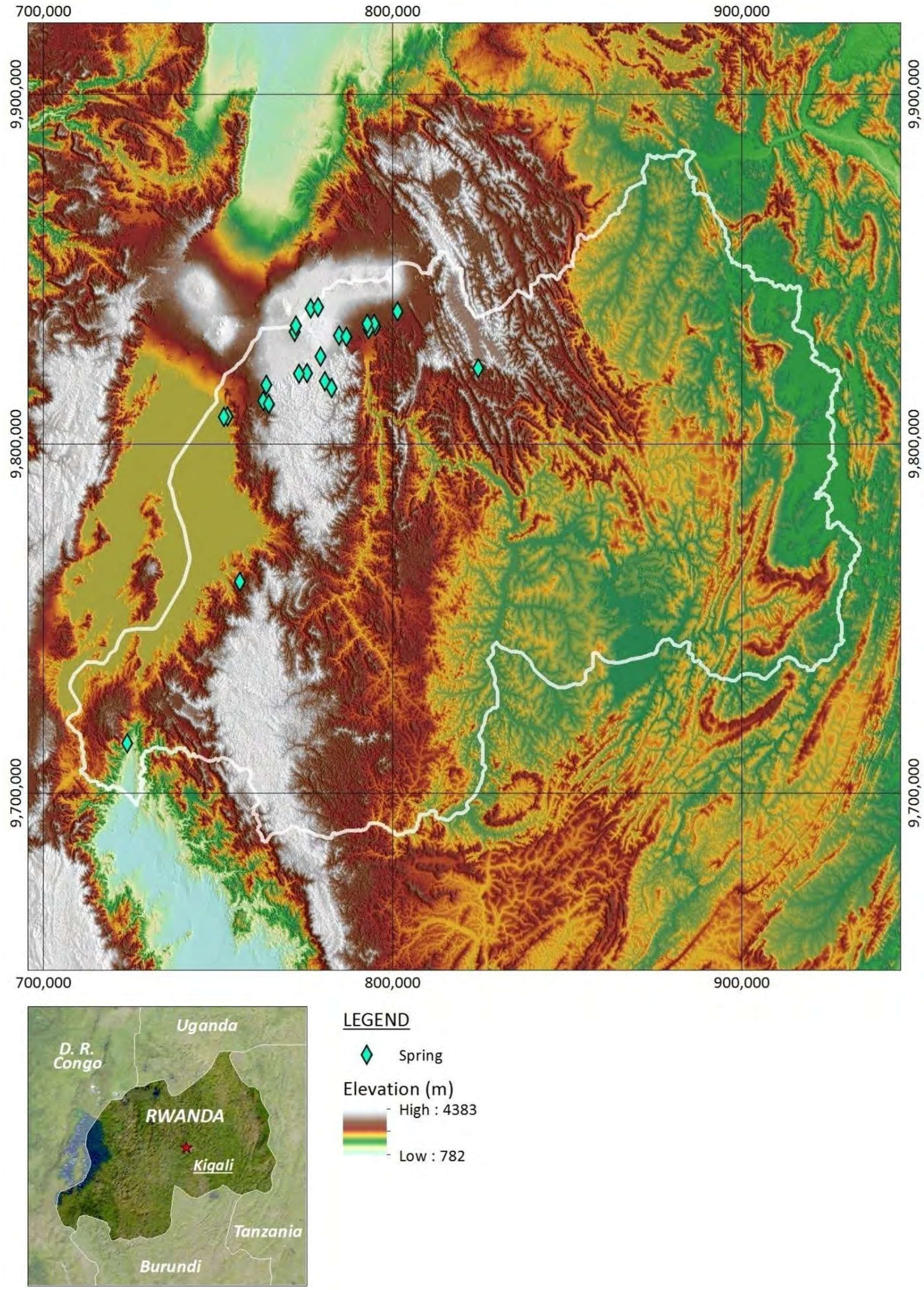
With regard to the Landsat-7/ETM+ and Landsat-8/OLI/TIRS data, 4 scenes of imagery data covering the whole territory of Rwanda were acquired, and the color composite images were created from the 4 scenes data by assigning primary colors (RGB) to the reflected intensity of three (3) optical wavebands from Landsat-7/ETM+'s eight (8) wavebands and Landsat-8/OLI/TIRS's eleven (11) wavebands (Fig. 3-2.11). The pixels that correspond to vegetation show as green, while rock and soil are a brownish-reddish to white color and water is a blackish to bluish color.

As for the ASTER/GDEM data, terrain analysis was carried out using DEM data covering the whole of Rwanda to gather information regarding geography and geology. An example of analytical results, an overlaid image of slope analysis and shaded relief image processed from ASTER/GDEM data, is shown in Fig. 3-2.13. Slope analysis is a method used to quantify the steepness of terrain, and has been shown to be of benefit for identification of terrain, geological structure and lithology. A shaded relief image is one analytical technique for imaging terrain in three dimensions, and consists of a raster image that shows changes in elevation and steepness using light and shadows on terrain from a given angle and altitude of illuminant (the sun). In the overlaid image of slope and shaded relief, tough and resistant terrains contrasting with the Proterozoic basement complex are shown in a dark bluish color. On the other hand, the Rift System from D. R. Congo, Lake Kivu to Burundi and the region in which Cenozoic volcanic rocks (lava-flow field) are distributed consist of flat terrain and were shown as a whitish color in the overlaid image. It should be easy to distinguish between Cenozoic lava-flow fields and volcanoes since volcanic bodies are represented by dark bluish color pixels forming an approximately circular shape. The boundaries between the Proterozoic basement complex on the one hand and the Rift system and Cenozoic volcanic rocks on the other are very clear, and the distribution of well-known hot springs is confined to the boundary between them and nearby volcanic bodies (Fig. 3-2.14 and Fig. 3-2.15). Therefore, analysis for information extraction in the geothermal prospects discussed below was conducted only near the Rift System and Cenozoic volcanic rocks.



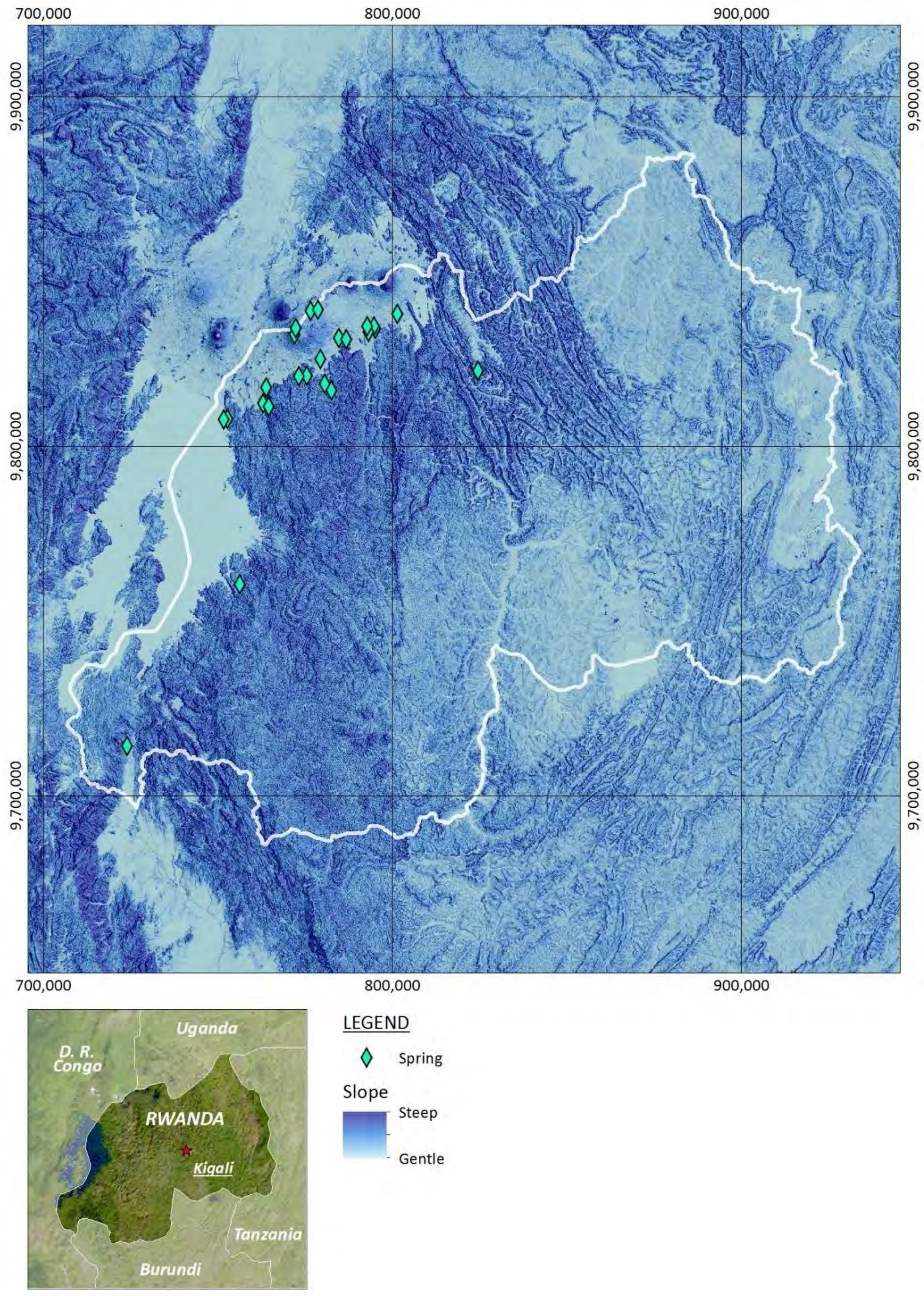

Source: JICA study team

Fig. 3-2.11 Landsat false color image



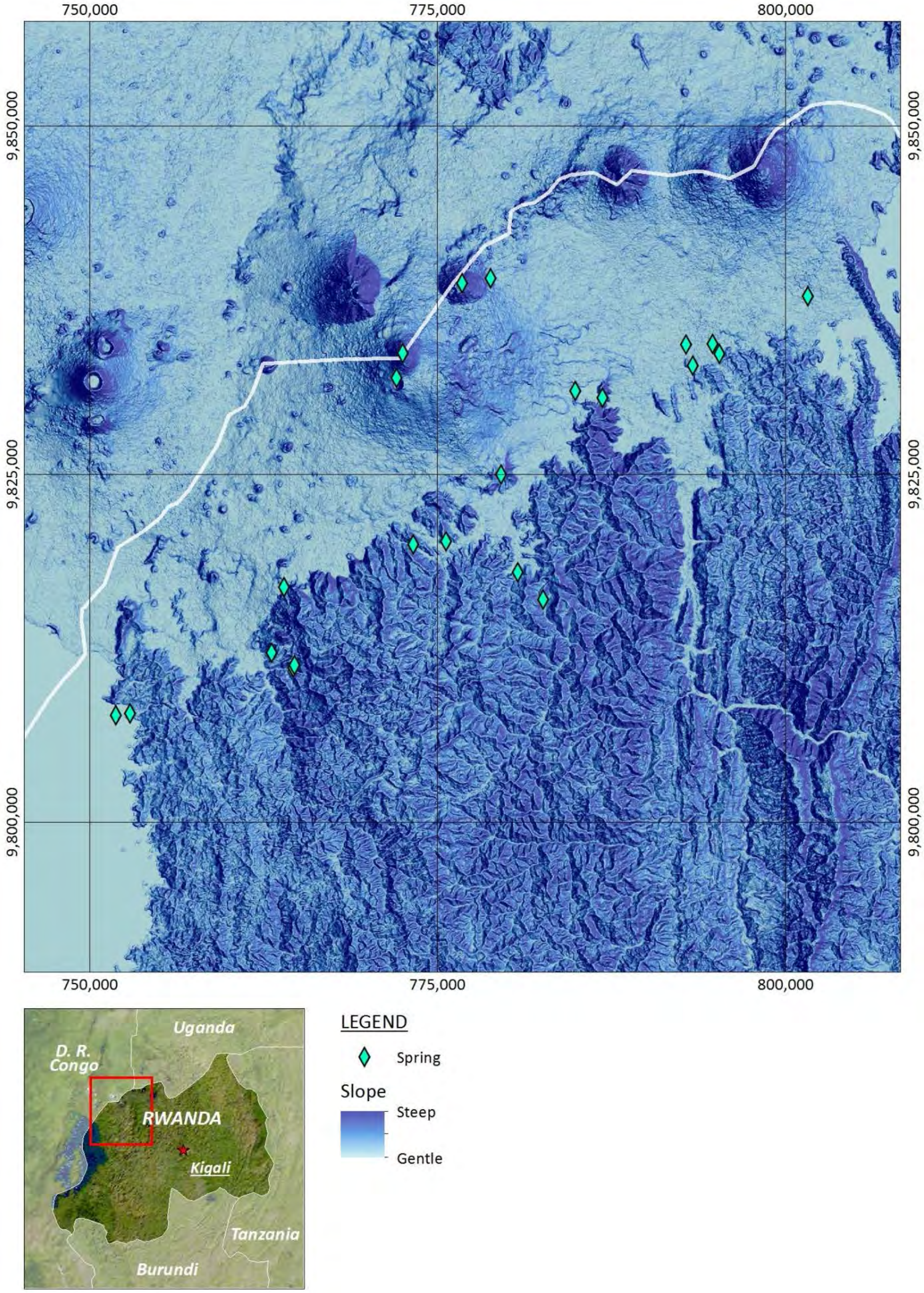

Source: JICA study team

Fig. 3-2.12 ASTER/GDEM color shaded image



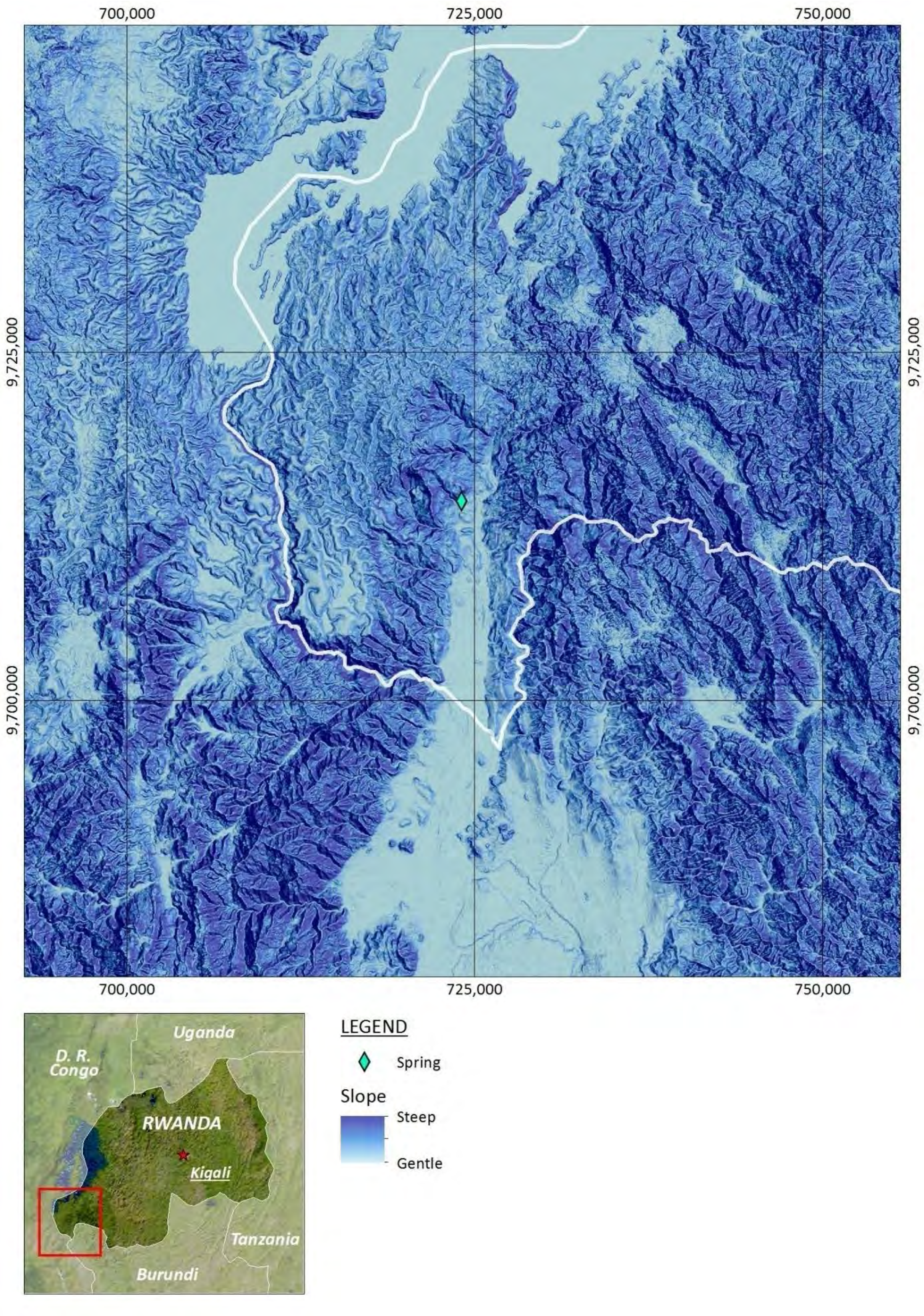

Source: JICA study team

Fig. 3-2.13 ASTER/GDEM overlaid image of slope analysis and shaded relief image




Source: JICA study team

Fig. 3-2.14 ASTER/GDEM overlaid image of slope analysis and shaded relief image in the northwestern part of Rwanda




Source: JICA study team

Fig. 3-2.15 ASTER/GDEM overlaid image of slope analysis and shaded relief image in the southwestern part of Rwanda

### (3) Preparation of establishment of profile of geothermal fields using GIS

The profile is to contain information such as the location and coordinates (northing, easting) of the field, geology, geological structures, volcanoes, hydrothermal alteration, location of hot/cold springs, geochemistry and temperature of hot/cold springs, natural parks and reservation forest etc.. After integrated analysis of the geoscientific data and resource potential evaluation for each field, a profile of the geothermal fields have compiled and utilized for the formulation of a geothermal development plan.

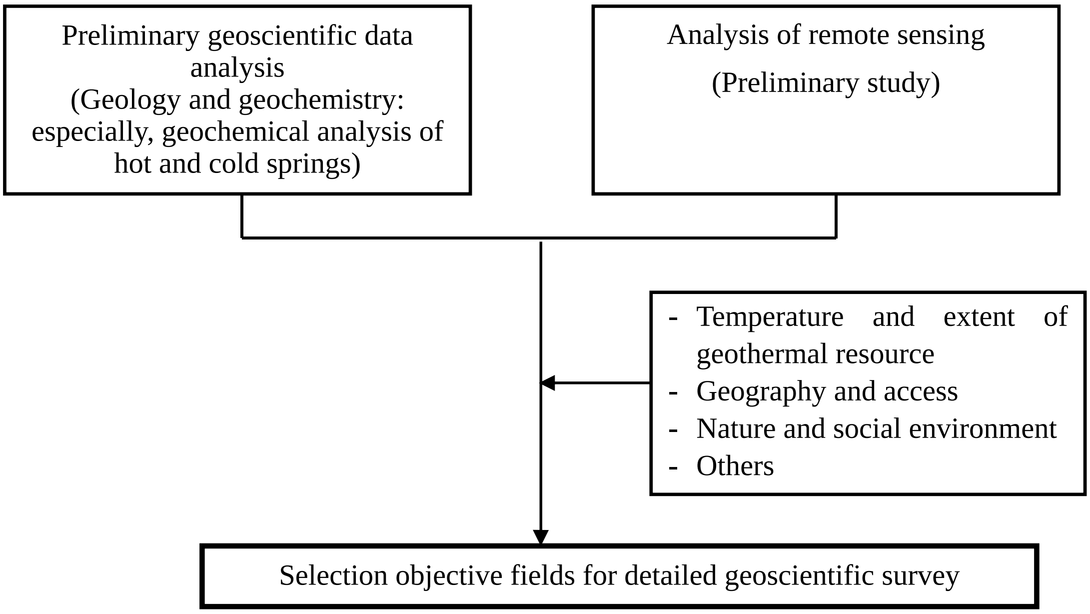
### (4) Selection of objective fields for detailed geoscientific survey

Candidate fields for detailed geoscientific survey were detected based on a review and analysis of previously collected data and information, and preliminary satellite imagery analysis. The flow of the selection process for fields is shown in Fig. 3-2.16. Four (4) criteria were considered in the selection of objective fields for detailed geoscientific survey as shown in Table 3-2.1.

The primary work with the existing information on geothermal resources in Rwanda, as shown in previous section, focused on reviewing the important or interesting geothermal regions or areas identified in some previous work. As mentioned in the previous section, important geothermal fields have been recognized in the northwestern part of Rwanda. Most of the researchers have listed up the geothermal fields shown below as the most promising fields, where it is worth carrying out detailed studies to evaluate the geothermal resource potential.

- Karisimbi
- Kinigi
- Gisenyi
- Bugarama

The JICA study team has agreed that these four (4) prospects deserve more detailed geoscientific survey. The team has also investigated other areas to detect promising fields by reviewing previously conducted geoscientific study results and remote sensing.




Source: JICA study team

Fig. 3-2.16 Flow of selection process of objective fields for detailed geoscientific survey

Table 3-2.1 Criteria of selection of objective fields for detailed geoscientific survey

| Item | Contents |
|---|---|
| 1. Exploration Stage | − Preliminary surface geoscientific study<br>− Detailed surface geoscientific study<br>− Well drilling (thermal gradient hole/exploratory well)<br>− Existing exploration plan |
| 2. Resource Potential | − Confirmation of reservoir presence<br>− Active geothermal manifestations (hot spring/fumarole)<br>− Past (active) geothermal manifestations (hydrothermally altered zones)<br>− Volcanic Activity and Possible Heat Source<br>− Geological structure suitable for formation of geothermal reservoir |
| 3. Natural/Social Environmental Constraints | − Protected forest / National park<br>− Social constraints |
| 4. Topography/Accessibility | − Topography<br>− Access roads, and other infrastructure |

Source: JICA study team

All of the geothermal fields are in the survey stage. Regional surface surveys have been completed in all areas. Detailed geological, geochemical and MT/CSMT surveys have already been conducted in Karisimbi, Kinigi and Gisenyi fields in the northwestern area, though gravity and magnetic surveys have not yet been conducted in any of those areas. Although aerial gravity and magnetic survey has been conducted for the entire area of Rwanda, the four important areas were not included these surveys. Therefore, gravity and magnetic data for these four areas are not available. A geothermal exploratory well was drilled only in Karisimbi, but no geothermal reservoir suitable for power generation was discovered there.

In the selection of objective fields for detailed geoscientific survey, information concerning “Resource Potential”, “Natural/Social Environmental Constraints” and “Topography/Accessibility” are reviewed. The results of this review can be summarized as follows.

1) Resource potential

i) Review of geological data and information.

Table 3-2.2 summarizes geology, geological structure and volcanic activity in major geothermal prospects in Rwanda.

Table 3-2.2 Review of geological data in important or interesting geothermal regions

| Field Name | Geology | Geological structure | Surface hydrothermal alteration | Fumarole, Hot spring | Volcanism |
|---|---|---|---|---|---|
| Karisimbi | Surface to few hundred meters: Tephrite-basanite and trachy-andesites lavas and pyroclastic rocks Basement: Proterozoic granites with pegmatite lenses and spatially related gneisses | NE-SW ternding faults and NW-SE trending faults | None | None*1) | Located in the chain of Quaternary volcanoes, Karisimbi, Visoke, Sabyinyo, Gahinga, and Muhabura,along the Rwanda-Uganda-Congo border (the East Virunga Range). Some have had historic eruptions (Visoke and Muhabura, for example) |
| Kinigi | Surface to few hundred meters: Tephrite-basanite and trachy-andesites lavas and pyroclastic rocks Basement: Proterozoic granites with pegmatite lenses and spatially related gneisses | Regional geological structure: the field is located in a NW-SE fracture zone between the Visoke and Sabinyo Volcanoes. The tectonic features are materialized by NW-SE, N-S and NE-SW trending faults. | None | None | |
| Gisenyi | (Tephrite-basanite and trachy-andesites lavas and pyroclastic rocks: thinner or absent) Basement: Proterozoic granites with pegmatite lenses and spatially related gneisses | The field is located in normal fault zone near the eastern boundary of the East African Rift. | None | Hot spring (Na-HCO3 type) : 70 - 75°C | |
| Bugarama | Tertiary volcanic rocks (basaltic lavas) are at both south and west of the hot spring area. Basement: granites, quartzites, phyllites and other Proterozoic rocks belonging the Cyangugu Complex | The field is located at graben formed by normal faults. | Travertine | Hot spring (Na-HCO3 type) : 50 - 65°C | Tertiary volcanic rocks are in the field, but no data of the age. Toshibinda volcano (in DRC) is located 40km NW of Bugarama hot spring |

1) There is a possibility of that hot spring and hydrothermal alteration occurs at Bonde crater in Karisimbi (EWSA staff's comment)

Source: JICA study team

Considering the regional geological settings and volcanism in Rwanda described above, the northwestern part of Rwanda, where some volcanoes erupted in the late Quaternary and the occurrence of geothermal fields with high potential is expected, is the most interesting region. The heat source in Bugarama, located in southwestern part of Rwanda, is unclear.

Investigation of high permeable structures related to fluid flow shows that fractures and faults seem to play the role of permeable structures in regions where metamorphic rock is widely distributed, such as the northwestern and southwestern part of Rwanda. The presence of faults was estimated in previously conducted geoscientific studies for both the northwestern and southwestern parts of Rwanda.

