The Federal Democratic Republic of Ethiopia
Geological Survey of Ethiopia (GSE)

THE PROJECT FOR FORMULATING MASTER PLAN ON DEVELOPMENT OF GEOTHERMAL ENERGY IN ETHIOPIA

FINAL REPORT

APRIL 2015

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

NIPPON KOEI CO., LTD.
JMC GEOTHERMAL ENGINEERING CO., LTD.
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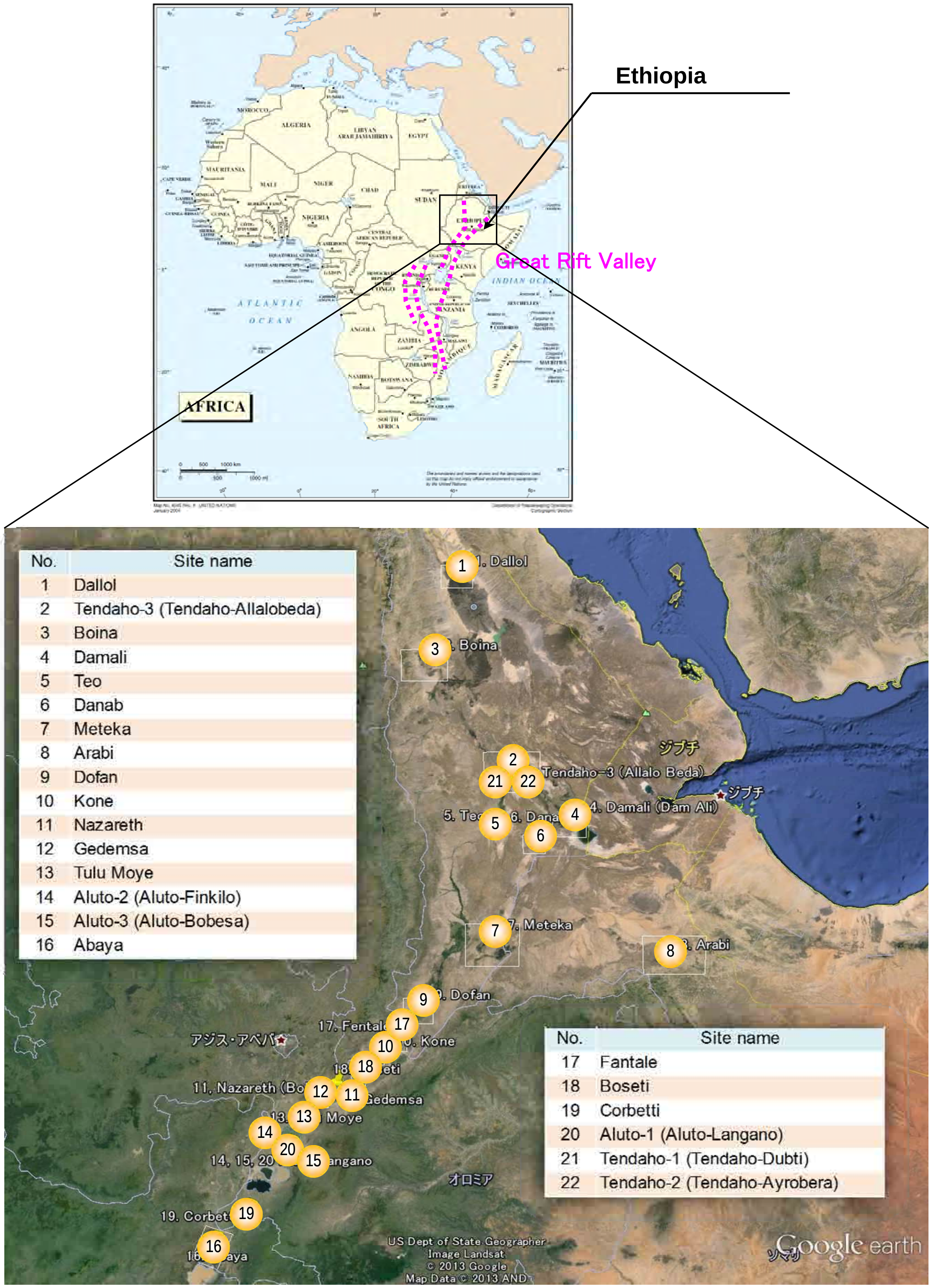


Source: Google Earth Pro

Location Map

THE PROJECT FOR FORMULATING MASTER PLAN N DEVELOPMENT OF GEOTHERMAL ENERGY IN ETHIOPIA

EXECUTIVE SUMMARY

1. BACKGROUND AND PURPOSE OF THE PROJECT

1.1 Background

The total installed capacity of electricity power plants in Ethiopia amounted to 2,100 MWe, as of January 2010; more than 90% are of hydropower. Under such circumstances, the Ethiopia electric sector addresses the development of indigenous energy such as geothermal and/or wind power, with recognition of the importance of energy diversity and energy mixture.

Among other indigenous types of energy, geothermal energy has become more important as a base load power. Geothermal potential survey was commenced in Ethiopia in 1969. Since then, step-by-step potential surveys have identified more than 16 promising geothermal sites for electricity development. However, development stages vary from site to site, only two sites, i.e., Aluto Landano site and Corbetti site, are being developed towards commercial operation.

The Geological Survey of Ethiopia (GSE) requested the Government of Japan for technical assistance in formulating a master plan for geothermal development including technical capacity building for geothermal development. In response to the request, the Japan International Cooperation Agency (hereinafter referred to as "JICA") dispatched the JICA Project Team to Ethiopia for the implementation of "The Project for Formulating Master Plan on Development of Geothermal Energy in Ethiopia" (hereunder referred to as "the Project").

1.2 Objectives and Scope of Work of the Project

1.2.1 Objectives

The objectives of the Project are as follows:

1) To conduct geothermal surface survey;
2) To prioritize geothermal prospects with a unique set of criteria;
3) To formulate the master plan for geothermal development based on the above; and
4) To contribute to capacity development of GSE under the process of formulating the master plan.

1.2.2 Counterpart and Relevant Organizations

The counterpart organization and the Joint Coordination Committee are as follows:

1) Counterpart:

Geological Survey of Ethiopia (GSE), Ministry of Mines of Ethiopia

2) Joint Coordination Committee (JCC)

i) Ethiopian Organizations

- Director General of GSE / Chief Geologist of GSE
- Director of Geothermal Resource Directorate, GSE
- Representative from the Ministry of Mines (MoM)
- Representative from the Ministry of Water, Irrigation and Energy (MoWIE)
- Representative from the Ethiopian Electric Power (EEP)
- Representative from the Ministry of Finance and Economic Development (MoFED)

ii) Japanese Organizations

- Resident Representative of JICA Ethiopia Office
- JICA Project Team
- Other personnel concerned to be proposed by JICA

iii) Observer

- Representative from the Embassy of Japan

Note that EEPCo was restructured in December 2013 into two companies: a) Ethiopia Electric Power (EEP) responsible for power generation and transmission, and b) Ethiopian Electric Utility (EEU) for delivering electricity services (distribution, and sale of electric power). The EEP will be managed by the Ethiopian CEO, whereas the EEU will be managed for two years by an Indian company (Power Grid Corporation).

1.2.3 Target Sites

The target sites are listed in Table 1.1 below. The approximate locations are shown in the location map at the beginning of this report.

Table 1.1 Target Sites

Geothermal Sites		Prioritization / Data base	Remote Sensing	Site Survey
1	Dallol	☑	☑	GSE
2	Tendaho-3 (Tendaho-Allalobeda)	☑	☑	☑
3	Boina	☑	☑	GSE
4	Damali	☑	☑	GSE
5	Teo	☑	☑	GSE
6	Danab	☑	☑	GSE
7	Meteka	☑	☑	☑
8	Arabi	☑	☑	GSE
9	Dofan	☑	☑	☑
10	Kone	☑	☑	☑
11	Nazareth	☑	☑	☑
12	Gedemsa	☑	☑	☑
13	Tulu Moye	☑	☑	-
14	Aluto-2 (Aluto-Finkilo)	☑	☑	☑
15	Aluto-3(Aluto-Bobesa)	☑	☑	☑
16	Abaya	☑	☑	-
(17)	Fantale	☑	☑	-
(18)	Boseti	☑	☑	☑
(19)	Corbetti	☑	☑	-
(20)	Aluto-1 (Aluto-Langano)	☑	☑	-
(21)	Tendaho-1 (Tendaho-Dubti)	☑	☑	-
(22)	Tendaho-2 (Tendaho-Ayrobera)	☑	☑	☑

(Source: JICA Project Team)

☑:Target for the M/P formulation project
GSE: The sites where GSE should undertake the site survey due to access and/or security issues.
Source: Proposed by the JICA Project Team based on the R/D (11 June 2013) and subsequent discussions betw een GSE and the JICA Project Team

2. ELECTRICITY DEVELOPMENT PLAN

2.1 Growth and Transformation Plan

The latest government development plan is the Five-year Growth and Transformation Plan (GTP) for the period 2010/11-2014/15. The strategic directions of the energy sector are development of renewable energy, expansion of energy infrastructure, and creation of an institutional capacity that can effectively and efficiently manage such energy sources and infrastructure. The main objective of the energy sector is to meet the demand for energy in the country by providing sufficient and reliable power supply that meets international standards at all time. The main targets of the energy sector are summarized in Table 2.1.

Table 2.1 GTP Targets of the Energy Sector

Description of Target	2009/10	2014/15
1. Hydroelectric power generating capacity (MW)	2,000	10,000
2. Total length of distribution lines (Km)	126,038	258,000
3. Total length of rehabilitated distribution lines (Km)	450	8,130
4. Reduce power wastage (%)	11.5	5.6
5. Number of consumers with access to electricity	2,000,000	4,000,000
6. Coverage of electricity services (%)	41	75
7. Total underground power distribution system (Km)	97	150

Source: GTP (2010/11-2014/15)

2.2 Overview of Power Sector

2.2.1 Policy, Laws, Regulations, and Strategy

The Plan for Accelerated and Sustained Development to End Poverty (PASDEP) was presented as a five-year (2005/06-2009/10) development strategy in 2006. Following PASDEP, the GTP mentioned the current national policy for the period 2010/11 – 2014/15 and has targets to increase the installed capacity by 8,000 MW of renewable energy resources. Table 2.2 presents the targets of PASDEP and GTP.

Table 2.2 Targets in the PASDEP/GTP Period 2005-2015

Item	2005/06	PASDEP 2005/06-2009/10	2012	GTP 2010/11-2014/15
Installed Capacity	791MW	2,218 MW (+1,427MW)	2,168 MW	10,000 MW
Electrification Rate	16%	50% (+34%)	17%	75%
Length of Transmission/Distribution Line	-	13,054km	12,461 km	258,000 km
Electricity Loss	19.5%	13.5%	-	5.6%

Source: PASDEP/GTP (summarized by the JICA Project Team)

The Ethiopian Electric Power Corporation (EEPCo), former the national electricity utility in charge of power generation plan, completed the "Ethiopian Power System Expansion Master Plan" for the next 25 years (2013–2037) in February 2014.

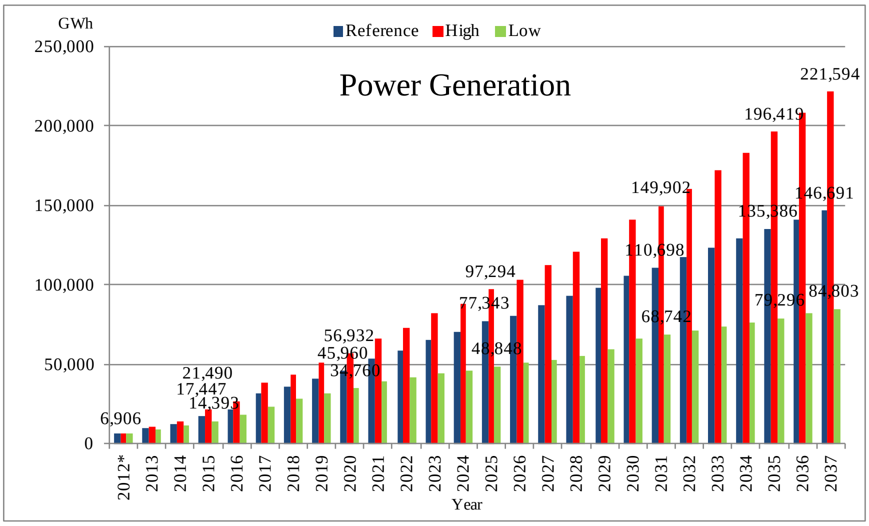
2.2.2 Power Sector Institutions

There are five major institutions engaging in the power sector, namely: (i) Ministry of Mines (MoM),

(ii) Geological Survey of Ethiopia (GSE), (iii) Ministry of Water, Irrigation and Energy (MoWIE), (iv) Ethiopian Electric Power (EEP) and Ethiopian Power Utility (EEU), and (v) Independent Power Producers (IPPs). The MoM and MoWIE undertake policy- and regulation-making; while GSE conducts geothermal exploration, and EEP, EEU, and IPPs undertake construction and operation of power supply system (generation, transmission and distribution).

2.2.3 Power Demand Forecast

The Ethiopian Power System Expansion Master Plan (2014) forecasted that the energy demand would grow from 1,445 GWh of 2013 to 146,691 GWh in 2037 as shown in Figure 2.1; Energy export sales are forecast to grow from 1,445 GWh in 2013 to 35,303 GWh by 2037, and the total demands (MW) of exports are forecast to grow from 140 MW in 2012 to 4,080 MW by 2037.



*Actual record in 2012

Source: Ethiopian Power System Expansion Master Plan, EEPCo, arranged by JICA Project Team

Figure 2.1 Energy Requirement Forecast including Exports (2012-2037)

2.2.4 Power Generation Planning

Table 2.3 shows the existing electricity development plan indicated in the EEPCo master plan, except geothermal power plant.

Ethiopia is blessed with high hydropower potential. In the last five years (2009 – 2013), a total of 1,200 MW of hydropower plants at four sites were put into operation which has made the installed capacity as triple as the before. The government of Ethiopia intends to continue to develop its hydro-potential as shown in the Table 2.3.

Table 2.3 Existing Electricity Development Plan (except geothermal)

Power Plant	Status	Installed Capacity (MW)	Power Generation (GWh)
Hydropower	Under Construction	8,124	21,826
	Candidate	12,407	59,279
Wind Farm	Committed	153	424
	Candidate	1500	4,765
Solar	Candidate	300	526
Biomass	Candidate	120	578
Energy from Waste	Committed	25	186
Sugar Factory	Candidate	474	2,283
Gas Turbine	Candidate	280	2208
CCGT	Candidate	420	3219
Diesel	Candidate	70	515

Source: EEPCo 2014, summarized by the Project Team

2.2.5 Transmission Planning

Transmission expansion plan was developed in the EEPCo master plan study based on the demand forecast and generation plan mentioned above. The transmission expansion plan was considered to connect the candidate power plants meeting the electrical demand forecast in two stages, i.e., short-term from 2013 to 2020 and long-term from 2021 to 2037. This development plan includes the generation plan of committed geothermal project including Aluto-Langano and Corbetti. Most of the other geothermal prospects in this project are located along the existing and planned networks which also run along the Great Rift Valley.

2.2.6 Financing and Tariff

Table 2.4 shows the published consumer tariffs in Ethiopia for 50 years from 1959 to 2003. The domestic tariff is reduced to around ETB 0.47/kWh (equivalent to around USD 0.03/kWh) with a large amount of subsidies, so that the poverty group can have access to electricity.

Table 2.4 Consumer Tariffs

	Description	Historical Flat Tariff Rate (Birr/kWh) EFY													
		1952-1964	1965-1971			1972-1978			1979-1987			1988-1989	1990	1991-1998	1999-2003
		EEPCo	ICS	SCS	EEPCo	ICS	SCS	EEPCo	ICS	SCS	EEPCo	EEPCo	EEPCo	EEPCo	EEPCo
1	House Hold	0.1250	0.1250	0.1250	0.1250	0.1425	0.1513	0.1468	0.1425	0.1513	0.1468	0.1772	0.2809	0.3897	0.4735
2	Commercial	0.0750	0.1250	0.1650	0.1436	0.1525	0.1975	0.1735	0.3436	0.4146	0.3774	0.3653	0.4301	0.5511	0.6723
3	Street Light		0.1100	0.1500	0.1285	0.1100	0.1500	0.1285	0.3322	0.4146	0.3711	0.3333	0.3087	0.3970	0.4843
4	Small Industry		0.1333	0.1733	0.1520	0.1333	0.1733	0.1520	0.2232	0.4597	0.3203				
5	LV		0.0475	0.0875	0.0645	0.0625	0.1175	0.0857	0.2232	0.4397	0.3133	0.2563	0.3690	0.4736	0.5778
6	HV 15kV		0.0288	0.0780	0.0474	0.0588		0.0588	0.2029		0.2029	0.2341	0.2597	0.3349	0.4086
7	HV 132kV												0.2416	0.3119	0.3805
	Total Flat Rate	0.0968	0.0824	0.1241	0.1011	0.1027	0.1556	0.1165	0.2341	0.3500	0.2735	0.2645	0.3086	0.4020	0.4900

LV: Low Voltage、HV: High Voltage

Source: Ethiopian Power System Expansion Master Plan, EEPCo, arranged by the JICA Project Team

2.3 Geothermal Power Development

2.3.1 Committed Geothermal Power Development Plans

In this master plan study, considering the latest information on donor involvements and GSE plan, existing and committed geothermal sites are ranked in priority order of development. Table 2.5 summarizes the committed geothermal prospects.

Table 2.5 Committed and Planned Geothermal Prospects

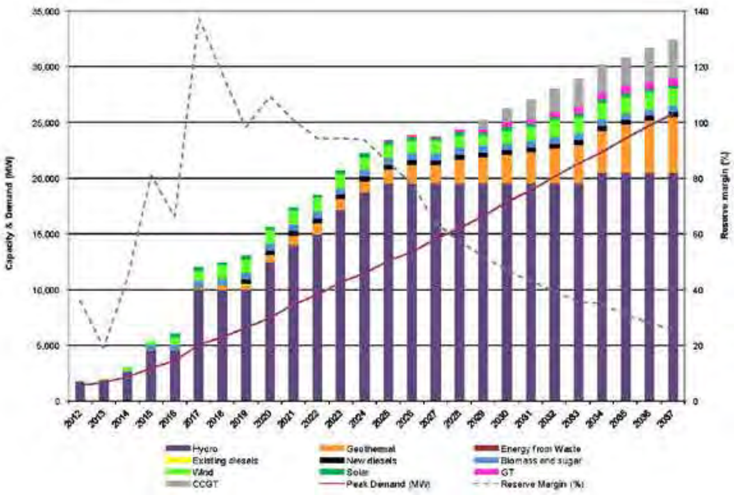
MP S No.	Site	Planned Capacity and COD		Status of Commitment
2	Tendaho-3 (Allalobeda)	25 MW	2017	ICEIDA/NDF assists surface survey including MT survey.
19	Corbetti	20 MW 80 MW 200 MW 200 MW	2015 2016 2017 2018	Reykjavík Geothermal (RG)'s PPA: maximum of 1,000 MW in the next 8-10 years. Using GRMF fund, GSE is conducting a study.
20	Aluto-1(Aluto-Langano)	75 MW	2018	The Government of Japan and World Bank has assisted in drilling of wells.
21	Tendaho-1(Dubti)	10 MW	2018	AFD assists in well drilling for 10 MW.
Total		**610 MW**		

MP S.No.: Site numbering in this MP study, AFD: French Development Agency

Source: JICA Project Team

2.3.2 Existing Geothermal Development Plans

In the EEPCo master plan, all candidate geothermal power plants are sized in multiples of 100 MW capacities for simplicity without considering the site specific potential and installation plans based on forecast demand.



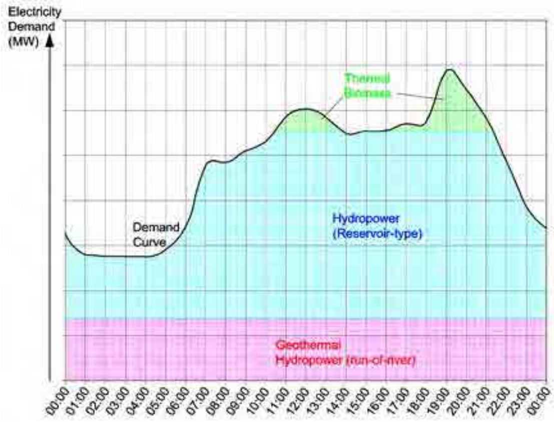
Source: Ethiopian Power System Expansion Master Plan, EEPCo

Figure 2.1 Installed Capacity and Reserve Margin

2.3.3 Superiority of Geothermal Power Generation

Geothermal power generation will be of the most important energy together with the hydropower in Ethiopia, from the following reasons.

- Energy Security
- Energy Mix
- Reliable Electrical Supply
- Greenhouse Gas Mitigation



Source: JICA Project Team, based on demand curve provided by EEP

Figure 2.2 Schematic Image of Electrical Supply Composition against Electricity Demand in a day

3. GEOTHERMAL POTENTIAL SURVEY

3.1 Collection of Existing Information

3.1.1 Objective

All the available existing geological papers, articles, and reports were collected for each geothermal site as the background information for this Project.

3.1.2 Regional Survey Reports

Basic and comprehensive geological investigations were carried out from the early 70s to 80s. Comprehensive investigations and researches were conducted by the United Nations Development Programme (UNDP) in 1973, the Ministry of Mines in 1984, and Electroconsul/Geothermica in 1987; thereby, most of the prospective geothermal areas were determined. As a result, those investigations summarized that Aluto and Tendaho sites have the highest potential of all the prospective geothermal sites in Ethiopia.

3.1.3 Detailed Geothermal Survey

Detailed surveys have been conducted since the 1980s at most of the sites. The status of surveys at each site is shown in Table 3.1.

Table 3.1 Status of Detailed Survey at Each Site

No.	Geothermal Sites	Geological Survey	Geochemical Survey	Geophysical Prospecting	Other Surveys
1	Dallol	☑	☑	-	
2	Tendaho-3 (Tendaho-Allalobeda)	☑	☑	☑	
3	Boina	☑	☑	-	
4	Damali (Lake Abbe)	☑	☑	-	
5	Teo	☑	☑	-	
6	Danab	☑	☑	-	
7	Meteka	☑	☑	-	
8	Arabi	-	☑	-	
9	Dofan	☑	☑	-*	
10	Kone	☑	-	-	
11	Nazreth (Boku-Sodole)	☑	☑	☑	
12	Gedemsa	☑	☑	-*	TG well
13	Tulu Moye	☑	-	-	
14	Aluto-2 (Aluto-Finkilo)	☑	☑	-*	TG well
15	Aluto-3 (Aluto-Bobesa)	☑	☑	-*	
16	Abaya	☑	☑	-	
17	Fantale	☑	☑	-	Magnetic Survey
18	Boseti	☑	☑	-	
19	Corbetti	☑	☑	☑	
20	Aluto-1 (Aluto-Langano)	☑	☑	☑	
21	Tendaho-1 (Tendaho-Dubti)	☑	☑	☑	
22	Tendaho-2 (Tendaho-Ayrobera)	☑	☑	☑	Radon Survey

☑: done, - : not done, -*: to be done, TG Well: Thermal Gradient well
Note: The sites having limited data, are also classified as "done".

Source: JICA Project Team

It was confirmed that at least the geological survey and geochemical survey were conducted at each site. However, the quality and quantity of the results are not unified, e.g., entire site was not covered, location of geological manifestations was not shown, or location of sampling was not shown.

3.1.4 Feasibility Study

Feasibility (or pre-feasibility) study was conducted at Tendaho-1 (Tendaho-Dubti), Tendaho-2 (Tendaho-Ayrobera), and Aluto-1 (Aluto-Langano) geothermal sites. In 1986, Electroconsul/Geothermica conducted geothermal reservoir evaluation, design of facilities, and economical evaluation, by drilling nine wells at Aluto-Langano. In 1996, the Ethiopian Institute of Geological Survey (former GSE)/Aquater conducted geothermal reservoir evaluation by drilling three wells at Tendaho-1 (Tendaho-Dubti) and Tendaho-2 (Tendaho-Ayrobera). Afterward, GSE continued the drilling of three wells by themselves from 1995 to 1998.

3.1.5 Geothermal Plant Construction /Operation and Maintenance

The first geothermal power plant was constructed at Aluto-1 (Aluto-Langano) in 1992, based on the above feasibility study. Reports were issued for operation and maintenance of geothermal wells after the power plant construction.

3.2 Satellite Data Analysis

3.2.1 Objectives

Prior to the field survey, alteration zoning, mineral and lithological mapping, topographic interpretation, and geological structure analysis were carried out using satellite images. Field survey was conducted based on the results of the satellite data analysis and review of existing reports.

3.2.2 Methodology

Japanese satellite products, ASTER L3A and PALSAR L1.5, were used.

In ASTER data analysis, the band composite image and the band ratio image are created by using Short Wavelength Infrared (SWIR) bands; thereby distributions of various alteration zones were detected, rock facies and mineral mapping and interpretation of geological structures were conducted. In PALSAR data analysis, the mosaic image of geothermal development sites was created; thereby such geological structures as lineaments/faults, craters, caldera, lava domes and/or lava flows were identified.

The integrated analysis on GIS was conducted with the results of ASTER DEM data compiled together with the results of the ASTER and PALSAR data analysis. As the result, the outcrop distributions of altered rocks were extracted and geological structures were interpreted.

3.2.3 Results

The results of each site are as follows.

- All 22 target sites are located in the East African Great Rift Valley,
- In all targets sites, a number of major lineaments/faults running parallel to the direction of the rift valley were identified,
- Geothermal sites are in general classified into (1) Volcanic body, (2) Caldera form, and (3) Graben; distribution of those are more or less parallel to the direction of the rift valley,
- Hydrothermal alterations were identified in areas of volcanic bodies and calderas. Intensity of such alteration varies from site to site; whereas particular alterations were not identified in Graben areas possibly due to coverage with unconsolidated new sedimentary deposits.

Information obtained from the satellite image analysis was used not only in field to determine the targets sites to be visited, but also to classify the targets area for reservoir volume estimations.

3.3 Results of the Field Survey and Laboratory Analysis

3.3.1 Geological Survey

(1) Objectives

This site reconnaissance was conducted for the following purposes:

- Confirmation of geology (Topography, rocks, structures, and alteration zones: supplemental survey for existing site survey result);
- Confirmation of alteration zones which were determined by remote sensing; and
- Collection of samples for rocks and alteration minerals.

(2) Methodology

- Site Survey
  The site reconnaissance was conducted in two stages. Exact survey points were selected based on the existing data, remote sensing data, and interview results from local residents. The Dallol and Arabi areas were investigated by GSE experts only.

- Geological Analysis
  The samples collected during site reconnaissance were analyzed by x-ray fluorescence (XRF) for determining rock composition and by X-ray diffraction (XRD) for determining alteration minerals.

Table 3.2 Methodology of Geological Analysis

Type of Samples		Analysis Method	Objective
Rock Samples		XRF	Composition of Rock (%) (SiO_2, Al_2O_3, CaO, MgO, Na_2O, K_2O, Cr_2O_3, TiO_2, MnO, P_2O_5, SrO, BaO)
Alteration Minerals	Zeolite and Others	XRD (powder specimen)	Determination of alteration mineral
	Clay Minerals	XRD (oriented specimen)	Determination of clay mineral
		- Treated by Ethylene Glycol - Treated by HCl	Identification of clay minerals (Chlorite- Kaolinite, Chlorite- Smectite)

Source: JICA Project Team

(3) Results

The results of the geological survey are as follows:

1) Site Survey Results

The results of the site reconnaissance were summarized in the following categories.

i) Topography and route map
ii) General geology
iii) Geological structure, fault, and others
iv) Geothermal manifestation
v) Alteration
vi) Photos and others

In addition, the sites were grouped in accordance to geological and geo-morphological characteristics based on the field reconnaissance and the remote sensing analysis as shown in Table 3.3. The results were used for reservoir resource assessment.

Table 3.3 Geological, Geo-morphological Classifications of the Target Area

Classification	Volcanic body	Caldera	Graben
Target Sites	Dallol Boina Damali Dofan Tulu Moye Aluto Abaya Fantale Boseti	Gedemsa Kone Nazareth Corbetti	Tendaho-Allalobeda Tendaho-Ayrobeda Tendaho-Dubti Teo, Danab Meteka Arabi Butajira

Source: JICA Project Team

2) Results of Laboratory Analysis (XRF and XRD)

The results of the geological laboratory analysis (XRF and XRD) are shown in Table 3.4. The results are as follows:

3) Result of XRF Analysis for Rock Composition

<u>SiO_2-K_2O+Na_2O Diagram (TAS Diagram)</u>

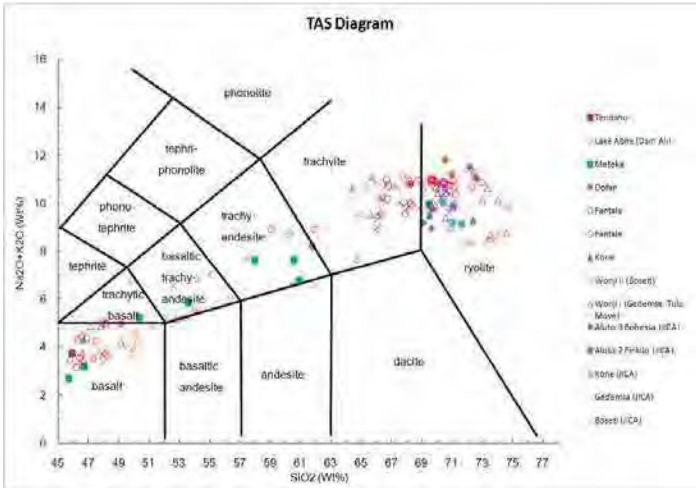
Figure 3.1 shows the results of analysis for the project with the results of existing reports (Electroconsult/Geotermica, 1987; UNDP, 1973).

The results are as follows:

- The analyzed data were in good agreement with the data in existing reports, classified as alkali rock series.
- The compositions of trachyte and rhyolite are similar to that of Olkaria of Kenya. Most of the target sites in Ethiopia are considered to be geologically promising site in the entire African Rift.

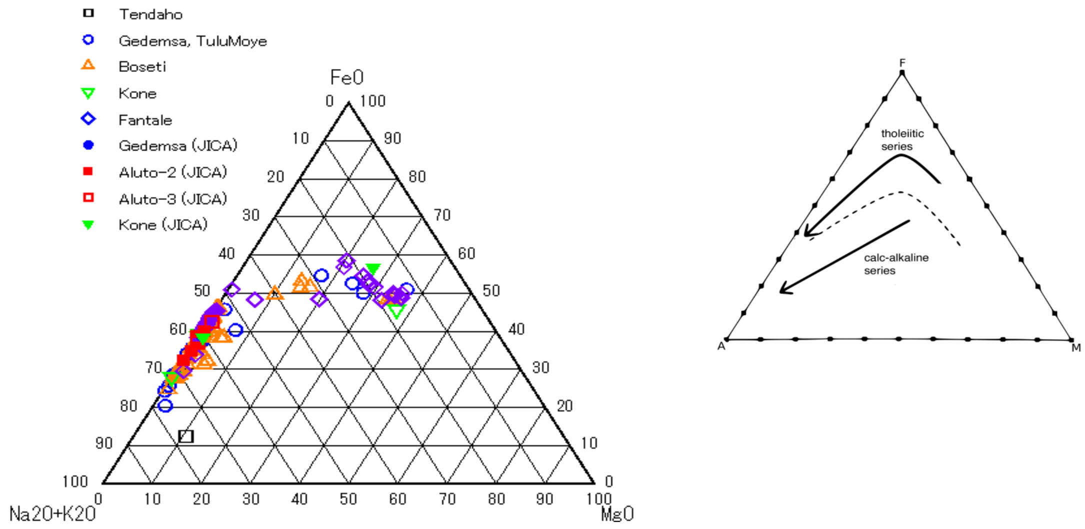
<u>FeO-MgO-K_2O+Na_2O Diagram</u>

FeO-MgO-K_2O+Na_2O Diagram is commonly used for the trend of magmatic segregation in rock series. Figure 3.2 shows the results of analysis for the project with the results of existing reports. Analyzed data were in good agreement with the data in existing reports. Almost all the samples showed similar trends to that of tholeiitic series. All the sites are considered to have similar characteristics such as depth of magma chamber, cooling speed, and others.



Source: JICA Project Team

Figure 3.1 SiO_2-K_2O+Na_2O Diagram (TAS Diagram)



Source: JICA Project Team

Figure 3.2 FeO-MgO-K_2O+Na_2O Diagram

4) Result of XRD Analysis for Alteration Minerals

Table 3.4 shows the results of determination of minerals by XRD.

Table 3.4 Mineral Occurrence by XRD

No.	Site	Location	Sample	Quartz	Opal - CT	Opal - A	Clinoptilolite	Kaolinite	Halloysite	Smectite
140119-02	Bobesa (Aluto-2)	Bobessa	Altered Clay					△		+
140120-03A	Bobesa	Bobessa	Altered Obsidian						+	−
140120-03B	Bobesa	Bobessa	Zeolite						+	−
140120-04	Bobesa	Bobessa	Altered Rock						−	+
140120-05	Bobesa	Bobessa	Secondary Mineral			+				
140120-06	Bobesa	Gebiba	Clay Mineral							+
140121-03	Finkilo (Aluto-3)	Finkilo	Yellow Tuff						−	−
140122-02	Finkilo	Adoshe	Yellow Clay						+	+
140122-03	Finkilo	Adoshe	Red Clay						−	−
140122-04	Finkilo	Adoshe	White Mineral	○		−				
140122-05	Finkilo	Humo	Clay	−					+	+
140122-06	Finkilo	Humo	White Mineral			+				
140122-07	Finkilo	Shutie	Clay	△					+	
140122-08	Finkilo	Shutie	White Mineral	△		−				
140125-01	Gedemsa	Sambo	Zeolite Vein	−		+		+		
140125-03	Gedemsa	Sambo	Altered Welded Tuff	○						
140125-04	Gedemsa	Sambo	White Mineral	○	+		+			
140126-01	Nazereth	Boko	Yellow Tuff		△		○			
140131-03	Boseti	Kintano	Altered Andesite						−	−
140131-04	Boseti	Kintano	White Mineral	+		+				

Source: JICA Project Team

Rock alteration was observed only around geothermal manifestations. Wider areas of alteration zone were not identified, except for Dofan and Meteka sites.

Table 3.4 shows that sites are characterized by the occurrence of Quartz, Opal-A, Opal-CT, Clinoptilorite, Halloysite, Smectite, which suggests that low-grade alteration occurred in those sites. The occurrence of Kaolinite at Gedemsa and Finkilo sites shows trace of hydrothermal alteration.

3.3.2 Geochemistry –Summary

(1) Objectives

In order to characterize the geothermal reservoirs, site reconnaissance of geothermal manifestations, sampling and analysis of geothermal fluid and gas, and examination of the analysis results were conducted. The results of the examination are summarized below.

(2) Methodology

In the site reconnaissance, geothermal manifestations, river, and lake were surveyed at 71 points in total. At the survey points, location (coordinate), altitude, temperature, pH, and conductivity were measured, and samples (32 water and 11 gas samples) were collected from 41 points. The survey areas are as follows:

The second site reconnaissance: Aluto, Bobesa, Finkilo, Gedemsa, Nazreth, Boseti, and Kone

The third site reconnaissance: Dofan, Meteka, Dubti (Tendaho-1), Ayrobeda (Tendaho-2), Allalobeda (Tendaho-3), Seha, Lake Loma, Boseti (additional survey), Dallol, Arabi, and Erer

(3) Results

- Site reconnaissance

The results of the site reconnaissance revealed the facts as below.

In the southwestern part of the Ethiopian Rift Valley, a main geothermal manifestation is fumarole located in uplands. Fumaroles whose temperature is more than 90°C are located in Aluto, Bobesa, and Gebiba; only the fumaroles in Gebiba show a boiling temperature in the southwestern part. The other fumaroles are of lower temperatures (70-90°C) less than a boiling temperature. Hot springs are distributed mainly in lowlands around Langano Lake and the Nazareth area. Their temperatures are middle to low, ranging from 65° to 35°C, and boiling spring were not found. Relatively high temperatures are 65°C of Ouitu (Langano Lake) and 50°C of Sodere (Nazareth).

In the northeastern part of the Ethiopian Rift Valley, fumaroles and hot springs are distributed in upland and lowland areas. The manifestations show temperatures higher than those in the southwestern part. Fumaroles with temperatures higher than 90°C are located in Dofan, Dubti, Ayrobeda. In Dubti and Ayrobeda, temperatures of fumaroles are slightly higher than a boiling temperature. Hot springs distributed in Dofan, Meteka, Allalobeda, and Seha; there are hot springs with the temperature higher than 80°C, except for Dofan. A boiling hot spring is located at Allalobeda.

Taking a wide view of the Ethiopian Rift Valley, Aluto-Langano and Tendaho are the remarkable sites showing prominent activity of geothermal manifestations.

(4) Interpretation of analytical results of samples

- Origin of geothermal fluid

Origin of geothermal fluid can be meteoric water as inferred by the isotopic composition of the geothermal and river/lake waters.

Main anion composition, pH, and isotopic composition of water samples show regional properties in chemical composition as below.

- The geothermal waters in Lake District and Southern Afar are rich in HCO_3, on the contrary, the geothermal waters in Northern Afar are rich in Cl.
- In Lake District, the anion composition of the surface water rich in HCO_3 is unchangeable in the geothermal reservoir where the surface water penetrates, and hence HCO_3-rich water can be reservoir water in the southwestern part of the Ethiopian Rift Valley.
- The similarity in the anion composition between geothermal wells and hot springs indicates that the geothermal fluid taken from Aluto and Langano areas belong to a single geothermal system.
- The geothermal waters in Northern Afar are rich in Cl, and hence similar to those in the geothermal systems in subduction zones.
- The geothermal waters in Tendaho show oxygen shift in the isotopic composition, which means a progress of water-rock interaction.
- The chemistry of Dallol hot spring can be strongly affected by volcanic HCl gas.

(5) Application of geochemical thermometers to geothermal fluid

Na-K-Mg diagram implies that waters from geothermal wells in Tendaho and hot springs in Allalobeda are fully equilibrated with surrounding rock. On the contrary, waters from geothermal wells in Aluto and hot springs of Oiutu in Langano are partially equilibrated with surrounding rock and the other hot spring waters are immature in the state of water-rock interaction.

Comparison among geochemical temperatures and temperatures obtained by well loggings provides conditions as follows: [1] the quartz thermometer shows a good agreement with well-logging temperatures of geothermal wells, [2] temperatures calculated with the quartz thermometer converge within a narrow range in each survey site, so that the quartz temperatures can be recognized as a representative one of the hot spring aquifer, [3] geochemical temperatures of hot springs, except for quartz temperatures of Allalobeda, are lower than those of geothermal wells. [4] There is no a single trend in the orders of temperatures between quartz and Na-K/Na-K-Ca temperatures throughout the all survey sites.

The conditions above demonstrate that no geochemical temperature of hot spring can directly indicate plausible reservoir temperature. For this reason, with an assumption where the temperature difference between the geothermal reservoir and hot spring aquifer is represented by the difference in quartz temperature between a geothermal well in Aluto and hot springs in Langano, the reservoir temperatures were estimated by adding the temperature difference to the quartz temperatures of hot springs for each survey site.

Using the estimated reservoir temperatures and distribution density and activity of geothermal manifestations, the conditions of the reservoir temperature used in a volumetric method were arranged in the four classes of temperature ranges: A: 240°C–290°C, B: 210°C–260°C, C: 170°C–220°C, D: 130°C–170°C.

(6) Geochemical properties of fumarolic gas and steam from a geothermal well

Chemical and noble gas isotopic compositions of fumarolic gas and steam from a geothermal well demonstrate that the origin of the geothermal gas in the Ethiopian Rift Valley is gas emanating from the mantle. The mantle component in the geothermal gas, thus, can be an indicator of the mantle or the magma generated from the mantle as the heat source. Furthermore, the movement of the gas indicates a flow path running from a depth to the surface, that is, a fracture zone. Therefore, it can be said that the obvious contribution of the mantle component in the geothermal gas indicates a highly potential geothermal reservoir at a depth.

(7) Verification of analytical precision at GSE

In order to verify the precision of chemical analysis at GSE, GSE and the JICA study team analyzed shared water samples, and compared the both results. The results and conclusions of the comparison are as follows.

- GSE has sufficient analytical precision for pH, EC (electric conductivity), Cl, SO_4, HCO_3, F, Na, and K.
- GSE’s results show that insufficient analytical precision for a high concentration of SiO_2. A cause of this issue might be a lack of digesting of polymerized silica in the process of the analysis.
- Because K is an important component used in geochemical thermometers, it is preferable for GSE to improve the analytical precision of K in high concentration.
- GSE's analytical precision is insufficient for Ca and Mg. A solution to this problem is use of ICP atomic emission spectroscopy.
- The top priority in the chemical analysis at the GSE laboratory is to achieve sufficient analytical precision for a high concentration of SiO_2 and K. For this reason, in the training course for GSE in Japan, engineers were trained in SiO_2 measurement with spectrophotometry, and Na and K with flame atomic emission spectroscopy. These methods are simple and required apparatus is relatively inexpensive, so that the

employment of these methods is effective in capacity building of the GSE laboratory.

3.4 Preliminary Reservoir Assessment

3.4.1 Objectives

The preliminary geothermal reservoir source assessment was conducted to facilitate the results as basic information for formulating Master Plan on Geothermal Energy Development.

3.4.2 Definition of Resource and Reserve

For this study, the geothermal resource was described according to the definition of Australian Geothermal Energy Group Geothermal Code Committee (AGRCC) in the "Geothermal Lexicon for Resources and Reserves Definition and Reporting Edition 2 (2010)". This definition is the most distinct for resource evaluation at the early stage among similar studies according to the International Energy Agency (IEA)'s comparative study.

The Federal Democratic Republic of Ethiopia's Scaling-Up Renewable Energy Program Ethiopia Investment Plan (Draft Final) shows that the planning aspects of geothermal projects consist of eight stages. The comparison between these eight stages and AGRCC's categories is shown in Table 3.5.

Table 3.5 Comparison between Eight Stages and AGRCC's Categories

Eight Development Stages in Ethiopia	AGRCC, 2010	
	Resource	**Reserve**
(i) Review of existing information on a prospect	Inferred	-
(ii) Detailed surface exploration (geology, geochemistry, and geophysics)		
(iii) Exploration drilling and testing (minimum of three wells)	Indicated	Probable
(iv) Appraisal drilling and well testing		
(v) Feasibility studies	Measured	Proven
(vi) Productive drilling, power plant design, EIA, and reservoir evaluation		
(vii) Power station construction and commissioning		
(viii) Reservoir management and further development		

(Source: JICA Project Team)

There are no boring holes drilled in the geothermal reservoir in the surveyed sites except Aluto and Tendaho. Therefore, the geothermal resources of all other sites are classified under "inferred resources". On the other hand, Aluto-1 (Aluto-Langano) and Tendaho-1(Tendaho-Dubti) sites are classified as "indicated resource" and/or "measured resource".

3.4.3 Methodology of Reservoir Resource Assessment – Volumetric Method

The Volumetric method is used for the reservoir resource assessment. The method was introduced by

USGS (1978) for a rapid assessment. However, the USGS calculation method has appeared not to be prevailing in references. Instead, an equation, similar to USGS's in form but different from it in concept, has been used in many references; therein, unreasonably higher temperatures have been used as the reference temperature. Instead, the JICA Team herein uses a rational and practical calculation method for the assessment of reservoir with temperature not less than 180 ºC shown below.

3.4.4 Probabilistic Approach － Monte-Carlo Method

As a probabilistic approach, the Monte Carlo method was used. The software was the Cristal Ball of Oracle Company. The calculation conditions are given in the table below.

3.4.5 Proposed the parameters

There has not been much information to determine the necessary parameters for the volumetric method. Hereunder described explanations on how the essential parameters have been proposed for future reviews as development states should proceed.

(1) Proposal of the reservoir volumes

In most of the target geothermal sites, surface geological and geochemical surveys only were conducted. Under this circumstance, reservoir volumes were determined with the following procedures.

- The target sites were grouped into three categories (i.e. volcano type, caldera type and graben type) based on the satellite image analysis and site survey;
- Maximum plane area of each site was first determined.
- Most likely plane area of each site then was determined with reference to the existing survey information of Aluto-Langano, Tendaho-Dubti and Corbetti, where MT/TEM survey was already conducted;
- The most likely plane area determined above was adjusted to accommodate field conditions in accordance with intensity of geothermal manifestations and/or fractures.
- Minimum plane area is assumed as zero.

(2) Determination of Reservoir thickness

The parameters shown in the Table 3.6 were assumed.

Table 3.6 Determination of Geothermal Reservoir Thickness

Items	Minimum	Maximum	Most Probably	Notes
Depth to Reservoir top (GL-)	0.5 km	1.0 km	0.8 km	Existing information was referred to for "most probably" determination
Depth to Reservoir bottom (GL-)	3.0 km	3.0 km	3.0 km	－A depth economically reachable by the present or near future technology
Reservoir Thickness	**2.5 km**	**2.0 km**	**2.2 km**	－

Source: JICA Project Team

(3) Determination of Average Reservoir Temperatures

The reservoir average temperatures were proposed in Table 3.7 based on the geochemical assessment conducted by the Master Plan Project.

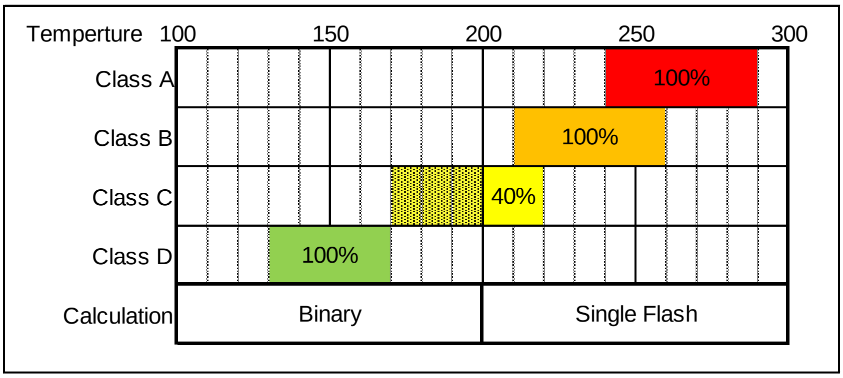
Table 3.7 Average Reservoir Temperatures

Class	Min	Max	Most Probably	Remarks
Class A	240	290	265	6 sites (Tendaho and Aluto)
Class B	210	260	235	7 sites (Boseti, Meteka, etc.)
Class C	170	220	195	7 sites (Nazareth, Arabi, etc)
Class D	130	170	150	2 sites (Gedemsa and Kone)

Source: JICA Project Team

(4) Geothermal Power Plant Type Assumed

A typical single flash power plant a-is assumed for average reservoir temperature not less than 200 ºC and binary power plant for average reservoir temperature less than 200 ºC. The Class C geothermal reservoir includes both temperature categories above 200 ºC and below 200 ºC. For such case, a flash type power plant was selected from a practical and economical point of view, by assuming that 40% of the geothermal reservoir would be above 200 ºC. There will be possibilities that double flash type or Flash/binary combined type may be adopted. However, there are not be sufficient information to examine such possibilities at this stage; and possible increment due to those option will be minimal compared to cost impact, thus those examination was not included in this assessment.



Source: JICA Project Team

Figure 3.3 Average Reservoir Temperature and Power Plant Type

3.4.6 Results of Reservoir Assessment

The assessment results are shown in Table 3.8. The assessment resulted that the most likely value ('mode' in statistic term) is 4,200 MW, value at occurrence probability 80% is 2,000 MW and the value at occurrence probability 20% is 11,000 MW. There 12 geothermal prospects that may have resources more than 100 MW.

It is noted that this calculation results provided the resource estimation of "Inferred level" in principle. However, the total calculation result (91 MW) of Aluto-1 (Aluto-Langano) will include 70 MW of 'Indicated Resource' and 5 MW of 'Measured Resource'; because 70 MW has been estimated by a numerical simulation and 5 MW is the power output of the pilot plant. Similarly, 10 MW of (Indicated resource) that was estimated by a Pre-feasibility Study (2014) is included in 290 MW of Tendaho-1 (Dubti).

Table 3.8 Resource assessment

Unit: MW

Target Site

Site No.		Cumulative probability 80%	Most Probable (mode)	Cumulative probability 20%
19	Corbetti	480	960	2400
16	Abaya	390	790	1900
13	Tulu Moye	202	390	1100
18	Boseti	160	320	800
21	Tendaho-1	140	290	660
4	Damali	120	230	760
7	Meteka	61	130	290
2	Tendaho-3	64	120	320
17	Fantale	64	120	320
14	Aluto-2	58	110	290
22	Tendaho-2	47	100	230
3	Boina	56	100	350
20	Aluto-1	49	91	180
9	Dofan	41	86	200
15	Aluto-3	23	50	110
1	Dallol	23	44	120
12	Gedemsa	20	37	100
11	Nazreth	17	33	100
10	Kone	7	14	42
6	Danab	6	11	30
5	Teo	4	9	23
8	Arabi	4	7	36
New/ Divided Site				
7-2	Meteka-Ayelu	47	53	250
7-1	Meteka-Amoissa	28	89	150
23	Butajira	6	16	30
	Total	**2114**	**4200**	**10791**

Updated After MT/TEM Survey (See Chapter 7)

18	Boseti	175	265	490
22	Tendaho-2	120	180	320

Source: JICA Project Team

4. ENVIRONMENTAL AND SOCIAL CONSIDERATIONS

4.1 Outline of Environmental and Social Impact Assessment Study

The Environmental and Social Impact Assessment (ESIA) study was conducted to evaluate potential environmental impacts due to the geothermal energy development at Initial environmental examination (IEE) level with a comparison of several alternatives.

4.1.1 Objectives of ESIA Study

The main objectives of the ESIA Study are as follows:

- To collect natural and social environmental baseline information in order to identify and assess the potential impacts caused by the Project.
- To identify and assess potential impacts on the social/natural environment and pollution caused by the Project, and
- To prepare the management and monitoring plan for necessary actions toward the potential environmental and social impacts as well as to proposed mitigation measures.

4.1.2 Tasks of ESIA Study

The ESIA Study consists of the following six main tasks.

- Baseline survey (collection and compilation of readily available data and information, and literature review);
- Study on alternative plans applying the concept of strategic environment assessment (SEA);
- Scoping of the environmental impacts caused by the Project activities;
- Prediction and assessment of natural and socio-environmental impacts caused by the Project in the level of initial environmental examination (pre-IEE);
- Mitigation and monitoring plan study; and
- Stakeholders' meeting.

4.2 Environmental Laws and Regulations

4.2.1 Framework of environmental and social laws and regulations

Major Regulations, Guidelines and Proclamations applicable to the geothermal energy development project are listed in Table 4.1 below.

Table 4.1 Major Regulations, Guidelines and Proclamations

No.	Title	No.	Date of Issue
1	Environmental Impact Assessment Proclamation	299	31 Dec, 2002
2	Environmental Pollution Control Proclamation	300	03 Dec, 2002
3	Environmental Protection Organs Establishment Proclamation	295	31 Oct, 2002
4	Expropriation of Landholdings for Public Purposes and Payment of Compensation Proclamation	455	15 Jul, 2005
5	Rural Land Administration and land Use Proclamation, Proclamation	456	15 Jul, 2005
6	Ethiopian Water Resource Management Proclamation	197	Mar, 2000
7	Solid Waste Management Proclamation	513	12 Feb, 2007
8	Environmental Impact Assessment Procedural Guideline Series 1		Nov, 2003
9	Draft EMP for the Identified Sectoral Developments in the Ethiopian Sustainable Development & Poverty Reduction (ESDPRP)		01 May, 2004
10	Investment Proclamation	280	02 Jul, 2002
11	Council of Ministers Regulations on Investment Incentives and Investment Areas Reserved for Domestic Investors	84	07 Feb, 2003
12	The FDRE Proclamation, “Payment of Compensation for Property Situated on Landholdins Expropriated for Public Purposes”	455	2005
13	Council of Ministers Regulation, “Payment of Compensation for Property Situated on Landholdins Expropriated for Public Purposes”	135	2007
14	Oromia Regional Administration Council Directives, “Payment of Compensation for Property Situated on Landholdins Expropriated for Public Purposes”	5	2003
15	Investment (Amendment) Proclamation	373	Oct, 2003

Source: JICA Project Team

4.2.2 Environmental Impact Assessment

(1) Laws and regulations relating to EIA in Ethiopia

According to the EIA Procedural Guideline, projects are categorized into three schedules:

Schedule-1: Projects, which may have adverse and significant environmental impacts and therefore require a full Environmental Impact Assessment.

Schedule-2: Projects whose type, scale or other relevant characteristics have potential to cause some significant environmental impacts but are not likely to warrant a full EIA study.

Schedule-3: Projects which would have no impact and do not require an EIA.

Projects for geothermal power plant fall under the schedule I activities.

(2) EIA Process

The general description of the EIA process and the permit requirements are detailed in the EIA Procedural Guideline Series 1 of the FDRE. As a minimum, the following descriptions shall be presented:

- the nature of the project, including the technology and processes to be used and their physical impacts;
- the content and amount of pollutants that will be released during implementation as well as during operation;
- source and amount of energy required for operation;

- characteristics and duration of all the estimated direct or indirect, positive or negative impacts on living things and the physical environment;
- measures proposed to eliminate, minimize, or mitigate negative impacts;
- a contingency plan in case of accidents;
- Procedures of internal monitoring and auditing during implementation and operation.
- Environment related standards and Limit Values

The following standard and limit values were indentified for an application to geothermal energy development projects.

- Draft Standards for Industrial Emission and Effluent Limits (Ethiopian EPA)
- National Noise Standard at Noise Sensitive Areas
- Environmental, Health and Safety (EHS) Guidelines for Emission Gas (World Bank)
- EHS Guidelines for Effluent (World Bank)
- EHS Guidelines for Noise Management (World Bank)

(3) Legislation related to the resettlement and land acquisition

Constitution (1995) assure right of private property for citizen but not land ownership. The land is recognized as public common property and its usufruct right can be processed, sold and transferred by citizens. “Federal Democratic Republic of Ethiopia Rural Land Administration and land Use Proclamation, Proclamation No.456/2005” provides the rural land use right. The law also prescribes the governmental responsibility that regional government have obligation to organize adequate legislative administration under the central governmental policy.

Principle of the land acquisition for the public purpose is provided in the constitution (1995) and the detail procedure such as expropriation process and compensation standard are prescribed in “the Expropriation of Landholding for Public Purposes and Payment of Compensation Proclamation, Proclamation No. 455/2005”. “Payment of Compensation for Property Situated on Landholdings Expropriated for Public Purposes, Council Ministers Regulation No. 135/2007” also provides further detail standard such as compensation standard for the each expropriating asset. According to the regulation (2007), land expropriation is implemented by local government, Woreda or Urban administration exclusively for the public purpose and it should be adequately compensated to PAPs.

(4) Gaps between Ethiopian Legislations and JICA Guidelines (2010) Policies on Environmental Assessment

The JICA Environmental guidelines and the legislation in the country do not have major contradiction, except perhaps certain procedural adjustments during project implementation such as public consultation and public disclosure.

4.2.3 Institutional Framework of Environmental Management in Ethiopia

The most important step in setting up the legal framework for the environmental in Ethiopia has been the establishment of the Environmental Protection Authority (EPA). The EPA, established under the proclamation no. 295/2002, is now a ministerial level environmental regulatory and monitoring body. The objectives of the EPA are to formulate policies, strategies, laws and standards. It is, therefore, the responsibility of the EPA. in the EIA process.

The proposed geothermal power plants are subject to several policies and programs aimed at development and environmental protection. The EPA regulates the environmental management system for all projects across the country. Following shows the major institutions or organizations.

- Regional Government
- The Geological Survey of Ethiopia (GSE)
- Ministry of Water and Energy (MoWE)
- Ethiopian Electric Power Corporation (EEPCo)
- Pastoralist and Agricultural and Rural Development Office of Regional State
- Corporate Planning Department of EEP

4.3 Baseline Survey

4.3.1 Methodology of Baseline survey

Standard methodologies to collect data and information at the prospective geothermal energy development sites were applied.

4.3.2 The Baseline data

As the baseline, following data were collected.

- Profile of the Study Area
- Natural, Historical and Cultural Heritages
- Ecological Protected Area
- Possible Impacts by Transmission Line

4.4 Strategic Environmental Assessment (SEA)

Although implementation of SEA for development projects is not compulsory at present in Ethiopia, considering the definition and the concept of SEA mentioned above, SEA for geothermal energy projects were discussed in this report in the following point of views.

- Ethiopian **energy policy on geothermal development,**
    - Conservation strategy of Ethiopia (CSE)
    - Environmental Policy of Ethiopia (EPE)

- National Energy Development Policy

- **Project alternatives including “do-nothing” option**
  - Energy Resource Alternatives
  - Project Alternatives
- **Project perspective from guidelines of financial institutions,**
- **Alignment of JICA guidelines with national policies**

4.5 Implementation of IEE

An Initial Environmental Examination (IEE) was carried out based on the baseline data and information, namely readily available information including existing data and simple field surveys.

4.5.1 Project Categorization

(1) General

According to the JICA Environmental Guidelines (April 2010), projects are classified into four categories. Table 4.2 below shows the comparison of projects categorization defined by JICA and Ethiopian national EPA Guideline.

Table 4.2 Environmental Categorization of Projects

Project type	JICA Guidelines	Ethiopia EPA Guideline	EIA requirement
Likely to have significant adverse impacts on the environment and society. Projects with complicated or unprecedented impacts that are difficult to assess, or projects with a wide range of impacts or irreversible impacts	Category A	Schedule-1	Full EIA
Have potential adverse impacts on the environment and society are less adverse than those of Category A projects. Generally, they are site-specific; few if any are irreversible; and in most cases, normal mitigation measures can be designed more read	Category B	Schedule-2	Not likely to warrant a full EIA study
Have are likely to have minimal or little adverse impact on the environment and society.	Category C	Schedule-3	Environmental review will not proceed after categorization
Projects which satisfy the following JICA’s requirements: projects of JICA’s funding to a financial intermediary or executing agency; the selection and appraisal of the sub-projects is substantially undertaken by such an institution only after JICA’s approval of the funding, so that the sub-projects cannot be specified prior to JICA’s approval of funding (or project appraisal); and those sub-projects are expected to have a potential impact on the environment.	Category FI	-	Environmental review will proceed after categorization

(Source: JICA Study Team)

(2) Classification of geothermal energy development project

Appendix I (Schedule of Activities) of the Environmental Impact Assessment Guideline Document (May 2000) classifies projects by their type of activities. Based on the project classification, geothermal energy development projects with capacities more than 25 MW require the implementation of full scale EIA.

4.5.2 Scoping for Initial Environmental Examination

Geothermal energy is generally more environmentally sound compare to other energy sources such as fossil fuel burnings, there are certain negative impacts that must be considered and managed when geothermal energy is to be developed.

Most of potentially important impacts of geothermal power plant development are associated with groundwater use and contamination, and with related concerns about land subsidence and induced seismicity as a result of water injection and production into and out of a fractured reservoir formation. Some considerations should also be taken for issues of air pollution, noise, safety, and land use.

4.5.3 Socio-environmental Interactions

In order to grasp the livelihood conditions in and around the prospective sites, questionnaire surveys for energy and water sector offices at woreda levels were conducted.

The survey revealed that the main source of energy both for cooking and light was fuel wood, coal and dung. In addition to this, energy consumption per capita of the community is very low.

With regard to water source and supply, there is critical shortage of sufficient and uninterrupted water supply. But in all other sites, access to potable (treated) water is still a priority. There seemed to be water resource competition and fast land use change in some of the surveyed areas. The finding revealed that the community believed the project would bring about little negative impact. However in terms of the serious shortage of water all community in all sites required the supply of water. Thus there is a strong need of residents to implement community projects to access potable water source, parallel to the main geothermal project.

4.5.4 Displacement and Resettlement

The scale of geothermal energy development project is not yet determined at present, some of the areas within the prospective sites shall be acquired by the project proponent for implementation of the project. Data and Information on land clam were collected through interviews at kebele level in the prospective sites. After the determination of the project site and the project scale, detailed land boundary should be settled according to the land acquisition procedure of the government of Ethiopia.

4.6 Environmental Management Plan

4.6.1 Environmental Management Plan (EMP)

Environmental Management Plan (EMP) is prepared on the basis of identified impacts and their level of significance. Significant impacts that are detailed in the previous section shall be mitigated through appropriate methods and then subject to mechanisms of environmental management plan using monitoring and auditing as instrument.

4.6.2 Monitoring plan

Environmental monitoring plan is included in the EMP. Environmental monitoring and auditing shall be undertaken in all phases of project activities to check that the proposed environmental management measures are being satisfactorily implemented and that they are delivering appropriate level of environmental performances. A general form of monitoring plan to be applied to the prospective sites was given in this report.

4.7 Consultation with stakeholder

Stakeholder Consultations were implemented in the ESIA Study, namely at scoping stage, through the interviews at communities (March –July 2014).

Consultation with stakeholder at the prospective sites had been conducted through interview and using questionnaires. Interview and questionnaire surveys had been conducted at seven woreda-level sector offices, and more than 100 officials from different sectors were participated. In order to remove the issues and concerns of the community, due regards and detailed explanations were given to the community based on the legal, social and environmental land regulations stated in the proclamation of Federal Republic of Ethiopia No. 1/1995..

4.8 Recommendation6

Geothermal energy development projects with a capacity more than 25 MW shall require the implementation of full scale EIA prior to the implementation of the project. The EIA process consists of series of several procedural phases starting from pre-screening consultation with EPC and submission of a screening report and ending up by obtaining an EIA approval. The project proponent should start the EIA procedures in cooperation with other sectoral agencies such as Ministry of Water, Irrigation and Energy (MoWIE), regional governments, etc. For the implementation of the EIA, followings should be noted:

- EIA should be conducted in accordance with the Ethiopian EIA process.
- EIA should be carried out for the selected site by the project proponent according to the Ethiopian Guidelines and/or international requirements.

- After the determination of the project site(s), EIA should start prior to the test drillings, and continuously conducted parallel to the test drilling.
- The EIA report prepared based on above shall be revised considering the results of the test drilling above. Results of ESIA survey conducted in this master plan study can be utilized for the implementation of the EIA
- Additional EIA should be conducted if necessary according to the revised EIA report.
- The EIA is to be conducted considering the specific features of environmental impacts of geothermal energy development.
- EIA approval should be obtained before the application of the development right of the project.

5. FORMULATION OF MASTER PLAN

5.1 Target and Methodology

The master plan was formulated by first setting out the development targets and then by prioritizing the identified candidate projects to meet the targets set out.

5.1.1 Target of the Master Plan

Table 5.1 gives the development targets for this master plan.

Table 5.1 Development Target of the Master Plan

Item	Target		Remarks
Period	2015–2037 (23 years) Short term: 2015-2018 (4 years) Medium term: 2019-2025 (7 years) Long term: 2026-2037 (12 years)		EEP MP: 2013–2037 (25 years) Wind and Solar MP: 2011–2020 (10 years)
Installed Capacity	Short term	700 MW	Committed and ongoing sites
	Medium term	1,200 MW	Same target as EEP MP
	Long term	5,000 MW	Same target as EEP MP

MP: Master Plan
Source: JICA Project Team

5.1.2 Methodology of the Master Plan

Five criteria are used: (i) development status, (ii) environmental risks, (iii) geothermal potential, (iv) economics, and (v) site specific factors.

5.2 Multi-Criteria Analysis for Prioritizing the Geological Prospects

5.2.1 Factors to be Considered

(1) Development Status

Using the Australian Geothermal Reporting Code Committee classification, reliability of geothermal resource evaluation was classified.

Table 5.2 below shows the classification of geothermal resources. Aluto-1 (Aluto-Langano) and Tendaho-1 (Dubti), where some test drillings were already done, are evaluated as “measured” and “indicated” resource, respectively. Other sites where any detailed exploration surveys have yet to be done are evaluated as inferred resource.

(2) Socio-environmental Impact

According to the environmental and social consideration, Fantale geothermal prospect is located in/around the Awash National Park. For this reason, Fantale prospect is given a low priority in the ranking. The other 21 geothermal sites are not located in the range of the national park and do not have immitigable adverse environmental risks and impacts.

(3) Geothermal Potential

In this study, the installed capacity of each power plant is set as equal to the geothermal potential (at the most probable case) in each prospect except Aluto-1 (Aluto-Langano). Other donors of a private firm have started development and drilling surveys of some of the prospects, such as Corbetti, Aluto-1 (Aluto-Langano), and Tendaho-1 (Dubti). Kone and Gedemsa where the estimated temperature were as low as 130~170 °C (based on the geochemical analysis), were suitable only for binary-type generation. Therefore, Kone and Gedemsa prospects were placed at a lower priority due to extremely low power output with higher energy cost.

Table 5.2 Development Status and Geothermal Resource

Site		Temperature Class	Geothermal Resource		
			Inferred	Indicated	Measured
1	Dallol	B	44	N/A	N/A
2	Tendaho-3 (Allalobeda)	A	120	N/A	N/A
3	Boina	C	100	N/A	N/A
4	Damali	C	230	N/A	N/A
5	Teo	B	9	N/A	N/A
6	Danab	B	11	N/A	N/A
7	Meteka	B	130	N/A	N/A
8	Arabi	C	7	N/A	N/A
9	Dofan	B	86	N/A	N/A
10	Kone	D	14	N/A	N/A
11	Nazareth	C	33	N/A	N/A
12	Gedemsa	D	37	N/A	N/A
13	Tulu Moye	C	390	N/A	N/A
14	Aluto-2 (Finkilo)	A	110	N/A	N/A
15	Aluto-3 (Bobessa)	A	50	N/A	N/A
16	Abaya	B	790	N/A	N/A
17	Fantale	C	120	N/A	N/A
18	Boseti	B	265	N/A	N/A
19	Corbetti	B	1000[*1]	N/A	N/A
20	Aluto-1 (Aluto-Langano)	A	16	70[*2]	5
21	Tendaho-1 (Dubti)	A	280	10[*3]	N/A
22	Tendaho-2 (Ayrobera)	A	180	N/A	N/A

N/A: Not available

[*1] *Reykjavík Geothermal*
[*2] *Study on Geothermal Power Development Project in the Aluto Langano Field, Ethiopia, METI (Japan), 2010,* [*3] *Consultancy Services for Tendaho Geothermal Resources Development feasibility Study, ELC, 2013*

Source: JICA Project Team

(4) Economics of Candidate Plants

The project economics are measured by two indicators: (i) generation cost and (ii) economic viability.

- Cost of Electricity Generation

To compare the competing power plants (geothermal, hydropower and other plant types), the electricity generation costs (cost of generation) per kWh are calculated.

The results are shown in Table 5.3 below.

Table 5.3 Ranking Order of the Geothermal Prospects

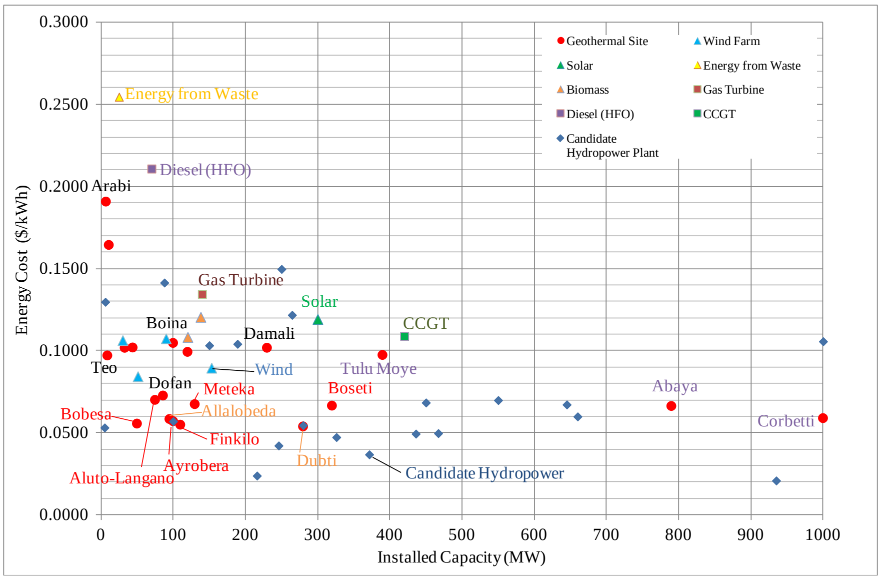
Ranking Order	Geothermal Site	Temp. Class	Installed Capacity (MW)	Cost of Genaration ($/kWh)	Remarks
1	Tendaho-1(Dubti)	A	290	0.0572	Shallow reservoir is committed.
2	Aluto-2 (Finkilo)	A	110	0.0585	
3	Corbetti	B	1,000	0.0589	Committed site
4	Aluto-3 (Bobesa)	A	50	0.0592	
5	Tendaho-2 (Ayrobera)	A	180	0.0593	
6	Tendaho-3 (Allalobeda)	A	120	0.0621	Committed site
7	Aluto-1 (Langano)	A	75	0.0700	Committed site
8	Abaya	B	790	0.0717	
9	Boseti	B	265	0.0721	
10	Meteka	B	130	0.0731	
11	Dofan	B	86	0.0783	
12	Tulu Moye	C	390	0.1037	
13	Teo	B	9	0.1040	
14	Fantale	C	120	0.1050	
15	Dallol	B	44	0.1076	
16	Damali	C	230	0.1084	
17	Nazareth	C	33	0.1091	
18	Boina	C	100	0.1111	
19	Danab	B	11	0.1700	
20	Arabi	C	7	0.1872	
-	Gedemsa	D	37	-	Low temperature
-	Kone	D	14	-	Low temperature

Source: JICA Project Team

Figure 5.1 and Figure 5.2 compares the generation costs of geothermal and hydropower, and geothermal and other power plants respectively.

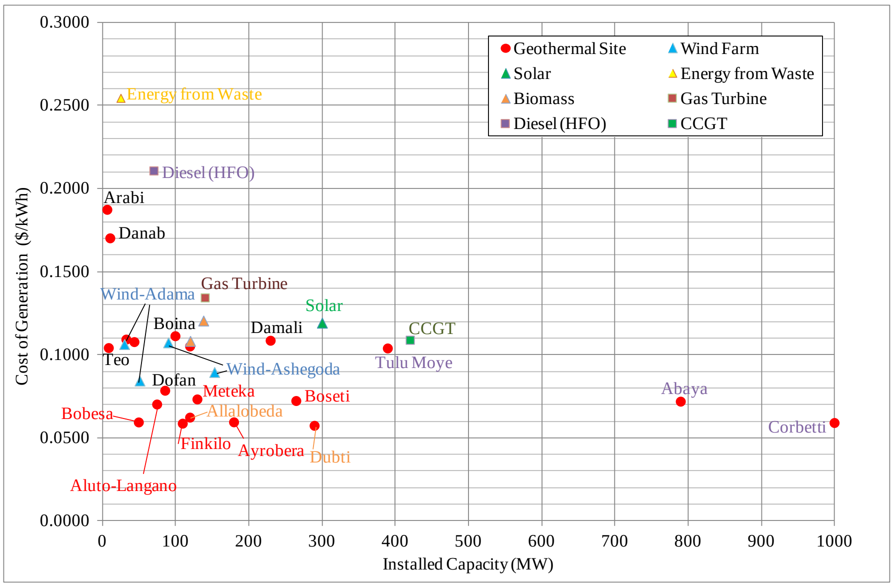
Generally, the generation cost of hydropower is lower than that of geothermal power plants. However, some geothermal power plants are much more competitive and are more reasonable than some candidate hydropower plants with similar capacity. In comparison with other renewable energy and thermal power plants, the geothermal prospects ranked No.1 to No.11 in Table 5.3 are superior to even Adama and Ashegoda wind farm that exceeds US$0.08/kWh.

Therefore, from the point of view of least cost generation, geothermal must be prioritized over wind and solar in Ethiopia. The geothermal prospects with generation cost of US$0.10/kWh are almost equal to wind and solar and more economical than gas turbine and diesel. The diesel generation and waste from energy are much more expensive than the geothermal prospects.



Source: JICA Project Team

Figure 5.1 Generation Cost of Geothermal and Hydropower Plants



Source: JICA Project Team

Figure 5.2 Generation Cost of Geothermal and Other Power Plants

If the Government of Ethiopia adopts preferential policy such as advantageous interest rate to promote geothermal development, geothermal is expected to become more competitive.

- Economic Viability

The economic viability of a geothermal plant is evaluated using the economic internal rate of return (EIRR). The EIRRs are given in Table 5.2. Out of 18 projects, 16 are economically viable since the EIRRs are more than the hurdle rate of 10%. Two projects (Danab and Arabi) are not economically viable.

Table 5.4 Ranking of Geothermal Power Plants and EIRR

Ranking Order	Geothermal Site	Installed Capacity (MW)	Cost of Genaration ($/kWh)	EIRR (%)
1	Tendaho-1(Dubti)	290	0.0572	31.7%
2	Aluto-2 (Finkilo)	110	0.0585	31.1%
3	Corbetti	1,000	0.0589	-
4	Aluto-3 (Bobesa)	50	0.0592	30.7%
5	Tendaho-2 (Ayrobera)	180	0.0593	30.8%
6	Tendaho-3 (Allalobeda)	95	0.0621	29.1%
7	Aluto-1 (Langano)	75	0.0700	-
8	Abaya	790	0.0717	25.2%
9	Boseti	265	0.0721	25.0%
10	Meteka	130	0.0731	24.7%
11	Dofan	86	0.0783	23.1%
12	Tulu Moye	390	0.1037	17.0%
13	Teo	9	0.1040	17.4%
14	Fantale	120	0.1050	16.7%
15	Dallol	44	0.1076	16.6%
16	Damali	230	0.1084	16.2%
17	Nazareth	33	0.1091	16.2%
18	Boina	100	0.1111	15.8%
19	Danab	11	0.1700	9.9%
20	Arabi	7	0.1872	8.7%
-	Gedemsa	37	-	-
-	Kone	14	-	-

Source: JICA Project Team

(5) Site Specific Factors

i) Socio-environmental Impact

Social and environmental impact, except for national park, is taken into consideration for the prioritization. In addition, it was judged that there would be a potential conflict with local people in the Dofan prospect. Therefore, Dofan was adjusted to be ranked below the level of the economy group.

ii) Accessibility to the Sites

Taking into consideration the topography along the access road as well as for security measures, cost of civil works for the access road and earthworks in the site was estimated as preparatory work in the construction cost mentioned above. Because the poor accessibility reflects the generation cost, prospects located in remote areas such as Damali and Danab are evaluated low in the rank order of the generation cost.

5.2.2 Prioritization of the Geothermal Prospects

To sum up the prioritization of geothermal prospects using multi-criteria analysis mentioned above, the prioritization order is summarized as shown in Table 5.5.

Table 5.5 Prioritization Order of the Geothermal Prospects

Ranking Order	Geothermal Site	Installed Capacity (MW)	Remarks	
Priority-S: Committed Project			COD	Donor
S	Tendaho-3 (Allalobeda)	25	2017	WB
S	Corbetti	500	2018	RG
S	Aluto-1 (Langano)	70	2018	Japan/WB
S	Tendaho-1 (Dubti)-Shallow reservoir	10	2018	AFD
Priority-A: Very High Economy			Energy Cost (US$/kWh)	
1	Tendaho-1 (Dubti)-Deep reservoir	280	0.0572	Deep reservoir
2	Aluto-2 (Finkilo)	110	0.0585	
3	Aluto-3 (Bobesa)	50	0.0592	
4	Tendaho-2 (Ayrobera)	180	0.0593	
5	Tendaho-3 (Allalobeda)	95	0.0621	Expantion
Priority-B: High Economy			Energy Cost (US$/kWh)	
6	Abaya	790	0.0717	RG has license
7	Boseti	265	0.0721	
8	Meteka	130	0.0731	
Priority-C: Low Economy			Energy Cost (US$/kWh)	
9	Tulu Moye	156	0.1037	RG has license
10	Teo	9	0.1040	
11	Damali	92	0.1084	
12	Nazareth	13.2	0.1091	
13	Boina	40	0.1111	
14	Dofan	86	0.0783	Conflict with residents
15	Dallol	44	0.1076	Difficult due to low pH
Priority-D: Less Feasible			Energy Cost (US$/kWh)	
16	Danab	11	0.1700	Poor access
17	Arabi	2.8	0.1872	Poor access
D	Gedemsa	37	-	Low temperature
D	Kone	14	-	Low temperature
D	Fantale	48	-	Overlapped with national park

Source: JICA Project Team

5.3 Implementation Plan

5.3.1 General Consideration

Development process of geothermal power plant before the start of generation consists of nine stages: (i) preliminary survey, (ii) exploration, (iii) appraisal drilling and well testing, (iv) Feasibility survey, (v) environmental impact assessment, (vi) well/power plant design, (vii) well drilling, (viii) power station construction and (ix) start-up and commissioning. Taking into consideration the various development status, which may allow omitting the preliminary survey and exploration, development plans for each prospect with respect to the fastest case are discussed in the next section based on the model case above.

5.3.2 Development Plan

Table 5.6 shows overall schedule of geothermal power development taking into account the fastest case discussed in previous section.

Table 5.6 Overall Schedule of Geothermal Power Development

Ranking Order	Prospect	Installed Capacity (MW)	Cost of Generation (US$/kWh)	COD	Year of 20**																							
					Short-term					Medium-term							Long-term											
					14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
S	Tendaho-3	25	-	2017				◎																				
S	Corbetti	500	-	2018					◎																			
S	Aluto-1	75	-	2018					◎																			
S	Tendaho-1	10	-	2018					◎																			
-	Sub-total	610		-				25	610	610	610	610	610	610	610	610	610	610	610	610	610	610	610	610	610	610	610	610
1	Tendaho-1	280	0.0572	2020							◎																	
2	Aluto-2	110	0.0585	2020							◎																	
3	Aluto-3	50	0.0592	2021								◎																
4	Tendaho-2	180	0.0609	2021								◎																
5	Tendaho-3	95	0.0624	2021								◎																
-	Corbetti	500	0.0585	2022	Lisenced by RG								◎															
6	Abaya	790	0.0717	2024	Lisenced by RG										◎													
7	Boseti	265	0.0720	2024											◎													
8	Meteka	130	0.0731	2024											◎													
	Sub-total	2400	-	-							390	715	1215	1215	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
9	Tulumoya	390	0.0974	2027														◎										
10	Teo	9	0.0971	2027														◎										
11	Damali	230	0.1017	2029																◎								
12	Nazareth	33	0.1017	2029																◎								
13	Boina	100	0.1047	2029																◎								
14	Dofan	86	0.0726	2030																	◎							
15	Dallol	44	0.1019	2030																	◎							
16	Danab	11	0.1643	2036																							◎	
17	Arabi	7	0.1907	2036																							◎	
-	Gedemsa	37	-	2036																							◎	
-	Kone	14	-	2036																							◎	
-	Fantale	120	-	2036																							◎	
	Sub-total	691	-	-														399	399	762	892	892	892	892	892	892	1081	1081
total		3701						25	610	610	1000	1325	1825	1825	3010	3010	3010	3409	3409	3772	3902	3902	3902	3902	3902	3902	4091	4091

◎: Commencement of Operation

Source: JICA Project Team

<u>Short-term (2014–2018)</u>

From 2015 to 2018, a total output of 610 MW from the geothermal power plants will be developed in the short-term in this master plan.

The committed geothermal power plants and large-scale hydropower plants under construction, such as the grand renaissance dam, are expected to generate much more electricity than the forecasted electricity demand in the short-term. Therefore, some of other power plants generated with other sources could be implemented in a later stage than planed in EEP master plan as explained below

<u>Medium-term (2019–2025)</u>

According to economic evaluation, the Priority-A and -B prospects are more economical than other power generation schemes such as wind farms and solar power. Therefore, their development should be prioritized over other power generation schemes in terms of least-cost power generation plan. EEP master plan has an expected total of 1,200 MW from wind farms and solar power generation which are not specified projects in the short-term up to 2018. The JICA Project Team would like to propose that wind farms and solar power generation projects that are not specified should be delayed and construction of geothermal power plants, which are mainly planned in the long-term, should be moved forward instead.

<u>Long-term (2026–2037)</u>

Since most of the hydropower potential in Ethiopia is expected to be developed in the long-term and electricity demand is forecasted to exceed 20,000 MW in the early 2030s, more geothermal potential is anticipated to be developed. In this master plan, all geothermal potential 4,100 MW is planned to be developed by 2037.

5.4 Financial Considerations for Geothermal Development

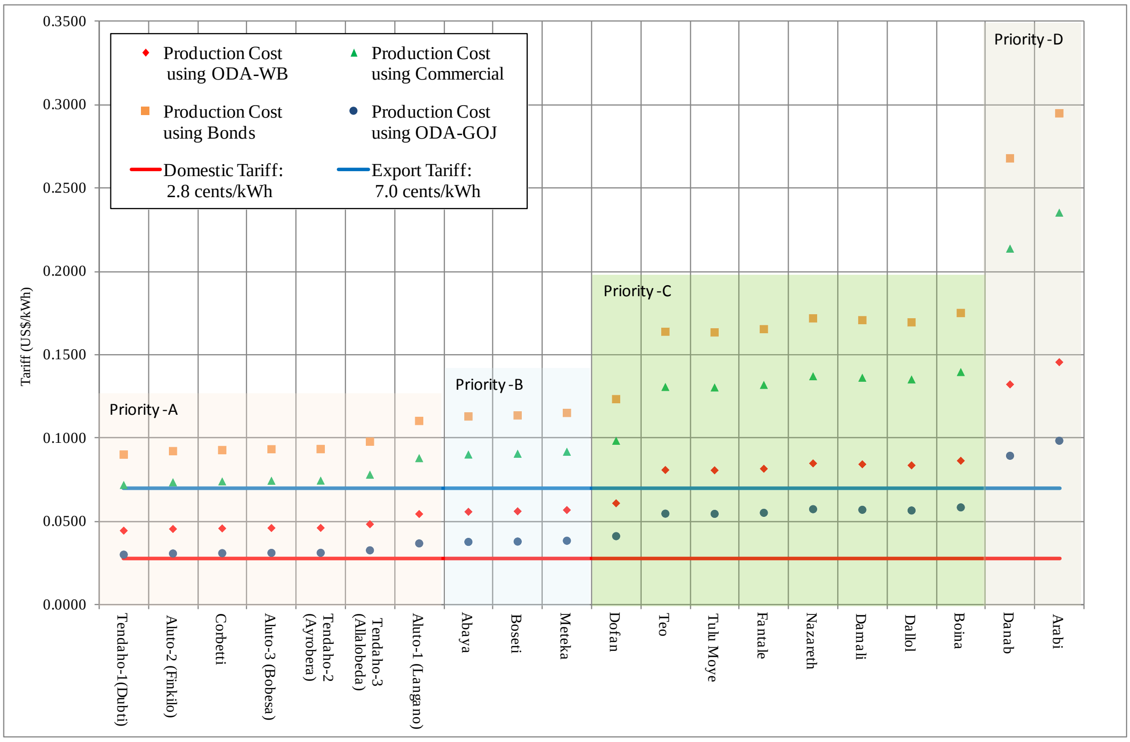
There will be four possible sources of funds: Word Bank ODA loans, Japan's ODA loan, commercial banks loans and bonds issue. Their financing conditions (interest rates and repayment periods) are summarized in Table 5.7.

Figure 5.3 shows the comparison with capital costs of each condition and existing power price (consumer price). It is concluded that concessional public loans such as Japan's ODA and/or WB loans should be utilized to construct geothermal power plants.

Table 5.7 Possible Funds Loan Conditions

Item	ODA-WB	ODA-GOJ	Commercial Banks	Bonds
Interest (%)	5.0	3.0	6.0	5.0
Repayment period (year)	20	30	10	7

Source: IDA



Source: JICA Project Team (Fund procurement condition is referred to IDA)

Figure 5.3 Tariff and Production Cost using Several Funds

5.5 Implementation Structure

The energy cost of geothermal power generation shall be below the presently adopted electricity retail tariffs under the conditions of the present energy price policy.

A case study was conducted where four value chain models were assumed with tariff variation for each case. Tariffs here are defined as the sales tariffs charged for the electricity generated by the geothermal power plant at the delivery point to off-takers (Figure 5.4). With the current tariff levels, possible and sustainable options are a fully public model for the domestic supply project, and Models C or D for the export supply project.

Business Model	Preliminary Survey	Exploration	Test drilling	F/S & planning	Field development	Plant construction	Operation: Field	Operation: Plant	Tariff ($/kWh)	Remarks
A	Public	Private							0.15	Corebetti
B	Public		Private						0.13	
C	Public			Private					0.10	
D	Public					Private	Public	Private	0.05	Tendaho
Full Public	Public								0.03	Aluto Langano

Source: IFC

Figure 5.4 PPP Model Options and Tariff

The Project Team recommended establishing a new public enterprise EEGeD (Ethiopian Enterprise for Geothermal Energy Development) by merging the geothermal relevant organizations in GES and EEP.

6. GEOPHYSICAL SURVEY

6.1 Purpose

At two selected geothermal sites, the geophysical survey was conducted to contribute to the creation and estimation of geothermal reservoir model and the planning of test drilling survey.

6.2 Selection of the Sites

The master plan presented in the section 5 nominated three priority sites, Tendaho-2 (Ayrobera), Boseti and Meteka, as green fields for development. Among those, we selected Tendaho-2 (Ayrobera) and Boseti for the geophysical survey under the master plan project. It is expected that GSE will undertake the geophysical survey in Meteka with equipment and training provided by JICA

6.3 Outline of Methodology

At the project, MT/TEM survey was conducted. The outline of methodology is described below.

6.3.1 Survey Method

- MT method with far remote reference site
- TEM method with central loop system（for static correction of MT data）

6.3.2 Number of stations

The number of survey stations and the locations of the remote reference are given in Table 6.1.

Table 6.1 Number of survey stations and location of remote reference station

Survey site	Stations	location of remote reference station	Remarks
Tendaho-2 (Ayrobera)	24	Mille	Adding the existing 81 stations for data analysis
Boseti	30	Koka	-

Source: JICA Project Team

6.3.3 Acquired data

The acquired data were as follows.

Table 6.2 Acquired data of geophysical survey

Survey method	Acquired data	Remarks
MT method	Time series data • 3 components in magnetic field (Hx, Hy, Hz) • 2 components in electric field (Ex, Ey)	Measurement time: more than 14 hour per one station
TEM method	Transient response 1 component in magnetic field (Hz)	-

Source: JICA Project Team

6.4 Survey results

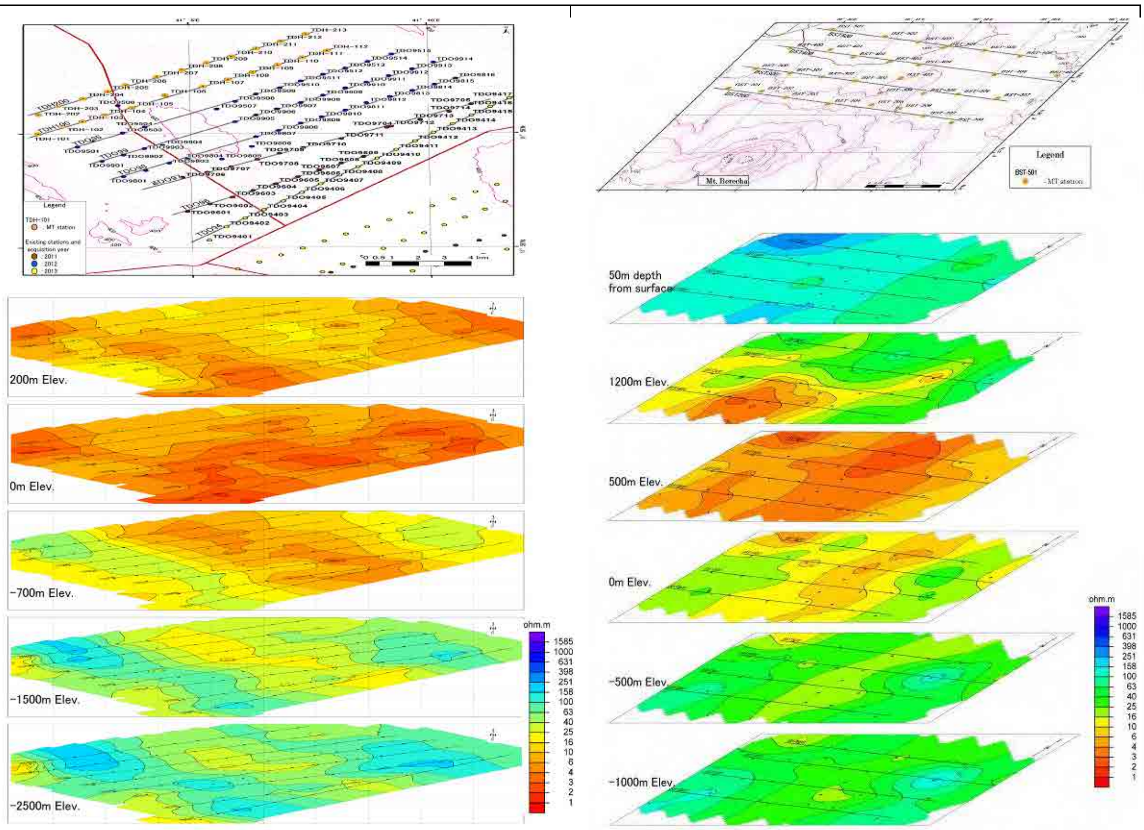
The panel diagrams of the resistivity plan map created on the basis of the results of MT/TEM survey at Tendaho-2 (Ayrobera) site and Boseti site are shown in Figure 6.1. The resistivity structures are described below.

6.4.1 Tendaho-2 (Ayrobera) site

- Generally the resistivity structure composed of three zones namely conductive overburden, resistive zone and conductive zone at depth from surface to -5,000 m elevation. The resistivity distribution is roughly in the range of 1 ohm-m to 250 ohm-m.
- The conductive belt of NW-SE direction distributes from -700 m elevation to the deep zone and composes the channel structure of low resistivity in the center of the site. That channel structure shows the strike direction of the resistivity structure clearly.
- The resistivity variation between the channel structure composed by the distribution of low resistivity and the distribution of high resistivity at the outside of the channel structure is steep and indicates resistivity discontinuity.
- The channel structure of low resistivity is rather narrow in width and shows a little constriction characteristically around profile TDO97. This characteristic suggests the resistivity discontinuity across the channel structure.

6.4.2 Boseti site

- Generally the resistivity structure composed of three zones namely resistive overburden, conductive zone and resistive zone at depth from surface to -3,000 m elevation. The resistivity distribution is roughly in the range of 1 ohm-m to 600 ohm-m.
- The distribution of the conductive belt of NNE-SSW direction continues form 500 m elevation to the deep zone and composes the channel structure of low resistivity in the center of the site. That channel structure shows the strike direction of the resistivity structure clearly.
- The resistivity variation between the channel structure composed by the distribution of low resistivity and the distribution of high resistivity at the outside of the channel structure is steep and indicates the resistivity discontinuity.
- The distribution of low resistivity under the highland in the northern slope of Mt. Bericha continues from shallow zone to deeper zone. At 1,200 m elevation, the high contrast of resistivity variation is shown around the border between this low resistivity distribution and high resistivity distribution at the northern part and its contour lines are straight in WNW-ESE direction and indicate the resistivity discontinuity.



Tendaho-2 (Ayrobera) site | Boseti site

(Source: JICA Project Team)

Figure 6.1 The panel diagrams of the resistivity plan maps created from MT/TEM survey results

6.5 Interpretation of Resistivity Structure in Geothermal Sites

6.5.1 Tendaho-2 (Ayrobera) Site

Figure 6.2 shows the resistivity distribution maps at different elevations, EL+200 m, EL+0 m, EL-700 m, EL-1,500 m, and EL-2,500 m. In this diagram, low resistivity zones (less than 10 ohm-m) are remarkably dominant at EL 200 m and EL 0 m level; a low resistivity zone extending NW-SE direction becomes apparent at El.-700 m level and downward though the distinctiveness tends to fade out downward. The zone of NW-SE direction that is well in accordance to the general trend of the Tendaho Graben, is considered to be an intensely fractured zone, delineated higher resistive zones (intact rock zones) on both side of the west and the east. The fractured zone could be a reservoir because high permeability would be expected.

For interpreting the cross sectional model, existing information are available here in Tendaho. In Tendaho-1 (Dubti), about 13 km south-east from the site, six (6) test wells were drilled from 1994 to 1998. Among those, TD-1 and TD-2 are useful to refer. The relevant information of the two wells were summarized in Table 6.3. According to the table, the depth of the measured resistivity 5 ohm-m ranges from 530 m to 580 m; whereas the depth of the measured temperature 245 – 250 ^{o}C ranges from 450 m to 600 m. From this well corresponding relation between the depths of the resistivity and the temperature, the depth of 5 ohm-m may be considered as the bottom of the cap layer or the top of the reservoir in Tendaho area.

Table 6.3 Existing Test Well Data in Tendaho-1 (Dubti)

Name of Zone	TD-1			TD-2		
	Resistivity (Measured depth)	Temperature (Measured depth)	Alteration, Inferred Temp. (Measured depth)	Resistivity (Measured depth)	Temperature (Measured depth)	Alteration, Inferred Temp. (Measured depth)
1) Resistive over burden	Resistive	<150 ºC	Non-alteration 50-100 ºC , (95 m)	Resistive	<150 ºC	Non-alteration , 50-100 ºC, (50 m)
2) Low resistive zone	<5 ohm-m, (580 m)	150 - 250 ºC, (600 m)	Argillized , 100-250 ºC, (350 m)	<5 ohm-m (530 m)	150 º- 245 ºC (450 m)	Argillized , 100-250 ºC, (280 m)
3) High resistive zone	>5 ohm-m	250 ºC	Chlorite-Epidote, 250-300 ºC	>5 ohm-m	245 ºC	Chlorite-Epidote, 250-300 ºC

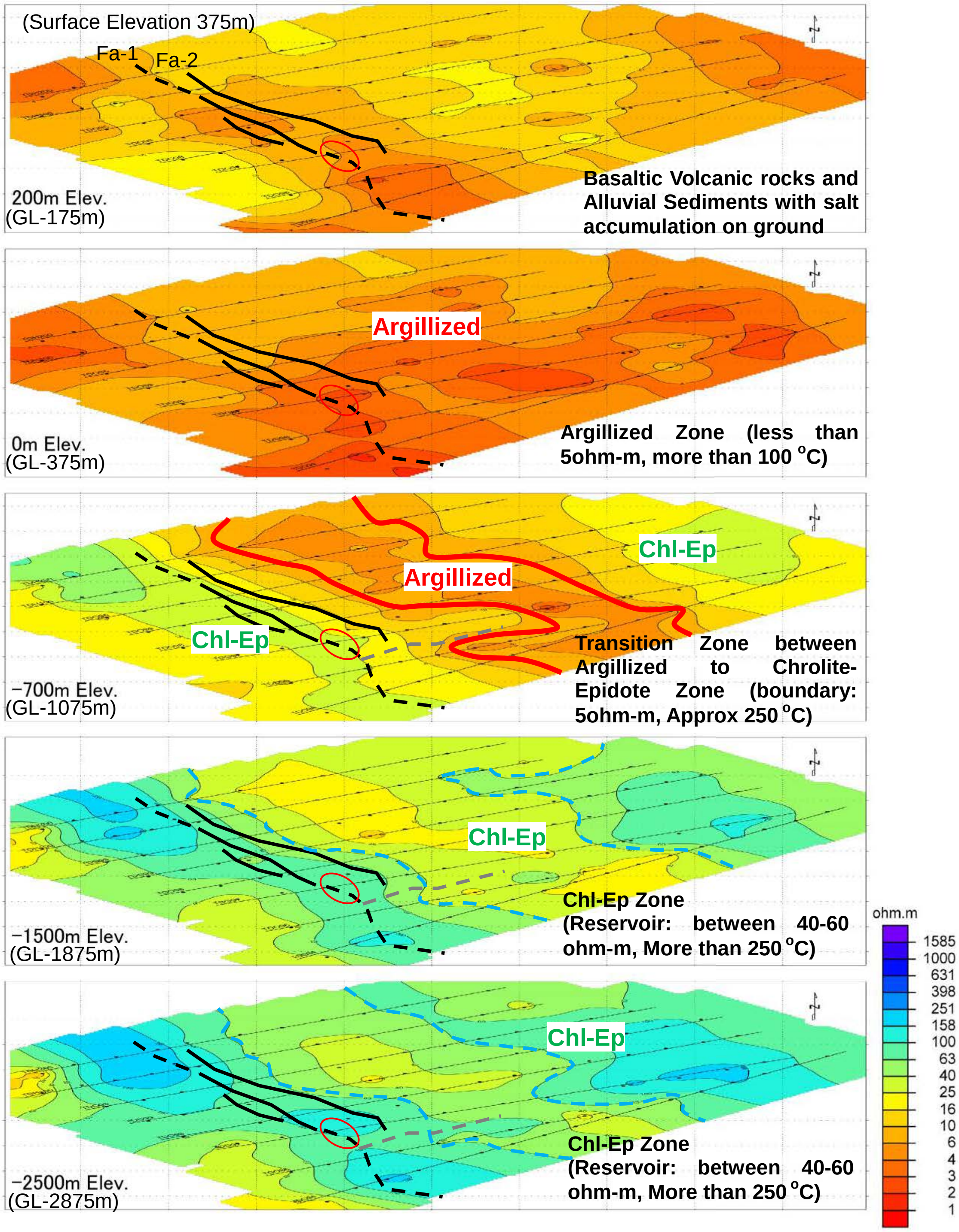
Source: Aquator (1994) and Aquator (1995), Compiled by JICA Project Team

Figure 6.3 shows NE-SW cross section of the resistivity. In the Figure 6.3, it is apparent that a zone of low resistivity goes down at the middle part of the analysis section. This low resistivity zone was interpreted as a fault fracture zones that runs NW-SE direction, and the fault zone may be the reservoir. From the Figure 6.2, it is apparent that the reservoir is capped by a low resistivity layer, and delineated by high resistivity zones on both sides. As the layer with resistivity lower that 5 ohm-m was interpreted as cap layer ("Cap rock"), the bottom depth of the cap layer is estimated to range from 300 m to 1,200 m on the top of the inferred reservoir. Table 6.4 summarized the interpretation of the reservoir structure.

Table 6.4 Interpretation of MT/TEM Survey Results with Alteration Mineral Occurrence and Temperature in Tendaho-2 (Ayrobera)

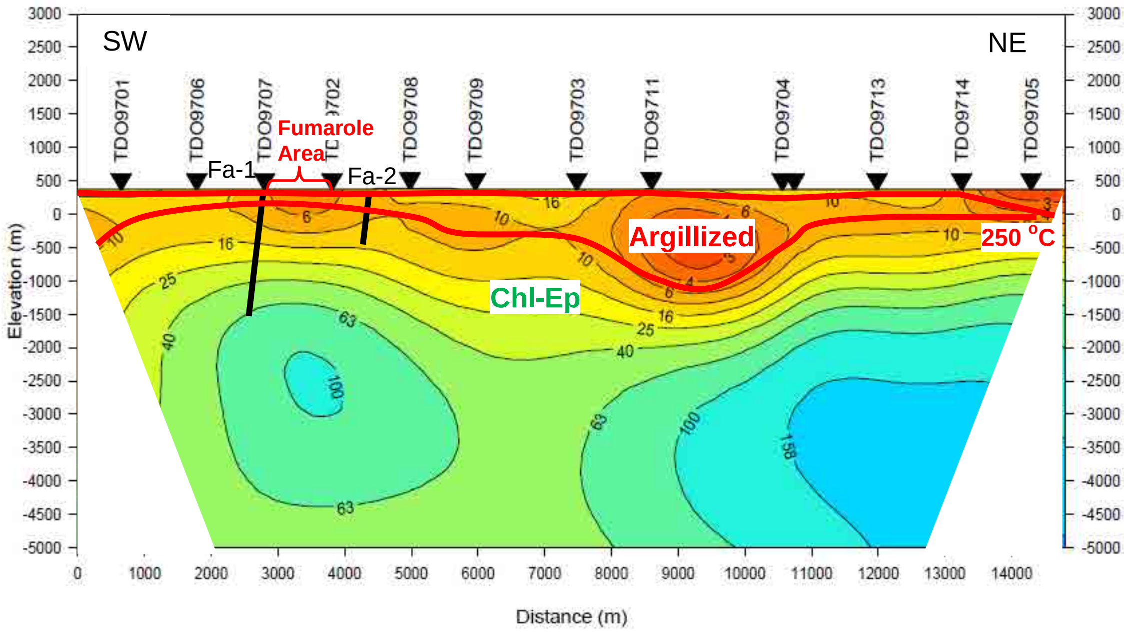
Zone	Interpretation of Reservoir		
	Resistivity	Depth (GL-m)	Interpretation of Temperature
1) Resistive overburden	>10 ohm-m	Less than 100 m	50-100 ^{o}C
2) Low resistivity zone	Less than 5 ohm-m	Approximately 100–500 m	100-250 ^{o}C
3) High resistive zone	>5 ohm-m (40–60 ohm-m)	Deeper than 300–1,200 m	250-300 ^{o}C

Source: JICA Project Team



Source: JICA Project Team

Figure 6.2 Schematic Panel Diagram of Resistivity Distribution and Interpretation in Tendaho-2 (Ayrobera)



Source: JICA Project Team

Figure 6.3 Schematic Section of Tendaho-2 (Ayrobera)

6.5.2 Boseti Geothermal Site

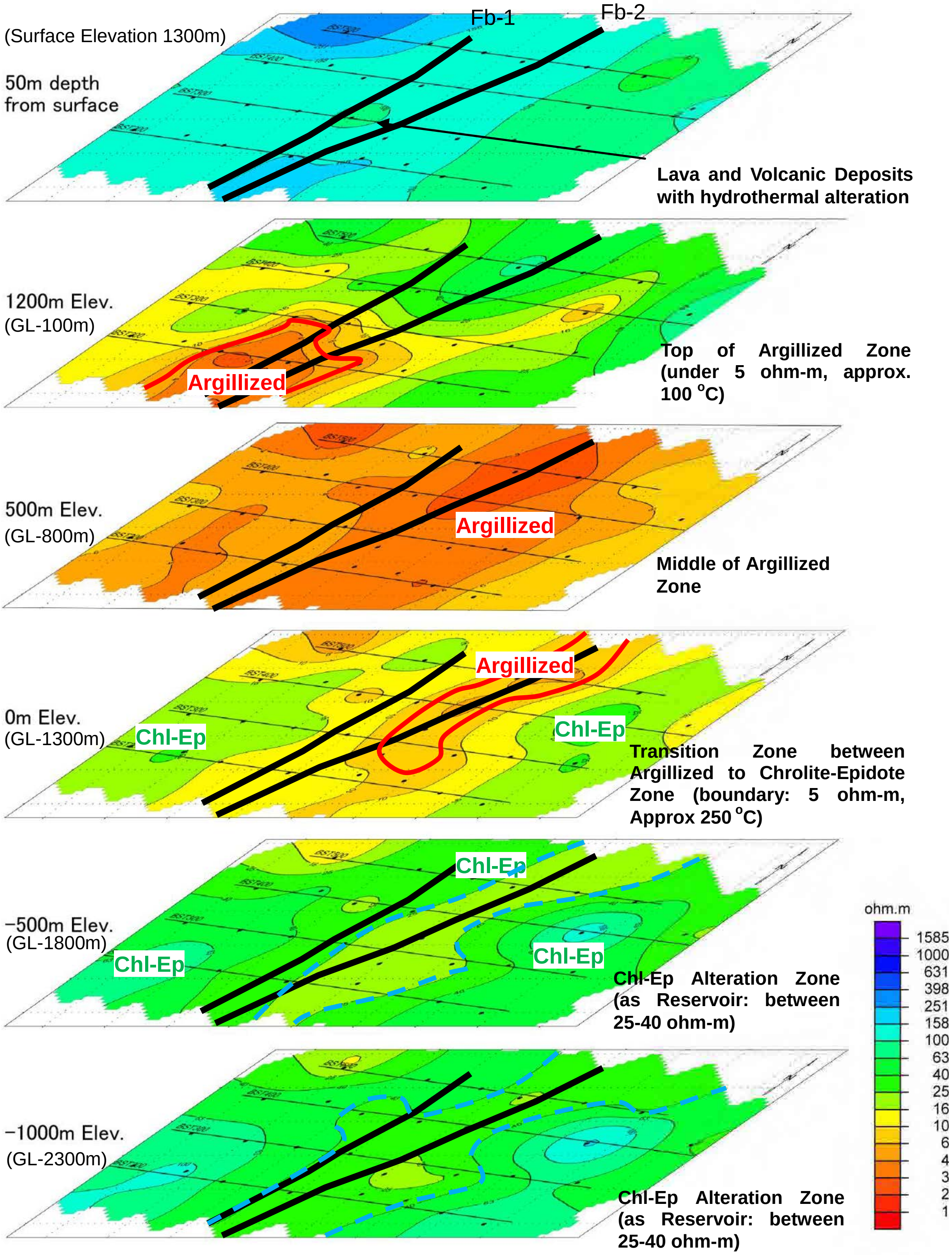
Figure 6.4 shows the resistivity distribution maps at different elevations, EL+1,250 m, EL+1,200 m, EL+50m, EL±0 m, EL-500 m and EL-1,000 m. In this diagram, resistivity higher than 100 ohm-m observed at surface level is interpreted as a new lava layer. The lower resistivity zones less than 5 ohm-m are remarkably dominant at EL 500 m level: a low resistivity zone extending N-S direction becomes apparent at EL 0 m level and downward though the distinctiveness tends to fade out downwards. The zone is well in accordance to the faults extending to NNE-SSW direction. The low resistivity zone therefore may be interpreted as a fault zone delineated on the both sides by resistive zones.

Figure 6.5 shows the WNW-ESE cross section of the resistivity. In Figure 6.5, it is apparent that a wide zone (channel) of lower resistivity goes down. The low resistivity zone was interpreted in this figure as a fault zone running NNE-SSW direction. It is apparent that the reservoir is capped by a low resistivity layer, and delineated by higher resistivity zones on both side. Therefore, the low resistivity zone could be interpreted as a geothermal reservoir. It was interpreted in Tendaho that the layer of resistivity lower that 5 ohm-m would be a cap layer (cap rock), the bottom depth of the cap layer is estimated to range from GL-800 m to GL-900 m as shown in Figure 6.5. Table 6.5 summarized the interpretation of the inferred reservoir.

Table 6.5 Interpretation of MT/TEM Survey Results with Alteration Mineral Occurrence and Temperature in Boseti

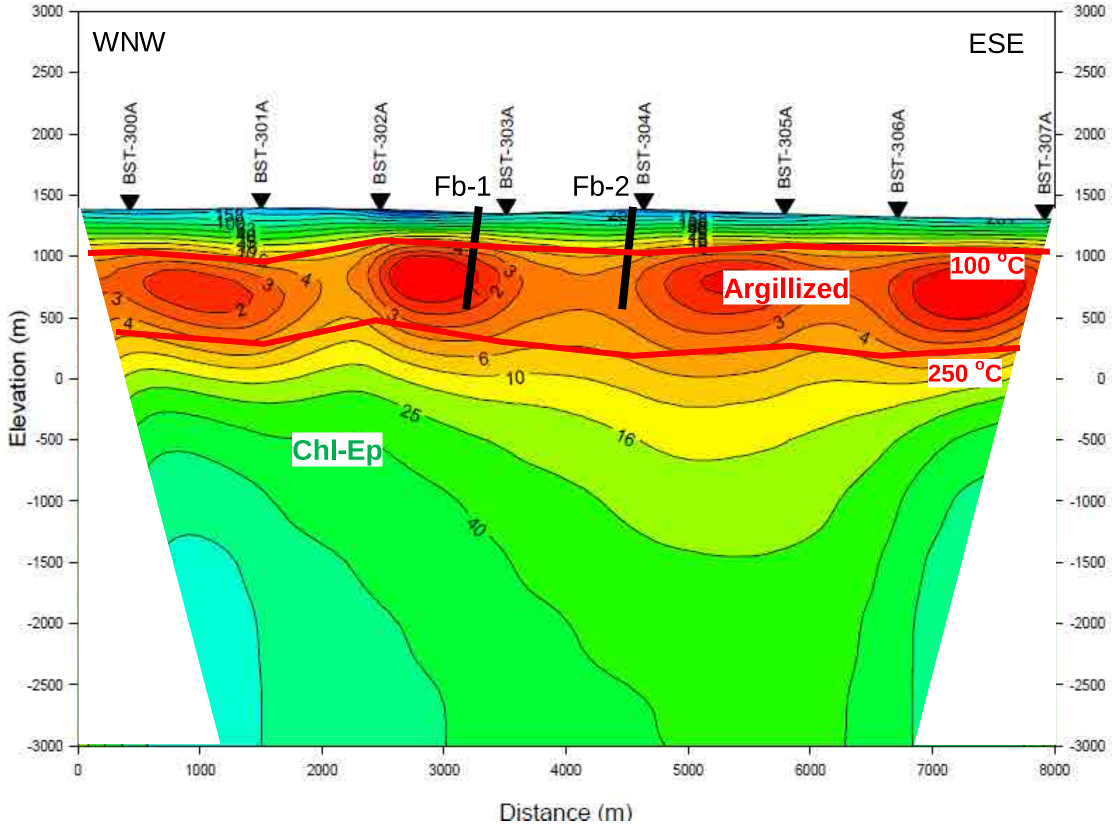
Zone	Interpretation of Reservoir		
	Resistivity	**Depth (GL-m)**	**Interpretation of Temperature**
1) Resistive overburden	10–150 ohm-m	Less than 300–500 m	50-100 ^{o}C
2) Low resistivity zone	Less than 5 ohm-m	Approximately 500–900 m	100-250 ^{o}C
3) High resistive zone	>5 ohm-m (25–40 ohm-m)	Deeper than 800–900 m	250-300 ^{o}C

Source: JICA Project Team



Source: JICA Project Team

Figure 6.4 Schematic Panel Diagram of Resistivity Distribution and Interpretation in Boseti



Source: JICA Project Team

Figure 6.5 Schematic Section of Boseti Geothermal Site

7. PROPOSAL FOR PRELIMINARY GEOTHERMAL RESERVOIR MODEL AND TARGET FOR GEOTHERMAL TEST WELLS

7.1 Purpose

Based on the geological, geochemical and geophysical survey conducted, preliminary reservoir model was proposed. Targets of test wells was also proposed on the basis of the proposed reservoir models

7.2 Purpose

Based on the geological, geochemical and geophysical survey conducted, preliminary reservoir model will be proposed in this chapter. Targets of test wells will also proposed on the basis of the proposed reservoir models

7.3 Tendaho-2 (Ayrobera) Geothermal Site

7.2.1 Interpretation of Survey Results

Table 7.1 shows the summary and interpretation of survey results and features as topographic features, result of geological and geochemical surveys and MT/TEM survey that is necessary for preparing preliminary geothermal structural model in Tendaho-2 (Ayrobera) site.

Table 7.1 Summary and Interpretation of survey results and features for Geothermal Structural Modelling

<table>
<tr><th colspan="2">Items</th><th>Features</th></tr>
<tr><td rowspan="2">Geology</td><td>Papers
Satellite Imagery
Field Survey</td><td>・ Located at Manda-Harraro Graben.
・ Mainly composed of basaltic lavas and pyroclastics, and sediments of Afar Stratoid (Pliocene-Pleistocene). Recent basalt lava (Pleistocene) by fissure eruption is observed at the southwest of the survey area.
・ Those volcanic rocks are covered by alluvial deposit in Ayrobera.</td></tr>
<tr><td>Test Well</td><td>・ Six test wells were drilled at Tendaho-3 (Dubti) located at 9-12km south of the site.
・ Altered clay minerals (GL-50 to 350m), chlorite – epidote (below GL-350m) are observed at some test wells, interpreted as cap rock and geothermal reservoir.
<table>
<tr><th>Test well</th><th>Flow rate</th><th>Temp.</th><th>Depth (GL-)</th></tr>
<tr><td>TD-2</td><td>13kg/s, 46.8t/h</td><td>220℃</td><td>890m</td></tr>
<tr><td>TD-4</td><td>70kg/s, 252t/h</td><td>216℃</td><td>250m</td></tr>
<tr><td>TD-1</td><td>Very low</td><td>270℃</td><td>880-900m
1,190-1,265m</td></tr>
</table>
・ Thick sedimentary rock intercalated with basaltic rock was observed at the depth of approx. 2,000m at TD-4 test well (located at 9km southwest of the site)
・ Basaltic rocks are observed below 2,000m at TD-4.</td></tr>
<tr><td>Fault/ Fracture System</td><td>Papers
Satellite Imagery
Field Survey</td><td>・ The Graben is under tensile stress and NW-SE normal fault and fracture system is developed.
・ Spreading axis is located at the southwest of the site, and steep normal faults, dipping to the southwest, are well developed.
・</td></tr>
</table>

Items		Features
	Geophysical Survey	・ NW-SE low resistivity zone are found at the depth of GL-700m to GL-2,500m in the center of the survey area by MT/TEM survey. ・ According to the result of gravity survey, the above-mentioned zone is the boundary between high-gravity area (northeast) and low-gravity area (southwest). ・ According to the result of magnetic survey, the above-mentioned zone is the boundary between high-magnetic intensity area (northeast) and low-magnetic intensity area (southwest). (Yohannes L.,2007) ・ TD-4 is located at southwest area, therefore the combination of low-gravity and low-magnetic intensity was resulted by thick sedimentary rock. ・ NW-SE low resistivity zone obtained by MT/TEM Survey is consistent with the boundary of other geophysical survey results, interpreted as fault zone.
Heat Source	Geophysical Survey	・ Resistivity value is lower at the depth below 4,000m, may indicates heated zone caused by intrusion of basaltic magma.
Geothermal Fluid	Topography Satellite Imagery	・ Discharge is expected by Awash River and marsh zone, located at the north of the site.
	Geochemical Analysis	・ Fumaroles of 99.3ºC were observed at the southwestern part. ・ Result of geochemical analysis indicates 240-290ºC of geothermal fluid temperature (by silica thermometer)
	Test Well	・ Self flow of 1.8t/h (13kg/s), 220 ºC was confirmed at TD-2 Test well in Tendaho-3 (Dubti). (DAmore et al., 1997)
Cap Rock Structure	Geophysical Survey	・ A low resistivity zone (less than 5ohm-m) were found at the depth of GL-100m to GL-500m), may compose cap rock structure.
	Test Well	・ Altered clay minerals and zeolites are found at the depth of GL-50m to 350m in existing test wells in Tendaho-3 (Dubti). ・ The depth for occurrence of those minerals may be corresponded with the low resistivity zone (less than 5ohm-m).

Source: JICA Project Team

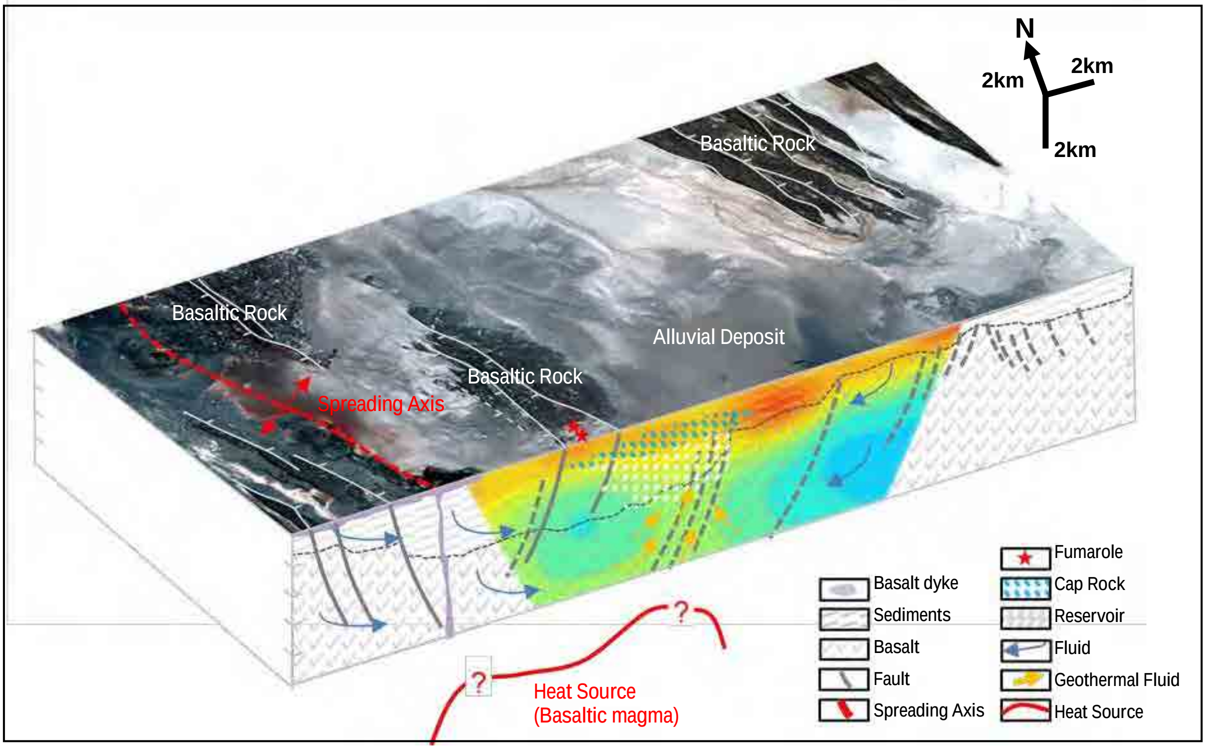
7.2 Preliminary Geothermal Reservoir Model

The Conceptual Geothermal Reservoir Model in Ayrobera, which is indicated by the above features, is prepared. The characteristics of the model is shown in Table 7.2, diagram and section are shown in Figure 7.1 and Figure 7.2.

Table 7.2 Characteristics of Geothermal Reservoir

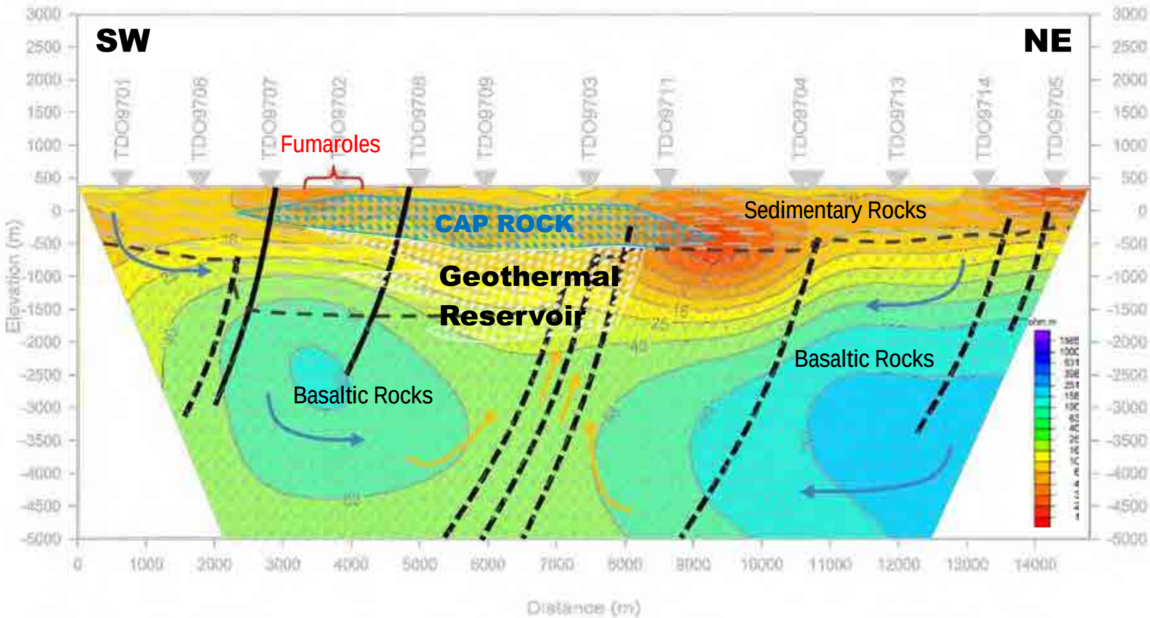
Item	Description
Geothermal Reservoir	Geothermal reservoir may be porous basalts and sandstones. North-eastern margin of the reservoir would be clear with normal faults in basaltic rock, where south-western margin would be along many sand layers in sedimentary rocks. Altered basaltic rocks, fine sandstones and siltstones would be distributed at the top of the reservoir as cap rock.
Geothermal Fluid	Geothermal fluid may be discharged by Awash River and the ground, convecting in the ground restricted by faults and fault zones. Up-flow zone would be formed along the fault zone in the center of the survey area.
Heat Source	Basaltic magma is expected as a heat source in the area, which would be located at the depth of 5-6 km.

Source: JICA Project Team



Source: JICA Project Team

Figure 7.1 Preliminary Geothermal Reservoir Model in Tendaho-2 (Ayrobera) Site



Source: JICA Project Team

Figure 7.2 Preliminary Geothermal Reservoir Model (Section) in Tendaho-2 (Ayrobera) Site

7.2.3 Preliminary Target for Test Well Drilling

According to the geothermal model, a wide channel of NW-SE high temperature convective zone (low resistivity zone) in the centre of the study area. It is expected that the drilling depth needs to be about 2,000 m to drill up to the assumed faults and high temperature convective zone. Tentative target and specification of the test well drilling is summarized in Table 7.3 and Table 7.4. Selected drilling locations are shown in Figure 7.3 and Figure 7.4.

Table 7.3 Tentative Target for Test Well Drilling in Tendaho-2 (Ayrobera)

Area	Target	Well Type
AY-1 Area	NW-SE subsurface normal fault zone (dipping to SW)	Directional well
AY-2 Area	NW-SE subsurface normal fault zone (dipping to SW)	Vertical Well
AY-3 Area	NW-SE Normal faults at Fumaroles Point (dipping to SW)	Vertical Well

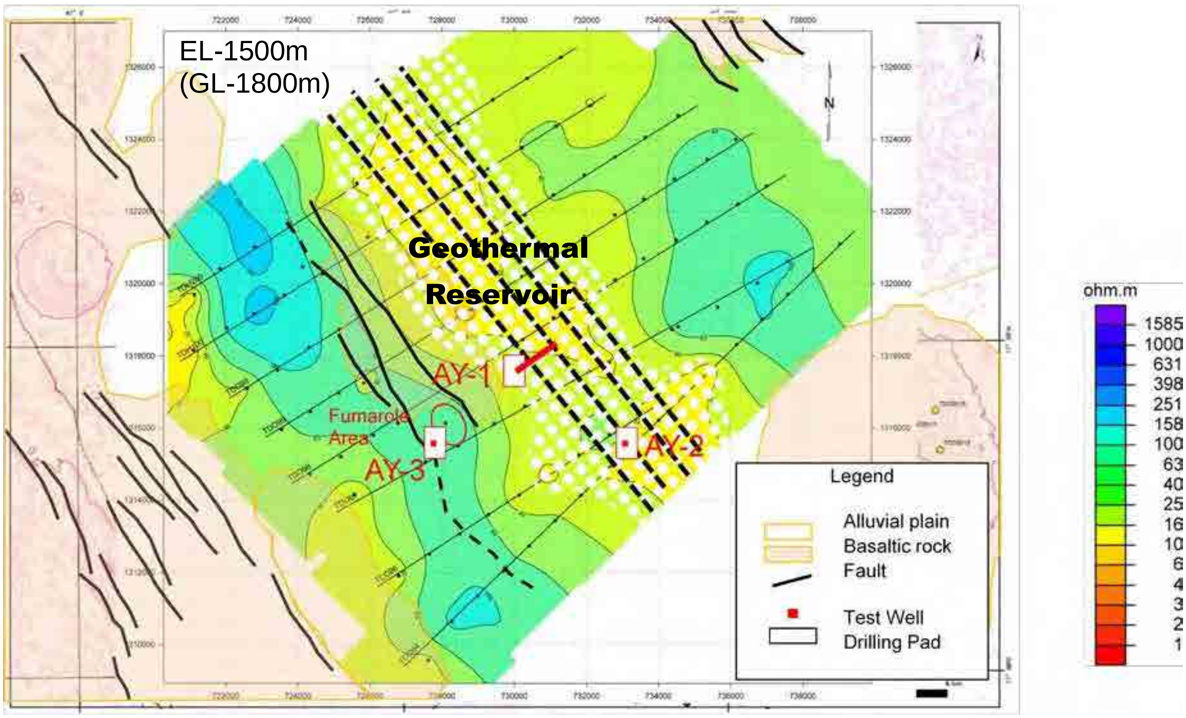
Source: JICA Project Team

Table 7.4 Tentative Specification of Test Well Drilling in Tendaho-2 (Ayrobera)

Item	AY 1	AY 2	AY 3
Outline of the target	Aiming at NW-SE low resistivity zone (Fault zone) at the centre.	Aiming at NW-SE low resistivity zone (Fault zone) at northern part.	Aiming at NW-SE Fault zone at Fumaroles point.
Location of the target from well head	Direction from True North standard : N 57° E, Vertical depth: 1,840 m Horizontal distance: 600 m	Vertical depth: 2,000 m	Vertical depth: 2,000 m
Approximate depth of the target (GL-m)	1,000–1,840	1,500-2,000	1,500–2,000
Estimated temperature at the target	Approx. 250–300 °C	Approx. 250–300 °C	Approx. 250–300 °C
KOP	800 m	-	-
Drilling depth to bottom	1,840 m	2,000 m	2,000 m

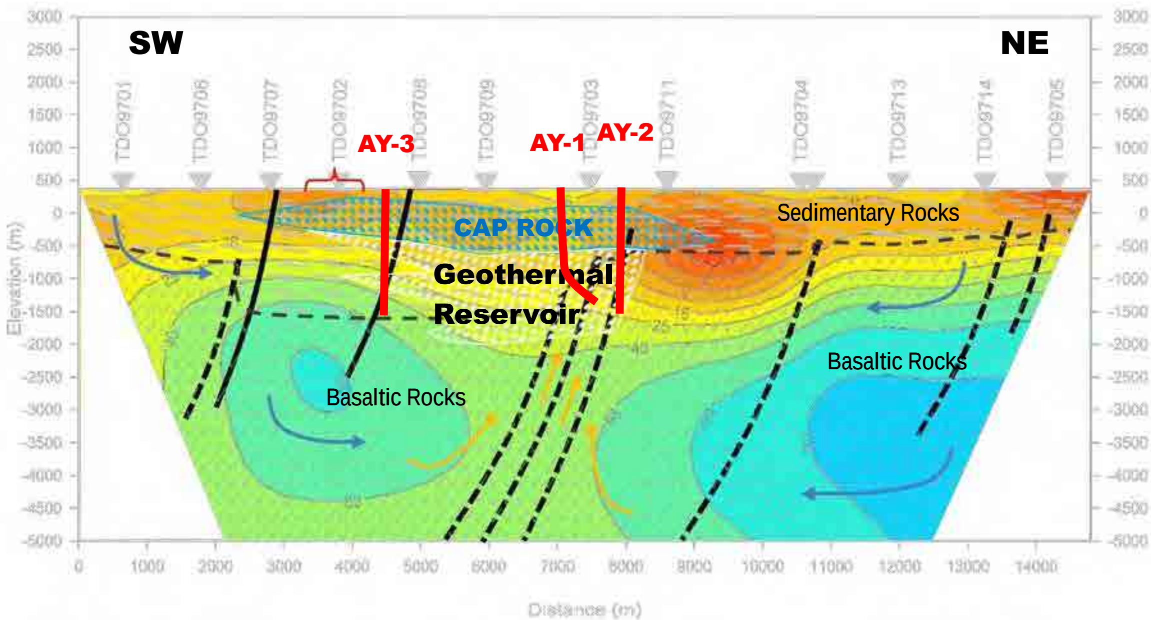
KOP :Kick-Off Point

Source: JICA Project Team



Source: JICA Project Team

Figure 7.3 Test Well Drilling Plan in Ayrobera (Tendaho-2)



Source: JICA Project Team

Figure 7.4 Schematic Section of Test Well Drilling in Ayrobera (Tendaho-2)

7.3 Boseti Geothermal Site

7.3.1 Interpretation of Survey Results

Table 7.5 shows the summary and interpretation of survey results and features as topographic features, result of geological and geochemical surveys and MT/TEM survey that is necessary for preparing preliminary geothermal structural model in Boseti site.

Table 7.5 Summary and Interpretation of survey results and features for Geothermal Structural Modelling

Item		Features
Geology	Geology	・ Composed of basaltic-rhyolitic lava and pyroclastic rocks, and sedimentary rocks (conglomerate-sandstone) of Nazreth Group (Pliocene-Pleistocene). ・ Boseti volcano and erupted lavas (obsidians), basalt lava at the surface in the northern part are classified as Wonji Group (Pleistocene), underlain by Nazreth group with unconformity.
Fault/Fracture System	Satellite Imagery Geology	・ Many normal faults are developed at the direction of NNE-SSW, which is concordant with the direction of Rift Valley.
	Geophysical Survey	・ Low resistivity zone is observed at the depth of GL-800m to GL-2,300m in the center of survey area and its direction is concordant with normal faults on the ground.
Heat Source	Geology	・ According to the result of topographic analysis, lavas were intruded and erupted along the NNE-SSW fault (Fb-2) in the center of survey area (Korme et.al., 1997).
	Gravity Survey	・ High-density rock is assumed at the depth of GL-2,000m below Boseti Volcano (D.G. Cornwell et al., 2006).
Geothermal Fluid	Geochemical Analysis	・ Fumaroles are observed along NNE-SSW fault (Fb-1) in the survey area. ・ Temperature of geothermal fluid would be 170-220°C, classified as Class C (by Silica Thermometer)
Cap Rock Structure	Geophysical Survey	・ Low resistivity zone (less than 5ohm-m) which was found at the depth of GL-800m to GL-900m is interpreted as cap rock.

Source: JICA Project team

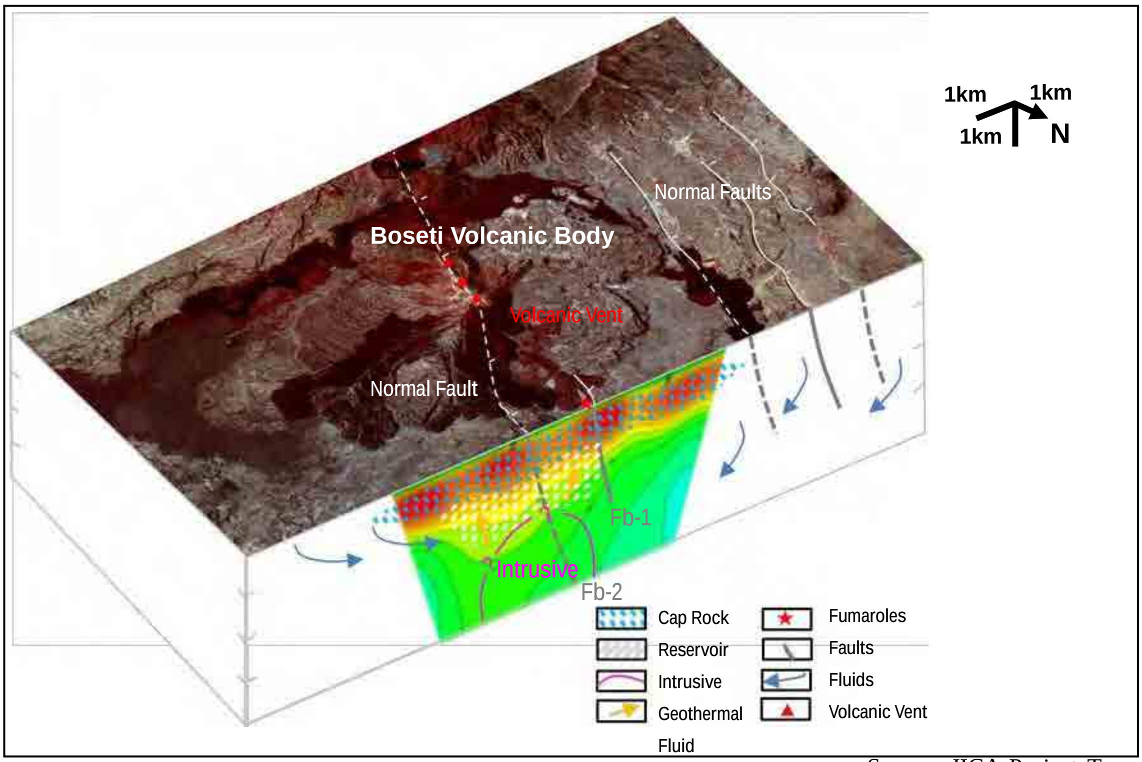
7.3.2 Preliminary Geothermal Reservoir Model

The Conceptual Geothermal Reservoir Model in Boseti, which is indicated by the above features, is prepared. The characteristics of the model is shown in Table 7.6, diagram and section are shown in Figure 7.5 and Figure 7.6.

Table 7.6 Characteristics of Geothermal Reservoir

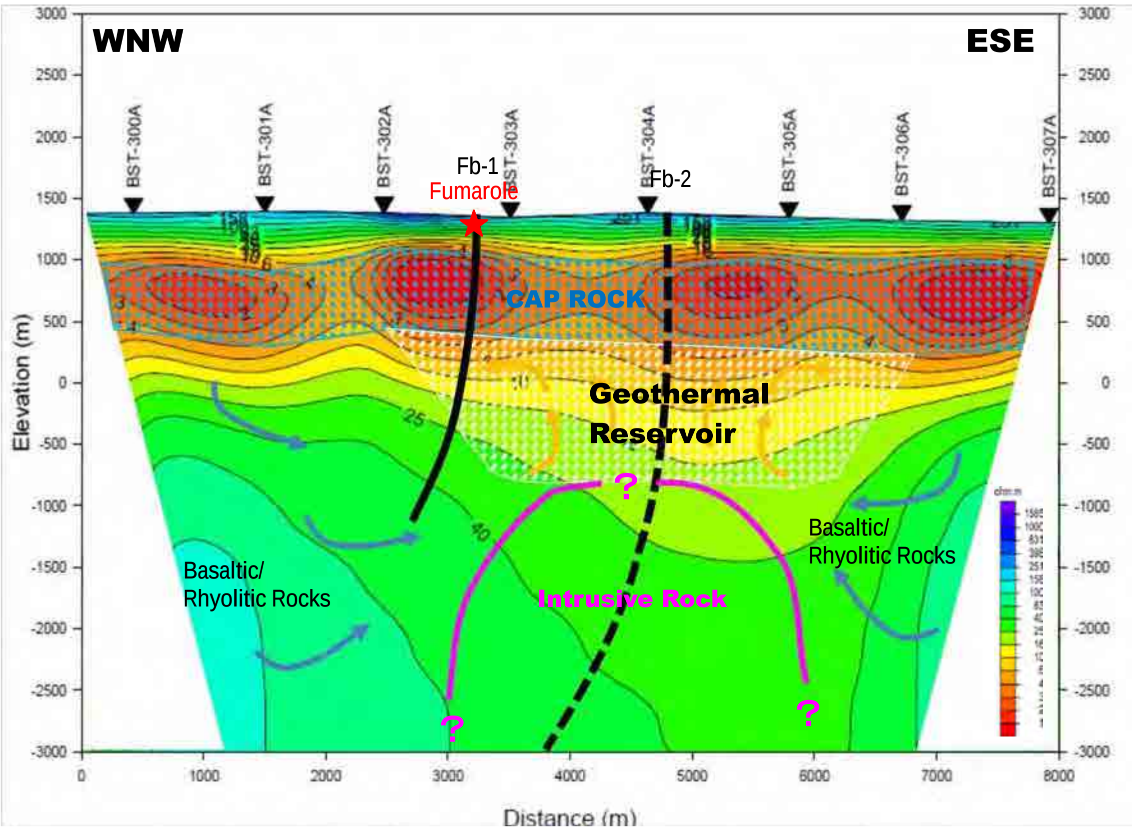
Item	Description
Geothermal Reservoir	Basalt-rhyolite lava and pyroclastic rocks, and sedimentary rocks along the NNE-SSW normal faults are expected as a geothermal reservoir in the area. The margin would be clearly divided by steep faults and/or fractures. Cap rock is assumed at the top of reservoir, which is mainly composed of clay layers altered from basaltic-rhyolitic rocks.
Geothermal Fluid	Fluid may be discharged by the surface and aquifers in Nazreth Group. Geothermal fluid is convecting in the ground restricted by faults and fault zones. Up-flow zone would be formed along the fault zone in the center of the survey area.
Heat Source	Intrusive rock(s) which may be distributed along NNE-SSW at the depth below 2,000m.

Source: JICA Project team



Source: JICA Project Team

Figure 7.5 Preliminary Geothermal Reservoir Model in Boseti site



Source: JICA Project Team

Figure 7.6 Preliminary Geothermal Reservoir Model (Section) in Boseti site

7.3.3 Preliminary Target for Test Well Drilling

According to the geothermal model, a wide channel of NNE-SSW high temperature convective zone (low resistivity zone) associated with two distinctive faults are observed on the ground, namely Fb-1 and Fb-2. This high-temperature zone may continue toward the south, below Boseti Volcano, and it seems that the reservoir temperature may increase as the zone gets closer to the volcano. It is expected that the drilling depth needs to be about 2,000 m to drill up to the assumed high temperature convective zone with subsurface fault zones. Tentative target and specification of the test well is proposed in Table 7.7 and Table 7.8. Selected drilling locations are shown in Figure 7.7 and Figure 7.8.