Preliminary work with existing information about and remote sensing of geothermal resources in Rwanda led to the listing of geothermal fields in the northwestern and southwestern part of Rwanda as promising fields in pre-selection work (Fig. 3-2.14 and 3-2.15).

ii) Review and preliminary analysis of geochemical data for surface spring water

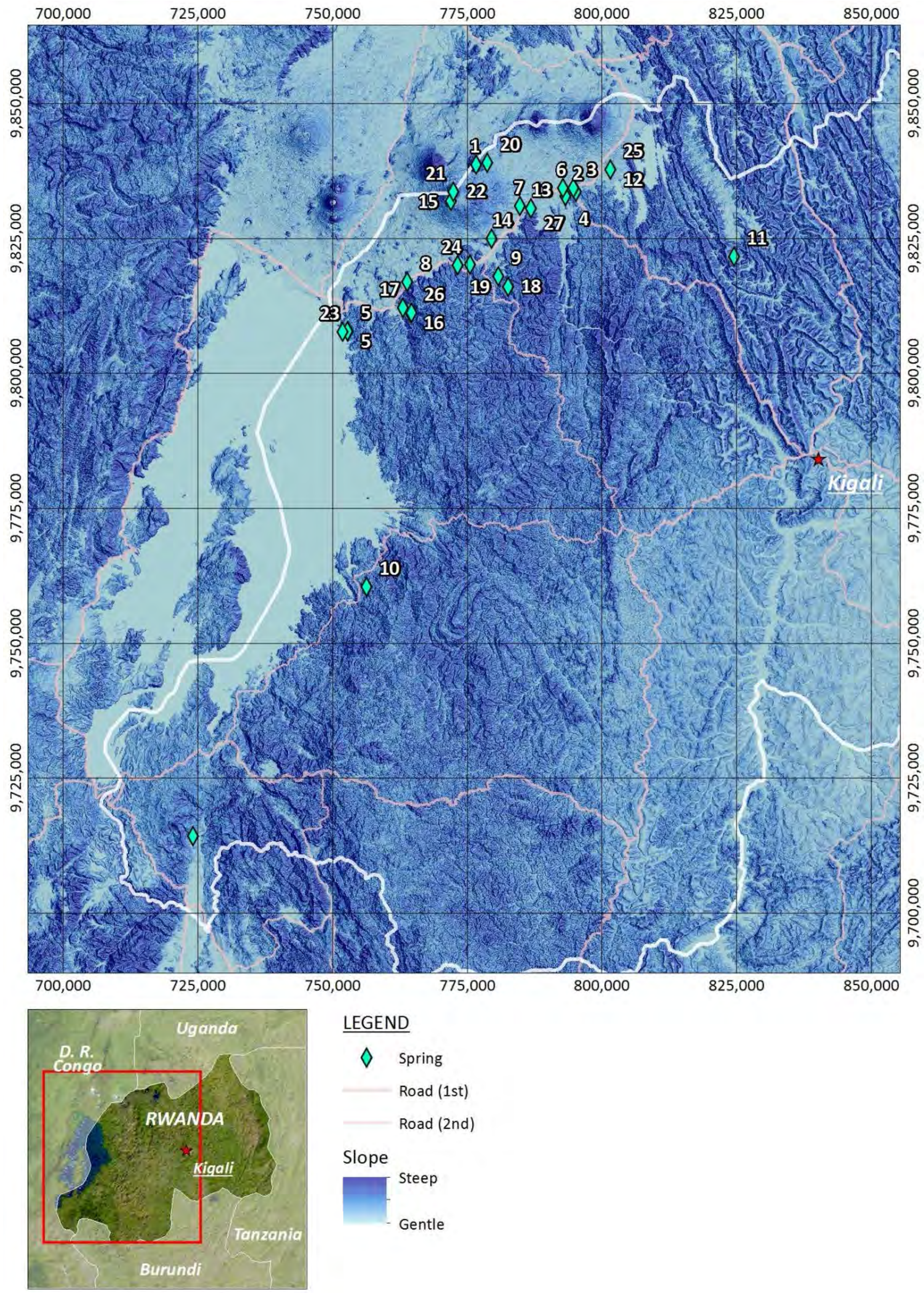
In the early stage of exploration of a geothermal resource, geochemical study of the surface spring water is the most useful tool for resource evaluation. The geochemical study allows inferences to be made concerning the occurrence of hot geothermal water and the possible temperature of the subsurface water. Preliminary geochemical analysis of the available chemical data provided by EWSA was conducted.

a) Geochemical data collection and arrangement

Several geochemical field surveys have been undertaken to assess the significance of the natural discharge of thermal fluids and gasses within the geothermal prospects in northern Rwanda and Bugarama.

Existing chemical analysis data for hot spring and surface water were compiled by Chevron (2006) and BGR (2009). The survey by Chevron (2006) was conducted as an assessment of geothermal energy potential in Gisenyi and Mashyuza fields. And the survey by BGR (2009) was conducted to assess the geothermal energy potential of the Virunga field in northwest Rwanda. Sampling points of hot spring and surface water samples are shown in Fig. 3-2.17, and chemical data for hot spring and surface water samples are listed Table 3-2.3. Charge balances using major constituents that all analyses have acceptable as indicated by the sum of major cations and anions. Also, the survey by BGR (2009) included sampling of gas discharges from hot and cold springs. Spring gas compositions are shown in Table 3-2.4.

Extensive soil gas surveys were undertaken in surveys by BGR (2009) and KenGen (2010). The survey by BGR (2009) covered most of the prospect field (500km$^2$) and included measurements of $CO_2$, $CH_4$, and $H_2S$, as well as sampling of trace gasses such as He, Ar, and Rn. The survey by KenGen (2010) was conducted over a smaller area (300km$^2$) mainly covering the South Karisimbi field and included measurements of $CO_2$, Rn and a test of whether Hg is present. The results of soil gas surveys are shown in Fig. 3-2.18. The results of these gas surveys appear to contribute little to a better understanding of the geochemical setting of the whole prospect. The diffusive discharge of anomalous $CO_2$ gas is found throughout most of the prospect fields from Gisenyi to Kinigi. This distribution does not support the assumption that the gas discharge is associated with a magma source at some crustal depth beneath Karisimbi volcano (IESE, 2012).




Source: JICA study team

Fig. 3-2.17 Location map of spring and surface water samples

Table 3-2.3 Chemical and isotopic composition of spring and surface waters

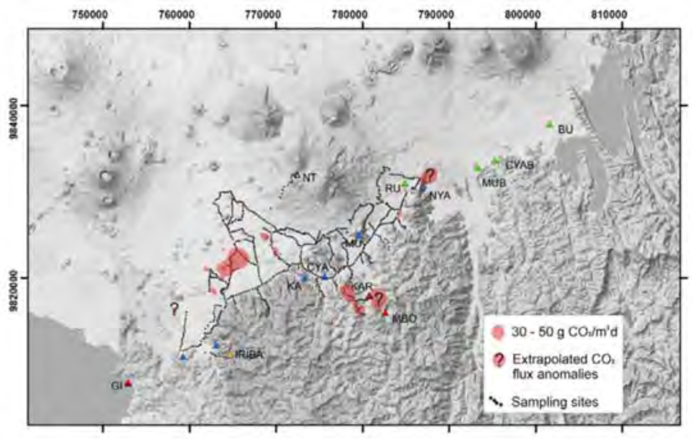
| Ser. No. | No. | Name | x | y | m asl | T ℃ | E.C. μS/cm | pH | Na mg/L | K mg/L | Ca mg/L | Mg mg/L | Cl mg/L | $SO_4$ mg/L | $HCO_3$ mg/L | B mg/L | $SiO_2$ mg/L | δD ‰ | $\delta^{18}O$ ‰ | Tritium (TU) | $^{87}Sr/^{86}Sr$ | Refer. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | Gisenyi | 752918 | 9807842 | 1454 | 68 | 2450 | 7.4 | 495 | 38.2 | 35.3 | 11.2 | 195 | 55.8 | 1140 | 2.14 | 56.2 | -9.7 | -3.5 | 0.03 | 0.7671 | 1 |
| 2 | 9 | Karago | 780826 | 9817960 | 2288 | 64.1 | 1250 | 7.2 | 253 | 14.7 | 21.2 | 2.4 | 76.6 | 77.9 | 537 | 0.34 | 84 | -12.4 | -3.72 | 0.07 | 0.7844 | 1 |
| 3 | - | Mashyuza | - | - | - | 47 | - | 6.5 | 307.8 | 48 | 76 | 55 | 128 | 46 | 1061.7 | 4.5 | 75.1 | - | - | - | - | 2 |
| 4 | 11 | Bitagata | 824694 | 9821590 | 1859 | 36.6 | 458 | 7.1 | 5.9 | 9 | 38.3 | 31 | 5 | 7.68 | 289 | 0.07 | 23.2 | -16.6 | -4.17 | - | - | 1 |
| 5 | 18 | Mbonyebyombi | 782654 | 9816022 | 2220 | 34.5 | 921 | 7 | 187 | 11.5 | 20.2 | 2.4 | 51.8 | 44.2 | 414 | 0.22 | 60.3 | -12.8 | -3.86 | 0.3 | 0.7893 | 1 |
| 6 | 10 | Mpatsi | 756430 | 9760506 | 1698 | 31.2 | 1670 | 7 | 208 | 23.1 | 144 | 16.8 | 40.8 | 31.2 | 1050 | 1.28 | 86.3 | -11.2 | -3.61 | - | - | 1 |
| 7 | 16 | Iriba | 764682 | 9811128 | 2016 | 22.3 | 2290 | 7 | 394 | 17.2 | 76.6 | 23.2 | 287 | 67 | 846 | 0.42 | 58.3 | -8.8 | -3.44 | 0.42 | 0.8004 | 1 |
| 8 | 25 | Nyakageni | - | - | 1878 | 20.5 | - | 7.3 | 229 | 43.1 | 71.3 | 23.2 | 72.6 | 31.5 | 854 | - | 62.7 | - | - | - | - | 1 |
| 9 | 12 | Buseruka | 801673 | 9837772 | 1823 | 17.4 | 4080 | 6.5 | 239 | 226 | 149 | 356 | 12.9 | 69.4 | 3200 | 0.43 | 99.8 | -11.8 | -4.32 | 0.05 | 0.7065 | 1 |
| 10 | 4 | Mubona | 793373 | 9832788 | 1803 | 19.5 | 3050 | 6.7 | 160 | 180 | 112 | 225 | 22.3 | 41.4 | 2200 | 0.28 | 72.1 | -10.5 | -3.77 | 0.3 | 0.7069 | 1 |
| 11 | 2 | Cyabararika | 795307 | 9833654 | 1816 | 18.5 | 2880 | 6.4 | 157 | 159 | 121 | 204 | 7.6 | 44.6 | 2100 | 0.25 | 69.2 | -9.5 | -3.77 | 0.3 | 0.7071 | 1 |
| 12 | 7 | Rubindi | 784924 | 9831002 | 2104 | 18 | 1960 | 7.1 | 105 | 114 | 32.9 | 145 | 14.7 | 12.2 | 1320 | 0.17 | 94.3 | -10 | -3.63 | 0.05 | 0.7086 | 1 |
| 13 | 14 | Mutera | 779612 | 9824965 | 2383 | 17.4 | 215 | 7.4 | 4.5 | 5.1 | 21.6 | 9.9 | 2.6 | 6.51 | 91.2 | 0.02 | 55.7 | -9.6 | -3.02 | 1.92 | 0.7086 | 1 |
| 14 | 17 | Bukeri | - | - | - | - | 247 | 7.5 | 9.9 | 9.3 | 21.3 | 9.4 | 5.6 | 16.1 | 98.3 | 0.02 | 57.4 | -5 | -2.72 | 1.89 | 0.7115 | 1 |
| 15 | 19 | Cyamabuye | 775639 | 9820169 | 2361 | 16 | 442 | 7 | 13.9 | 21.3 | 34.9 | 17.4 | 12.5 | 24.6 | 158 | 0.04 | 47.7 | -7.1 | -2.77 | - | - | 1 |
| 16 | 24 | Kagohe | - | - | - | - | 456 | 7 | 19.2 | 6.2 | 46.6 | 15.3 | 11.7 | 34 | 166 | 0.03 | 41.3 | -9.3 | -3.36 | 1.63 | 0.7264 | 1 |
| 17 | 1 | Bisoke crater lake | 776795 | 9838704 | 3586 | 10.2 | 28 | 4.5 | 0.5 | 1.3 | 0.6 | 0.3 | 1.5 | 1.47 | 3.5 | <0.01 | 2.1 | -3.9 | -2.29 | - | - | 1 |
| 18 | 3 | Mpenge River | 794832 | 9834356 | 1824 | 15.5 | 757 | 7 | 37.7 | 52 | 28.3 | 44.8 | 4.4 | 7.15 | 478 | 0.04 | 52.6 | -8.8 | -3.52 | - | - | 1 |
| 19 | 8 | Mutura waterfall | 764004 | 9816898 | 2245 | 16.1 | 190 | 6.9 | 7.1 | 7.9 | 15.9 | 7.7 | 3.4 | 15.8 | 78.3 | 0.01 | 35.6 | -5.9 | -2.97 | - | - | 1 |
| 20 | 20 | Bushokoro (Bisoke) | 778849 | 9839060 | 2678 | 11.4 | 94 | 6.7 | 4.2 | 4.8 | 8 | 3.4 | 1 | 2.68 | 51.9 | 0.02 | 36.8 | -10.6 | -3.77 | - | - | 1 |
| 21 | 15 | Ntango (Karisimbi) | 772094 | 9831936 | 3574 | 10.9 | 37 | 7.3 | 1.2 | 2 | 2 | 0.9 | 2 | 6.5 | 6 | 0.02 | 13 | -5.8 | -2.98 | - | - | 1 |
| 22 | 23 | Lake Kivu | - | - | - | - | 1189 | 9 | 102 | 83.9 | 9.3 | 78.1 | 25 | 16.6 | 780 | 0.15 | 7.3 | - | - | - | - | 1 |
| 23 | 6 | Rainwater Ruhengeri | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 3.7 | -2.18 | - | - | 1 |
| 24 | 21 | Karisimbi, partly | 772561 | 9833680 | 4516 | 2.6 | - | - | - | - | - | - | - | - | - | - | - | -99.7 | -14.63 | - | - | 1 |
| 25 | 22 | Karisimbi, completely | 751898 | 9807709 | 1468 | 24 | - | - | - | - | - | - | - | - | - | - | - | -97.5 | -14.22 | - | - | 1 |

Table 3-2.4 Chemical and isotopic compositions of spring gasses

| Ser. No. | No. | Name | $^{3}He/^{4}He$ | $N_2$ vol% | $O_2$ vol% | $CO_2$ vol% | $\delta^{13}C$ ‰ | $CH_4$ ppm | Refer. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | Gisenyi | 2.30E-07 | 23.8 | 5.7 | 70.1 | -8.0 | 2881 | 1 |
| 2 | 9 | Karago | 1.01E-09 | 39.2 | 3.1 | 57.1 | -9.5 | 5705 | 1 |
| 3 | 18 | Mbonyebyombi | 1.02E-07 | 76.7 | 7.4 | 15.7 | -13.3 | 944 | 1 |
| 4 | 16 | Iriba | 1.18E-07 | 54.4 | 4.5 | 41.0 | -11.5 | 202 | 1 |
| 5 | 25 | Nyakageni | 1.29E-06 | 7 | 2.1 | 90.9 | -5 | 96 | 1 |
| 6 | 12 | Buseruka | 1.87E-06 | 5.7 | 1.8 | 92.5 | -9.6 | 5 | 1 |
| 7 | 4 | Mubona | - | 15.9 | 4.1 | 80 | -9 | 99 | 1 |
| 8 | 2 | Cyabararika | 2.46E-06 | 12.9 | 3.1 | 84 | -8.4 | 30 | 1 |

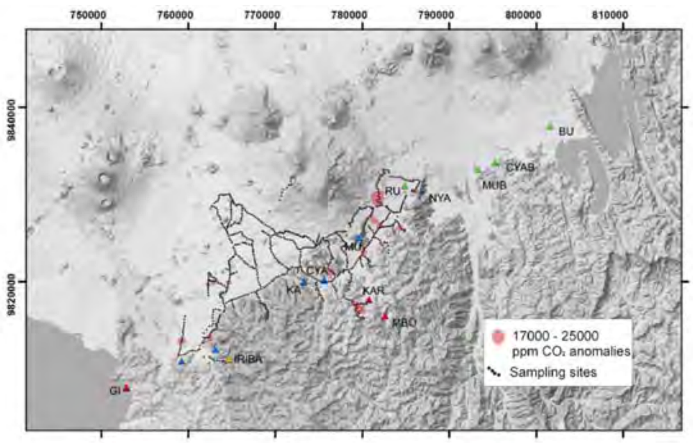
Hot spring (High temp.)
Hot spring (Low temp. )
Cold spring (High $HCO_3$)
Cild spring
Surface/Rain water

Reference
1: BGR (2009)
2: Chevron (2006)



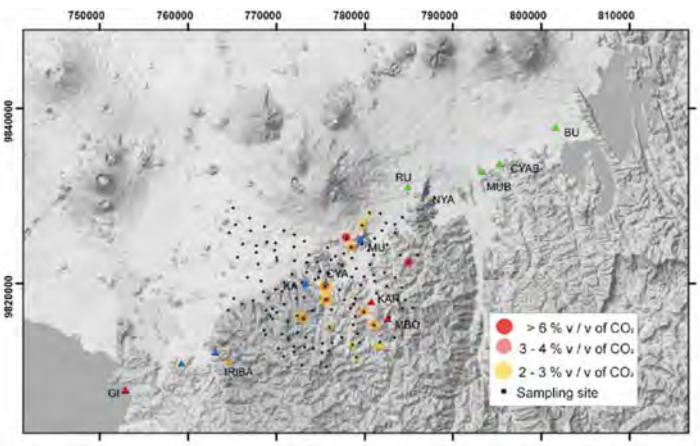

Source: BGR, 2009

(1) $CO_2$ (Surface) flux measurements




Source: BGR, 2009

(2) $CO_2$ soil gas measurements




Source: Kengen, 2010

(3) $CO_2$ soil gas measurements

Fig. 3-2.18 Results of $CO_2$ gas surveys

b) Preliminary analysis based on the existing data

A preliminary geochemical assessment based on the data from Chevron (2006) and BGR (2009) was carried out.

Chemical composition of hot springs

The chemical composition of the hot springs and cold springs is of neutral $HCO_3$ type (Fig. 3-2.19), and they are classified into four subtypes (Table 3-2.5).

- High temperature hot springs (Type I)

Hot springs such as Gisenyi, Karago and Mashyuza are classified into type I. These hot springs are of neutral $HCO_3$ type and component of major cation are Na+K. Temperature of the hot springs shows above 47°C, the highest temperature is 68°C of Gisenyi. Chloride (Cl) concentration is relatively high, Gisenyi is 195mg/L.

- Low temperature hot springs (Type II)

Hot springs such as Bitagata, Mbonyebyombi, Mpatsi, Iriba and Nyakabeni are classified into type II. These hot springs are of neutral $HCO_3$ type and the major cation components are Na+K. The temperature of the hot springs is between 20.5°C and 36.6°C. The chloride (Cl) concentration is relatively low, except Iriba of 287mg/L.

- Cold springs with high $HCO_3$ content (Type III)

Cold springs such as Buseruka, Mubona, Cybararika and Rubindi are classified into type III. These cold springs are of neutral $HCO_3$ type and the major cation components are Ca+Mg. The temperature of the cold springs is between 17.5°C and 19.5°C. The bicarbonate ($HCO_3$) concentration is relatively high at between 1,320 to 3,200mg/L.

- Cold springs with low $HCO_3$ content (Type IV)

Cold springs such as Mutera, Bukeri, Cyamabuye, and Kagohe are classified into type IV. These cold springs are of neutral $HCO_3$ type and the major cation components are Ca+Mg. The chemical composition of the cold springs shows the characteristics of average ground water.

The concentration of bicarbonate（$HCO_3$）in surface water is relatively high in Mpenge river and Lake Kivu, reaching 478mg/L and 780mg/L , respectively.

Hot spring gas components

Analysis of gas discharging from cold springs (Type III; Buseruka, Cyabararika, and Mubona) and low-temperature hot spring Nyakageni (Type II) show that these gases contain an anomalously high volume of $CO_2$ gas (between 80% and 92% of total gas). The $CO_2$ gas appears to be of deeper crustal or even mantle origin, as indicated by its low $CH_4$ content, its δ13C ($CO_2$) and 3He/4He isotope signature (IESE, 2012).

Isotope data for spring waters

- Hydrogen and Oxygen isotopes

Hydrogen and Oxygen isotope values are plotted with respect to some standard water lines (Fig. 3-2.20). Hot and cold spring water values show an anomalous negative isotope shift, away from the local meteoric water line of Uganda (Bahati, 2005) and this prospect area (JICA, 2013). Further consideration is necessary since these relationships are not clear.

- Tritium isotope values

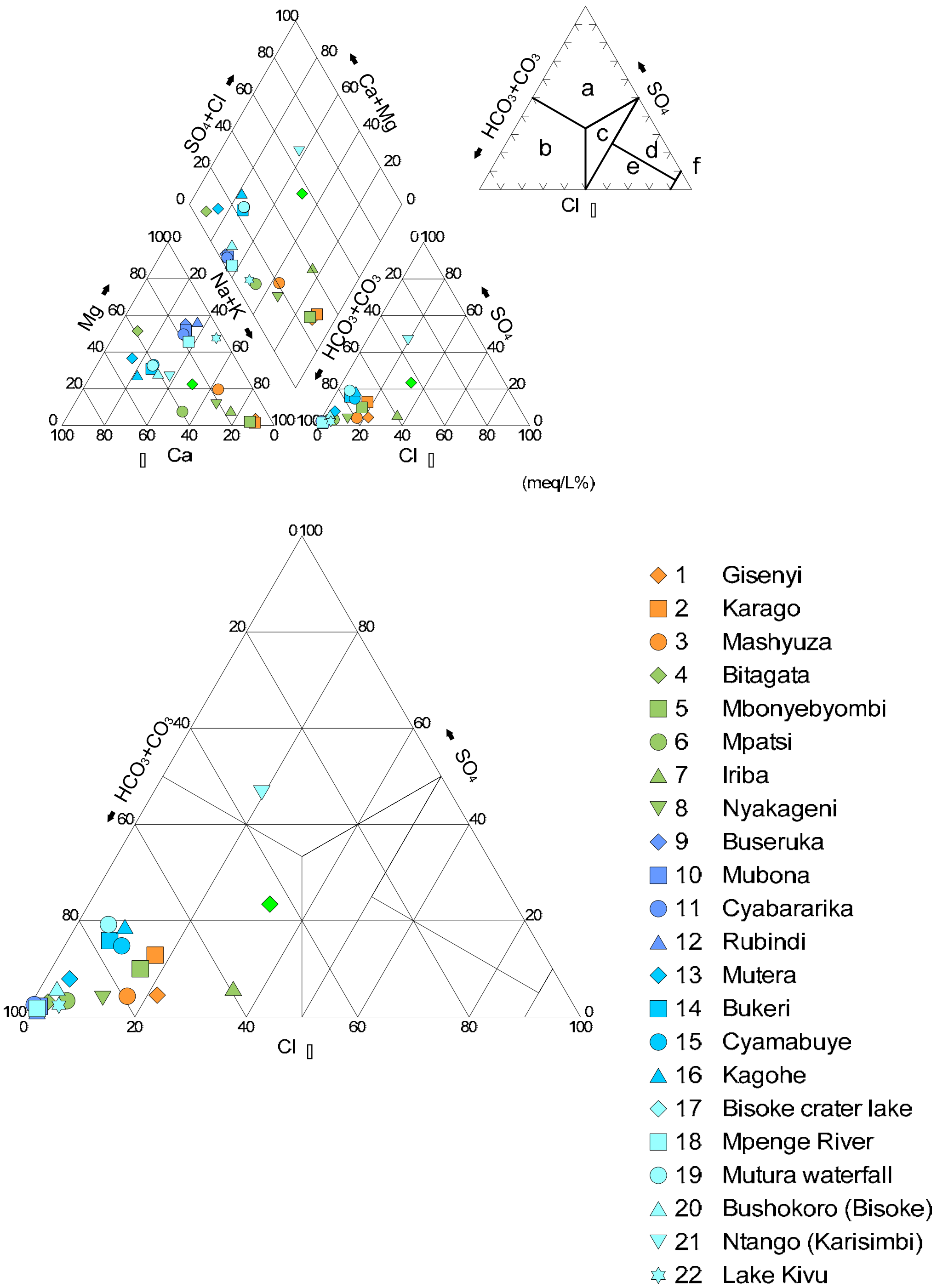
The tritium isotope values of hot spring waters and cold spring waters are listed in Table.3-2.5. These values are classified into two groups of high tritium value and low tritium value (Fig.3-2.21). Cold spring waters (Type IV) have high tritium values, which can be associated with short and shallow path length. On the other hand, type I, II, and III springs have lower tritium values of <0.42TU (Tritium units). Long surface flow travel times are indicated for these spring waters. In particular, Gisenyi and Karago hot springs show lower tritium values of <0.07TU. Since Mbonyebyombi and Iriba hot springs are of rather low temperature and show high tritium values, these hot springs are likely diluted by surface cold water. Long surface flow travel times are indicated for Buseruka and Rudini, which also have low tritium values.

- Strontium isotopes

The strontium isotope values of hot spring waters and cold spring waters are listed in Table.3-2.5. These values are classified into two groups having either high isotope values or low isotope values (Fig.3-2.22). Gisenyi, Karago, Mbonyebyombi and Iriba, classified as types I and II, have high strontium isotope values (>0.76). Hot springs and cold springs classified as type III and IV have low strontium isotope values. Strontium isotopes ($^{87}Sr/^{86}Sr$) are useful indicators of water-rock interaction and can be used as a tracer for ground water movement. Lava flows of the Virunga volcanics show strontium isotope values between 0.7060 and 0.7100 (Rogers et al., 1988). Their average value of 0.709 is similar to the strontium isotope values of 0.7065 to 0.7086 observed in cold springs (Type III) issuing from lava flows in the Kinigi sector (IESE, 2012). Strontium values of basement rocks were measured in nearby Uganda, where gneissic rocks near Kibiro have strontium isotope values of 0.784 (Bahiti et al., 2005). Granites of the Pre-Proterozoic basement produce somewhat lower strontium isotope values of 0.726 near Buranga, similar to the strontium isotope values of Kagohe cold spring (Type IV). Type I and II hot springs of the prospect have high strontium isotope values between 0.767 and 0.800 indicating some dominant flow paths through gneisses (IESE, 2012).