Table 7.7 Tentative Specification of Test Well Drilling in Boseti

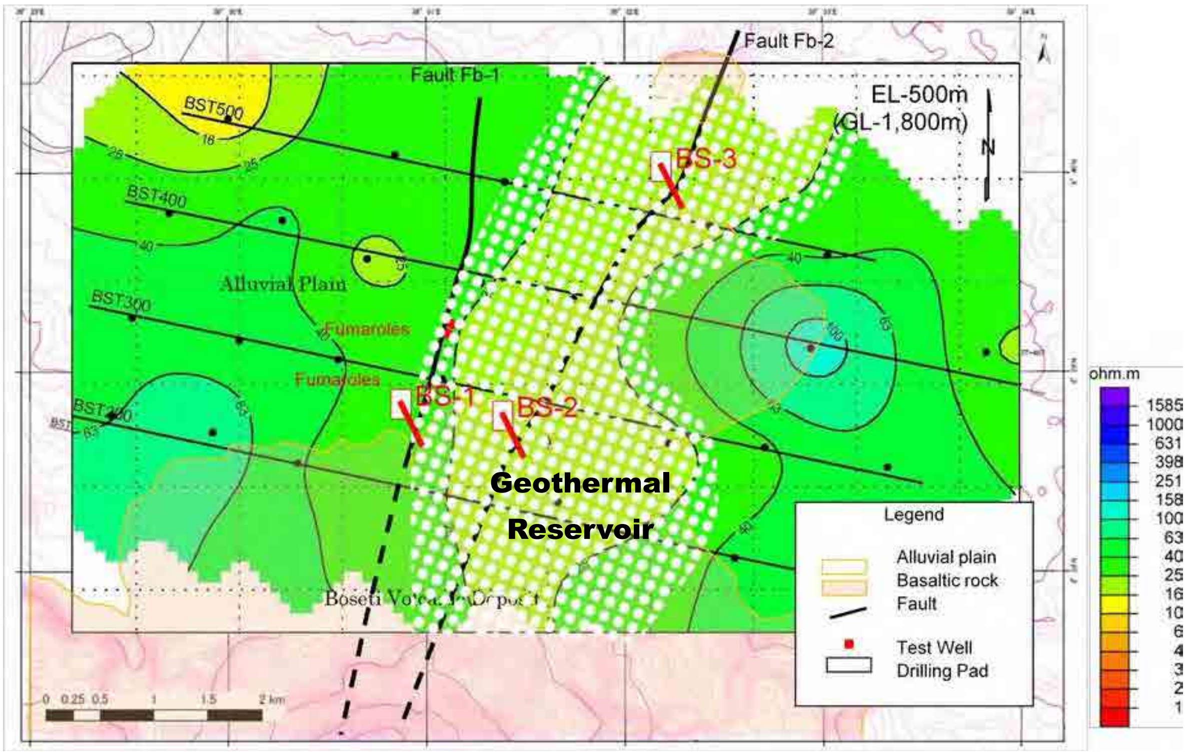
Target Area	Target	Test Drilling
BS-1 Area	NNE-SSW low resistivity zone along Fault Fb-1 where many fumaroles are located.	Directive Well
BS-2 Area	Center of the reservoir (low resistivity zone) along Fault Fb-2 near the volcanic body.	Directive Well
BS-3 Area	Center of the reservoir (low resistivity zone) along Fault Fb-2 where the Fault is clearly observed on the ground.	Directive Well

Source: JICA Project Team

Table 7.8 Tentative Specification of Test Well Drilling in Boseti

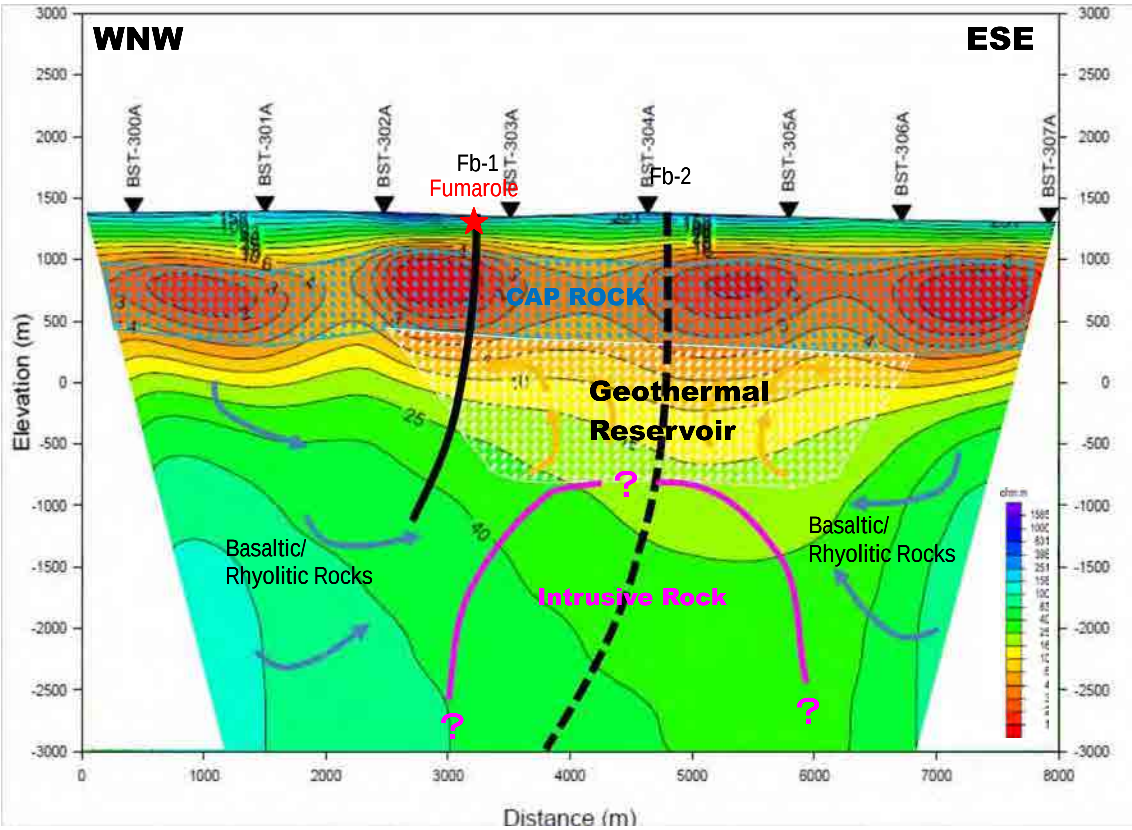
Item	BS-1	BS-2	BS-3
Outline of the target	Aiming at NNE-SSW low resistivity zone along Fault Fb-1.	Aiming at NNE-SSW low resistivity zone along Fault Fb-2.	Aiming at NNE-SSW low resistivity zone along Fault Fb-2.
Location of the target from wellhead	Direction from true North standard : S 30° E, Vertical depth: 1,840 m Horizontal distance: 600 m	Direction from true North standard : S30° E, Vertical depth: 1,840 m Horizontal distance: 600 m	Direction from true North standard : S30° E, Vertical depth: 1,840 m Horizontal distance: 600 m
Approximate depth of the target (GL-m)	1,000–1,840	1,000–1,840	1,000–1,840
Estimated temperature at the target	Approx. 250–300 °C	Approx. 250–300 °C	Approx. 250–300 °C
KOP (kick off point)	800 m	800 m	800 m
Drilling depth to bottom	1,840 m	1,840 m	1,840 m

Source: JICA Project Team



Source: JICA Project Team

Figure 7.7 Test Well Drilling Plan in Boseti



Source: JICA Project Team

Figure 7.8 Schematic Section of Test Well Drilling in Boseti

8. DATABASE CONSTRUCTION

8.1 Objective and Utilization of the Database

A geothermal database was constructed to systematically store various geothermal data such as geological, geochemical, and geophysical test results as well as information on topography and infrastructures. “G*BASE” has been produced by Geothermal Energy Research and Development (GERD) Co. Ltd., Japan based on Oracle7/8TM exclusively for geothermal-related database.

8.2 Structure of the Database

The database was constructed using the G*BASE software by digitizing all information for each prospect. The data and information that may be input in G*BASE are summarized in Table 8.1.

Table 8.1 Database Structure of “G*BASE”

Data Type	Information Examples
Depth (Z, numerical data)	Well logging, lost circulation/feed point. casing program, well direction coordinates, geologic column
2D Discrete data (X, Y, numerical)	Altitude, depth to the top of rock phases, planar distributions of geophysical and geochemical survey
3D Discrete data (X, Y, X; numerical)	Geophysical survey (MT resistivity, vertical electronic sounding, etc.), reservoir simulation results
Chronological data (t; numerical)	Well test, production-reinjection well record, pressure-temp monitoring, geochemistry monitoring, etc.
Mark data	Place name, manifestation point (hot spring, fumaroles), sampling point coordination, volcano
Polygon data	Road, river, lake, facilities, boundary line, geological maps, faults, caldera
Image data (planar or sectional pictorial image)	Satellite imagery, geological maps, geological cross sections, seismic reflection survey, planar section at depths
Geochemical data	Geochemical analysis results

Source: JICA Project Team

Instructions and training were given to the GSE staff through training in Japan and on-the-job training in Ethiopia so that GSE is able to update the database in Ethiopia. A detailed operations manual for G*BASE is provided to GSE in a separate volume.

8.3 Data and Information in G*BASE

The JICA Project Team constructed the database and input geothermal data provided by GSE and acquired in this study. Table 8.2 presents the list of input data and information.

Table 8.2 Geothermal Data in G*BASE

Classification	Input Data
Basic Information	Topographic Contour
	River
	Lake
	Primary Roads
	Railway
Geological Data	Geological Map
	Fault
	Volcano
	Caldera
Topography (Remote Sensing Data)	Hydrothermal Alternation
	Circular Landform
	Lineament
Surface Survey	Geothermal Manifestation
	Sampling Location
Geochemical	Geochemical Analysis Result
Geophysical	MT/TEM Survey Map
	VES Map
	Magnetic Sounding Map
	Bouguer Anomaly Map
	Microseismic Map
Drilling Well Data	Well Location
	Well Curve
	Casing Program
	Geological Column
	Well Event (Lost circulation point)
Well Logging Data	Temperature Logging
	Pressure Logging
	Well Head Pressure Test
	Injection Test
	Fall-off Test
	Production Test
	Discharge Flow Test
	Inference Test
	Build-up Test

Source: JICA Project Team

The JICA Project Team had imported into the database not only the survey results of this study but also data collected from GSE. Using one of the applications in G*BASE, the 2-D and 3-D model may be built that enables to construct geothermal reservoir models and to conduct fluid simulation.

8.4 Management and Upgrading of the Database

It is necessary that GSE upgrade and manage the database properly when it obtains new geothermal data. Before commencement of this study, existing geothermal data had not been utilized fully by the GSE staff because most of the data were scattered and not accumulated properly. Moreover, there were some missing data (including logging data, acquisition date, test conditions, and data unit, etc.). To avoid the same mistakes, GSE is expected to accumulate all data into the G*BASE database properly. In utilizing the database, GSE should plan further geothermal surveys and drilling programs and simulate several tests of geothermal reservoirs and fluids.

9. PROPOSED SURVEY UP TO TEST WELL DRILLING

We made recommendations on further surface surveys and an approach to creating the new implementation organization EEGeD.

9.1 Recommendations on Surface Surveys in the Selected Sites

9.1.1 Target sites to be additionally surveyed

In addition to Tendaho-2 (Ayrobera) and Boseti, we proposed to include Butajira in the survey program as a portfolio approach. Butajira was recognized as a seemingly promising site that was accidentally identified in May 2014.

9.1.2 Approach of the additional survey

We recommend adopting a two step approach, namely, the first step for additional surface survey in the nominated three sites, and the second step for temperature gradient well drillings as shown in Table 9.1.

Table 9.1 Proposed Additional Surface Survey and TG Wells

Step	Survey Items	Ayrobera	Boseti	Butajira (if additionally requested)	GSE Input		JICA Assistance
					Capacity Building	Equipment	
1st	Micro-seismicity	☑	-	-	- Geologists, - Geophysists, - Reservoir engineers	-	T/C, Survey equipment
	Gravity Survey	(Existing data)	☑	☑		-	T/C, Survey equipment
	Magnetic Survey	(Existing data)	☑	☑		Survey equipment	T/C
	MT/TEM Survey	☑	-	☑		Survey equipment	T/C
	MT 3D Analysis	☑	-	-		-	T/C
	2m Depth Temperature Survey	☑	☑	☑		-	T/C, Survey materials
	Geological and Geochemical survey	done	done	☑	- Geologist, - Geochemist	Labo analysis	T/C, Survey materials
	Preliminry ESIA	done	done	☑	-	-	T/C, (out-sourcing)
2nd	TG wells	At one or two promising site/s			- Drilling service, - Drilling managers, - Geologists, - Reservoir engineers	Drilling machine, Supporting equipment, Drilling crew	T/C, Drilling consumables
3rd	Test Wells	At the most promising site					

Note: TG wells: Temperature gradient wells; T/C: Technical cooperation
ESIA: Environmental, Social Impact Assessment

(Source: JICA Project Team)

9.2 Proposal for on Master Plan Formulation Project on Establishment of EEGeD

9.2.1 Special Purpose Public Entity (Enterprise)

The recommended new special purpose entity temporarily named as Ethiopian Enterprise for Geothermal Energy Development (EEGeD). The mandates of EEGeD may be as follows:

- To undertake the geothermal resource surface survey and test drilling,
- To undertake project feasibility study when necessary for a future business of EEGeD,
- To undertake field development wherever possible, and
- To operate steam production and sales wherever possible.

There may be a possibility that EEGeD may extend its operation to power generation. The merits of forming EEGeD are as follows:

- EEGeD will be able to concentrate its efforts to geothermal development mainly for the purpose of electricity generation;
- EEGeD will also be able to accumulate its knowledge and experiences within the organization, which will accelerate geothermal development; and
- EEGeD, as the single focal point for geothermal development in Ethiopia, will be able to attract donors' attention, which will make financial arrangement much easier.

9.2.2 Characteristics of EEGeD

The new geothermal-specialized public entity EEGeD shall be financially sustainable once it becomes a fully-fledged operation. It is for this reason that EEGeD shall undertake steam production and sales, thereby ensuring stable revenue.

9.2.3 Proposal for the Master Plan Formulation Project on Establishment of EEGeD

To establish the new enterprise EEGeD, a design of institutional and regulations will be necessary. Even though the final status of EEGeD shall be a financially sustainable organization, there will be a transitional period when the EEGeD may need financial supports until its fully-fledged operation. Thus, we would propose a Master Plan Formulation Project to be implemented. The proposed Terms of Reference is shown in the Table

Table 9.2 Proposed TOR of a Master Plan Project on Establishment of EEGeD

• Rationale for EEGeD • Vision and Mission • Situation analysis (Assessment of human, physical and financial resources) • Business model (Value chain mapping and ownership structure) • Human Resource Development (Organization and staffing) • Legal and regulatory framework • Geothermal resource development • Financial plan • Steam Sales Agreement (SSA) • Action Plan for Formation of EEGeD

10. THE WAY FORWARD: CONCLUSIONS AND RECOMMENDATIONS

The Project Team assessed geothermal resources of the nominated 22 sites in Ethiopia based on existing information, remote sensing analysis, field geological and geochemical survey followed by its laboratory analysis, and environmental-social impact assessment. Thereby, the Team formulated the Master Plan on Development of Geothermal Energy in Ethiopia.

Prior to describing conclusions and recommendations, we would first reconfirm and emphasize its significances of the geothermal energy development in Ethiopia:

- Geothermal power generation provides reliable electricity supply as base load throughout a year;
- Geothermal energy is supreme to other climate-dependent renewable energies such as wind, solar and/or others;
- Geothermal energy will reduce drought risks of hydropower-dependent Ethiopian power supply;
- Thus, priority has to be given to the earliest and the maximum development of geothermal energy.

The conclusions and recommendations the Project Team reached are as follows.

10.1 Conclusions

- The geothermal resources of the target sites are estimated at a 4,200 MW as the most probable occurrence probability (O/P), a 2,100 MW as 80% O/P, and a 10,800 MW as the 20% O/P. This estimation is classified as "inferred geothermal resource" since only surface surveys were conducted for the estimation. This estimation needs to be refined to a level of "indicated or measured geothermal resources" through conducting geophysical survey and test well drilling for formulating more specific development plans.
- The environmental and social impact assessment identified no significant adverse impacts on natural and social environment with a few exceptions that were eventually ranked at lower priorities.
- The 22 sites are classified into the five priority groups, i.e. Priority-S, A, B, C and D on the basis of the multi-criteria analysis conducted. The analysis concluded that a 610 MW of the Priority-S should be developed for the period of 2014 to 2018, an approximately 2,800 MW of the Priority A and B for the period of 2019 to 2025, and an approximately 1,100 MW of the Priority-C and D for the period of 2026 to 2037.
- The analysis also concluded that the geothermal sites of the Priority A and B should first be developed prior to some of the wind and solar power generating facilities planed by EEP. EEP presently plans to install a total of an approximately 1,200 MW of wind and solar power

facilities by 2018.

- The financial analysis revealed that the generation cost could be below the present domestic tariff level only when the Priority-A sites are developed with most concessional financing programs such as Japan's ODA loans; The generation cost could then be below the present exporting tariff level when the Priority-A and B sites are developed with more concessional financing programs such as World Bank loans; the generation cost will exceed the both tariff levels if geothermal sites are developed with private funds. In other words, public financing schemes shall be utilized for the geothermal development under the present tariff policy. If private investments are to be promoted, financial and/or institutional supporting policies will have to be established.
- The geothermal development has to be implemented by a public entity who shall handle projects with public financing schemes. A new public entity named EEGeD needs to be established by merging the existing geothermal related sections in GSE and EEP. Financial sustainability of EEGeD could be maintained by selling steam to the electricity producer (EEP, etc). Private firms, however, should be allowed to participate in any stage of the geothermal energy development.
- The Project Team identified three priority sites, i.e. Tendaho-2 (Ayrobera) of Priority-A, and Boseti and Meteka of Priority-B, from green fields where other donors or private firms have not yet committed. Out of those three, geophysical survey was conducted in Tendaho-2 (Ayrobera) and Boseti. Based on the geophysical survey conducted, the outer limits of geothermal reservoir were preliminarily inferred for each site; thereby, targets of test wells were proposed.

10.2 Recommendations

Geothermal power generation will be of paramount importance as stable base load energy for the hydropower dependent Ethiopia power supply system, which is susceptible to climate change and unstable in drought years. The Project Team proposes the following recommendations in order to accelerate the geothermal development in Ethiopia.

- To ensure the smooth implementation of the Priority-S projects that are already committed by other donors or a private firm;
- To implement, at an earliest convenient, an additional surface survey including temperature gradient wells at Tendaho-2 (Ayrobera) and Boseti. In Butajira that was first identified in 2014, surface survey including geophysical survey shall be conducted.
- To realize, as earliest as possible after the above survey, test well drillings at Tendaho-2 (Ayrobera), Boseti or Butajira wherever deemed to be the most promising;
- To conduct, as an urgent requirement, a master plan project for the establishment of EEGeD; to implement capacity building to EEGeD, at very earliest convenient, in order to accelerate the geothermal development; and
- To review and update the geothermal resource assessment as further exploration proceeds,

- To review and update the Master Plan from time to time, since the Ethiopia economy is being rapidly growing and the world economic circumstances are drastically changing.

THE PROJECT FOR FORMULATING MASTER PLAN ON DEVELOPMENT OF GEOTHERMAL ENERGY IN ETHIOPIA

FINAL REPORT

APRIL 2015

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(as of April 2015)
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1 ETB = 5.929 JPY

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Tables

Abbreviations

AFD	French Development Agency
AfDB	African Development Bank
AGRCC	Australian Geothermal Energy Group Geothermal Code Committee
ARGeo	African Rift Geothermal Development Facility
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AUC	Africa Union Commission
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
CCGT	Combined Cycle Gas Turbine
COD	Commercial Operation Date
EAPP	Eastern African Power Pool
EEA	Ethiopian Energy Agency
EELPA	Ethiopian Electric Light and Power Authority
EEP	Ethiopian Electric Power
EEPCo	Ethiopian Electric Power Corporation
EEU	Ethiopian Electric Utility
EG	Ethylene Glycol
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
EPA	Environmental Protection Authority
ESIA	Environmental and Social Impact Assessment
ESMF	Environment and Social Management Framework
FS, F/S	Feasibility Study
GHI	Global Horizontal Irradiance
GIS	Geographical Information System
GPS	Global Positioning System
GRMF	Geothermal Risk Mitigation Facility for Eastern Africa
GSE	Geological Survey of Ethiopia
GSDP	Geothermal Development Project
GTP	Growth and Transformation Plan
HVAC	high voltage alternate current
HVDC	high voltage direct current
IAEA	International Atomic Energy Agency
ICEIDA	Iceland International Development Agency
ICS	Inter-Connected System
IDA	International Development Agency
IEE	Initial Environmental Examination
IFC	International Finance Corporation

IPP	Independent Power Producer
JCC	Joint Coordination Committee
JICA	Japan International Cooperation Agency
KfW	Kreditanstalt für Wiederaufbau
Ma	Million age
MCA	Multi-Criteria Analysis
MER	Main Ethiopian Rift
MoM	Ministry of Mines
MoFED	Ministry of Finance and Economic Development
MoWIE	Ministry of Water, Irrigation and Energy
MP, M/P	Master Plan
MT	Magneto-Telluric Method
NDF	Nordic Development Fund
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PASDEP	Plan for Accelerated and Sustainable Development to End Poverty
PPA	Power Purchase Agreement
RG	Reykjavik Geothermal
SCS	Self-Contained System
SEA	Strategic Environment Assessment
SREP	Scaling up Renewable Energy Program
SWIR	Short Wave Infrared Radiometer
TBD	To be decided
TEM	Transit Electro-Magnetic Method
TICAD	Tokyo International Conference on African Development
TIR	Thermal Infrared Radiometer
UEAP	Universal Electricity Access Program
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USAID	US Agency for International Development
VNIR	Visible and Near-infrared Radiometer
WB	The World Bank
WFB	Wonji Fault Belt
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

CHAPTER 1 BACKGROUND

1.1 Background

The total installed capacity of electricity power plants in Ethiopia amounted to 2,100 MWe, as of January 2010; more than 90% of such are of hydropower. Ethiopia intends to develop its huge hydropower potential, estimated to be up to 45,000 MWe in the country, to satisfy the increasing national demand as well as to export surplus electricity to surrounding countries.

However, yearly fluctuation of precipitation has become larger possibly due to global climate change, which has aggravated the reliability of hydropower electricity generation. Economic and industrial activities in the country are to be affected by the unexpected fluctuation of power supply that presently depends heavily on hydropower.

Under such circumstances, the Ethiopia Electricity Power Cooperation (EEPCo) addresses the development of indigenous energy such as geothermal and/or wind power, with recognition of the importance of energy diversity and energy mixture.

Among other indigenous types of energy, geothermal energy has become more important as a base load power, as well as the following: i) a substitute to fossil fuel being imported, ii) a major backup to hydropower electricity supply, iii) a service to arid and semi-arid areas in the country where hydropower is unavailable, and iv) contribution to the United Nations Framework Convention on Climate Change (UNFCCC) effort of reducing global warming.

Geothermal potential survey was commenced in Ethiopia in 1969. Since then, step-by-step potential surveys have identified more than 16 promising geothermal sites for electricity development. The total geothermal potential is estimated at 5,000 MWe.

However, development stages of the sites vary (only two sites, i.e., Aluto-Langano site and Corbetti site, are being developed towards commercial operation, whereas there are sites where development has been suspended, as follows: i) after test well drillings (Tendaho-1 (Dubti) site and Gedemsa site), ii) after slim hole drillings; and iii) after surface geological and geochemical surveys. Under this condition, a priority comparison with reasonable datasets is required for geothermal development.

The Geological Survey of Ethiopia (GSE) requested the Government of Japan for technical assistance in formulating a master plan for geothermal development including geothermal potential evaluation and prioritization, and technical capacity building for geothermal development. In response to the request, the Japan International Cooperation Agency (hereinafter referred to as "JICA") conducted a preparatory survey for survey planning in February 2013, that resulted in the Records of Discussion (R/D) with Ethiopia for the implementation of "The Project for Formulating Master Plan on Development of Geothermal Energy in Ethiopia" (hereunder referred to as "the Project").

Based on the R/D, JICA dispatched the JICA Project Team headed by Mr. TAKAHASHI Shinya of Nippon Koei Co., Ltd., Japan to conduct the Project.

1.2 Objectives and Scope of Work of the Project

1.2.1 Objectives

The objectives of the Project are as follows:

1) To conduct geothermal surface survey for 16[1] geothermal prospects;
2) To prioritize geothermal prospects with a unique set of criteria with database construction;
3) To formulate the master plan for geothermal development based on the above; and
4) To contribute to capacity development of GSE under the process of formulating the master plan.

1.2.2 Counterpart and Relevant Organizations

The counterpart organization and the Joint Coordination Committee are as follows:

1) Counterpart:
   Geological Survey of Ethiopia (GSE), Ministry of Mines of Ethiopia
2) Joint Coordination Committee (JCC)
   i) Ethiopian Organizations
      - Director General of GSE / Chief Geologist of GSE
      - Director of Geothermal Resource Directorate, GSE
      - Representative from the Ministry of Mines (MoM)
      - Representative from the Ministry of Water, Irrigation and Energy (MoWIE)
      - Representative from the Ethiopian Electric Power (EEP)
      - Representative from the Ministry of Finance and Economic Development (MoFED)
   ii) Japanese Organizations
      - Resident Representative of JICA Ethiopia Office
      - JICA Project Team
      - Other personnel concerned to be proposed by JICA

[1] According to R/D (11 June 2013)

iii) Observer

- Representative from the Embassy of Japan

Note that EEPCo has been restructured into two companies: a) Ethiopia Electric Power (EEP) responsible for power generation and supply, and b) Ethiopian Electric Utility (EEU) for delivering electricity services (transmission, distribution, and sale of electric power). The EEP will be managed by the Ethiopian CEO, whereas the EEU will be managed for two years by an Indian company (Power Grid Corporation).

1.2.3 Target Sites

The target sites are listed in Table 1.2.1 below. The approximate locations are shown in the location map at the beginning of this report.

Table 1.2.1 Target Sites

Geothermal Sites		Prioritization / Data base	Remote Sensing	Site Survey
1	Dallol	☑	☑	GSE
2	Tendaho-3 (Tendaho-Allalobeda)	☑	☑	☑
3	Boina	☑	☑	GSE
4	Damali	☑	☑	GSE
5	Teo	☑	☑	GSE
6	Danab	☑	☑	GSE
7	Meteka	☑	☑	☑
8	Arabi	☑	☑	GSE
9	Dofan	☑	☑	☑
10	Kone	☑	☑	☑
11	Nazareth	☑	☑	☑
12	Gedemsa	☑	☑	☑
13	Tulu Moye	☑	☑	-
14	Aluto-2 (Aluto-Finkilo)	☑	☑	☑
15	Aluto-3(Aluto-Bobesa)	☑	☑	☑
16	Abaya	☑	☑	-
(17)	Fantale	☑	☑	-
(18)	Boseti	☑	☑	☑
(19)	Corbetti	☑	☑	-
(20)	Aluto-1 (Aluto-Langano)	☑	☑	-
(21)	Tendaho-1 (Tendaho-Dubti)	☑	☑	-
(22)	Tendaho-2 (Tendaho-Ayrobera)	☑	☑	☑

Source: JICA Project Team

☑:Target for the M/P formulation project
GSE: The sites where GSE should undertake the site survey due to access and/or security issues.
Source: Proposed by the JICA Project Team based on the R/D (11 June 2013) and subsequent discussions between GS E and the JICA Project Team

Among the 22 sites listed above, sites #01 to #16 are included in the R/D (11 June 2013), while sites #17 to #22 are newly included in the Master Plan Formulation Project, as a result of the inception report meeting held on 14 October 2013 at the GSE head office and other follow-up meetings.

1.2.4 Member and Schedule of Project

Member list of this project is shown in Table 1.2.2.

Table 1.2.2 Project Member

Name	Position	Company
Shinya TAKAHASHI	Team Leader / Geothermal Development	Nippon Koei Co., Ltd.
Toshiaki HOSODA	Acting Team Leader / Geology	Nippon Koei Co., Ltd.
Tsukasa YOSHIMURA	Geothermal Reservoir Evaluation	Nippon Koei Co., Ltd.
Daisuke FUKUDA	Geochemistry	JMC Geothermal Engineering Co., Ltd.
Naoki KAWAHARA	Electric Power Development / Database	Nippon Koei Co., Ltd.
Nobuhiro MORI	Economic Analysis	Nippon Koei Co., Ltd. (KRI International Corp.)
Shinsuke SATO	Socio-Environmental Assessment	Nippon Koei Co., Ltd.
Masahiro TAKEDA	Geophysical Survey-1	Sumiko Resources Exploration & Development Co., Ltd
Akira KIKUCHI	Geophysical Survey-2	Sumiko Resources Exploration & Development Co., Ltd
Yasushi MOMOSE	Donor Coordination-1 / Geothermal Reservoir Evaluation-2	Nippon Koei Co., Ltd.
Masako TERAMOTO	Donor Coordination-1 / Geochemistry -2	Nippon Koei Co., Ltd.

Source: JICA Project Team

CHAPTER 2 ELECTRICITY DEVELOPMENT PLAN

2.1 Growth and Transformation Plan

2.1.1 Overview

The latest government development plan is the Five-year Growth and Transformation Plan (GTP) for the period 2010/11-2014/15. The GTP has been prepared with clear objectives and targets through wide public participation at both the federal and regional levels. The Council of Ministers and the House of People’s Representative have adopted the GTP as the national planning document of the country for the period 2010/11-2014/15. The GTP’s main objectives, strategies, and targets are clearly set out in the document. During the GTP period, special emphasis will be given to agricultural and rural development, industry, infrastructure, social and human development, good governance, and democratization.

The Ministry of Finance and Economic Development is responsible for preparing, implementing, and monitoring the GTP. The visions, objectives, and strategic pillars are summarized in Table 2.1.1.

Development programs that will be implemented in the five-year GTP period will have a strong focus on improving the quality of public services provided. Thus, special emphasis is given to investments in infrastructure and in the social and human development sectors. It is clear that implementation of the GTP will require mobilization of considerable financial and human resources, especially for infrastructure development. For this reason, mobilization of domestic financial and human resources, as well as improvements in domestic savings, are considered to be critical.

Table 2.1.1 Growth and Transformation Plan (2010/11-2014/15)

Factor	Description
Ethiopia’s vision guiding the GTP	“to become a country where democratic rule, good governance, and social justice reign upon the involvement and free will of its peoples, and once extricating itself from poverty to reach the level of a middle-income economy as of 2020-2023.”
Vision on economic sectors	“building an economy which has a modern and productive agricultural sector with enhanced technology and an industrial sector that plays a leading role in the economy, sustaining economic development and securing social justice and increasing per capita income of the citizens so as to reach the level of those in middle-income countries.”
Objectives	1. Maintain at least an average real gross domestic product (GDP) growth rate of 11% and attain the millennium development goals (MDGs); 2. Expand and ensure the qualities of education and health services and achieve MDGs in the social sector; 3. Establish suitable conditions for sustainable nation building through the creation of a stable democratic and development state; and 4. Ensure the sustainability of growth by realizing all the above objectives within a stable macroeconomic framework.
Strategic pillars	1. Sustaining rapid and equitable economic growth, 2. Maintaining agriculture as major source of economic growth, 3. Creating conditions for the industry to play key role in the economy, 4. Enhancing expansion and quality of infrastructure development, 5. Enhancing expansion and quality of social development, 6. Building capacity and deepen good governance, and 7. Promote gender and youth empowerment and equity.

Source: GTP (2010/11-2014/15)

2.1.2 Energy Sector Plan

The strategic directions of the energy sector are development of renewable energy, expansion of energy infrastructure, and creation of an institutional capacity that can effectively and efficiently manage such energy sources and infrastructure. During the GTP period, the gap between the demand for and supply of electricity will be minimized.

The main objective of the energy sector is to meet the demand for energy in the country by providing sufficient and reliable power supply that meets international standards at all time. This objective will be achieved by accelerating and completing the construction of new hydropower plants, as well as geothermal plants, and strengthening the existing transmission lines to provide improved access to rural villages all over the country. An additional objective is to export power to the neighboring countries. Modernizing the distribution system will also be considered to reduce power losses.

The main targets of the energy sector are summarized in Table 2.1.2.

Table 2.1.2 GTP Targets of the Energy Sector

Description of Target	2009/10	2014/15
1. Hydroelectric power generating capacity (MW)	2,000	10,000
2. Total length of distribution lines (Km)	126,038	258,000
3. Total length of rehabilitated distribution lines (Km)	450	8,130
4. Reduce power wastage (%)	11.5	5.6
5. Number of consumers with access to electricity	2,000,000	4,000,000
6. Coverage of electricity services (%)	41	75
7. Total underground power distribution system (Km)	97	150

Source: GTP (2010/11-2014/15)

The implementation strategies for power generation and transmission are set out as follows:

For power generation: Ethiopia has a potential to generate 45,000 MW of hydroelectric power and 5,000 MW of geothermal power. However, currently only 2,000 MW has been developed. It is planned to increase this level of generated power by four times. The implementation strategies are: (i) to promote a best mix of energy sources by developing hydro, geothermal, and other renewable energies including wind and solar power; (ii) to prevent power losses and promote proper utilization of energy; (iii) to reduce unit costs of power generation investments and operations; and (iv) to provide electricity at affordable prices.

For power transmission: To ensure a reliable electricity supply and transmit the electric power efficiently and economically to consumers, construction of a reliable transmission and distribution networks is essential. To this end, due emphasis will be given in the Universal Electrification Access Program to construct new transmission lines and connect them to the national grid as economically as possible and to reduce power losses.

The GTP policy matrix for the energy sector, which stipulates who will do what by when and will be verified by how, is set out as follows:

Table 2.1.3 GTP Policy Matrix for Energy Sector

Objective	Output	Indicator	Base year (2009/10)	Annual Targets (20**/**)					Implementing Agency	Means of Verification
				10/11	11/12	12/13	13/14	14/15		
Increase quality electric power supply service coverage	Increased in electric power users	Number of consumers with access to electricity (in million)	2.03	2.13	2.33	3.70	3.30	4.00	MoWIE	MoWIE annual report
	Increased in electric power distribution	Coverage of electricity services (%)	41	50	55	65	70	75		
	Increased in construction of electric distribution station	Total length of distribution lines (Km)	126,038	1E+05	1E+05	2E+05	2E+05	3E+05		
		Total length of rehabilitated distribution lines (Km)	450	967	3,258	5,694	8,130	8,130		
		reduce power wastage of power transmission lines (%)	11.0	10.8	8.5	5.6	5.6	5.6		
Modernizing the distribution and transmission system, so as to reduce power losses to international benchmark levels	Increased in constructed electric sub-stations and gridlines their quality	Total underground power distribution system (Km)	97	53					MoWIE	MoWIE annual report
		High voltage (500 kV) electric grid line constructed (Km)				434	434	434		
		High voltage (400 kV) electric grid line constructed (Km)	710	710	714	1,082	1,377	1,377		
		Voltage grid lines with 230, 132, 66 kV constructed (Km)	10,730	11,397	12,954	13,604	14,404	15,189		
		Proportion of rehabilitated distribution sub-stations (%)		50	100					
		Reduce power wastage of power transmission and distribution sub-stations	5.34	4.5	4.0	4.0	4.0	3.0		
Increased electric power generation and production	Increased in generation and produced electric power	Power generating capacity (MW)	2,000	2,045	2,582	3,117	5,054	10,000	MoWIE	MoWIE annual report
		Electric power produced (GWh)	7,653	7,923	10,576	12,140	19,234	32,656		

MoWIE: Ministry of Water, Irrigation, and Energy

Source: GTP (2010/11-2014/15) (modified by the JICA Project Team)

2.2 Overview of Power Sector

2.2.1 Policy, Laws, Regulations, and Strategy

The Transitional Government of Ethiopia released its first National Energy Policy in March 1994. This is still in force as the policy of the Government of Ethiopia and is currently being revised. It aims to address household energy problems by promoting agro-forestry, increasing the efficiency with which biomass fuels are utilized, and facilitating the shift to greater use of modern fuels. Furthermore, the policy states that the country will rely mainly on hydropower to increase its electricity supply, and also take advantage of geothermal, solar, wind, and other renewable energy resources, where appropriate. It also refers to the need to encourage energy conservation in the industry, transport, and other major energy-consuming sectors, to ensure that energy development is economically and environmentally sustainable.

The Plan for Accelerated and Sustained Development to End Poverty (PASDEP) was presented as a five-year (2005/06-2009/10) development strategy by the Government of Ethiopia in 2006, which aims to become a middle income country in 20-30 years. The PASDEP had set its target in the energy sector to increase the access rate from 16% (2005/06) to 50% (2009/10) by the augmentation of energy generation from 791 MW to 2,218 MW and the expansion of the grid to 13,054 km. Energy loss was also planned to be reduced from the current level of 19.5% to the international average of 13.5% during the PASDEP period. The total cost for these plans was estimated to be ETB 51 billion (equivalent to USD 5.3 billion) for five years which was almost equal to the annual national budget.

Following PASDEP, the GTP mentioned in Section 2.1 is the current national policy for the period 2010/11 – 2014/15 and has targets for energy sector to increase the installed capacity by 8,000 MW of renewable energy resources. Table 2.2.1 presents the targets of PASDEP and GTP.

Table 2.2.1 Targets in the PASDEP/GTP Period 2005-2015

Item	2005/06	PASDEP 2005/06-2009/10	2012	GTP 2010/11-2014/15
Installed Capacity	791MW	2,218 MW (+1,427MW)	2,168 MW	10,000 MW
Electrification Rate	16%	50% (+34%)	17%	75%
Length of Transmission/Distribution Line	-	13,054km	12,461 km	258,000 km
Electricity Loss	19.5%	13.5%	-	5.6%

Source: PASDEP/GTP (summarized by the JICA Project Team)

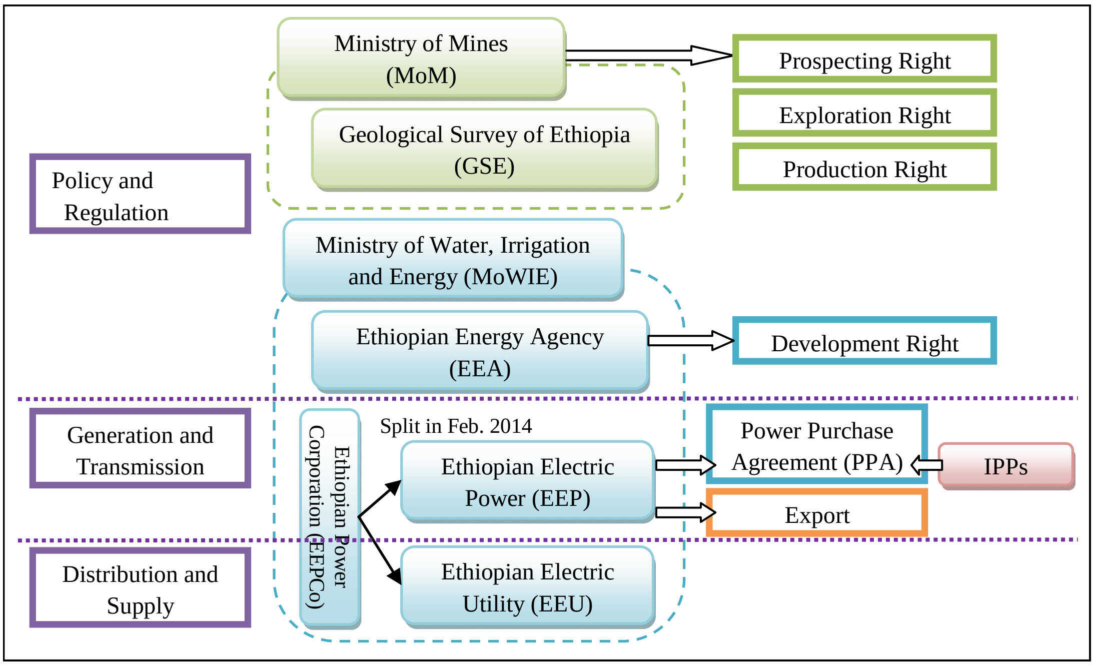
The Ethiopian Electric Power Corporation (EEPCo), which was the national electricity utility and in charge of power generation plan, completed the "Ethiopian Power System Expansion Master Plan" in February 2014. The objective of the study is to update the least cost Power System Expansion Program for the development of Ethiopia's generation and transmission systems for the next 25 years (2013–2037).

Based on the national policies above new hydropower plants have been commissioned and a number of power plants using renewable energy resource has been committed for construction in the next ten years. The Prime Minister of Ethiopia, Hailemariam Desalegn, also mentioned the necessity of Africa's transformation and enhanced the importance of energy development in his speech given on 29 September 2013 in New York. He also stated that Ethiopia will develop around 80,000 MW of hydro, geothermal, wind, and solar power over the next 30 years, not just for Ethiopia, but for neighboring countries as well.

On the other hand, the Government of Japan agreed to the Yokohama Declaration 2013 that prioritizes investment promotion for renewable energy including hydro, solar, and geothermal, in the Fifth Tokyo International Conference on African Development (TICAD V) held on 3 June 2013. And also Japan's Prime Minister, Shinto Abe, expressed his intention to resume the Japanese Yen Loan and conveyed his expectation that its first project would be the expansion of Aluto-Langano Geothermal Power Plant. He also expressed his interest in the development potential of geothermal energy in Ethiopia.

2.2.2 Power Sector Institutions

The power sector is managed by the national government. There are five major institutions engaging in the sector, namely: (i) Ministry of Mines (MoM), (ii) Geological Survey of Ethiopia (GSE), (iii) Ministry of Water, Irrigation and Energy (MoWIE), (iv) Ethiopian Electric Power (EEP) and Ethiopian Power Utility (EEU), and (v) Independent Power Producers (IPPs). Functionality-wise, the MoM and MoWIE undertake policy-making and regulation while GSE conducts geothermal exploration and EEP, EEU, and IPPs undertake construction and operation of power supply system (generation and transmission and distribution) as shown in Figure 2.2.1.



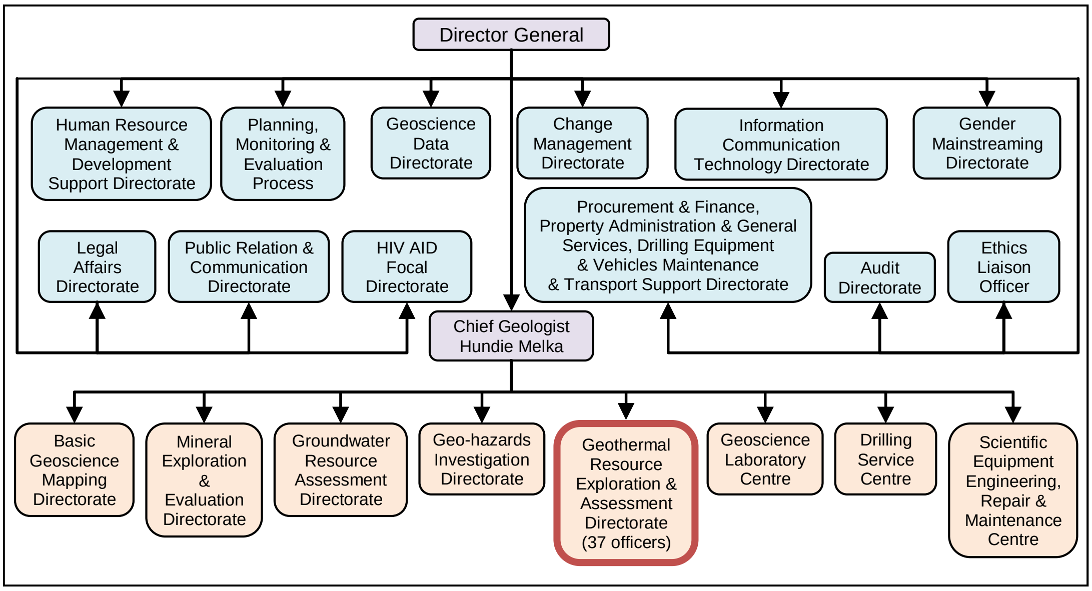
Source: JICA Project Team

Figure 2.2.1 Organizational Chart of Power Sector in Ethiopia

(1) Geological Survey of Ethiopia (GSE)

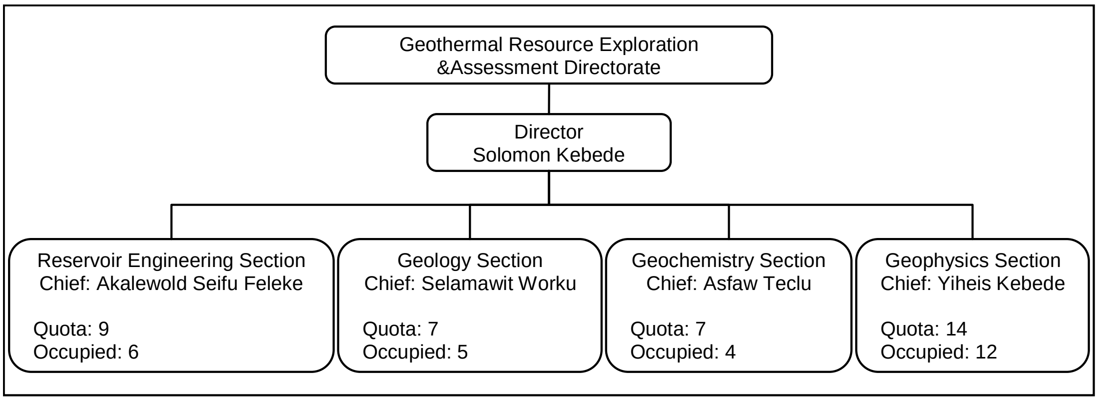
GSE is responsible for geothermal exploration as part of the mineral exploration of the country. GSE was established under the Ministry of Mines and has been involved in geothermal exploration since the work started with reconnaissance surveys in the Ethiopian Rift Valley between 1969 and 1973 funded by the United Nations Development Programme (UNDP). It is currently responsible for all scientific exploration works including the drilling and testing of wells. EEP then takes over the power station construction and operation. This is the model used for the development of the Aluto- Langano and Tendaho fields.

Figure 2.2.2 and Figure 2.2.3 shows organization chart of GSE and Geothermal Resource Exploration & Assessment Directorate. GSE has eight technical sections, which are managed by the chief geologist under the director general. Geothermal Resource Exploration & Assessment Directorate has responsibility about geothermal resource exploration in GSE.



Source: GSE

Figure 2.2.2 GSE Organization Chart



Source: GSE

Figure 2.2.3 Organization Chart of Geothermal Section

(2) Ministry of Mines (MoM)

MoM is the ministry responsible for geothermal development in Ethiopia through GSE headed by its Director General. There is no staff at the ministry dealing specifically with geothermal activities.

(3) Ministry of Water, Irrigation and Energy (MoWIE)

MoWIE is the responsible organization of the Government of Ethiopia that is responsible for the country's energy sector development and expansion. MoWIE has two sections, namely: energy section and water supply section and the energy section has six divisions and has jurisdiction over Ethiopian Energy Agency (EEA), Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU). Energy related directorates within MoWIE are responsible for energy policy drafting, implementation follow up and supervision. They are also responsible for conducting research and studies including development and promotion of rural energy-efficient technologies.

(4) Ethiopian Energy Agency (EEA)

The Electricity Proclamation No. 86/1997 of June 1997 paved the way for the establishment of the Ethiopian Electricity Agency as an autonomous federal government organization. The Ethiopian Energy Authority (EEA), which was established in 2000, replaced the Ethiopian Electricity Agency in 2013 by the Energy Proclamation No.810/2013, and is tasked to oversee EEP/EEU and controls the investments in the country. EEA is responsible for the regulation of operations in the electricity supply sector including licensing and ensuring safety and quality standards and has also set prices for the private and state power distributors.

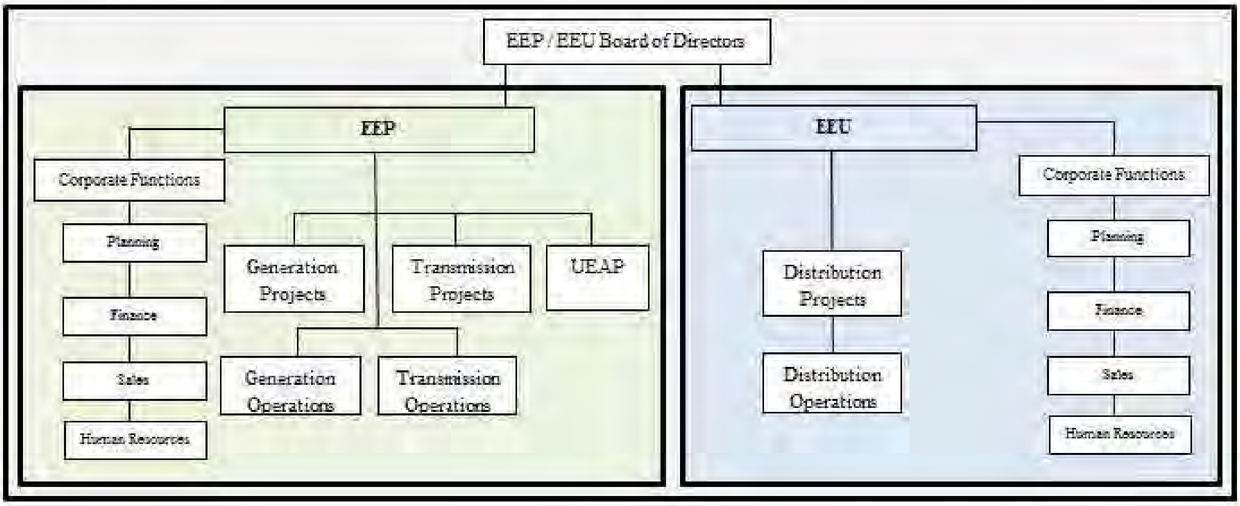
To regulate electricity generation, transmission, distribution, and sale of electricity, EEA is responsible for setting the tariffs and regulating and supervising access by private operators to the electricity grid, which includes the approval of power purchase agreements (PPAs).

(5) Ethiopian Electric Power (EEP)/ Ethiopian Electric Utility (EEU)

Ethiopian Electric Power Corporation (EEPCo) was the only government body that is responsible for planning, investing, commissioning, and operating electricity generation, transmission, distribution, and sale of electricity throughout Ethiopia. The predecessor, Ethiopian Electric Light and Power Authority (EELPA) was established in 1956 and rebuilt as EEPCo in 1997 by Regulation Number 18/1997.

As shown in Figure 2.2.4, EEPCo was split into two public enterprises in December 2013, i.e., namely Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU). The aim of this restructuring was to create modern entities capable of providing efficient, reliable, and high-quality services. EEP is responsible for construction and operation of the power generation and transmission while EEU is responsible for construction and operation of power distribution and sales. EEU which is in charge of the electricity delivery has already awarded a consortium of three Indian companies a two-year and half management contract for USD 21 million in August 2013. The companies have responsibility for increasing the efficiency of the operation, distribution and sale of electric power and also support the efficiency increase and capacity building of generation operation and transmission operation of EEP.

Geothermal development projects including on-going projects of Aluto-Langano and Corbetti are managed by the Generation Projects section in EEP and overall electric generation planning is conducted by the Planning section of the Corporate Functions in Figure 2.2.4.



Source: World Bank

Figure 2.2.4 EEP and EEU Organization Chart

2.2.3 Power Demand Forecast

For the purpose of formulating the master plan on development of geothermal energy, the demand forecast for power given by EEP was reviewed. The latest forecast is conducted by former EEPCo in the study of “Ethiopian Power System Expansion Master Plan (hereinafter EEPCo master plan)” based on the records up to 2011.

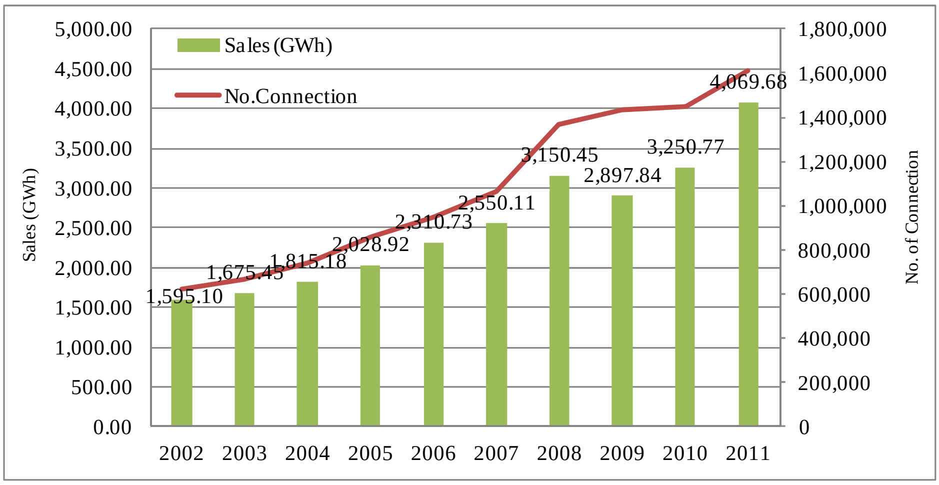
(1) Past Growth of Power Demand

Table 2.2.2 and Figure 2.2.5 show the historical energy sales from 2002 to 2011. Total electricity sales has increased with high growth rates of around 5% to 25%, and reached 4,069.68 GWh in 2011, although sales temporarily decreased in 2009 due to a worldwide economic crisis. The electricity consumer is divided into four categories based on tariff category as shown in Figure 2.2.6, namely, domestic (1,632.86 GWh, 40%), commercial (955.56 GWh, 23%), street light (25.75 GWh, 1%), industrial LV (711.47 GWh, 18%), and industrial HV (744.04 GWh, 18%). By category, because of the increase in number of connections with an electrification growth in the Universal Electricity Access Program (UEAP), domestic power demand has greatly increased and has tripled in the past decade.

Table 2.2.2 Electricity Sales (GWh: 2007-2012)

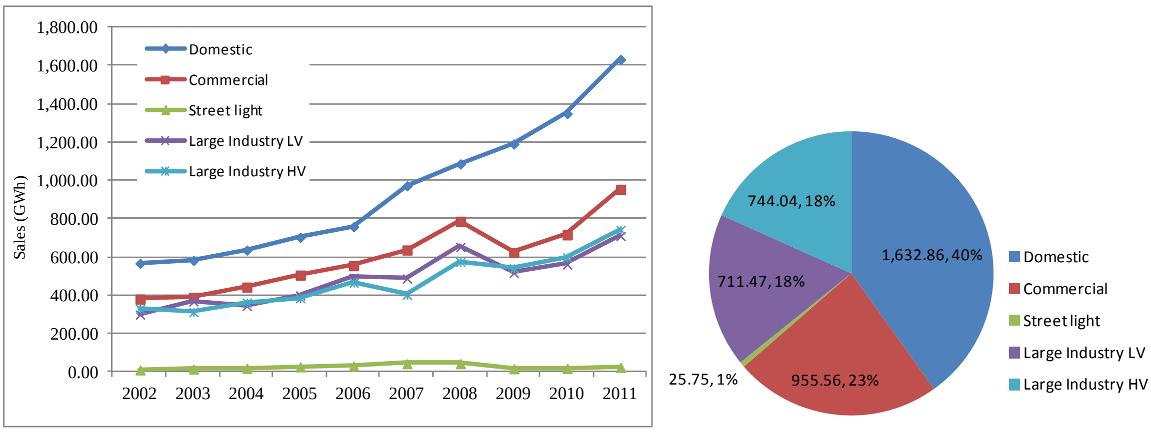
No.	Category	Type	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1	Domestic	Sales (GWh)	568.66	583.92	637.94	704.58	759.76	973.11	1,087.42	1,191.68	1,350.34	1,632.86
		No.Connection	535,254	571,975	637,016	739,009	820,514	923,390	1,177,627	1,250,802	1,263,655	1,381,963
		kWh/Connection	1,062	1,021	1,001	953	926	1,054	923	953	1,069	1,182
2	Commercial	Sales (GWh)	381.95	391.32	444.81	507.70	556.73	638.24	788.08	625.12	717.42	955.56
		No.Connection	79,731	83,806	91,863	104,331	114,281	125,853	166,233	165,351	166,166	202,475
		kWh/Connection	4,791	4,669	4,842	4,866	4,872	5,071	4,741	3,781	4,317	4,719
3	Street light	Sales (GWh)	12.55	16.60	21.18	28.35	32.13	44.80	44.94	18.79	20.38	25.75
		No.Connection	985	1,139	1,267	1,546	1,782	2,105	2,455	2,635	1,959	3,013
		kWh/Connection	12,743	14,574	16,717	18,338	18,030	21,283	18,305	7,131	10,403	8,546
4	Large Industry LV	Sales (GWh)	301.02	369.65	346.88	401.46	494.06	489.16	654.01	519.24	562.93	711.47
		No.Connection	7,957	8,204	8,871	10,036	11,422	12,083	18,432	18,104	14,682	21,071
		kWh/Connection	37,831	45,057	39,103	40,002	43,255	40,483	35,482	28,681	38,342	33,765
5	Large Industry HV	Sales (GWh)	330.92	313.96	364.37	386.83	468.05	404.80	576.00	543.01	599.70	744.04
		No.Connection	96	93	101	122	131	154	200	169	114	163
		kWh/Connection	3,447,106	3,375,914	3,607,624	3,170,738	3,572,901	2,628,571	2,880,000	3,213,077	5,260,526	4,564,663
	Sub Total	Sales (GWh)	**1,595.10**	**1,675.45**	**1,815.18**	**2,028.92**	**2,310.73**	**2,550.11**	**3,150.45**	**2,897.84**	**3,250.77**	**4,069.68**
		Growth Rate (%)	**-**	**5.04%**	**8.34%**	**11.78%**	**13.89%**	**10.36%**	**23.54%**	**-8.02%**	**12.18%**	**25.19%**
		No.Connection	**624,023**	**665,217**	**739,118**	**855,044**	**948,130**	**1,063,585**	**1,364,947**	**1,437,061**	**1,446,576**	**1,608,685**
		kWh/Connection	**2,556.16**	**2,518.65**	**2,455.87**	**2,372.88**	**2,437.14**	**2,397.66**	**2,308.11**	**2,016.50**	**2,247.22**	**2,529.82**

Source: Ethiopian Power System Expansion Master Plan, EEPCo (modified by the JICA Project Team)



Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by the JICA Project Team)

Figure 2.2.5 Electrical Sales and Number of Customers



Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by the JICA Project Team)

Figure 2.2.6 Electrical Sales Growth by Category and Share in 2011 (GWh)

Table 2.2.3 shows the electrical energy sold and generated for the years 2002 to 2011 and the system peak load and load factor. In 2011, an electric power of 4,954 GWh was generated by all power plants with total installed capacity of 2,167 MW in Ethiopia. Energy loss varying from 10%–20% from 2002 to 2011 has been comparatively high because of transmission distribution loss. System peak demand has also increase more than twice in the past decade and was recorded 914 MW.

Table 2.2.3 Generated Energy Sent out and Peak Demand (2002-2011)

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Energy Sales (GWh)	1,595.10	1,675.45	1,815.18	2,028.92	2,310.73	2,550.11	3,150.45	2,897.84	3,250.77	4,069.68
Generation Sent-Out (GWh)	1,784	2,028	2,278	2,540	2,845	3,269	3,502	3,665	3,946	4,954
Energy Loss (%)	10.6%	17.4%	20.3%	20.1%	18.8%	22.0%	10.0%	20.9%	17.6%	17.9%
System Maximum Demand (MW)	391	405	454	521	587	623	675	673	767	914
System Load Factor (%)	52%	57%	57%	56%	55%	60%	59%	62%	59%	62%

Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by the JICA Project Team)

Based on the Eastern Africa Power Pool (EAPP) framework and the power purchase agreements (PPAs) between Ethiopia and its neighboring countries, Ethiopia has exported electricity to neighboring countries such as Djibouti, Kenya and Sudan. Summary of the agreement regarding the power purchase is shown below.

- First 400 MW to Kenya (Around 3,000 GWh)
- 100 MW to Djibouti (Around 570 GWh)
- First 100 MW to Sudan (Around 880 GWh)
- First 200 MW to South Sudan/Egypt (Around 1,300 GWh)
- First 200 MW to Tanzania (Around 1,399 GWh)

(2) Power Demand Forecast

As mentioned above, the power demand has increased with a high growth rate in the past decade. The power demand is expected to increase in the future not only due to increase in domestic consumers but also new consumers such as railway constructions, large-scale irrigation facilities, new industries, and electricity exports. The EEPCo master plan conducted the electricity forecast for the period from 2013 to 2037 and covers reference, high and low cases.

The EEPCo master plan study has conducted the forecast for each category such as domestic, commercial, industrial, and irrigation using a combination of regression analysis load forecast model and end-user models.

The total energy requirement in Ethiopia is forecasted from 6,425 GWh in 2012 to 111,388 GWh in 2037 as shown in Table 2.2.4. It was forecasted to have high growth. In particular, the growth for the first ten years is very high because of the large growth in the industrial and irrigation sectors, and the new electrical demand of the new railway.

Table 2.2.4 Energy Requirement Forecast in Categories (Reference Case)

Year	Sales Forecast (GWh)												
	Domestic	UAEP	Commercial	Street Lighting	LV Industrial	HV Industrial	New Industry	Transport (Railway)	Irrigation	Sugar	Total Sales	Total Losses	Genaration Sent-out
2012	1,912	22	1,193	33	711	744	302	-	-	5	4,922	1,503	6,425
2013	2,192	206	1,350	35	711	744	1,036	-	-	49	6,323	1,910	8,233
2014	2,358	401	1,529	37	711	744	2,376	-	156	101	8,413	2,513	10,926
2015	2,512	605	1,736	39	711	744	4,303	404	389	101	11,544	3,143	14,687
2016	2,648	821	1,928	41	711	744	6,723	633	778	101	15,128	3,595	18,723
2017	2,761	1,051	2,143	44	711	744	9,729	938	1,167	101	19,389	3,972	23,361
2018	2,853	1,300	2,383	46	711	744	12,638	1,062	1,561	101	23,399	4,097	27,496
2019	2,926	1,556	2,646	48	711	744	14,805	1,185	2,214	101	26,936	4,312	31,248
2020	2,982	1,845	2,937	51	711	744	16,461	1,477	2,866	101	30,175	4,790	34,965
2021	3,025	2,144	3,255	54	711	744	18,393	1,642	3,519	101	33,588	5,287	38,875
2022	3,058	2,502	3,602	57	1,072	1,153	20,324	1,818	4,172	101	37,859	5,909	43,768
2023	3,082	2,936	3,980	60	1,466	1,602	20,324	2,162	4,824	101	40,537	6,273	46,810
2024	3,100	3,460	4,389	64	1,896	2,095	20,324	2,373	5,477	101	43,279	6,639	49,918
2025	3,114	4,039	4,833	67	2,362	2,633	20,324	2,583	6,130	101	46,186	7,024	53,210
2026	3,124	4,708	5,313	71	2,867	3,219	20,324	2,849	6,782	101	49,358	7,441	56,799
2027	3,131	5,455	5,833	75	3,412	3,855	20,324	3,135	7,435	101	52,756	7,883	60,639
2028	3,137	6,266	6,393	79	3,998	4,542	20,324	3,456	8,088	101	56,384	8,425	64,809
2029	3,141	7,128	6,996	83	4,625	5,282	20,324	3,789	8,740	101	60,209	8,997	69,206
2030	3,144	8,029	7,642	88	5,294	6,076	20,324	4,123	9,393	101	64,214	9,595	73,809
2031	3,146	8,939	8,331	92	6,006	6,924	20,324	4,542	10,046	101	68,451	10,228	78,679
2032	3,148	9,871	9,065	98	6,758	7,825	20,324	4,994	10,699	101	72,883	10,890	83,773
2033	3,149	10,822	9,842	103	7,551	8,779	20,324	5,448	11,351	101	77,470	11,576	89,046
2034	3,150	11,789	10,668	109	8,384	9,785	20,324	5,923	11,967	101	82,200	12,283	94,483
2035	3,150	12,772	11,536	115	9,253	10,841	20,324	6,398	12,583	101	87,073	13,011	100,084
2036	3,151	13,773	12,444	121	10,157	11,943	20,324	6,880	13,199	101	92,093	13,761	105,854
2037	3,151	14,485	13,391	128	11,093	13,088	20,324	7,331	13,816	101	96,908	14,480	111,388

Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by JICA Project Team)

The peak demand in Ethiopia was estimated from the total sales forecast. The peak demand will reach 21,731 MW in 2037 from 1,186 MW in 2012 in the reference case. The averaged growth rate is 12.3%.

Table 2.2.5 Peak Demand Forecast (Reference Case)

Year	Max Demand			
	Max Demand at Comsumer Level (MW)	Power Loss (%)	Max Demand (MW)	Power Load Factor (%)
2012	847	28.6%	1,186	61.8%
2013	1,087	28.3%	1,516	62.0%
2014	1,436	27.9%	1,992	62.6%
2015	1,951	26.1%	2,641	63.5%
2016	2,543	23.8%	3,335	64.1%
2017	3,229	21.4%	4,107	64.9%
2018	3,876	19.2%	4,795	65.5%
2019	4,499	18.1%	5,496	64.9%
2020	5,092	18.1%	6,219	64.2%
2021	5,704	18.1%	6,962	63.7%
2022	6,439	18.0%	7,848	63.7%
2023	6,976	18.0%	8,504	62.8%
2024	7,527	18.0%	9,176	62.1%
2025	8,108	17.9%	9,881	61.5%
2026	8,738	17.9%	10,644	60.9%
2027	9,410	17.9%	11,455	60.4%
2028	10,123	17.9%	12,335	60.0%
2029	10,870	18.0%	13,256	59.6%
2030	11,647	18.1%	14,213	59.3%
2031	12,461	18.1%	15,215	59.0%
2032	13,306	18.1%	16,254	58.8%
2033	14,176	18.2%	17,322	58.7%
2034	15,063	18.2%	18,410	58.6%
2035	15,973	18.2%	19,526	58.5%
2036	16,906	18.2%	20,669	58.5%
2037	17,777	18.2%	21,731	58.5%

Source: Ethiopian Power System Expansion Master Plan, EEPCo

As mentioned above, the Government of Ethiopia has agreed electricity purchase with neighboring countries. The maximum demand and energy sales of the export were forecasted as shown below. Energy export sales are forecast to grow from 1,445 GWh in 2013 to 35,303 GWh by 2037, and the total demands (MW) of exports are forecast to grow from 140 MW in 2012 to 4,080 MW by 2037.

Table 2.2.6 Coincident Export Maximum Demand and Energy Forecast (Reference Case)

Year	Coincident Export Maximum Demand (MW)							Energy Export (GWh)						
	Djibouti	Sudan	Sudan and Egypt	Kenya	Kenya II	Tanzania	Total	Djibouti	Sudan	Sudan and Egypt	Kenya	Kenya II	Tanzania	Total
(MW)	100	100	200-3100	400	200-1200	200-400		100	100	200-3100	400	200-1200	200-400	
Load factor	65%	100%	75%	85%	75%	75%		65%	100%	75%	85%	75%	75%	
2012	40	100	0	0	0	0	140	395	68	0	0	0	0	463
2013	65	100	0	0	0	0	165	569	876	0	0	0	0	1,445
2014	65	100	0	0	0	0	165	569	876	0	0	0	0	1,445
2015	65	100	150	0	0	0	315	569	876	1,314	0	0	0	2,759
2016	65	100	150	0	0	0	315	569	876	1,314	0	0	0	2,759
2017	65	100	450	340	0	0	955	569	876	3,942	2,978	0	0	8,365
2018	65	100	450	340	0	0	955	569	876	3,942	2,978	0	0	8,365
2019	65	100	600	340	0	0	1105	569	876	5,256	2,978	0	0	9,679
2020	65	100	600	340	0	150	1255	569	876	5,256	2,978	0	1,314	10,993
2021	65	100	900	340	150	150	1705	569	876	7,884	2,978	1,314	1,314	14,935
2022	65	100	900	340	150	150	1705	569	876	7,884	2,978	1,314	1,314	14,935
2023	65	100	1200	340	150	300	2155	569	876	10,512	2,978	1,314	2,628	18,877
2024	65	100	1200	340	300	300	2305	569	876	10,512	2,978	2,628	2,628	20,191
2025	65	100	1500	340	450	300	2755	569	876	13,140	2,978	3,942	2,628	24,133
2026	65	100	1500	340	450	300	2755	569	876	13,140	2,978	3,942	2,628	24,133
2027	65	100	1650	340	600	300	3055	569	876	14,454	2,978	5,256	2,628	26,761
2028	65	100	1650	340	750	300	3205	569	876	14,454	2,978	6,570	2,628	28,075
2029	65	100	1650	340	900	300	3355	569	876	14,454	2,978	7,884	2,628	29,389
2030	65	100	1950	340	900	300	3655	569	876	17,082	2,978	7,884	2,628	32,017
2031	65	100	1950	340	900	300	3655	569	876	17,082	2,978	7,884	2,628	32,017
2032	65	100	2175	340	900	300	3880	569	876	19,053	2,978	7,884	2,628	33,988
2033	65	100	2250	340	900	300	3955	569	876	19,710	2,978	7,884	2,628	34,645
2034	65	100	2250	340	900	300	3955	569	876	19,710	2,978	7,884	2,628	34,645
2035	65	100	2325	340	900	300	4030	569	876	20,367	2,978	7,884	2,628	35,302
2036	65	100	2325	340	900	300	4030	569	876	20,367	2,978	7,884	2,628	35,302
2037	65	100	2325	340	900	300	4030	569	876	20,367	2,978	7,884	2,628	35,302

Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by JICA Project Team)

Table 2.2.7 presents the overall load forecast including exports in each case at the generation sent-out level. Figure 2.2.7 shows the total energy generation while Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by JICA Project Team)

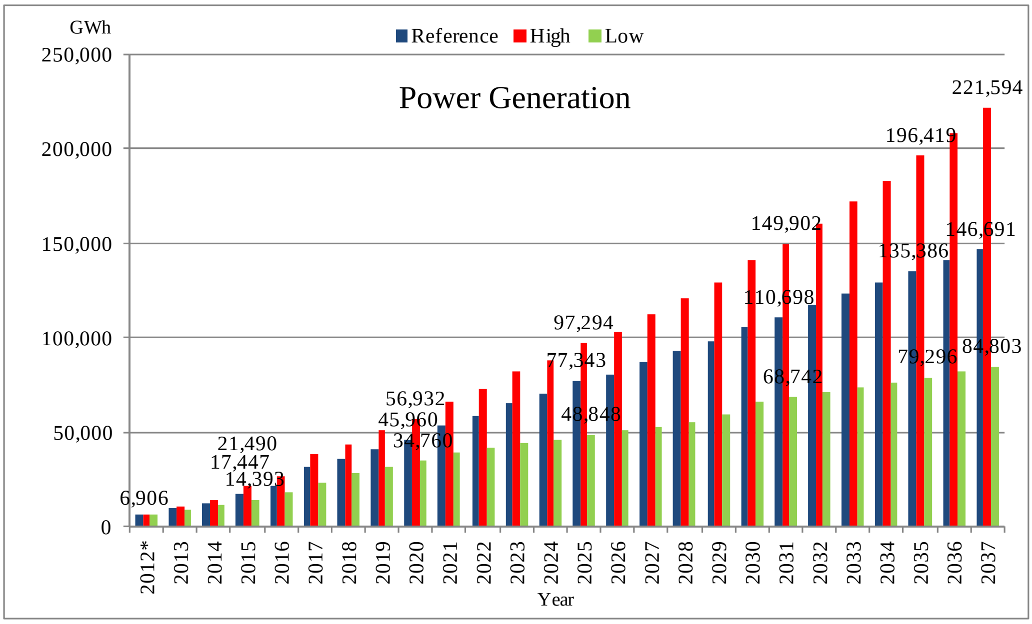
Figure 2.2.8 shows the peak demand. Energy generation and peak demand in reference case are forecasted to reach 146,691 GWh and 25,761 MW by 2037, respectively.

Table 2.2.7 Energy Requirement and Peak Demand Forecast including Exports (2012-2037)

Year	Total Energy Requirement (GWh)			Total Peak Demand (MW)		
	Reference	High	Low	Reference	High	Low
2012*	6,906	6,906	6,906	1,378	1,378	1,378
2013	9,680	10,763	9,034	1,681	1,884	1,575
2014	12,371	14,171	11,272	2,157	2,483	1,975
2015	17,447	21,490	14,393	2,956	3,560	2,499
2016	21,482	26,462	18,376	3,650	4,392	3,139
2017	31,729	38,469	23,700	5,062	6,037	3,938
2018	35,862	43,582	28,411	5,750	6,872	4,651
2019	40,929	50,918	32,045	6,601	8,037	5,270
2020	45,960	56,932	34,760	7,474	9,080	5,798
2021	53,811	66,454	39,073	8,667	10,525	6,506
2022	58,703	73,037	42,220	9,553	11,685	7,094
2023	65,689	82,171	44,006	10,659	13,113	7,510
2024	70,110	88,210	45,748	11,481	14,206	7,927
2025	77,343	97,294	48,848	12,636	15,671	8,504
2026	80,933	103,018	50,790	13,399	16,788	8,964
2027	87,401	112,572	52,838	14,510	18,373	9,448
2028	92,885	120,831	55,044	15,540	19,854	9,970
2029	98,597	129,718	59,968	16,611	21,440	10,812
2030	105,827	141,098	66,263	17,868	23,331	11,817
2031	110,698	149,902	68,742	18,870	24,955	12,392
2032	117,761	160,036	71,300	20,134	26,756	12,983
2033	123,693	172,152	73,929	21,277	28,808	13,587
2034	129,127	182,951	76,591	22,365	30,726	14,193
2035	135,386	196,419	79,296	23,556	32,972	14,809
2036	141,157	208,659	82,045	24,699	35,105	15,433
2037	146,691	221,594	84,803	25,761	37,341	16,061

*Actual record in 2012

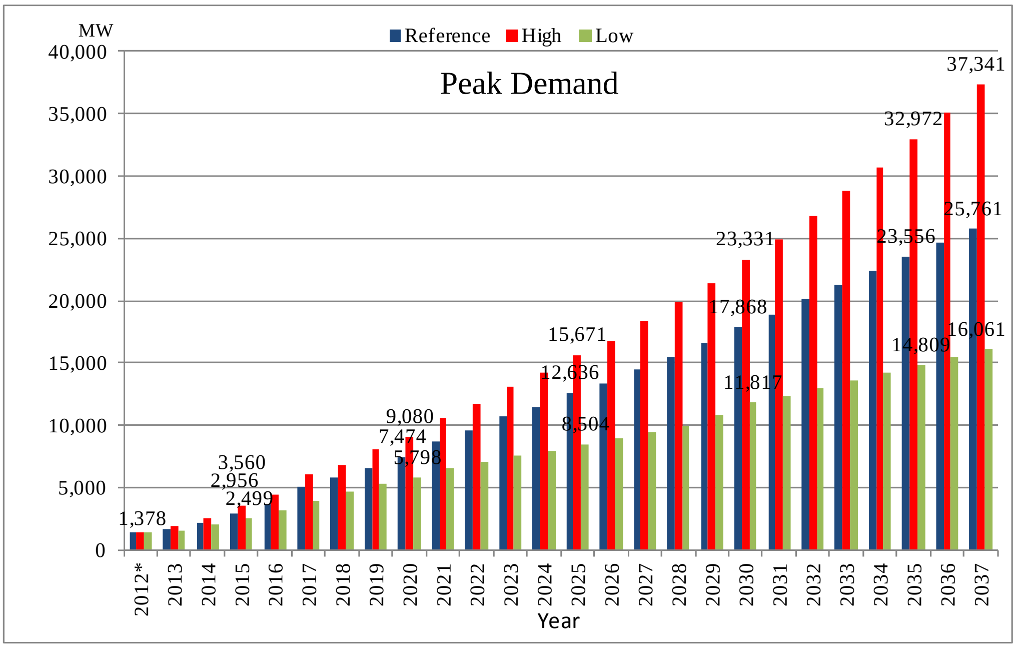
Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by JICA Project Team)



*Actual record in 2012

Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by JICA Project Team)

Figure 2.2.7 Energy Requirement Forecast including Exports (2012-2037)



*Actual record in 2012

Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by JICA Project Team)

Figure 2.2.8 Peak Demand Forecast including Exports (2012-2037)

2.2.4 Power Generation Planning

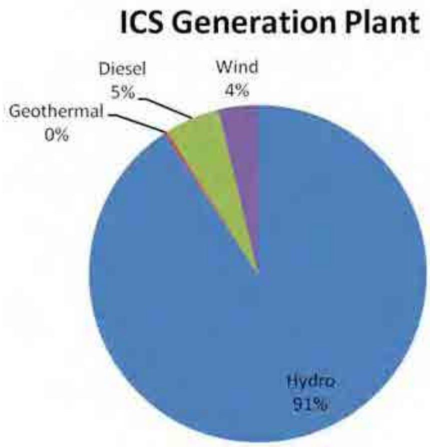
(1) Existing Power Plant

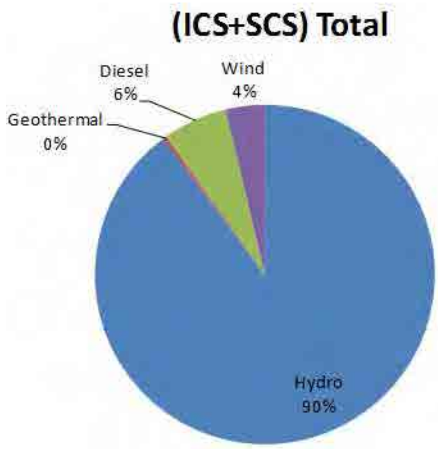
There are two electrical supply systems in Ethiopia, namely, on-grid Inter-Connected System (ICS) and off-grid Self-Contained System (SCS). Table 2.2.8 shows the installed capacity for both ICS and SCS. According to Facts in Brief 2011/12 of EEPCo and the EEPCo master plan study, total capacities of ICS and SCS are 2,140.20 MW and 26.80 MW, respectively in 2012, with a total capacity of 2,167 MW. The number and type of power plants in ICS are: 12 hydropower (1,940.6 MW), 13 diesel (112.3 MW), 1 geothermal (7.3 MW), and 2 wind, which generate about 6,000 GWh. Table 2.2.9 shows the power generation in the past five years. Because of new hydropower plants such as Gigel Gibe II, Tana Beles, Tekeze and Amerti Neshe, power generation has been largely increasing for the past two years.

The Aluto-Langano Geothermal Power Plant is the only geothermal power plant in Ethiopia at present, which is a binary generation of 7.3 MW commissioned in 1999. Due to leak in the heat exchanger tubes, the plant was shut down 18 months after starting its operation. The plant was rehabilitated but current generation was decreased to 5 MW. As of April 2014, the plant has not been in production due to maintenance problem.

Table 2.2.8 Installed Capacity of ICS and SCS, as of July 7, 2012 (2004 E.F.Y)

No.	Power Plant	Capacity (MW)	Initial Year
ICS Generation Plant			
Hydro		**1940.6**	
1	Koka	43.2	1960
2	Tis Abay I	11.4	1964
3	Awash II	32.0	1966
4	Awash III	32.0	1971
5	Finchaa	134.0	1973/2003
6	Meleka Wakana	153.0	1988/refurb in 2014
7	Tis Abay II	73.0	2001
8	Gilgel Gibe	184.0	2004
9	Gilgel Gibe II	420.0	2010
10	Tana Beles	460.0	2010
11	Tekeze	300.0	2010
12	Amerti Neshe	98.0	2011
Geothermal		**7.3**	
1	Aluto Langano	7.3	1999
Diesel		**112.3**	
1	Alemaya	2.3	1958
2	Ghimbi	1.1	1962/1984
3	Dire Dawa (mu)	4.5	1965
4	Axum	3.2	1975/1992
5	Shire	0.8	1975/1991/1995
6	Nekempt	1.1	1984
7	Mekelle	5.7	1984/1991/1993
8	Adigrat	2.5	1992/1993/1995
9	Adwa	3.0	1998
10	Kaliti	14.0	2004
11	Dire Dawa	38.0	2004
12	Awash 7 Kilo	35.0	2004
13	Jimma	1.1	
Wind		**81.0**	
1	Ashegoda	30.0	Jan/2012
2	Adama I	51.0	Mar/2012
	ICS Total	**2,141.2**	
SCS Generation Plant			
Hydro		**6.15**	
1	Yadot	0.35	
2	Sor	5.00	
3	Dembi	0.80	
Diesel		**20.65**	Isolated diesel power plants
	SCS Total	**26.8**	
(ICS+SCS) Total		**2,168.0**	

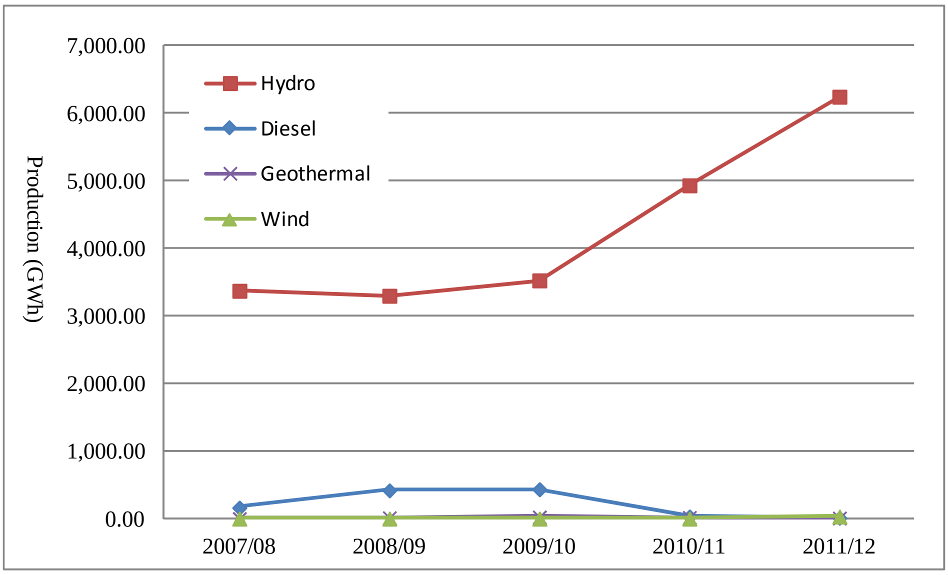




Source: Facts in Brief 2011/12, EEPCo

Table 2.2.9 Power Production (GWh)

System	Generation Type	2007/08	2008/09	2009/10	2010/11	2011/12
ICS	Hydro	3,353.60	3,277.14	3,503.79	4,922.00	6,239.29
	Diesel	133.13	381.78	407.41	14.00	0.00
	Geothermal	-	13.87	23.61	18.00	7.98
	Wind	-	-	-	-	29.40
	Sub-total	3,486.73	3,672.79	3,934.81	4,954.00	6,276.67
SCS	Hydro	16.49	19.23	20.11	9.00	1.84
	Diesel	28.48	35.77	26.15	17.00	11.07
	Sub-total	44.97	55.00	46.26	26.00	12.91
Total	**Hydro**	**3,370.09**	**3,296.37**	**3,523.90**	**4,931.00**	**6,241.13**
	Diesel	**161.61**	**417.55**	**433.56**	**31.00**	**11.07**
	Geothermal	-	**13.87**	**23.61**	**18.00**	**7.98**
	Wind	-	-	-	-	**29.40**
	Total	**3,531.70**	**3,727.79**	**3,981.07**	**4,980.00**	**6,289.58**



Source: Facts in Brief 2011/12, EEPCo

(2) Planned and Committed Power Plants (Non-geothermal)

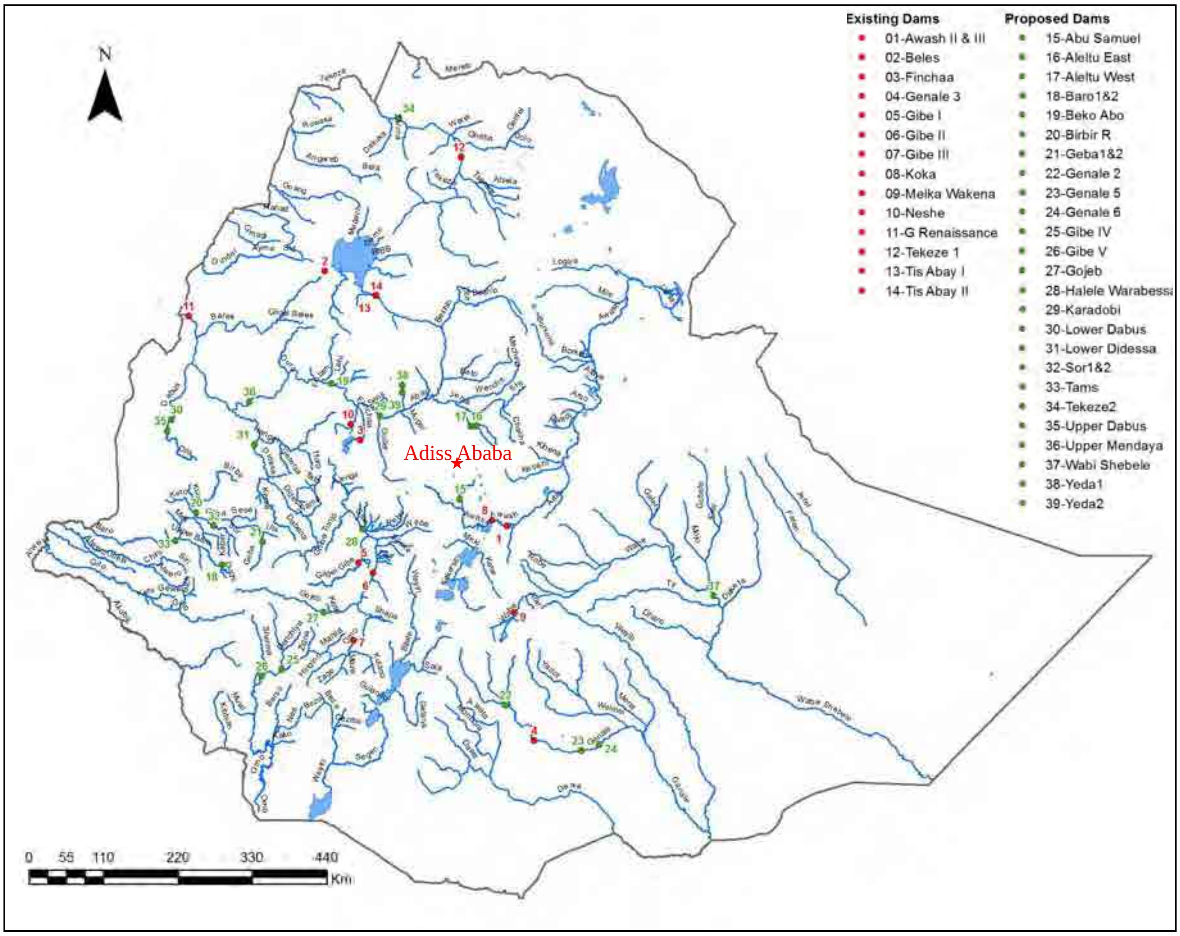
Hydropower

Ethiopia has a very high hydropower potential available for power generation. In the past five years (2009-2013), four hydro power plants with a total capacity of around 1,200 MW were commissioned and tripled the overall capacity in Ethiopia. There are 12 existing plants with installed capacity of around 1,800 MW and one plant has been under refurbishment. Figure 2.2.9 shows the location map of existing, committed, and proposed hydropower plants. Three plants, i.e., Gilgel Gibe III, Genale Dawa III, and Grand Renaissance, are under construction. If their constructions are completed in five years as scheduled, the total installed capacity of hydropower will be around 10,000 MW in 2018. The progress of the three hydropower plants under construction is mentioned below.

Gilgel Gibe III: The construction of the dam, which is 243m high, was started in 2006, and is 88% complete as of October 2014 and expected to reach 92% by the end of this fiscal year. The first of ten planned turbines was scheduled to start generating 187 MW in September 2014, but due to financial problem, the project has been delayed. The following nine turbines are expected to take about a year for the dam to be fully operational and generate 1,870 MW.

Genale Dawa III: The construction was started in mid-2012 and around 25% complete in 2013 and 60% as of October 2014. It is expected to be fully completed by 2015 and to provide 254 MW.

Grand Renaissance: The construction of the Grand Ethiopian Renaissance Dam was started since April 2011. The dam with 6,000 MW of installed capacity will be the largest hydroelectric power plant in Africa when completed, as well as the 8th largest in the world. The construction of the dam progressed to around 20% at the end of 2013, and was at 40% complete as of October 2014. The first stage of the dam will be operational from June 2015 and will produce 700 MW of electricity. The rest of the units will be completed and a total of 6,000 MW will be generated in 2018.



Source: Ethiopian Power System Expansion Master Plan, EEPCo

Figure 2.2.9 Location Map of Existing, Committed, and Proposed Hydropower Plants

There have been many hydropower plant schemes proposed over the years. There are 28 schemes that contribute to the overall capacity of around 12,400 MW. Table 2.2.10 shows the list of committed and proposed hydropower plants. In the new EEPCo master plan study, the averaged levelized cost of each proposed hydropower plant was estimated, and was used in ranking the candidate hydropower plants.

Table 2.2.10 Committed and Proposed Hydropower Plant

Power Plant		Inst. (MW)	Avil. Cap. (MW)	Ave. Gen. (GWh)	COD
Hydro - Under Construction		**8124.0**	**6274.0**	**21826.0**	
1	Gilgel Gibe III (enters 2014)	748.0	427.0	2148.0	2014
-	Gilgel Gibe III (enters 2015)	1122.0	640.0	3222.0	2015
2	Genale Dawa III	254.0	250.0	1695.0	2015
3	Grand Renaissance (enters 2015)	500.0	413.0	1230.0	2014
-	Grand Renaissance (enters 2017)	5500.0	4544.0	13531.0	2018
Hydro - Candidate		**12406.9**	**12062.6**	**59279.3**	
1	Beko Abo	935.0	935.0	6632.2	2022
2	Genji	216.0	214.0	910.2	2020
3	Upper Mendaya	1700.0	1700.0	8582.3	2023
4	Karadobi	1600.0	1493.9	7857.2	2021
5	Geba I + Geba II	371.5	343.6	1709.4	2020
6	Genale VI	246.0	237.2	1532.4	2020
7	Gibe IV	1472.0	1409.6	6146.4	2020
8	Upper Dabus	326.0	326.0	1460.3	2020
9	Sor II	5.0	4.8	38.5	2017
10	Birbir R	467.0	443.7	2724.1	2020
11	Halele + Werabesa	436.0	417.2	1972.8	2020
12	Yeda I + Yeda II	280.0	275.9	1089.4	2020
13	Genale V	100.0	100.0	574.6	2020
14	Gibe V	660.0	603.5	1904.9	2020
15	Baro I + Baro II	645.0	645.0	2614.3	2020
16	Lower Didessa	550.0	550.0	975.6	2020
17	Tekeze II	450.0	450.0	2720.7	2020
18	Gojeb	150.0	134.2	561.7	2020
19	Aleltu East	189.0	173.8	804.1	2020
20	Tams	1000.0	1000.0	6057.2	2020
21	Abu Samuel	6.0	6.0	15.7	2020
22	Aleltu West	264.6	262.7	1067.3	2020
23	Wabi Shebele	87.8	86.5	691.0	2020
24	Lower Dabus	250.0	250.0	637.0	2020

Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by the JICA Project Team)

Wind Power

The Ethiopian government has planned to generate up to 890 MW of wind energy by the end of the Growth and Transformation Plan (GTP) period. In 2009, the first wind farm in Ethiopia was constructed in Adama, which has 34 x 1.5 MW wind turbines. The Ashegoda Wind Farm, which is 10 km from Mekelle, was completed in 2013. The total installed capacity of the Ashegoda Wind Farm will be 120 MW. The Ashegoda Project, which costs about EUR 210 million, was funded by the French bank- BNP Paribas, the French Development Agency, and EEPCo. The Adama II Wind Farm Project, an extension of the Adama Project, is in progress. EEPCo signed an agreement with the Chinese GCOC Company and Hydrochina Company for the construction of a wind farm with 102 x 1.5 MW wind turbines, with a total capacity of 153 MW. The project costs USD 340 million, and the Chinese Export & Import Bank provides a soft loan.

Ethiopia has an estimated 10 GW of potential wind capacity. The Hydrochina Corporation collaborated with the Ministry of Water and Energy and formulated the Wind Power and Solar Energy

Master Plan in 2012 with financial support from the Chinese government. The master plan study identified 51 candidates for wind farm located mainly on high terrain.

Table 2.2.11 Existing and Committed Wind Farm

No.	Wind Farm	Capacity (MW)	Generation (GWh)	Annual Load Factor	COD
Existing Wind Farm		**171**	**428**		
1	Adama I	51	150	33.6%	2012
2	Ashegoda (enters 2012)	30	70	26.5%	2012
-	Ashegoda (enters 2014)	90	208	26.4%	2014
Committed Wind Farm		**153**	**424**		
1	Adama II	153	424	31.6%	2015
Total		**324**	**852**		

Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by the JICA Project Team)

<u>Solar Power</u>

In general, Ethiopia is rich in solar radiation resource, as it is located on a low latitude region with approximately perpendicular incidence of sunshine. But currently, solar power is only used for off-grid systems such as telecommunications equipment in rural areas. In rural electrification schemes, there is a plan to use solar power. However, there is no scheme to connect ICS, and no plant has been committed so far.

Some studies, including the Wind Power and Solar Energy Master Plan conducted by the Hydrochina Corporation, has conducted the analysis and identified some potential site for photovoltaic power plants. Table 2.2.12 summarizes the candidates examined in the EEPCo master plan study. The study expected 100 MW of solar power generation per plant.

Table 2.2.12 Candidate Sites for Solar Power Generation

No.	Solar Power Plant	GHI (kWh/m2)	Yield (kWh/kWp/year)	Energy Output MWh/year	CF (%)	Solar Plant Size (MW)
Candidate Site						
1	Mekele	2391.2	20,542	205,420	23.4%	100
2	Jijiga	2379.7	20,184	201,840	23.0%	100
3	Addis Ababa	1934.5	16,639	166,390	19.0%	100
4	Border Ethiopia – Kenya	1903.6	15,561	155,610	17.8%	100
5	Border Ethiopia – Somalia	2086.0	16,697	166,697	19.1%	100

GHI: Global Horizontal Irradiance, CF: Capacity Factor

Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by the JICA Project Team)

<u>Biomass Energy</u>

Ethiopia has utilized biomass such as fuel wood, residue of agricultural crops, and animal manure for basic energy instead of electricity. Two biomass plants, namely Bamza and Meikasedi thermal power plants, have been planned as candidate plants. As the biomass plants use bagasse as fuel, these are unavailable for four months during the off-crop season. Table 2.2.13 summarizes the proposed biomass energy plants.

Table 2.2.13 List of Proposed Biomass Energy Plants

Biomass Power Plant	Bamza	Meikasedi
Rated Power (MW)	120	138
Nominal Output (MW)	60	60
First Year of Operation	2016	2016
Fuel Type	Wood Fuel Bagasse	Prosopis Bagasse

Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by the JICA Project Team)

Waste Power Generation

EEPCo finalized a turnkey contract with the Cambridge Industries Ltd. to design and construct a 50 MW capacity waste-to-energy plant in the Repi area, Addis Ababa in 2013. This will be the first waste-to-energy plant in Ethiopia. And also, Cambridge Industries Ltd. has conducted detailed feasibility studies throughout Ethiopia to recommend future projects in various cities including Dire Dawa, Adama, Mekelle, Gonder, Behar Dar, Hawasa, and Jimma. Table 2.2.14 summarizes the committed waste-to-energy plants.

Table 2.2.14 Proposed Waste-to-Energy Sites

Item	Addis Ababa Waste Energy Plant
Rated Power (MW)	50
Nominal Output (MW)	20
First Year of Operation	2015
Fuel Type	Municipal solid waste and selected industrial waste

Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by the JICA Project Team)

Sugar Factories

The Ethiopian sugar factories have planned to sell their surplus electricity to the grid. The electricity is generated by the process of burning bagasse. Power generation is conducted only in the period from October to May because of bagasse production.

Table 2.2.15 below shows the installed capacity and energy which can be exported to the grid in each factory.

Table 2.2.15 List of Proposed Sugar Factories

Sugar Factories	Installed Capacity (MW)	Export (MW)	Exported Energy (GWh)	COD
Wenji	30	16	77	2013
Finchaa	31	10	48	2013
Tendaue/Ende	120	70	337	2015
Beles 1	30	20	96	2015
Beles 2	30	20	96	2015
Wolkayit	133	82	395	2015
Omo Kuraz 1	60	20	96	2015
Kessem	26	16	77	2015
Beles 3	30	20	96	2016
Omo Kuraz 2	60	40	193	2016
Omo Kuraz 3	60	40	193	2016
Omo Kuraz 4	60	40	193	2017
Omo Kuraz 5	60	40	193	2017
Omo Kuraz 6	60	40	193	2019
Total		**474**	**2,283**	

Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by the JICA Project Team)

Thermal Power Plant

At present, there are 11 thermal power plants using heavy fuel oil and light fuel oil as shown in Table 2.2.8. There is no committed power plant using gas and oil. The new EEPCo master plan proposed to operate gas turbines, combined cycle gas turbines (CCGT), and diesel power plants from 2018.

To correspond to the increasing power demand from 2030 or later, thermal power plants will be needed because the hydropower and geothermal potential could not cover the demand even though all of them are being developed.

2.2.5 Transmission Planning

(1) Existing and Committed Transmission Lines

Most of the power plants have been connected with the ICS to the consumers though transmission lines of 400 kV, 230 kV, 132 kV, 66 kV, and 45 kV. Table 2.2.16 presents the total length of the existing transmission lines and Figure 2.2.10 shows the map of existing and planned transmission network.

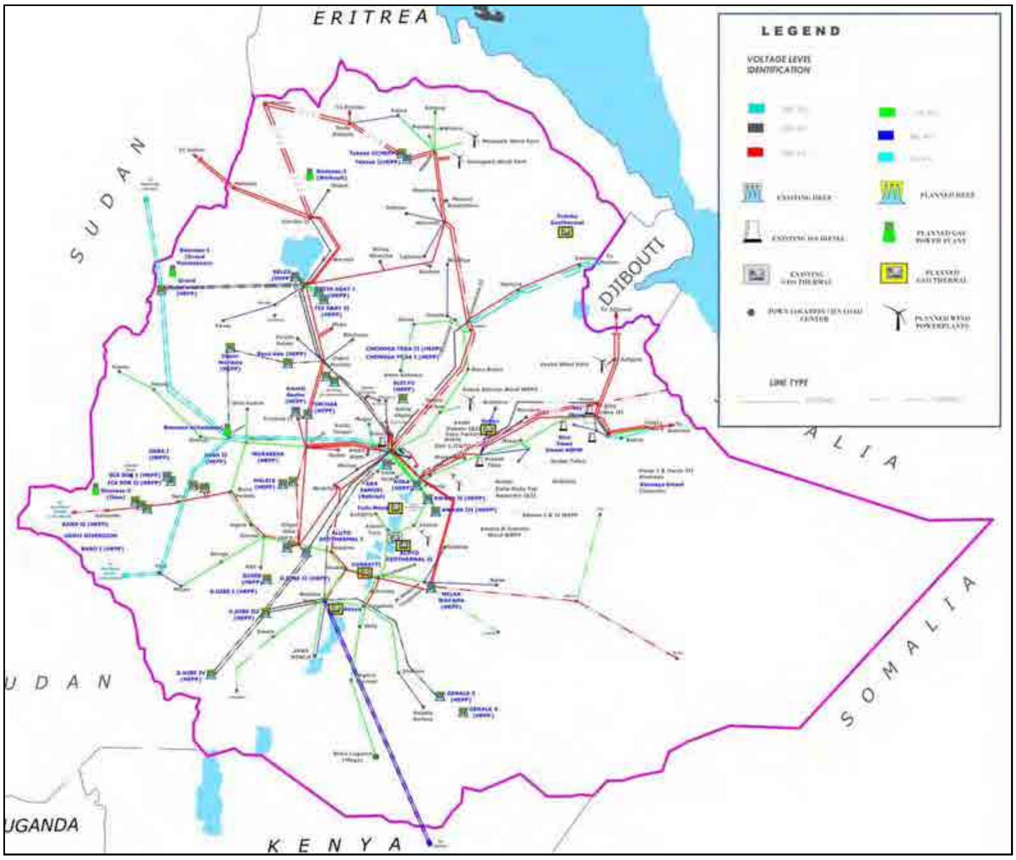
There are many areas where ICS does not connect to/in Ethiopia. SCS, which has supplied electricity to such areas not connected to ICS, is now starting to sequentially connect to ICS in these past few years.

EEP (former EEPCo) has connected the transmission line to towns and villages at its expense. However, the distribution line to houses and offices has to be connected individually at the expense of the end-user, therefore leaving many poor people unable to pay for connection and access to electricity.

Table 2.2.16 Existing Transmission Line Length (km)

No.	Voltage Level	Single Circuit	Double Circuit	Total
1	400 kV	621	63	684
2	230 kV	3,376	1,607	4,983
3	132 kV	4,509	133	4,641
4	66 kV	1,902		1,902
5	45 kV	243	9	252
Total		**10,650**	**1,811**	**12,461**

(Source: EEP, summarized by the JICA Project Team)



Source: EEP 2014

Figure 2.2.10 Existing and Committed Electrical Grid in Ethiopia

(2) Universal Electricity Access Program (UEAP)

The Universal Electricity Access Program (UEAP) was started by EEPCo from 2005/06 as part of the power sector development program to embody the targets of PASDEP, which aimed at connecting a total of 6,878 towns and villages to the grid, provide energy supply to 24 million people, and attain an electrification rate of 50% in 2015. Also, it aimed to increase the energy generation capability to 6,386 GWh by 2010. The total cost of the UEAP was estimated at ETB 8.8 billion and the World Bank (WB) is financing part of it.

Although the aspired target was not fully met, electricity generation increased by 53% from 2,587.2 GWh in 2005 to 3,981.07 GWh in 2010. However, the production increase did not keep pace with the grid extension activities. Transmission lines increased, from a total length of 8,003.93 km in 2006 to

10,884.24 km in 2010, while distribution lines' total length even quadrupled from 33,000 km in 2005 to 126,038 km in 2010.

(3) Transmission Expansion Plan

Transmission expansion plan was developed in the EEPCo master plan study based on the demand forecast and generation plan mentioned above. The transmission expansion plan was considered to connect the candidate power plants meeting the electrical demand forecast in two stages, i.e., short-term from 2013 to 2020 and long-term from 2021 to 2037.

New 118 transmission substations, 77 substation reinforcements and 13,550 km of new transmission lines (66 to 500 kV) are planned in the short-term plan, and new 78 transmission substations, 41 substation reinforcements and 9,257 km of new transmission line (132 to 400 kV) as shown in Table 2.2.17.

Table 2.2.17 Plan of New Substation and Transmission Line

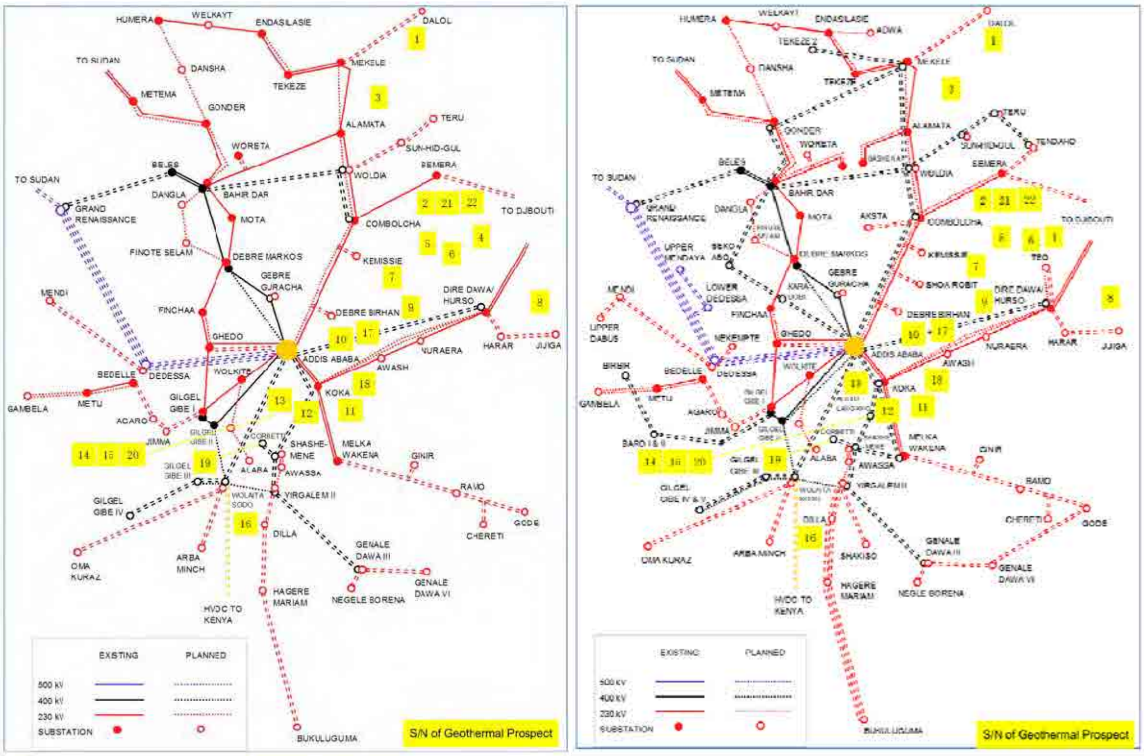
Year	New Substation	New Substation Reinforcements	Transmission Lines (km)
2013	11	10	2,343
2014	9	3	1,167
2015	48	43	4,188
2017	25	6	2,470
2020	25	15	3,383
Short-Term: Total	**118**	**77**	**13,551**
2025	24	8	2,422
2030	24	17	2,809
2037	29	30	3,185
Long-Term: Total	**77**	**55**	**8,416**

Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by the JICA Project Team)

Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by the JICA Project Team)

Figure 2.2.11 presents the development plan of major transmission line from 230 to 500 kV by 2020 and 2037 and location of the geothermal prospects. The transmission line of 500 kV is limited to the grand renaissance dam to Addis Ababa and the international connection to Sudan based on the cost comparison analysis. The main network will comprise 230 and 400 kV transmission lines.

This development plan includes the generation plan of committed geothermal project including Aluto-1 (Aluto-Langano) and Corbetti. Most of the other geothermal prospects in this project are located along the existing and planned networks which also run along the Rift Valley.



Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by the JICA Project Team)

Figure 2.2.11 Expansion Network Plan (left: short-term, right: long-term)

(4) International Connection

Eastern African Power Pool (EAPP)

According to the generation plan mentioned above, Ethiopia is expected to have a capacity of over 13,000 MW by year 2020 and over 24,000 MW by year 2030. Excess generation capacity in Ethiopia will be available for export to neighboring countries of the Eastern Africa Community. For this purpose, the EAPP has undertaken an interconnection program schematically represented in Table 2.2.18.

The program has already been partially implemented from the Ethiopia side interconnecting with Sudan through a 230 kV transmission line, operational for the supply of 100 MW, to be increased in the future, and the interconnection with Djibouti through a 230 kV transmission line.

Table 2.2.18 Planned Interconnected Transmission Line

No.	Connecting	Voltage (kV)	Capacity (MW)	Date
1	Tanzania-Kenya	400	1520	2015
2	Tanzania-Uganda	220	700	2023
3	Uganda-Kenya	220	440	2023
4	Ethiopia-Kenya	DC500	2000	2016
5	Ethiopia-Sudan	500	2 x1600	2016
6	Egypt-Sudan	DC600	2000	2016
7	Ethiopia-Kenya	DC500	2000	2020
8	Ethiopia-Sudan	500	1600	2020
9	Egypt-Sudan	DC600	2000	2020
10	Ethiopia-Sudan	500	1600	2025
11	Egypt-Sudan	DC600	2000	2025

Source: EAPP

Ethio-Kenya Electricity Highway Project

The transmission line construction in the Ethio-Kenya Highway Project under Phase 1 of the Regional Eastern Africa Power Pool Program was started in 2013, and is expected to be completed by 2018. The governments of Ethiopia and Kenya have received loans from the African Development Bank (AfDB), and the Government of Kenya has applied for a loan from the French Development Agency (AFD) for the project cost. The total project cost is about USD 1.3 billion. The project is mainly comprised of a 1,045 km, ± 500 kV high voltage direct current (HVDC) over-head transmission line from Wolayita-Sodo in Ethiopia to Logonot in Kenya. EEP and the Kenya Electricity Transmission Company Limited intend to manage the project jointly. Table 2.2.19 shows the project contents.

Table 2.2.19 Ehio-Kenya Electricity Highway Project

No.	Location		Size	Number
	Form	To		
1	Wolaita Sodo ss	Logonot ss	500 kV HVDC line	1066 km
2	Converter at each ss		1000 MW	
3	Gilgel Gibe III	Wolaita Sodo ss	400 kV HVAC line	55 km
4	Logonot ss	Ishinya ss	400 kV HVAC line	80 km
5	Synchronous Condenser at Lognot ss		200 MVA	1

ss: sub-station, HVDC: high voltage direct current, HVAC: high voltage alternate current

Source: EEP, arranged by the JICA Project Team

(5) Power Loss

The power loss in Ethiopia is around 20%, which is higher than the international average of 12–13%. According to EEP, most of the loss happened during the distribution from the national grid to end users. Therefore, WB has financed some projects of a Swedish company that promotes efficiency in Addis Ababa and a French company that automates the distribution system.

2.2.6 Financing and Tariff

(1) Electric Power Selling

Table 2.2.20 shows the published consumer tariffs in Ethiopia for 50 years from 1959 to 2003. The domestic tariff is reduced to around ETB 0.47/kWh (equivalent to around USD 0.03/kWh) with a large amount of subsidies, so that the poverty group can have access to electricity.

It is suggested that the rich who utilize more electricity should bear more of the costs by progressive tariffs, which would still ensure the access of the poor whose utilization of electricity is minimal. This also contributes to the increment of finance of the EEP, which is necessary to expand the service to achieve the ambitious targets of the GTP.

Table 2.2.20 Consumer Tariffs

	Description	Historical Flat Tariff Rate (Birr/kWh) EFY													
		1952-1964	1965-1971			1972-1978			1979-1987			1988-1989	1990	1991-1998	1999-2003
		EEPCo	ICS	SCS	EEPCo	ICS	SCS	EEPCo	ICS	SCS	EEPCo	EEPCo	EEPCo	EEPCo	EEPCo
1	House Hold	0.1250	0.1250	0.1250	0.1250	0.1425	0.1513	0.1468	0.1425	0.1513	0.1468	0.1772	0.2809	0.3897	0.4735
2	Commercial	0.0750	0.1250	0.1650	0.1436	0.1525	0.1975	0.1735	0.3436	0.4146	0.3774	0.3653	0.4301	0.5511	0.6723
3	Street Light		0.1100	0.1500	0.1285	0.1100	0.1500	0.1285	0.3322	0.4146	0.3711	0.3333	0.3087	0.3970	0.4843
4	Small Industry		0.1333	0.1733	0.1520	0.1333	0.1733	0.1520	0.2232	0.4597	0.3203				
5	LV		0.0475	0.0875	0.0645	0.0625	0.1175	0.0857	0.2232	0.4397	0.3133	0.2563	0.3690	0.4736	0.5778
6	HV 15kV		0.0288	0.0780	0.0474	0.0588		0.0588	0.2029		0.2029	0.2341	0.2597	0.3349	0.4086
7	HV 132kV												0.2416	0.3119	0.3805
	Total Flat Rate	0.0968	0.0824	0.1241	0.1011	0.1027	0.1556	0.1165	0.2341	0.3500	0.2735	0.2645	0.3086	0.4020	0.4900

LV: Low Voltage、HV: High Voltage

Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by the JICA Project Team)

2.3 Geothermal Power Development

2.3.1 Existing Geothermal Development Plans

There are two existing geothermal development plans as shown in Table 2.3.1, i.e., one by GSE and one by the EEPCo master plan study. These existing plans need to be improved since they do not reflect recent activities of several donors including the power purchase agreement (PPA) between EEPCo and Reykjavík Geothermal agreed in September 2013 for Corbetti Geothermal Development of 500 MW to 1,000 MW. Likewise in the EEPCo master plan, all candidate geothermal power plants are sized in multiples of 100 MW capacities for simplicity without considering the site specific potential and installation plans based on forecast demand.

Table 2.3.1 Existing Geothermal Development Plans

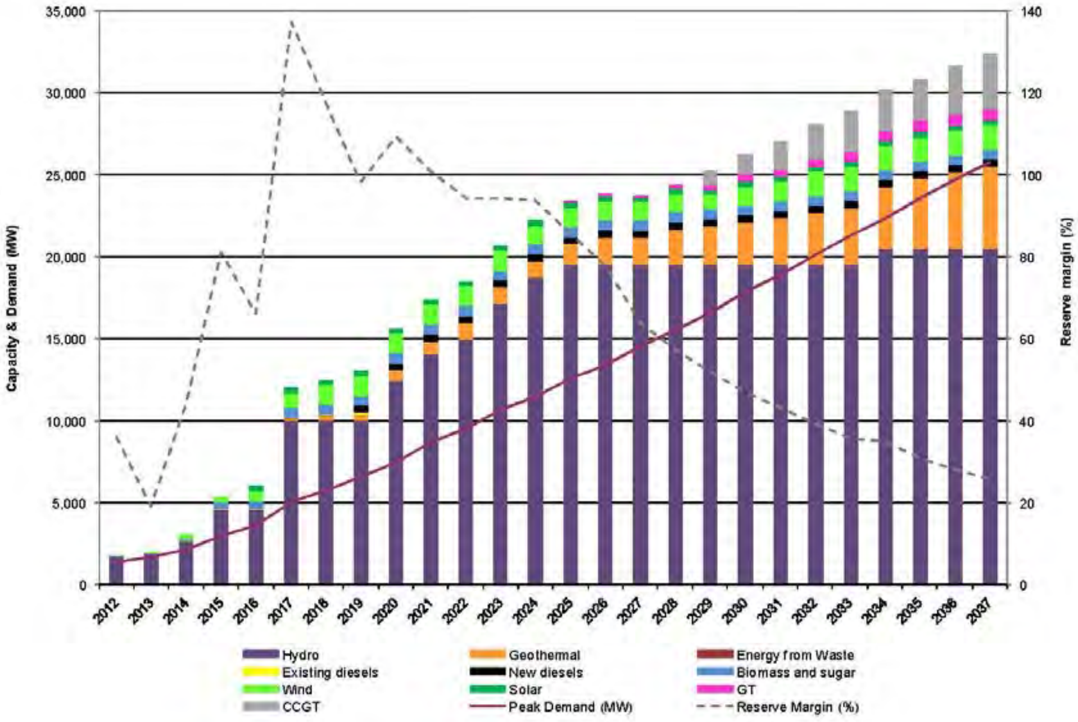
Year	GSE[*1]		
	Site	Installed Capacity (MW)	Total (MW)
2014	Aluto Langano		5
2015			5
2016	Aluto Langano II	70	75
2017			75
2018	Tendaho	100	175
	Corbetti	75 ~ 300	250 ~ 475
	Tulu Moye	40	290 ~ 515
	Dofan Fantale	60	350 ~ 575
2019			350 ~ 575
2020	Abaya	100	450 ~ 675

Year	EEPCo[*2]		
	Intalled Units	Site	Total (MW)
2014	0	Aluto Langano	5
2015	0		5
2016	0		5
2017	0		5
2018	2	Coebetti	200
2019	1	Corbetti	300
2020	2	Corbetti	500
2021	2	Aluto Langano	700
2022	2	Tendaho	900
2023	0		900
2024	0		900
2025	3	Tendaho, Abaya	1200
2026	4	Tendaho, Abaya, Tulu Moya	1600
2027	0		1600
2028	5	Dofan, Fantale, Tulu Moya, Gedemsa	2100
2029	2	Tendaho	2300
2030	2	Teo	2500
2031	3	Corbetti	2800
2032	3	Teo, Gedemsa	3100
2033	3	Aluto Langano, Dofan, Fantale	3400
2034	3	Tulu Moya, Dofan, Fantale	3700
2035	5	Corbetti, Dofan, Fantale, Dallol	4200
2036	4	Dallol, Teo	4600
2037	4	Teo, Abhe	5000

Source: [*1]GSE, 2010: (Tendaho indicates Tendaho-1 (Dubti) and -3(Allalo Beda) according to interview with GSE)
[*2]Ethiopian Power System Expansion Master Plan, EEPCo, February 2014: (Tendaho includes Tendaho-1, -2 and -3. Aluto-Langano includes Aluto-1, -2 and -3)
(arranged by the JICA Project Team)

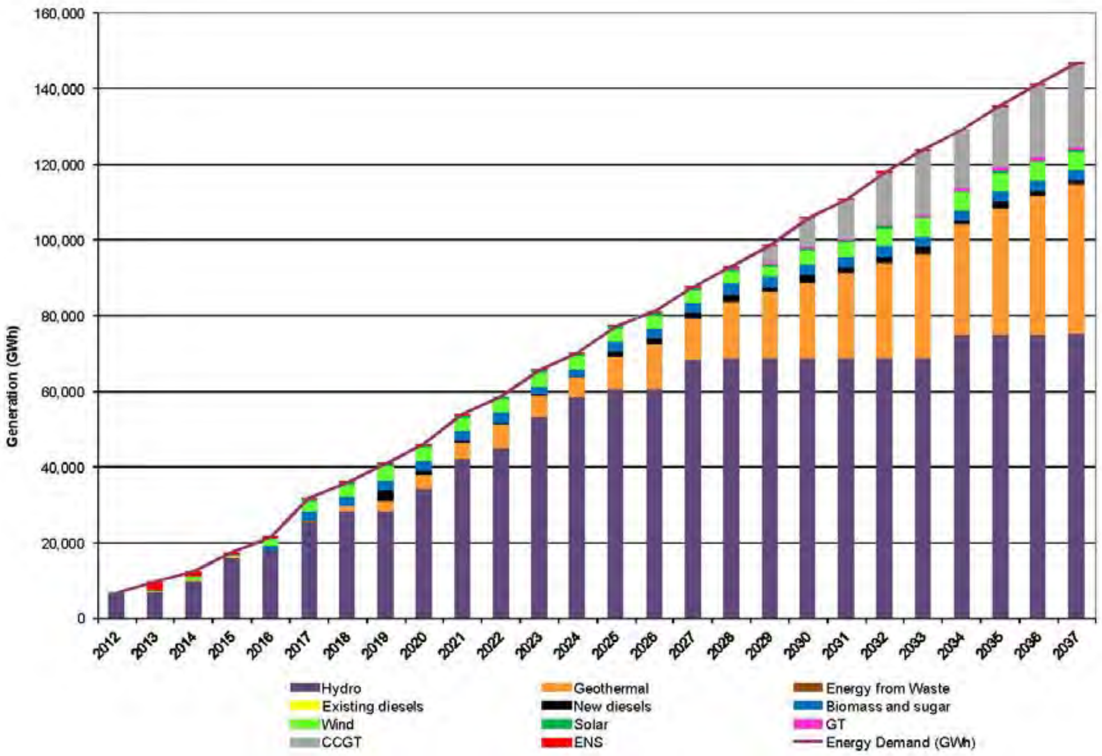
The EEPCo master plan formulated an overall power generation plan by plant type as shown in Figure 2.3.1 while corresponding energy is presented in Figure 2.3.2. Comparing the electric demand, the reserve margin will exceed 120% in 2017 with the commissioning of the Grand Ethiopian Renaissance Dam, but from 2017, it will decline to around 25% by 2037.

Hydropower generation is the largest source of energy and capacity throughout the period. Following hydropower, geothermal power becomes the next largest energy producer, followed by combined cycle gas turbine (CCGT) in 2037. Hydropower and geothermal will occupy around 50% and 25% of total installed capacity, and around 55% and 33% of total power generation in 2037, respectively. In the EEPCo master plan, wind and solar power generation are planned prior to geothermal power, which is mainly planned to be developed after 2025, when most of candidate hydropower plants are completed.



Source: Ethiopian Power System Expansion Master Plan, EEPCo, February 2014

Figure 2.3.1 Installed Capacity and Reserve Margin



Source: Ethiopian Power System Expansion Master Plan, EEPCo, February 2014

Figure 2.3.2 Energy Generation by Plant Type

2.3.2 Committed Geothermal Power Development Plans

In this master plan study, considering the latest information on donor involvements and GSE plan, existing and committed geothermal sites are ranked in priority order of development.

Table 2.3.2 summarizes the committed geothermal prospects. The expansion of Aluto-Langano Geothermal Power Plant has been implemented to boost its capacity to 70 MW from the previous 7 MW. The four drilling wells up to 2,500 m deep have been started and aim to generate 77 MW of power by 2018. The cost of the project will be covered by the financial assistance from the Government of Japan and WB as well as the Government of Ethiopia.

In October 2013, Reykjavík Geothermal signed a PPA with EEPCo for the Corbetti geothermal development of up to 1,000 MW in installed capacity. Reykjavík Geothermal will start drilling up to five wells with an initial 20 MW output.

The Geothermal Risk Mitigation Facility (GRMF) agreed on 3 March 2014 to give the Ethiopia Ministry of Mines, a USD 976,872 grant in order to conduct a study in Dofan and Corbetti, Ethiopia. GRMF was established by the African Union Commission in collaboration with the German Federal Ministry for Economic Cooperation and Development and the EU-Africa Infrastructure Trust Fund via KfW Entwicklungs.

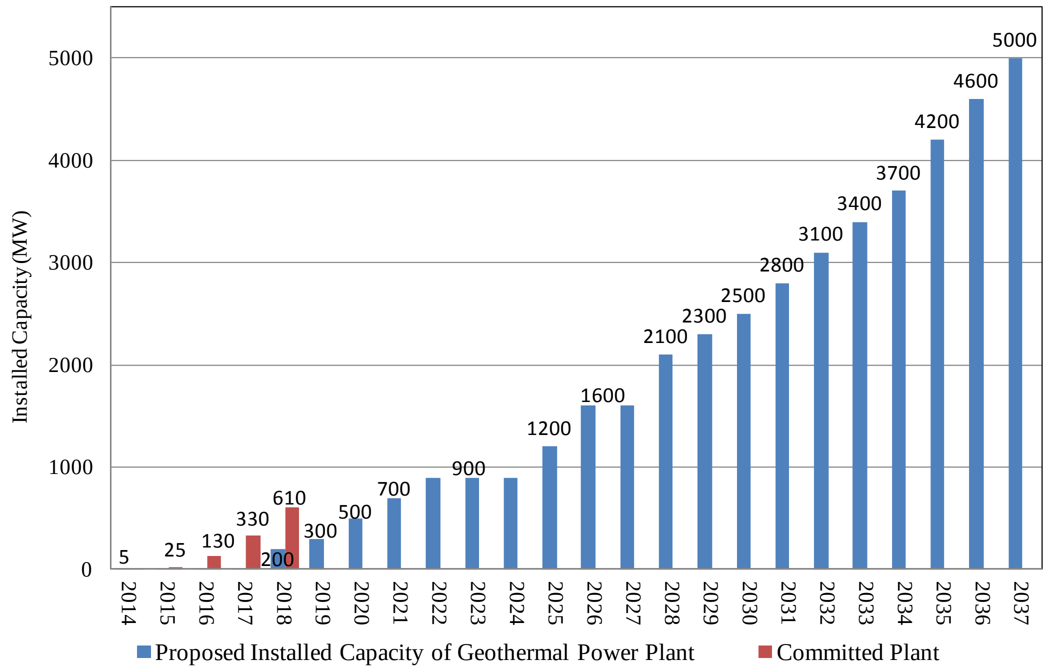
Table 2.3.2 Committed and Planned Geothermal Prospects

MP S No.	Site	Planned Capacity and COD		Status of Commitment
2	Tendaho-3 (Allalobeda)	25 MW	2017	ICEIDA/NDF assists surface survey including MT survey.
19	Corbetti	20 MW 80 MW 200 MW 200 MW	2015 2016 2017 2018	Reykjavík Geothermal has agreed with Ethiopian ministries and agreed to PPA with EEPCo that Reykjavík Geothermal develops maximum of 1,000 MW in the next 8-10 years. Using GRMF fund, GSE is conducting a study.
20	Aluto-1 (Aluto-Langano)	75 MW	2018	The Government of Japan and World Bank has assisted in drilling of wells.
21	Tendaho-1 (Dubti)	10 MW	2018	AFD assists in well drilling for 10 MW.
Total		**610 MW**		

MP S.No.: Site numbering in this MP study, AFD: French Development Agency Source: JICA Project Team

2.3.3 Target of the Geothermal Power Development

Target of the geothermal power development is set based on the EEPCo master plan since it formulates the power generation plan comprehensively taking into consideration economics by plant type. However, the EEPCo master plan did not include those currently under construction and committed geothermal power plants; therefore, incorporating the latest information on the donor involvements in this master plan study, the targets of each term are established as shown in Figure 2.3.3. According to the said figure, the target is set at 700 MW up to 2018, 1,200 MW up to 2025 and 5,000 MW up to 2037. Furthermore, based on geothermal potential derived from the various geological surveys in this study, the JICA Project Team will compare the economics of geothermal to that of other candidate plants, and will propose the development order including other plant types.



Year	Short term up to 2018	Medium term up to 2025	Long term up to 2037
Installed Capacity (MW)	610	1,200	5,000

Source: EEP, GSE (arranged by the JICA Project Team)

Figure 2.3.3 Targeted Installed Capacity of Geothermal Power Plant

2.3.4 Superiority of Geothermal Power Generation

As mentioned in Section 2.2.4, the EEPCo master plan forecasts the electricity sales and peak demand which greatly increase to 221,594 GWh and 25,761 MW, respectively, up to 2037 in the reference case. Hydropower plants that will produce around 8,000 MW has been committed and under construction at present, and will have the largest proportion in power development in the future. Meanwhile, even if all geothermal resources with a total potential of 5,000 MW is developed in Ethiopia, it can only meet around 25% of the entire energy requirement. As such, geothermal energy should be prioritized as the base-load power for the following reasons:

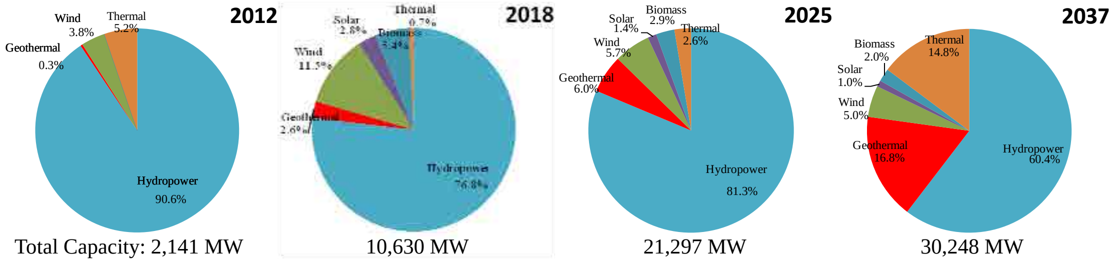
(1) Energy Security

Geothermal is valuable pure-domestic energy as well as hydropower, and is very effective in terms of energy security. By developing geothermal resources, it is possible to reduce the amount of fossil fuel which is planned to be used for thermal power plants in the future.

(2) Energy Mix

At present, neither the Government of Ethiopia nor EEP have clear targets of energy mix. Electrical supply will overly depend on hydropower generation from the present into the future (see Figure 2.3.4).

Geothermal, which will be next largest electrical source, is expected to be developed as much as possible in order to improve the energy mix and mitigate risk in drought mentioned below.

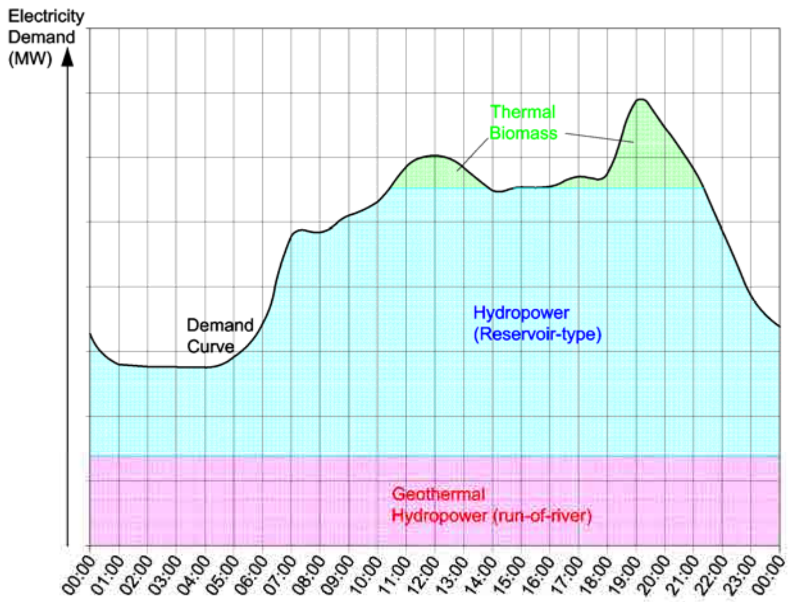


Source: Ethiopian Power System Expansion Master Plan, EEPCo (arranged by the JICA Project Team)

Figure 2.3.4 Composition of Electrical Supply in EEPCo Master Plan

(3) Reliable Electrical Supply

Geothermal, which is not affected by climate change and weather condition, is extremely reliable energy, that its load factor is as high as 80-90% worldwide. On the other hand, hydropower is exposed to large drop of its available generation capacity in drought period as mentioned below. And wind and solar power generation cannot be applied as base-load because their power generation is not stable due to climate and weather condition. Moreover, in general, because wind farm needs same size of storage battery or thermal power plant for back-up, its initial cost is expected to be double and more. Therefore, geothermal, which is reliable and not affected by external condition, should be developed for base-load in Ethiopia where a sufficient quantities of electricity is not supplied.



Source: JICA Project Team, based on demand curve provided by EEP

Figure 2.3.5 Schematic Image of Electrical Supply Composition against Electricity Demand in a day

(4) Mitigation of the Risk of Hydropower in Drought Season

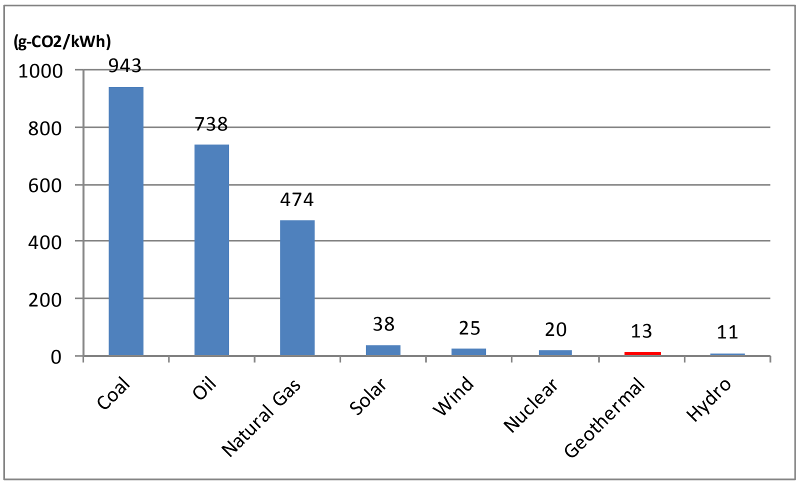
Hydropower is exposed to large depression of power generation in drought period, and available generation capacity of hydropower plant in Ethiopia is assumed to decrease up to 80% of installed capacity when drought occurs. The EEPCo master plan analyzed hydrological data for the past 45 years and formulated the generation plan. However, it is concerned that larger scale of drought than the past occurs with climate change in the future. To mitigate risk of hydropower, geothermal should be developed as reliable base-load plants.

(5) Reduction of Cost for Diesel Power Plants/Surplus Fossil Fuel Export

As mentioned above, diesel power plant mainly belonging to the CSC has been operated, and thermal power plants such as gas turbine, combined cycle gas turbine (CCGT), and diesel power plants are proposed to be installed from 2018 in EEPCo master plan. By developing geothermal which can replace fuel and is pure-domestic energy, it is possible not only to save the high cost of diesel power generation but to reduce the usage of fossil fuel and export the surplus fuel to other countries.

(6) Greenhouse Gas Mitigation

As shown in Figure 2.3.6, geothermal power generation emits less amount of CO_2 among other renewable energies and is very environmental-friendly power generation method. Therefore, geothermal should be developed also for the reason of prevention of a global warming. Furthermore, selling the electricity produced by geothermal to neighboring countries contributes to suppress the CO_2 emission in East-Africa region.



Source: E. Imamura and K. Nagano, Central Research Institute of Electric Power Industry, Japan, July 2010

Figure 2.3.6 CO_2 Emission by Energy

CHAPTER 3 GEOTHERMAL POTENTIAL SURVEY

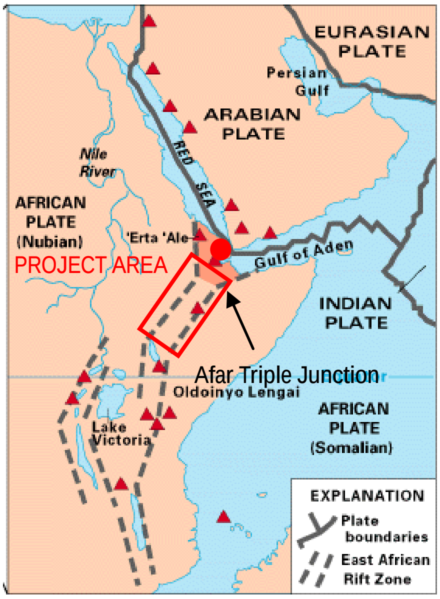
3.1 Geology

3.1.1 Tectonics

The study area belongs to the African Rift. The African Rift is connected from Afar Triple Junction (see Figure 3.1.1) and continues in the SW-SSW direction across the eastern African countries of Djibouti, Eritrea, Ethiopia, Kenya, Uganda, and Tanzania.

Generally, the valley is characterized by the geological occurrence of active faults, active volcanoes, and hot springs, which indicates a geothermal area. Geophysical and petrologic data show that the lithosphere is thinning due to the intrusion of hot mantle below the valley.

The valley is considered to be a separation boundary of the African Plate. The eastern plate is called the Somalian Plate and the western plate is the Nubian Plate. Both plates are separating at a speed of 5 mm/year (Stamps et al., 2008).



Source: http://people.dbq.edu/faculty /deasley/ Essays/EastAfricanRift.html

Figure 3.1.1 Distribution of the African Rift Valley

3.1.2 Regional Geological Setting

The study area belongs to the central-southern part of the Main Ethiopian Rift (MER). MER has been developed since Oligocene until Quaternary. During that period, major volcanic episodes are recognized in Oligocene, middle Miocene, late Miocene, early-middle Pleistocene, and Holocene (WoldeGabriel et al., 1990). The abstract is as follows:

The oldest volcanic activities are basalt and rhyolite flows exposed in and around the rift margins (e.g., Blue Nile gorge) during Oligocene, which formed lava plateau in the surrounding area. By middle Miocene time, the rift was formed in some parts with containment basaltic flows. During Pliocene, a huge pyroclastic flow covered the northern part of the study area. This characteristic pyroclastic flow deposit is currently observed at a depth of around 2,100 m in the basin floor by geothermal well, which indicates a minimum of 2 km of downthrown in the rift basin since its eruption (WoldeGabriel et al., 1990, WoldeGabriel et al., 2000).

During Pleistocene, Wonji Fault Belt (WFB), which is the main spreading axis of MER, is formed at the rift floor, and floor basalt and rhyolite are erupted along WFB. The volcanic activities are characterized by peralcaline fissure basaltic eruptions and rhyolitic eruptions which formed volcanoes and calderas. MER was formed as a symmetrical depression zone during this period and many lakes appeared and disappeared due to the obstruction of volcanic deposits and/or climate change.

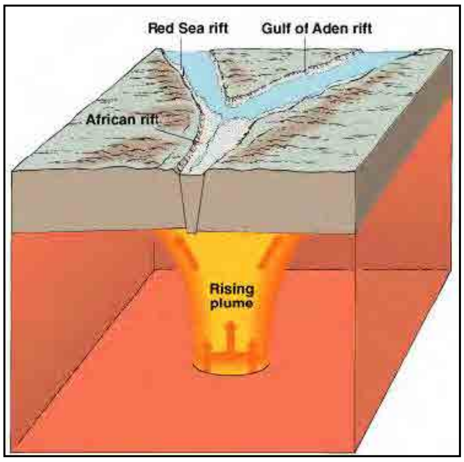
3.1.3 Regional Geological Structure

The MER was created by a complex system of NE-SW trending tensional faults, cut by a more recent system of NNE-SSW trending faults known as Wonji Fault Belt.

The rift is connected from Afar Depression in the north, and continues to symmetrical grabens at the center. The continuation of the rift is distinctive near the border between Ethiopia and Kenya, wherein small asymmetrical basins are formed. Finally, the rift is connected to the Kenya Rift which has a N-S direction.

The initial stage of MER formulation is closely related to the Red Sea and the Aden Sea. During Mesozoic time, north-central MER was bulged considering the thickness of the Mesozoic sediments in Kella (North of Butajira) and Blue Nile gorge.

In Oligocene, large and huge volcanic activity created lava plateau. In early Miocene, three radial rifts might have occurred in the plateau. After that, two rifts were spread and downthrown to the sea, which became the Red Sea and the Aden Sea. The other rift did not spread well and became MER.



(Source: http://www3.interscience.wiley.com:8100/legacy/college/levin/0470000201/chap_tutorial/ch07/chapter07-1.html)

Figure 3.1.2 Schematic Diagram for Development of the Red Sea Rift, the Aden Sea Rift, and the Failed African Rift (MER)

Such kind of tectonic activity is considered to occur in the initial stage when the continent is apart, and is caused by the rising of hot plume from the mantle (Figure 3.1.2).