Geothermometry of spring waters

Some spring water geothermometers are shown in Table 3-2.6. The three components Na-K-Mg are not in an equilibrium condition, since the Mg concentration is high (Fig.3-2.23). The Na-K-Ca geothermometers estimated underground temperatures between 159°C and 204°C for Gisenyi, Karago and Mashyuza high-temperature hot springs.




Source: JICA study team

Fig. 3-2.19 Trilinear diagram of spring and surface waters

Table 3-2.5 Summary of the characteristics of spring waters

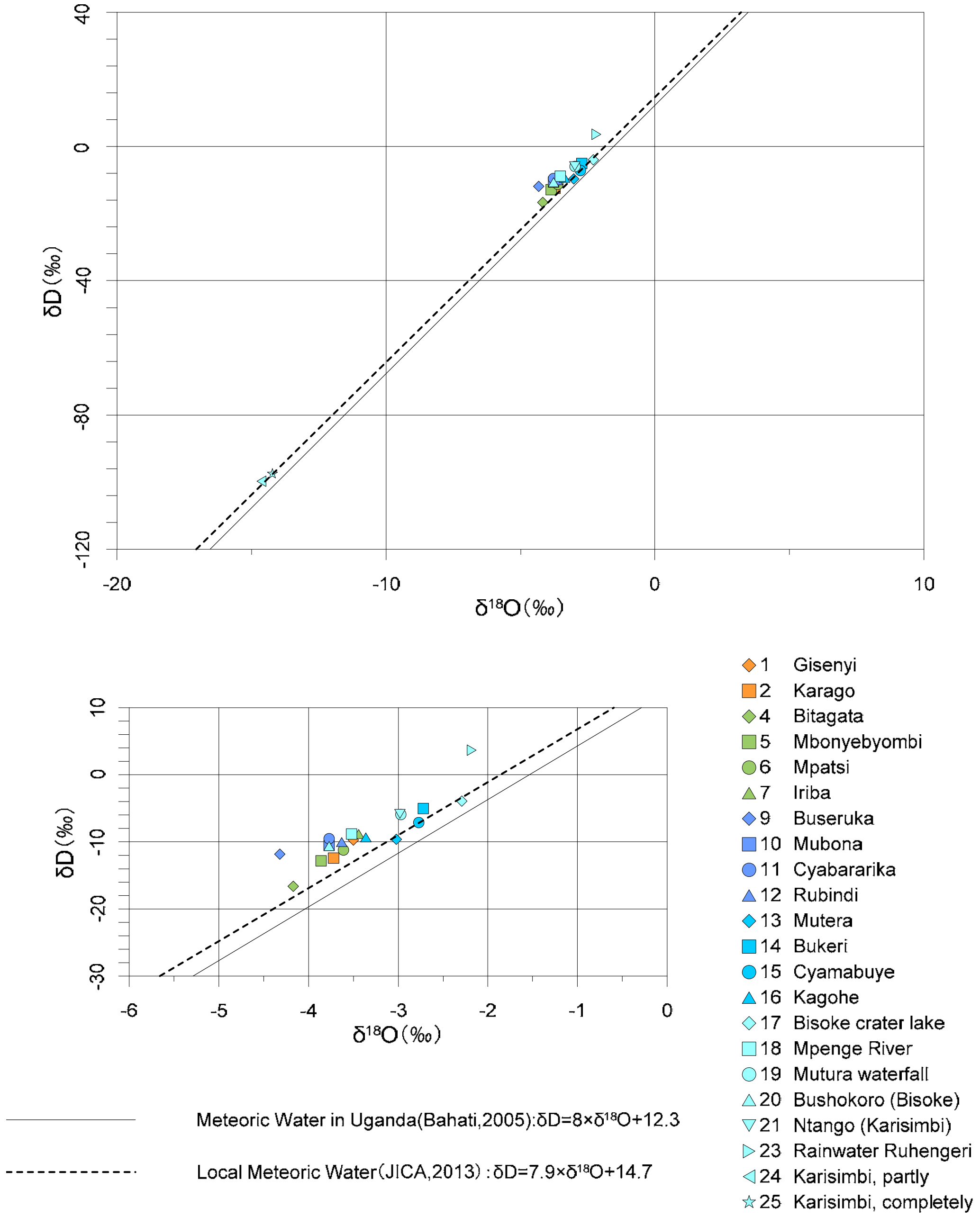
| Type | | Temp. (℃) | pH | E.C. (μS/cm) | Chemical Composition Cation | Chemical Composition Anion | Cl (mg/L) | $HCO_3$ (mg/L) | Tritium (TU) | $^{87}Sr/^{86}Sr$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Ⅰ | Hot Spring (High Temp.) | 47.0-68.0 | 6.5-7.4 | 1250-2450 | Na+K | $HCO_3$ | 76.6-195 | 537-1140 | 0.03-0.07 | 0.767-0.784 |
| Ⅱ | Hot Spring (Low Temp.) | 20.5-36.6 | 7.0-7.3 | 458-2290 | Na+K | $HCO_3$ | 5-287 | 289-1050 | 0.3-0.42 | 0.790-0.800 |
| Ⅲ | Cold Spring (High $HCO_3$) | 17.4-19.5 | 6.4-7.1 | 1960-4080 | Ca+Mg | $HCO_3$ | 7.6-22.3 | 1320-3200 | 0.05-0.3 | 0.707-0.709 |
| Ⅳ | Cold Spring (Low $HCO_3$) | 16.0-17.4 | 7.0-7.5 | 215-456 | Ca+Mg | $HCO_3$ | 2.6-12.5 | 91.2-166 | 1.63-1.92 | 0.709-0.726 |

Source: JICA study team

Table 3-2.6 Geothermometry of spring waters

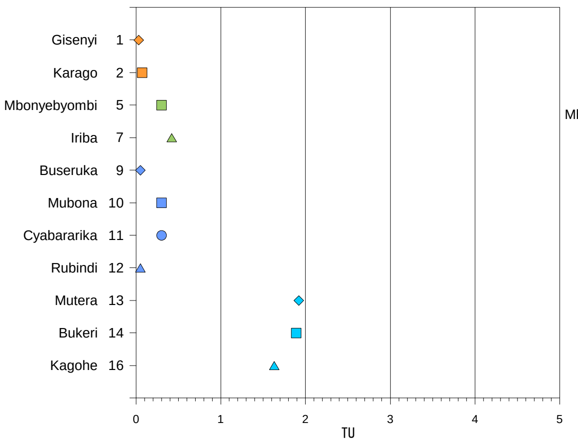
| Ser. No. | Name | Temp. ℃ | $SiO_2$ (adia.) ℃ | $SiO_2$ (cond.) ℃ | $SiO_2$ (chalc.) ℃ | Na-K (Truesdell,1976) ℃ | Na-K (Fournier,1979) ℃ | K-Na (Giggenbach,1992) ℃ | Na-K-Ca (Truesdell,1975) ℃ | K-Mg (Giggenbach,1992) ℃ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Gisenyi | 68.0 | 107 | 107 | 78 | 161 | 196 | 212 | 181 | 98 |
| 2 | Karago | 64.1 | 125 | 128 | 100 | 136 | 174 | 192 | 159 | 93 |
| 3 | Mashyuza | 47.0 | 120 | 122 | 94 | 241 | 258 | 270 | 204 | 83 |
| 4 | Bitagata | 36.6 | 74 | 69 | 37 | - | - | - | 52 | 52 |
| 5 | Mbonyebyombi | 34.5 | 110 | 111 | 82 | 140 | 179 | 196 | 157 | 87 |
| 6 | Mpatsi | 31.2 | 126 | 129 | 102 | 199 | 226 | 241 | 91 | 80 |
| 7 | Iriba | 22.3 | 109 | 109 | 80 | 113 | 155 | 174 | 142 | 69 |
| 8 | Nyakageni | 20.5 | 112 | 113 | 84 | 267 | 278 | 288 | 211 | 91 |
| 9 | Buseruka | 17.4 | 133 | 137 | 110 | - | - | - | - | 99 |
| 10 | Mubona | 19.5 | 118 | 120 | 91 | - | - | - | - | 99 |
| 11 | Cyabararika | 18.5 | 116 | 118 | 89 | - | - | - | - | 97 |
| 12 | Rubindi | 18.0 | 130 | 134 | 107 | - | - | - | - | 93 |
| 13 | Mutera | 17.4 | 107 | 107 | 77 | - | - | - | - | 52 |
| 14 | Bukeri | - | 108 | 108 | 79 | - | - | - | - | 65 |
| 15 | Cyamabuye | 16.0 | 101 | 100 | 70 | - | - | - | - | 77 |
| 16 | Kagohe | - | 95 | 93 | 63 | - | - | - | - | 51 |

Source: JICA study team



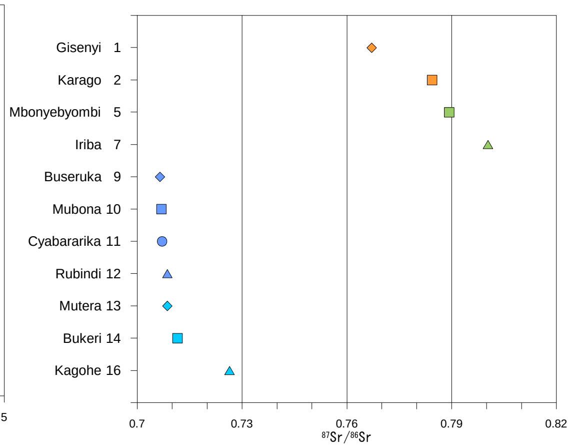

Source: JICA study team

Fig. 3-2.20 Relation between δD and $\delta^{18}$O of spring and surface waters



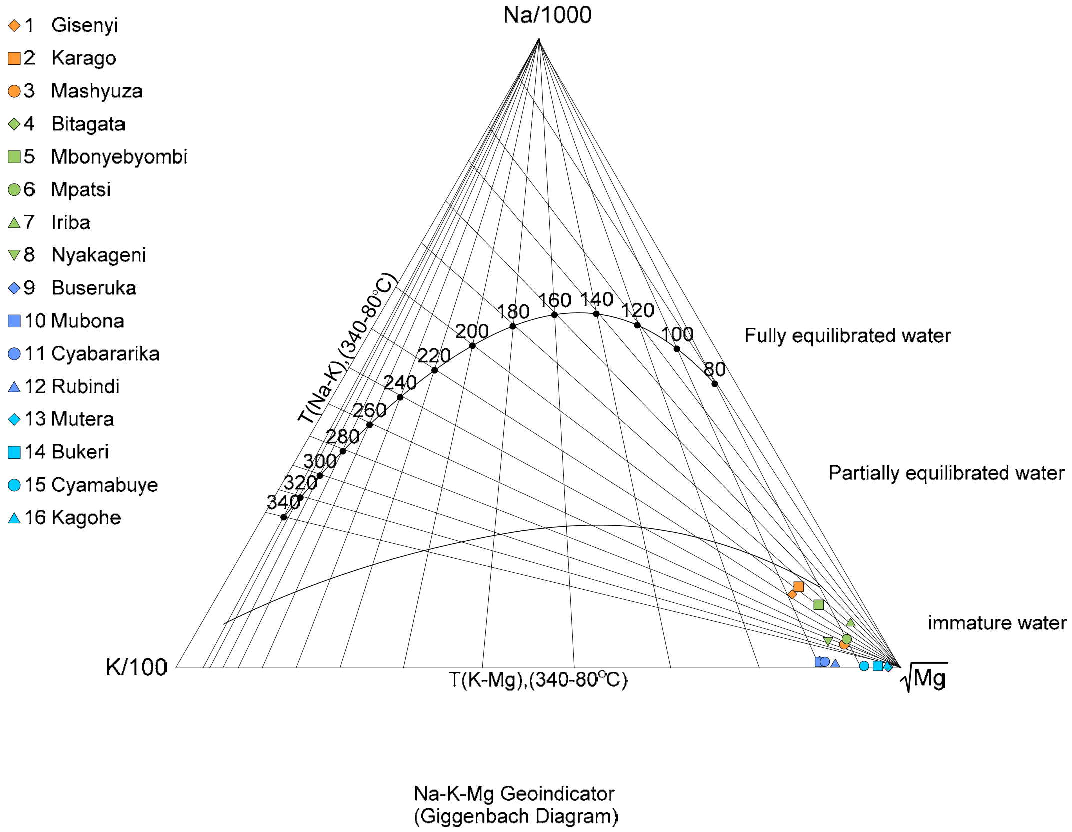

Source: JICA study team

Fig. 3-2.21 Tritium values of spring waters




Source: JICA study team

Fig. 3-2.22 Strontium isotope values of spring waters




Source: JICA study team

Fig. 3-2.23 Ternary diagram for Na-K-Mg

iii) Results of site visits

Site visits to geothermal prospects were conducted to confirm the geothermal activity associated with Gisenyi and Mashyuza hot springs located in Bugarama and Cyabararika and Rubindi cold springs with high $HCO_3$ concentration (Fig. 3-2.24 and Table 3-2.7).


Fig. 3-2.24 Location map of site visits to geothermal prospects

Table 3-2.7 Geochemical characteristics of spring waters

| No. | Spring | Date | GPS No. | Temp. | pH | Cond. (μS/cm) | Flow Rate (L/min) | Remarks |
|---|---|---|---|---|---|---|---|---|
| 1 | Mashyuza | 15/1/2014 | 22 | 41.0 | — | — | (1000+) | Loc.1 |
| 2 | | | 24 | 53.7 | 6.4 | 2,280 | – | Loc.1 |
| 3 | | | 30 | 36.4 | 8.3 | 2,020 | 200 | Loc.3 |
| 4 | | | 31 | 43.0 | 6.5 | 2,170 | 200 | Loc.2 |
| 5 | Cyabararika | 17/1/2014 | 46 | 18.5 | 6.3 | 3,090 | 100 | Cold spring |
| 6 | | | 47 | 17.8 | 7.1 | 1,063 | – | River |
| 7 | | | 48 | 17.0 | 7.2 | 1,000 | – | River |
| 8 | Rubindi | 17/1/2014 | 56 | 17.9 | 6.6 | 2,090 | 100 | Loc.1 |
| 9 | | | 57 | 17.6 | 7.1 | 299 | 200 | Loc.2 |
| 10 | Gisenyi | 18/1/2014 | 69 | 73.0 | 7.5 | 2,770 | 20 | Loc.1 |
| 11 | | | 71 | 68.4 | – | – | 10 | Loc.1 |
| 12 | | | 73 | 72.5 | – | – | – | Loc.1 |
| 13 | | | 74 | 70.3 | 7.1 | 2,690 | 5 | Loc.2 |
| 14 | | | 75 | 57.5 | 7.3 | 2,720 | 10 | Loc.2 |

Source: JICA study team

a) Gisenyi field

Gisenyi field is situated north of Lake Kivu, where high-temperature hot springs (above 70°C) gush out with gas bubbles from the lakeshore. There are two thermal areas where hot springs gush out (Photo 3-2.1 – 3-2.3). One area occupies approximately 20 x 30m on the south side of the peninsula (Loc.1). The maximum temperature of the hot spring is 73°C, with a pH of 7.5. The other area covers approximately 20 x 20m on the north side of the peninsula (Loc. 2). The maximum temperature of this hot spring is 70.3°C, with a pH of 7.1.


Source: Google earth

Photo 3-2.1 Gisenyi field

Two thermal areas where hot springs gush out (Loc.1 and Loc.2); image is from Google earth.


Photo 3-2.2 (1) Gisenyi field (Loc.1)
Thermal area covers an area 20m×30m

Photo 3-2.2 (2) Gisenyi field (Loc.1)
Maximum temperature is 73°C


Photo 3-2.3 (1) Gisenyi field (Loc.2)
Thermal area covers an area 20m×20m


Photo 3-2.3 (2) Gisenyi field (Loc.2)
Maximum temperature is 70.3$^{o}$C

b) Bugarama field (Mashyuza hot spring)

Mashyuza hot spring is located in the southern part of Bugarama district, where several hot springs gush out. The main geothermal activity in this field is a hot spring pool (50m x 100m) and hot springs that are found around the hot spring pool (Photo 3-2.4 - 3-2.7). In the hot spring pool (Loc.1), hot spring water gushes out from bottom and western side of the pool with gas bubbles, and the lake surface is raised a few cm by hot spring water at the major gushing point. The maximum temperature of the hot spring water is 53.7°C, with a pH of 6.4. A hot spring wells up on the road (Loc.2) about 500m from the hot spring pool (Loc.1). On the other side, hot spring water forms a small hot water river (36.4°C) northeast of the hot spring pool.


Source: Google earth

Photo 3-2.4 Bugarama field (Mashyuza Hot Spring)

Loc.1: Hot spring pool, Loc.2: Hot spring wells up on the road, Loc.3: Hot spring river.

Travertine is spread in this area.


Photo 3-2.5 (1) Mashyuza hot spring (Loc.1)

Hot spring pool, surface is raised a few cm

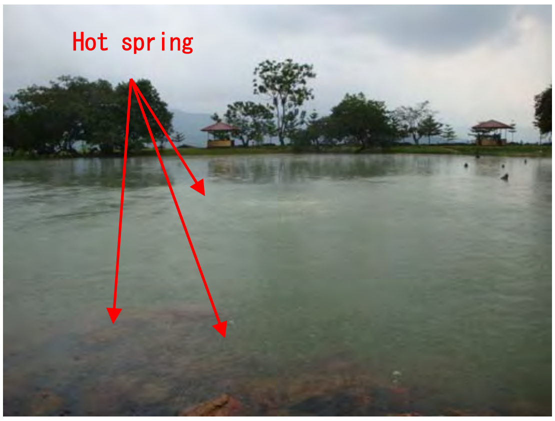



Photo 3-2.5 (2) Mashyuza hot spring (Loc.1)

Hot spring pool, gushing out with gas


Photo 3-2.6 Mashyuza hot spring (Loc.2)

Temperature 43°C

Photo 3-2.7 Mashyuza hot spring (Loc.3)

Hot spring river, temperature 36.4°C

c) Cyabararika cold spring

Cyabararika cold spring is located east of Ruhengeri, and wells up with a large amount of gas bubbles. The temperature of the cold spring is 18.5°C, and spring water is gushing out with gas bubbles in the river (Photo3-2.8).


Photo 3-2.8 (1) Cyabararika cold spring


Photo 3-2.8 (2) Cyabararika cold spring

With a large amount of gas bubbles (18.5°C)

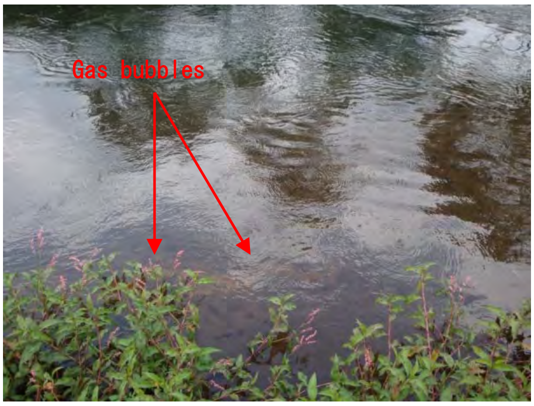



Photo 3-2.8 (3) Cyabararika cold spring

Springs well up with gas bubbles

Photo 3-2.8 (4) Cyabararika cold spring

Basaltic lava is distributed around the springs

d) Rubindi cold spring

There are two main welling-out points, one is from the riverbed (Loc.1) and the other is from a pipe installed on the slopes (Loc.2) of Rubindi springs (Photo 3-2.9 - 3-2.11).


Photo 3-2.9 Rubindi cold spring


Photo 3-2.10 (1) Rubindi cold spring (Loc.1)

The spring wells out with gas bubbles.


Photo 3-2.10 (2) Rubindi Cold Spring (Loc.1)
Perspective view


Photo 3-2.11 Rubindi Cold Spring (Loc2)

e) Karago hot spring

According to information furnished by EWSA, since the water level had risen at Lake Karago, Karago hot spring was submerged at the time of the site visit. We have been provided some photos of Karago hot spring and other information by EWSA (Photo 3-2.12). The temperature of the Karago hot spring water is rather high (64.1°C) and the pH is neutral (7.2), but the total flow is low. According to IESE (2012), there are warm springs and $CO_2$ discharges from a small swampy area on the south shore of Lake Karago. The total mass flow is low, little more than 1 liter per second.

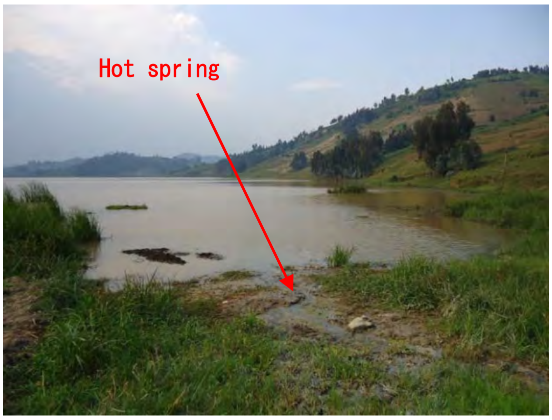



Photo 3-2.12 (1) Karago hot spring
Perspective view (Photo provided by EWSA)


Photo 3-2.12 (2) Karago hot spring
Hot spring discharge (Photo provided by EWSA)

2) Natural/social environmental constraints and topography/accessibility

Natural/social environmental constraints and topography/accessibility are summarized in Table 3-2.8.

In this study, an infrastructure survey has been conducted at major geothermal prospects. The main purpose of the infrastructure survey is to clarify the field condition and to obtain basic information necessary for future geothermal development including access to and water supply in the fields.

Table 3-2.8 Summary of Natural/social environmental constraints and topography/accessibility in the major four fields

| Field Name | Altitude (m. a.s.l.) | Base camp (hours to the site) | Site Condition | Topography | Surface Condition | Land Use | Water for Drilling | Natural/Social and Environmental Constraints |
|---|---|---|---|---|---|---|---|---|
| Karisimbi | 2,675 m (at the KW-01) | 60 minutes from Gisenyii city by car (40 km). | No resident | Flat location and gentle slope at the foot of Mt. Karisimbi | Soft soils. Many boulders and outcrops of volcanic rocks | Cultivated area (Irish potatoes) | No stream exists. Drilling water of exploratory wells is taking at lake Karago (18 km from KW-01 to the water in-take point along the road) | Close to the Volcanoes National Park Following constraints are arised: 1) compensation of cultivated area 2) impact to the ecosystem in lake Karago due to taking drilling water |
| Kinigi | 2,576 m (at the proposed drilling site No.1) | 30 minutes from Ruhengeri city by car (20 km). 5 km to the site, unpaved road | Few residents | Flat location and gentle slope | Soft soils. Many boulders and outcrops of volcanic rocks | Cultivated area (Irish potatoes) | No stream exists. 20 km from Ruhengeri 41 km from Lake Karago 30 km from Lake Ruhodo via Ruhengeri | Close to the Volcanoes National Park. Following constraints are arised: 1) resettlement of residents 2) compensation of cultivated area |
| Gisenyi | 1,470 m (at hot spring site) | 25 minutes from Gisenyi city by car (6 km). | Hot spring is close to residensial area (distance: 100m) Bath use of the hot spring | High relief topography at the coast of Kivu lake | Soft soils. Outcrops of hard metamorphic rocks at steep slope. | Uncultivated area | Close to the Lake Kivu | |
| Bugarama | 1,180 m (at hot spring site) | 50 minutes from Cyangugu city by car (15 km). From Kibangiro town to the site, unpaved road | No resident. Hot spring is located close to cement factory. Bath use of the hot spring | Flat location. Hot spring is located at topographic boundary of graben (flat) and steep slope of the mountain | Hard travertine deposits (thick) near hot spring. In the graben, gravels and alluvium. In the mountains, hard. | Mining area of travertine deposits near hot spring. In the graben, cultivated area (rice) | A river runs in the bottom of the graben. 1.2 km from the river to the hot spring | |

Source: JICA study team

3) Selection of objective fields for detailed geoscientific survey in Rwanda

Based on the analysis and review of existing data and information, as well as preliminary remote sensing analysis and field reconnaissance surveys, the northwestern and southwestern parts of Rwanda have been selected as objective fields for detailed geoscientific survey in consideration of criteria grouped under the four headings “Exploration Stage”, “Resource Potential”, “Natural/Social Environmental Constraints” and “Topography/Accessibility”. Table 3.2-9 shows a review of each criterion for the selected fields, and Table 3.2-10 gives a summary for selected fields.

Table 3-2.9 Summary of "Exploration Stage" and "Resource Potential" criteria (as of Feb. 2014)

| Field Name | Exploration Stage | | | | Resource Potential | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Detailed Geological and Geochemical Study | Geophysical Study | Exploratry Well Drilling | Existing Exploration Plan | Confirmation of Reservoir Existance | Active geothermal manifestations (Hot spring/Fumarole) | Past - (Active) geothermal manifestations (hydrothermally-altered zones) | Volcanic activity and possible heat source | Geological structure suitable for formation of geothermal reservoir: Geological structures | Geological structure suitable for formation of geothermal reservoir: Geophysical exploration data |
| **Karisimbi** | Done | Gravity:None MT/CSMT:Done | KW-01: 3,015m KW-02: Suspended | Presence | None | None | None | Presence of Quaternary volcanoes | NE-SW ternding faults and NW-SE trending faults | Data seems to be not sufficient for detection of structures |
| **Kinigi** | Done | Gravity:None MT/CSMT:Done | None | Presence | None | None | None | | Regional geological structure: the field is located in a NW-SE fracture zone between the Visoke and Sabinyo Volcanoes. | Data seems to be not sufficient for detection of structures |
| **Gisenyi** | Done | Gravity:None MT/CSMT:Done | None | Presence | None | Presence (Na-K-Ca: 181℃) | None | | The field is located in normal fault zone near the eastern boundary of the East African Rift. | Data seems to be not sufficient for detection of structures |
| **Bugarama** | None | Gravity:None MT/CSMT:None | None | Presence | None | Presence (Na-K-Ca: 204℃) | Travertine | Not exist in and around the field. Toshibinda volcano (in DRC) is located 40km NW of Bugarama hot spring | The field is located at graben formed by normal faults. | Data seems to be not sufficient for detection of structures |
| **Other Fields** | at preliminary study stage | | | unknown | None | Presence (Karago, etc.) (in Karago Na-K-Ca: 159℃) | unknown | - | - | - |

* Orange colored cells are positive information for the selction of promising fields

Source: JICA study team

Table 3-2.10 Evaluation of "Exploration Stage" and "Resource Potential "in pre-selected objective fields for detail geoscientific survey

| Field | Exploration Stage/Plan | Geothermal Resource |
|---|---|---|
| Karisimbi | − There is detailed geoscientific data for reconstruction of a geothermal model<br>− There is exploratory well data<br>− There is an exploration plan (additional geoscientific data will be obtained) | − Evidence of recent volcanic activity<br>− Detected geological structures |
| Kinigi | − There is detailed geoscientific data for reconstruction of a geothermal model<br>− There is an exploration plan (additional geoscientific data will be obtained) | − Evidence of recent volcanic activity<br>− Detected geological structures |
| Gisenyi | | − Evidence of recent volcanic activity<br>− Active geothermal manifestations present<br>− Detected geological structures |
| Bugarama | | − Active geothermal manifestations present<br>− Detected geological structures |
| Other fields | − At Preliminary stage | − Karago and Mbonyebyombi were tentatively selected as objective fields for supplemental geological and geochemical study |

Source: JICA study team

In addition to the four (4) major geothermal fields (Karisimbi, Kinigi, Gisenyi and Bugarama), two (2) hot spring sites: Karago and Mbonyebyombi have been selected as objective fields for supplemental geological and geochemical study for the following reasons.