Structural and stratigraphic relations of volcanic rocks along both rift escarpments of MER indicate a two-stage rift development. The early phase started during late Oligocene-early Miocene time and was characterized by a series of alternating and opposed half grabens. The half grabens evolved into a symmetrical rift during the late Miocene period. The area also was characterized by active rifting during Plio-Pleistocene, wherein around 2,000 m of subsidence was estimated (WoldeGabriel et al., 1990).

Nowadays, the rift floor is covered by lakes, lacustrine sediments, alkali basalts from fissure eruptions, volcanic ash deposits, and NNE-SSW faulting activities by WFB. These strata are classified as Wonji Group in Figure 3.1.1.

Table 3.1.1 Stratigraphy of Main Ethiopian Rift (MER)

Period/Epoch		Age (Ma)	WoldeGabriel et al. (1990)	EWTEC (2008)	Halcrow (2008)
Quaternary	Holocene	0.0117	Wonji Group	Wonji Group	Wonji Group
	Pleistcene	2.58			
Neogene	Pliocene		Chilalo Trachytes	Nazareth Group	Chilalo Trachytes
		5.33	Butajira Ignimbrites		Nazret Group/Afar Group
	Miocene		Guraghe Basalts	"Ancher Basalts", "Arba Guracha Silicics"	"Ancher Basalts", "Arba Guracha Silicics"
			Shebele Trachytes		
		23.03			A laji Formation
Paleogene	Oligocene		Kella Basalts		
		33.9			

(Source: JICA Study Report, 2011)

3.2 Collection of Existing Information

3.2.1 Objective

All the existing geological papers, articles, and reports were collected for each geothermal site as the background information for this Project. This information was reviewed based on the stage of geothermal development as follows:

3.2.2 Regional Reports

Some basic and comprehensive geological investigations were carried out from the early 70s to 80s for the purpose of exploring natural resources and geothermal development. Comprehensive investigations and researches were conducted by the United Nations Development Programme (UNDP) in 1973, the Ministry of Mines in 1984, and Electroconsul/Geothermica in 1987, and most of the prospective geothermal areas were determined. Furthermore, these investigations summarized that Aluto and Tendaho sites have the highest potential of all the prospective geothermal sites in Ethiopia.

3.2.3 Detailed Geothermal Survey

Detailed surveys have been conducted since the 1980s at most of the sites. These surveys consisted of detailed geological survey (incl. geological mapping), geochemical survey/analysis, and geophysical prospecting (MT/TEM survey). The status of surveys at each site is shown in Table 3.2.1.

Table 3.2.1 Status of Detailed Survey at Each Site

No.	Geothermal Sites	Geological Survey	Geochemical Survey	Geophysical Prospecting	Other Surveys
1	Dallol	☑	☑	-	
2	Tendaho-3 (Tendaho-Allalobeda)	☑	☑	☑	
3	Boina	☑	☑	-	
4	Damali	☑	☑	-	
5	Teo	☑	☑	-	
6	Danab	☑	☑	-	
7	Meteka	☑	☑	-	
8	Arabi	-	☑	-	
9	Dofan	☑	☑	-*	
10	Kone	☑	-	-	
11	Nazareth	☑	☑	☑	
12	Gedemsa	☑	☑	-*	TG well
13	Tulu Moye	☑	-	-	
14	Aluto-2 (Aluto-Finkilo)	☑	☑	-*	TG well
15	Aluto-3 (Aluto-Bobesa)	☑	☑	-*	
16	Abaya	☑	☑	-	
17	Fantale	☑	☑	-	Magnetic Survey
18	Boseti	☑	☑	-	
19	Corbetti	☑	☑	☑	
20	Aluto-1 (Aluto-Langano)	☑	☑	☑	
21	Tendaho-1 (Tendaho-Dubti)	☑	☑	☑	
22	Tendaho-2 (Tendaho-Ayrobera)	☑	☑	☑	Radon Survey

☑: done, - : not done, -*: to be done, TG Well: Thermal Gradient well
Note: The sites having limited data, are also classified as "done". Source: JICA Project Team

It was confirmed that at least the detailed geological survey and geochemical survey were done at each site. However, the quality and quantity of the results are not unified, e.g., entire site was not covered, location of geological manifestations was not shown, or location of sampling was not shown.

3.2.4 Feasibility Study

Feasibility (or pre-feasibility) study was conducted at Tendaho-1 (Tendaho-Dubti), Tendaho-2 (Tendaho-Ayrobera), and Aluto-1 (Aluto-Langano) geothermal sites. In 1986, Electroconsul/Geothermica conducted geothermal reservoir evaluation, design of facilities, and economical evaluation, by drilling nine wells at Aluto-Langano. In 1996, the Ethiopian Institute of Geological Survey (former GSE)/Aquater conducted geothermal reservoir evaluation by drilling three wells at Tendaho-1 (Tendaho-Dubti) and Tendaho-2 (Tendaho-Ayrobera). Afterward, GSE continued the drilling of three wells by themselves from 1995 to 1998.

3.2.5 Geothermal Plant Construction /Operation and Maintenance

The first geothermal power plant was constructed at Aluto-1 (Aluto-Langano) in 1992, based on the above feasibility study. Some reports were issued for operation and maintenance of geothermal wells after the power plant construction.

3.3 Satellite Data Analysis

3.3.1 Objectives

Prior to the field survey, alteration zoning, mineral and lithological mapping, topographic interpretation, and geological structure analysis were carried out using satellite images for the purpose of obtaining data of the geothermal potential in the study area. Field survey was conducted based on the results of the satellite data analysis and review of existing reports.

3.3.2 Methodology

For the remote sensing data, Japanese satellite products, namely, ASTER L3A and PALSAR L1.5, were used. ASTER is an optical sensor which has visible and near infrared (VNIR) bands, short wavelength infrared (SWIR) bands, and thermal infrared (TIR) bands as multi bands sensor (14 bands) and high resolution (15-30 m). PALSAR is an active microwave sensor, which is not affected by weather conditions and operable during both daytime and nighttime and has L band of multi polarization and high resolution (15-30 m). ENVI (Ver. 5.0) software of ESRI, USA was mainly used for the processing and analysis of satellite data.

In ASTER data analysis, the band composite image and the band ratio image are created by using SWIR bands and the apparent distributions of various alteration zones are detected. Rock facies and mineral mapping and interpretation of geological structures are conducted. In PALSAR data analysis, the mosaic image of geothermal development sites is created and extraction of geological structures of lineament is conducted.

In the analysis of ASTER image, vegetation, water, cloud, and shadow of cloud areas where data analysis is impossible are masked. Then, the band composite images, displaying band 4 as red color, band 6 as green color, and band 8 as blue color, are created. After calculating the band ratios between bands, the band ratio images, displaying band 4/band 6 as red color, band 5/band 6 as green color, and band 5/band 8 as blue color, are created. By analyzing these images, extraction of the apparent distribution of various alteration zones, rock facies and mineral mapping, and geological structure analysis are conducted. In the band composite image (RGB=B4, B6, B8), advanced argillic alteration including alunite and kaolinite mainly shows peachy color; phyllic alteration including sericite mainly shows yellowish color; and propylitic alteration including chlorite and epidote mainly shows greenish color. In the band ratio image (RGB=B4/B6, B5/B6, B5/B8), advanced argillic alteration shows reddish color and propylitic alteration shows purplish red color ~ deep bluish color.

As mentioned above, using ASTER data makes it easy to identify the distribution of various hydrothermal alteration zones. However, whether these zones include apparent distribution has to be considered.

PALSAR data, which are synthetic aperture radar data, are useful to grasp topography and ground surface condition. In PALSAR data analysis, the mosaic images are created by using ortho-corrected level 1.5 products of HH single polarized wave. From these images, lineament, fault cliff, crater, caldera, lava dome, and lava flows are extracted. In PALSAR image, outcrops of mountain range show texture of topography with sharp edge. In and around survey areas, it is interpreted that the topography and geological structure have NNE-SSW direction, which is clearly the same as the East African Rift, as great geological structure. The secondary sediment areas are classified by tone according to sediment type (difference of roughness) and texture. It is inferred that the diameter of gravel is small and roughness is small in dark colored areas. On the contrary, in bright areas, the diameter of gravel and roughness are large. Although the secondary sediment areas which show large roughness have the same tone as the outcrops of mountain range, it is possible to distinguish them by texture.

3.3.3 Results

In the analysis of the ASTER data, the band composite images, which have band 4 as red color, band 6 as green color, and band 8 as blue color, and the band ratio images, which have band 4/band 6 as red color, band 5/band 6 as green color, and band 5/band 8 as blue color, were created. The band ratio images of several areas are shown in the Attachment 2.1 to 2.5..

In the analysis of the PALSAR data, PALSAR mosaic images were created from HH single polarized wave data and are shown in the Attachment 2.6 to 2.10.

The integrated analysis of GIS, where the results of ASTER DEM data were compiled as well as the results of the ASTER and PALSAR data analysis, was conducted. As a result, the outcrop distributions of altered rocks were extracted and geological structures were interpreted. The results will be reflected in the next field survey as reference. The results of each site are as follows:

(1) From Dallol Site to Boina Site

In one area in the northwest region and three areas in the southeast region of Dallol site, the distributions of hydrothermal alteration are shown and aligned in the NW-SE direction. There are lots of volcanic topographies and circle structures lining toward the NW-SE direction. In the central region of Boina site, small hydrothermal alteration is shown northwest of the caldera. There is a zonal distribution of volcanic topographies and circle structures in the NW-SE direction at the western side of the caldera.

(2) Arabi Site

In Arabi site, there is zonal distribution of a lot of small volcanic topographies and circle structures in the EW direction, accompanied by several small hydrothermal alterations in various places.

(3) Northern Sites (Tendaho Site ~ Meteka Site)

In and around Tendaho-3 (Tendaho-Allalobeda) site, there are no obvious hydrothermal alterations. Many lineaments in the NW-SE direction are in the southwest side. In and around Dubti site, there are no obvious hydrothermal alterations. As unconsolidated sediments largely cover the ground surface, there is no lineament. In and around Tendaho-2 (Tendaho-Avrobeda) site, there are a lot of parallel lineaments in the NW-SE direction clearly in the western side of the site. A line of volcanic topographies and circle structures in the NW-SE direction is in the northern side of the site and the distribution of hydrothermal alteration is shown in the central part of the site. In the central part of Meteka site, several small distributions of hydrothermal alteration are on the mountain body. From the central part to the southern side, there are comparatively large circle structures. In the northern side, there are some small circle structures and volcanic topographies. The distribution of hydrothermal alteration is shown in the western side of the mountain body.

(4) Central Sites (Dofan Site ~ Tulu Moye Site)

In the central part of Boseti site, small circle structures and volcanic topographies are in the center of the mountain body. Toward the southwest direction, there is a line of some circle structures. Around the end of that line, volcanic structures are largely distributed. The small distributions of hydrothermal alteration are at the western end and northeastern end of the mountain body. At the eastern end of the site, there is a zonal distribution of volcanic topographies in the NE-SW direction. There are lots of lineaments in the NE-SW and NNE-SSW directions. From the central part and to the western part of Gedemsa site, there is a large circle structure. Inside the large circle structure, there are some small circle structures and volcanic topographies which overlap with the distributions of hydrothermal alteration. There are many lineaments in the NNE-SSW direction outside of the large circle structure. Especially, there are clear lineaments at the eastern end of the large circle structure.

(5) Southern Sites (Aluto Site ~ Abaya Site)

In Aluto-1 (Aluto-Langano) site, there is no distribution of hydrothermal alteration. There are some circle structures at the northeast and southwest ends of the site. No lineament is in the site. In Aluto-2 (Aluto-Finkilo) site, one small distribution of hydrothermal alteration is in the central part of the site. No lineament is in the site. In Aluto-3 (Aluto-Bobesa) site, there is no distribution of hydrothermal alteration. In the western part, outside the site, there are circle structures and volcanic topographies. There is no lineament in the site and many lineaments in the NE-SW direction are in the west, outside the site.

3.4 Results of the Field Survey and Laboratory Analysis

3.4.1 Geological Survey

(1) Objectives

This site reconnaissance was conducted for the following purposes:

i) Confirmation of geology (Topography, rocks, structures, and alteration zones: supplemental survey for existing site survey result);
ii) Confirmation of alteration zones which were determined by remote sensing; and
iii) Taking samples for rocks and alteration minerals.

(2) Methodology

(i) Site Survey

The site reconnaissance was conducted in two stages, which are called the second and third site reconnaissance in the study. Detailed survey points were selected based on the existing data, results of remote sensing, and hearing from local residents. In the third site reconnaissance, the Dallol and Arabi areas were investigated on April 30, 2014 by GSE experts only for security reasons. The sites of the second and third site reconnaissance were as shown in Table 3.4.1.

Table 3.4.1 Schedule of Site Survey

Period	Target Site	Remarks
From: 17th Jan 2014 To: 1st Feb 2014 (Second site reconnaissance)	- Aluto-1 (Aluto-Langano) - Aluto-2 (Finkilo) - Aluto-3 (Bobessa) - Gedemsa - Nazreth (Boku, Sodore) - Boseti - Kone	The survey was jointly conducted by GSE and the JICA Project Team
From: 4th Apr 2014 To: 17th Apr. 2014 (Third site reconnaissance)	- Dofan - Meteka - Tendaho-1 (Dubti) - Tendaho-2 (Ayrobera) - Tendaho-3 (Allalobeda) - Seha, Lake Loma (Tendaho) - Boseti (Supplemental)	The survey was jointly conducted by GSE and the JICA Project Team
From: 1st May 2014 To: 18th May 2014 (Third site reconnaissance)	- Dallol - Arabi	The survey was conducted by GSE

(Source: JICA Project Team)

(ii) Geological Analysis

The samples taken during site reconnaissance were analyzed by x-ray fluorescence (XRF) for determining rock composition and by x-ray diffraction (XRD) for determining alteration minerals.

Table 3.4.2 Methodology of Geological Analysis

Type of Samples		Analysis Method	Objective
Rock Samples		XRF	Composition of Rock (%) (SiO_2, Al_2O_3, CaO, MgO, Na_2O, K_2O, Cr_2O_3, TiO_2, MnO, P_2O_5, SrO, BaO)
Alteration Minerals	Zeolite and Others	XRD (powder specimen)	Determination of alteration mineral
	Clay Minerals	XRD (oriented specimen)	Determination of clay mineral
		- Treated by Ethylene Glycol - Treated by HCl	Identification of clay minerals (Chlorite- Kaolinite, Chlorite- Smectite)

(Source: JICA Project Team)

(3) Results

The results of the geological survey are as follows:

(i) Site Survey Results

The second and third site reconnaissances have been conducted The results of the site reconnaissance are summarized by the following items as shown in Table 3.4.3.

i) Topography and route map
ii) General geology
iii) Geological structure, fault, and others
iv) Geothermal manifestation
v) Alteration
vi) Photos and others

Table 3.4.3 Example of Site Reconnaissance Sheet

Site No. 2	Site Name: Tendaho-3 (Tendaho-Allalobeda)	Regional State: Afar

Satellite Imagery and Route Map

N **0.5 km**

Legend

- Surveyed Route
- Fumarole
- Hot Spring
- Other Geological Feature

Center Coord. (WGS84)
Lat: N 11°38'34.29"
Lon: E41°00'58.70"

Surveyed Date:
12 April, 2014

by Google Earth
Pro: http://www.google.com/earth

General Geology
The site is located at the western edge of Manda-Hallaro Graven. Layered basalt and andesite lava of Afar Stratoid are observed (1-4Ma, by V. Accolela et.al. (2008))

Geological Structure, Fault and Others
The site is located along NW-SE marginal fault of Manda- Halaro Graven, associated with minor faults. The height of fault scarp is approx. 200m.

Manifestation
More than 20 hot springs and geysers are found along NW-SE marginal fault within 1 km diameter, showing definite relationship between the faults and manifestations. Whitish gray amorphous silica is deposited around the springs.

Alteration
No alteration was observed at the host rock.

Others
Remote sensing result shows no indication of alteration; due to no alteration minerals were found.

Photos

Overview

Geyser

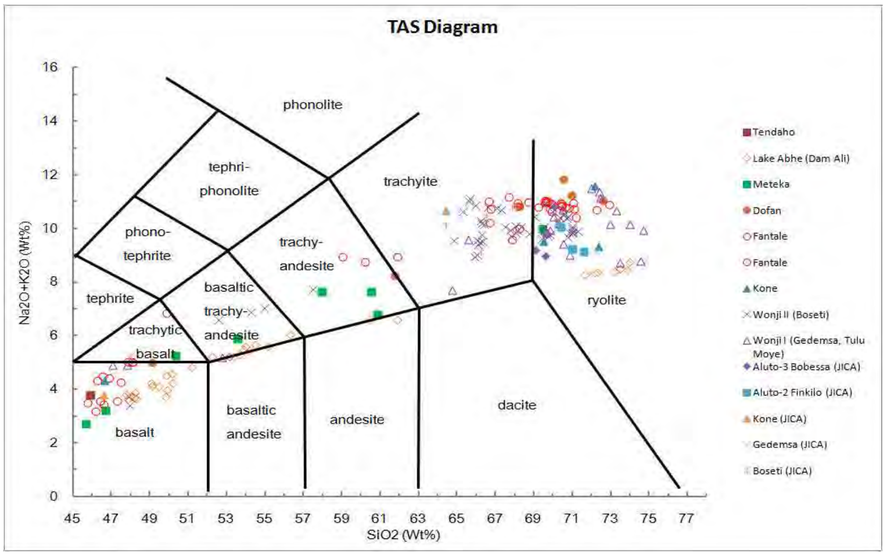
(ii) Results of Laboratory Analysis (XRF and XRD)

The results of the geological laboratory analysis (XRF and XRD) are shown in Table 3.4.4. The results are as follows:

- Result of XRF Analysis for Rock Composition

<u>SiO_2-K_2O+Na_2O Diagram (TAS Diagram)</u>

SiO_2-K_2O+Na_2O Diagram is commonly used for classifying rock series and type. Figure 3.4.1 shows the results of analysis for the project with the results of existing reports (Electroconsult/Geotermica, 1987; UNDP, 1973).



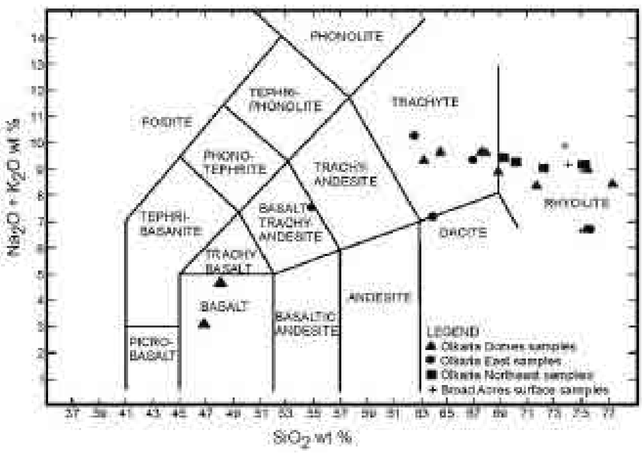
Source: JICA Project Team

Figure 3.4.1 SiO_2-K_2O+Na_2O Diagram (TAS Diagram)

The results are as follows:

Analyzed data were concordant with the data in existing reports and showed alkali rock series.

Figure 3.4.2 shows the same diagram for Olkaria Geothermal Field in Kenya. The composition of trachyte and ryolite is similar to that of Olkaria. It is considered that most of the target sites in Ethiopia are geologically promising site in the entire African Rift.

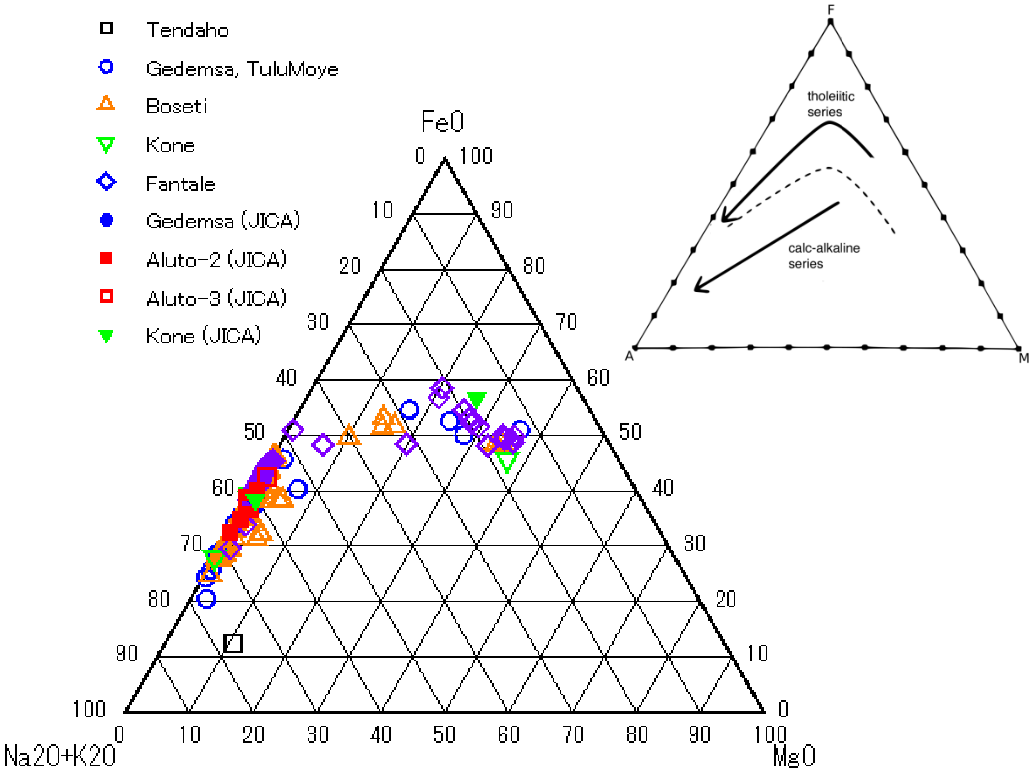


Source: J.K.Regat (2004)

Figure 3.4.2 SiO_2-K_2O+Na_2O Diagram in Olkaria Geothermal Field in Kenya

FeO-MgO-K_2O+Na_2O Diagram

FeO-MgO-K_2O+Na_2O Diagram is commonly used for the trend of magmatic segregation in rock series. Figure 3.4.3 shows the results of analysis for the project with the results of existing reports.



Source: JICA Project Team

Figure 3.4.3 FeO-MgO-K_2O+Na2O Diagram

Analyzed data were concordant with the data in existing reports and almost all the samples showed similar trends to that of tholeiitic series. It is considered that all the sites may have similar characteristics such as depth of magma chamber, cooling velocity, and so on.

Table 3.4.4 XRF Analysis Results

No.	Date	Site	Type of Rock	Coordination (WGS84) Latitude	Coordination (WGS84) Longitude	Altitude, masl (m)	SiO2 %	Al2O3 %	Fe2O3 %	CaO %	MgO %	Na2O %	K2O %	Cr2O3 %	TiO2 %	MnO %	P2O5 %	SrO %	BaO %	LOI %	Total %
140119-01	19-Jan-14	Bobessa	Trachytic Andesite	N 7°47'24.0"	E 38°49'10.1"	2018	69.60	10.96	6.05	0.18	0.06	4.71	4.29	<0.01	0.38	0.14	0.02	<0.01	0.04	2.24	98.67
140119-03	19-Jan-14	Bobessa	Trachytic Andesite	N 7°47'31.7"	E 38°49'08.2"	2028	69.63	11.37	6.53	0.28	0.13	5.15	4.72	<0.01	0.39	0.19	0.02	<0.01	0.05	1.25	99.68
140120-01	20-Jan-14	Bobessa	Obsidian	N 7°46'42.9"	E 38°48'51.2"	2061	70.07	9.74	7.52	0.34	0.03	6.38	4.45	<0.01	0.42	0.30	0.02	<0.01	0.03	-0.18	99.12
140120-02	20-Jan-14	Bobessa	Trachyte	N 7°46'44.1"	E 38°48'50.1"	2061	69.11	10.50	7.72	0.30	0.16	4.74	4.48	<0.01	0.44	0.28	0.01	<0.01	0.03	2.16	99.92
140120-07	20-Jan-14	Bobessa	Trachyte	N 7°44'32.2"	E 38°48'17.3"	1808	69.62	11.54	6.72	0.16	0.06	5.12	4.70	<0.01	0.42	0.35	0.01	<0.01	0.05	1.31	100.05
140121-01	21-Jan-14	Finkilo	Trachyte	N 7°46'50.7"	E 38°47'07.7"	2057	70.38	11.67	5.39	0.21	0.04	5.31	4.74	<0.01	0.35	0.15	0.02	<0.01	0.03	0.87	99.14
140121-02	21-Jan-14	Finkilo	Trachyte	N 7°46'45.6"	E 38°46'39.3"	2066	71.56	9.65	6.84	0.32	0.10	4.68	4.45	<0.01	0.31	0.27	0.01	<0.01	0.02	1.18	99.38
140122-01	22-Jan-14	Finkilo	Trachytic Andesite	N 7°47'27.9"	E 38°45'27.6"	2079	70.97	10.87	5.55	0.28	0.06	4.74	4.50	<0.01	0.34	0.21	0.02	<0.01	0.04	1.75	99.34
140124-03	24-Jan-14	Kone	Porphyry	N 8°51'44.6"	E 39°41'44.7"	1454	64.39	13.53	7.48	1.01	0.22	6.20	4.45	<0.01	0.60	0.30	0.07	<0.01	0.15	0.67	99.09
140125-02	25-Jan-14	Gedemsa	Trachyte	N 8°22'37.3"	E 39°08'20.0"	1720	72.26	9.53	6.60	0.31	0.05	4.59	4.59	<0.01	0.34	0.20	0.01	<0.01	<0.01	0.81	99.29
140127-01	27-Jan-14	Boseti	Trachyte lava	N 8°37'40.8"	E 39°27'44.0"	1585	64.41	9.25	11.54	0.59	0.13	5.80	4.35	<0.01	0.67	0.46	0.02	<0.01	0.06	1.89	99.17
140127-03	27-Jan-14	Boseti	Trachyte lava	N 8°37'50.5"	E 39°27'33.5"	1561	66.54	13.68	5.96	0.64	0.19	6.48	3.98	<0.01	0.47	0.34	0.04	<0.01	0.10	0.58	98.98
140127-04	27-Jan-14	Boseti	Trachyte lava	N 8°37'51.9"	E 39°28'37.6"	1494	66.22	8.41	10.58	0.83	0.09	4.95	4.21	<0.01	0.58	0.43	0.03	<0.01	0.09	2.28	98.70
140130-01	30-Jan-14	Kone	Andesite lava	N 8°50'09.5"	E 39°41'54.6"	1293	46.58	14.05	14.25	11.15	6.05	2.91	0.88	0.03	3.10	0.22	0.82	0.05	0.08	-0.25	99.91
140131-01	31-Jan-14	Boseti	Basic Andesite Lava	N 8°39'16.8"	E 39°31'07.2"	1326	47.97	14.69	15.14	8.35	4.58	3.99	1.26	0.01	3.29	0.24	0.53	0.05	0.08	-0.11	100.05
140131-02	31-Jan-14	Boseti	Pl-Andesite Massive Lava	N 8°38'48.2"	E 39°30'59.6"	1372	67.85	13.25	4.95	0.86	0.08	6.13	4.70	<0.01	0.31	0.17	0.03	<0.01	0.03	0.71	99.05

Source: JICA Project Team

(iii) Result of XRD Analysis for Alteration Minerals

Table 3.4.5 shows the results of determination of minerals by XRD.

Table 3.4.5 Mineral Occurrence by XRD

No.	Site	Location	Sample	Quartz	Opal - CT	Opal - A	Clinoptilolite	Kaolinite	Halloysite	Smectite
140119-02	Bobesa (Aluto-2)	Bobessa	Altered Clay					△		+
140120-03A	Bobesa	Bobessa	Altered Obsidian						+	−
140120-03B	Bobesa	Bobessa	Zeolite						+	−
140120-04	Bobesa	Bobessa	Altered Rock						−	+
140120-05	Bobesa	Bobessa	Secondary Mineral			+				
140120-06	Bobesa	Gebiba	Clay Mineral							+
140121-03	Finkilo (Aluto-3)	Finkilo	Yellow Tuff						−	−
140122-02	Finkilo	Adoshe	Yellow Clay						+	+
140122-03	Finkilo	Adoshe	Red Clay						−	−
140122-04	Finkilo	Adoshe	White Mineral	○		−				
140122-05	Finkilo	Humo	Clay	−					+	+
140122-06	Finkilo	Humo	White Mineral			+				
140122-07	Finkilo	Shutie	Clay	△					+	
140122-08	Finkilo	Shutie	White Mineral	△		−				
140125-01	Gedemsa	Sambo	Zeolite Vein	−		+		+		
140125-03	Gedemsa	Sambo	Altered Welded Tuff	○						
140125-04	Gedemsa	Sambo	White Mineral	○	+		+			
140126-01	Nazereth	Boko	Yellow Tuff		△		○			
140131-03	Boseti	Kintano	Altered Andesite						−	−
140131-04	Boseti	Kintano	White Mineral	+		+				

Source: JICA Project Team

According to the results of site reconnaissance, rock alteration was observed only around geothermal manifestations. It was not observed in wider areas such as alteration zone, except for Dofan and Meteka sites.

The above results shows that low-grade alteration has occurred in many sites, and is characterized by the occurrence of Quartz, Opal-A, Opal-CT, Clinoptilorite, Halloysite, Smectite, which is concordant with the site reconnaissance. The occurrence of kaolinite at Gedemsa and Finkilo sites shows trace of hydrothermal alteration.

3.4.2 Geochemistry

(1) Objectives

The main objective of geochemical study is to characterize the geothermal reservoirs using geochemical properties of fluid and gas collected from geothermal manifestations (hot springs and fumaroles). For this reason, the study includes site reconnaissance of geothermal manifestations, measurement of the location, temperatures, and other properties, and sampling of fluid and gas. The reservoir temperature and origin of geothermal fluid and gas are interpreted based on the geochemical properties (chemical and isotopic compositions) of the fluid and gas samples.

Some collected samples are analyzed by the JICA study team in Japan, and also by GSE at the GSE laboratory. The analytical results are used to verify the analytical precision of GSE by comparing the results of GSE and the JICA study team.

(2) Methodology

(i) Site reconnaissance

Site reconnaissance was carried out in the second and third site reconnaissance survey. Because of a security reason, Dallol, Arabi, and Erer areas were surveyed by only GSE members. The survey areas are as follows:

The second site reconnaissance: Aluto, Bobesa, Finkilo, Gedemsa, Nazreth, Boseti, and Kone

The third site reconnaissance: Dofan, Meteka, Dubti (Tendaho-1), Ayrobeda (Tendaho-2), Allalobeda (Tendaho-3), Seha, Lake Loma, Boseti (additional survey), Dallol, Arabi, and Erer

The following operations were conducted on site.

1. Measurement of coordinate and altitude of geothermal manifestations (by using a portable GPS navigator)
2. Observation of geothermal manifestations
3. On-site measurement of temperature, pH, and conductivity of geothermal manifestations, river and lake water
4. Sampling of hot spring water, fumarolic gas, water and steam from geothermal wells, and river/lake water.

The results of the site reconnaissance are summarized in Table 3.4.6 (the southwestern part of the rift valley), and Table 3.4.7 (the northeastern part). The total survey locations are 71 points, from which 41 samples (32 water and 11 gas samples) were collected.

Table 3.4.6 Summary of the site reconnaissance in the southwestern part of the Ethiopian Rift Valley

No.	Code#	Date	Area	Location	Manifestation	Latitude	Longitude	Altitude (GPS), m asl	Water/steam temperature, °C	pH	EC, µS/cm	Sampling: Water	Sampling: Gas	Sampling: Noble gas	Note
1	ALT-001	2014/01/18	Alto	LA-6	Production well at the Alto-Langano GPP	N 7° 47' 36.94"	E 38° 47' 54.83"	1964	68.2	7.67	3345	✓	–	–	LA-6 had been shut-in before this survey. Although blowing was tried using 1/2" gauge valve at a bleed valve of the wellhead, steam was not produced. Instead, slightly high-temperature water was collected as a reference.
2	ALT-002	2014/01/19	Alto	LA-8	Production well at the Alto-Langano GPP	N 7° 48' 06.69"	E 38° 47' 31.17"	1904	94.0 (BP at 816 hPa)	9.58	4800	✓	✓	✓	Water sample is flash brine.
3	ALT-003	2014/01/20	Alto	Bulbula River	River	N 7° 50' 51.80"	E 38° 43' 12.59"	1633	21.1	8.43	490	✓	–	–	
4	ALT-004	2014/01/21	Alto	Artu Hujuba	Fumarole (moderate)	N 7° 46' 51.92"	E 38° 47' 07.39"	2082	92.1	–	–	–	–	–	Temperature is equivalent to the boiling point at the ambient pressure.
5	ALT-005	2014/01/21	Alto	Oiutu	Hot spring at a shore of Lake Langano	N 7° 42' 46.11"	E 38° 45' 54.33"	1592	47.1	–	–	–	–	–	
6	ALT-006	2014/01/21	Alto	Oiutu	Hot spring at a shore of Lake Langano	N 7° 42' 44.73"	E 38° 45' 57.27"	1588	48.1	–	–	–	–	–	
7	ALT-007	2014/01/21	Alto	Oiutu UNDP#84	Hot spring at a shore of Lake Langano	N 7° 42' 42.28"	E 38° 46' 00.51"	1592	56.4	7.42	3797	✓	–	–	
8	ALT-008	2014/01/21	Alto	Lake Langano	Lake	N 7° 42' 41.61"	E 38° 46' 03.31"	1578	30.4	9.11	2135	✓	–	–	
9	ALT-009	2014/01/21	Alto	Oiutu UNDP#2	Hot spring at a shore of Lake Langano	N 7° 42' 48.72"	E 38° 46' 25.60"	1576	65.3	7.33	3683	✓	–	–	
10	BBS-001	2014/01/19	Bobesa	Bobessa (top)	Fumarole (moderate)	N 7° 47' 23.85"	E 38° 49' 10.36"	2022	89.7	–	–	–	✓	✓	
11	BBS-002	2014/01/19	Bobesa	Bobessa (bottom)	Fumarole (moderate)	N 7° 47' 22.43"	E 38° 49' 07.45"	2004	92.3	–	–	–	✓	–	
12	BBS-003	2014/01/20	Bobesa	Artu Boko	Fumarole (weak)	N 7° 46' 43.37"	E 38° 48' 50.37"	2065	55.4	–	–	–	–	–	
13	BBS-004	2014/01/20	Bobesa	Gebiba	Fumarole (strong)	N 7° 44' 33.11"	E 38° 48' 16.50"	1807	94.3	–	–	–	✓	✓	Temperature is equivalent to the boiling point at the ambient pressure.
14	FKL-001	2014/01/21	Finkilo	A weak fumarole	Fumarole (very weak)	N 7° 47' 17.80"	E 38° 46' 17.17"	1998	52.4	–	–	–	–	–	
15	FKL-002	2014/01/22	Finkilo	Adoshe	Fumarole (weak)	N 7° 47' 28.17"	E 38° 45' 27.71"	2083	78.9	–	–	–	–	–	
16	FKL-003	2014/01/22	Finkilo	Humo	Fumarole (weak)	N 7° 47' 24.95"	E 38° 46' 03.47"	2017	78.4	–	–	–	–	–	
17	FKL-004	2014/01/22	Finkilo	Shutie	Fumarole (weak)	N 7° 48' 33.79"	E 38° 46' 00.78"	1987	86.8	–	–	–	–	–	
18	GDM-001	2014/01/25	Gedemsa	Sambo 01	Humid hole (higher temperature than an ambient temperature)	N 8° 22' 37.18"	E 39° 08' 19.10"	1742	34.1	–	–	–	–	–	
19	GDM-002	2014/01/25	Gedemsa	Sambo 02	Dry hole (higher temperature than ambient temperature)	N 8° 22' 24.61"	E 39° 08' 07.26"	1790	32.4	–	–	–	–	–	
20	GDM-003	2014/01/29	Gedemsa	Shenemaya	Warm water well (Hot spring)	N 8° 19' 03.46"	E 39° 11' 11.76"	1703	40.6	7.61	1970	✓	–	–	
21	GDM-004	2014/01/29	Gedemsa	Jano	Fumarole (very weak)	N 8° 15' 10.89"	E 39° 09' 36.82"	1816	44.2	–	–	–	–	–	
22	GDM-005	2014/01/29	Gedemsa	Lake Koka (Haro Ropi)	Lake	N 8° 18' 24.75"	E 39° 05' 13.37"	1605	25.1	8.81	323	✓	–	–	
23	BKO-001	2014/01/26	Nazreth	Boko	Fumarole (weak)	N 8° 29' 15.52"	E 39° 16' 13.73"	1708	72.5	–	–	–	✓	–	
24	SDR-001	2014/01/26	Nazreth	Sodere, Resort Hotel 01	Hot spring	N 8° 23' 46.21"	E 39° 23' 50.83"	1362	50.3	–	–	–	–	–	
25	SDR-002	2014/01/26	Nazreth	Sodere, Awash River	River	N 8° 23' 41.60"	E 39° 23' 54.84"	1358	20.2	8.18	334	✓	–	–	
26	SDR-003	2014/01/26	Nazreth	Sodere, Resort Hotel 02	Hot spring	N 8° 23' 44.63"	E 39° 23' 52.93"	1358	49.8	7.47	2271	✓	–	–	The location of 02 is upstream to 01 and available direct sampling even though 02 shows a slightly low temperature than 01.
27	GGD-001	2014/01/28	Nazreth	Gergedi (Hippo Pool)	Hot spring	N 8° 27' 37.79"	E 39° 11' 32.11"	1549	41.8	8.19	965	✓	–	–	
28	KNE-001	2014/01/30	Kone	Gur	Fumarole (very weak)	N 8° 50' 09.69"	E 39° 41' 54.59"	1293	32.0	–	–	–	–	–	
29	BST-001	2014/01/30	Boseti	Welenchiti	Warm water well (Hot spring)	N 8° 39' 52.28"	E 39° 26' 05.62"	1459	36.8	7.65	747	✓	–	–	
30	BST-002	2014/01/31	Boseti	Quintano	Fumarole (weak)	N 8° 39' 22.34"	E 39° 31' 09.06"	1326	43.4	–	–	–	–	–	
31	BST-003	2014/01/31	Boseti	Quintano	Fumarole (weak)	N 8° 39' 16.62"	E 39° 31' 07.32"	1330	43.8	–	–	–	–	–	
32	BST-004	2014/01/31	Boseti	Quintano	Fumarole (weak)	N 8° 39' 16.46"	E 39° 31' 07.68"	1330	45.9	–	–	–	–	–	
33	BST-005	2014/01/31	Boseti	Quintano	Fumarole (weak)	N 8° 39' 15.16"	E 39° 31' 07.24"	1330	47.7	–	–	–	–	–	Fumaroles distribute along a fault.
34	BST-006	2014/01/31	Boseti	Quintano	Fumarole (weak)	N 8° 38' 46.65"	E 39° 30' 59.13"	1398	75.1	–	–	–	✓	–	
35	BST007	2014/04/09	Boseti	Quintano	Fumarole (very week)	N 8° 39' 03.60"	E 39° 31' 03.28"	1345	35.6	–	–	–	–	–	
36	BST008	2014/04/09	Boseti	Quintano	Fumarole (very weak)	N 8° 39' 13.13"	E 39° 31' 06.71"	1338	43.4	–	–	–	–	–	

Source: JICA Project Team

Table 3.4.7 Summary of the site reconnaissance in the northeastern part of the Ethiopian Rift Valley

No.	Code#	Date	Area	Location	Manifestation	Latitude	Longitude	Altitude (GPS), m asl	Water/steam temperature, °C	pH	EC, μ S/cm	Sampling: Water	Sampling: Gas	Sampling: Noble gas	Note
37	BSK001	2014/04/09	Awash	Lake Beseka	Lake	N 8° 54' 12.40"	E 39° 54' 21.51"	953	31.3	9.56	7100	✓	–	–	A lake expanding due to rift activity
38	DFN001	2014/04/06	Dofan	Dofan (on the north side of Dofan terara)	Hot spring (small)	N 9° 22' 48.38"	E 40° 07' 43.93"	734	52.3	8.60	1483	–	–	–	Small hot spring
39	DFN002	2014/04/06	Dofan	Dofan (on the north side of Dofan terara)	Hot spring (a seep)	N 9° 22' 48.32"	E 40° 07' 44.60"	734	42.0	–	–	–	–	–	A seep of hot spring
40	DFN003	2014/04/06	Dofan	Dofan (on the north side of Dofan terara)	Hot spring (large)	N 9° 22' 52.57"	E 40° 07' 48.97"	736	52.1	8.13	1472	✓	–	–	A hot spring pool with a high flow rate
41	DFN004	2014/04/06	Dofan	Dofan (on the north side of Dofan terara)	Hot spring	N 9° 22' 53.74"	E 40° 07' 48.80"	742	44.6	8.00	1402	✓	–	–	A hot spring flow from a crack in lava
42	DFN005	2014/04/06	Dofan	Dofan (on the north side of Dofan terara)	Fumarole (very weak)	N 9° 22' 42.68"	E 40° 07' 49.14"	750	40.8	–	–	–	–	–	A humid hole for a remedy
43	DFN006	2014/04/06	Dofan	Dofan (on the north side of Dofan terara)	Fumarole (very weak)	N 9° 22' 35.07"	E 40° 07' 50.60"	741	47.4	–	–	–	–	–	A humid hole for a remedy
44	DFN007	2014/04/07	Dofan	Dofan Demaegona	Fumarole (weak and hot)	N 9° 21' 48.03"	E 40° 07' 13.99"	819	91.8	–	–	–	✓	–	In a reddish alteration zone with white minerals. Temperature is slightly below B.P. (97.4°C at 924 hPa)
45	DFN008	2014/04/07	Dofan	Dofan Demaegona	Fumarole (weak and hot)	N 9° 21' 47.28"	E 40° 07' 13.16"	818	94.4	–	–	–	✓	–	In a white alteration zone. Temperature is slightly below B.P. (97.4°C at 924 hPa)
46	DFN009	2014/04/07	Dofan	Dofan Demaegona	Fumarole (from a cliff with a high flux)	N 9° 21' 36.47"	E 40° 07' 11.19"	825	87.3	–	–	–	–	–	Widely steaming at high places of the cliffs
47	MKT001	2014/04/05	Meteka	Meteka	Hot spring	N 9° 58' 37.62"	E 40° 32' 30.86"	579	47.8	8.19	1155	✓	–	–	Used for bathing
48	MKT002	2014/04/05	Meteka	Meteka	Hot spring	N 9° 59' 42.56"	E 40° 33' 01.63"	581	77.0	6.97	7100	✓	–	–	Discharging from a bottom of a gutter
49	MKT003	2014/04/05	Meteka	Meteka	Hot spring with gas	N 9° 59' 31.60"	E 40° 32' 53.13"	579	86.9	7.10	7500	✓	✓	✓	Discharging with bubbles
50	MKT004	2014/04/05	Meteka	Meteka	Hot spring in the river	N 9° 59' 44.59"	E 40° 33' 04.05"	579	70.5	–	–	–	–	–	Discharing from a river bank under the water
51	MKT005	2014/04/05	Meteka	Meteka	River water (Awash R.)	N 9° 59' 40.36"	E 40° 32' 58.78"	579	30.3	7.67	758	✓	–	–	Awash river in Meteka region
52	DBT001	2014/04/11	Dubti (Tendaho 1)	Dubti	Mud pool (relict mud pot)	N 11° 46' 18.16"	E 41° 08' 22.58"	367	51.3	–	–	–	–	–	A mud pot with warm water caused from irregation development in the region
53	DBT002	2014/04/11	Dubti (Tendaho 1)	Dubti	Fumarole (above a boiling temperature)	N 11° 46' 18.43"	E 41° 08' 22.25"	367	99.2	–	–	–	✓	–	A somewhat strong steam vent with a sound adjacent to DBT001, having a temperature higher than the boiling temperautre (98.8°C at 972 hPa)
54	DBT003	2014/04/11	Dubti (Tendaho 1)	Dubti	Fumarole (relict mud pot)	N 11° 46' 53.08"	E 41° 07' 43.99"	369	99.1	–	–	–	–	–	A steam vent on a relict mud pot, having a temperature higher than a boiling temperautre (98.8°C at 972 hPa)
55	DBT004	2014/04/11	Dubti (Tendaho 1)	Dubti	Mud pot	N 11° 46' 58.48"	E 41° 07' 33.24"	364	–	–	–	–	–	–	A large mud pot
56	ALB001	2014/04/12	Allalobeda (Tendaho 3)	Allalo Beda	Hot spring (boiling)	N 11° 38' 18.20"	E 41° 00' 55.29"	405	99.2	8.81	2789	✓	–	–	Boiling hot spring (B.P. 98.8°C at 971 hPa)
57	ALB002	2014/04/12	Allalobeda (Tendaho 3)	Allalo Beda	Hot spring "Devil's pool" (large and deep)	N 11° 38' 29.82"	E 41° 00' 51.65"	408	96.9	8.47	2803	✓	–	–	A large and deep spirng
58	ALB003	2014/04/12	Allalobeda (Tendaho 3)	Allalo Beda	Hot spring seeping and causing swamp	N 11° 38' 09.67"	E 41° 01' 09.83"	401	80.7	–	–	–	–	–	Several seeping points of hot water distributes along a boundary between flats and a basalt hill.
59	ALB004	2014/04/12	Allalobeda (Tendaho 3)	Allalo Beda, Awash River at the Tendaho dam	River	N 11° 41' 33.02"	E 40° 57' 26.27"	404	28.5	8.32	700	✓	–	–	Sampled at the Tendaho dam
60	SHA001	2014/04/13	Seha	Seha	Fumarole (very weak)	N 12° 03' 42.36"	E 40° 56' 52.57"	382	57.1	–	–	–	–	–	Basalt lava caves with small flow of moisture
61	SHA002	2014/04/13	Seha	Seha	Hot spring seeping and causing swamp	N 12° 03' 55.56"	E 40° 56' 32.11"	351	83.3	8.16	2340	✓	–	–	Several seeping points of hot water distribute along a boundary between flats and a basalt hill (T=43.3°C to 83.3°C).
62	AYB001	2014/04/14	Ayrobera (Tendaho 2)	Ayro Beda	Fumarole (above boiling temperature)	N 11° 53' 37.09"	E 41° 05' 33.19"	372	99.3	–	–	–	✓	✓	Wide distribution (NE-SW and NW-SE trends) of steam seeping to the surface. At the sampling point, a strong steam flow has a sound and a temperature higher than a boiling temperautre (98.9°C at 974 hPa).
63	LMA001	2014/04/15	Loma Lake	Lake Loma (crater lake)	Lake	N 11° 58' 07.51"	E 40° 56' 57.68"	362	31.7	9.29	13300	✓	–	–	A crater lake
64	Dallol-1	2014/05/07	Dallol	Dallol	Hot spring	N 14° 08' 34.51"	E 40° 10' 46.74"	-94	109.7	–	–	✓	–	–	Covered by hard salt and swampy salt deposits
65	Dallol-2	2014/05/07	Dallol	Dallol	Lake	N 14° 07' 41.12"	E 40° 11' 57.12"	-123	42	–	–	✓	–	–	Gas bubbling, browne colored sulfur containing water
66	Dallol-3	2014/05/08	Dallol	Dallol	Pool	N 14° 07' 58.76"	E 40° 10' 18.41"	-125	46.4	–	–	✓	–	–	Black water 10 m -diameter Hot spring
67	Dallol-4 As-Ale	2014/05/08	Dallol	Dallol	Lake	N 14° 03' 12.20"	E 40° 12' 51.23"	-112	46.7	5.96	–	✓	–	–	Lake is colorless
68	Erer-1	2014/05/15	Erer	Erer	Hot spring	N 9° 20' 02.00"	E 41° 14' 16.91"	1119	39	7.86	2922	✓	–	–	El-Gel (camel hot spring)
69	Erer-2	2014/05/15	Erer	Erer	Hot spring	N 9° 18' 52.74"	E 41° 14' 04.88"	1186	43.3	7.58	3492	✓	–	–	People use the spring water for bathing.
70	Arabi-1	2014/05/16	Arabi	Arabi	Hot spring	N 9° 34' 27.34"	E 42° 24' 59.80"	1103	72	7.2	3745	✓	–	–	Sirerlae- meaning bed like wooden structure built on the hot spring
71	Arabi-2	2014/05/16	Arabi	Arabi	Hot spring	N 9° 34' 21.43"	E 42° 25' 36.30"	1106	93	7.6	3820	✓	–	–	Silica terraces

Source: JICA Project Team

(ii) Sampling

i) Hot spring water, water from geothermal wells, and river/lake water

Hot springs measuring the highest temperature and flow rate in the site were preferentially sampled. At Shenemaya (Gedemsa) and Welenchiti (Boseti), water wells were sampled as a hot spring because they showed higher temperature than the ground temperature. LA-6 and LA-8, which are geothermal wells in the Aluto area, were also sampled as a representative of reservoir fluid.

Water sample was once put in a jug, and then transferred into polyethylene bottles that can be tightly capped. Before the sampling, the jog and bottles were rinsed three times or more with sample water. Sample water was divided into several bottles depending on the analytical components and methods. The samples were pretreated with a proper amount of HCl (1:1) solution for analysis of metal, ammonia, and silica, with cadmium acetate (5%) solution for hydrogen sulfide, and with potassium hydroxide for carbon dioxide, respectively.

ii) Fumarolic gas and steam from a geothermal well

Fumaroles measuring the highest temperature and flow rate in the site were preferentially sampled. At the Aluto area, steam from well LA-8 was sampled as a representative of reservoir steam containing geothermal gas.

In the sampling for fumaroles, a funnel was put over a fumarole vent, and then sealed on its rim with soil or mud to prevent air contamination during the sampling. After that, a rubber tube was connected to the funnel in order to extract gas. As to a geothermal production well LA-8, a sampling separator was connected to a sampling valve on the two-phase line, then a rubber tube was connected to a nozzle of steam sampling valve on the separator. A sampling apparatus called gas burette that was filled with an alkaline solution was connected to the rubber tube to introduce the gas or steam into the gas burette. In the gas burette, CO_2 and H_2S were dissolved in the alkaline solution, and residual gas (R gas) accumulated at the head of the gas burette. After collecting a sample, R gas was transferred from the gas burette to a gas collector (a glassware), and then, the alkaline solution was washed out into a measuring flask, and diluted to 250 ml with distilled water. The diluted alkaline solution was divided into two polyethylene bottles dedicated to analysis of CO_2 and H_2S, respectively. A cadmium acetate (5%) solution was added into the samples for H_2S analysis on site.

(iii) Analysis of samples

Table 3.4.8 and Table 3.4.9 show analytical components and analytical methods, respectively.

Table 3.4.8 Analytical components

Type of sample	Aqueous chemical component	Gaseous chemical component	Isotopic component
Water: hot spring, geothermal well (water), river, and lake	pH, EC, SiO_2, Cl, SO_4, T-CO_2 (HCO_3, CO_3), F, Na, K, Ca, Mg, Al, Fe, NH_4, H_2S, B, As	–	δD (H_2O), $\delta^{18}O$ (H_2O)
Steam/gas: fumaroles, geothermal well (steam)	-	CO_2, H_2S, H_2, N_2, CH_4, O_2, Ar, He	$^3He/^4He$, $^4He/^{20}Ne$

Source: JICA Project Team

Table 3.4.9 Analytical methods

Aqueous species	Analytical Method
pH	pH meter
EC	Conductivity meter
SiO_2	Spectrophotometric (Molybdenum yellow method) or Gravimetric
Cl, SO_4, F	Ion chromatography
CO_2	Infrared (IR) spectroscopy
HCO_3, CO_3	Calculation based on dissociation of carbonic acid
Na, K	Flame emission spectroscopy
Ca, Mg, Al, Fe, B, As	ICP/AES
NH_4	Indophenol blue spectroscopy
H_2S	Iodometric titration
δD, $\delta^{18}O$	Mass spectrometry

Gaseous species	Analytical Method
H_2S	Iodometric titration
CO_2	Infrared spectroscopy
H_2, N_2, CH_4, O_2, He, Ar	Gas chromatography
$^3He/^4He$, $^4He/^{20}Ne$	Mass spectrometry

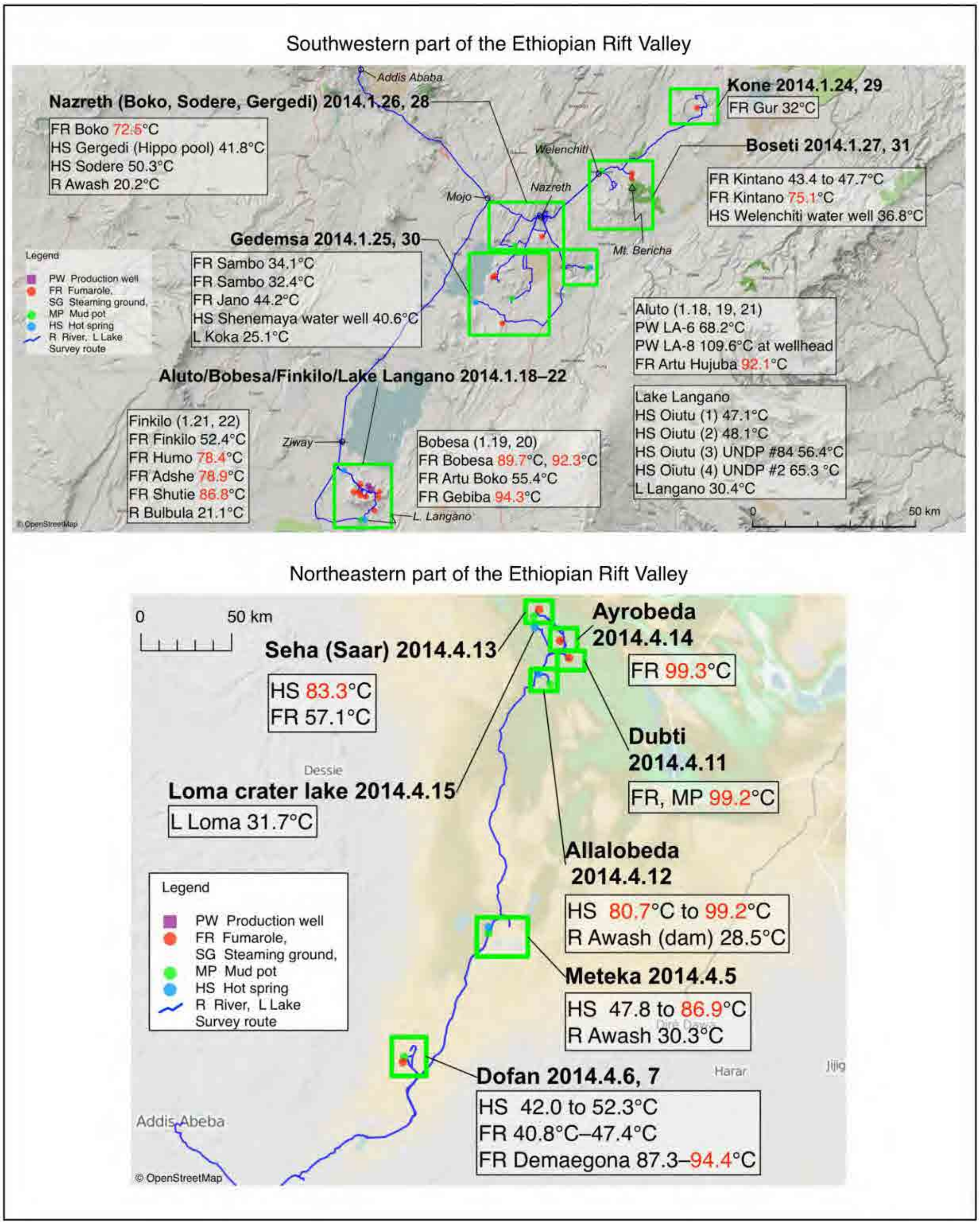
Source: JICA Project Team

(3) Results

(i) Profile of geothermal manifestations in the Ethiopian Rift Valley

Location (coordinate), altitude, and temperature of survey points are summarized in Tables 3.4.6 and 3.4.7, and the distribution of temperature of geothermal manifestations is shown in Figure 3.4.4.

In the southwestern part of the Ethiopian Rift Valley, a main geothermal manifestation is fumarole located in uplands. Fumaroles whose temperature is more than 90°C are located in Aluto, Bobesa, and Gebiba; only the fumaroles in Gebiba show a boiling temperature in the southwestern part. The other fumaroles are of lower temperatures (70-90°C) less than a boiling temperature. The low temperature suggests that steam generated at a depth is cooled during its ascending to the surface by surrounding rock. In this cooling process, a part of the steam condensates into liquid (water), resulting in a change of chemical composition from the original one controlled by the reservoir temperature. Gas geochemical thermometers thus cannot be applied to the low-temperature fumarolic gases.



Source: JICA Project Team

Figure 3.4.4 Distribution of geothermal manifestations in the Ethiopian Rift Valley

Hot springs are distributed mainly in lowlands around Langano Lake and the Nazareth area. Their temperatures are middle to low, ranging from 65° to 35°C, and boiling spring cannot be found. Relatively high temperatures are 65°C of Ouitu (Langano lake) and 50°C of Sodere (Nazareth).

In the northeastern part of the Ethiopian Rift Valley, fumaroles and hot springs are distributed in upland and lowland areas. The manifestations show temperatures higher than those in the southwestern part. Fumaroles with temperatures higher than 90°C are located in Dofan, Dubti, Ayrobeda. In Dubti and Ayrobeda, temperatures of fumaroles are slightly higher than a boiling temperature. Hot springs distribute in Dofan, Meteka, Allalobeda, Seha; there are hot springs with the temperature higher than 80°C, except for Dofan. A boiling hot spring is located at Allalobeda.

Taking a wide view of the Ethiopian Rift Valley, Aluto-Langano and Tendaho (Allalobeda, Ayrobeda, Dubti, Seha) are the remarkable sites showing prominent activity of geothermal manifestations.

(ii) Results of analysis of samples

The analysis results of chemical and isotopic compositions are shown in Table 3.4.10 for water and Table 3.4.11 for gas. Geochemical characteristics of geothermal water and gas are examined with those results and reference data. The reference data are taken from Aquater (1980, 1991), ELC/Geotermica (1987), Gonfiantini et al. (1973), UNDP (1973, 1976, 1977), Panichi (1995), D'Amore et al, (1997). For description of the locations of sampling points, the survey areas are divided into four major regions; they are, along a direction from southwest to northeast in the rift valley, [1] Lake District (Abaya to Wonji), [2] Southern Afar (Fantale to Meteka), [3] Northern Afar (Teo/Danab to Tendaho), and [4] Danakil Depression (Dallol).

(iii) Origin of geothermal fluid

Origin of geothermal fluid (water from geothermal wells and hot springs) is examined using the relationship between δD and $\delta^{18}O$. As shown in Figure 3.4.5, waters from the geothermal manifestation, rivers, and lakes are plotted close to the meteoric water line, which means that meteoric water is the origin of the geothermal waters. Much higher isotopic values in both oxygen and hydrogen are seen in Figure 3.4.5, indicating isotopic mass fractionation caused by intense evaporation (see the evaporation line in the figure) in the rift valley as mentioned by Panichi (1995).

Table 3.4.10 Results of chemical and isotopic analysis for water samples

Sample	Type	Date	Temp.	pH	EC	SiO_2	Cl	SO_4	CO_2	HCO_3	CO_3	F	Na	K	Ca	Mg	Al	Fe	NH_4	H_2S	B	As	δD	$\delta^{18}O$
			°C		µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	‰SMOW	‰SMOW
Southwest area of Ethiopian rift valley																								
LA-6	Geothermla well	2014/1/18	68.2	7.9	3220	672	375	71	877	1174	7.1	28	648	183	1.2	0.09	1.9	0.32	N/A	N/A	6.8	0.82	N/A	N/A
LA-8	Geothermla well	2014/1/19	94.0	9.2	4630	706	534	42	1310	1616	194	60	1060	138	0.45	0.39	4.6	1.2	1.1	1.4	4.2	0.34	-2	-0.7
Oiutu UNDP#84	Hot spring	2014/1/21	56.4	7.7	3640	218	407	19	1380	1822	6.9	30	850	80	7.6	2.4	<0.01	0.08	0.55	<0.5	1.9	<0.01	-2	-1.3
Oiutu UNDP#2	Hot spring	2014/1/21	65.3	7.6	3500	246	459	26	1240	1620	4.9	27	811	61	9.6	3.0	<0.01	0.19	0.58	<0.5	2.6	0.11	-2	-1.0
Shenemaya	Water well (hot spring)	2014/1/29	40.6	7.9	1840	116	151	102	624	836	5.0	14	400	25	23	3.3	<0.01	<0.01	0.01	<0.5	1.6	0.02	-12	-2.4
Sodere Resort H.	Hot spring	2014/1/26	50.3	7.7	2130	123	112	113	950	1254	4.8	5.0	483	30	19	12	<0.01	<0.01	0.04	<0.5	1.0	0.04	-12	-2.6
Gergedi (Hippo Pool)	Hot spring	2014/1/28	41.8	8.4	891	103	23	26	411	554	11	13	213	13	3.2	0.68	<0.01	<0.01	0.05	<0.5	0.24	0.02	-6	-1.9
Welenchiti	Water well (hot spring)	2014/1/30	36.8	8.6	724	108	8.0	8.0	375	502	15	2.2	128	14	19	12	<0.01	<0.01	0.05	N/A	0.19	0.01	-20	-3.9
Bulbula River	River water	2014/1/20	21.1	7.6	437	35	11	6.4	197	257	0.8	1.5	66	12	18	8.6	1.4	1.1	N/A	N/A	0.06	0.02	+32	+5.0
Awash River (Sodere)	River water	2014/1/26	20.2	8.0	312	17	13	10	110	148	1.1	1.2	29	5.5	26	5.0	0.45	0.37	N/A	N/A	0.04	0.02	+1	-0.4
Lake Langano	Lake water	2014/1/21	30.4	9.1	1970	139	182	17	644	813	77	16	470	29	6.0	3.1	17	13	N/A	N/A	0.72	<0.01	+42	+7.2
Lake Koka (Haro Ropi)	Lake water	2014/1/29	25.1	7.6	313	15	13	9.0	92.6	121	0.4	1.0	26	6.0	29	5.3	0.31	0.25	N/A	N/A	0.04	0.01	+3	0.0
Northeast area of Ethiopian rift valley																								
– Sampling and analysis conducted by JICA study team																								
Beseka Lake 001	Lake water	2014/4/9	31.3	9.5	6540	66	512	509	1850	2061	494	31	1670	62	2.4	0.36	0.33	0.30	0.09	<0.5	3.1	0.081	+47	+8.7
Dofan 003	Hot spring	2014/4/6	52.1	8.5	1500	104	139	174	386	519	12	8.7	311	15	6.1	2.9	0.01	0.02	<0.01	<0.5	0.86	0.005	-7	-1.3
Dofan 004	Hot spring	2014/4/6	44.6	8.4	1430	96	133	133	372	501	10	8.6	289	16	11	3.4	0.02	0.03	<0.01	<0.5	0.93	0.007	-7	-1.0
Meteka 001	Hot spring	2014/4/5	47.8	8.6	1170	56	108	93	338	452	14	1.8	243	11	4.2	2.2	0.01	0.02	<0.01	<0.5	0.56	0.006	-15	-2.7
Meteka 002	Hot spring	2014/4/5	77.0	8.1	6950	194	1350	943	643	867	8.3	4.8	1470	58	61	16	<0.01	0.12	2.3	<0.5	4.0	0.11	-21	-3.0
Meteka 003	Hot spring	2014/4/5	86.9	8.2	7200	212	1480	780	815	1100	13	5.6	1570	66	46	19	6.9	11	3.1	<0.5	4.0	0.053	-19	-3.1
Awash River (Meteka)	River water	2014/4/5	30.3	8.0	770	32	62	41	211	284	2.2	2.2	130	9.0	27	4.7	<0.01	0.03	N/A	N/A	0.29	0.003	+9	+0.5
Allalobeda 001	Hot spring	2014/4/12	99.2	9.2	2860	328	714	203	39	48	5.7	0.56	516	37	25	0.01	0.18	0.01	0.71	<0.5	2.2	0.14	-21	-1.4
Allalobeda 002	Hot spring	2014/4/12	96.9	8.8	2900	316	713	209	36	48	2.3	0.62	523	38	27	0.01	0.19	0.01	1.7	<0.5	2.0	0.066	-20	-1.0
Awash River (Tendaho)	River water	2014/4/12	28.5	8.4	720	22	46	53	219	295	5.6	1.8	118	6.5	25	9.2	<0.01	0.01	N/A	N/A	0.18	0.042	+18	+2.7
Seha 002	Hot spring	2014/4/13	83.3	8.4	2390	142	514	162	211	284	5.4	3.6	477	26	6.1	0.24	0.18	0.18	0.63	<0.5	3.7	0.017	+2	+0.4
Loma Lake 001	Lake water	2014/4/15	31.7	9.4	14100	192	3400	937	1160	1347	256	13	3180	315	1.2	0.32	<0.01	0.01	N/A	N/A	18	0.006	+42	+10.0
– Sampling was conducted by GSE, and analysis by JICA study team																								
Dallol-1	Hot spring	2014/5/7	109.7	-0.48	189000	128	209000	4030	<0.5	-	-	384	89400	11100	4000	4220	534	19700	16	<0.5	438	0.66	-	-
Dallol-2	Hot spring	2014/5/7	42.0	0.82	52700	140	421000	31	82	0	0	77	1510	1700	14500	50700	<0.01	<0.01	N/A	<0.5	191	<0.001	-36	-22
Dallol-3	Hot spring	2014/5/8	46.4	1.2	67000	278	353000	53	46	0	0	16	1670	700	8990	114000	<0.01	2090	1.6	<0.5	111	<0.001	-	-22
Dallol-4 (As Ale)	Hot spring	2014/5/8	46.7	6.4	169000	24	204000	286	5.4	3.9	0	13	88200	5700	25000	4540	<0.01	<0.01	N/A	<0.5	46	0.005	+23	-
Erer-1	Hot spring	2014/5/15	39.0	7.7	3140	28	191	1370	5.5	7.3	0.03	3.8	473	6.0	240	3.2	<0.01	0.21	<0.01	<0.5	0.74	<0.001	-14	-4.0
Erer-2	Hot spring	2014/5/15	43.3	7.5	3630	32	199	1730	5.7	7.4	0.02	4.2	485	10	316	38	<0.01	0.99	<0.01	<0.5	1.3	0.003	-11	-3.0
Arabi-1	Hot spring	2014/5/16	72.0	7.9	3880	80	656	572	356	477	2.9	8.3	773	38	43	3.6	0.13	0.14	<0.01	<0.5	0.20	0.004	-12	-2.9
Arabi-2	Hot spring	2014/5/16	93.0	8.0	3960	76	680	590	329	442	3.4	8.7	796	39	42	3.6	0.04	0.72	0.07	<0.5	0.30	<0.001	-10	-2.2

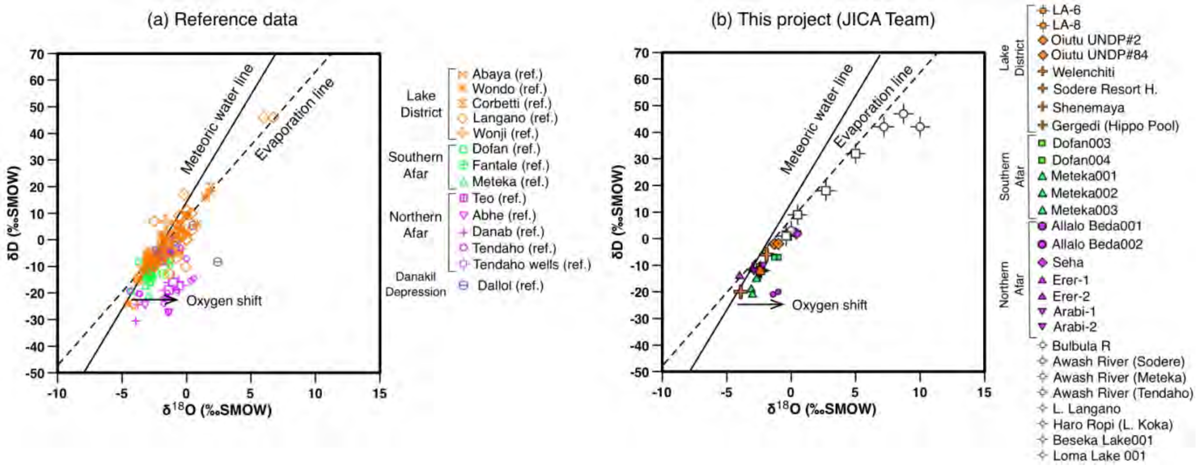
Source: JICA Project Team

Table 3.4.11 Results of chemical and isotopic analysis for gas samples

Location			LA-8	Gebiba	Bobesa	Bobesa	Boko	Boseti	Meteka	Dofan	Dofan	Dubuti	Ayrobera
Code			ALT 002	BBS 004	BBS 001	BBS 002	BKO 001	BST 006	MTK003	DFN007	DFN008	DBT002	AYB001
Date			2014/1/19	2014/1/20	2014/1/19	2014/1/19	2014/1/26	2014/1/31	2014/4/5	2014/4/7	2014/4/7	2014/4/11	2014/4/14
Temperature (°C)			109.6	94.3	89.7	92.3	72.5	75.1	86.9	91.8	94.4	99.2	99.3
Noncondensable gases													
H_2O and NCG (total 100%)	H_2O	(vol%)	97.88	99.18	0	0	0	0	0	0	0	99.83	99.94
	NCG	(vol%)	2.12	0.82	100	100	100	100	100	100	100	0.17	0.06
NCG composition (total 100%)	H_2S	(vol%)	0.1	0.1	2.9	0.6	2.2	2.2	0.0	0.0	0.0	2.1	0.0
	CO_2	(vol%)	99.6	99.0	59.2	68.4	65.6	59.5	91.7	73.5	82.0	94.8	84.4
	R gas	(vol%)	0.3	0.9	37.9	31.0	32.2	38.3	8.3	26.5	18.0	3.1	15.6
R gas composition (total ~100%)	H_2	(vol%)	12.1	1.66	0.003	0.004	0.002	0.001	0.059	0.0038	0.986	26.6	0.014
	N_2	(vol%)	32.2	65.6	78.3	78.0	78.2	78.1	74.9	78.4	79.9	47.4	85.2
	CH_4	(vol%)	52.6	27.2	0.09	0.56	0.01	0.005	19.9	nd	0.04	21.0	12.3
	O_2	(vol%)	2.3	4.2	20.7	20.5	20.8	21.0	3.8	20.7	18.2	4.0	0.56
	He	(vol%)	0.18	0.079	0.001	0.003	0.001	0.001	0.16	0.0006	0.0013	0.027	0.066
	Ar	(vol%)	0.66	1.17	0.93	0.93	0.94	0.94	1.27	0.93	0.89	0.92	1.83
NCG composition (total 100%)	H_2S	(vol%)	0.1	0.1	2.9	0.6	2.2	2.2	nd	nd	nd	2.1	nd
	CO_2	(vol%)	99.6	99.0	59.2	68.4	65.6	59.5	91.7	73.5	82.0	94.8	84.4
	H_2	(vol%)	0.0363	0.0149	0.001	0.001	0.0005	0.0004	0.0049	0.0010	0.177	0.825	0.0022
	N_2	(vol%)	0.0966	0.591	29.7	24.2	25.2	29.9	6.22	20.8	14.4	1.47	13.3
	CH_4	(vol%)	0.158	0.245	0.04	0.18	0.003	0.002	1.65	nd	0.007	0.652	1.92
	O_2	(vol%)	0.0068	0.038	7.8	6.34	6.70	8.04	0.31	5.48	3.27	0.12	0.088
	He	(vol%)	0.00055	0.00072	0.0005	0.0009	0.0002	0.0002	0.013	0.0002	0.0002	0.00084	0.010
	Ar	(vol%)	0.0020	0.011	0.35	0.29	0.30	0.36	0.105	0.25	0.16	0.029	0.286
NCG composition (total ~100%, corrected for air contamination)	H_2S	(vol%)	0.1	0.1	4.6	0.9	3.2	3.6	nd	nd	nd	2.1	nd
	CO_2	(vol%)	99.6	99.2	94.7	98.1	96.4	96.4	93.1	99.5	97.2	95.4	84.8
	H_2	(vol%)	0.0363	0.0149	0.002	0.002	0.0008	0.0006	0.0049	0.0014	0.210	0.830	0.0022
	N_2	(vol%)	0.0712	0.450	0.643	0.786	0.332	nd	5.12	0.483	2.59	1.01	13.0
	CH_4	(vol%)	0.158	0.246	0.06	0.25	0.005	0.003	1.67	nd	0.008	0.66	1.93
	He	(vol%)	0.00055	0.00072	0.0008	0.001	0.0003	0.0004	0.013	0.0002	0.0003	0.00085	0.010
	Ar	(vol%)	0.0017	0.0089	0.0055	0.0068	0.0041	nd	0.0927	0.0021	0.017	0.023	0.283
Isotopic ratios of noble gases													
$^3He/^4He$			17.2±0.2	9.75±0.11	8.29±0.12	–	–	–	14.6±0.1	–	–	–	5.84±0.05
$^4He/^{20}Ne$			524	26.2	0.635	–	–	–	184	–	–	–	0.486

nd: not detected
–: not analyzed

Source: JICA Project Team



Source: JICA Project Team

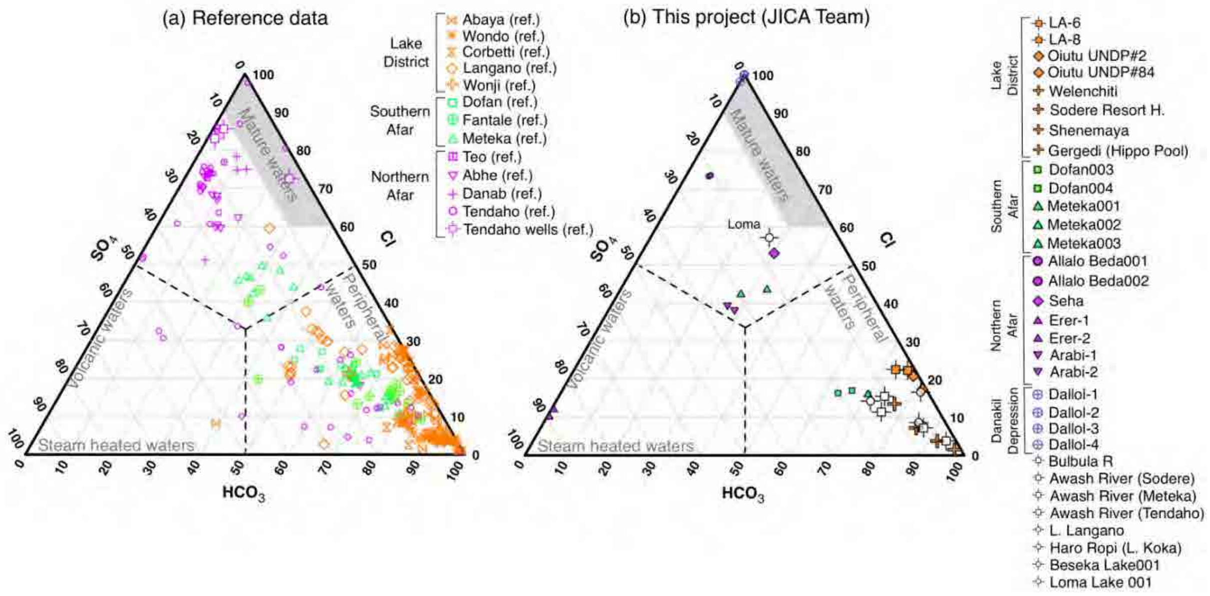
Figure 3.4.5 Relationship between δD and $\delta^{18}O$ of geothermal and surface waters

(iv) Characteristics of main anions in geothermal water

Relative concentrations of main anions (Cl, SO_4, HCO_3) are shown in Figure 3.4.6 (based on Giggenbach, 1991). This figure illustrates that the anion composition of waters from geothermal wells and hot springs differs by the sample locations; the geothermal waters in Lake District and Southern Afar are rich in HCO_3, on the contrary, the geothermal waters in Northern Afar are rich in Cl. The Cl-rich waters in Northern Afar are similar to those from geothermal systems developed in subduction zones (see mature waters in the figure). Water samples of Meteka and Arabi show intermediate relative concentration of HCO_3 and Cl. Dallol in Danakil Depression has extremely high concentration of Cl and extremely low pH (Cl 197000 mg/l, pH < 1 in Table 3.4.10). This suggested that the chemistry of Dallol hot spring is strongly affected by volcanic HCl gas.

In Lake District, waters are rich in HCO_3 among surface water (river and lake), hot spring, and geothermal well discharges. This observation indicates that the anion composition of the surface water is unchangeable in the geothermal reservoir where the surface water penetrates. Giggenbach (1991) states that HCO_3-rich waters are found at margins of a thermal area in the geothermal systems developed close to the subduction zones. The observation in Lake District, however, indicates that HCO_3-rich water can be reservoir water in the southwestern part of the Ethiopian Rift Valley.

Looking at Figure 3.4.6(b) closely, geothermal wells in Aluto and hot springs in its neighboring area, Langano, together show very similar anion composition. This similarity demonstrates that the geothermal fluids from Aluto and Langano are originated in a single geothermal system. This point of view is used to estimate reservoir temperature as mentioned later.



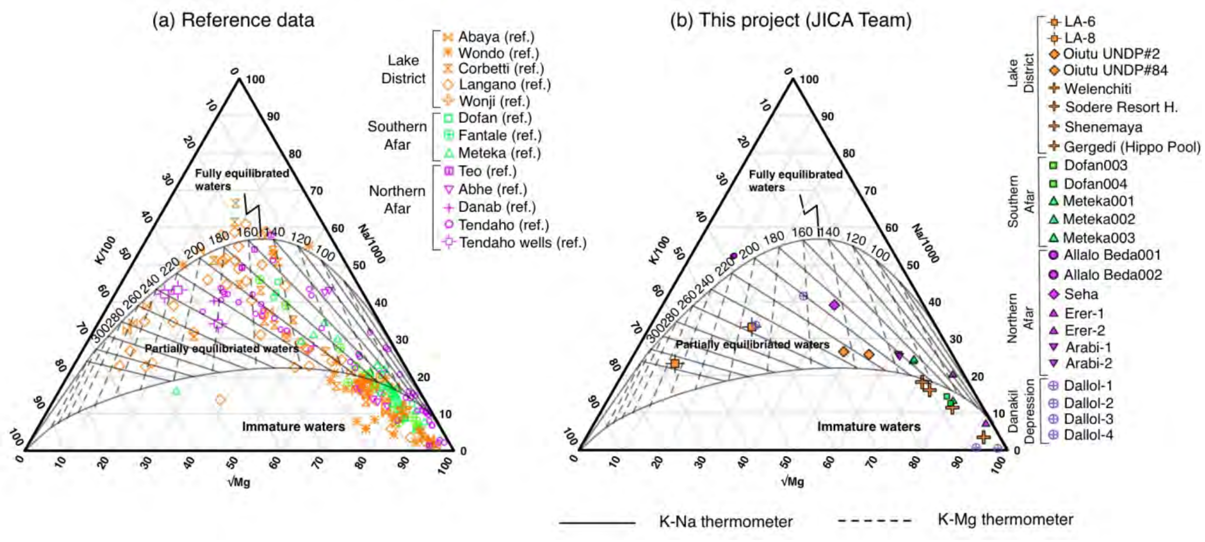
Source: JICA Project Team

Figure 3.4.6 Relative Cl, SO_4, and HCO_3 contents of geothermal and surface waters on weight basis

In Tendaho, Northern Afar, unlike Aluto-Langano, geothermal waters and river waters are quite different in anion composition, which could be caused by the different condition in water-rock interaction. As can be seen in Figure 3.4.5, geothermal waters in Tendaho demonstrate the oxygen shift with which geothermal water becomes rich in heavy oxygen isotope compared to surface (recharge) water as a result of water-rock interaction. Those observations of the anion and isotopic composition in Northern Afar and Aluto-Langano indicate that the water-rock interaction is probably progressed more in Northern Afar.

(v) Estimation of reservoir temperature based on geochemical thermometers

In order to estimate the progress of water-rock interaction, Na-K-Mg diagram (Giggenbach, 1988) is drawn in Figure 3.4.7. This figure implies that waters from geothermal wells in Tendaho and hot springs in Allalobeda is fully equilibrated with surrounding rock, which is consistent with the fact that the geothermal waters are rich in Cl and affected by oxygen shift in the isotopic composition. On the contrary, waters from geothermal wells in Aluto and hot springs of Oiutu in Langano are partially equilibrated with surrounding rock and the other hot spring waters are immature in the state of water-rock interaction. In some cases, geochemical thermometers using Na and K are unreliable where it is applied to the waters that are not fully equilibrated with the reservoir rock (Giggenbach, 1991). Reservoir temperature, therefore, can be examined by comparison among several geochemical thermometers including quartz thermometer in this study.



Source: JICA Project Team

Figure 3.4.7 Relative Na, K, and Mg contents of geothermal waters

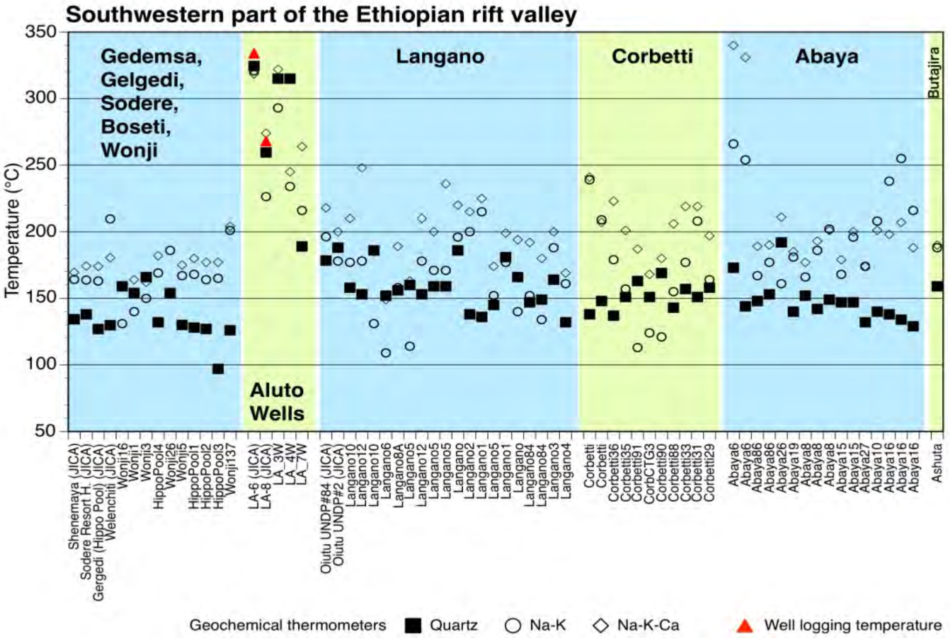
Table 3.4.12 summarizes the results of calculation of geochemical thermometers using the chemical compositions obtained in this work. These results are compared with geochemical temperatures calculated for the reference chemical data, and temperatures obtained in well loggings (Seifu, 2006; D'Amore et al., 1997) as shown in Figures 3.4.8 and 3.4.9. These figures provide observations as follows: [1] the quartz thermometer shows a good agreement with well-logging temperatures of geothermal wells (LA-6, LA-8, TD-1, TD-2, TD-4), [2] temperatures calculated with the quartz thermometer converge within a narrow range in each survey site, so that the quartz temperatures can be recognized as a representative one of the hot spring aquifer. In contrast, the calculation results using Na-K and Na-K-Ca thermometers vary widely within the each site. [3] Geochemical temperatures of hot springs, except for quartz temperatures of Allalobeda, are lower than those of geothermal wells. [4] There is no a single trend in the orders of temperatures between quartz and Na-K/Na-K-Ca temperatures throughout the all survey sites.

Table 3.4.12 Calculated results of geochemical thermometers for geothermal waters

Sample	Date	Manifestation	Temperature measured (°C)	Geothermometers (°C)						
				Quartz (silica)	Chalcedony (silica)	Na-K (A)	Na-K (F)	Na-K (G)	K-Mg (G)	Na-K-Ca
LA-6 *1	2014/1/18	Geothermal well (not boiling)	68.2	324	261	321	326	331	250	319
LA-8 *2	2014/1/19	Geothermal well	–	260	233	226	241	254	192	274
Oiutu UNDP#84	2014/1/21	Hot spring	56.4	178	159	196	212	228	144	218
Oiutu UNDP#2	2014/1/21	Hot spring	65.3	188	168	178	194	211	131	200
Shenemaya	2014/1/29	Drinking water well	40.6	134	118	164	180	197	103	169
Sodere Resort H.	2014/1/26	Hot spring	50.3	138	121	164	179	197	91	174
Gergedi (Hippo Pool)	2014/1/28	Hot spring	41.8	127	111	163	178	196	107	174
Welenchiti	2014/1/30	Drinking water well	36.8	130	113	210	225	240	72	181
Dofan 003	2014/4/6	Hot spring	52.1	128	111	147	162	180	91	163
Dofan 004	2014/4/6	Hot spring	44.6	123	107	156	171	189	91	164
Meteka 001	2014/4/5	Hot spring	47.8	94	79	143	157	176	87	159
Meteka 002	2014/4/5	Hot spring	77.0	170	151	134	148	168	105	160
Meteka 003	2014/4/5	Hot spring	86.9	176	157	138	152	171	106	167
Allalobeda 001	2014/4/12	Hot spring	99.2	213	191	174	190	207	224	181
Allalobeda 002	2014/4/12	Hot spring	96.9	210	188	175	191	208	226	181
Seha 002	2014/4/13	Hot spring	83.3	147	130	155	170	188	145	177
Dallol-1	2014/5/7	Hot spring	109.7	141	124	222	236	250	189	273
Dallol-2 *3	2014/5/7	Hot spring	42.0	146	129	–	–	–	87	328
Dallol-3 *3	2014/5/8	Hot spring	46.4	198	178	–	–	–	57	255
Dallol-4 (As Ale)	2014/5/8	Hot spring	46.7	56	42	167	182	200	162	207
Erer-1	2014/5/15	Hot spring	39.0	62	48	80	87	108	67	48
Erer-2	2014/5/15	Hot spring	43.3	68	53	101	111	131	52	57
Arabi-1	2014/5/16	Hot spring	72.0	112	97	148	163	181	114	163
Arabi-2	2014/5/16	Hot spring	93.0	109	94	148	163	181	115	164

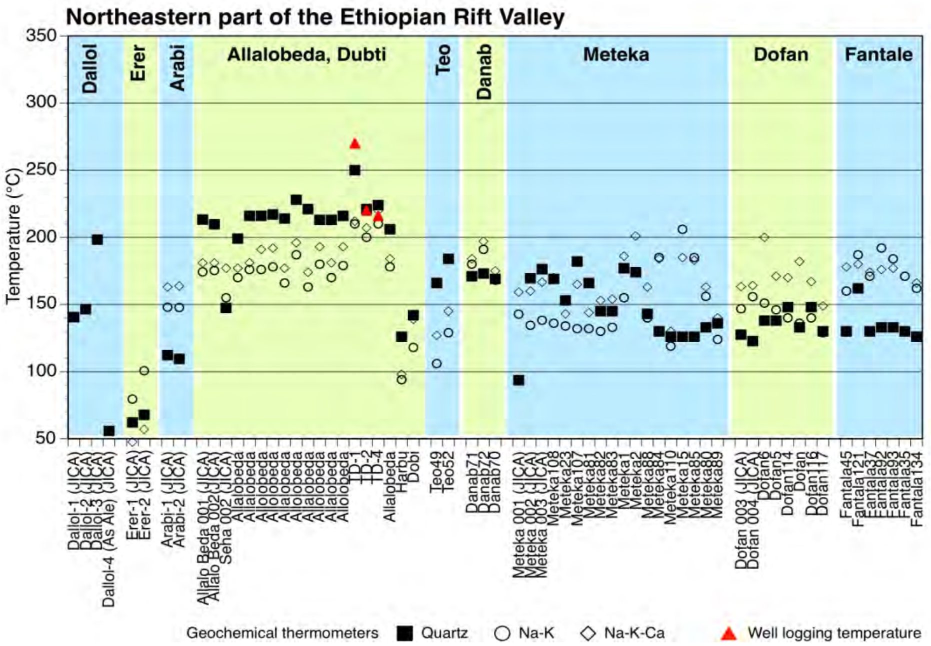
Reference of geothermometers: quartz from Arnórsson (2000), chalcedony from Arnórsson et al. (1983), Na-K(A) from Arnórsson (2000), Na-K (F) from Fournier (1979), Na-K (G) and K-Mg from Giggenbach (1988), Na-K-Ca from Fournier and Truesdell (1973)
*1 Water sample was collected in a probably unstable production state immediately after blowing started.
*2 Geothermometers of LA-8 were calculated from the chemical composition of produced water corrected for boiling at an atmospheric pressure.
*3 Water samples from Dallol are strongly acidic and not appropriate for calculation of geothermometers. Na-K thermometers show anomalous values that are not described in the table.

Source: JICA Project Team



Source: JICA Project Team

Figure 3.4.8 Comparison of temperatures calculated with geochemical thermometers for the southwestern part of the Ethiopian Rift Valley



Source: JICA Project Team

Figure 3.4.9 Comparison of temperatures calculated with geochemical thermometers for the northeastern part of the Ethiopian Rift Valley

Based on the conditions above, no geochemical temperature of hot spring can directly indicate plausible reservoir temperature. For this reason, we estimate reservoir temperature with the assumption in which Aluto-1 (Aluto-Langano) can be treated as a single geothermal system including a geothermal reservoir and hot spring aquifer, and conditions described above in [1] and [2]. In the process of estimation, it is assumed that the temperature difference between the geothermal reservoir and hot spring aquifer is represented by the deference in quartz temperature between a geothermal well and an Oiutu hot spring. In order to estimate a reservoir temperature, this temperature difference will be added to the quartz temperature of hot springs equally in each site. The temperature difference was calculated to be 70°C by subtracting the quartz temperature of the Oiutu hot spring from that of LA-8, which indicates an intermediate temperature among the geothermal wells in Aluto. This manner follows a principle taking a uniform process to estimate reservoir temperatures throughout the survey sites.

Gas geochemical thermometers can also be used for fumarolic gas to estimate reservoir temperature. However, in the Ethiopian Rift Valley, gas thermometers is considered unreliable because most of the fumaroles have temperatures less than a boiling temperature, and contain air in a large proportion. For this reason, gas geochemical thermometers were applied to the calculated gas chemical compositions corrected for mixing of air. As shown in Table 3.4.13, the calculation results of gas thermometers show a wide variety of temperatures with no tendency, which indicates that the use of gas thermometers should be avoided for estimation of the reservoir temperature, and that geochemical thermometers using water composition is more practical for the purpose.

Table 3.4.13 Calculated results of geochemical thermometers for geothermal gases

Location	Code	Date	Temperature at surface (°C)	Geothermometers (°C)			
				CO_2-H_2S-H_2-CH_4	H_2/Ar	CO_2/Ar	CH_4/CO_2
LA-8	ALT 002	2014/1/19	109.6	(194)	268	319	336
Gebiba	BBS 004	2014/1/20	94.3	(171)	191	286	320
Bobesa	BBS 001	2014/1/19	89.7	(176)	(137)	295	(371)
Bobesa	BBS 002	2014/1/19	92.3	(150)	(134)	291	319
Boko	BKO 001	2014/1/26	72.5	(173)	(124)	301	(482)
Boseti	BST 006	2014/1/31	75.1	(173)	–	–	(507)
Meteka	MTK003	2014/4/5	86.9	–	86	235	261
Dofan	DFN007	2014/4/7	91.8	–	161	315	–
Dofan	DFN008	2014/4/7	94.4	–	251	272	(458)
Dubuti	DBT002	2014/4/11	99.2	232	284	265	288
Ayrobera	AYB001	2014/4/14	99.3	–	28	207	255

Reference of geothermometers: CO_2-H_2S-H_2-CH_4 from D'Amor and Panichi (1980), H_2/Ar, CO_2/Ar, CH_4/CO_2 from Giggenbach (1991)
Temperatures in brackets indicate uncertainty of calculation results due to inadequate significant numbers of concentrations used in the equations.
Dash (–) indicates nonapplication of calculation due to lack of significant numbers of concentrations used in the equations.

Source: JICA Project Team

The estimated reservoir temperatures, which were calculated by adding the temperature difference (70°C) between the geothermal reservoir and hot spring aquifer to the quartz temperatures of hot springs, are shown in Table 3.4.14. For the sites where no chemical data of hot springs are available, the estimated reservoir temperatures are assumed to be the same as those of a neighboring site. On the basis of this estimation of reservoir temperatures, the temperature conditions were eventually arranged for practice of a volumetric method to assess the geothermal potential. In this condition setting, distribution density and activity of geothermal manifestations including fumaroles as well as hot springs are considered. The final conditions of the reservoir temperature are expressed by the four classes of temperature ranges, as follows (see also Figure 3.5.2): A: 240°C–290°C, B: 210°C–260°C, C: 170°C–220°C, D: 130°C–170°C.

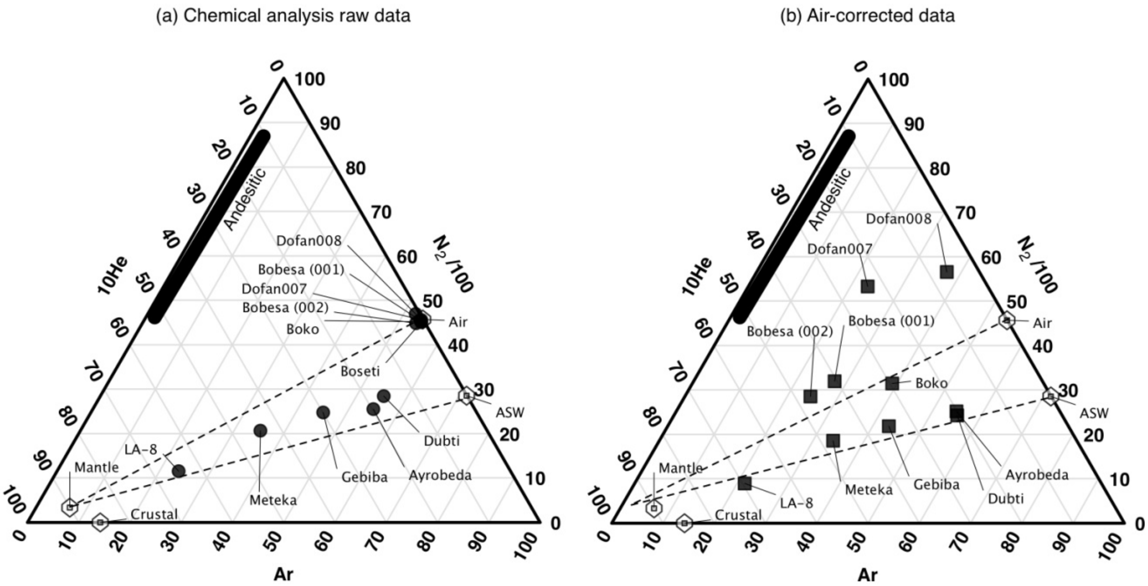
Table 3.4.14 Estimation of ranges of reservoir temperature for a volumetric method

No.	Site	Estimated reservoir temperature range (°C)		Tq+70°C	Tq: Quartz temperature (°C)	Additional factors or assumption for estimation of reservoir temperature
1	Dallol	B	210–260	210–220	140–150	
2	Tendaho-3 (Allalobeda)	A	240–290	270–290	200–220	
3	Boina	C	170–220	–	NO DATA	T same as neighboring sites
4	Damali	C	170–220	–	NO DATA	T same as neighboring sites
5	Teo	B	210–260	230–250	160–180	
6	Danab	B	210–260	240	170	
7	Meteka	B	210–260	240–250	170–180	
8	Arabi	C	170–220	180	110	
9	Dofan	B	210–260	190–210	120–150	
10	Kone	D	130–170	–	NO DATA	A lack of active manifestation
11	Nazareth	C	170–220	190–210	120–140	
12	Gedemsa	D	130–170	200	130	A lack of active manifestation
13	Tulu Moye	C	170–220	–	NO DATA	T same as neighboring sites
14	Aluto-2 (Finkilo)	A	240–290	250–260	NO DATA	T same as Aluto-1
15	Aluto-3 (Bobesa)	A	240–290	250–260	NO DATA	T same as Aluto-1
16	Abaya	B	210–260	210–230	140–160	
17	Fantale	C	170–220	200	130	
18	Boseti	B	210–260	200	130	Active steam vents
19	Corbetti	B	210–260	210–220	140–150	
20	Aluto-1 (Aluto-Langano)	A	240–290	250–260	180–190	
21	Thendaho-1 (Dubti)	A	240–290	270–290	NO DATA	T same as Allalobeda
22	Tendaho-2(Ayrobera)	A	240–290	270–290	NO DATA	T same as Allalobeda

Source: JICA Project Team

(vi) Relationship between the origin of geothermal gas and heat source

The origin of geothermal gas can be interpreted from chemical and noble gas isotopic compositions (Table 3.4.11) of gas samples. Figure 3.4.10 depicts He-Ar-N_2 relative concentration of gases along with the end members mentioned in Giggenbach (1966). Figure 3.4.10(a) plots analytical raw data. Gas from a geothermal well (LA-8), fumaroles having temperatures higher than a boiling temperature (Gebiba, Ayrobeda, Dubti), and bubbling gas in a Meteka hot spring are plotted close to a mixing line of Air-saturated water and a mantle component. The largest mixing ratio of the mantle component is seen in the gas from LA-8, so that the composition probably represents a gas composition in the geothermal reservoir. From these observations, it can be inferred that an origin of the gas is emanation gas from the mantle beneath the rift valley. On the other hand, gas samples form fumaroles with lower temperature (Boko, Boseti, Bobesa, and Dofan) are abundant in the air component, which could be gained by the fumarolic gas ascending through an unsaturated layer above a water label. Figure 3.4.10(b) uses calculated gas chemical compositions corrected for air mixing, and reveals the mantle component signature in such low-temperature fumarolic gases from Boko and Bobesa.

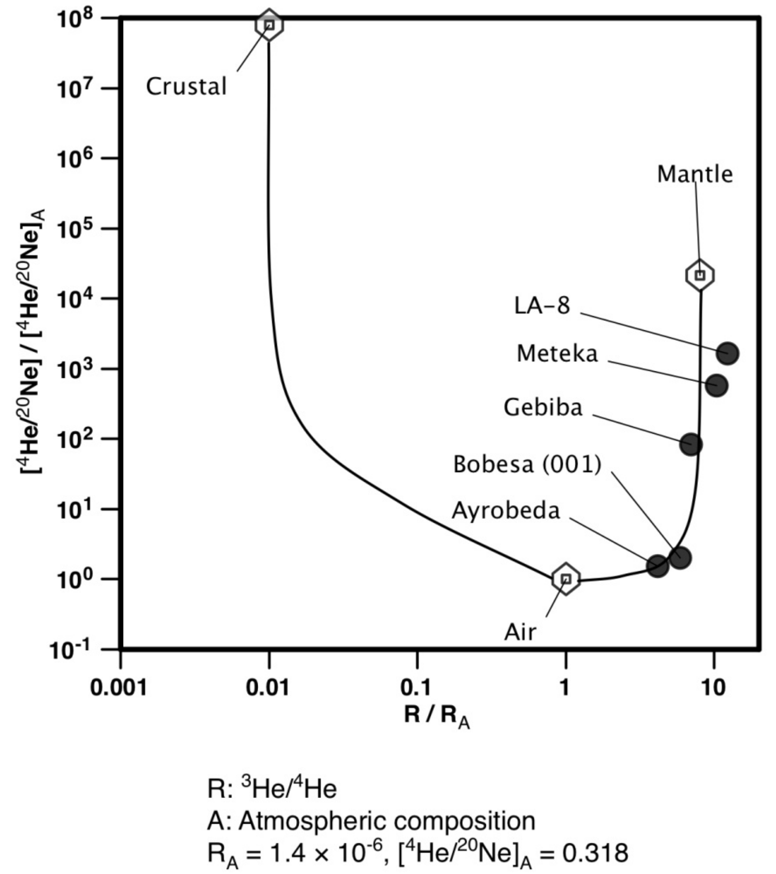


Source: JICA Project Team

Figure 3.4.10 Relative He, Ar, and N_2 contents of geothermal gases

The Mantle component in geothermal gas can be confirmed by noble gas isotopic ratio as inferred by the relationship between $^3He/^4He$ and $^4He/^{20}Ne$ with end members of air, crust, and mantle (Leśniak et al, 1997) in Figure 3.4.11. In the figure, geothermal gases in the Ethiopian Rift Valley are plotted close to the mixing line connecting the mantle and air components, which means that the geothermal gas contains emanation gas from the mantle.

The Great Rift Valley, where the upwelling movement of mantle splits the crust underneath, is supplied with a large quantity of heat from the mantle. The mantle component in geothermal gas, thus, can be an indicator for the mantle or magma generated from the mantle as the heat source. Furthermore, the movement of the gas indicates a flow path running from a depth to the surface, that is, a fracture zone. Because supply of meteoric (ground) water into the fracture zone develops a geothermal reservoir there, it can be said that the obvious contribution of the mantle component in the geothermal gas on the surface indicates a highly potential geothermal reservoir at a depth.

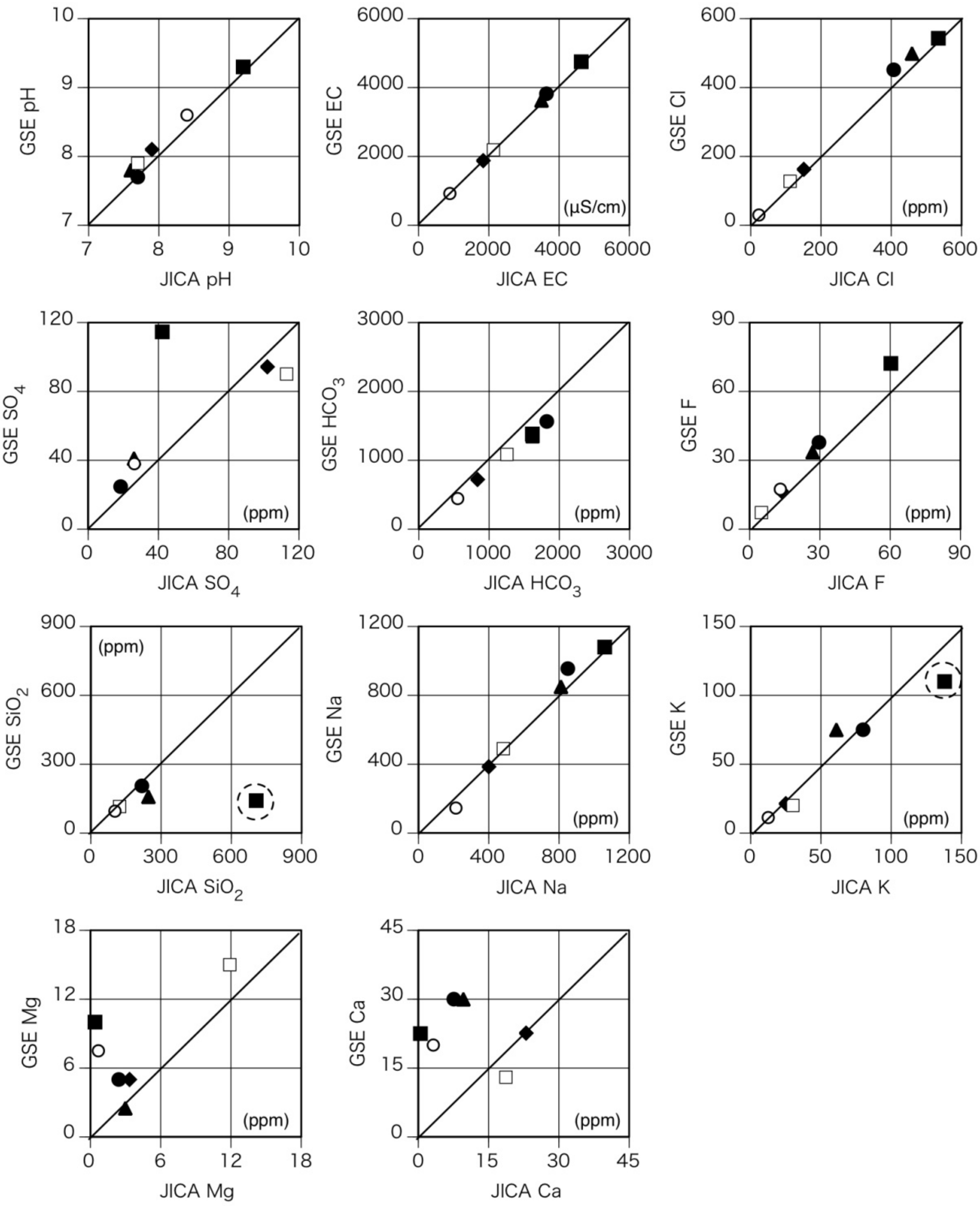


Source: JICA Project Team

Figure 3.4.11 Relationship between $^{3}He/^{4}He$ and $^{4}He/^{20}Ne$ of geothermal gases

(vii) Verification of chemical analysis quality of GSE

In order to verify the precision of chemical analysis at GSE, GSE and the JICA study team analyzed shared water samples, and compared the both results. For a practical comparison of the results, samples were selected from a wide variety of concentration of chemical components. The selected samples were of LA-8, Oiutu #2, Oiutu #84, Shenemaya, Sodere, Gergedi (6 samples). As shown in Figure 3.4.12, the comparison of the results between GSE and the JICA study team are summarized as below.



Source: JICA Project Team

Figure 3.4.12 Comparison of analytical results between GSE and the JICA study team

- Good agreement between GSE and the JICA study team can be seen in the analysis results of pH, EC (electric conductivity), Cl, SO_4, HCO_3, F, Na, and K, except for SO_4 of LA-8, which proves sufficient analytical precision of GSE.
- A large difference is found in a high concentration of SiO_2. A cause for the difference might be a lack of digesting of polymerized silica in the process of analysis at the GSE laboratory. Because SiO_2 concentration is frequently used in geochemical thermometers, improvement of SiO_2 measurement is the highest priority for GSE.

- Although there is no large difference in K concentrations between GSE and the JICA study team, a slight deference can be found in the high concentration of LA-8. Because K is an important component used in geochemical thermometers together with Na, it is preferable for GSE to improve the analytical precision of K in high concentration.
- GSE's analytical precision is insufficient for Ca and Mg. A solution to this problem is use of ICP atomic emission spectroscopy. GSE possesses an ICP spectrometer, but it is not operated. Use of this ICP spectrometer with proper maintenance would lead to a significant improvement in analysis of Ca and Mg. In addition, the ICP spectrometer can analyze many other elements, so that the spectrometer will enhance the capacity of GSE in chemical analysis.

Considering the conditions above, the top priority in the chemical analysis at the GSE laboratory is to achieve sufficient analytical precision for a high concentration of SiO_2 and K. For this reason, in the training course for GSE in Japan, engineers were trained in SiO_2 measurement with spectrophotometry, and Na and K with flame atomic emission spectroscopy. These methods are simple and required apparatus is relatively inexpensive, so that the employment of these methods is effective in capacity building of the GSE laboratory.

3.5 Preliminary Reservoir Assessment

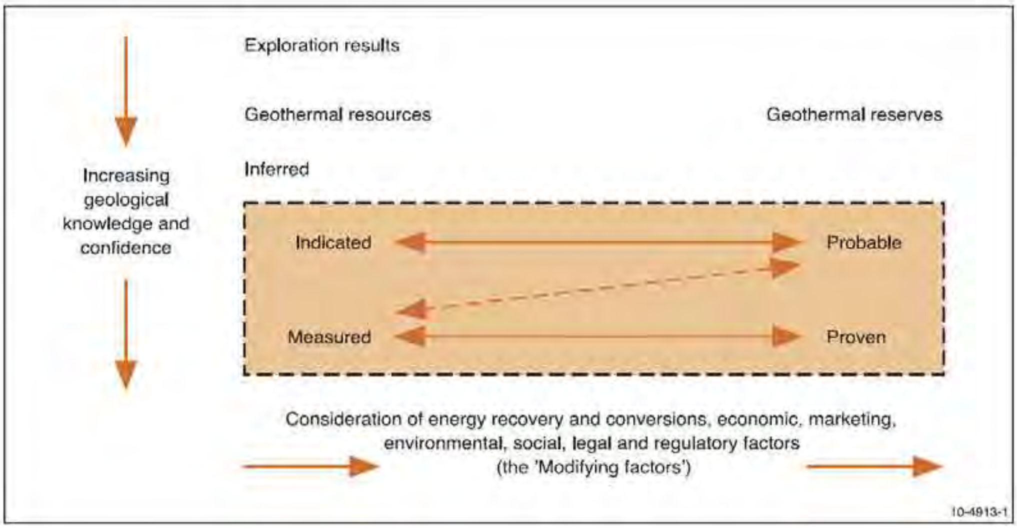
3.5.1 Objectives

The preliminary geothermal reservoir source assessment was conducted to facilitate the results to use as basic information for formulating Master Plan on Geothermal Energy Development.

3.5.2 Definition of Resource and Reserve

For the evaluation of potential in the oil industry, the potential is classified into “resource” and “reserve” in accordance to the project stage and economics. For geothermal projects, there are lots of studies that try to classify “resource” and “reserve” based on a similar concept. However, no universally recognized standards exist for classifying and reporting geothermal “resources” and “reserves”. For this study, the geothermal resource was described according to the definition of Australian Geothermal Energy Group Geothermal Code Committee (AGRCC) in the “Geothermal Lexicon For Resources and Reserves Definition and Reporting Edition 2 (2010)”. This definition is the most distinct for resource evaluation at the early stage among similar studies according to the International Energy Agency (IEA)’s comparative study. The conceptual model of this definition is shown in Figure 3.5.1.

The code recognizes three categories of geothermal “resources”, namely: “inferred”, “indicated”, and “measured”, which represent three different levels of geological knowledge and probability of occurrence. Two categories of “reserves” are recognized (“probable” and “proven”), based upon the likelihood and reliability of the modifying factors and the type of resource. The modifying factors depend on economic, environmental, and political context, and assess the commerciality of the "resources".



Source: AGRCC, 2010

Figure 3.5.1 Relations of Geothermal Sources, and Geothermal Reserves

The Federal Democratic Republic of Ethiopia's Scaling-Up Renewable Energy Program Ethiopia Investment Plan (Draft Final) shows that the planning aspects of geothermal projects consist of: (i) review of existing information on a prospect; (ii) detailed surface exploration (geology, geochemistry, and geophysics); (iii) exploration drilling and well testing (minimum of three wells); (iv) appraisal drilling (4-6 wells) and well testing; (v) feasibility studies; (vi) production drilling, power plant design, environmental impact assessment, and reservoir evaluation; (vii) power station construction and commissioning; and (viii) reservoir management and further development.

The comparison between these eight stages and AGRCC's categories is shown in Table 3.5.1.

Table 3.5.1 Comparison between Eight Stages and AGRCC's Categories

Eight Development Stages in Ethiopia	AGRCC, 2010	
	Resource	**Reserve**
(i) Review of existing information on a prospect (ii) Detailed surface exploration (geology, geochemistry, and geophysics)	Inferred	-
(iii) Exploration drilling and testing (minimum of three wells) (iv) Appraisal drilling and well testing	Indicated	Probable
(v) Feasibility studies (vi) Productive drilling, power plant design, EIA, and reservoir evaluation (vii) Power station construction and commissioning (viii) Reservoir management and further development	Measured	Proven

Source: JICA Project Team

According to the above comparison, the category of the survey sites is classified. There are no boring holes drilled in the geothermal reservoir in the surveyed sites except Aluto and Tendaho. Therefore, the geothermal resources of all other sites are classified under “inferred resources”. For Aluto-1 (Aluto-Langano) and Tendaho-1(Tendaho-Dubti) sites, there are boring holes drilled already that increased geological knowledge and confidence. Therefore, these two sites are classified as “indicated resource” and/or “measured resource”.

3.5.3 Methodology of Reservoir Resource Assessment – Volumetric Method

The Volumetric method is used for the reservoir resource assessment. The method was introduced by USGS (1978) for a rapid assessment. The method assumes the following conditions. 。

- Geothermal heat energy is stored or confined in a reservoir that has a finite volume under the ground;
- The outer limits of the reservoir are defined with parameters obtained by explorations. The outer limits shall be within reachable realm with current or near-future technology;
- The stored heat energy is recovered to the ambient as a form of geothermal fluid. The fluid is recharged from outside of the reservoir;
- The heat is not replenished to the reservoir from outside of the reservoir.
- The reservoir resource assessment is conducted in such a way that the heat energy is constantly recovered for the period of the plant life time; the heat energy will suddenly run out at the end of the plant life time; total recovered heat energy (kJ) is calculated and then converted to the power capacity (MW) of the power plant.
- In this regards however, recovery factor is considered in the calculation since not all the heat energy is recovered to the ambient.

The equations proposed by USGS (1978) are as follows

$$q_r = \rho C V (T_r - T_{ref}) \quad \text{[kJ]} \quad (1)$$

$$R_g = q_{WH} / q_r \quad \text{[-]} \quad (2)$$

$$q_{WH} = m_{WH} (h_{WH} - h_{ref}) \quad \text{[kJ] or [kW]} \quad (3)$$

(for a geothermal reservoir temperature > 150 ºC)

$$W_A = m_{WH} \left[h_{WH} - h_0 - T_0 (s_{WH} - s_0) \right] \quad \text{[kJ/s] or [kW]} \quad (4)$$

$$E = W_A \eta_u / (FL) \quad \text{[kJ/s] or [kW]} \quad (5)$$

q_r	: heat energy of the reservoir	$s_{\_WH}$	: specific entropy of fluid at wellhead
$q_{\_WH}$	: heat energy at well heat	s_0	: specific entropy of fluid at rej ection temperate
T_r	: reservoir temperature	ρC	: volumetric specific heat of the reservoir
T_{ref}	: reference temperature	V	: reservoir volume
T_0	: rejection temperature (Kevin)	R_g	: recovery factor
$m_{\_WH}$	: mass of geothermal fluid at wellhead	W_A	: available energy (exergy energy)
$h_{\_WH}$	: specific enthalpy of fluid at wellhead	E	: plant capacity
h_{ref}	: specific enthalpy of fluid at reference temperature	F	: plant factor (90%)
h_0	: specific enthalpy of fluid at rejection temperature	L	: plant life time (30year)

However, the USGS calculation method has appeared not to be prevailing in references, partially because that the equation (4) includes T_r dependent parameters (h_{WH} and s_{WH}) that render the calculation with probabilistic approach complicated and that the equation (4) shall be the equation (4)' when used with the equation (1), (2) and (3).

$$W_A = m_{WH}\left[\{(h_{WH} - h_{ref}) - h_0\} - T_0\{(s_{WH} - s_{ref}) - s_0\}\right] \quad \text{[kJ] or [kW]} \quad (4)'$$

It is noted that if all the recovered heat at the wellhead is to be cast directly into a flash cycle, then $(h_{WH} - h_{ref}) = h_{WH} \quad (h_{ref} = 0)$ with the condition that the final state of the recovered geothermal fluid is defined at the condenser of the rejection temperature (T_0); since the enthalpy of water is defined as zero at the triple point, i.e. $h_{ref} = 0$, then T_{ref} =0.01 ºC for the equation (1), (2), (3) and (4)'.

Instead, the following equation has been used in many references.

$$E = R_g \eta_c \rho C V (T_r - T_{ref})/(FL) \quad \textbf{[kJ/s] or [kW]} \quad \textbf{(6)}$$

Where η_c is conversion factor.

Unreasonably higher temperatures such as 150 ºC or 180 ºC or others have been used as the reference temperature, though rational reasons have appeared not to be given; the reasons on why and/or the conversion factor is selected have appeared either to be provided. Hence, it appears not to be appropriate to use such equation for the assessment of the reservoirs in Ethiopia.

Instead, the JICA Team herein use a rational and practical calculation method for the assessment of reservoir with temperature not less than 180 ºC shown below. The detailed explanation of this explanation has been provided in a paper attached as Appendix.

$$E = \eta_{ex} \zeta R_g \rho C V (T_r - T_{ref})/(FL) \quad \textbf{[kJ/s] or [kW]} \quad \textbf{(7)}$$

$$\rho C = (1-\varphi) C_r \rho_r + \varphi C_f \rho_f \quad \textbf{[kJ/s] or [kW]} \quad \textbf{(8)}$$

Where η_{ex} is exergy efficiency, ζ is "heat allocation function", φ is porosity of the reservoir rock mass, ρ_r is density of the reservoir rock, C_r is the specific heat of the reservoir rock, ρ_f is density of fluid in the void of the rock mass, and C_f is the specific heat of the fluid in the void of the rock mass, *Tref* =0.01 ºC(triple point).

With the typical conditions that the separator temperature and the condenser temperature are 151.8 ºC and 40 ºC respectively, the heat allocation function ζ is given below.

$$\zeta = 0.0000000127 T_r^3 - 0.0000124900 T_r^2 + 0.0046543806 T_r - 0.4591082158 \quad (9)$$

The exergy efficiency has been calculated for the case of separator temperature = 151.8 ºC and condenser temperature = 40 ºC based on the data of actually operating power plant all over the world. Note that this exergy efficiency is different from that of the utilization factor of the USGS and the conversion factor of the prevailing method.

$$\eta_{ex} = 0.77 \pm 0.05 \quad (9)$$

Recovery factor is as given below.

R_g= 0.05 – 0.20 (10)

Note that this calculation method gives similar results to the ones calculated by the USGS method, thus the validity has been confirmed.

In addition, when reservoir temperature is estimated below 180, binary system is assumed. For this case, the equation (5) was used with the parameters of η_c=0.05-0.08, T_{ref}=80 ºC.

3.5.4 Probabilistic Approach － Monte-Carlo Method

As a probabilistic approach, the Monte Carlo method was used. The soft-weir was the Cristal Ball of Oracle Company. The calculation conditions are given in the table below.

Table 3.5.2 Parameters for reservoir assessment

Parameter	Symbol	Unit	Range			Probabilistic distribution
			Min.	M.L	Max.	
Volume	V	m^3	0	*tbp*	*tbp*	Triangle
Reservoir temperature	T_r	ºC	*tbp*	*tbp*	*tbp*	Triangle
Rock density	ρ_r	kg/m^3	-	2600	-	fixed
Rock volumetric specific heat	C_r	kJ/kg	-	1.0	-	fixed
Fluid volumetric density	ρ_f	kg/m^3	-	950	-	fixed
Fluid specific heat	C_f	kJ/kg	-	5	-	fixed
Porosity	Φ	%	5	-	10	Uniform
Recovery factor	R_g	%	5		20	Uniform
Reference temperature for flash type	T_{ref}	ºC	-	0.02	-	fixed
Rejection temperature (condenser temperature) *	T_0	ºC	-	40	-	fixed
Separator temperature*	-	ºC	-	151.8	-	fixed
Exergy efficiency for flash	η_{ex}	%	72	77	82	Triangle
Reference temperature for binary type	T_{ref}	ºC	-	80	-	fixed
Conversion factor for binary	η_c	%	5	6.5	8	Triangle
Plant factor	F	%	-	90	-	fixed
Plant life	L	year	-	30	-	fixed
Min.: Minimum; Max.: Maximum, M.L.: Most likely; *tbp*: to be proposed; *: given in the heat allocation function						

Source: JICA Project Team

3.5.5 Proposed the parameters

There has not been much information to determine the necessary parameters for the volumetric method. Hereunder described explanations on how the essential parameters have been proposed for future reviews as development states should proceed.

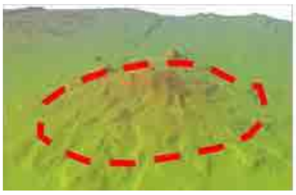
3.5.6 Proposal of the reservoir volumes

In most of the target geothermal sites, surface geological and geochemical surveys only were conducted. Under this circumstance, reservoir volumes were determined with the following procedures. Table 3.5.3 shows a summary of the procedure.

- The target sites were grouped into three categories (i.e. volcano type, caldera type and graben type) based on the satellite image analysis and site survey;

- Maximum plane area of each site was first determined.
- Most likely plane area of each site then was determined with reference to the existing survey information of Aluto-Langano, Tendaho-Dubti and Corbetti, where MT/TEM survey was already conducted;
- The most likely plane area determined above was adjusted to accommodate field conditions in accordance with intensity of geothermal manifestations and/or fractures.
- Minimum plane area is assumed as zero.

Table 3.5.3 Determination of Plane Area of Geothermal Reservoir

	Volcano Type	Caldera Type	Graben Type
Typical Landform			
1) Site	Dallol, Boina, Damali, Meteka (Ayelu and Amoissa), Dofan, Tulu Moye, Aluto (Langano, Finkilo, Bobesa), Abaya, Fantale, Boseti	Gedemsa, Kone, Nazareth, Corbetti	Tendaho-Allalobeda, Tendaho-Ayrobeda, Tendaho-Dubti, Teo, Danab, Meteka, Arabi, Butajira
2) Maximum area of reservoir	Area of volcanic body	Inner area of caldera	Area of geothermal manifestations in graben structure
3) Most likely area	20% of Maximum Area	15% of Maximum Area	100% of Maximum Area (Manifestation Area)
4) Site specific bonus point	+ 20% Alteration Bonus +20% Manifestation Bonus + 20% Fracture Bonus (where observed)	+ 20% Alteration Bonus + 20% Manifestation Bonus + 20% Fracture Bonus (where observed)	+ 20% Alteration Bonus + 20% Manifestation Bonus + 20% Fracture Bonus (where observed)
5) Minimum area	zero	zero	zero
References	MT/TEM Result at Aluto-Langano	MT/TEM Result at Corbetti	MT/TEM Result at Tendaho

Source: JICA Project Team

3.5.7 Determination of Reservoir thickness

The parameters shown in the Table 3.5.4 were assumed.

Table 3.5.4 Determination of Geothermal Reservoir Thickness

Items	Minimum	Maximum	Most Probably	Notes
Depth to Reservoir top (GL-)	0.5 km	1.0 km	0.8 km	Existing information was referred to for "most probably" determination
Depth to Reservoir bottom (GL-)	3.0 km	3.0 km	3.0 km	－A depth economically reachable by the present or near future technology
Reservoir Thickness	**2.5 km**	**2.0 km**	**2.2 km**	－

Source: JICA Project Team

3.5.8 Determination of Average Reservoir Temperatures

The reservoir average temperatures were proposed in Table 3.5.5 based on the geochemical assessment conducted by the Master Plan Project.

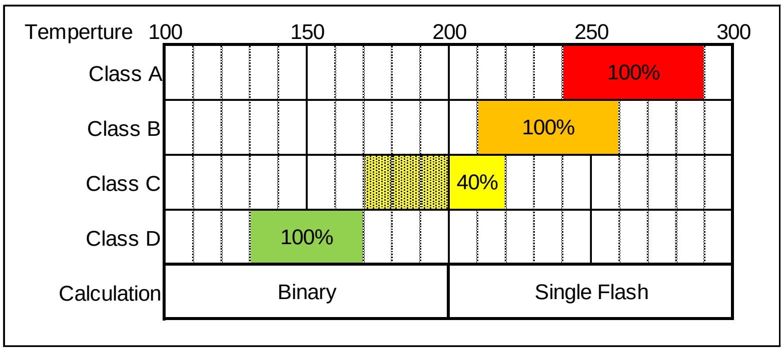
Table 3.5.5 Average Reservoir Temperatures

Class	Min	Max	Most Probably	Remarks
Class A	240	290	265	6 sites (Tendaho and Aluto)
Class B	210	235	260	7 sites (Boseti, Meteka, etc.)
Class C	170	220	195	7 sites (Nazareth, Arabi, etc)
Class D	130	170	150	2 sites (Gedemusa and Kone)

Source: JICA Project Team

3.5.9 Geothermal Power Plant Type Assumed

It was assumed that single flash power plant for average reservoir temperature not less than 200 ºC and binary power plant for average reservoir temperature less than 200 ºC. The Class C geothermal reservoir includes both temperature categories above 200 ºC and below 200 ºC. For such case, a flash type power plant was selected from a practical and economical point of view, by assuming that 40% of the geothermal reservoir would be above 200 ºC. There will be possibilities that double flash type or Flash/binary combined type may be adopted. However, there will not be sufficient information to examine such possibilities at this stage; and possible increment due to those option will be minimal compared to cost impact, thus those examination was not included in this assessment.



Source: JICA Project Team

Figure 3.5.2 Average Reservoir Temperature and Power Plant Type

3.5.10 Results of reservoir assessment

The assessment results are shown in Table 3.5.6.

The assessment resulted that the most likely value (‘mode’ in statistic term) is 4,200 MW, value at occurrence probability 80% is 2,000 MW and the value at occurrence probability is 11,000 MW. There 12 geothermal prospects that may have resources more than 100 MW. It is noted that this calculation results provided the resource estimation of “Inferred level” in principle. However, the total calculation result (91 MW) of Aluto-1 (Langano) will include 70 MW of ‘Indicated Resource’ and 5 MW of ‘Measured Resource’, because 70 MW has been estimated by a numerical simulation and 5 MW is the power output of the pilot plant. Similarly, 10 MW of (Indicated resource) that was estimated by a Pre-feasibility Study (2014) is included in 290 MW of Tendaho-1 (Dubti).

Table 3.5.6 Resource assessment

Unit: MW

Target Site

Site No.		Cumulative probability 80%	Most Probable (mode)	Cumulative probability 20%
19	Corbetti	480	960	2400
16	Abaya	390	790	1900
13	Tulu Moye	202	390	1100
18	Boseti	160	320	800
21	Tendaho-1	140	290	660
4	Damali	120	230	760
7	Meteka	61	130	290
2	Tendaho-3	64	120	320
17	Fantale	64	120	320
14	Aluto-2	58	110	290
22	Tendaho-2	47	100	230
3	Boina	56	100	350
20	Aluto-1	49	91	180
9	Dofan	41	86	200
15	Aluto-3	23	50	110
1	Dallol	23	44	120
12	Gedemsa	20	37	100
11	Nazreth	17	33	100
10	Kone	7	14	42
6	Danab	6	11	30
5	Teo	4	9	23
8	Arabi	4	7	36
New/ Divided Site				
7-2	Meteka-Ayelu	47	53	250
7-1	Meteka-Amoissa	28	89	150
23	Butajira	6	16	30
	Total	**2114**	**4200**	**10791**

Updated After MT/TEM Survey (See Chapter 7)

18	Boseti	175	265	490
22	Tendaho-2	120	180	320

(based on proposed calculation method)

Source: JICA Project Team

As a reference, the calculation results using the prevailing calculation method in Table 3.5.7. The calculation was conducted with ‘conversion factor = 0.13 – 0.16” and ‘Reference temperature=150 ºC’. If the reference temperature should be 180 ºC, the results will be approximately 20% less than those results.

Table 3.5.7 Comparison of the results of the Prevailing method and Proposed method

Site No.		Prevailing method			Proposed/Prevailing		
		Occurrence Probability 80%	Most likely (mode)	Occurrence Probability 20%	Occurrence Probability 80%	Most likely (mode)	Occurrence Probability 20%
19	Corbetti	480	960	2400	1.12	1.08	1.41
16	Abaya	390	790	1900	1.11	1.05	1.46
13	Tulu Moye	201.5	390	1100	1.03	0.93	1.55
18	Boseti	160	320	800	1.23	1.14	1.70
21	Tendaho-1	140	290	660	1.52	1.66	1.35
4	Damali	120	230	760	1.50	1.53	1.77
7	Meteka	60.7	130	290	1.12	1.08	1.45
2	Tendaho-3	63.5	120	320	1.09	1.00	1.39
17	Fantale	63.6	120	320	1.20	1.09	1.60
14	Aluto-2	57.8	110	290	1.18	1.10	1.45
22	Tendaho-2	47.3	100.4	230	1.10	1.06	1.44
3	Boina	55.7	100	350	1.33	1.25	1.59
20	Aluto-1	49.4	91.1	180	1.41	1.32	1.15
7-1	Meteka-Amoissa	27.9	88.9	150	0.65	1.33	1.25
9	Dofan	40.8	86.1	200	1.32	1.35	1.60
7-2	Meteka-Ayelu	46.5	53.4	250	2.21	1.16	3.29
15	Aluto-3	23.1	49.5	110	1.10	1.18	1.17
1	Dallol	22.6	44	120	1.13	1.07	1.48
12	Gedemsa	19.5	36.6	100	1.00	1.00	1.00
11	Nazreth	17.3	32.7	100	1.00	1.00	1.00
23	Butajira	5.7	16.35	30	1.00	1.00	1.00
10	Kone	7.3	13.7	42	1.00	1.00	1.00
6	Danab	5.9	11.4	30.2	1.18	1.04	1.44
5	Teo	4.4	8.6	22.6	1.00	1.08	1.41
8	Arabi	3.8	6.9	36.1	1.27	0.86	1.57
	total	2114.3	4199.65	10790.9	1.17	1.12	1.48

Source: JICA Project Team

Table 3.5.8 Parameters Used for Reservoir Resource Assessment

ρr(kg/m3)	Cr(KJ/Kg℃)	ρf(kg/m3)	Cf(KJ/Kg℃)	φ(%)	Rg(%)	F(%)	L(years)
2600	1	950	5	5〜10	5〜20	0.9	30

Type	No	Site name		Area of Reservoir (km2)										Thickness of Reservoir (km)							Reservoir Temperature		
			Temperature (ABCD)	Inner Dia. (Long: km) Length of major axis (Graben Type:km)	Inner Dia (Short: km) Length of mino axis (Graben Type: km)	Area (km2)	Maximum Area (km2)	Minimum Area (km2)	20% (Volcano), 15% (Caldera) of Maximum	Most Likely Area (km2) Minimum+manifestation, Alteration and Fractures bonus	Manifestation Remarkable: increase %	Alteration Remarkable: increase %	Fracture Remarkable: increase %	Upper Depth (- km from surface) Maximum (= Shallow Case)	Minimum (= Deep Case)	Most Likely	Bottom Depth (- km from surface)	Maximum Thickness (km)	Minimum Thickness (km)	Most Likely Thickness (km)	Maximum (℃)	Minimum (℃)	Most Likely (℃)
Caldera Type	10	Kone	D	6.40	4.80	24.10	24.10	0.00	3.60	9.60	0	0	0.2	0.5	1	0.8	3	2.5	2	2.2	170	130	150
	11	Nazareth	C	6.00	4.80	22.60	22.60	0.00	3.40	9.00	0	0	0.2	0.5	1	0.8	3	2.5	2	0.88	220	170	195
	12	Gedemsa	D	8.80	6.60	45.60	45.60	0.00	6.80	36.50	0.2	0.2	0.2	0.5	1	0.8	3	2.5	2	2.2	170	130	150
	19	Corbetti	B	10.10	15.10	119.80	119.80	0.00	18.00	71.90	0.2	0	0.2	0.5	1	0.8	3	2.5	2	2.2	260	210	235
Volcano type	1	Dallol	B	3.00	2.60	6.10	6.10	0.00	1.20	3.10	0.2	0	0	0.5	1	0.8	3	2.5	2	2.2	260	210	235
	3	Boina	C	11.60	9.20	83.80	83.80	0.00	16.80	25.10	0	0	0	0.5	1	0.8	3	2.5	2	0.88	220	170	195
	4	Damali	C	16.00	14.50	182.20	182.20	0.00	36.40	54.70	0	0	0	0.5	1	0.8	3	2.5	2	0.88	220	170	195
	7-2	Meteka-Ayelu	C	8.80	7.80	53.90	53.90	0.00	10.80	27.00	0	0	0.2	0.5	1	0.8	3	2.5	2	0.88	220	170	195
	7-3	Meteka-Amoissa	C	9.10	8.50	60.70	32.50	0.00	6.50	16.30	0	0	0.2	0.5	1	0.8	3	2.5	2	0.88	220	170	195
	9	Dofan	B	7.50	6.00	35.30	35.30	0.00	7.10	31.80	0.2	0.2	0.2	0.5	1	0.8	3	2.5	2	2.2	260	210	235
	13	Tulu Moye	C	20.00	15.00	235.60	235.60	0.00	47.10	117.80	0	0	0.2	0.5	1	0.8	3	2.5	2	0.88	220	170	195
	14	Aluto-2 (Aluto-Finkilo)	A	4.30	2.72	11.70	11.70	0.00	2.30	5.90	0.2	0	0	0.5	1	0.8	3	2.5	2	2.2	290	240	265
	15	Aluto-3 (Aluto-Bobesa)	A	2.30	1.50	3.45	3.50	0.00	0.70	3.20	0.2	0.2	0.2	0.5	1	0.8	3	2.5	2	2.2	290	240	265
	16	Abaya	B	12.50	12.50	122.70	90.00	0.00	18.00	63.00	0.2	0	0.2	0.5	1	0.8	3	2.5	2	2.2	260	210	235
	17	Fantale	C	11.00	7.30	63.10	63.10	0.00	12.60	44.20	0.2	0	0.2	0.5	1	0.8	3	2.5	2	0.88	220	170	195
	18	Boseti	B	8.40	6.70	44.20	44.20	0.00	8.80	22.10	0	0	0.2	0.5	1	0.8	3	2.5	2	2.2	260	210	235
Graben Type	2	Tendaho-3 (Tendaho-Allalobeda)	A	1.72	0.97	1.30	13.00	0.00	1.30	6.50	0.2	0	0.2	0.5	1	0.8	3	2.5	2	2.2	290	240	265
	5	Teo	B	0.50	0.30	0.12	1.20	0.00	0.12	0.60	0.2	0	0.2	0.5	1	0.8	3	2.5	2	2.2	260	210	235
	6	Danab	B	0.70	0.30	0.16	1.60	0.00	0.16	0.80	0.2	0	0.2	0.5	1	0.8	3	2.5	2	2.2	260	210	235
	7	Meteka	B	2.30	0.80	1.40	14.00	0.00	1.40	9.80	0.2	0.2	0.2	0.5	1	0.8	3	2.5	2	2.2	260	210	235
	8	Arabi	C	1.90	0.60	0.90	9.00	0.00	0.90	0.90	0	0	0	0.5	1	0.8	3	2.5	2	0.88	220	170	195
	21	Tendaho-1 (Tendaho-Dubti)	A	3.00	1.00	2.40	24.00	0.00	2.40	16.80	0.2	0.2	0.2	0.5	1	0.8	3	2.5	2	2.2	290	240	265
	22	Tendaho-2 (Tendaho-Ayrobera)	A	1.30	0.80	0.82	8.20	0.00	0.82	5.70	0.2	0.2	0.2	0.5	1	0.8	3	2.5	2	2.2	290	240	265
	(23)	Butajira	**B**	1.20	0.70	0.66	6.60	0.00	0.66	3.30	0.2	0	0.2	0.5	1	0.8	3	2.5	2	2.2	260	210	235
MT	20	Aluto-1 (Aluto-Langano)	A	2.55	1.18	3.01	6.00	1.05	—	4.80	0.2	0.2	0.2	0.5	1	0.8	3	2.5	2	2.2	290	240	265

Source: JICA Project Team

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CHAPTER 4 ENVIRONMENTAL AND SOCIAL CONSIDERATIONS

4.1 Outline of Environmental and Social Impact Assessment Study

The Environmental and Social Impact Assessment (ESIA) study was conducted to evaluate potential environmental impacts due to the geothermal energy development at Initial Environmental Examination (IEE) level with a comparison of several alternatives. Outline of the ESIA study is as follows.

4.1.1 Tasks of ESIA Study

The ESIA Study consists of the following six main tasks.

(1) Baseline survey (collection and compilation of readily available data and information, and literature review);

(2) Study on alternative plans applying the concept of strategic environment assessment (SEA) for the 16 candidate sites mentioned below;

(3) Scoping of the environmental impacts caused by the Project activities;

(4) Prediction and assessment of natural and socio-environmental impacts caused by the Project in the level of initial environmental examination (pre-IEE);

(5) Mitigation and monitoring plan study; and

(6) Stakeholders' meeting.

4.1.2 Objectives of ESIA Study

The main objectives of the ESIA Study are as follows:

- To collect natural and social environmental baseline information in order to identify and assess the potential impacts caused by the Project.

- To identify and assess potential impacts on the social/natural environment and pollution caused by the Project, and to prepare the management and monitoring plan for necessary actions toward the potential environmental and social impacts as well as to proposed mitigation measures.

The main point of the ESIA Study is to collect and compile the environmental-related data and information in and around the Project sites which enable the JICA Project Team to prioritize the candidate sites for the geothermal plant development.

4.1.3 Area Covered in the ESIA Study

The study area for the ESIA Study shall cover areas affected by the Project including power transmission line where differs by item of environmental and social considerations. The Project includes **sixteen (16) target sites** in total selected by JICA Study Team and GSE from twenty two (22) candidate sites shown in Table 4.1.1.

Table 4.1.1 The Target Sites

No.	Geothermal Sites	Group	Site Survey
1	Dallol	Group-2	GSE
2	Tendaho -3 (Allalobeda)		JICA
3	Boina		GSE
4	Damali (Dam Ali)		GSE
5	Teo		GSE
6	Danab		GSE
7	Meteka		JICA
8	Arabi		GSE
9	Dofan	Group-1	JICA
10	Kone		JICA
11	Nazareth		JICA
12	Gedemsa		JICA
13	Tulu Moya		-
14	Finkilo (Aluto 2)		JICA
15	Bobesa (Aluto 3)		JICA
16	Abaya		-
17	Fantale	Additional	-
18	Boseti		JICA
19	Corbetti		-
20	Aluto-1		-
21	Tendaho-1 (Dubti)		-
22	Tendaho-2 (Ayrobera)		JICA

JICA: The sites where JICA Study Team undertook the site survey.
GSE: The sites where GSE undertook the site survey due to access and/or security issues.