- These two fields are located relatively close to the Virunga volcanic range.
- The temperature of their hot spring water is relatively high compared to that of other spring water in Rwanda.
- Accessibility conditions are good.

The objective fields for detailed geoscientific survey were determined through discussion with our counterparts in Rwanda in the 2nd year of the project.

### 3.2.2. Geological and Geochemical Surveys in Selected Fields

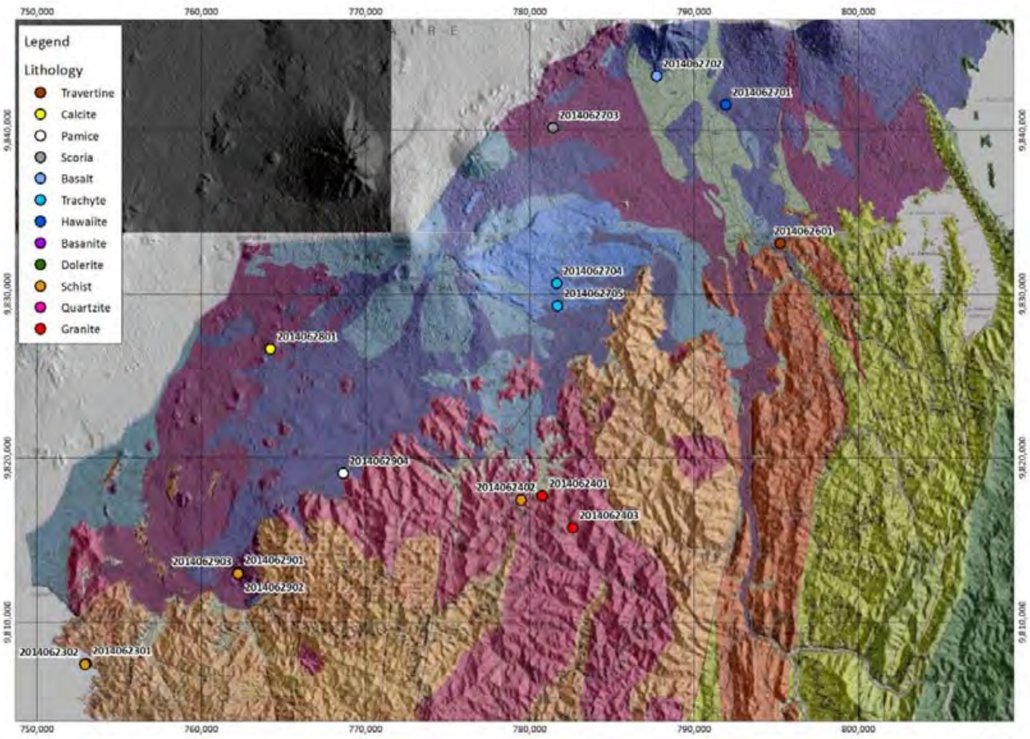
The geological and geochemical surveys in the selected fields were conducted by the JICA JICA study team during the 2nd period of Work in Rwanda. The team was comprised of experts from the JICA study team and some counterparts from EWSA, as shown below. The experts of JICA study team carried out geological and geochemical surveys through the field work, and also collected rock samples and water samples of hot or mineral springs for laboratory analysis. The objectives of these analyses were to identify alteration minerals in rock samples and to clarify the chemical/isotopic composition of water samples to provide additional data for cross-checking.

JICA team: Y. Soeda (geologist), S. Kageyama (geologist) and N. Uchiyama (geochemist)
EWSA: Jean Claude N. (geologist), Assouman M. (geologist) and Gilbert H. (geochemist)

(1) **Geological survey**

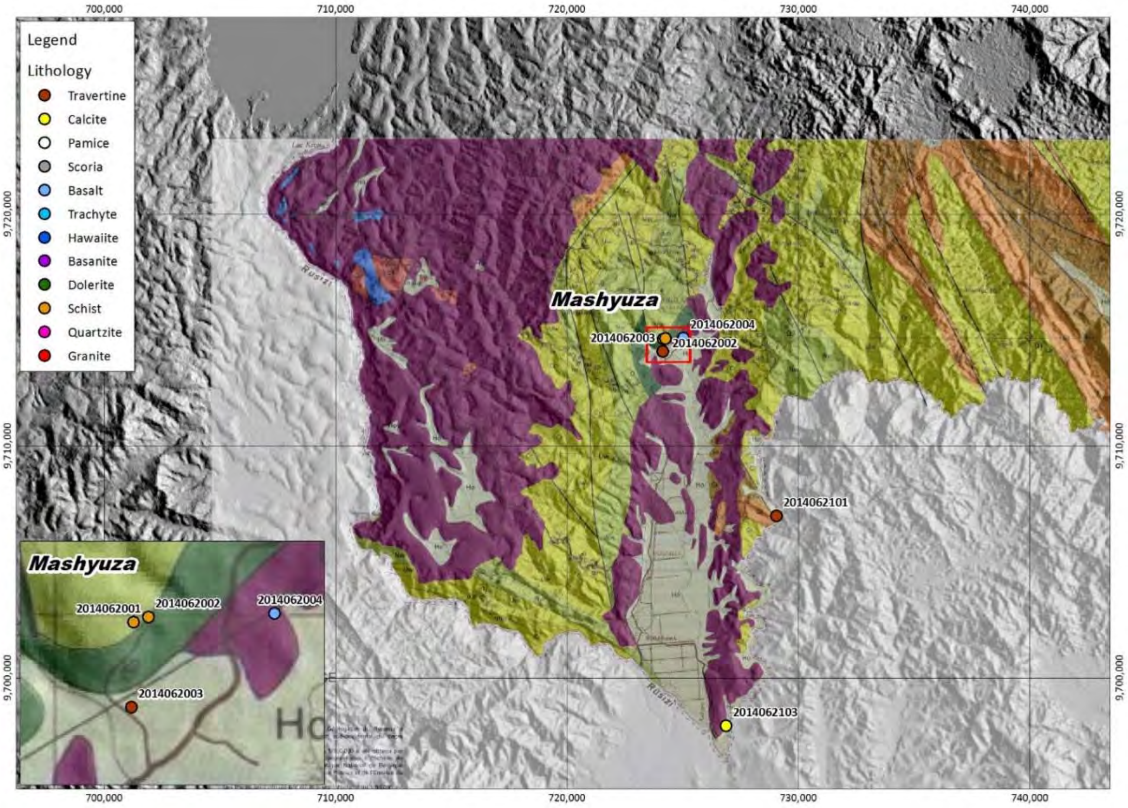
The purpose of geological survey was to obtain geological data to improve the precision of geothermal resource evaluation in selected fields. Field geological surveys were conducted to obtain additional geological data (stratigraphy, hydrothermal alteration, fractures etc.) to cross-check against the existing data. During field work, team members observed thermal manifestations, carried out geological surveys, and also collected rock samples for laboratory analysis.

Petrographic observation, X-ray diffraction analysis and spectral analysis were conducted to identify alteration minerals in the altered rocks sampled during geological survey in the fields. Information concerning alteration minerals is important data in constructing a geothermal conceptual model (extent of geothermal reservoir, fluid characteristics, geological structure which controls flow of geothermal fluids). The provenance of rock samples is shown in Fig 3-2.25 and Fig 3-2.26.




Source: JICA study team

Fig. 3-2.25 Provenance of rock samples from northwestern Rwanda




Source: JICA study team

Fig. 3-2.26 Provenance of rock samples from southwestern Rwanda

1) Laboratory analysis

i) Petrographic observation

The petrographic results are as follows. The petrography sheets are shown in Appendix 2-1.

**062004 (ID: 0620-13-02) ; Mashyuza, Bugarama**

The rock is basalt. The ground mass shows intergranular texture and consists of feldspar, pyroxene, olivine and opaque minerals. The feldspar is 0.2-0.3mm in diameter. The pyroxene, olivine and opaque minerals are under 0.1mm in diameter. Part of the ground mass has been altered to calcite.

**062902 (ID:0625-59-01) ; Iriba**

The rock is basalt. The phenocryst consists of pyroxene, olivine and feldspar. The ground mass shows intergranular texture and consists of feldspar, pyroxene, olivine and opaque minerals. The opaque minerals are under 0.1mm in diameter.

**062702 (ID: 0627-85-01) ; Southern flank of Mt. Sabinyo**

The rock is andesite. The phenocryst consists of feldspar, mica and hornblende. The ground mass consists of fine feldspar, mica, hornblende and opaque minerals.

ii) X-ray diffraction analysis

Table 3-2.11 shows the results of XRD analysis. The detected clay minerals are kaolinite, smectite, illite, mixed-layer mineral and laumontite. The detected carbonate minerals are calcite.

The clay rock of 062001 (ID:0620-07-01) (Mashyuza, Bugarama) is composed of quartz and mica. The clay minerals contained in the clay rock of 062001 (ID:0620-07-01) are composed of kaolinite and illite.

The travertine of 062003 (ID:0620-10-01) (Mashyuza, Bugarama) is composed of calcite. The clay mineral contained in the travertine of 062003 (ID:0620-10-01) is composed of smectite.

The travertine of 062301 (ID:0623-32-01) (Gisenyi) is composed of calcite, quartz and mica. The clay minerals contained in the travertine of 062301 (ID:0623-32-01) are composed of kaolinite, smectite, illite and mixed-layer mineral. Although quartz and mica are detected, it is presumed that these are of sedimentary origin.

The travertine of 062601 (ID:0626-76-01)(Cyabararika) is composed of calcite. The clay minerals contained in the travertine of 062601 (ID:0626-76-01) are composed of kaolinite and smectite.

The travertine of 062101 (ID:0621-17-01) (Bize, Bugarama) is composed of calcite and quartz. The clay minerals contained in the travertine of 062101 (ID:0621-17-01) are composed of illite and kaolinite.

The deposition at the crater wall in Bonde crater (062801 (ID:0628-96-01)) is composed of augite, laumontite, pyrite, prehnite and syngenite. The clay minerals contained in the calcite of 062801 (ID:0628-96-01) are composed of kaolinite and laumontite.

Table 3-2.11 Results of X-ray diffraction analysis

Results of X-ray diffraction analysis

| No. | Location | Sample ID | Bulk analyses (Quartz index) | | | | | | | | | Oriented analyses | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | quartz | mica | augite | kaolinite | laumontite | calcite | pyrite | prehnite | syngenite | illite | kaolinite | smectite | mixed layer | laumontite | feldspar |
| 1 | 062001 | 0620-07-01 | 46.1 | 14.5 | | 3.3 | | | | | | ○ | ○ | | | | |
| 2 | 062003 | 0620-10-01 | | | | | | 15.9 | | | | | | ○ | | | |
| 3 | 062301 | 0623-32-01 | 24.6 | 39.6 | | | | 14.9 | | | | ○ | ○ | ○ | ○ | | |
| 4 | 062601 | 0626-76-01 | | | | | | 16.2 | | | | | ○ | ○ | | | |
| 5 | 062101 | 0621-17-01 | 0.8 | | | | | 16.4 | | | | ○ | ○ | | | | |
| 6 | 062801 | 0628-96-01 | | | 2.5 | | 0.8 | | 1.0 | 1.6 | 2.2 | | ○ | | | ○ | |

Source: JICA study team

iii) K-Ar rock dating

K-Ar rock dating were condicted to crarify age of eruption of volcanic rock to obtain information of volcanic history. Results of dating are as follows.

**062004 (ID: 0620-13-02)；Mashyuza, Bugarama**

The rock is basalt. Obtained K-Ar age is 12.2 ±0.4 Ma.

**062902 (ID:0625-59-01)；Iriba**

The rock is basalt. Obtained K-Ar age is 1.0 ±0.4 Ma.

**062702 (ID: 0627-85-01)；Southern flank of Mt. Sabinyo**

The rock is andesite. Obtained K-Ar age is 0.5 ±0.1 Ma.

**062904 (ID: 0629-107-01)；Ngangare crater**

The rock is basanite. Obtained K-Ar age is 1.8 ±0.1 Ma.

iv) Spectral analysis

Infrared reflectance measurements were conducted to clarify the clay and carbonate mineralogy of rock samples. The reflectance curves of each sample are shown in Appendix 2-2.

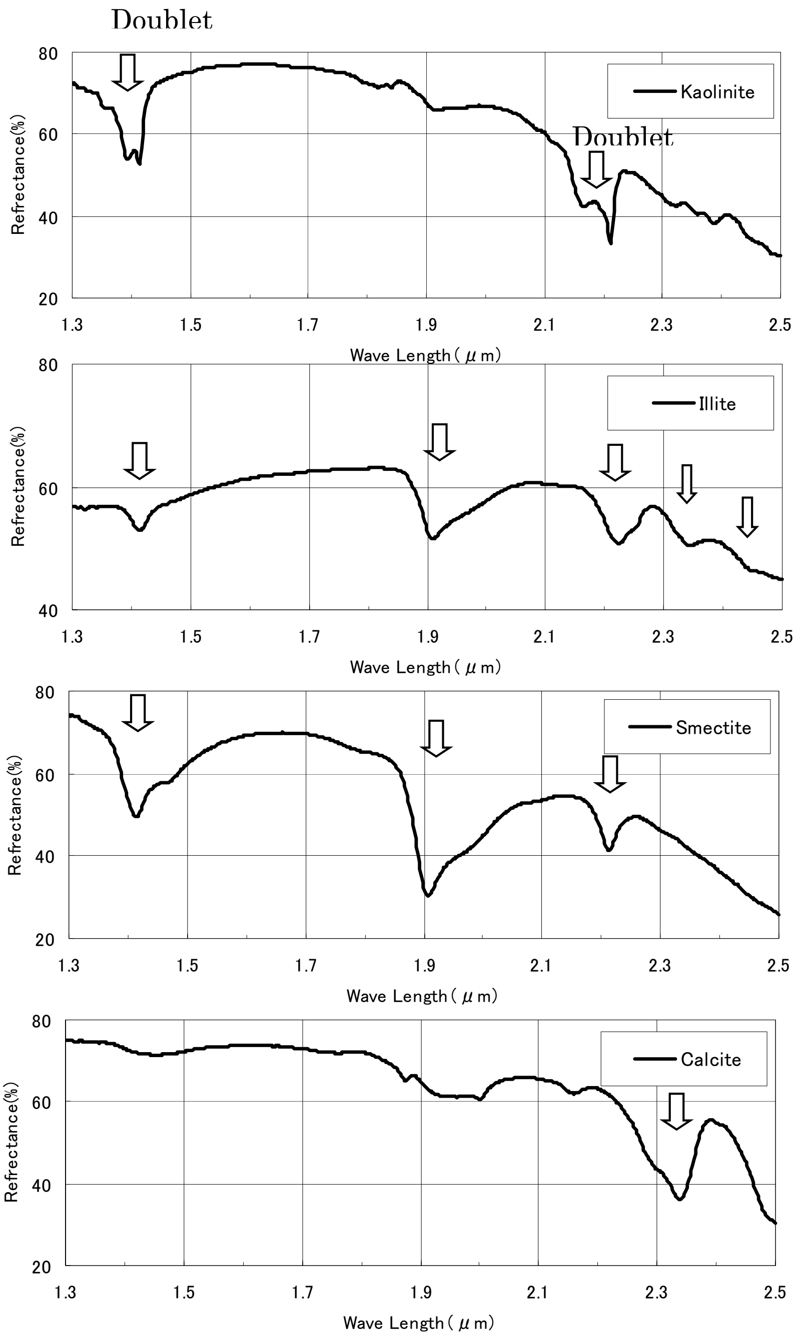
SWIR (shortwave infrared region) reflectance spectroscopy is a very sensitive analytical method for clay mineral groups and carbonate mineral groups. The wave length of SWIR ranges from 1,300 to 2,500nm. Fig. 3-2.27 shows the typical reflectance curves of kaolinite, smectite and sericite (illite) from the USGS spectral library. In SWIR, clay minerals and carbonate minerals have specific absorption features at 1,400nm, 1,900nm and between 2,165 and 2,440nm. These absorption features are caused by water and Al-OH-molecular vibration processes in minerals, allowing spectroscopy to identify types of minerals and chemical components. For example, kaolinite is identified by the absorption feature of doublet or shoulder shape in the region between 2,165 and 2,200nm and the weak absorption at 2,385nm. Illite (sericite) shows broad absorption near 2,200 and 2,345nm, and overlaps with that for smectite which has the shaper absorption at 2,200nm. Calcite shows broad and deep absorption at 2,330nm.

The results of spectral analysis are shown in Table 3-2.12. The detected minerals are kaolinite, sericite (illite), smectite, nontronite, jarosite, muscovite and calcite. Kaolinite is detected in all schist (062001, 062002, 062401, 062402 and 062903) and granite (062401). Illite (sericite) is detected in the schist, granite, travertine (062301), sandstone (062302) and pumice (062902). Smectite and nontronite (iron-rich member of smectite group) are mainly detected in the basalt and travertine collected in the southwestern part of Rwanda (062003 – 062103). All travertine samples show the specific absorption feature of calcite. The results of the mineral identification of 4 samples (062001, 062003, 062301 and 062601) are similar to the results of X-ray diffraction analysis. On the other hand, no minerals are detected from most samples of volcanic rock collected in the southern part of Rwanda.

Table 3-2.12 Spectral measurement results

| Sample | Rock Name | kaolinite | illite (sericite) | smectite | nontronite | jarosite | muscovite | calcite | Remark |
|---|---|---|---|---|---|---|---|---|---|
| 062001 | schist | ○ | ○ | | | | | | Same as 0620-07-01 for X-ray analysis. |
| 062002 | schist | ○ | ○ | | | | | | Strongly kaolinized. |
| 062003 | travertine | | | | ○ | | | ○ | Same as 0620-10-01 for X-ray analysis. |
| 062004 | basalt | | | ○ | | ○ | | | |
| 062101 | travertine | | | ○ | | | | ○ | |
| 062102 | basalt | | | ○ | ○ | | | | |
| 062103 | basalt | | | | ○ | | | | |
| 062301 | travertine | | ○ | ○ | ○ | | | ○ | Same as 0623-32-01 for X-ray analysis. |
| 062302 | sandstone | | ○ | | | ○ | ○ | | Medium to coase grained. |
| 062401 | granite | ○ | ○ | | | | | | |
| 062402 | schist | ○ | | | | | | | With pegmatite. |
| 062403 | granite | | ○ | ○ | | | | | |
| 062601 | travertine | | | | | | | ○ | Same as 0626-76-01 for X-ray analysis. |
| 062701 | hawaiite | | | | | | | | |
| 062702 | basalt | | | | | | | | |
| 062703 | scoria | | | | | | | | |
| 062704 | trachyte | | | | | | | | |
| 062705 | trachyte | | | | | | | | |
| 062801 | basanite | | | | | | | | |
| 062901 | scoria | | | | | | | | |
| 062902 | pamice | | ○ | | | | | | |
| 062903 | schist | ○ | ○ | | | | | | |
| 062904 | pamice | | | | | | | | |

Source: JICA study team




Source: USGS data

Fig. 3-2.27 Spectral Reflectance of Typical Clay Minerals and Calcite

2) Information Extraction in Geothermal Prospects

In geothermal prospects, information extraction has been conducted using Terra/ASTER data with high spatial resolution and high spectral resolution. ALOS/PALSAR data less affected weather conditions were also used in conjunction with the Terra/ASTER data. ASTER (Advanced Spaceborne Thermal Emission and Reflectance Radiometer) is a high-performance optical sensor developed by the Ministry of Economy, Trade and Industry of Japan (METI). ASTER is mounted on the earth observation satellite Terra of the National Aeronautics and Space Administration (NASA). ASTER has 14 observation wavebands in the spectral region from visible to thermal infrared and can acquire information about various phenomena on the Earth's surface (geology, vegetation, atmosphere, oceans, volcanos, etc.) on a local or a regional scale. PALSAR (Phased-Array type L-band Synthetic Aperture Radar) is a kind of SAR mounted on the Japanese earth observation satellite ALOS of Japan Aerospace Exploration Agency (JAXA) and can observe various phenomena on the Earth's surface using L band microwaves (1.27 GHz) transmitted from PALSAR. The specifications of both sensors are shown in Table 3-2.13 and Table 3-2.14.

In this project, ten (10) scenes of Terra/ASTER data and four (4) scenes of ALOS/PALSAR data covering geothermal prospects with well-known hot springs were purchased and were used for detailed processing and analysis to extract information regarding geothermal manifestations. A false color image of Terra/ASTER data in the northwestern part of Rwanda is shown in Fig. 3-2.28 and an ALOS/PALSAR image of the same area are shown in Fig. 3-2.29. A similar pair of images of the southwestern part of the country is shown in Fig. 3-2.30 and Fig. 3-2.31. In addition, ALOS/PRISM image was used for topographic interpretation in Bugarama field where gravity survey was conducted.

Table 3-2.13 Specifications of Terra/ASTER

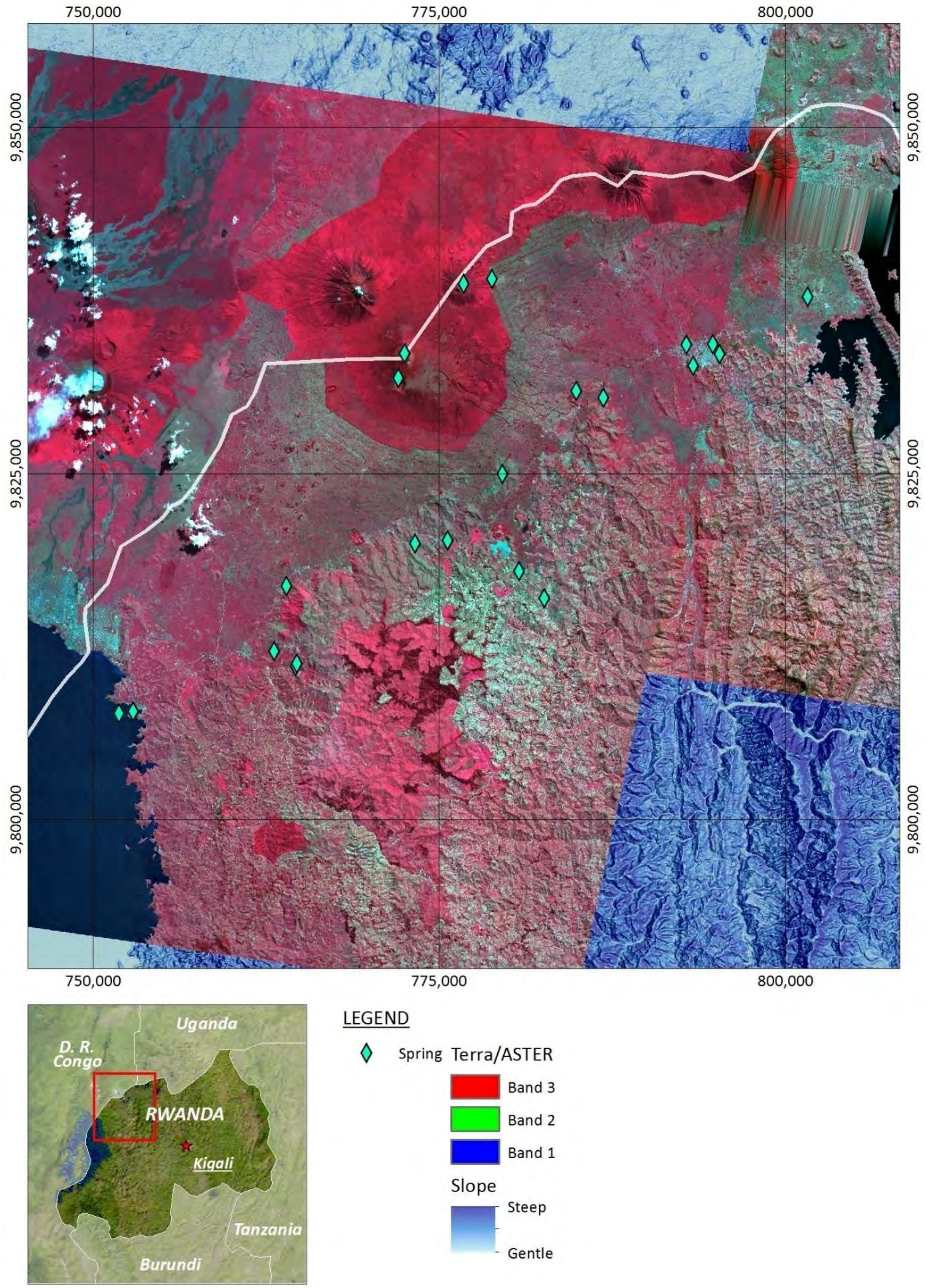
| | |
|---|---|
| Altitude | 705 km |
| Orbit | Sun-Synchronous Descending |
| Repeat Cycle | 16 days |
| Launch | 1999 |
| Type | Optical Sensor (Passive Sensor) |
| Sensor | ASTER(Advanced Spaceborne Thermal Emission and Reflection Radiometer）<br>Visible – Near Infrared Radiometer (VNIR)<br>Ground Resolution: 15m<br>Band 1: 0.52 – 0.60 micrometer<br>Band 2: 0.63 – 0.69 micrometer<br>Band 3: 0.78 – 0.86 micrometer<br>Short Wave Infrared Radiometer (SWIR)<br>Ground Resolution: 30m<br>Band 4: 1.600 – 1.700 micrometer<br>Band 5: 2.145 – 2.185 micrometer<br>Band 6: 2.185 – 2.225 micrometer<br>Band 7: 2.235 – 2.285 micrometer<br>Band 8: 2.295 – 2.365 micrometer<br>Band 9: 2.360 – 2.430 micrometer<br>Thermal Infrared Radiometer (TIR)<br>Ground Resolution: 90m<br>Band 10: 8,125 – 8.475 micrometer<br>Band 11: 8.475 – 8.825 micrometer<br>Band 12: 8.925 – 9.275 micrometer<br>Band 13: 10.25 – 10.95 micrometer<br>Band 14: 10.95 – 11.65 micrometer |

Source: JICA study team

Table 3-2.14 Specifications of ALOS/PALSAR

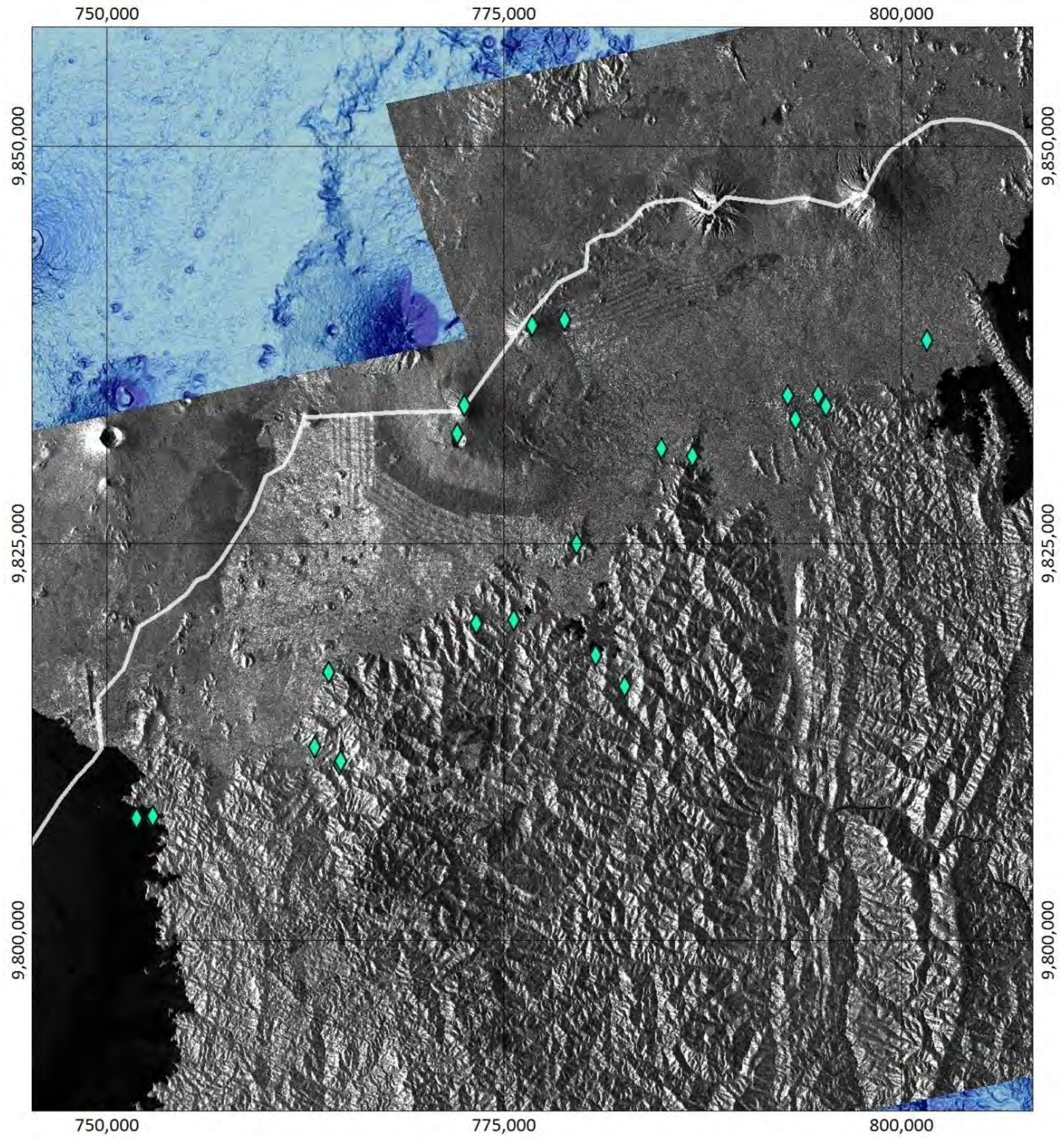
| | |
|---|---|
| Altitude | 626 km |
| Orbit | Sun-Synchronous Descending |
| Repeat Cycle | 46 days |
| Launch | 2006 |
| Type | Radar Sensor (Active Sensor) |
| Sensor | PALSAR<br>Ground Resolution: 7 m to 44 m (High Resolution Mode)<br>100 m (Wide Swath Mode)<br>L band Synthetic Aperture Radar (SAR): 1.27 GHz |

Source: JICA study team




Source: JICA study team

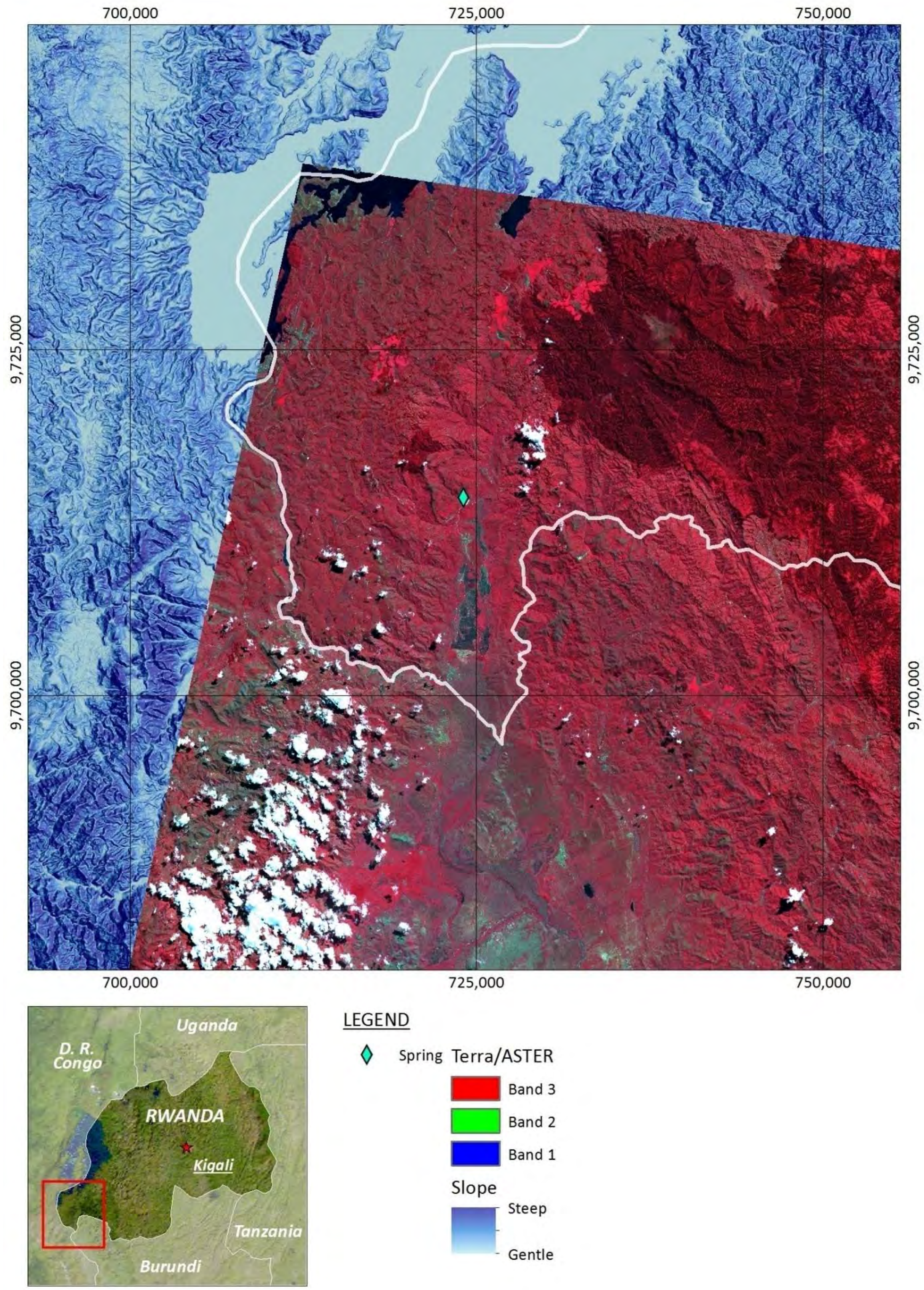
Fig. 3-2.28 Terra/ASTER false color image of the northwestern part of Rwanda





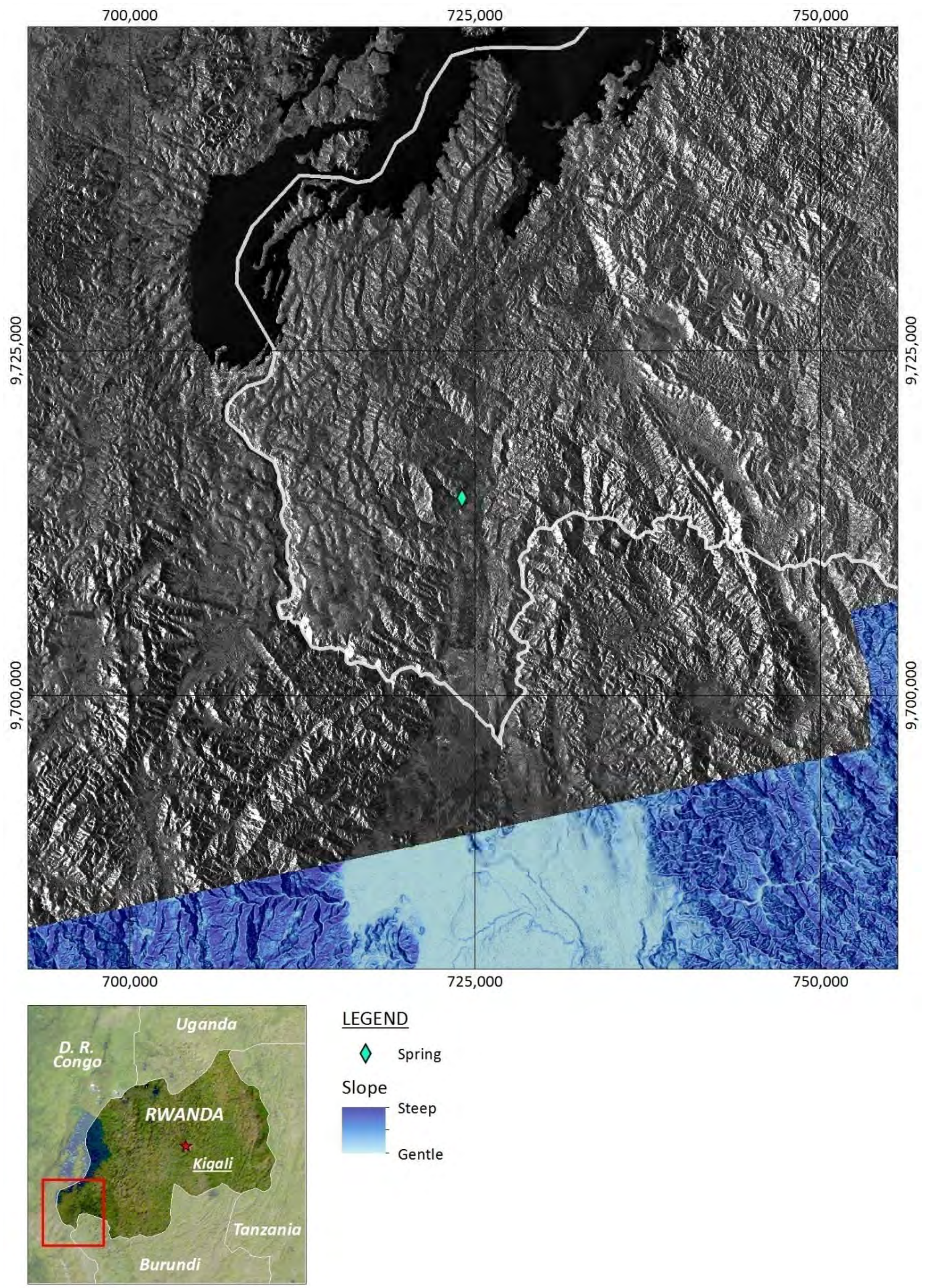
Source: JICA study team

Fig. 3-2.29 PALSAR image of the northwestern part of Rwanda




Source: JICA study team

Fig. 3-2.30 Terra/ASTER false color image of the southwestern part of Rwanda




Source: JICA study team

Fig. 3-2.31 PALSAR image of the southwestern part of Rwanda

3) Results of geological survey

Fig. 3-2.32 shows the result of image interpretation for the northwestern part of Rwanda. This area contains the Cenozoic Virunga volcanic complex, and its stratovolcanoes can be observed as ring-like and high topographic prominences with gently foothills. In the volcanic complex, many crater cones and circular structures related to volcanic activities have been detected from the satellite images and results of terrain analysis. The depression extending from the northern to southwestern part of this area corresponds to the Western Rift (Albertine Rift) of the East African Rift System. The boundaries between the volcanic complex, the Western Rift and the Proterozoic basement complex with tough and resistant terrains are very clear, and the well-known springs are located along these boundaries or lineaments extending in a N-S or NW-SE direction in the basement complex.

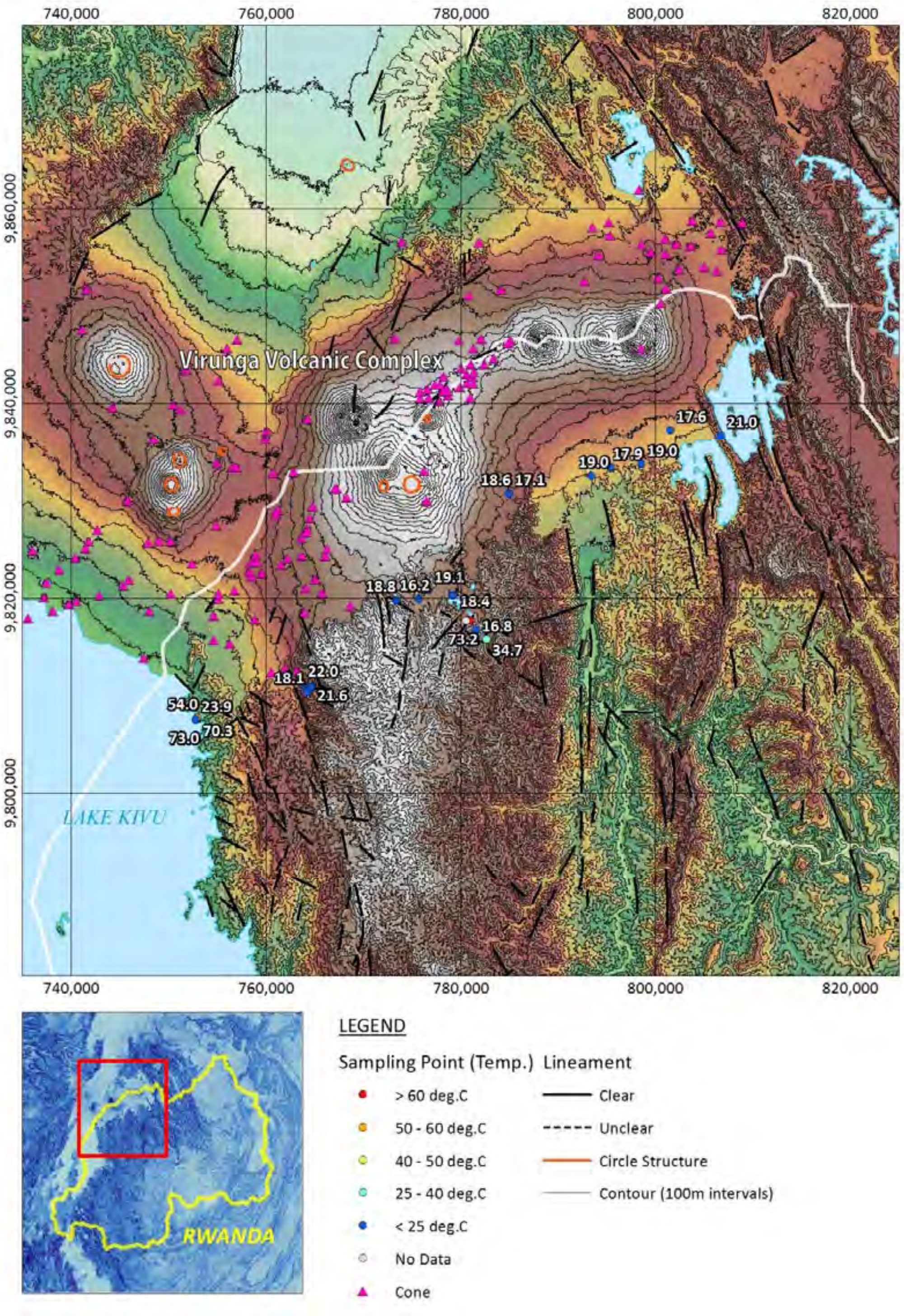
i) Karisimbi field

The Karisimbi field is located in the Nyabihu and Rubavu districts of the Western Province in northwestern part of Rwanda. The northern part of the Karisimbi field is situated in the Virunga Volcano Range (VVR) where there are some late quaternary volcanoes, such as Nyiragongo, Nyamuragira, Karisimbi, Bisoke, Mikeno, Sabinyo, Gahinga and Muhabura. In the southern part of the field, the Butare Horst is composed of Proterozoic mylonitised granitic and phyllitic complexes.

Some NE-SW and NW-SE trending faults were detected by KenGen (2010) and EWSA (2013). In the Butare Horst in the southern part of Karisimbi field, the geological structure is characterized by the presence of faults and fissures trending N-S. A NE-SW trending fault zone (called Accommodation Zone) is inferred between the Proterozoic basement in the Butare Horst and the Quaternary volcanic belt (BGR, 2009).

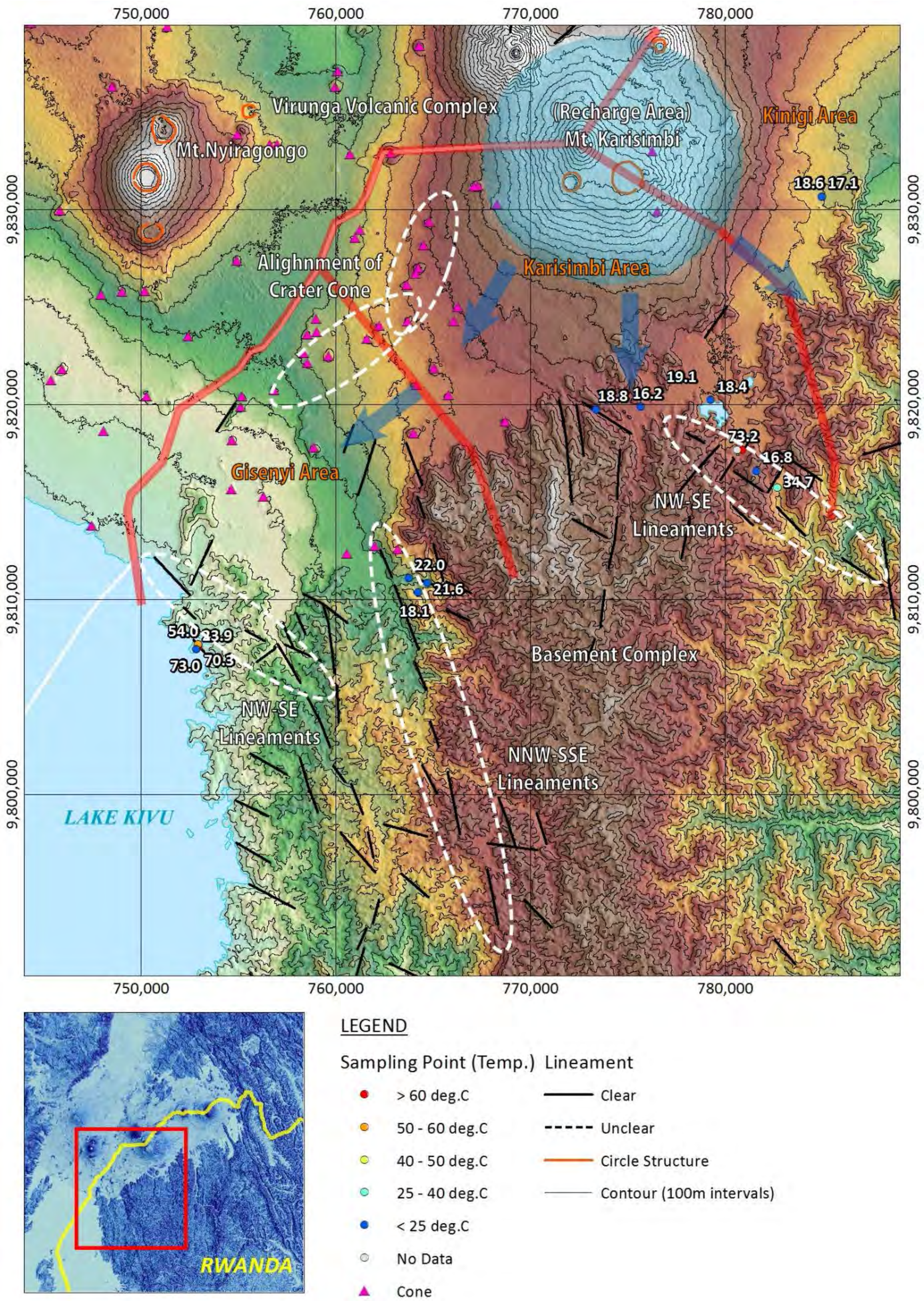
Fig. 3-2.33 shows the result of image interpretation for the Karisimbi and Gisenyi field. The stratovolcano of Mt. Karisimbi is on the northern margin of Karisimbi field. It is considered that the high topographic prominence of Mt. Karisimbi with relatively heavy precipitation could function as a good recharge area, and that groundwater infiltrated at the volcanic body flows toward the southern foot of Mt. Karisimbi through lavas and pyroclastic rocks with high permeability. Though many crater cones are observed at the western foot of the volcano, there are few cones at the eastern and southern foot. In addition, portions of the cones at the western foot are directionally aligned extending in a NNE-SSW to NE-SW direction, and it is suggested that these alignments correspond to some kind of fracture zone below ground. Many cold springs are located along the boundary extending in a NE-SW direction between the volcano complex and the basement complex, but the hot springs in Karago (73.2$^{o}$C) gush out along lineaments extending in a NW-SE direction in the basement complex.

No geothermal manifestations such as fumaroles, hot springs or altered ground have been recognized in the volcanic area in Karisimbi. In the Butare Horst, hot springs occur at Karago. The measured maximum temperature of the hot springs is 73.2°C. Hot springs with a maximum measured temperature of 34.7°C occur in Mbonyebyombi, located 2.6 km southeast of Karago hot springs. These hot spring areas are composed of granite. There is no obvious hydrothermal alteration or hydrothermal deposit in either Karago or Mbonyebyombi springs. Photo 3-2.13 shows scenes of field observation work.