Source: JICA Study Team

Among the above 22 sites, the sites from #01 to #16 are included the RD (11 June 2013), the sites from #18 to #22 are newly included in the Master Plan Formulation project as a result of IC/R meeting held on 14th October 2013 at GSE head office and other follow-up meeting.

4.2 Environmental Laws and Regulations

4.2.1 Framework of environmental and social laws and regulations

Ethiopia adopted its Constitution in 1995, which provides the basic and comprehensive principles and guidelines for environmental protection, and management. The concept of Sustainable Development and Environmental Rights are enshrined in Articles 43[1], 44[2] and 92[3] of the Constitution of FDRE4. Based on the Constitution, several laws and regulations which concern the development of geothermal energy have been enacted. Among these laws and regulations, “Environmental Impact Assessment

[1] Article 43: the Right to development,
[2] Article 44: Environmental Rights,
[3] Article 92: Environmental Objectives

Proclamation no. 299/2002" (EIA Proclamation) and "Environmental Pollution Control Proclamation no. 300/2002" are the most concerned proclamations applicable to the development of geothermal energy. The EIA Proclamation provides EIA with mandatory legal prerequisite for the implementation of major development projects, programs and plans. This proclamation is a proactive tool and a backbone to harmonizing and integrating environmental, economic and social considerations into a decision making process in a manner that promotes sustainable development. The Environmental Pollution Control Proclamation was promulgated with a view to eliminate or, when not possible to mitigate pollution as an undesirable consequence of social and economic development activities. This proclamation is one of the basic legal documents, which need to be observed as corresponding to effective EIA administration.

As for the framework of resettlement and land acquisition issue, the Constitution (1995) provides basic policy on the private asset and its compensation. "Expropriation of Landholding for Public Purposes and Payment of Compensation Proclamation, Proclamation No. 455/2005" and "Payment of Compensation for Property Situated on Landholdings Expropriated for Public Purposes, Council Ministers Regulation No. 135/2007" provide the detail procedure such as expropriation process and compensation standard.

Major Regulations, Guidelines and Proclamations applicable to the geothermal energy development project are listed in Table 4.2.1 below. The contents of listed regulations are summarized in Appendix 4.1.

Table 4.2.1 Major Regulations, Guidelines and Proclamations Applicable to the Geothermal Energy Development Project

No.	Title	No.	Date of Issue
1	Environmental Impact Assessment Proclamation	299	31 Dec, 2002
2	Environmental Pollution Control Proclamation	300	03 Dec, 2002
3	Environmental Protection Organs Establishment Proclamation	295	31 Oct, 2002
4	Expropriation of Landholdings for Public Purposes and Payment of Compensation Proclamation	455	15 Jul, 2005
5	Rural Land Administration and land Use Proclamation, Proclamation	456	15 Jul, 2005
6	Ethiopian Water Resource Management Proclamation	197	Mar, 2000
7	Solid Waste Management Proclamation	513	12 Feb, 2007
8	Environmental Impact Assessment Procedural Guideline Series 1		Nov, 2003
9	Draft EMP for the Identified Sectoral Developments in the Ethiopian Sustainable Development & Poverty Reduction (ESDPRP)		01 May, 2004
10	Investment Proclamation	280	02 Jul, 2002
11	Council of Ministers Regulations on Investment Incentives and Investment Areas Reserved for Domestic Investors	84	07 Feb, 2003
12	The FDRE Proclamation, "Payment of Compensation for Property Situated on Landholdins Expropriated for Public Purposes"	455	2005
13	Council of Ministers Regulation, "Payment of Compensation for Property Situated on Landholdins Expropriated for Public Purposes"	135	2007
14	Oromya Regional Administration Council Directives, "Payment of Compensation for Property Situated on Landholdins Expropriated for Public Purposes"	5	2003
15	Investment (Amendment) Proclamation	373	28 Oct, 2003

(1) Environmental Impact Assessment

1) Laws and regulations relating to EIA in Ethiopia

In order to manage and avoid and/or minimize negative impacts on the natural and social environment with the implementation of various development projects as well as to promote positive impacts, EIA has been developed. Its use has been adopted into planning regulations in a number of countries including Ethiopia. The EIA Proclamation no. 299/2002 aims to ensure that environmental impact assessment is used to predict and manage the environmental effects of development activities resulting from their design, citing, installation and operation. EIA is a law-based procedure, and the EIA Proclamation no. 299/2002 and "Environmental Impact Assessment Procedural Guideline Series 1, November 2003" issued by the EPA have made EIA procedures compulsory[5] to obtain approval for major development projects. According to the EIA Procedural Guideline, projects are categorized into three schedules:

Schedule-1: Projects, which may have adverse and significant environmental impacts and therefore require a full Environmental Impact Assessment.

Schedule-2: Projects whose type, scale or other relevant characteristics have potential to cause some significant environmental impacts but are not likely to warrant a full EIA study.

Schedule-3: Projects which would have no impact and do not require an EIA.

Projects for geothermal power plant fall under the schedule I activities.

Development activities such as geothermal resource development to be designated by directive require, before their implementation, the authorization of the EPA, in case of projects that are licensed by the Federal Government or where they would be likely to have trans-regional environmental impact. Regional environmental agencies have that authority in the case of projects that are licensed at the regional level. The authorization would be based on an Environmental Impact Study (EIS) provided by the project proponent. The EIS is required to meet requirements specified by the EPA directive as to the issues to be addressed. Project owners are required to consult with the communities likely to be affected by the project.

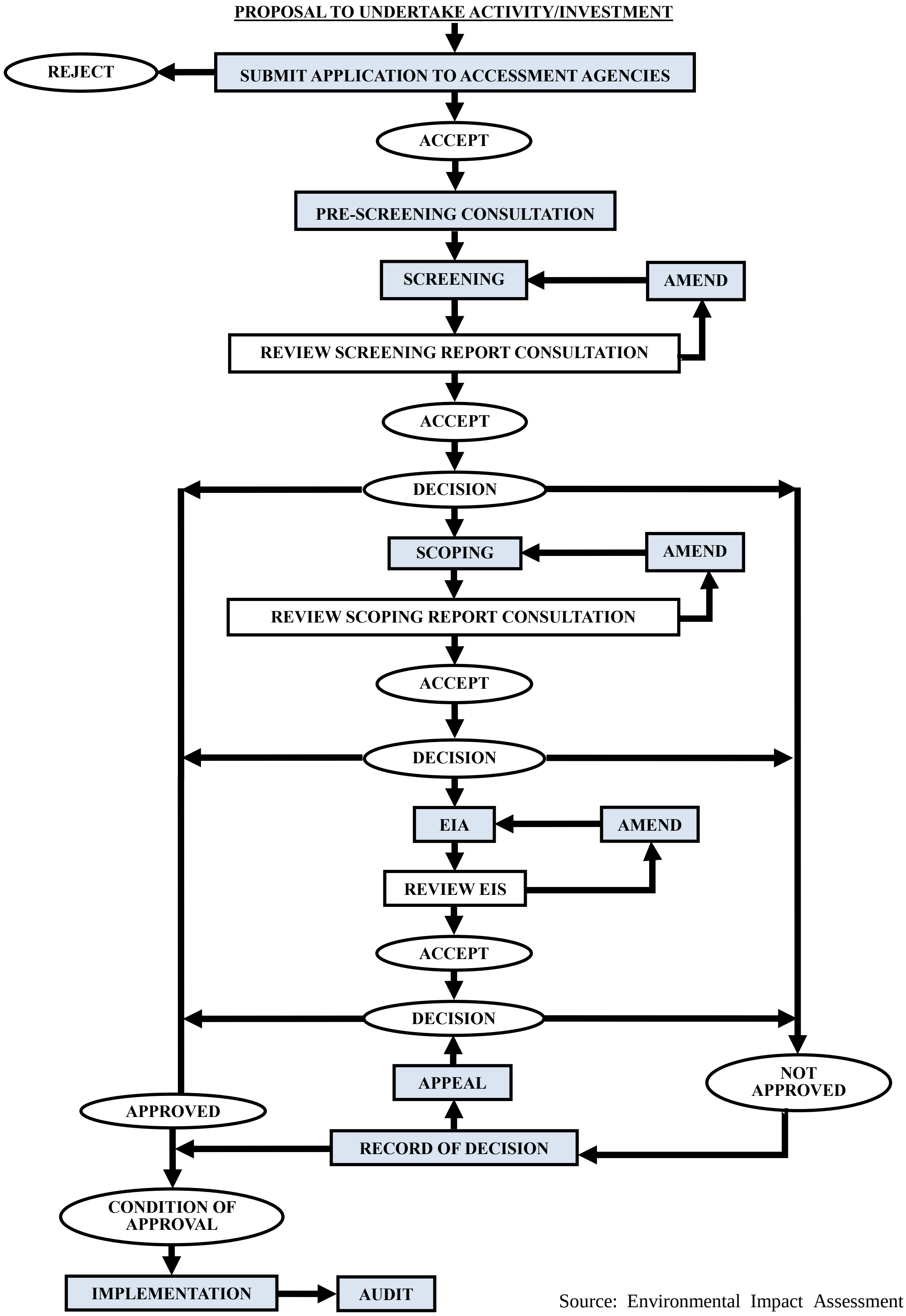
2) EIA Process

The general description of the EIA process and the permit requirements are detailed in the EIA Procedural Guideline Series 1 of the FDRE. As per the Guidelines, it involves sufficient information that enable the determination of whether and under what conditions the project shall proceed. Thus, as a minimum, the following descriptions shall be presented:

5 Appendix 1 of the EIA Procedural Guideline Series 1, Schedule of Activities, prescribes that the thermal water extraction projects which exceed 25 Mega Watt, or geothermal steam capable of generating equivalent power for industrial and other purposes are required full EIA.

- the nature of the project, including the technology and processes to be used and their physical impacts;
- the content and amount of pollutants that will be released during implementation as well as during operation;
- source and amount of energy required for operation;
- characteristics and duration of all the estimated direct or indirect, positive or negative impacts on living things and the physical environment;
- measures proposed to eliminate, minimize, or mitigate negative impacts;
- a contingency plan in case of accidents; and,
- procedures of internal monitoring and auditing during implementation and operation.

Figure 4.2.1 shows the outline of process and procedures of EIA in Ethiopia. Detailed EIA procedural flow is shown in Appendix 4.2.



Source: Environmental Impact Assessment Procedural Guideline Series 1, 2003

Figure 4.2.1 Outline of Process and Procedures of EIA in Ethiopia

(2) Environment related standards and Limit Values

For the preservation of the national environmental quality, the EPA of FDRE set national environmental quality standards for air, water, noise, etc. The EPA also provided industrial pollution control standards in order to manage negative impacts on the environment caused by the industrial and economical projects or programs. But some of these standards remain still in draft form at present. In such cases, International Standards are commonly relied upon. Geothermal energy development projects should follow these standards at the implementation of projects. In case where sector specific standards are not available, then general standards for industrial effluent and for gaseous emission are adopted from other countries such as South Africa or international ones. Table 4.2.2 to Table 4.2.7 below summarize the Ethiopian and the World Bank's standards of Environmental, Health, and Safety Guidelines (EHS) applied to geothermal energy development projects.

Table 4.2.2 Draft Standards for Industrial Emission and Effluent Limits (Ethiopian EPA)

	Parameter	Unit	Draft Standard
Discharge of Wastewater	pH	-	6 – 9
	BOD5 at 20℃	mg/L	25
	COD	mg/L	150
	Total Phosphorous P	mg/L	5
	Suspended solids	mg/L	50
	Mineral oil at the oil trap/interceptor	mg/L	20
Emission of pollutant	Total particulates	mg/Nm3	150
	SO_2	mg/Nm3	1,000
	NO_2	mg/Nm3	2,000

Source: Ethiopia EPA

Table 4.2.3 Draft Standards for Ambient Air Condition (Ethiopian EPA)

Parameter	Average time	Standard (μ g/m3)
SO_2	10 min	500
	24 hr	125
	1 yr	50
NO_2	24 hr	200
	1 yr	40
CO	15 min	100,000
	30 min	60,000
	1 yr	30,000
PM10	24 hr	150
	1 yr	50

Source: Ethiopia EPA

Table 4.2.4 National Noise Standard at Noise Sensitive Areas

Area Category	Limits in dB(A) Leq		Remark
	Day time	Night time	
Industrial	75	70	Day time: from 6 am to 9 pm Night time: from 9 pm to 6 am
Commercial	65	55	
Residential	55	45	

(Note: Noise sensitive areas include domestic dwellings, hospitals, schools, places of worship, or areas of high amenity)

Source: Ethiopia EPA

Table 4.2.5 EHS Guidelines for Emission Gas

Pollutants	Units	Value
Particulate matter	mg/Nm3	30 (a)
Dust	mg/Nm3	50
SO2	mg/Nm3	400
NOx	mg/Nm3	600
HCl	mg/Nm3	10 (b)
Total organic carbon	mg/Nm3	10
Dioxins-Furans	mg TEQ/Nm3	0.1 (b)
Total metals	mg/Nm3	0.5
Notes		
(*) Emissions from the stack unless otherwise noted. Daily average values corrected to 273K, 101.3 kPa, 10 percent O2 and dry gas, unless otherwise noted.		
10 mg/Nm3, if more than 40 percent of resulting heat release comes from hazardous waste.		
if more than 40 percent of resulting heat release comes from hazardous waste average values over the sample period of a minimum of 30 minutes and a maximum of 8 hours.		
(c) Total metals: Arsenic (As), Lead (Pb), Cobalt (Co), Chromium (Cr), Copper (Cu), Manganese (Mn), Nickel (Ni), Vanadium (Vn), and Antimony (Sb)		

Source: EHS Guidelines

Table 4.2.6 EHS Guidelines for Effluent

Pollutants	Units	Value
pH	-	6 – 9
BOD	mg/L	30
COD		125
Total Nitrogen		10
Total Phosphorous		2
Oil and Grease		10
Total suspended solids		50
Total coliform bacteria	MPN/100ml (b)	400 (a)
Notes		
Not applicable to centralized, municipal, waste water treatment systems which are included in guidelines for Water and Sanitation EHS		
MPN: Most Probable Number		

Source: EHS Guidelines

Table 4.2.7 EHS Guidelines for Noise Management

Receptor	Day time	Night time
	07:00 – 22:00	22:00 – 07:00
Residential, institutional, educational (a)	55	45
Industrial, commercial	70	70
(*) Guidelines values are for noise levels measured out of doors. Source: Guidelines for Community Noise, WHO, 1999		
For Acceptable indoor noise level for residential, institutional, and educational settings, WHO, 1999		

Source: EHS Guidelines

(3) Legislation related to the resettlement and land acquisition

Geothermal Power Generation Plant requires construction of the geothermal production well, reinjection well (to return waste hot water to underground), pipeline, geothermal generation facilities such as steam separator, vapor turbine, generator, cooling tower, generating facilities, transformer facilities for transmission into the electrical grid, etc. In order to accommodate those facilities, adequate scales of the land are requires and those may associate with the land acquisition.

Constitution (1995) assure right of private property for citizen but not land ownership. The land is recognized as public common property and its usufruct right can be processed, sold and transferred by citizens. Also, farm land can be used by the citizen freely as long as the person possess the rural land use right. "Federal Democratic Republic of Ethiopia Rural Land Administration and land Use Proclamation, Proclamation No.456/2005" provides the rural land use right. The law also prescribes the governmental responsibility that regional government have obligation to organize adequate legislative administration under the central governmental policy. Hens, related to the farm land, regional governments work for the grant and management of the rural land use right.

Principle of the land acquisition for the public purpose is provided in the constitution (1995) and the detail procedure such as expropriation process and compensation standard are prescribed in "the Expropriation of Landholding for Public Purposes and Payment of Compensation Proclamation, Proclamation No. 455/2005". "Payment of Compensation for Property Situated on Landholdings Expropriated for Public Purposes, Council Ministers Regulation No. 135/2007" also provides further detail standard such as compensation standard for the each expropriating asset.

According to the regulation (2007), land expropriation is implemented by local government, Woreda or Urban administration exclusively for the public purpose and it should be adequately compensated to PAPs. As the principle of the compensation, transferring cost for the asset on the land is compensated for the residential land and 10 times of the annual income which is averaged the incomes in last 5 years is compensated for the farm land. The one of the preferable way, the regulation prescribes that provision of the alternative land which enable to be utilized equal to the previous land.

(4) Gaps between Ethiopian Legislations and JICA Guidelines (2010) Policies on Environmental Assessment

From the above discussions, it can be concluded that the JICA Environmental guidelines and the legislation in the country do not have major contradiction, except perhaps certain procedural adjustments during project implementation such as public consultation and public disclosure. Appendix 4.3 shows the gaps between current relevant regulations in Ethiopia and JICA Guidelines for Environmental and Social Considerations (April, 2010) as well as Safeguard Polices in the World Bank.

4.2.2 Institutional Framework of Environmental Management in FDRE

The Federal Democratic Republic of Ethiopia (FDRE) consists of 2 chartered cities, namely Addis Ababa and Dire Dawa, and 9 regional states. Proclamations 33/1992, 41/1993 and 4/1995 define the duties and responsibilities of the regional states which include planning, directing and developing social and economic development programs as well as protection of natural resources. The most important step in setting up the legal framework for the environmental in Ethiopia has been the establishment of the Environmental Protection Authority (EPA). The EPA, which has been established under the proclamation no. 295/2002, is now a ministerial level environmental regulatory and monitoring body. The objectives of the EPA are to formulate policies, strategies, laws and standards, which promote social and economic development in a manner that enhance the welfare of humans and the safety of the environment sustainably, and to spearhead in ensuring the effectiveness of the process of their implantation. It is, therefore, the responsibility of the EPA in the EIA process to:

- ensure that the proponent complies with requirements of the EIA process;
- maintain co-operation and consultation between the different sectoral agencies throughout the EIA process;
- maintain a close relationship with the proponent and to provide guidance on the process; and
- evaluate and take decisions on the documents that arise from the EIA process.

On the other hand, the regional environmental agencies are responsible for:

- Adopt and interpret federal level EIA policies and systems or requirements in line with their respective local realities;
- Establish a system for EIA of public and private projects, as well as social and economic development policies, strategies, laws, or programs of regional level functions;
- Inform EPA about malpractices that affect the sustainability of the environment regarding EIA and cooperate with EPA in compliant investigations;
- Administer, oversee, and pass major decisions regarding impact assessment of:
    - projects subject to licensing by regional agency;
    - projects subject to execution by a regional agency;
    - projects likely to have regional impacts.

Similar to other developmental projects, the proposed geothermal power plants are subject to several policies and programs aimed at development and environmental protection. The EPA, in cooperation with other related organizations such as Ministry of Mines and Ethiopian Electric Power Corporation (EEPCo), regulates the environmental management system for all projects across the country. Following shows the major institutions or organizations which concern the development of geothermal energy.

- **Regional Government**: All prospective sites are located in three regional governments, namely, Afar, Oromia and Somali regional governments. The Region has Zones and Woredas. Within each Woreda there is many Kebele. Each administrative unit has its own local government elected by the people. Feature of these three regional governments are summarized in Table 4.3.1.

- **The Geological Survey of Ethiopia (GSE)**: The Geological survey of Ethiopia (GSE), under the Ministry of Mines, has the organizational mandate and legislative instruments that empower it to execute geothermal projects to the end of the exploration stage. These include:

    - Surface exploration
    - Exploratory drilling

- Well testing and feasibility studies

- **Ministry of Water and Energy (MoWE)**: The Ministry of Water and Energy is the regulatory body for the energy sector. Based on the delegation from EPA, the whole draft EIA document shall be submitted to the Ministry for comments and recommendations. The Ministry will also certify the implementation of the project and monitor the performance of the development project.

- **Ethiopian Electric Power Corporation (EEPCo)**: The Ethiopian Electric Power Corporation (EEPCo) is a national electricity utility established as a public enterprise by Council of Ministers regulation No. 18/1997. According to the regulation, EEPCo is mandated to engage in the business of power generation, transmission, distribution and selling of electric energy and to carry out any other activities that would enable it to achieve its stated mission.

- **Pastoralist and Agricultural and Rural Development Office of Regional State**: The Ministry of Agriculture and the EPA have delegated their authority to the regional bureau of Pastoralist and Agriculture and Rural Development.

- **Corporate Planning Department of EEPCo**: Corporate Planning of EEPCo comprises environmentalists and sociologists to address environmental and social issues that may arise due to its operation. The project office shall be instituted in this organization with defined roles, responsibilities, and authority to implement the socio-environmentally critical actions such as implementation of EIA, EMP and so on to be undertaken.

4.3 Baseline Survey

4.3.1 Methodology of Baseline survey

Standard methodologies to collect data and information at the prospective geothermal energy development sites were applied to carry out the study that included primary and secondary data reviewing. Additionally, the ESIA study team collected data and information at the prospective geothermal energy development sites using questionnaires, and visiting the governmental and the local organizations which are responsible for environment, social, economic, cultural, and so on located in Oromia, Afar and Somali regions. For the implementation of the study above, following eight kinds of questionnaires were used:

- Questionnaire for Kebele level cultural and ecological related questionnaire
- Kebele level education related questionnaire
- Kebele level health related questionnaire
- Kebele level water resource related questionnaire
- Kebele level water and energy resource related questionnaire
- Questionnaire for household
- Kebele level Economic related Questionnaire
- Questionnaire for Focus Group Discussion (FGD)- Community CONSULTATIONS

The ESIA study team visited the following 7 Woreda sector offices for the collection of baseline data at each site.

- Agriculture /pastoralist office,
- Economic & finance office,
- Education office,
- Health office,
- Culture &tourism office,
- Land use and environment office, and
- Water & energy office

As for surveys at #4 Damali and #05 Teo in Table 4.1.1, the surveys were conducted only through data/information collection and literature review, due to the difficulty of accessibility to these two sites.

4.3.2 Outline of the Baseline data

(1) Profile of the Study Area

Data and information collected through the ESIA study have been summarized in terms of the environmental and the social conditions such as i) natural and geological conditions, ii) socio economic conditions, and iii) accessibility/road, together with notable potential environmental and social impacts when geothermal energy development projects are implemented at 15 prospective sites respectively. Summary table is shown in Appendix 4.4. Major data and information collected are shown below.

The 16 prospective geothermal energy development sites are located either in Afar Depression or Main Rift Valley. Among the 15 prospective sites, 8 geothermal energy development sites are located in Afar Depression and the rest 7 sites are located in the Main Ethiopian Rift Valley.

The three study Regional States, namely the regions of Afar, Oromo, and Somali, more or less share similar features. They border with each other. Oromia borders Afar, Amhara and Benshangul/Gumuz Regions in the north; in the south Oromia borders Kenya; in the south and in the east Oromia borders Somali. In the West, Oromia borders Sudan. On the other hand, Afar borders Eritrea in the north-east, Tigray in the northwest, and Amhara and Oromia in south and south west respectively. Somali Regional state borders Afar Region and Djibouti in the north, Kenya in the south, Oromia Region in the west, and Somalia in the east and in the South.

While the bigger size of Afar Region lies within the Ethiopian Rift Valley, only some parts of Oromia and Somali that lie in the Rift Valley. With respect to population, Oromia Region has the largest figure, roughly 35, 500,000, followed by Somali, roughly 5,850,000 and Afar, roughly 1,830,000, respectively. Profiles of the three regions are summarized in the table below (Table 4.3.1).

Table 4.3.1 Profile of Three Regions

Region	Afar	Oromia	Somali
Location	Mainly at eastern part of Ethiopia	Mainly at the west, south, and	Mainly at the eastern and

Region	Afar	Oromia	Somali
		eastern part of Ethiopia	southeastern of Ethiopia
Topography	Dominantly low land located within Great Rift Valley, dominantly, sandy and rocky.	Varied topography, from low land to high lands varied relief features: rugged mountain ranges, plateaus, gorges and deep incised river valleys, and rolling plain.	Mainly low land, about 80% of the topography is flat and sandy.
Climatic conditions	From 25℃during the rainy season (September-March) to 48℃ during the dry season.	Varied with amiable climatic condition, dry, tropical rainy and temperate rainy climate.	Bigger proportion (85%) is dry and hot, characterized by 20℃ to 40℃.
Area	96,707 km2	284,538 km2	279,252 km2
Population	1,828,504 (up dated for 2014)	35,522,174 (up dated for 2014)	5,849,605 (up dated for 2014)
Religious	More than 90% Muslim	More than 90% are proportionally Muslim and Christians	More than 90% Muslim
Language	Dominantly Afar but Amharic is widely spoken	Dominantly Oromo language but Amharic is widely spoken	Dominantly Somali but Oromo and Amhara language are widely spoken.
Administration	5 administrative zones and about 30 woredas	12 zones administrative and about 180 woredas	9 administrative zones and more than 45 woredas
Capital city	Semera	Addis Ababa, defacto Adama (Nazareth)	Jigjiga
Livelihood	Mainly cattle rearing/pastoralists	Mainly farming	Mainly cattle rearing/pastoralists
Agri products	Maize, beans, sorghum, papaya, banana, and orange	Maize, teff, wheat, barley, peas, bean, oil seed, coffee	Mainly sorghum and maize, and some wheat harvested
Animals	22% of camel, 4% of goats, 2% of sheep, and 1% of cattle	45.4% of cattle, 40% of goats, 38% of sheep, 12% of asses, 31% of camels	2% of cattle, 3% of sheep, 6% of goats, 4% of asses and 37% of camels
National Attractions	Afar Depression-Ertale, Awash and Yangudi Rassal National Parks, Human fossil sites such as Hadar and Ramis	National Parks Bale mountains, the Rift Valley lakes, caves like Sof-Omar and a number of hot springs are located	As part of the great Rift Valley hot springs are located in some parts
Minerals	Major minerals include: salt, potash, sulfur, manganese, bentonite, aluminium, marble, gypsum	Gold, soda ash, platinum, limestone, gypsum, clay soil, tantalum, and ceramic	Natural gum, salt, and gas oil

Data source: CSA and other relevant documents

(2) Natural, Historical and Cultural Heritages

In general, there are no natural and historical points found near or around all of the proposed sites. However, the views the community to the hot springs (in Teo/Kone, Meteka, Boku, and Arabi), the claims of Orthodox Church (in Boku), and the location of the Orthodox Church (in Meteka) needs special consideration. The detail is shown in Table 4.3.2.

Table 4.3.2 Natural, Historical and Cultural Heritages

Site	Status of Heritage	Socio-economic uses
Allelobeda	No heritage is located	-Few un identified stone tombs is observed within the site which requires further study
Dallol	No heritage is located	-Traditional salt near the site and modern potash mining around it widely exploited
Damal	-	-
Danab	-	-
Erebti	No heritage is located	-
Tone/Kone	No heritage is located	-People take bath in the hot spring, thus fewer local people use it for healing purpose
Meteka	An Orthodox Church is built close to the site	-Local people including residents of Gewane town widely use the hot spring for bathing, and washing cloth and cars.
Bobesa/Aluto 2/3	No heritage is located	-
Gedemsa	No heritage is located	-
Nazreth/Boku	Two of the springs are already claimed by Orthodox church	- The hot spring believed to heal and therefore lots of sick people from different regions take bath
Arabi	No heritage is located	The hot spring believed to heal and therefore sick people from different regions take bath
Source of data: Data source: Filed assField Asessement		

Source: ESIA Study Report

(3) Ecological Protected Area

All legally protected areas such as national park, wildlife reserve and controlled hunting areas are avoided from the prioritized project sites in the study at the Master Plan establishment stage. The project contains 15 project sites located in the 3 regions i.e.; Afar, Somali and Oromia regions. The environmentally important area in Ethiopia is protected as National Parks, Wildlife Reserves and Controlled Hunting Areas and the areas fallen into the project related 3 regions are shown in the below table(Table 4.3.3). With the progress of the project stage, further confirmation should be conducted to minimized impact to those areas.

Table 4.3.3 Distribution of sensitive environmental features surrounding the project

National Parks			
Site	**Managed by**	**Established**	**Area in ha**
AbijataShala Lakes	Oromia	1963	88,700
Awash	Oromia & Afar	1958	75,600
Geralle	Somali	1998	385,800
YangudiRassa	Afar	1969	473,100
Wildlife Reserves			
Alledeghi	Afar		193,389
Awash west	Afar		415,000
Gewane	Afar		-
Mille Serdo	Afar		650,354
Controlled Hunting Areas			
Aluto	Oromia		28,000
Bilen Hertalie	Afar		109,000
MelkeSadi	Afar		-
TelalkDewe	Afar		72,000

(Data source: Different Publications)

Source: ESIA Study Report

(4) Possible Impacts by Transmission Line

The Project includes the construction of high voltage Power transmission lines. High voltage Power transmission lines may have an impact on the visual capacities of birds and may result in collisions depending on sites of installation. Because of the exact routes where the transmission lines are going to be developed are not yet determined, it is not possible to envisage the degree of the impacts caused by the installation of the transmission lines on migratory birds. Although the prospective geothermal development sites in this study are not included in National Parks or Conservation Areas of Ethiopia, there exist a few National Parks near some prospective sites. The ESIA study revealed that the two National Parks vicinity to some prospective sites located on important migration flyways. One is Yangudi Rassa National Park which is in the center of the Afar Region (in northern section of the Rift Valley) between the towns of Gewanae and Mille, and 500km from Addis Ababa. Yangudi Mountain lies on its south-eastern boundary, and is surrounded by the Rassa plains. Many migratory species have been found in this area including *Falco naumanni* and *Circus macrourus*, both of which are recorded regularly on migration during winter season. Another National Park which locates on a migratory flyway is Abijata-Shalla Park in Oromia Region which was established combining Lakes Abijata and Shalla. It has several hot springs around the shore, and nine islands of which at least four are important breeding sites for birds. This Park locates on a major flyway for both Palearctic and African migrants, particularly raptors, flamingos and other water birds. Detailed migratory flyways should be investigated in the EIA study for the determination of the routes of high voltage transmission lines in order to avoid or minimize the impacts on migratory birds.

4.4 Strategic Environmental Assessment (SEA)

Strategic environmental assessment (SEA) is a systematic decision support process, aiming to ensure that environmental and possibly other sustainability aspects are considered effectively in policy, plan and program making. Therefore, an SEA is conducted before a corresponding EIA is undertaken. This means that SEA focuses mainly policy level issues before implementing certain projects or programs.

Although implementation of SEA for development projects is not compulsory at present in Ethiopia, considering the definition and the concept of SEA mentioned above, SEA for geothermal energy projects should be discussed the following point of views.

- Ethiopian energy policy on geothermal development,
- Project alternatives including “do-nothing” option
- Project perspective from guidelines of financial institutions,
- Alignment of JICA guidelines with national policies

4.4.1 Ethiopian energy policy on geothermal development

(1) Conservation Strategy of Ethiopia (CSE)

Since the early 1990s, the Federal Government has undertaken a number of initiatives to develop regional, national and sector strategies for environmental conservation and protection based on the Conservation Strategy of Ethiopia (CSE) approved by the Council of Ministers. The CSE provided a strategic framework for integrating environmental planning into new and existing policies, programs and projects. The CSE also provides a comprehensive and rational approach to environmental management in a very broad sense, covering national and regional strategies, sectoral and cross sectoral strategy, action plans and programs, as well as providing the basis for development of appropriate institutional and legal frame works for implementation.

(2) Environmental Policy of Ethiopia (EPE)

The Environmental Policy (EPE) of the FDRE was approved by the Council of Ministers in April 1997based on the CSE. It is fully integrated and compatible with the overall long term economic development strategy of the country, known as Agricultural Development Led Industrialization (ADLI), and other key national policies. EPE's overall policy goals may be summarized in terms of the improvement and enhancement of the health and quality of life of all Ethiopians and the promotion of sustainable social and economic development through the adoption of sound environmental management principles. Specific policy objectives and key guiding principles are set out clearly in the EPE, and expand on various aspects of the overall goal. The policy contains sector and cross-sector policies and also has provisions required for the appropriate implementation of the policy itself.

(3) National Energy Development Policy

The National Energy Policy of 1994 has the objective of facilitating the development of energy resources for economical supply of energy to consumers in an appropriate form and in the required quantity and quality. The strategies consist of the accelerated development of indigenous energy resources and the promotion of private investment in the production and supply of energy.

According to the National Energy Development Policy, the main priorities of current energy policy in Ethiopia are:

- Equitable development of the energy sector together with other social and economic developments.
- Development of indigenous resources with minimum environmental impact and equitably distribution of electricity in all the regions.

4.4.2 Energy Resource Alternatives

The Ethiopian Government has embarked upon various plans and programs to explore and develop different energy resources (i.e., hydropower, geothermal, wind and solar) to achieve the major goals of accelerating economic growth and reducing poverty. Development of geothermal energy exerts both positive and negative impacts on the natural and the social environment. There is no combustion process with geothermal energy plant, geothermal energy is generally accepted as being an environmentally kind and gentle energy source comparing to fossil fuel energy source. Considering the characteristic of geothermal energy source, geothermal energy source also has several advantages even compared to other renewable energy sources. Table 4.4.1 and Table 4.4.2 below show the characteristics and the advantages of geothermal energy compared to other energy sources.

Table 4.4.1 Environmental Characteristics of Geothermal Energy

	Geothermal energy	Other renewable energy
Availability/reliability	Most reliably available Not rely on uncontrollable outside forces	Such as solar or wind, are only available when the weather cooperates.
Natural condition	Less constrained by natural topography for selection of site	Required to meet specific natural condition (effective wind or solar farm)
Land claim	Not require as much land to produce equivalent power as do other clean energies.	Roughly 10 times of amount of land is needed for a solar farm to produce the same amount of energy
Cleanness/Cost effectiveness	Cleaner, more efficient, and more cost-effective than burning fossil fuels	Burning fossil fuels generate dust, NOx, SOx and other noxious substances
Emission of CO_2 and others	Geothermal plant releases a less amount of CO_2 produced by fossil fuel plant	Fossil fuel plants produce more amount of CO_2

Source: JICA Study Team

Table 4.4.2 Advantages of Geothermal Energy Compared to other Renewable Energy Sources

Characteristics	Geothermal	Wind	Solar	Biomass	Hydro
Base lord capacity	◎	×	×	◎	◎
Unlimited potential	◎	◎	◎	×	×
No fuel costs	◎	◎	◎	×	◎
Negligible CO_2 emission	◎	◎	◎	×	
Low impact landscape	◎	×	×	◎	×
Competitive costs	◎	◎	×	◎	◎
Capacity factor (%)	89-97	26-40	22.5-32.2	80	-
Exploration risk	**?**	◎	◎	◎	◎

Source: Ultra-deep-geothermal/energy,A Guide to Geothermal Energy and Environment, Geothermal Energy Association, USA 2007)

Above tables show that geothermal energy is a renewable and environmentally friendly energy generation option, compared to other energy sources particularly compared with fossil fuel.

Besides the advantages of geothermal energy source above, there are several positive impacts on the social environment. Main positive impacts of geothermal energy development are: stimulation of economic growth of the country, improvement of the living standard of the population, benefits to the local people (temporary employment opportunity) and local economy development. The proposed geothermal energy development would encourage investors to invest in the region, ultimately creating more job opportunities. The proposed project will also allow the reduction of carbon dioxide emissions from electricity generation using renewable geothermal energy instead of other fossil fuel burning power generation. This suggests that the application of Clean Development Mechanism (CDM) to the projects.

4.4.3 Project Alternatives

One of the main objectives of SEA is to analyze the alternatives of the proposed project including “do-nothing” option. To overcome the growing demand, planning for energy diversification is very important. Therefore, the formulation of geothermal energy development by this study is an important step to diversify electricity generation which will enable to backup the other energy sources. The impact caused the implementation of the project on the environment and social is localized and can be minimized by applying proper mitigation and management measures.

Considering the features of geothermal energy development, possible alternatives at SEA stage could be:

- a "do-nothing" option of the project to consider the environmental conditions in the absence of the project (without project),
- drilling the wells at different depths, to exploit different reservoirs (with project)

Table 4.4.3 below summarizes the advantage and the disadvantage two alternatives above.

Table 4.4.3 Comparison of Alternative

	Alternatives			Advantage	Disadvantage
1	Without project	Do-nothing		No additional environmental impacts related to the project	No social and socio-economic benefits to the country. Worsening of the deforestation problem. No promotion educational, commercial and industrial development.
2	With project	Drilling wells at different depth	Drilling and exploiting wells only from the deep reservoir	Less or no subsidence risks	More expensive, longer solution
			Drilling and exploiting wells only from the shallow reservoir	Cheaper and faster solution	Subsidence risks
		Drilling wells in different location	Drilling in the sites prioritized in this study (Tendaho, Ayrobera)	Higher environmental appropriateness (See Appendix 4.4)	Dispossession of grazing land, water use competition, etc. (See Appendix 4.4)
			Drilling in the sites other than above sites	No residential areas (See Appendix 4.4)	Bad accessibility, etc. (See Appendix 4.4)

Source: Tendaho Geothermal Development F/S Report, 2013, Italy

The “no project option” implies that the power plant will not be established at the project site and the site would continue to remain as it were. No socio-economic benefits would accrue either to the nearby communities or to the country at large. Choosing the “no project option” therefore will mean loss of benefit to the nation, what is more, no new employment opportunities would be created.

Selecting the depth / location of wells is very critical for the feasibility of a project. Therefore, proper and comprehensive analysis of location and site selection shall be carried out utilizing different factors and criteria.

4.5 Implementation of IEE

An Initial Environmental Examination (IEE) is carried out based on the baseline data and information, namely readily available information including existing data and simple field surveys.

4.5.1 Project Categorization

(1) General

According to the JICA Environmental Guidelines (April 2010), projects are classified into four categories depending on the extent of environmental and social impacts, taking into account an outline of project, scale, site condition, etc. Table below shows the comparison of projects categorization defined by JICA and Ethiopian national EPA Guideline.

Table 4.5.1 Environmental Categorization of Projects

Project type	JICA Guidelines	Ethiopia EPA Guideline	EIA requirement
Likely to have significant adverse impacts on the environment and society. Projects with complicated or unprecedented impacts that are difficult to assess, or projects with a wide range of impacts or irreversible impacts	Category A	Schedule-1	Full EIA
Have potential adverse impacts on the environment and society are less adverse than those of Category A projects. Generally, they are site-specific; few if any are irreversible; and in most cases, normal mitigation measures can be designed more read	Category B	Schedle-2	Not likely to warrant a full EIA study
Have are likely to have minimal or little adverse impact on the environment and society.	Category C	Schedule-3	Environmental review will not proceed after categorization
Projects which satisfy the following JICA's requirements: projects of JICA's funding to a financial intermediary or executing agency; the selection and appraisal of the sub-projects is substantially undertaken by such an institution only after JICA's approval of the funding, so that the sub-projects cannot be specified prior to JICA's approval of funding (or project appraisal); and those sub-projects are expected to have a potential impact on the environment.	Category FI	-	Environmental review will proceed after categorization

Source: JICA Study Team

(2) Classification of geothermal energy development project

Appendix I (Schedule of Activities) of the Environmental Impact Assessment Guideline Document (May 2000) classifies projects by their type of activities as follows:

APPENDIX 1: SCHEDULE OF ACTIVITIES
(In order of level)

Schedule 1: Project which may have adverse and significant environmental impacts, and may, therefore, require full EIA.

⇩

C. Production Sector

⇩

11. Minerals extraction and processing (Large scale Mining Operation, Which the annual run of mine ore exceed:)

⇩

f. Thermal Water
(25 Mega Watt, or geothermal steam capable of generating equivalent power for industrial and other purposes)

Source: Environmental Impact Assessment Guideline Document, May 2000

Based on the project classification above, geothermal energy development projects which have capacities more than 25 mega watt may be required the implementation of full scale EIA.

4.5.2 Scoping for Initial Environmental Examination

Geothermal energy is generally more environmentally sound compare to other energy sources such as fossil fuel burnings, there are certain negative impacts that must be considered and managed when geothermal energy is to be developed. Following table summarizes the considerable negative impacts when geothermal energy is developed.

In order to assess likely significant environmental and social impacts, the conceivable adverse environmental and social impacts by the Project were initially indentified based on the project description and overall environmental and social conditions in the surrounding area. The impacts of pollution, natural environment, and social environment were classified from A to D as shown in Table 4.5.2. Most of potentially important impacts of geothermal power plant development are associated with groundwater use and contamination, and with related concerns about land subsidence and induced seismicity as a result of water injection and production into and out of a fractured reservoir formation. Some considerations should also be taken for issues of air pollution, noise, safety, and land use. Overall environmental Scoping Checklist is shown in Appendix 4.4).

Table 4.5.2 Environmental Scoping Checklist for the Project for Formulating Master Plan on Development of Geothermal Energy in Ethiopia project

No	Likely Impacts	Reason and Description	Rating
Social Environment			
1	Involuntary resettlement	**Planning phase:** Land for geothermal plant is required. There are residents in the prospect site area and the impact should be minimized to avoid resettlements and land area. The approximate number of land owner for the prospect sites are 50 persons in total. Detail study should be conducted.	C-
2	Living and Livelihood	**Construction phase:** Surface disturbance of wilderness has high impact as active sites tend to be in rare landscape types of very high scenic and touristic (economic) value including 'colorful striking landscapes, hot springs, lavas and glaciers. Disturbance includes roads, power lines, factories, heavy lorries and drilling equipment.	B-
		Construction phase & Operation phase: Job opportunities for the surrounding area for project sites are increased.	B+
3	Land use and utilization of local resources	**Planning phase & Construction phase:** The project areas are used mainly as farmland and grazing land, with dispersedly located houses, while few of them (Erabti, Dallol, Derail and Teo) are nearly uninhabited. Meteka, Bobessa, Finkilo, and Dofan sites are populated; particularly Meteka is densely settled by town residents. The rest sites Arabi, Tone, Allelobeda, Boset, Gedemsa and Boku are dominantly used either for cultivation or grazing. One special scenario is the case of Bobessa and Finkilo (Alluto 2 and 3). Here, the site is in adjacent to geothermal power facility which has been under construction by Ethiopian Energy and Power Corporation (EEPC) for the last few years.	B-
		Operation phase: The effective land use is expected in the area.	B+
4	The poor, indigenous and ethnic people	No particular indigenous people and ethnic people are identified in the area at the moment.	D
5	Local conflicts of interests	No particular impact is envisaged at the moment.	D
6	Water usage or water rights and rights of common	**Planning phase, Construction phase and Operation phase:** The project may be associated with the well drillings such as testing, geothermal production and reinjection wells. Also, construction and operation of power generation plant may require freshwater. The impact should be minimized based on the study at the detail design stage.	C-
7	Hazards(Risks) (infectious disease such as HIV/AIDS)	No particular impact is envisaged at the moment.	D
8	Working Conditions	No particular impact is envisaged at the moment.	D
9	Disaster	No particular impact is envisaged at the moment.	D
Natural Environment			
10	Topography and geographic features	**Construction phase:** Surface disturbance of wilderness has high impact as active sites tend to be in rare landscape types of very high scenic and toursitic (economic) value including 'colourful striking landscapes, hot springs, lavas and glaciers. Disturbance includes roads, power lines, factories, heavy lorries and drilling equipment.	B-
11	Land subsidence	**Operation phase:** Subsidence, or the slow, downward sinking of land, may be linked to geothermal reservoir pressure decline. Injection technology, employed at all geothermal sites in the United States, is an effective mitigating technique.	B-
12	Climate	**Operation phase:** Local weather changes caused by emission of steam affecting clouds.	B-
13	Soil erosion	**Construction phase:** Landslides can occur due to temperature and water level in rocks, especially in tectonically active areas.	B-
14	Wetlands, rivers and lakes	Planning phase, Construction phase, Operation phase: Some project sites such as Meteka and Kone are located closely to wetland. Some impact may be associated with the project.	B-
15	Fauna and flora and biodiversity	**Planning phase and Construction phase:** The protected areas are basically avoided for the site selection. For detail survey should be conducted at the implementation of full EIA study (ESIA). Before geothermal construction can begin, an environmental review may be required to categorize potential effects upon plants and animals. Power plants are designed to minimize the potential effect upon wildlife and vegetation, and they are constructed in accordance with a host of state and federal regulations that protect areas set for development.	B-
16	Landscape	**Construction phase:** Surface disturbance of wilderness has high impact as active sites tend to be in rare landscape types of very high scenic and touristic (economic) value including 'colorful striking landscapes, hot springs, lavas and glaciers. Disturbance includes roads, power lines, factories, heavy lorries and drilling equipment.	B-
17	Ground water	**Planning phase, Construction phase and Operation phase:** The project may be associated with the well drillings such as testing, geothermal production and reinjection wells. Also, construction and operation of power generation plant may require freshwater. The impact should be minimized based on the study at the detail design stage.	C-
Pollution			
18	Air pollution	**Construction phase:** Due to construction work in the city area, air quality is likely affected due to congestion of traffic and other construction machinery. Geothermal power plants release very few air emissions because they do not burn fuel like	B-

No	Likely Impacts	Reason and Description	Rating
		fossil fuel plants. Geothermal plants emit only trace amounts of nitrogen oxides, almost no sulfur dioxide or particulate matter, and small amounts of carbon dioxide. The primary pollutant some geothermal plants must sometimes abate is hydrogen sulfide, which is naturally present in many subsurface geothermal reservoirs. With the use of advanced abatement equipment, however, emissions of hydrogen sulfide are regularly maintained below Ethiopian standards. Emissions of H2S –distinguished by its "rotten egg" odor and detectable at 30 parts per billion – are strictly regulated to avoid adverse impacts on plant and human life.	
19	Water contamination (Water use & Water contamination)	**Planning Phase, Construction Phase and Operation Phase:** Liquid streams from well drilling, stimulation, and production may contain a variety of dissolved minerals, especially for high-temperature reservoirs (>230°C) which may not be the case at most of the geothermal prospect areas in Ethiopia. Some of these dissolved minerals (e.g., boron and arsenic) could poison surface or ground waters and also harm local vegetation only in some locations. Liquid streams may enter the environment through surface runoff or through breaks in the well casing. Surface runoff can be controlled by directing fluids to impermeable holding ponds and by injection of all waste streams deep underground. It is important to monitor wells during drilling and subsequent operation, so that any leakage through casing failures can be rapidly detected and managed. Toxic waste water may enter clean aquifers due to lowering of the water table.	B-
20	Wastes	**Planning Phase, Construction phase and Operation phase:** At the detail survey and construction, sludge from the drilling work may be generated. Also, construction waste and general waste at the operation may be generated even those amount are not large. Adequate treatment should be conducted following the standard.	C-
21	Noise and vibration	**Planning Phase (Well drilling and testing phase):** Generally noise generation in this phase does not exceed the Ethiopian noise regulations. Much like the construction phase of development mentioned below, well-drilling and testing are temporary, and the noise pollution they produce is not permanent. It is estimated that well drilling operations would not exceed 54 dBA. However, unlike the construction phase of development, well-drilling operations typically take place 24 hours per day, seven days a week. This temporary noise pollution can last anywhere from 45 to 90 days per well. **Construction phase (Noisiest phase):** Noise may be generated from construction of the well pads, transmission towers, and power plant. The noisiest phase of geothermal development, but the past experiences show generally remains below 65 dBA. Noise pollution associated with the construction phase of geothermal development is a temporary impact that ends when construction ends. Well pad construction can take from a few weeks or months to a few years, depending upon the depth of the well. In addition, construction noise pollution is generally only an issue during the daytime hours and is not a concern at night. **Operation phase:** Noise from normal power plant operation generally comes from the three components of the power plant: the cooling tower, the transformer, and the turbine-generator building. It is estimated, noise from normal power plant operation at the site boundary would occupy a range of 15 to 28 dBA—below the level of a whisper Several noise muffling techniques and equipment are available for geothermal facilities. During drilling, temporary noise shields can be constructed around portions of drilling rigs. Noise controls can also be used on standard construction equipment, impact tools can be shielded, and exhaust muffling equipment can be installed where appropriate.	B-
22	Odor	**Planning phase, Construction phase and Operation phase:** Even temporary, emission of hydrogen sulfide (H2S) may associate with the Geothermal production test at detail survey and construction. At the operation, also hydrogen sulfide (H2S) may be discharged. The impact should be minimized based on the study at the detail design stage.	C-
23	Accidents	**Construction phase and Operation phase:** There was an example that violent explosions caused by buildup of a 'steam pillow' in empty hot underground reservoirs, which have previously killed people working in geothermal plants. While earthquake activity, or seismicity, is a natural phenomenon, geothermal production and injection operations have at times resulted in low-magnitude events known as ―micro earthquakes.‖ These events typically cannot be detected by humans, and are often monitored voluntarily by geothermal companies.	B-

Source: JICA Study Team

<Rating>

A-: Serious impact is expected, if any measure is not implemented to the impact.

B-: Some impact is expected, if any measure is not implemented to the impact.

C-: Extent of impact is unknown (Examination is needed. Impact may become clear as study progresses.)

D : No impact is expected.

A+: Remarkable effect is expected due to the project implementation itself and environmental improvement caused by the project.

B+: Some effect is expected due to the project implementation itself and environmental improvement caused by the project.

4.5.3 Socio-environmental Interactions

In order to grasp the livelihood conditions in and around the prospective sites, questionnaire surveys for energy and water sector offices at woreda levels were conducted. In this questionnaire surveys, interviewee were professionals, experts and guidelines about the proposed geothermal projects and related issues.

With respect to energy, in few households kerosene lamps and solar cells are becoming to be used particularly in health posts and schools. However, the survey revealed that the main source of energy both for cooking and light was fuel wood, coal and dung. The impact of wide use of wood and coal would be not significant as the number of rural community is few and scattered, compared to the available resource and its regenerative capacity. In addition to this, energy consumption per capita of the community is very low. Social impacts such as unnecessary time and labor wastage should also be addressed.

With regard to water source and supply, in most of the surveyed sites except Tendaho-3 (Alallobeda), Arabi, Dofan, Meteka, and Kone, there is critical shortage of sufficient and uninterrupted water supply. But in all other sites, access to potable (treated) water is still a priority. Water resource competition from currently growing (expanding) sugar industries is pessimistically perceived by the community. In addition to this, some individual investors use water from hot springs/when available for irrigation. So there seemed water resource competition and fast land use change in some of the surveyed areas.

Respondents were asked about the negative impact of the project on water in terms of pollution, water supply/ system; the possible competition of the project for the existing water resources; and options to reduce or avoid the impacts. The finding revealed that the community believed the project would bring about little negative impact. However in terms of the serious shortage of water all community in all sites required the supply of water at least in their respective kebeles. Thus there is a strong need of residents to implement community projects to access potable water source (characterized by community participation in collaboration with other development organizations), parallel to the main geothermal project.

Table 4.5.3 below summarizes the conditions of the livelihood in fifteen (15) prospective sites.

Table 4.5.3 Livelihood at the prospective sites

No.	Site	Livelihood
1	Dallol	Wage and revenue earned from salt mining and transporting the commodity is the back bone of the livelihood of the community of Amed-ale. And yet since what is earned doesn’t cover households’ living expense, large proportions of them are under food relief program.
2	Tendaho-3 (Allalobeda)	The community is totally dependent on subsistence livestock. Thus food security in the woreda is seriously threatened. Thus since there is no farming practiced across the kebele, the community is under food relief assistance throughout the year.
3	Boina	Bahri kebele is entirely dependent on subsistence livestock breeding and therefore agriculture is not practiced. As food security is seriously threatened, the community relies on food support distributed by the Government.
4	Damali	Located in the Afar region at the central part Afar depression, administrated by Asayta Woreda. The area is in arid and dry land which has also very low and erratic rain fall pattern with below 300 mm precipitation. Located at low altitude, which is in between 250 500 meter above sea level.

No.	Site	Livelihood
5	Teo	Located in the Afar region at the central part Afar depression, administrated by Mile Woreda. The area is in arid and dry land which has also very low and erratic rain fall pattern. The annual rain fall ranges between 300 – 500 mm precipitation. Located at low altitude, which is in between 250 - 500 meter above sea level.
6	Danab	Located in the Afar region at the central part Afar depression, administrated by Dubti Woreda. The area is in arid and dry land which has also very low and erratic rain fall pattern. The annual rain fall ranges between 300 – 500 mm precipitation. Located on the next elevated mountain plateau which have relatively high altitudes ranging 500 – 800 meter above sea level.
7	Meteka	Unlike other kebeles, Meteka is semi-urban small town. Thus, although agriculture is practiced in most other kebeles, the community of Meteka is either employed in different sectors or engaged in small businesses. As per the information obtained from the woreda office, the revenue that most residents generate from their business/employment hardly covers their costs of living. Due to this, some of the households are regular receivers of food assistance.
8	Arabi	The main agricultural activities (both commercial and subsistence) of the kebele are livestock keeping and crop production. In the areas surrounding the project site, the major cash crops produced are maize, sorghum, tomato, onion and fruits. The assessment reveals absence of big farms; what is more, neither animal husbandry, nor livestock keeping is dominant. Although, people living in the small town of Arabi engaged in the production of different kinds of fruits, the kebele is characterized by food insecurity mainly due to poor weather conditions, lack of water and infertility of the land. Relief food has been granted by the Ethiopian Government for the victims throughout the year. As reported, food prices increase as the result of more demand to food items. This poses a significant challenge for those pastoralists who never engaged in crop production and fully relied in purchasing food items
9	Dofan	The communities of Dofan live on livestock breeding, though insignificant numbers of them are wage earners in big government and private farms. As many of Afar kebeles, the pastoralists of Dofan are not food secured thus receive food assistant regularly.
10	Kone	The livelihood of the community is based on subsistent farming and livestock keeping. In the areas surrounding the project site, the community is self sufficient in food. Using the available inconsistent rain some of the kebele dwellers produce cash crops including maize, tomato, onion and fruits.
11	Nazareth	As far as food insecurity is concerned Boku kebele is relatively safe. Although part of the community is still far below the poverty line, the kebele is categorized under food secured kebeles and doesn't receive food assistance from the government.
12	Gedemsa	The principal economy of the kebele is derived from agriculture products. Despite the inconsistent rain, absence of water and lack of irrigation practice, the kebele is one of the few areas known for food sufficiency. A better strategy such as supply of agricultural inputs, and access to water can increase productivity and could sustain the present status of food security.
14	Aluto-2 (Altu-Finkilo)	Agriculture is the dominant means of livelihood in the two sites. While maize, wheat, and teff are the major agriculture products, to some extent fruits and vegetables such as onions and tomato are grown by few farmers. Productivity is highly limited because of lack of access to irrigation system and shortage of rain which is the only source for growing crops. As the result, the community is suffered from food insecurity. According to the woreda administration office, out of 43 kebeles in the woreda 23 rural kebeles (including Finkilo and Bobessa) are dependent on the food relief program sponsored by the Government of Ethiopia.
15	Aluto-3 (Aluto-Bobessa)	
18	Boseti	Although there is a shortage of land in the kebele, majority of households produce adequate amount varieties of crops food thus the kebele is secured as far as food is concerned.
22	Tendaho-2 (Ayrobera)	The community is totally dependent on subsistence livestock. Thus food security in the woreda is seriously threatened. Thus since there is no farming practiced across the kebele, the community is under food relief assistance throughout the year.

Source: ESIA Study Report

4.5.4 Utilization of Water

For development of geothermal energy, accessibility of water is one of the crucial matters to be confirmed. As mentioned above, water is one of the most serious challenges for nearly half of the kebeles/sites. For example, two of the kebeles need to travel from 15 to 30 km to fetch water. Even the sources of water that are easily accessible have not been safe. Only households from three kebeles claimed the water they consume is safe and clean. Respondents from Meteka, Boset and Arabi reported they accesses pipe water. However in the case of Boseti, there are times when they face scarcity of water, particularly from January to May. Table 4.5.4 summarizes the statuses of water access in fifteen prospective sites.

Table 4.5.4 Statuses of Water Access in 15 Prospective Sites

Site	Water source		Distance (Km)	Scarcity period	Water quality
	For people	**For** animals			
Afar region					
Allalobeda (Tendaho-3)	River	River	0.5 - 2	-	Not safe water
Dallol	Pond	Pond	25 – 30	All year	Not safe water
Danab	River	River	-	All year	Not safe water
Damali	River	River	-	All year	Not safe water
Dofan	River	River	0.5 - 1	-	Not safe water
Boina	Rain/Pond	Rain/Pond	15 - 20	April - June	Not safe water
Kone	Lake	Lake	0.5 - 1	-	Not safe water
Meteka	Borehole	River	0.5	-	Safe water
Teo	River	-	-	-	Not safe water
Ayrobera(Tendaho-2)	-	-	-	-	-
Oromia region					
Boseti	Pipe	Pond	2	Jan - May	Safe water
Bobessa (Aluto-3)	Lake/River	Lake/River	7	-	Not safe water
Finkilo (Aluto-2)	Lake/River	Lake/River	7	-	Not safe water
Gedemsa	River	River	7	Summer	Not safe water
Nazareth	Birka	River	0.5	-	Safe water
Somali region					
Arabi	Borehole	River	0.5	-	Safe water

Source: ESIA Study Report

4.5.5 Displacement and Resettlement

The scale of geothermal energy development project is not yet determined at present, some of the areas within the prospective sites shall be acquired by the project proponent for implementation of the project. Data and Information on land clam were collected through interviews at kebele lebel level in the prospective sites.

Table 4.5.5 below addresses the possible conditions that could lead to displacement of residents before implementation of the project.

Table 4.5.5 Displacement and Resettlement/Land claim

No.	Site	Current status	No. of land owner around the site	Size of the land owned (ha)	No. of people grazing around the site
1	Dallol	This area of the site is neither exploited for residential houses nor for, farming or grazing. However it is part of the resource for traditional salt mining.	1	1	-
2	Tendaho-3 (Allalobeda)	Allalobeda geothermal project site is found in Dubti woreda in Gurmudela Kebele. The project site is situated 15 km away from Logia town which at 586 km from Addis Ababa. Allallobeda, is not fertile for agriculture due to shortage of rain/water, both for drinking and farming. The community depends on water redirected from Awash River. This Geothermal site is located in an area where there are no residential houses and farming plots. However, the community uses the springs for drinking their animals and grazing livestock. The Tendaho geothermal fields are at an advanced exploration stage, including deep exploratory wells. The site is specifically located within Ayirolef Kebele borders and closely located to Semera Town (9kms NE).	6	6.5	10

No.	Site	Current status	No. of land owner around the site	Size of the land owned (ha)	No. of people grazing around the site
3	Boina	The site is located at the top of a mountain, very far away from human movement. Thus it is not used for grazing livestock or other related purpose.	0	-	-
4	Damali	Not residential area around the site	-	-	-
5	Teo	Not residential area around the site	-	-	-
6	Danab	Not residential area around the site	-	-	-
7	Meteka	The Geothermal site is located within the village of Meteka Kebele where many residential houses and shops are built. There is also an Orthodox Church (St. Mary Church) within the site. In terms of this, therefore, there will be dislocation.	5	12	2
8	Arabi	The project site is located about 4 km away from residential areas; therefore, there is no risk of demolishing huts/houses of the community. Grazing lands however could be included in the site.	3	14.5	1
9	Dofan	Dofan geothermal sites are located in the Southern part of Afar Region near Awash River and Melka Werer town. Administratively it is located in Hugub Kebele, Dulecha Woreda. There are two potential geothermal sites which are located on the mountainous caldera/cone created by the Rhyolitic volcanic centers deposition. The woreda town Dulecha is located about 27 km from the site/Dofan. Both the woreda and the kebele are situated in area where public transport is not available. The Predominant land cover types in Dofan and surrounding areas are Intensively Cultivated land, State Farm land, Open Grassland, Open Shrub Grassland and Perennial Marsh. State Farm land (Amibara Farm) and Intensively Cultivated land units are closely located to these geothermal sites. People in the Dofan site live on mainly livestock breeding and very few of them are working in the big sugar cane farms, although the majorities are minorities from different regions.	9	12	4
10	Kone	Kone project site is located far from villages; the surrounding area however is used for common grazing.	6	8.5	2
11	Nazareth	There are no residential huts around this site; however the springs located in the middle of farming plots of land belong to different individual farmers. Moreover, an Orthodox Church already claimed two of the thermal pits on which the Church has built bathing rooms.	2	unknown	4
12	Gedemsa	The site is located far from residential areas however it is used for grazing livestock. In addition, the site is surrounded by farming plots which belong to individual community members.	1	3	3
14	Aluto-2 (Aluto-Finkilo)	According to the National Geothermal Energy Resource survey map, there are three potential sites in Aluto area, namely Aluto Langano, Aluto Bobessa and Aluto Finkilo. Out of these, Aluto Langano geothermal prospect is under development. These geothermal sites are located south of Lake Ziway (8kms) and north of Lake Langano (9 kms). Administratively Aluto Finkilo geothermal site is located in Golba Aleto kebele and Aluto Bobessa is in Aluto Kebele (Ziway Dugda woreda, Arsi Zone, Oromia Region). Bobessa and Finkilo are located adjacent to each other. Although the actual size of the projects is not yet determined, there are a few huts within the caldera. Besides since the project area is exploited as a grazing land for the same community, unspecified size of the land will be included in the site. In general these sites are densely settled by town residents. Although the actual size of the projects is not yet known, there are few huts within the caldera. Besides since the project area is exploited as a grazing land for the same community, unspecified size of the land will be included in the site.	8	13	7
15	Aluto-3 (Aluto-Bobessa)		7	11.5	2
18	Boseti	Boseti Geothermal site is closely located to Welenchiti town (10km) to south west direction. Administratively Boseti geothermal potential site is located in Gara Dera Kebele, (Boset woreda, East Shewa Zone, Oromia Region). The site also closely located/ along border with Rukecha Boqore & Sifa Bote Kebeles. With regard to elevation,	2	4.5	1

No.	Site	Current status	No. of land owner around the site	Size of the land owned (ha)	No. of people grazing around the site
		Boseti locality has comparatively high altitude, which ranges 1,250-2,650mts above sea level, while the geothermal site is located on the mountainous caldera/cone created by the Rhyolitic volcanic centers deposition, which have relatively high altitudes around 1,800-2,200 m above sea level. The Predominant land cover types in Boseti and surrounding areas are Dense Shrubland, Intensive Cultivated land, Moderately Cultivated land and Open Shrubland. Boseti geothermal site is specifically located on Dense Shrubland unit with close location with Intensively cultivated lands.			
22	Tendaho-2 (Ayrobera)	Not residential area around the site	-	-	-
		Total	50		

Source: ESIA Report

After the determination of the project site and the project scale, detailed land boundary should be settled according to the land acquisition procedure of the government of Ethiopia. Site specific adverse impacts, both on natural and social environment, are summarized in Appendix 4.4.

4.6 Environmental Management Plan

4.6.1 Environmental Management Plan (EMP)

Environmental Management Plan (EMP) is prepared on the basis of identified impacts and their level of significance. The objective of this EMP is to identify project specific environmental and social actions that will be undertaken to manage impacts associated with the development and operation of the proposed geothermal power plant. Significant impacts that are detailed in the previous section shall be mitigated through appropriate methods and then subject to mechanisms of environmental management plan using monitoring and auditing as instrument. Site specific environmental impacts caused by the implementation of geothermal projects are summarized in Appendix 4.4.

The EMP is to be prepared in the process of EIA study. Detailed mitigation measures and management plan need to be formulated after determination of the project site, along with techno-economic feasibility studies. However, it is quite necessary to deal this issue in a comprehensive manner so as to induce basic requirements for the upcoming project level design and full EIA studies. Table 4.6.1 summarizes the mitigation measures to be taken at the beginnings of construction phase.

Table 4.6.1 Mitigation Measures for EMP

Activities	Components	Potential Impacts	Mitigation Measures
Land acquisition	Land securing	Dislocation of affected people	Project office shall implement all necessary protocols for conversation of land use pattern for the project site from grazing to industrial use.
		Relocation of displaced people	It will be ensured that all legal requirements are implemented with respect to Ethiopian regulations pertaining to use of land for industrial use.
	Benchmarking	Asset dispossession	Site boundary will be marked out. It will be ensured that land taken during construction of project is restricted to pre-agreed area.
		Change in life style	All requisite permits will be obtained prior to project activities.
		Disturbance to existing ecosystem	Disturbance to hot spring present around project area will be minimal. The streams shall be protected and preserved and natural drainage pattern shall not be disturbed.
	Fencing	Loss of vegetation cover	Relocation site and/or compensation incentives will be in place based on Ethiopian regulation.
		Change in ecology and land use pattern	Plantation of the surroundings area will start with the commencement of construction activities.
Movement of manpower, machinery and materials	Increase in traffic movement	Disturbance to community & its safety	Planning activities in consultation with local communities so that activities with the greatest potential to generate noise are planned during periods of the day resulting in minimum disturbance.
	Encroachment of are for parking and construction	Contribution of dust and gaseous pollutants like SO2, NOx, CO, VOC to ambient air quality	Preventive maintenance of vehicles and machinery at regular intervals.
		Contribution to ambient noise level	Advice traffic police about the activities. Traffic will be controlled by deploying local people at sensitive accident prone locations who will also oversee the movement of livestock on these roads.
Site leaning, levelling & excavation	Operation of heavy earth moving machinery & equipment	Disturbance to native vegetation and habitats	Plantation of the surroundings area will start with the commencement of construction activities.
	Removal of	Change in land use	All equipment will be operated within specified

Activities	Components	Potential Impacts	Mitigation Measures
	vegetation at site	pattern	design parameters (Site preparation and construction phases)
	Piling of soil	Disturbance to existing nearby land users creating visual impact	Regular monitoring of noise level and vibration level due to construction activities at site and in the local areas to conform to the standard as prescribed by most financial institutions.
	Storage of oil	Increase to ambient noise level	Design additional methods to support already existing business opportunities and community development.

Source: JICA Study Team

4.6.2 Monitoring plan

Environmental monitoring plan is included in the EMP. Environmental monitoring and auditing shall be undertaken in all phases of project activities to check that the proposed environmental management measures are being satisfactorily implemented and that they are delivering appropriate level of environmental performances. Here it might be necessary to emphasize that mitigation measures and auditing plans are not developed for mere purpose of project licensing but are legally enforcing document to be followed and performed accordingly throughout project life. A general form of monitoring plan to be applied to the prospective sites is given in Table 4.6.2 below.

Table 4.6.2 Monitoring Plan for Geothermal Energy Development Project

Impact	Method	Parameters	Monitoring place/location	Frequency
Air quality	Measurement/Sample	PM/PM10, NOx, SOx	Processing stacks	Half-yearly
		Concentration & exposure time	Point source of non-condensable gases	Half-yearly
		PM/PM10, CO_2, Temp., Oxygen level, combustion efficiency	Combustion source	Half-yearly
Noise	Measurement Leq	dB(A)	Drilling sites	Half-yearly and upon complaints
Surface and groundwater, if any	Sampling	Temp., pH, Oil, SS, COD	Groundwater wells, Oil/grease traps, water separators, sedimentation tanks	Quarterly
Soil	Sampling	Moisture content, pH, salinity, N, P, Cl, K, Na	Agricultural plots near and in projects sites	Annual
		Heavy metals (Mn, Fe, etc.)		Every three years
Domestic solid waste	Audit, photographic documentation, interviews	Generation, storage, recycling, transport and disposal	Plant premises	Quarterly
Biodiversity	Visual inspection and photographic documentation	General condition of the floral cover	Plant and landscaped areas	Annual
Resource use	Metering	Water and energy consumption	Plant and surrounding areas	Continuously
	Audit	Raw material consumption	Plant and surrounding areas	Continuously
Health and safety	Health and safety survey	Proper use of PPE, presence of safety signs, firs aid kit, fire fighting devices, injury illness records, emergency exit and plans, Accident statistics recording in accordance with ILO standards.	Plant road linking plant to project site	Continuously
Socio-economic	Field questionnaire	Local population an Authorities	Plant and surrounding areas	Annually
	Interviews	Employment records and	Plant	Continuously

Impact	Method	Parameters	Monitoring place/location	Frequency
		Worker association		
Operations monitoring	Visual inspection and documentation	Production rate, gas flow rates, counter readings, pressure valves, temperatures, abnormal readings, overloads, stoppages	All facilities and major equipment at Plant area	Daily

Source: JICA Study Team

4.7 Consultation with stakeholder

Stakeholder Consultations were implemented in the ESIA Study, namely at scoping stage, through the interviews at communities (March –July 2014).

Stakeholder Consultation at scoping stage

Consultation with stakeholder at the prospective sites had been conducted through interview and using questionnaires shown in section 4.3.1 (Methodology of Baseline Study) in the ESIA study. As mentioned in section 4.3.1, hearings and questionnaire surveys had been conducted at seven Woreda level sector offices, and more than 100 officials from different sectors were participated. The contents of questions developed for the survey and the stakeholder consultation are summarized as follows:

- Existence of any directive/guidelines in the offices relevant for establishment and resource utilization around the proposed project areas.
- Existence of development plan in or around the proposed project area.
- Personal opinion of interviewee on establishment of this geothermal energy development project in the area.