Source: JICA study team

Fig. 3-2.32 Result of regional image interpretation for the northwestern part of Rwanda




Source: JICA study team

Fig. 3-2.33 Result of regional image interpretation for the Karisimbi and Gisenyi field

| | | |
|---|---|---|
| <br>Karago hot spring | <br>The outcrop of granite near Karago hot spring. | <br>Mbonyebyombi hot spring |
| <br>The outcrop of granite near Mbonyebyombi hot spring. | <br>Cold spring in Iriba | <br>Mica schist and Pegmatite (Gw) along Bikore river, Iriba field |
| <br>Bisate cone | <br>Bisate cone consists of scoria | <br>Trachyte outcrops at the eastern foot of Branca (Mt. Karisimbi) |
| <br>Trachyte at the eastern foot of Branca (Mt. Karisimbi) | <br>Crater wall of Bonde crater | <br>Cold spring in Chamabuye |

Photo 3-2.13 Field observation in Karisimbi field

ii) Kinigi field

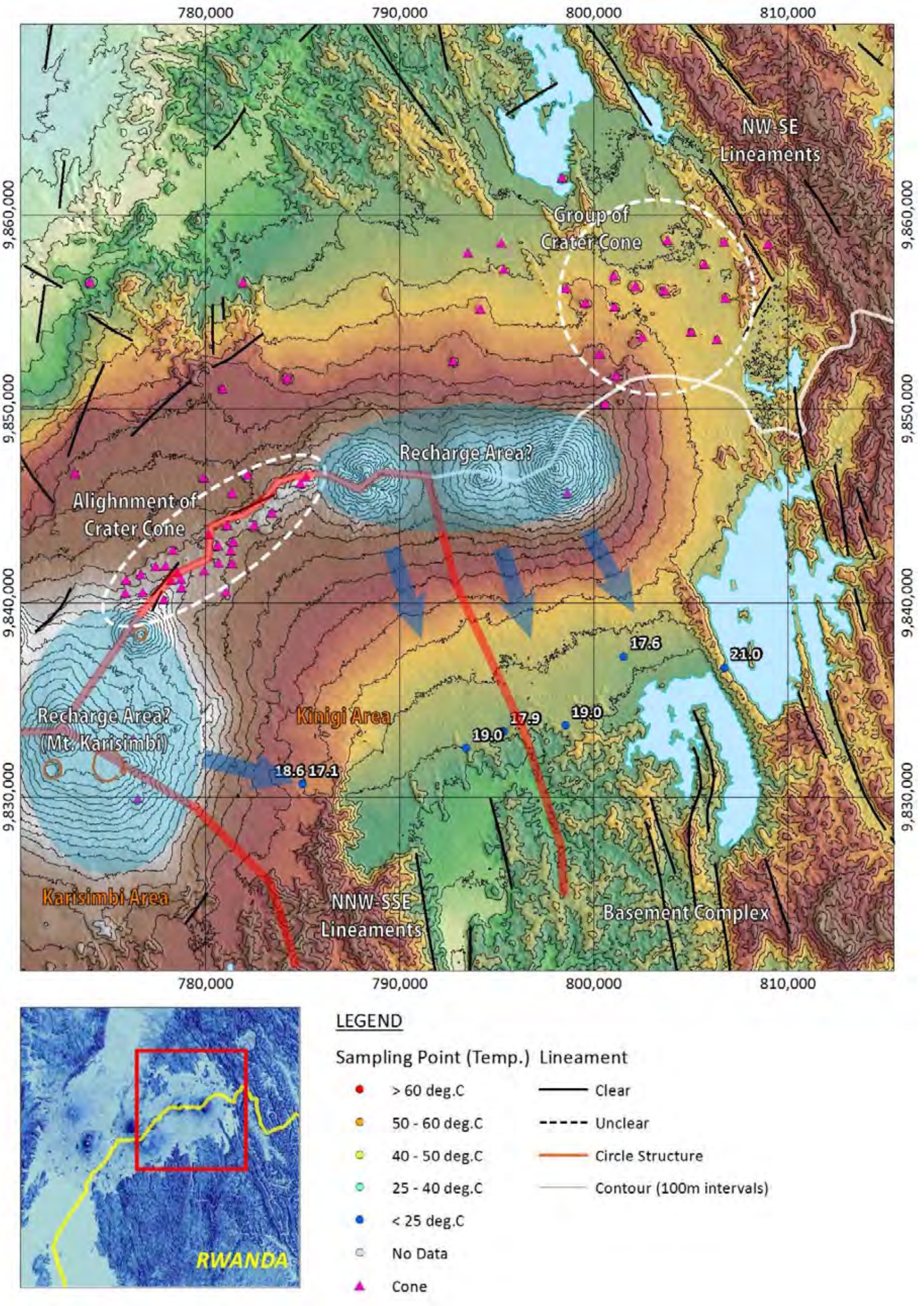
The Kinigi field is located in the northwestern part of Rwanda. The northern part of the Kinigi field is situated in Virunga Volcano Range (VVR) where there are some late Quaternary volcanoes. The southern part of the field is in the Butare Horst composed of Proterozoic mylonitised granitic and phyllitic complexes.

The surface geology of the northern part of Kinigi field is characterized by lavas derived from Sabinyo volcano and only minor flows from Visoke. The area also contains lahars and debris flows (boulder deposits) evidently mostly derived from Sabinyo but these are thin.

Fig. 3-2.34 shows the result of image interpretation for the Kinigi and Buseruka field. The stratovolcanoes of Mt. Karisimbi, Mt. Visoke and Mt. Sabinyo are on the northern margin of the Kinigi area. These volcanic bodies also could serve as a good recharge area, with infiltering water flowing toward the western and southern foot of these mountains through lavas and pyroclastic rocks constituting a suitable aquifer. Some cold springs (17.1 to 19.0$^{o}$C) are located on the boundary between the volcano complex and the basement complex. Many crater cones extending in an ENE-WSW direction are observed on the ridge between Mt. Visoke and Mt. Sabinyo, and this alignment suggests the presence of a fracture zone below ground.

In the Butare Horst area in the southern part of Kinigi field, the geological structure is characterized by the presence of faults and fissures trending N-S to NNW-SSW.

No geothermal manifestations such as fumaroles, hot springs, or altered ground have been recognized in the volcanic area in Kinigi. Cold springs such as Rubindi, Mubona, Cyabararika, etc. occur at the topographic boundary of the volcanic area in the north and in the Butare horst in the south, where the Accommodation Zone is found. The cold spring water contains $CO_2$ gas. Travertines consisting of calcite are developed around the springs. Scenes of field observation are shown in Photo 3-2.14.




Source: JICA study team

Fig. 3-2.34 Result of regional image interpretation for the Kinigi field

| | | |
|---|---|---|
| <br>Cold spring with gas bubbling at Mubona | <br>Volcanic rocks (basanite) at Mubona | <br>Travertine developed at the surface of volcanic rocks in Mubona |
| <br>Cold spring with gas bubbling in Cyabararika<br>Springs water discharges from volcanic rocks | <br>Travertine developed at the surface of volcanic rocks in Cyabararika | <br>Cold spring with gas bubbling at Rubindi<br>Discharge point is located at the margin of lava flow |
| <br>Lava plateau at the southern foot of Mt. Sabinyo. | <br>Volcanic rock (andesite) at the southern foot of Mt. Sabinyo. | <br>Debris flow deposit is observed at the garry wall at the foot of Mt. Sabinyo. These deposits form a gently sloping surface at the foot of the mountain.<br>(It is shown as Hov in the geological map) |

Photo 3-2.14 Field observation in Kinigi field

iii) Gisenyi Field

The Gisenyi field is located in the northwestern part of Rwanda. The northern part of the Gisenyi field is situated in the Virunga Volcano Range (VVR) where there are some late Quaternary volcanoes. The southern part of the field is in the Butare Horst composed of Proterozoic mylonitised granitic and phyllitic complexes.

Gisenyi field is located in a normal fault zone related to the Great Rift Valley. Geological structures in Gisenyi are characterized by two major faults, the "recent" Border Fault trending north to south and the Accommodation Zone (BGR, 2009).

Gisenyi field is located in flat terrain in the relatively narrow region between the stratovolcanoes or feet of Mt. Karisimbi and Mt. Nyiragongo in D. R. Congo and the shore of Lake Kivu (Fig. 3-2.33). Some crater cones are observed in this area, but no alignment of crater cones has been found. On the other hand, lineaments extending in a NE-SW direction can be extracted from the topographic features, and this trend corresponds to the direction of aligned crater cones in the Karisimbi field. Cold springs in Iriba (18.1 to 22.0°C.) are located along lineaments extending in a NNW-SSE direction in the boundary between the Cenozoic volcanics and the basement, and some crater cones have been detected near the lineaments. Hot springs in Gisenyi (70.3 to 73.0°C.) are located on the shore of Lake Kivu, and lineaments extending in a NW-SE direction are observed around the hot springs.

Some hot springs and sinter deposits are distributed on the coastline of Lake Kivu (Gisenyi hot spring). The measured maximum temperature of the hot springs is 73.0°C. Cold springs occur at Iriba, where late Quaternary volcanic cones are located. Scenes of field observation are shown in Photo 3-2.15.

| | | |
|---|---|---|
|  Gisenyi hot spring. Travertine is observed around the spring. |  Butare Formation (Gw): metamorphic sand stone and mud stone outcrops near Gisenyi hot spring. |  Concretion of gravel at Kivu lakeside near Gisenyi hot spring |
|  Boulder of dolerite in Iriba field |  Iriba Cold spring |  Mica schist and Pegmatite (Gw) outcrop on the Bikore river floor in Iriba |
|  Contact (unconformity) of volcanic products (Hawaiite) and mica schist (Gw) in Iriba. Discussion between Counterparts and JICA team. |  Bisate cone. |  Bisate cone consists of scoria. |
|  Trachyte outcrops at the eastern foot of Branca (Mt. Karisimbi) |  Trachyte outcrops at the eastern foot of Branca (Mt. Karisimbi) |  Kirerema cone consists of scoria |

| | | |
|---|---|---|
| <br>Bonde crater | <br>Crater wall of Bonde crater | <br>Syngenite observed in the wall of Bonde crater |
| <br>Gikobe crater, located in 3km northwest of Iriba cold spring | <br>Gikobe crater | <br>Sequence of volcanic products showing a series of eruptions, observed in Gikobe crater. |
| <br>Scoria at the top of Gikobe crater cone. | <br>Mica schist and quarzite (Gw) outcrops inside crater | <br>Mica schist and quarzite (Gw) outcrops inside crater |
| <br>Ngangare crater | <br>Scoria at the top of Ngangare crater | <br>Volcanic rocks at the top of Ngangare crater |

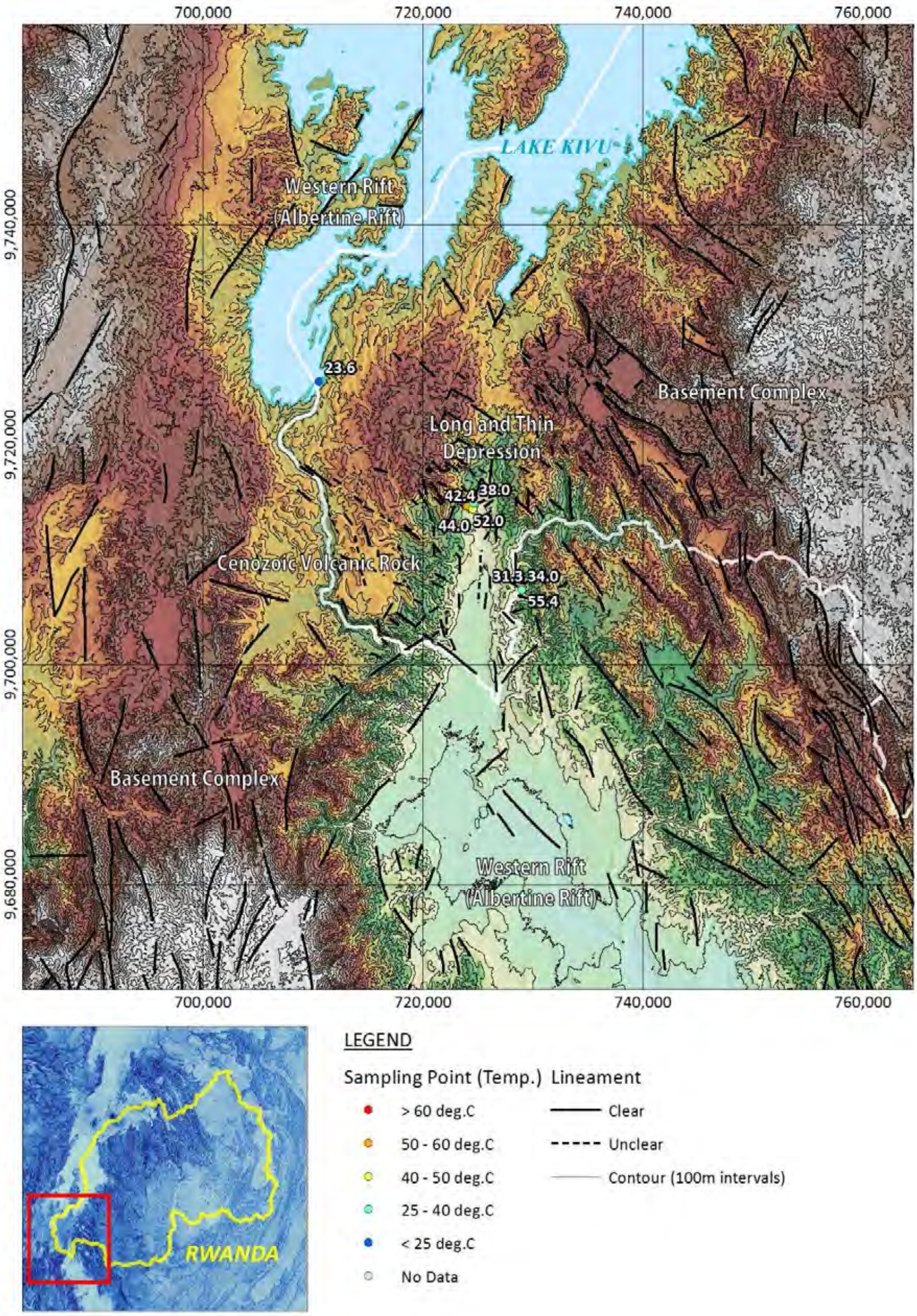
Photo 3-2.15 Field observation in Gisenyi field

iv) Bugarama Field

Fig. 3-2.35 shows a result of image interpretation for the southwestern part of Rwanda. This area consists of a Proterozoic basement complex and Cenozoic volcanic rock, but no stratovolcanos and no crater cones have been observed, unlike in the northwestern part of Rwanda. The depression with continuous lineaments in the northern part of this area (Lake Kivu) corresponds to the Western Rift of EARS. In addition, a long, thin depression can be extracted in the central part, and the shape of this depression broadens as it extends south from the central area.

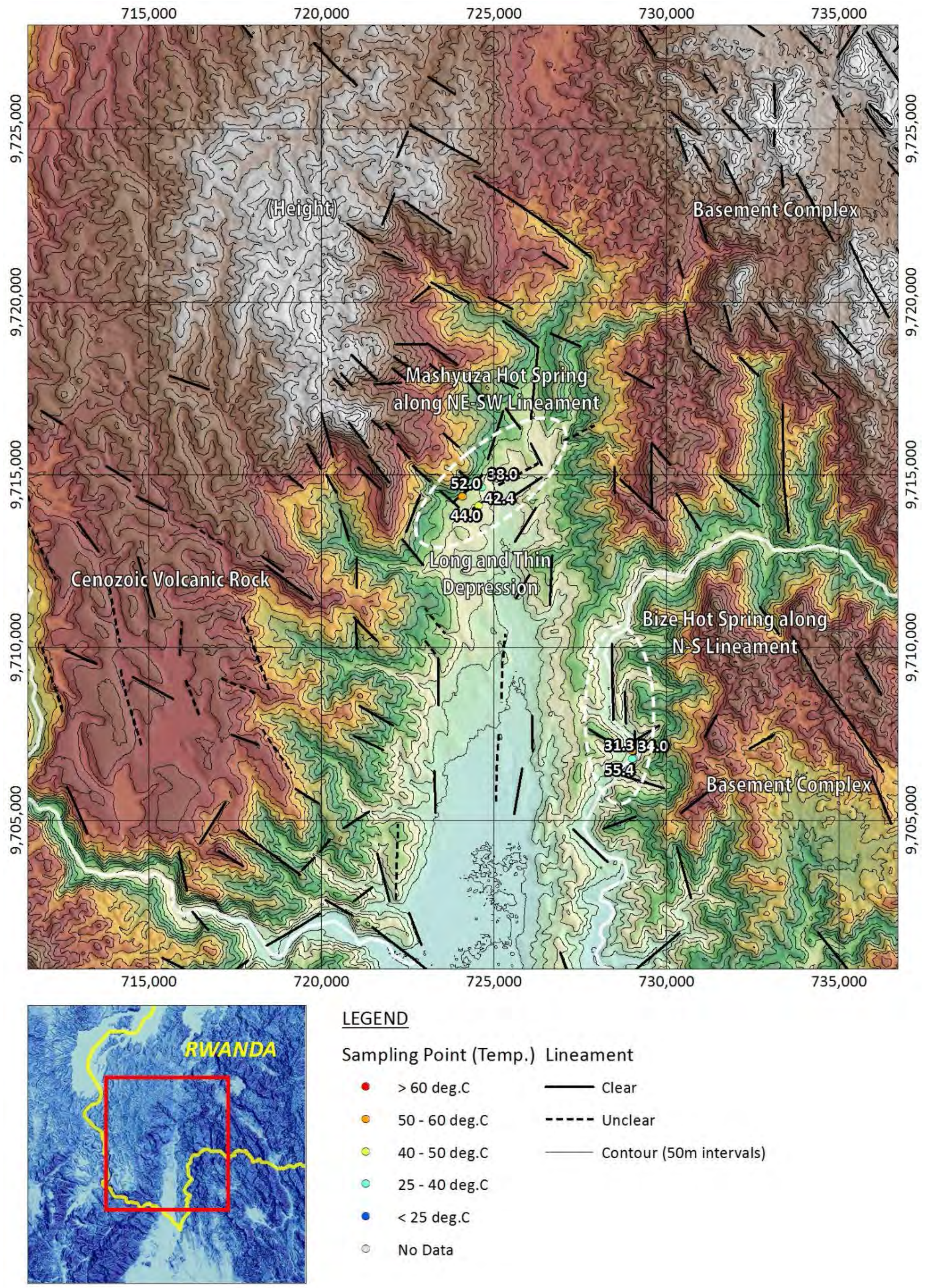
Some hot springs, sinter deposits and hydrothermal alterations occur in the field. Major thermal manifestations are recognized at the western margin of the basin, where the hot springs form a large pool on top of the travertine deposit. The measured maximum temperature of the hot springs in Mashyuza is 52.0°C. Sinter deposits are developed around the hot springs, and hydrothermal alterations can be observed near the hot springs. Thermal manifestations in Bize can be observed 8 km southeast of Mashyuza hot springs. Hot springs and sinter deposits are observed in the valley floor of the Ruhwa river. The maximum temperature of the hot springs in Bize is measured as 55.4°C.

Fig. 3-2.36 shows a result of image interpretation for the Bugarama area. A long, thin depression extends from north to south through the central part of this area, becoming narrower toward to the north. Lineaments extending in a N-S direction run parallel with the depression dominating this area, but NW-SE and NE-SW trending lineaments are also observed in places. The hot springs in Mashyuza (38.0 to 52.0°C) are distributed along the NE-SW lineament, and the hot springs in Bize (34.0 to 55.4°C) are located along the N-S trending lineament. In the Mashyuza field, the highest elevation is located northwest of the hot springs, and this height could become a recharge area for the local groundwater flow system in this area (Fig. 3-2.37). In addition, the NW-SE lineament distributed between those heights and these fractures could function as a migration pathway for ground water. Scenes of field observation are shown in Photo 3-2.16.



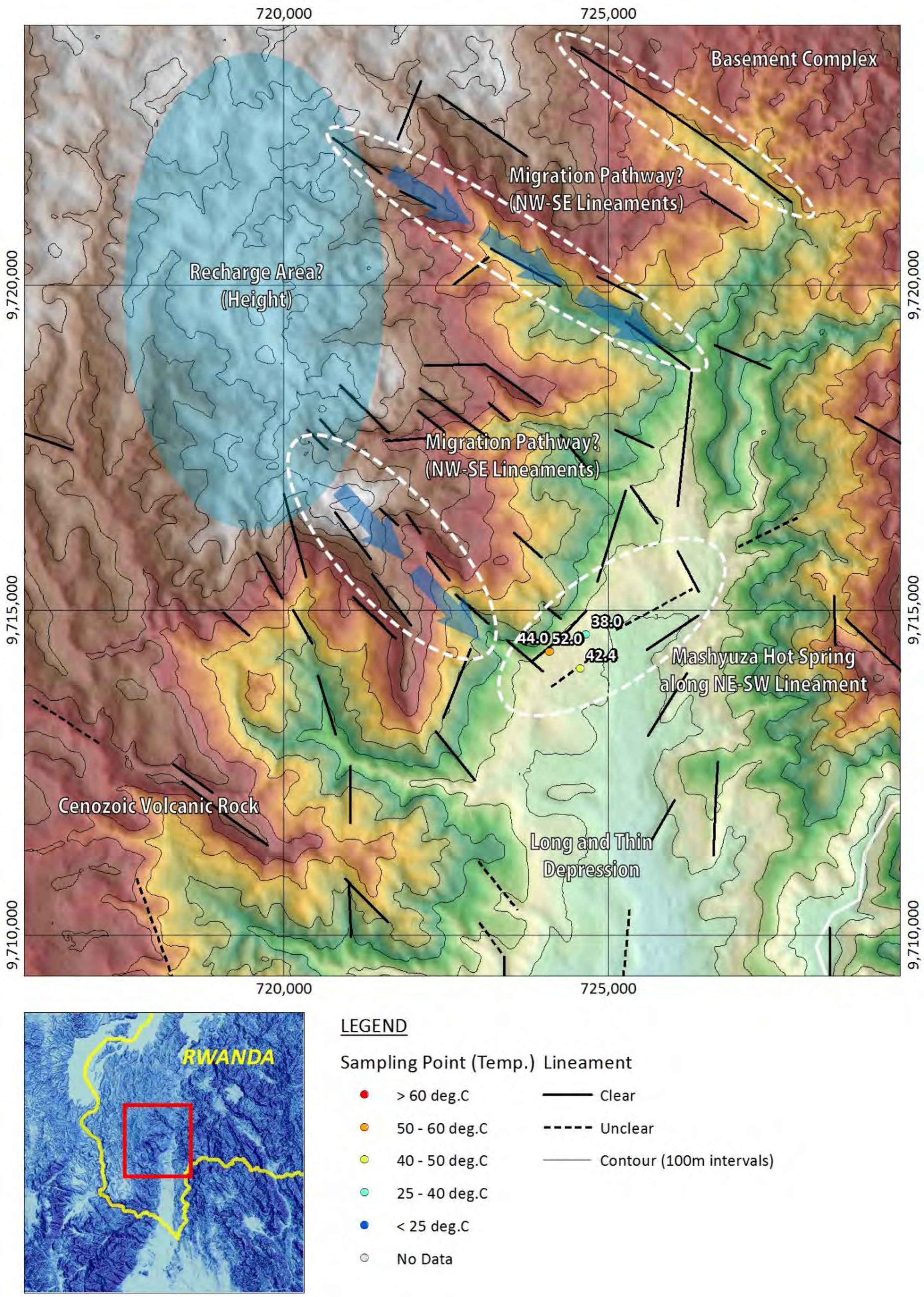

Source: JICA study team

Fig. 3-2.35 Result of regional image interpretation for the southwestern part of Rwanda




Source: JICA study team

Fig. 3-2.36 Result of regional image interpretation for the Bugarama field




Source: JICA study team

Fig. 3-2.37 Result of regional image interpretation for Mashyuza hot springs

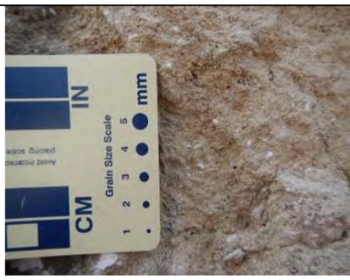
| | | |
|---|---|---|
| <br>Mashyuza hot spring which discharges at the terrain boundary between mountains and lowland. | <br>Outcrop of a fault in the Nyungwe Formation (Nw) near Mashyuza hot spring | <br>Nyungwe Formation (Nw) altered to kaolinite |
| <br>Thick travertine deposit (calcite) downstream from Mashyuza hot spring | <br>Fossils of shells contained in the travertine | <br>Bize hot spring discharges on the right bank of Ruhwa river which is the border with Burundi. There are also hot springs on the Burundi side. |
| <br>Travertine observed near Bize hot spring. | <br>Basalt (Tertiary volcanic rock) is widely distributed in the Bugarama field. | <br>Nyungwe Formation (Nw) which is altered and fractured. |

Photo 3-2.16 Field observation in Bugarama field

(2) **Geochemical Survey**

We took 31 water samples (hot spring water and surface water like lake water) during the reconnaissance survey (Table 3-2.15). Among them, 21 samples were analyzed in Japan (Table 3-2.16). Detailed geochemical analysis results are shown below for each area: Karisimbi, Kinigi, Gisenyi and Bugarama.

Table 3-2.15 Reconnaissance survey water sample list

| Location No. | date | place | air | hot water | pH | | EC | Longitude | Latitude | Elevation |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | °C | °C | - | °C | mS/m | degree(E) | degree(N) | m |
| Ma1 | 20-Jun | Mashyuza | 27.0 | 44.0 | 6.3 | (53) | 200 | -2.58266 | 29.01562 | 1,193 |
| Ma2 | 20-Jun | Mashyuza | 27.0 | 52.0 | 6.2 | (51) | 220 | -2.58274 | 29.01551 | 1,197 |
| Ma3 | 20-Jun | Mashyuza | 27.0 | 42.4 | 6.5 | (42) | 220 | -2.58506 | 29.01984 | 1,143 |
| Ma4 | 20-Jun | Mashyuza | 27.0 | 38.0 | 8.4 | (38) | 220 | -2.58032 | 29.02058 | 1,153 |
| Bi1 | 21-Jun | Bize | 27.2 | 55.4 | 6.6 | (53) | 290 | -2.64922 | 29.05995 | 1,051 |
| Bi2 | 21-Jun | Bize | 27.2 | 31.3 | - | - | - | -2.65120 | 29.06024 | 1,046 |
| Bi3 | 21-Jun | Bize | 27.2 | 34.0 | 7.0 | (35) | 230 | -2.65133 | 29.05991 | 1,040 |
| Ki1 | 21-Jun | Lake Kivu -S | 23.7 | 23.6 | 9.2 | (24) | 123 | -2.47986 | 28.89402 | 1,457 |
| Gi1 | 23-Jun | Gisenyi | 22.0 | 73.0 | 7.0 | (32) | 270 | -1.73990 | 29.27396 | 1,463 |
| Gi2 | 23-Jun | Gisenyi | 22.0 | 70.3 | 7.2 | (36) | 270 | -1.73899 | 29.27367 | 1,467 |
| Gi3 | 23-Jun | Gisenyi | 22.0 | 54.0 | - | - | - | -1.73877 | 29.27360 | 1,463 |
| Ki2 | 23-Jun | Lake Kivu -N | 22.0 | 23.9 | 9.1 | (25) | 127 | -1.74091 | 29.27292 | 1,462 |
| Kalw1 | 24-Jun | Karago | 12.9 | - | - | - | 14 | -1.64793 | 29.52383 | 2,273 |
| Ka1 | 24-Jun | Karago | 12.9 | 73.2 | 7.8 | (23) | 138 | -1.64810 | 29.52459 | 2,278 |
| Karw | 24-Jun | Karago | 12.9 | - | - | - | - | -1.64825 | 29.52221 | 2,293 |
| Mb1 | 24-Jun | Mbonyebyombi | 15.5 | 34.7 | 6.9 | (32) | 103 | -1.66558 | 29.54093 | 2,217 |
| Mb2 | 24-Jun | Mbonyebyombi | 15.5 | 16.8 | 6.8 | (18) | 19 | -1.65787 | 29.53121 | 2,475 |
| Kalake | 24-Jun | Karago Lake | - | 18.4 | 7.7 | (20) | 20 | -1.62504 | 29.51017 | 2,302 |
| Nt1 | 25-Jun | Nteranya | 19.0 | 18.1 | 7.0 | (19) | 51 | -1.71450 | 29.37526 | 2,043 |
| Ir1 | 25-Jun | Iriba | 19.0 | 21.6 | 6.4 | (21) | 260 | -1.70997 | 29.37955 | 2,098 |
| Ir2 | 25-Jun | Iriba | 19.0 | 22.0 | 7.9 | (23) | 103 | -1.70787 | 29.37092 | 1,961 |
| Ru1 | 25-Jun | Rubindi | 24.4 | 18.6 | 6.3 | (20) | 250 | -1.53061 | 29.56135 | 2,110 |
| Ru2 | 25-Jun | Rubindi | 24.4 | 17.1 | 7.0 | (18) | 31 | -1.53061 | 29.56135 | 2,110 |
| Mu1 | 25-Jun | Mubona | 23.4 | 19.0 | 6.4 | (20) | 310 | -1.51399 | 29.63706 | 1,808 |
| Cy1 | 26-Jun | Cyabararika | 21.6 | 17.9 | 6.3 | (19) | 300 | -1.50611 | 29.65443 | 1,809 |
| Mt1 | 26-Jun | Mata | 21.6 | 19.0 | 6.9 | (20) | 29 | -1.50327 | 29.68294 | 1,854 |
| Bu1 | 26-Jun | Buseruka | 24.5 | 17.6 | 6.3 | (19) | 320 | -1.47121 | 29.70993 | 1,821 |
| Bl1 | 26-Jun | Lake Bulera | 25.0 | 21.0 | 8.0 | (22) | 13 | -1.47640 | 29.75660 | 1,861 |
| Kg1 | 29-Jun | Kagohe | 19.0 | 18.8 | 6.9 | (20) | 53 | -1.62954 | 29.45733 | 2,376 |
| Cm1 | 29-Jun | Cyamabuye | 21.5 | 16.2 | 6.7 | (18) | 53 | -1.62817 | 29.47783 | 2,362 |
| Ny1 | 29-Jun | Nyirakigugu lake | 18.8 | 19.1 | 8.7 | (19) | 25 | -1.62065 | 29.48685 | 2,339 |

Source: JICA study team

### Table 3-2.16 Chemical analysis results for sampled water

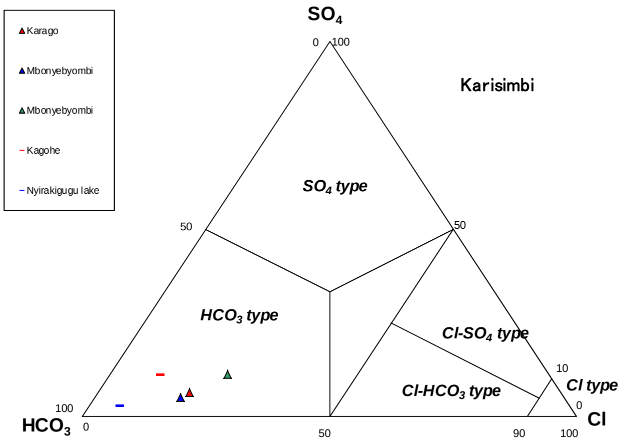
| Sample name | Date | Chemical component | | | | | | | | | | | | | | Isotope | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | pH | EC | Na | K | Li | $NH_4$ | Ca | Mg | Cl | $SO_4$ | $HCO_3$ | F | B | T-$SiO_2$ | δD ($H_2O$) | $\delta^{18}O$ ($H_2O$) |
| | | -(℃) | mS/m | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | ‰ | ‰ |
| Ma1 | 2014/6/20 | 7.01 (25) | 196 | 296 | 47.0 | 1.10 | 0.03 | 75.8 | 55.3 | 127 | 43.4 | 1110 | 1.61 | 2.21 | 41 | - | - |
| Ma2 | 2014/6/20 | 6.83 (26) | 201 | 323 | 49.1 | 1.08 | 0.22 | 76.9 | 55.6 | 126 | 49.2 | 1100 | 1.68 | 1.18 | 42 | -5 | -2.4 |
| Bi1 | 2014/6/21 | 6.99 (26) | 252 | 346 | 111 | 1.38 | 0.56 | 82.6 | 79.5 | 150 | 106 | 1400 | 2.85 | 2.06 | 50 | -5 | -2.3 |
| Ki1 | 2014/6/21 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 25 | 3.8 |
| Gi1 | 2014/6/23 | 7.20 (26) | 243 | 555 | 46.0 | 0.46 | 0.09 | 36.8 | 11.0 | 230 | 60.7 | 1130 | 5.47 | 0.63 | 58 | -10 | -3.0 |
| Gi2 | 2014/6/23 | 7.19 (26) | 248 | 553 | 46.9 | 0.45 | 0.12 | 36.0 | 10.7 | 220 | 59.9 | 1180 | 5.16 | 0.57 | 59 | -10 | -3.2 |
| Ki2 | 2014/6/23 | 8.85 (26) | 117 | 106 | 82.6 | <0.01 | <0.01 | 8.52 | 79.4 | 26.0 | 16.6 | 626 | 1.41 | 0.04 | 8 | 26 | 3.8 |
| Ka1 | 2014/6/24 | 7.64 (26) | 126 | 255 | 15.3 | 0.42 | 0.18 | 21.2 | 2.35 | 79.3 | 78.1 | 555 | 8.04 | 0.08 | 91 | -11 | -3.6 |
| Mb1 | 2014/6/24 | 7.21 (26) | 91.2 | 178 | 11.8 | 0.29 | 0.05 | 19.1 | 2.34 | 54.0 | 44.7 | 415 | 6.36 | 0.05 | 62 | -13 | -3.7 |
| Mb2 | 2014/6/24 | 6.60 (26) | 15.4 | 5.72 | 1.06 | <0.01 | 0.04 | 12.7 | 5.41 | 5.1 | 6.7 | 24 | 0.40 | <0.01 | 31 | -9 | -3.2 |
| Nt1 | 2014/6/25 | 6.63 (26) | 39.8 | 9.59 | 8.48 | <0.01 | 0.92 | 40.5 | 15.6 | 8.9 | 10.1 | 220 | 0.58 | <0.01 | 48 | -3 | -2.3 |
| Ir1 | 2014/6/25 | 6.79 (26) | 248 | 439 | 19.1 | 0.52 | 0.10 | 86.7 | 25.1 | 320 | 75.0 | 970 | 2.87 | 0.11 | 58 | -9 | -3.2 |
| Ru1 | 2014/6/25 | 6.61 (26) | 238 | 149 | 150 | 0.07 | 0.03 | 44.2 | 206 | 23.6 | 16.8 | 1660 | 1.30 | 0.05 | 110 | -10 | -3.1 |
| Ru2 | 2014/6/25 | 7.06 (26) | 28.1 | 12.5 | 17.0 | <0.01 | 0.02 | 16.2 | 12.0 | 6.6 | 7.1 | 144 | 0.53 | <0.01 | 46 | -5 | -2.3 |
| Mu1 | 2014/6/25 | 6.51 (26) | 294 | 172 | 185 | 0.05 | 0.03 | 117 | 243 | 22.5 | 42.0 | 2140 | 1.92 | 0.06 | 76 | -10 | -3.4 |
| Cy1 | 2014/6/26 | 6.50 (26) | 286 | 175 | 171 | 0.05 | 0.04 | 130 | 230 | 16.9 | 44.2 | 2090 | 1.94 | 0.06 | 75 | -10 | -3.5 |
| Mt1 | 2014/6/26 | 6.80 (26) | 20.7 | 5.85 | 5.13 | <0.01 | 0.03 | 16.9 | 10.4 | 5.0 | 3.1 | 109 | 0.17 | <0.01 | 35 | -7 | -2.4 |
| Bu1 | 2014/6/26 | 6.56 (26) | 305 | 184 | 175 | 0.05 | 0.06 | 131 | 253 | 15.6 | 57.5 | 2260 | 1.92 | 0.07 | 80 | -13 | -3.7 |
| Bl1 | 2014/6/26 | 7.57 (26) | 12.5 | 7.33 | 7.49 | <0.01 | 0.03 | 6.54 | 3.94 | 5.4 | 4.4 | 61 | 0.43 | <0.01 | 2.71 | 15 | 2.0 |
| Kg1 | 2014/6/29 | 6.84 (26) | 46.7 | 18.9 | 5.94 | 0.04 | 0.02 | 49.3 | 14.5 | 12.1 | 35.7 | 159 | 1.38 | <0.01 | 38 | -9 | -3.0 |
| Ny1 | 2014/6/29 | 7.34 (26) | 24.2 | 5.66 | 7.27 | <0.01 | 0.12 | 21.7 | 12.1 | 5.0 | 6.2 | 124 | 0.76 | <0.01 | 14 | 8 | 0.2 |

Source: JICA study team

1) Karisimbi field

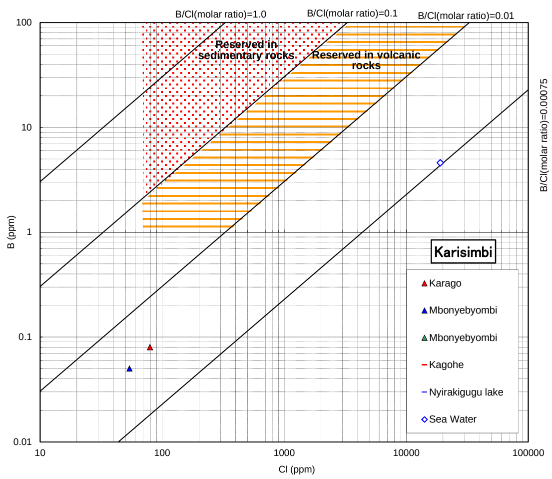
The samples from this field come from an area ranging from Karago, Kagohe, and Mbonyebyombi hot springs to Nyirakigugu lake. All of the water is dominated by $HCO_3$ anions with a concentration of up to 626 mg/L (Table 3-2.16), and is classified as being of the conductively heated type ($HCO_3$ type, Fig.3-2.38). A high Cl concentration would indicate a source in a deep high-temperature reservoir, but the concentration ranges only up to 79.3mg/L. The Cl-B diagram (Fig.3-2.39) also suggests conductively heated water. The isotopic composition is almost the same as for meteoric water, and there is no oxygen shift that would indicate water-rock interaction under high temperature (Fig.3-2.40). The diagram of temp-$SiO_2$ and Cl concentration (Fig.3-2.41) shows a mixing correlation between the Karago and Mbonyebyombi waters, implying that those waters are diluted from same parental fluid.

In determining the underground temperature, Na-K-Mg thermometry was not applicable, as these three components were not in equilibrium, but showed a high Mg concentration (Fig.3-2.42). This may be caused by a remarkable amount of $HCO_3$ being added to a relatively shallow, low-temperature aquifer. Of the calculated geothermometers (Fig.3-2.43, Table 3-2.17), only the silica geothermometer is reliable, as it is based on the solubility. Among the silica geothermometers, alpha-cristobalite will be most suitable here in Karisimbi, based on Fig.3-2.44. The maximum estimated geothermometry temperature is 81 degrees Celsius (Karago).



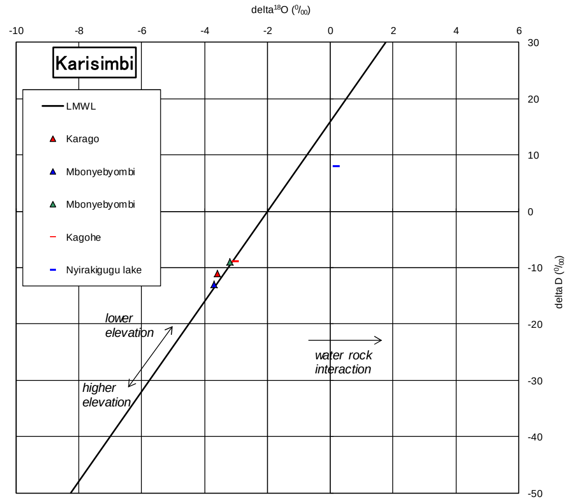

Source: JICA study team

Fig. 3-2.38 Ternary diagram of the major anions (Karisimbi field)



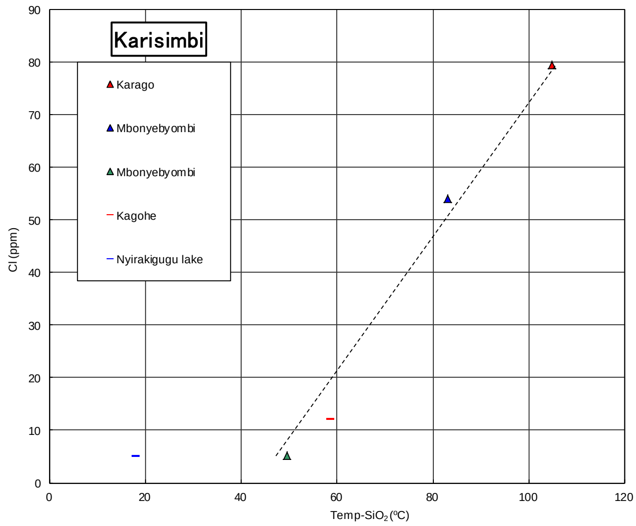

Source: JICA study team

Fig. 3-2.39 Cl-B diagram of hot spring waters (Karisimbi field)



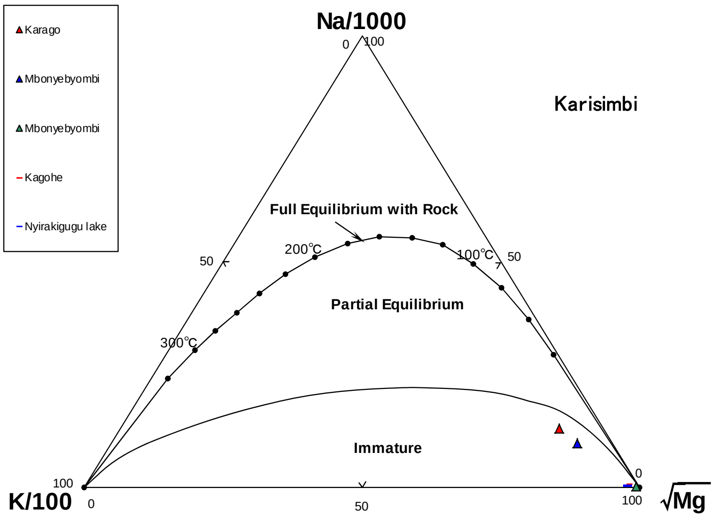

Source: JICA study team

Fig. 3-2.40 Delta-D and Delta-$^{18}$O diagram of waters (Karisimbi field)



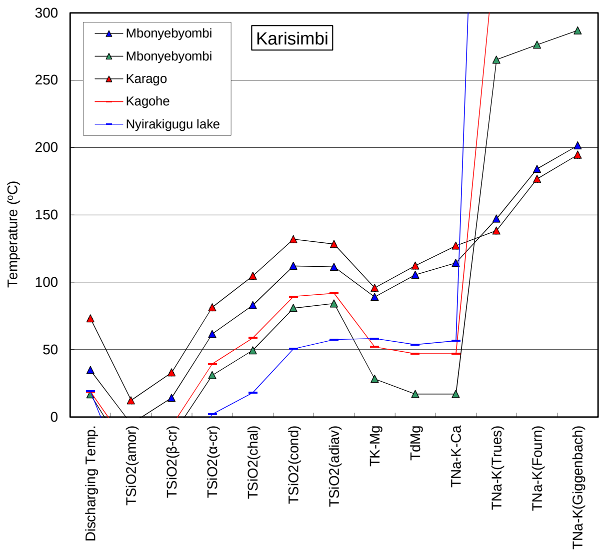

Source: JICA study team

Fig. 3-2.41 Diagram of temp-$SiO_2$ and Cl concentration (Karisimbi field)



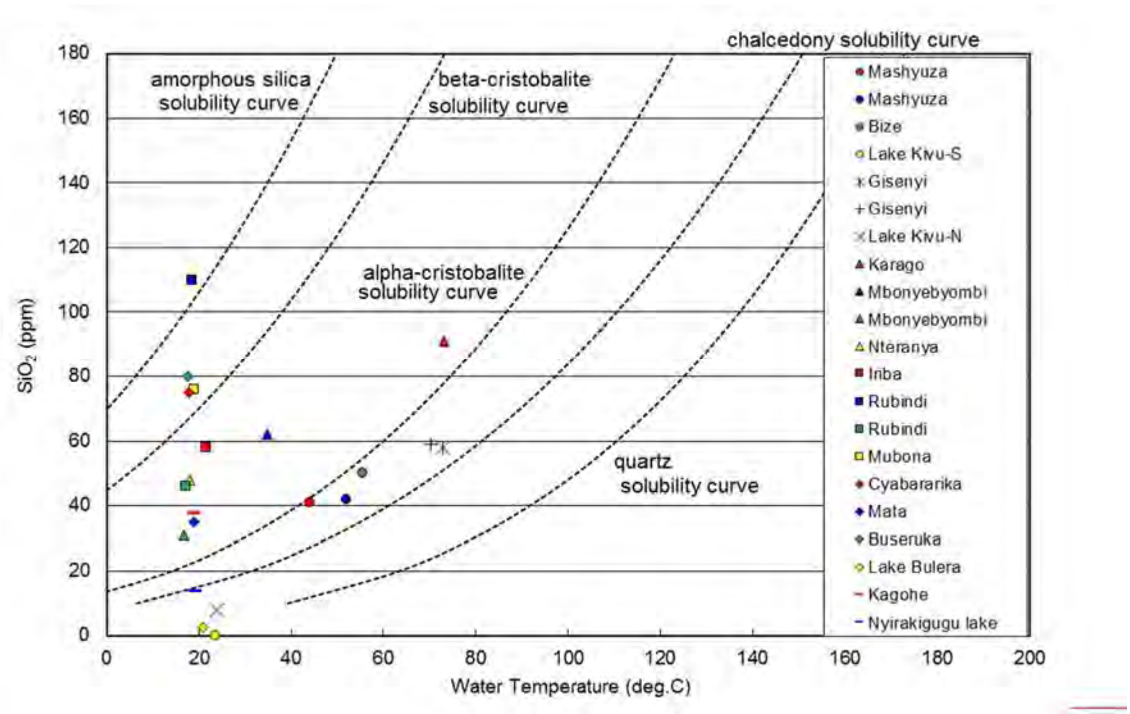

Source: JICA study team

Fig. 3-2.42 Ternary Na-K-Mg diagram (Karisimbi field)




Source: JICA study team

Fig. 3-2.43 Calculated geothermometers for Karisimbi field




Source: JICA study team

Fig. 3-2.44 Diagram of water temperature and $SiO_2$ concentration

Table 3-2.17 Calculated geothermometers

| | Area | Karisimbi | | | | | Kinigi + NE | | |
|---|---|---|---|---|---|---|---|---|---|
| | Site | Karago | Mbonyebyombi | Mbonyebyombi | Kagohe | Nyirakigugu lake | Rubindi | Rubindi | Mubona |
| | Sample No. | Ka1 | Mb1 | Mb2 | Kg1 | Ny1 | Ru1 | Ru2 | Mu1 |
| (℃) | Discharging Temp. | 73.2 | 34.7 | 16.8 | 18.8 | 19.1 | 18.6 | 17.1 | 19.0 |
| Geothermometry (℃) | TSiO2(amor) | 12 | -5 | -32 | -25 | -56 | **22** | -17 | 4 |
| | TSiO2(β-cr) | 33 | 14 | -14 | -7 | -41 | 43 | 1 | **24** |
| | TSiO2(α-cr) | **81** | **62** | **31** | **39** | 2 | 92 | **48** | 72 |
| | TSiO2(chal) | 105 | 83 | 49 | 59 | 18 | 116 | 68 | 94 |
| | TSiO2(cond) | 132 | 112 | 81 | 89 | 51 | 143 | 98 | 122 |
| | TSiO2(adiav) | 128 | 111 | 84 | 92 | 57 | 137 | 99 | 120 |
| | TK-Mg | 96 | 89 | 28 | 52 | 58 | 97 | 78 | 101 |
| | TdMg | 112 | 106 | 17 | 47 | 54 | not applicable | 35 | not applicable |
| | TNa-K-Ca | 127 | 114 | 17 | 47 | 57 | 209 | 99 | 186 |
| | TNa-K(Truesdell) | 138 | 147 | 265 | 356 | 870 | 728 | 909 | 763 |
| | TNa-K(Fournier) | 177 | 184 | 276 | 340 | 612 | 549 | 629 | 565 |
| | TNa-K(Giggenbach) | 195 | 201 | 287 | 344 | 574 | 522 | 587 | 536 |

| | Area | Kinigi + NE | | | | Gisenyi | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Site | Cyabararika | Mata | Buseruka | Lake Bulera | Gisenyi | Gisenyi | Nteranya | Iriba |
| | Sample No. | Cy1 | Mt1 | Bu1 | Bl1 | Gi1 | Gi2 | Nt1 | Ir1 |
| (℃) | Discharging Temp. | 17.9 | 19.0 | 17.6 | 21.0 | 73.0 | 70.3 | 18.1 | 21.6 |
| Geothermometry (℃) | TSiO2(amor) | 3 | -28 | 6 | -94 | -8 | -7 | -16 | -8 |
| | TSiO2(β-cr) | **23** | -10 | **26** | -82 | 11 | 12 | 3 | 11 |
| | TSiO2(α-cr) | 71 | **36** | 74 | -43 | 58 | 59 | 50 | 58 |
| | TSiO2(chal) | 93 | 55 | 97 | -31 | **79** | **80** | **70** | **79** |
| | TSiO2(cond) | 122 | 86 | 125 | 2 | 109 | 110 | 100 | 109 |
| | TSiO2(adiav) | 120 | 89 | 122 | 13 | 109 | 109 | 101 | 109 |
| | TK-Mg | 99 | 52 | 98 | 71 | 105 | 106 | 59 | 72 |
| | TdMg | not applicable | 52 | not applicable | 49 | 76 | 77 | 54 | 60 |
| | TNa-K-Ca | 179 | 52 | 180 | 85 | 174 | 176 | 54 | 106 |
| | TNa-K(Trues) | 713 | 663 | 700 | 736 | 168 | 170 | 666 | 112 |
| | TNa-K(Fourn) | 542 | 517 | 536 | 553 | 201 | 203 | 519 | 155 |
| | TNa-K(Giggenbach) | 517 | 496 | 511 | 525 | 218 | 219 | 498 | 174 |

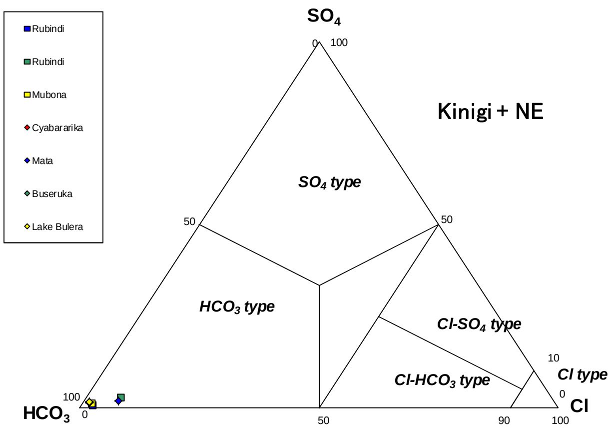
| | Area | Gisenyi | Bugarama | | |
|---|---|---|---|---|---|
| | Site | Lake Kivu-N | Mashyuza | Mashyuza | Bize |
| | Sample No. | Ki2 | Ma1 | Ma2 | Bi1 |
| (℃) | Discharging Temp. | 23.9 | 44.0 | 52.0 | 55.4 |
| Geothermometry (℃) | TSiO2(amor) | -71 | -22 | -21 | -14 |
| | TSiO2(β-cr) | -57 | -4 | -3 | 5 |
| | TSiO2(α-cr) | -15 | 43 | 44 | 51 |
| | TSiO2(chal) | -1 | **62** | **63** | **72** |
| | TSiO2(cond) | 32 | 93 | 94 | 102 |
| | TSiO2(adiav) | 41 | 95 | 96 | 103 |
| | TK-Mg | 94 | 84 | 85 | 102 |
| | TdMg | not applicable | 21 | 22 | 19 |
| | TNa-K-Ca | 234 | 141 | 204 | 184 |
| | TNa-K(Trues) | 613 | 243 | 238 | 360 |
| | TNa-K(Fourn) | 492 | 260 | 256 | 343 |
| | TNa-K(Giggenbach) | 475 | 272 | 268 | 346 |

Source: JICA study team

2) Kinigi field

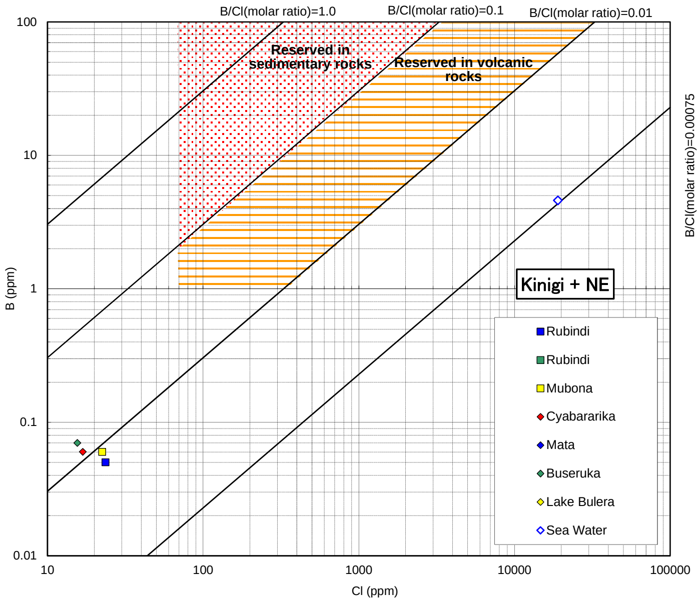
This field includes samples from an field ranging from Rubindi, Mubona, Cyabararika, Mata, and Buseruka hot springs to Bulera lake. All of the water is dominated by $HCO_3$ anions in a concentration that is up to 2,260 mg/L (Table 3-2.16), and is classified as being of the conductively heated type ($HCO_3$ type, Fig.3-2.45). A high Cl concentration would indicate a source in a deep high-temperature reservoir, but the concentration ranges only up to 23.6mg/L. The Cl-B diagram (Fig.3-2.46) also suggests conductively heated water. The isotopic composition is almost the same as for meteoric water, and there is no oxygen shift that would indicate water-rock interaction under high temperature (Fig. 3-2.47). The diagram of temp-$SiO_2$ and Cl concentration (Fig.3-2.48) shows a mixing correlation between Rubindi and Mata water, implying that those waters are diluted from same parental fluid.

In determining the underground temperature, Na-K-Mg thermometry was not applicable, as these three components were not in equilibrium, but showed a high Mg concentration (Fig.3-2.49). This may be caused by a remarkable amount of $HCO_3$ being added to a relatively shallow, low-temperature aquifer. Of the calculated geothermometers (Fig.3-2.50, Table 3-2.17), only the silica geothermometer is reliable, as it is based on the solubility. Among the silica geothermometers, amorphous silica (Rubindi) and beta-cristobalite (other than Rubindi) will be most suitable here in Kinigi, based on Fig.3-2.44. The maximum estimated geothermometry temperature is 26 degrees Celcius (Buseruka).



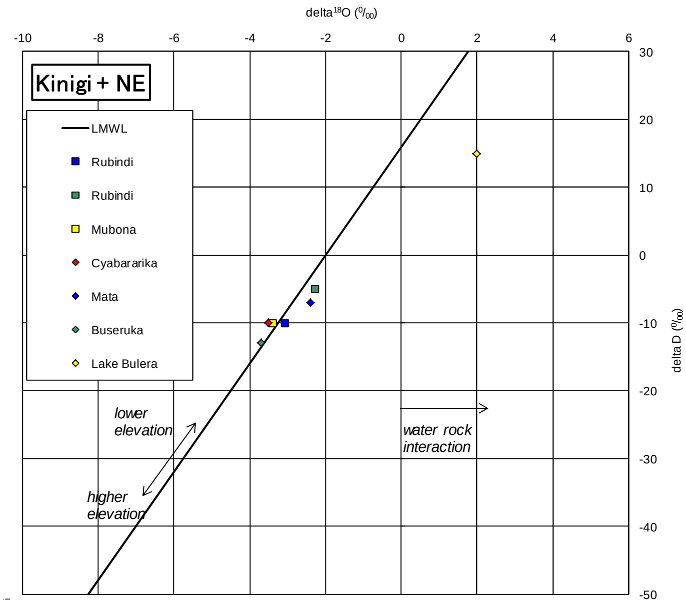

Source: JICA study team

Fig. 3-2.45 Ternary diagram of the major anions (Kinigi field)



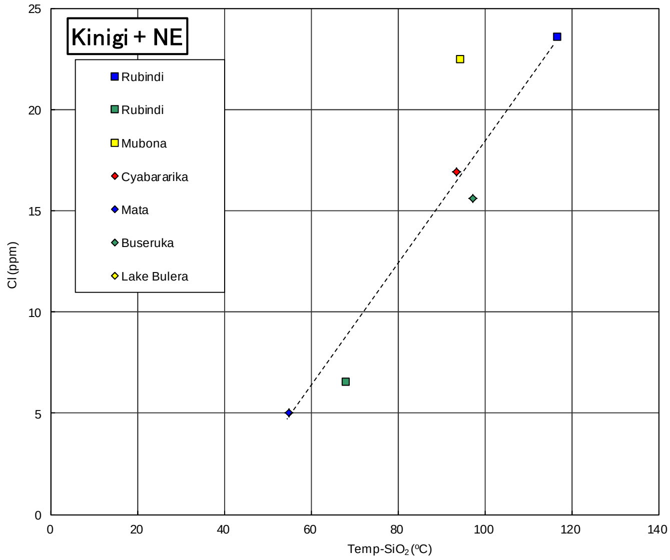

Source: JICA study team

Fig. 3-2.46 Cl-B diagram of hot spring waters (Kinigi field)



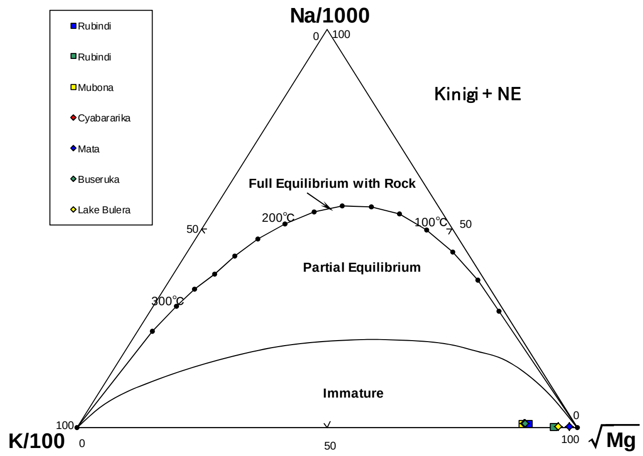

Source: JICA study team

Fig. 3-2.47 Delta-D and Delta-$^{18}$O diagram of waters (Kinigi field)



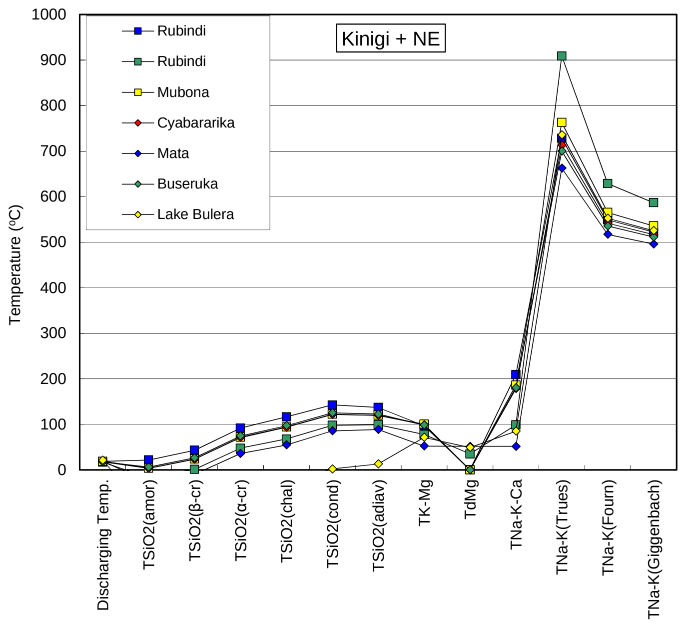

Source: JICA study team

Fig. 3-2.48 Diagram of temp-$SiO_2$ and Cl concentration (Kinigi field)




Source: JICA study team

Fig. 3-2.49 Ternary Na-K-Mg diagram (Kinigi field)



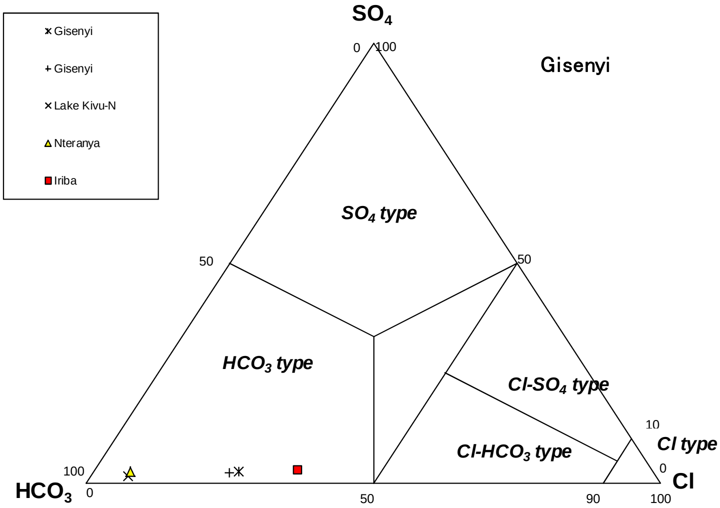

Source: JICA study team

Fig. 3-2.50 Calculated geothermometers for Kinigi field

3) Gisenyi field

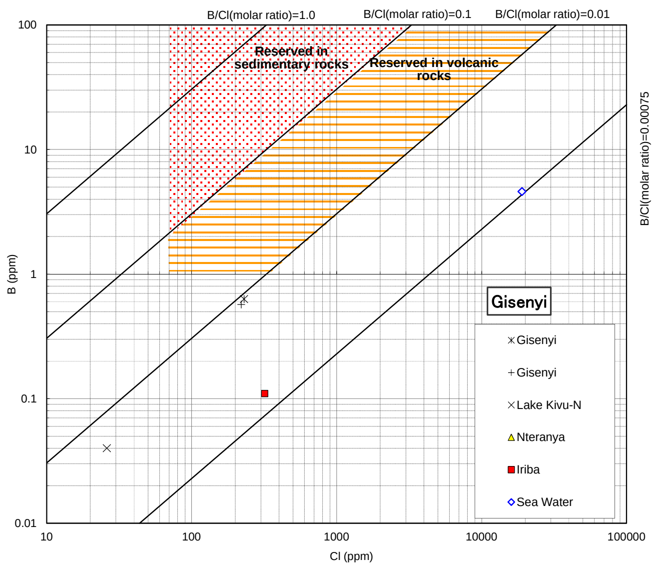
The samples from this field come from an area ranging from Gisenyi, Iriba, and Nteranya hot springs to Lake Kivu. All of the water is dominated by $HCO_3$ anions with a concentration of up to 1,180 mg/L (Table 3-2.16), and is classified as being of the conductively heated type ($HCO_3$ type, Fig.3-2.51). The Cl concentration shows a maximum of 320 mg/L, implying some mixing of deep high-temperature reservoir water. The boron concentration was lower than the Cl concentration, in contrast to normal hot springs (Fig.3-2.52), with metamorphic rock seeming to play some role for those hot springs. The isotopic composition is almost the same as for meteoric water, and there is no oxygen shift that would indicate water-rock interaction under high temperature (Fig.3-2.53). The diagram of temp-$SiO_2$ and Cl concentration (Fig.3-2.54) shows no mixing correlation between Gisenyi and Iriba water, implying that those waters do not derive from the same parental fluid.

In determining the underground temperature, Na-K-Mg thermometry was not applicable, as these three components were not in equilibrium, but showed a high Mg concentration (Fig.3-2.55). This may be caused by a remarkable amount of $HCO_3$ being added to a relatively shallow, low-temperature aquifer. Of the calculated geothermometers (Fig.3-2.56, Table 3-2.17), only the silica geothermometer is reliable, as it based on the the solubility. Of the silica geothermometers, chalcedony will be most suitable here in Gisenyi, based on Fig.3-2.44. The maximum estimated geothermometry temperature is 80 degrees Celcius (Gisenyi).



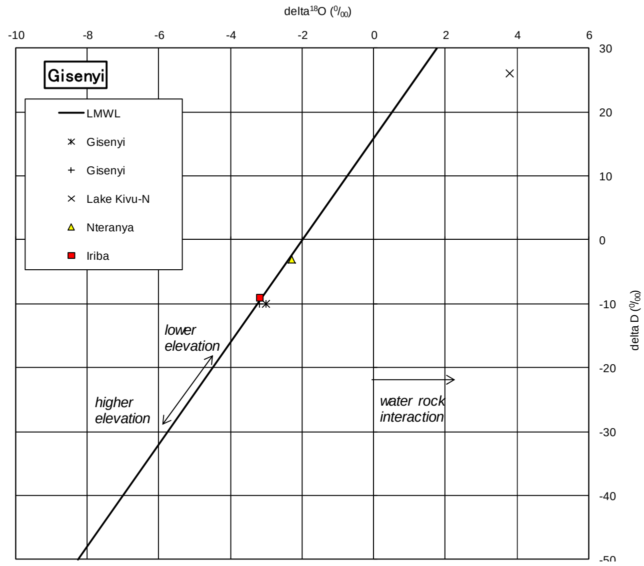

Source: JICA study team

Fig. 3-2.51 Ternary diagram of the major anions (Gisenyi field)



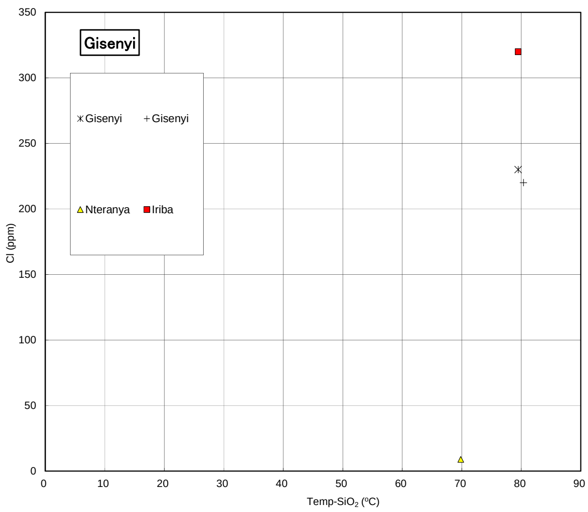

Source: JICA study team

Fig. 3-2.52 Cl-B diagram of hot spring waters (Gisenyi field)



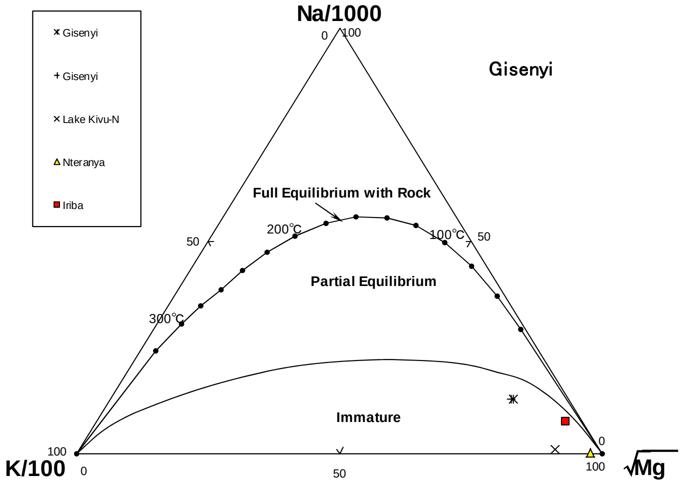

Source: JICA study team

Fig. 3-2.53 Delta-D and Delta-$^{18}$O diagram of waters (Gisenyi field)



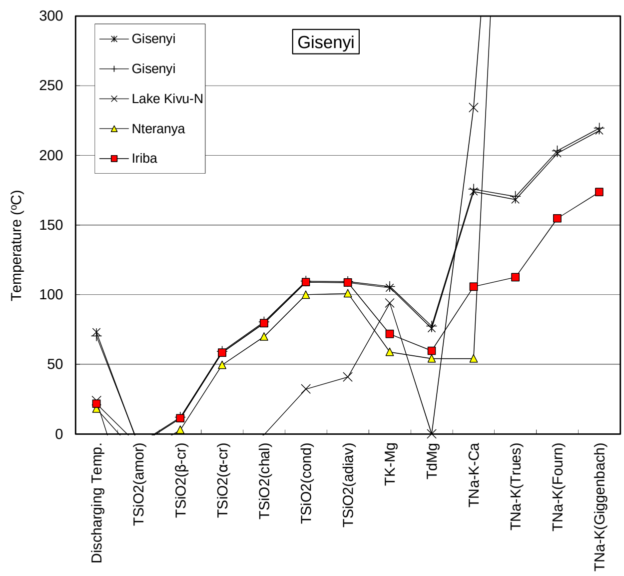

Source: JICA study team

Fig. 3-2.54 Diagram of temp-$SiO_2$ and Cl concentration (Gisenyi field)




Source: JICA study team

Fig. 3-2.55 Ternary Na-K-Mg diagram (Gisenyi field)



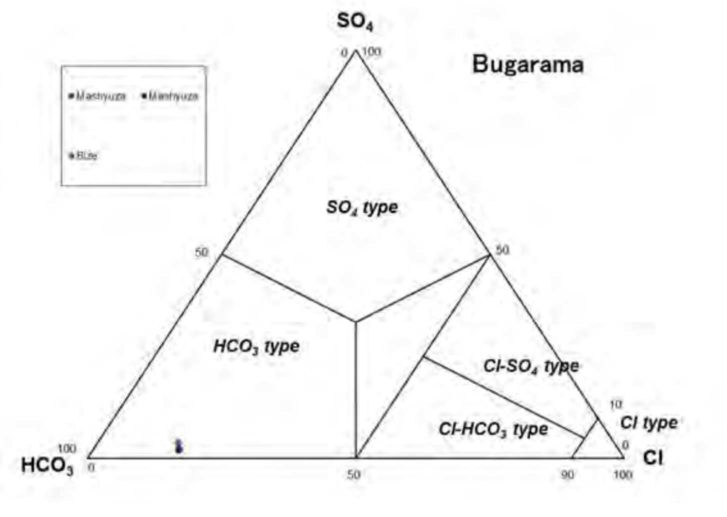

Source: JICA study team

Fig. 3-2.56 Calculated geothermometers for Gisenyi field

4) Bugarama field

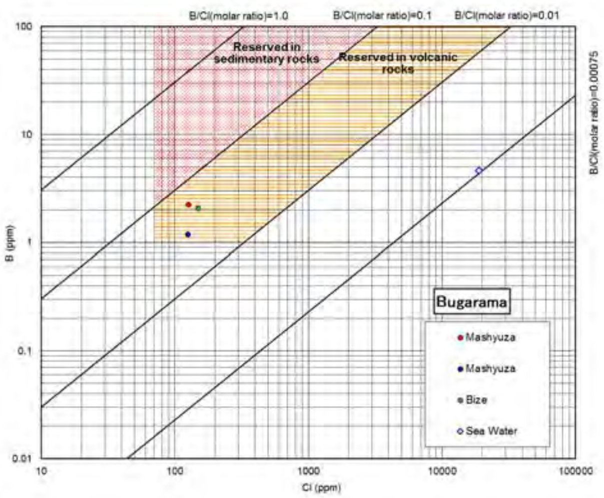
The samples in this field come from an area including Mashyuza and Bize hot spring waters. All of the water is dominated by $HCO_3$ anions with a concentration of up to 1,400 mg/L (Table 3-2.16), and is classified as being of the conductively heated type ($HCO_3$ type, Fig.3-2.57). The Cl concentration reaches a maximum of 150 mg/L, implying some mixing of deep, high-temperature reservoir water. The boron and Cl ratios shows that these hot spring waters are stored in volcanic rocks (Fig.3-2.58). The isotopic composition is almost the same as for meteoric water, and there is no oxygen shift that would indicate water-rock interaction under high temperature (Fig.3-2.59). The diagram of temp-$SiO_2$ and Cl concentration (Fig.3-2.60) shows a mixing correlation between Bize and Mashyuza water, implying that those waters are diluted from the same parental fluid.

In determining the underground temperature, Na-K-Mg thermometry was not applicable, as these three components were not in equilibrium, but showed a high Mg concentration (Fig.3-2.61). This may be caused by remarkable amount of $HCO_3$ being added to a relatively shallow, low-temperature aquifer. Of the calculated geothermometers (Fig.3-2.62, Table 3-2.17), only the silica geothermometer is reliable, as it is based on the solubility. Of the silica geothermometers, chalcedony will be most suitable here in Gisenyi, based on Fig.3-2.44. The maximum estimated geothermometry temperature is 72 degrees Celcius (Bize).



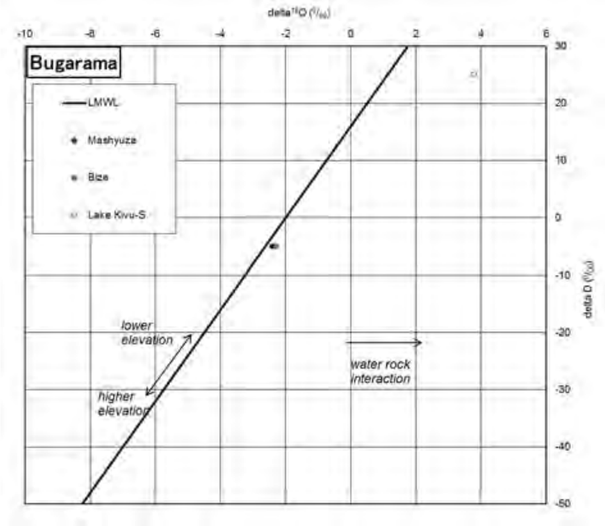

Source: JICA study team

Fig. 3-2.57 Ternary diagram of the major anions (Bugarama field)



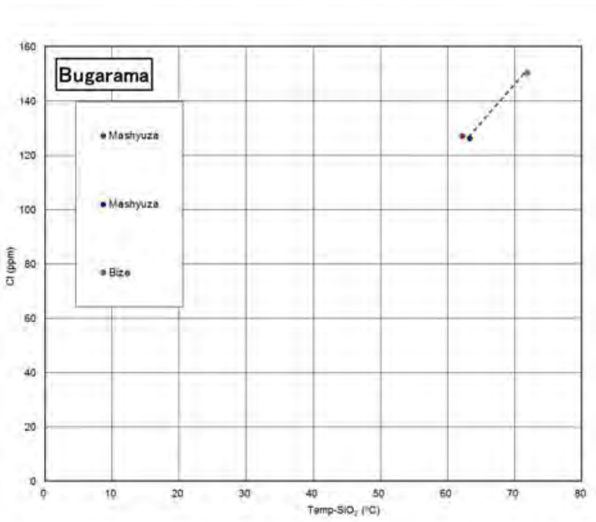

Source: JICA study team

Fig. 3-2.58 Cl-B diagram of hot spring waters (Bugarama field)



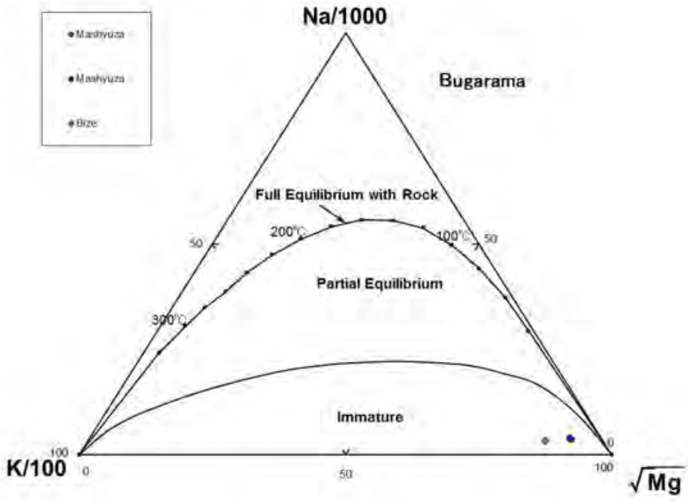

Source: JICA study team

Fig. 3-2.59 Delta-D and Delta-$^{18}$O diagram of waters (Bugarama field)



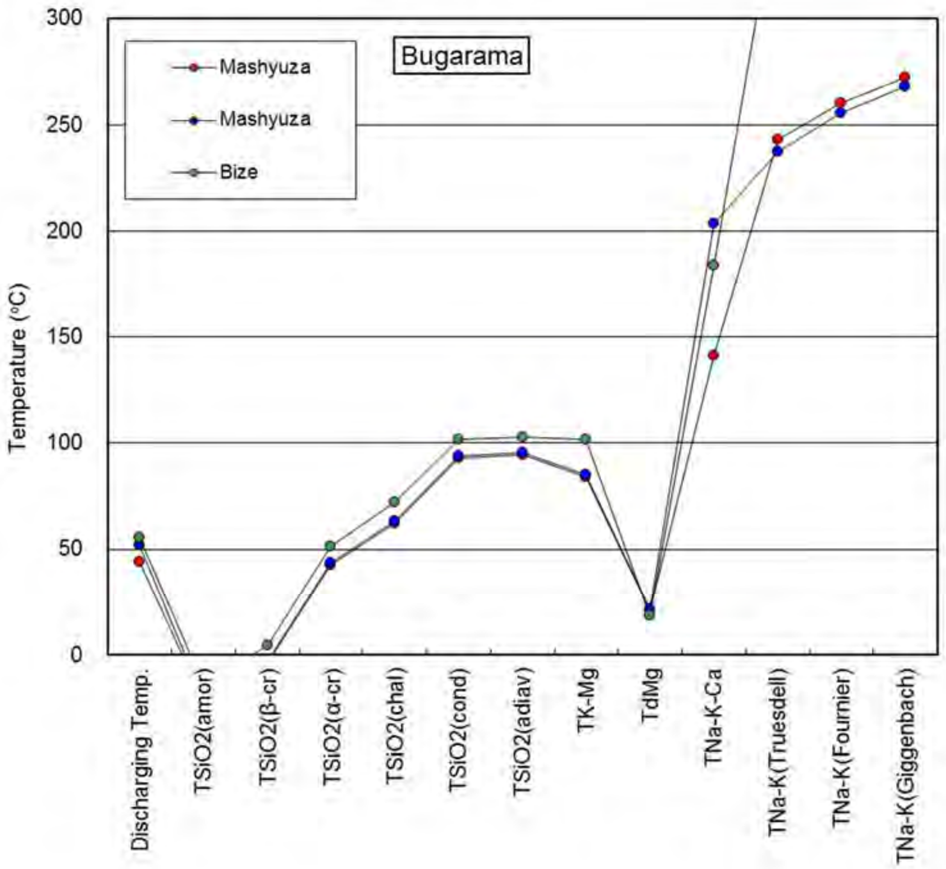

Source: JICA study team

Fig. 3-2.60 Diagram of temp-$SiO_2$ and Cl concentration (Bugarama field)




Source: JICA study team

Fig. 3-2.61 Ternary Na-K-Mg diagram (Bugarama field




Source: JICA study team

Fig. 3-2.62 Calculated geothermometers for Bugarama field