Together with above, themes of discussion developed for group discussion are as follows:

- Have you heard about geothermal energy?
- What are the major constrains of the community?
- What potential benefits do you expect from the geothermal project?
- What potential negative impacts do you expect from the geothermal project?
- If there are negative effects of the project what do you recommend avoid/minimize the impacts?
- Are there minority groups in the area, and what problems do they face?
- Is there conflict story due to resource or other causes among the community?
- If the project requires relocation of people, do you think the concerned group will agree?
- In what form do you think the relocated households should/want to receive the compensation?
- Any other comments

As results of the stakeholder consultations, the discussions with local people were almost same for the prospective areas as follows:

- Up to now there is no directives that prevent the geothermal energy development projects from establishment along the proposed sites.
- For the establishment of the project, necessary precautionary measures for resource utilization

should be taken.

- All of interviewed officials expressed their positive support for establishment of the geothermal energy development projects with necessary measures.

Together with the opinion of officials above, meeting with people who had potential directly affected by the project revealed the following opinions:

- Fear of losing farm lands and inability to get lands of equivalent land conditions.
- Fear of losing free large grazing land for livestock.
- Fear of declining cattle population due to shortage of such grazing land elsewhere and its implication on family income.
- Fear of losing plain playground of their children.
- Loss of proximity to nearby town social facilities such as big market, health center, access to transport service, etc.
- Fear of getting appropriate compensation for their assets.

In order to remove the issues and concerns of the community above, due regards and detailed explanations were given to the community based on the legal, social and environmental land regulations stated in the proclamation of Federal Republic of Ethiopia No. 1/1995.

Names, responsibilities and status of respondents and interviewees are listed in Appendix 4.6.

4.8 Conclusion and Recommendation

4.8.1 Conclusion

The environment and social impact assessment study on the geothermal energy development was conducted. The study included site surveys and collection of readily available data for the prospective sites, and IEE for scoping of potential impacts caused by the implementation of geothermal energy development projects. The study revealed the followings:

- Although implementation of geothermal energy development project will affect some environmental and social impacts on the sites, both positive and negative, there are no prospective sites which would be affected negative impacts seriously by the implementation of the geothermal energy development project in terms of the environment.
- According to the stakeholder consultation conducted at the prospective sites of Woreda level, all of interviewed officials expressed their positive support for development of the geothermal energy with necessary measures such as proper land compensation.
- The stakeholder consultation also revealed that the main concern of potentially project affected people (PAP) is fear of losing farm land, grazing land for livestock. Due regards and detailed explanations should be made to PAPs in case the geothermal energy development projects are to implement at some of the prospective sites.
- As for the gaps between Ethiopian Legislations and JICA Guidelines (2010) for policies on

Environmental Assessment, it can be concluded that the JICA Environmental guidelines and the legislation in Ethiopia do not have major contradictions as well as Safeguard Polices in the World Bank, except perhaps certain procedural adjustments during project implementation such as public consultation and public disclosure. The studies on policy aspects in this study showed that the projects for geothermal energy development were classified under CATEGORY I by the Ethiopian environmental project categorization. This means that the geothermal energy development projects are required to conduct a full EIA study complying with national standards set by the country.

- The National Energy Development Policy in Ethiopia states that; i) Equitable development of the energy sector together with other social and economic developments, and ii) Development of indigenous resources with minimum environmental impact and equitably distribution of electricity in all the regions. In addition to the National Energy Development Policy mentioned above, the National Environmental Policy also states to promote the development of renewable energy sources and reduce the use of fossil energy resources both ensuring sustainability and for protecting the environment, as well as for their continuation into the future.
- Geothermal energy is one of the environmental sound indigenous renewable energies in Ethiopia. Proceedings of geothermal energy development comply with the national policies of Ethiopia.

4.8.2 Recommendation

Geothermal energy development projects which have an electricity generation capacity more than 25 MW are required the implementation of full scale EIA in accordance with EIA related laws and regulations of Ethiopia prior to the implementation of the project. As shown in section "4.2 Environmental Laws and Regulations", EIA process consists of series of several procedural phases starting from pre-screening consultation with EPC and submission of a screening report and ending up by obtaining an EIA approval. The project proponent should start the EIA procedures in cooperation with other sectoral agencies such as Ministry of Water, Irrigation and Energy (MoWIE), regional governments, etc. For the implementation of the EIA, followings should be noted:

- EIA should be conducted in accordance with the Ethiopian EIA process.
- EIA should be carried out for the selected site by the project proponent according to the Ethiopian Guidelines and/or international requirements.
- After the determination of the project site(s), EIA should start prior to the test drillings, and continuously conducted parallel to the test drilling.
- The EIA report prepared based on above shall be revised considering the results of the test drilling above. Results of ESIA survey conducted in this master plan study can be utilized for the implementation of the EIA
- Additional EIA should be conducted if necessary according to the revised EIA report.
- The EIA is to be conducted considering the specific features of environmental impacts of geothermal energy development.
- EIA approval should be obtained before the application of the development right of the project.

CHAPTER 5 Formulation of Master Plan

5.1 Target and Methodology

The master plan is formulated by first setting out the development targets (how much installed capacities are required and when) and then by prioritizing the identified candidate projects using a multi-criteria analysis to meet the targets set out.

5.1.1 Target of the Master Plan

Table 5.1.1 gives the development targets for this master plan. Target year is set as the same period as in the EEP master plan. In order to make the plan more concrete, the master plan period is divided into three terms, namely: short, medium, and long. First, the committed and ongoing projects are expected to be completed in the short term. Secondly, high priority prospects aim to develop around 500 MW in the exact same way as in the EEP generating plan. And last, a total of 5,000 MW of geothermal power is expected to be developed in the long term in Ethiopia.

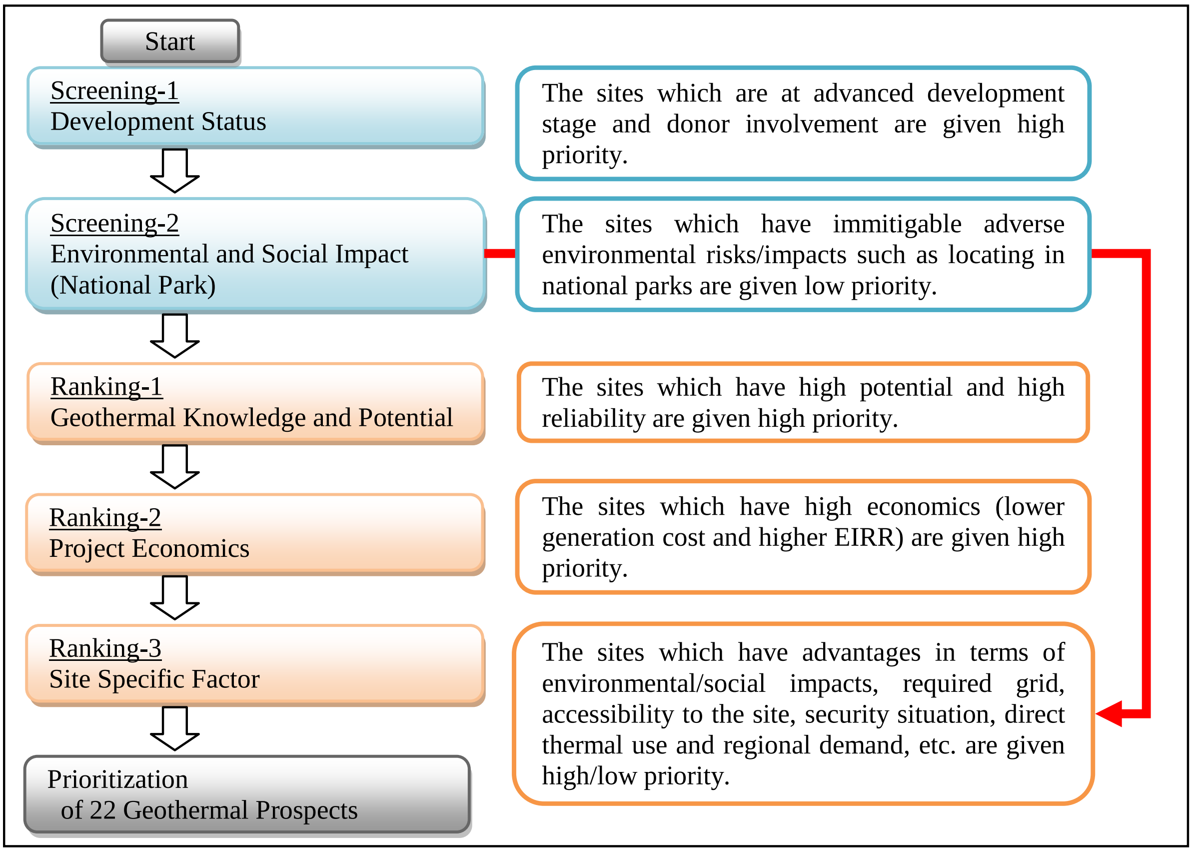
Table 5.1.1 Development Target of the Master Plan

Item	Target		Remarks
Period	2015–2037 (23 years) Short term: 2015-2018 (4 years) Medium term: 2019-2025 (7 years) Long term: 2026-2037 (12 years)		EEP MP: 2013–2037 (25 years) Wind and Solar MP: 2011–2020 (10 years)
Installed Capacity	Short term	700 MW	Committed and ongoing sites
	Medium term	1,200 MW	Same target as EEP MP
	Long term	5,000 MW	Same target as EEP MP

MP: Master Plan Source: JICA Project Team

5.1.2 Methodology of the Master Plan

This master plan is formulated by prioritizing the 22 geothermal prospects identified based on the results of various kinds of geological survey and collected data from past surveys, using multi-criteria analysis. The multi-criteria analysis is the method of prioritizing the candidate projects by screening and ranking them using multiple criteria as shown in Figure 5.1.1. Five criteria are used: (i) development status, (ii) environmental risks, (iii) geothermal potential, (iv) economics, and (v) site specific factors. First, depending on the development status and commitment of the donors, the committed prospects are prioritized by giving them a high rank. In the following screening, the prospect which has severe adverse environmental impact, for example those located in the national park, is given low priority. Other sites are ranked based on economics estimated using geothermal potential, installed capacity, drilling well, plant cost, and other required facilities. And finally, taking into consideration site specific factors such as other socio-environmental impacts, minor arrangement of the ranking is discussed.



Source: JICA Project Team

Figure 5.1.1 Flow of Multi-Criteria Analysis

5.2 Multi-Criteria Analysis for Prioritizing the Geological Prospects

5.2.1 Factors to be Considered

(1) Development Status

In general, with the progress of the development status, the reliability of the geothermal resource is increased. Using the Australian Geothermal Reporting Code Committee [1] classification, the development status and geothermal reliability of the 22 geothermal prospects are evaluated and categorized into three sections, namely: 1) measured, 2) indicated, and 3) inferred geothermal resource.

Table 5.2.1 shows the development status of the 22 geothermal prospects. Aluto-1 (Aluto-Langano) and Tendaho-1 (Dubti), where some test drillings were already done, are evaluated as measured and

[1] Global Review of Geothermal Reporting Terminology, Feb. 2013, Hot Dry Rocks Pty Ltd

indicated resource, respectively. Other sites where any detailed exploration surveys have yet to be done are evaluated as inferred resource.

Table 5.2.1 Development Status and Geothermal Resource

Site		Temperature Class	Geothermal Resource		
			Inferred	Indicated	Measured
1	Dallol	B	44	N/A	N/A
2	Tendaho-3 (Allalobeda)	A	120	N/A	N/A
3	Boina	C	100	N/A	N/A
4	Damali	C	230	N/A	N/A
5	Teo	B	9	N/A	N/A
6	Danab	B	11	N/A	N/A
7	Meteka	B	130	N/A	N/A
8	Arabi	C	7	N/A	N/A
9	Dofan	B	86	N/A	N/A
10	Kone	D	14	N/A	N/A
11	Nazareth	C	33	N/A	N/A
12	Gedemsa	D	37	N/A	N/A
13	Tulu Moya	C	390	N/A	N/A
14	Aluto-2 (Finkilo)	A	110	N/A	N/A
15	Aluto-3 (Bobesa)	A	50	N/A	N/A
16	Abaya	B	790	N/A	N/A
17	Fantale	C	120	N/A	N/A
18	Boseti	B	265	N/A	N/A
19	Corbetti	B	1000[*1]	N/A	N/A
20	Aluto-1 (Aluto-Langano)	A	16	70[*2]	5
21	Tendaho-1 (Dubti)	A	280	10[*3]	N/A
22	Tendaho-2 (Ayro Beda)	A	180	N/A	N/A

N/A: Not available

[*1] *Reykjavík Geothermal*
[*2] *Study on Geothermal Power Development Project in the Aluto Langano Field, Ethiopia, METI (Japan), 2010,*
[*3] *Consultancy Services for Tendaho Geothermal Resources Development feasibility Study, ELC, 2013*

Source: JICA Project Team

(2) Socio-environmental Impact

According to the environmental and social consideration study mentioned in Chapter 4, Fantale geothermal prospect is located around the Awash National Park and it is expected that it will be difficult to develop. Therefore, Fantale prospect is given a low priority in the ranking. With the exception of Fantale prospect, the 21 other geothermal sites do not encroach on the range of the national park and do not have immitigable adverse environmental risks and impacts.

(3) Geothermal Potential

Based on the various geological surveys carried out in this study, geothermal potential of each site is assessed and discussed in Chapter 3. The result of the reservoir assessment is summarized in Table 5.2.1. As per the electrical development plan mentioned in Chapter 2, the electrical demand is forecasted to increase much higher than the sum of hydropower and geothermal potential in the early 2030s. Therefore, EEP requests the development of the maximum possible geothermal potential. In this study, the installed capacity of each power plant is set as equal to the geothermal potential in each prospect.

As mentioned in Section 2.4, several donors have started development and drilling surveys of some of the prospects, such as Corbetti, Aluto-1 (Aluto-Langano), and Tendaho-1 (Dubti). The inferred potential of Corbetti geothermal prospect is estimated at 1000 MW referring to publicly available information from Reykjavík Geothermal (RG). Similarly, the indicated and measured potential of Aluto-1 (Aluto-Langano) and Tendaho-1 (Dubti) were taken from the existing simulation studies.

The reservoir temperature of Kone and Gedemsa prospects are assumed to be very low (100~170 °C based on the geochemical analysis) that those prospects cannot use flash-type generation but only binary-type generation. Therefore, plant construction cost of Kone and Gedemsa prospects are expected to be higher than any other prospects with Class A and B reservoir temperatures.

(4) Economics of Candidate Plants

The project economics are measured by two indicators: (i) generation cost and (ii) economic viability.

1) Cost of Electricity Generation

To compare the competing power plants (geothermal, hydropower and other plant types), the electricity generation costs (cost of generation) per kWh are calculated. Here the generation cost is defined as the sum of annualized capital cost and annual O&M cost of power plants, divided by the annual power production (kWh). The capital costs are annualized using a discount rate (social opportunity cost of capital) of 10% for the economic life. All the costs are expressed in 2012 price. The capital cost consists of direct costs (preparatory work, well drilling, fluid collection and reinjection system (FCRS), and power plant construction), indirect cost, and interest during construction (IDC).

The direct costs except for geothermal power plant are estimated from past results and plans provided by EEP. The economic life and plant factor of each power plant used for the calculation of capital recovery factor and electricity production are shown in the tables below. The economic life of geothermal power plants is adopted from the worldwide standard of “30 years”, and that of non-geothermal power plants is taken from the adopted value in the EEP master plan study.

Plant factor of geothermal power plants is taken as “90%”, adopted from standard geothermal power plants, and that of wind farms is taken from the past records of Adama and Ashegoda wind farms, while those for hydropower and other power plants are taken from the planned value in EEP master plan.

Table 5.2.2 Economic Life

Plant Type	Economic Life Time (years)
Geothermal	30
Hydropower	75
Wind	20
Solar	40
Energy from Waste	30
Biomass	25
Diesel	20
Gas Turbine	20
CCGT	25

Source: JICA Project Team

Table 5.2.3 Plant Factor

Plant Type	Plant Factor (%)
Geothermal	90.0
Hydropower	20.0 ~92.0
Wind	26.4 ~33.6
Solar	20.0
Energy from Waste	84.9
Biomass	23.9~27.5
Diesel	84.0
Gas Turbine	90.0
CCGT	87.5

Source: JICA Project Team

Table 5.2.4 gives the costs generation by the candidate hydropower plants which are calculated based on the basic data given by EEP. The generation costs of the candidate hydropower plants vary from US$0.02-0.15/kWh. Most of the candidate hydropower plants have more than 100 MW of installed capacity and are comparatively economical.

Table 5.2.4 Generation Costs of Candidate Hydropower Plants

Ranking Order	Candidate Hydropower Plant	Installed Capacity (MW)	Plant Factor (%)	Energy Production (GWh/year)	Construction Cost (mil $)	IDC Cost (mil $)	Total Cost (mil $)	Annualized Capital Cost (mil $/year)	O&M Cost (mil $/year)	Annualized Cost (mil $/year)	Cost of Genaration ($/kWh)
1	Beko Abo	935	81%	6632	1260.8	441.3	1702.1	126.18	12.6	138.79	0.0209
2	Genji	216	49%	910	197.6	69.1	266.7	19.78	2.0	21.75	0.0239
3	Upper Mendaya	1,700	58%	8582	2436.4	852.7	3289.1	243.83	24.4	268.20	0.0312
4	Karadobi	1,600	60%	7857	2576.0	901.6	3477.6	257.80	25.8	283.56	0.0361
5	Geba I + Geba II	372	57%	1709	572.0	200.2	772.2	57.25	5.7	62.97	0.0368
6	Genale VI	246	74%	1532	587.9	205.8	793.7	58.84	5.9	64.72	0.0422
7	Gibe IV	1,472	50%	6146	2588.3	776.5	3364.8	259.03	25.9	284.92	0.0464
8	Upper Dabus	326	51%	1460	628.2	219.9	848.1	62.87	6.3	69.15	0.0474
11	Sor II	5	92%	39	18.6	3.7	22.3	1.86	0.2	2.05	0.0532
10	Birbir R	467	70%	2724	1231.1	369.3	1600.4	123.21	12.3	135.52	0.0497
9	Halele + Werabesa	436	54%	1973	886.0	310.1	1196.1	88.67	8.9	97.53	0.0494
12	Yeda I + Yeda II	280	45%	1089	540.2	189.1	729.3	54.06	5.4	59.46	0.0546
13	Genale V	100	66%	575	297.7	89.3	387.0	29.79	3.0	32.77	0.0570
14	Gibe V	660	36%	1905	1036.9	311.1	1348.0	103.77	10.4	114.14	0.0599
15	Baro I + Baro II	645	46%	2614	1595.9	558.6	2154.5	159.72	16.0	175.67	0.0672
17	Lower Didessa	550	20%	976	619.2	185.8	805.0	61.97	6.2	68.16	0.0699
16	Tekeze II	450	69%	2721	1690.4	591.6	2282.0	169.17	16.9	186.08	0.0684
18	Gojeb	150	48%	562	526.8	184.4	711.2	52.72	5.3	57.99	0.1032
19	Aleltu East	189	53%	804	760.6	266.2	1026.8	76.12	7.6	83.73	0.1041
20	Tams	1,000	69%	6057	5814.9	2035.2	7850.1	581.95	58.1	640.10	0.1057
22	Abu Samuel	6	30%	16	18.5	2.8	21.3	1.85	0.2	2.04	0.1297
21	Aleltu West	265	46%	1067	1180.5	413.2	1593.7	118.14	11.8	129.95	0.1218
23	Wabi Shebele	88	91%	691	887.8	221.9	1109.7	88.85	8.9	97.73	0.1414
24	Lower Dabus	250	29%	637	866.3	259.9	1126.2	86.70	8.7	95.36	0.1497

Source: JICA Project Team (Data of candidate plants was given by EEP)

Table 5.2.5 presents the generation costs of other renewable energy and thermal power plants. The costs of Adama I and Ashegoda II wind farms are lowest and estimated at US$0.084-0.090/kWh. Following these, Bazma Biomass Power Plant has a lower generation cost. Except for the wind farm above, generation costs of all plants exceed US$0.10/kWh and are less economical than most of the candidate hydropower plants.

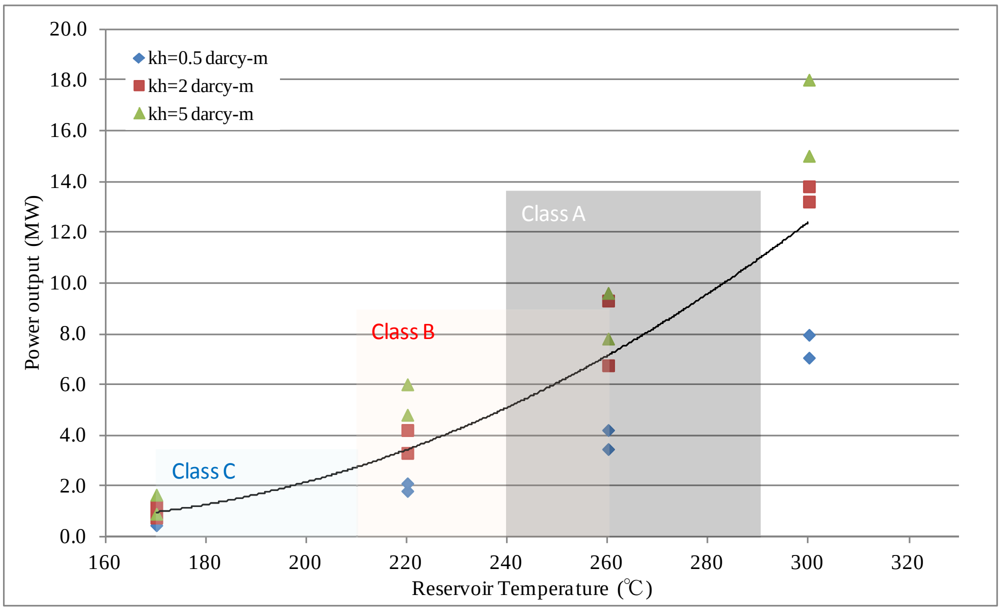
Table 5.2.5 Generation Costs of Non-Hydro and Non-Geothermal Plants

Plant Type	Candidate Plant	Installed Capacity (MW)	Plant Factor (%)	Energy Production (GWh/year)	Construction Cost (mil $)	IDC Cost (mil $)	Total Cost (mil $)	Annualized Capital Cost (mil $/year)	O&M Cost (mil $/year)	Annualized Cost (mil $/year)	Cost of Genaration ($/kWh)
Wind Farm	Adama-I	51.0	33.6%	150	96.9	9.7	106.6	11.38	1.3	12.66	0.0844
Wind Farm	Adama-II	30.0	26.6%	70	57.0	5.7	62.7	6.70	0.8	7.45	0.1064
Wind Farm	Ashegoda-I	90.0	26.4%	208	171.0	17.1	188.1	20.09	2.3	22.34	0.1074
Wind Farm	Ashegoda-II	153.0	31.6%	424	290.7	29.1	319.8	34.15	3.8	37.97	0.0896
Solar	EEPco MP	300.0	20.0%	526	540.0	54.0	594.0	55.22	7.5	62.72	0.1192
Energy from Waste	EEPco MP	25.0	84.9%	186	144.0	7.2	151.2	15.28	32.1	47.35	0.2545
Biomass	Bazma	120.0	27.5%	289	183.7	9.2	192.8	20.23	11.1	31.30	0.1083
Biomass	Meikasedi	138.0	23.9%	289	203.4	10.2	213.6	22.41	12.4	34.83	0.1205
Diesel (HFO)	EEPco MP	70.0	84.0%	515	144.2	14.4	158.6	15.89	92.7	108.59	0.2108
Gas Turbine	EEPco MP	140.0	90.0%	1104	70.0	10.5	80.5	8.22	140.2	148.43	0.1344
CCGT	EEPco MP	420.0	87.5%	3219	525.0	78.8	603.8	57.84	292.9	350.77	0.1090

Source: JICA Project Team (Data of each power was given by EEP)

The construction cost of geothermal power plants mainly consists of well drilling, FCRS, and power plant construction. Power plant construction and FCRS are estimated depending on the planned installed capacity, while the cost of well drilling is estimated based on target well depth in resource development, steam and brine flow per production well and the characteristics (depth and temperature) of the geothermal reservoir, taking into consideration geothermal models and characteristics of each prospect mentioned in Chapter 3. Regarding Aluto-1 and Corbetti, their construction costs are taken from the outgivings based on a more detailed study conducted in the past.

The JICA Project Team conducted well simulation to determine the relation between reservoir temperature and steam and brine flow per production, setting depth, pressure, and permeability of geothermal reservoir. Well drilling cost is estimated based on the simulation result and well depth based on previous survey results. Figure 5.2.1 presents the relation between reservoir temperature and power output converted from flow rate. Although it differs largely depending on the permeability, the result suggests higher reservoir temperature has a larger amount of steam and brine flow and bigger power output per production well.



Source: JICA Project Team

Figure 5.2.1 Well Simulation Results

The success rate of well drilling is also assumed to be 80% for the Aluto and Tendaho (Dubti and Ayrobera) area, where a study on depth and scale of geothermal reservoir was done, and 70% for the other sites at the initial stage. Based on the productivity of one production well and the success rate, the necessary number of production and reinjection wells is calculated. The diameter of production well is uniformly set at 8.5 inches at the bottom of the well which is the standard and applied in the past in Ethiopia. The drilling cost is given by multiplying the unit cost (US$1,750/m) which is determined with worldwide standard price[2] assuming fully contracting out. In case that GSE implements the drilling by his own rigs and equipments, the drilling cost is assumed to lower around US$1,500/m. In this case, the generation costs also come down with about US$0.003-0.013/kWh as shown in Table 5.2.6.

The power plant construction cost including FCRS is calculated assuming a 3-year construction period within the total development period of six years similar to the implementation plan shown in Section 5.3 and in reference to the model case of 70 MW power plants, which costs US$14 million in EEP master plan.

Table 5.2.6 shows the generation cost of the geothermal plants. As mentioned above, Kone and Gedemsa, which are assumed to have low reservoir temperatures, can use only binary-type generation. Therefore, they are excluded from the calculation of generation cost for flash-type geothermal power plants. As a result of the estimation, the generation costs in Aluto and Tendaho area, which are assumed to have high reservoir temperatures, are US$0.05-0.06/kWh and the lowest for all prospects. Corbetti, where RG already holds the license, is also US$0.059/kWh and more economical. Following them, Abaya, Boseti and Meteka, with large geothermal potential, are estimated to be US$0.07/kWh and economical. On the other hand, although Teo, Dallol, and Danab are assumed to have Class-B reservoir temperature, their generation costs are estimated to be more than US$0.10/kWh and less economical. It is caused by large cost for access as it was impossible for the JICA Project Team to conduct the site survey. The generation costs of Tulu Moye, Fantale, Nazareth, Damali, Boina, and Arabi, which are assumed to have Class-C reservoir temperature, are very high because of necessary large number of well and estimated more than US$0.10/kWh and less economical.

[2] Geothermal Handbook: Planning and Financing power generation, Energy Sector Management Assistance Program, World Bank, June 2012

Table 5.2.6 Generation Costs of Geothermal Power Plants

Ranking Order	Geothermal Site	Installed Capacity (MW)	Plant Factor (%)	Energy Production (GWh/year)	Construction Cost (mil $)	IDC Cost (mil $)	Total Cost (mil $)	Annualized Capital Cost (mil $/year)	O&M Cost (mil $/year)	Annualized Cost (mil $/year)	Cost of Genaration ($/kWh)	Cost of Genaration Drilled by GSE ($/kWh)
15	Dallol	44	90	346.9	321.5	48.2	369.7	34.10	3.2	37.32	0.1076	0.1019
6	Tendaho-3 (Allalobeda)	120	90	946.1	506.4	76.0	582.3	53.72	5.1	58.78	0.0621	0.0584
18	Boina	100	90	788.4	754.7	113.2	867.9	80.06	7.5	87.60	0.1111	0.1107
16	Damali	230	90	1,813.3	1,693.1	254.0	1,947.1	179.61	16.9	196.54	0.1084	0.1056
13	Teo	9	90	71.0	63.6	9.5	73.1	6.74	0.6	7.38	0.1040	0.0971
19	Danab	11	90	86.7	127.0	19.1	146.1	13.47	1.3	14.74	0.1700	0.1643
10	Meteka	130	90	1,024.9	645.3	96.8	742.1	68.45	6.5	74.90	0.0731	0.0674
20	Arabi	7	90	55.2	89.0	13.3	102.3	9.44	0.9	10.33	0.1872	0.3200
11	Dofan	86	90	678.0	457.4	68.6	526.0	48.52	4.6	53.09	0.0783	0.0726
-	Kone	14	90	110.4	-	-	-	-	-	-		-
17	Nazareth	33	90	260.2	244.5	36.7	281.2	25.94	2.4	28.38	0.1091	0.1051
-	Gedemsa	37	90	291.7	-	-	-	-	-	-		-
12	Tulu Moye	390	90	3,074.8	2,748.0	412.2	3,160.2	291.51	27.5	318.99	0.1037	0.0946
2	Aluto-2 (Finkilo)	110	90	867.2	437.0	65.6	502.6	46.36	4.4	50.73	0.0585	0.0549
4	Aluto-3 (Bobesa)	50	90	394.2	201.1	30.2	231.3	21.34	2.0	23.35	0.0592	0.0556
8	Abaya	790	90	6,228.4	3,849.1	577.4	4,426.4	408.31	38.5	446.80	0.0717	0.0663
14	Fantale	120	90	946.1	855.4	128.3	983.7	90.74	8.6	99.30	0.1050	0.0999
9	Boseti	265	90	2,089.3	1,298.1	194.7	1,492.9	137.71	13.0	150.69	0.0721	0.0665
3	Corbetti	1000	90	7,884.0	4,000.0	600.0	4,600.0	424.32	40.0	464.32	0.0589	0.0589
7	Aluto-1 (Langano)	75	90	591.3	356.7	53.5	410.2	37.84	3.6	41.41	0.0700	0.0700
1	Tendaho-1(Dubti)	290	90	2,286.4	1,126.6	169.0	1,295.6	119.51	11.3	130.78	0.0572	0.0538
5	Tendaho-2 (Ayrobera)	180	90	1,419.1	725.0	108.7	833.7	76.90	7.2	84.15	0.0593	0.0570

Source: JICA Project Team

To sum up the estimation of generation cost, the rank order of the geothermal prospects is summarized Table 5.2.7. Among 22 prospects, Aluto and Tendaho area are ranked highest except for Corbetti where RG has development license, and followed by Abaya. In addition to Aluto and Tendaho area, Boseti and Meteka, located between Aluto and Tendaho in the Great Rift Valley, are also ranked high.

Table 5.2.7 Ranking Order of the Geothermal Prospects

Ranking Order	Geothermal Site	Temp. Class	Installed Capacity (MW)	Cost of Genaration ($/kWh)	Remarks
1	Tendaho-1(Dubti)	A	290	0.0572	Shallow reservoir is committed.
2	Aluto-2 (Finkilo)	A	110	0.0585	
3	Corbetti	B	1,000	0.0589	Committed site
4	Aluto-3 (Bobesa)	A	50	0.0592	
5	Tendaho-2 (Ayrobera)	A	180	0.0593	
6	Tendaho-3 (Allalobeda)	A	120	0.0621	Committed site
7	Aluto-1 (Langano)	A	75	0.0700	Committed site
8	Abaya	B	790	0.0717	
9	Boseti	B	265	0.0721	
10	Meteka	B	130	0.0731	
11	Dofan	B	86	0.0783	
12	Tulu Moye	C	390	0.1037	
13	Teo	B	9	0.1040	
14	Fantale	C	120	0.1050	
15	Dallol	B	44	0.1076	
16	Damali	C	230	0.1084	
17	Nazareth	C	33	0.1091	
18	Boina	C	100	0.1111	
19	Danab	B	11	0.1700	
20	Arabi	C	7	0.1872	
-	Gedemsa	D	37	-	Low temperature
-	Kone	D	14	-	Low temperature

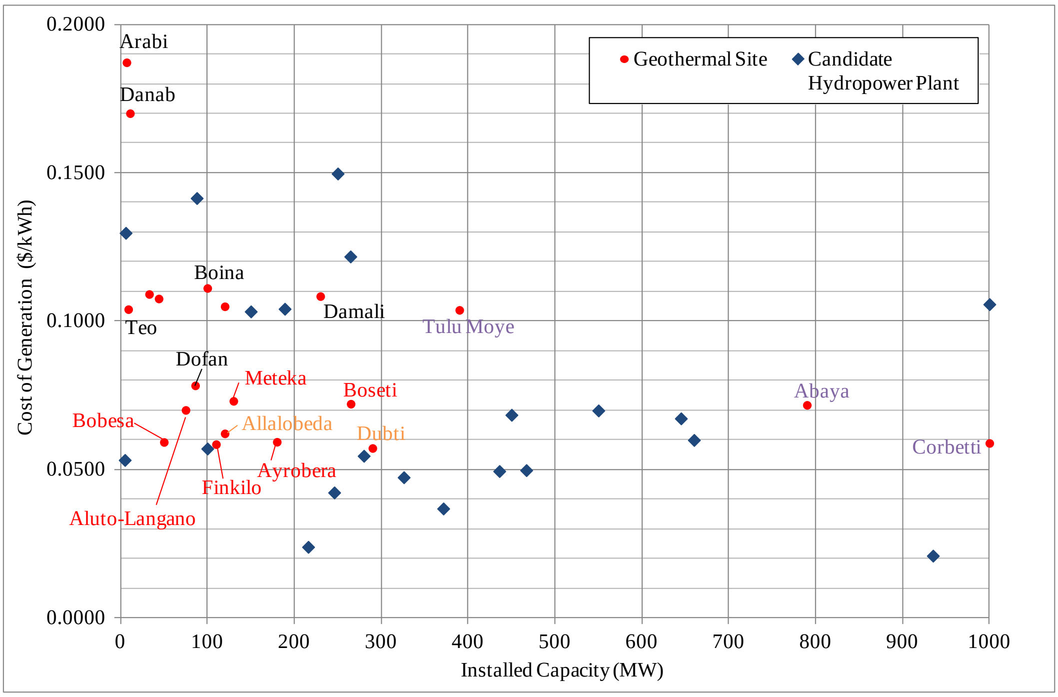
Source: JICA Project Team

In this master plan study, geothermal potential, which was not done in EEP master plan, has been assessed. In the comparison between the generation cost of hydropower and other plant types and that of geothermal based on the geothermal potential, the revised development prioritization of all plant types is proposed.

Figure 5.2.2 and Figure 5.2.3 compares the generation costs of geothermal and hydropower, and geothermal and other power plants respectively. Generally, the generation cost of hydropower is lower than that of geothermal power plants. However, some geothermal power plants are much more competitive and are more reasonable than some candidate hydropower plants with similar capacity. Prospects in Aluto and Tendaho area and Corbetti, with generation cost of around US$0.05-0.07/kWh, are as competitive as the most economical candidate hydropower plants. Abaya, Boseti, Meteka, and Dofan, whose generation costs are around US$0.07-0.08/kWh are also competitive and just above the range of reasonable hydropower plants.

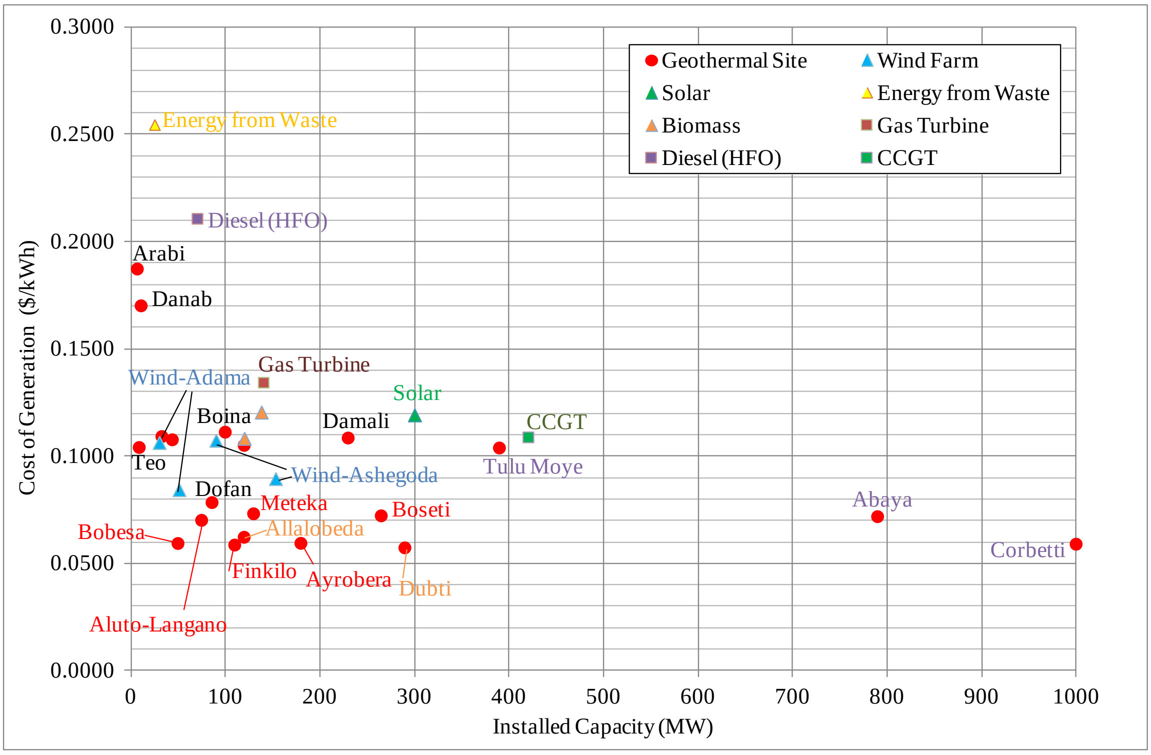
In comparison with other renewable energy and thermal power plants, even Adama and Ashegoda wind farms, which are the most reasonable and exceeds US$0.08/kWh, they are not competitive compared with the geothermal prospects ranked No.1 to No.11 in Table 5.2.7. Therefore, from the point of view of least cost generation, geothermal must be prioritized over wind and solar in Ethiopia. As mentioned in section 2.3.4, wind and solar power is unreliable which is influenced by climate and weather conditions. Meanwhile, geothermal resource provides reliable electrical supply as base load. Moreover, the Ethiopia's energy sector is overly depending on hydropower, which is exposed to drought risk. To reduce risk of drought, the geothermal resources should be exploited as much as possible. This will improve Ethiopia's energy mix, where the base load could be supported by geothermal energy and the peak load by hydropower. .

The geothermal prospects with generation cost of US$0.10/kWh are almost equal to wind and solar and more economical than gas turbine and diesel. The diesel generation and waste from energy are much more expensive than the geothermal prospects.



Source: JICA Project Team

Figure 5.2.2 Generation Cost of Geothermal and Hydropower Plants



Source: JICA Project Team

Figure 5.2.3 Generation Cost of Geothermal and Other Power Plants

If the Government of Ethiopia adopts preferential policy such as advantageous interest rate to promote geothermal development, geothermal is expected to become more competitive. In this master plan, based on the comparison of the generation cost of plant type, generation plan of geothermal power plants is proposed to the EEP master plan which has a rough plan for geothermal development.

2) Economic Viability

The economic viability of a geothermal plant is evaluated using the economic internal rate of return (EIRR). The EIRR is obtained by cost/benefit analysis using the cost of the geothermal plant as the cost and the cost of the alternative plant (diesel plant) as the benefit. The EIRR is a discount rate at which the present values of the streams of the cost and benefit are equal. The calculated EIRR is compared with the social opportunity cost of capital taken at 10%. The project is economically feasible if the EIRR is 10% or more.

The basic assumptions used for calculating the cost and benefit of the Tendaho-2 (Ayrobera) geothermal plant as an example are summarized as follows:

Table 5.2.8 Basic Assumptions Used for Economic Evaluation of Tendaho-2 (Ayrobera)

Geothermal Plant (Cost)	Alternative Diesel Plant (Benefit)
Installed capacity: 180 MW Plant factor: 90% Station use: 9% Economic life: 30 years Generated energy: 1,419.1 GWh Sales energy: 1,291.4 GWh Construction cost: US$725.0 million (2012 price) O&M cost: US$7.2 million/year (2012 price)	Installed capacity: 229 MW Plant factor: 67% Station use: 4% Economic life: 15 years Generated energy: 1,345.2 GWh Sales energy: 1,291.4 GWh Unit construction cost: US$800/kW (2012 price) Construction cost: US$183.4 million (2012 price) Fuel cost: US$0.171/kWh (2012 price) O&M cost: US$ 0.009/kWh (2012 price)

Source: JICA Project Team

The cost/benefit streams for the top five ranked plants (Tendaho-1, Aluto-2, Tendaho-2, Aluto-3, and Tendaho-3) are appended.

The EIRRs are given in Table 5.2.9 (ranking of geothermal power plants). Out of 18 projects, 16 are economically viable since the EIRRs are more than the hurdle rate of 10%. Two projects (Danab and Arabi) are not economically viable as the EIRRs are below the hurdle rate. As seen from the table, the costs of energy and the EIRRs are perfectly correlated: the lower the cost of energy, the higher the EIRR.

Table 5.2.9 Ranking of Geothermal Power Plants and EIRR

Ranking Order	Geothermal Site	Installed Capacity (MW)	Cost of Genaration ($/kWh)	EIRR (%)
1	Tendaho-1(Dubti)	290	0.0572	31.7%
2	Aluto-2 (Finkilo)	110	0.0585	31.1%
3	Corbetti	1,000	0.0589	-
4	Aluto-3 (Bobesa)	50	0.0592	30.7%
5	Tendaho-2 (Ayrobera)	180	0.0593	30.8%
6	Tendaho-3 (Allalobeda)	95	0.0621	29.1%
7	Aluto-1 (Langano)	75	0.0700	-
8	Abaya	790	0.0717	25.2%
9	Boseti	265	0.0721	25.0%
10	Meteka	130	0.0731	24.7%
11	Dofan	86	0.0783	23.1%
12	Tulu Moye	390	0.1037	17.0%
13	Teo	9	0.1040	17.4%
14	Fantale	120	0.1050	16.7%
15	Dallol	44	0.1076	16.6%
16	Damali	230	0.1084	16.2%
17	Nazareth	33	0.1091	16.2%
18	Boina	100	0.1111	15.8%
19	Danab	11	0.1700	9.9%
20	Arabi	7	0.1872	8.7%
-	Gedemsa	37	-	-
-	Kone	14	-	-

Source: JICA Project Team

3) Site Specific Factors

i) Socio-environmental Impact

Social and environmental impact, except for national park, is taken into consideration for the prioritization.

Environmental and social consideration study was conducted in this study. In the study, and also when the JICA Project Team visited and surveyed the site, it was determined that there may be a potential conflict with local people in the Dofan prospect. Therefore, Dofan is adjusted to be ranked below the level of the economy group.

ii) Accessibility to the National Grid

The required length of transmission line from the geothermal aspects to existing national grid/substation is measured after verification of the exact geothermal manifestation by site survey in this study. Table 5.2.10 shows the length and voltage of the required transmission line and substation which was examined based on the geothermal potential and installed capacity.

The extension of the national grid is to be implemented by EEP; therefore, the cost of the extension is not included in the project cost estimated above. Taking into account the accessibility to the national grid, the prioritization of the geothermal sites is reassessed. However, except for prospects such as Boina, Damali, and Danab, which are located in remote areas, most of the prospects have existing transmission lines and substations within 30 km from the site. In comparison with the construction cost of the geothermal plant, the estimated cost of transmission line is so small that it is not necessary to adjust the prioritization order.

Table 5.2.10 Required Length and Voltage of Transmission Line

	Geothermal Sites	Exsting TL (kV)	Connected Sub-station	Voltage (kV)	TL (km)	Cost (mil $)
1	Dallol	132	Wukro	132	90	23.4
2	Tendaho-3 (AllaloBeda)	230	Semera	230	15	5.6
3	Boina	230	Alamata	230	90	33.3
4	Damali	230	Semera	230	84	31.1
5	Teo	230	Semera	230	68	25.2
6	Danab	230	Semera	230	81	30.0
7	Meteka	66	Amibara	66	95	13.8
8	Arabi	230	Jijiga	230	65	24.1
9	Dofan	66	Amibara	66	7	1.0
10	Kone	132	Metehara	132	27	7.0
11	Nazareth	132	Nazareth	132	8	2.1
12	Gedemsa	230	Koka	230	12	4.4
13	Tulu Moye	132	Assela	132	30	7.8
14	Aluto-2 (Finkilo)	132	Adami Tulu	132	10	2.6
15	Aluto-3 (Bobesa)	132	Adami Tulu	132	13	3.4
16	Abaya	132	Sodo	400	35	19.3
17	Fantale	132	Metehara	132	8	2.1
18	Boseti	132	Nazareth	132	33	8.6
19	Corbetti	132	Shashamene	132	22	5.7
20	Aluto-1 (Langano)	132	Adami Tulu	132	14	3.6
21	Tendaho-1(Dubti)	230	Semera	230	11	4.1
22	Tendaho-2 (Ayrobera)	230	Semera	230	15	5.6

Source: JICA Project Team

iii) Accessibility to the Sites

Similar to the accessibility to the national grid, required access road to the site is measured after site survey in this study, as shown in Table 5.2.11. Taking into consideration the topography along the access road as well as for security measures, cost of civil works for the access road and earthworks in the site is estimated as preparatory work in the construction cost mentioned above.

Because the poor accessibility reflects the generation cost, prospects located in remote areas such as Damali and Danab are evaluated low in the rank order of the generation cost.

Table 5.2.11 Required Length and Topography of Access Road

	Geothermal Sites	Accessibility	Topography	Required Access Road (km)	Cost (mil $)
1	Dallol	Accessible	Rolling	7	3.5
2	Tendaho-3 (Allalobeda)	Good	Plane	12	6.0
3	Boina	Inaccessible	Mountainous	40	40.0
4	Damali	Difficult	Rolling	81	64.5
5	Teo	Difficult	Mountainous	12	12.0
6	Danab	Difficult	Rolling	80	64.2
7	Meteka	Good	Plane	3	1.3
8	Arabi	Difficult	Rolling	35	28.0
9	Dofan	Difficult	Rolling	35	28.0
10	Kone	Good	Plane	4	2.1
11	Nazareth	Good	Plane	2	0.8
12	Gedemsa	Accessible	Plane	19	9.4
13	Tulu Moye	Accessible	Rolling	12	6.0
14	Aluto-2 (Finkilo)	Good	Plane	1	0.5
15	Aluto-3 (Bobesa)	Good	Rolling	2	1.0
16	Abaya	Good	Plane	30	15.0
17	Fantale	Accessible	Rolling	16	7.8
18	Boseti	Good	Rolling	9	4.6
19	Corbetti	Good	Rolling	10	5.1
20	Aluto-1 (Langano)	Good	Plane	0	0.0
21	Tendaho-1(Dubti)	Good	Plane	10	4.9
22	Tendaho-2 (Ayrobera)	Good	Plane	7	3.3

Source: JICA Project Team

5.2.2 Prioritization of the Geothermal Prospects

To sum up the prioritization of geothermal prospects using multi-criteria analysis mentioned above, the prioritization order is summarized as shown in Table 5.2.12.

Table 5.2.12 Prioritization Order of the Geothermal Prospects

Ranking Order	Geothermal Site	Installed Capacity (MW)	Remarks	
Priority-S: Committed Project			COD	Donor
S	Tendaho-3 (Allalobeda)	25	2017	WB
S	Corbetti	500	2018	RG
S	Aluto-1 (Langano)	70	2018	Japan/WB
S	Tendaho-1 (Dubti)-Shallow reservoir	10	2018	AFD
Priority-A: Very High Economy			Energy Cost (US$/kWh)	
1	Tendaho-1 (Dubti)-Deep reservoir	280	0.0572	Deep reservoir
2	Aluto-2 (Finkilo)	110	0.0585	
3	Aluto-3 (Bobesa)	50	0.0592	
4	Tendaho-2 (Ayrobera)	180	0.0593	
5	Tendaho-3 (Allalobeda)	95	0.0621	Expantion
Priority-B: High Economy			Energy Cost (US$/kWh)	
6	Abaya	790	0.0717	RG has license
7	Boseti	265	0.0721	
8	Meteka	130	0.0731	
Priority-C: Low Economy			Energy Cost (US$/kWh)	
9	Tulu Moye	156	0.1037	RG has license
10	Teo	9	0.1040	
11	Damali	92	0.1084	
12	Nazareth	13.2	0.1091	
13	Boina	40	0.1111	
14	Dofan	86	0.0783	Conflict with residents
15	Dallol	44	0.1076	Difficult due to low pH
Priority-D: Less Feasible			Energy Cost (US$/kWh)	
16	Danab	11	0.1700	Poor access
17	Arabi	2.8	0.1872	Poor access
D	Gedemsa	37	-	Low temperature
D	Kone	14	-	Low temperature
D	Fantale	48	-	Overlapped with national park

Source: JICA Project Team

<u>Priority S: Committed Sites</u>

Four projects, the 25 MW Tendaho-3 (Allalobeda), Corbetti, Aluto 1 (Aluto-Langano), and the 10 MW shallow reservoir Tendaho-1 (Dubti), which were already committed by several donors, are prioritized over other sites and are expected to go forward on their schedule.

<u>Priority-A: Very High Economy</u>

Five prospects, the Tendaho-1 (Dubti), Aluto-2 (Finkilo), Aluto-3 (Bobesa), Tendaho-2 (Ayrobera), and Tendaho-3 (Allalobeda), which are assumed to have high temperature geothermal reservoirs and an estimated generation cost of US$0.05-0.06/kWh, are evaluated as next highest priority. Aluto and Tendaho in Priority-A is the most promising and can be prioritized over some of the candidate hydropower projects.

Since Tendaho-1 (Dubti) and Tendaho-3 (Allalobeda) have preceded the project above, an expansion project will be planned to develop the remaining geothermal potential in those sites. Several donors have also planned and conducted geophysical sounding and drilling surveys in those Priority-A sites. In this study, the JICA Project Team conducted magnetotelluric (MT) survey in Tendaho-2 (Ayrobera).

Priority-B: High Economy

Three prospects, i.e., Abaya, Boseti, and Meteka, which are assumed to have 210-260 °C reservoir temperature and an estimated generation cost of US$0.07-0.08/kWh, are categorized as Priority-B. Priority-B has less economic value than Priority-A geothermal prospects and some competitive hydropower plants, but is still more competitive than other renewable energy and thermal power plants.

Abaya has already been licensed by RG. However, development action has yet to be done so far. In addition to Tendaho-2 (Ayrobera), the JICA Project Team conducted MT/transient electromagnetic (TEM) survey in Boseti prospect in this study and the result is explained in the next chapter. In Meteka, no geophysical or drilling survey has been done as of this moment.

Priority-C: Low Economy

Following Priority-B, prospects with US$0.10-0.11/kWh generation cost such as Tulu Moye, Teo, Damali, Nazareth, Boina and Dallol are ranked Priority-C. Dofan's estimated generation cost is US$0.0783/kWh and does not have any serious adverse social impact. However, there is a potential conflict with local people. This is the reason why it is ranked lower in the group. Geothermal fluid in Dallol is highly acidic that geothermal power development is expected to be difficult because the materials and pipes that will be used should be resistant to strong acid corrosion. This is the reason why Dallol is ranked at the bottom of the group as well.

Priority-D: Less Feasible

Danab and Arabi, which are estimated to have more than US$0.17/kWh of generation cost are categorized as Priority-D. Their geothermal potentials are low and accessibilities to those sites are also poor, resulting in very high generation costs.

Kone and Gedemsa are assumed to have very low reservoir temperature in the range of 130-170 °C as mentioned above. Because only binary-type generation system, which is generally much more expensive than flash-type generation system, can be applicable for those two prospects, they are given the lowest priority.

As mentioned above, since Fantale overlaps the boundary of Awash National Park, the prospect is ranked at the bottom of all prospects.

Those prospects evaluated as Priority-D are unfortunately less feasible. If social, environmental, and technical issues are solved in some way in the future, they will become feasible projects.

5.3 Implementation Plan

5.3.1 General Consideration

Development process of geothermal power plant before the start of generation consists of nine stages as shown in Table 5.3.1: preliminary survey, exploration, appraisal drilling and well testing, environmental impact assessment, well/power plant design, well drilling, power station construction and start-up and commissioning.

In the preliminary survey like this study, data collection and surface reconnaissance are carried out and selection of location for exploration stage for MT/TEM survey and geochemical analysis are implemented. Based on these results, appraisal drilling and well testing, followed by simulation analysis, are conducted in order to estimate geothermal potential. From the studies above, the scale and depth of geothermal resources are assumed and size of power plant and its feasibility are discussed from the point of view of economy in the feasibility study. At the same time, the environmental impact assessment (EIA) is conducted. After approval of EIA, well drilling of production and reinjection well and power station construction are started based on the detailed well/power plant design. Construction of transmission line connecting to the geothermal power plant is basically the responsibility of EEP.

Table 5.3.1 Simplified Geothermal Development Period

	Stage	Tasks	year											
			1		2		3		4		5		6	
1	Preliminary Survey	Data collection, Site reconnaissance, Inventory survey, Site selection	↔	↔										
2	Exploration	Geological/Geophisical/ Geochemical survey, Sounding (MT/TEM, Seismic), Pre-feasibility study		↔	↔	↔								
3	Appraisal Drilling & Well Testing	Slim hole, Appraisal well, Well testing, Stimulation,Reservoir simulation				↔	↔	↔						
4	Feasibility Study	Feasibility study					↔	↔	↔					
5	EIA					↔	↔	↔	↔					
6	Well/Power Plant Design	Well design, Power plant deisgn					↔	↔	↔					
7	Well Drilling	Production/Reinjection wells							↔	↔	↔	↔	↔	
8	Power Station Construction	Power plant, Steam gathering system								↔	↔	↔	↔	↔
9	Start-up & Comissioning													★

Source: JICA Project Team

The preliminary survey was carried out for all prospects and geophysical survey (MT/TEM survey) was done in Tendaho-2 (Ayrobera) and Boseti prospects. In Aluto and Tendaho area, MT/TEM survey and exploration well were already carried out while Aluto-l (Aluto-Langano) has started geothermal power generation. Thus, taking into consideration the development status, which allows omitting the preliminary survey and exploration, development plans for each prospect with respect to the fastest case are discussed in the next section based on the model case above.

5.3.2 Development Plan

Table 5.3.2 shows overall schedule of geothermal power development taking into account the fastest case discussed in previous section. In the short-term, a total 610 MW of geothermal power plants committed by several donors is developed. In the medium-term, the geothermal prospects of

Priority-A and -B are aimed to be developed. As mentioned in section 5.2.1, those geothermal power plants above are more economical than wind and solar power. From the point of view of the least-cost power generation, a total 1,200 MW of wind farms and solar power generation plan in EEP master plan should be delayed, and geothermal development should be advanced instead. Therefore, adding to 1,200 MW of the target installed capacity in medium-term, an accumulated total installed capacity in the medium-term is 2,400 MW. In the long-term, other prospects are expected to be developed.

Table 5.3.2 Overall Schedule of Geothermal Power Development

Ranking Order	Prospect	Installed Capacity (MW)	Cost of Generation (US$/kWh)	COD	Year of 20**																							
					Short-term					Medium-term							Long-term											
					14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
S	Tendaho-3	25	-	2017				◎																				
S	Corbetti	500	-	2018					◎																			
S	Aluto-1	75	-	2018					◎																			
S	Tendaho-1	10	-	2018					◎																			
-	Sub-total	610		-				25	610	610	610	610	610	610	610	610	610	610	610	610	610	610	610	610	610	610	610	610
1	Tendaho-1	280	0.0572	2020							◎																	
2	Aluto-2	110	0.0585	2020							◎																	
3	Aluto-3	50	0.0592	2021								◎																
4	Tendaho-2	180	0.0609	2021								◎																
5	Tendaho-3	95	0.0624	2021								◎																
-	Corbetti	500	0.0585	2022	Lisenced by RG								◎															
6	Abaya	790	0.0717	2024	Lisenced by RG										◎													
7	Boseti	265	0.0720	2024											◎													
8	Meteka	130	0.0731	2024											◎													
	Sub-total	2400	-	-							390	715	1215	1215	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
9	Tulumoya	390	0.0974	2027														◎										
10	Teo	9	0.0971	2027														◎										
11	Damali	230	0.1017	2029																◎								
12	Nazareth	33	0.1017	2029																◎								
13	Boina	100	0.1047	2029																◎								
14	Dofan	86	0.0726	2030																	◎							
15	Dallol	44	0.1019	2030																	◎							
16	Danab	11	0.1643	2036																							◎	
17	Arabi	7	0.1907	2036																							◎	
-	Gedemsa	37	-	2036																							◎	
-	Kone	14	-	2036																							◎	
-	Fantale	120	-	2036																							◎	
	Sub-total	691	-	-														399	399	762	892	892	892	892	892	892	1081	1081
total		3701						25	610	610	1000	1325	1825	1825	3010	3010	3010	3409	3409	3772	3902	3902	3902	3902	3902	3902	4091	4091

◎: Commencement of Operation

Source: JICA Project Team

<u>Short-term (2014–2018)</u>

The development plan of Aluto-1 (Aluto-Langano), Tendaho-1 (Dubti), and Tendaho-3 (Allalobeda), which were committed by several donors, and Corbetti, which was licensed by RG, are summarized as shown in Table 5.3.3 below. From 2015 to 2018, a total output of 610 MW from the geothermal power plants will be developed in the short-term in this master plan. Those geothermal development projects are not reflected in the EEP master plan shown in Table 2.3.1. Therefore, it is necessary to revise the development plan in the short- and medium-term based on those projects. The committed geothermal power plants and large-scale hydropower plants under construction, such as the grand renaissance dam, are expected to generate much more electricity than the forecasted electricity demand in the short-term. Therefore, it is considered important to delay development of other electricity sources planned in EEP master plan. However, overall development process of some geothermal projects may be delayed due to the interruption of appraisal drilling. The Ethiopian government should monitor the development process carefully and move ahead with the development plan to meet its reviewed schedule.

Table 5.3.3 Short-term Development Plan

Rank	Site	Installed Capacity (MW)	COD	2014	2015	2016	2017	2018
S	Tendaho-3 (AllaloBeda)	25	2017	ICEAE/NFD/WB				
							Start-up & Comissioning	
S	Corbetti	500	2018	RG				
					Start-up & Comissioning			
S	Aluto-1 (Langano)	75	2018	WB/GoJ				
							Start-up & Comissioning	
S	Tendaho-1 (Dubti)	10	2018	AFD				
							Start-up & Comissioning	
				Development by Donors				

Source: JICA Project Team (Development plan were referred to published documents of several donors)

Medium-term (2019–2025)

According to economic evaluation, the Priority-A and -B prospects are more economical than other power generation schemes such as wind farms and solar power. Therefore, their development should be prioritized over other power generation schemes in terms of least-cost power generation plan. EEP master plan has an expected total of 1,200 MW from wind farms and solar power generation which are not specified projects in the short-term up to 2018. The JICA Project Team would like to propose that wind farms and solar power generation projects that are not specified should be delayed and construction of geothermal power plants, which are mainly planned in the long-term, should be moved forward instead.

Table 5.3.4 presents the geothermal development plan in the medium-term. Priority-A prospects are aimed to be developed by the year 2020 or 2021. Among the Priority-A prospects, Aluto and Tendaho area has some initial development activities such as geophysical exploration and drilling survey in the short-term and there are planned exploration by several donors, such as deep well drilling in Tendaho-1 (Dubti) funded by the *Agence Française de Développement* (AFD), MT survey in Aluto-2 (Finkilo), Aluto 3 (Bobesa), and Tendaho-3 (Allalobeda) by the World Bank (WB) and Icelandic International Development Agency (ICEIDA). Utilizing the results of those activities to shorten the process of Aluto and Tendaho projects, it is possible to start their operation by 2020 to 2021 at the earliest. Boseti and Meteka prospects of Priority-B are planned to start operations in 2025 which is the final year of the medium-term. Since there is sufficient preparation time for those prospects, GSE is expected to carry out detailed exploration to evaluate the possible geothermal resource amount and to plan for a drilling survey at an earlier time.

Table 5.3.4 Middle-term Development Plan

Rank	Site	Installed Capacity (MW)	COD	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
A	Tendaho-1 (Dubti)	280	2020	GSE (ELC) 2013		Preliminary Survey									
				AFD		Exploration (MT survey)									
				AFD		Appraisal drilling (Two Full size well)									
					Feasibility Study/EIA			Financial dicision on the 100MW project at the beginning of 2016							
						Well/Power Plant Design									
							Well Drilling								
							Power Station Construction								
										Start-up & Comissioning					
A	Aluto-2 (Finkilo)	110	2020	JICA	Preliminary Survey										
					ICEADA/NDF		Exploration (MT Survey)								
					Appraisal Drilling & Well Testing										
						Feasibility Study/EIA									
						Well/Power Plant Design									
							Well Drilling								
							Power Station Construction								
										Start-up & Comissioning					
A	Aluto-3 (Bobesa)	50	2021	JICA	Preliminary Survey										
					ICEADA/NDF		Exploration (MT Survey)								
						Appraisal Drilling & Well Testing									
						Feasibility Study/EIA									
						Well/Power Plant Design									
								Well Drilling							
								Power Station Construction							
											Start-up & Comissioning				
A	Tendaho-2 (Ayrobera)	180	2021	JICA	Preliminary Survey										
				JICA	Exploration (MT Survey, etc.)										
					(JICA)		Appraisal Drilling & Well Testing (Slim hole/Full size well)								
						Feasibility Study/EIA									
						Well/Power Plant Design									
								Well Drilling							
								Power Station Construction							
											Start-up & Comissioning				
A	Tendaho-3 (Allalobeda)	95	2021	ICEADA/NDF											
				ICEADA/NDF		Exploration (MT survey)									
					ICEAD/NDF/WB		Appraisal Drilling & Well Testing (25MW Development)								
						Feasibility Study/EIA									
						Well/Power Plant Design									
								Well Drilling							
								Power Station Construction							
											Start-up & Comissioning				
A	Corbetti	500	2022	Development by RG											
												Start-up & Comissioning			
B	Abaya	790	2024	Development by RG											
												Start-up & Comissioning			
B	Boseti	265	2024	JICA	Preliminary Survey										
				JICA	Exploration (MT Survey, etc.)										
									Appraisal Drilling & Well Testing						
										Feasibility Study/EIA					
										Well/Power Plant Design					
												Well Drilling			
												Power Station Construction			
												Start-up & Comissioning			
B	Meteka	130	2024	JICA	Preliminary Survey										
							Exploration								
									Appraisal Drilling & Well Testing						
										Feasibility Study/EIA					
										Well/Power Plant Design					
												Well Drilling			
												Power Station Construction			
												Start-up & Comissioning			

Source: JICA Project Team

Long-term (2026–2037)

Since most of the hydropower potential in Ethiopia is expected to be developed in the long-term and electricity demand is forecasted to exceed 20,000 MW in the early 2030s, more geothermal potential is anticipated to be developed. In this master plan, all geothermal potential is planned to be developed by 2037 as shown in Table 5.3.5.

In this study, characteristics and temperature of geothermal reservoir is evaluated by brief surface reconnaissance and geochemical analysis and by analysis of existing data in some prospects where the site survey is impossible for security and access reason. In order to clarify the scale and temperature of the geothermal reservoir in more detail to discuss their feasibility, it is necessary to carry out the detailed exploration.

Table 5.3.5 Long-term Development Plan

Rank	Site	Installed Capacity (MW)	COD	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
C	Teo	9	2027												
C	Tulu Moye	390	2027												
C	Nazareth	33	2029												
C	Damali	230	2029												
C	Boina	100	2029												
C	Dofan	86	2030												
C	Dallol	44	2030												
D	Danab	11	2036												
D	Arabi	7	2036												
D	Gedemsa	37	2036												
D	Kone	14	2036												
D	Fantale	120	2036												

Source: JICA Project Team

5.4 Financial Considerations for Geothermal Development

This section discusses financing aspect based on several funds. Due to its lack of own funds, the government cannot help but resort to external funds for geothermal development. The JICA Project Team sees four possible sources of funds: Word Bank ODA loans, Japan's ODA loan, commercial banks loans and bonds issue. Their financing conditions (interest rates and repayment periods) are summarized in Table 5.4.1. In this calculation the capital costs are annualized using the interest rate and the repayment period of each fund. This is in contrast with calculation of economic costs of generation in Section 5.2.1 in which the capital costs are annualized using a discount rate of 10% and an economic period of 30 years. Then the financial costs of generation thus calculated (hereafter called 'cost of production') are compared with the tariffs to see which funds are financially feasible. The tariffs might include transmission and distribution costs, but due to their smallness against generation costs and simplicity, the costs of generation are directly compared with the tariffs.

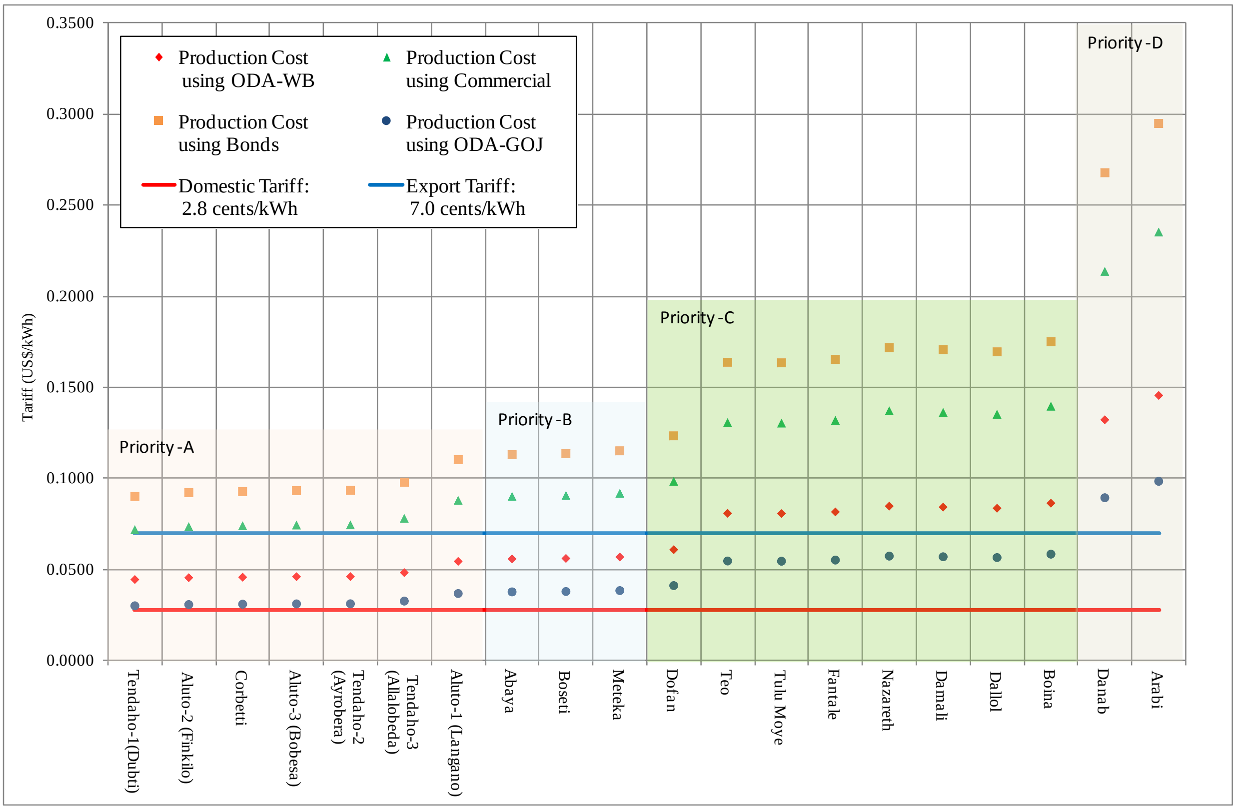
At present, the generation cost by dominant geothermal power plant in Ethiopia is estimated around US$0.05-0.06/kWh. On the other hand, the Ethiopian power market is receiving a large amount of subsidy to suppress the selling price of domestic electricity to about US$0.015-0.04/kWh, average US$0.03/kWh. And electricity has been exported at about US$0.07/kWh to neighboring countries such as Djibouti, based on the PPA between the countries. Figure 5.4.1 shows the comparison with capital costs of each condition and existing power price (consumer price). It is assumed that the existing subsidy would be maintained.

Even the Priority-A geothermal prospects, which is estimated to have the lowest capital cost of US$0.0301/kWh in the case of yen-loan by the Government of Japan (GoJ), has a slightly higher selling price of domestic electricity. On the other hand, the Priority-A and -B prospects are below the export price of US$0.07/kWh in the case of official development assistance (ODA) by WB and GoJ. In the case of loans by commercial banks and bonds, all prospects are over US$0.07/kWh. Thus, the project cost for geothermal development needs to be financed by WB or GoJ loan, or equivalent condition.

Table 5.4.1 Possible Funds Loan Conditions

Item	ODA-WB	ODA-GOJ	Commercial Banks	Bonds
Interest (%)	5.0	3.0	6.0	5.0
Repayment period (year)	20	30	10	7

Source: IDA



Source: JICA Project Team (Fund procurement condition is referred to IDA)

Figure 5.4.1 Tariff and Production Cost using Several Funds

5.5 Implementation Structure

5.5.1 Consideration of Structural Body for Geothermal Energy Development

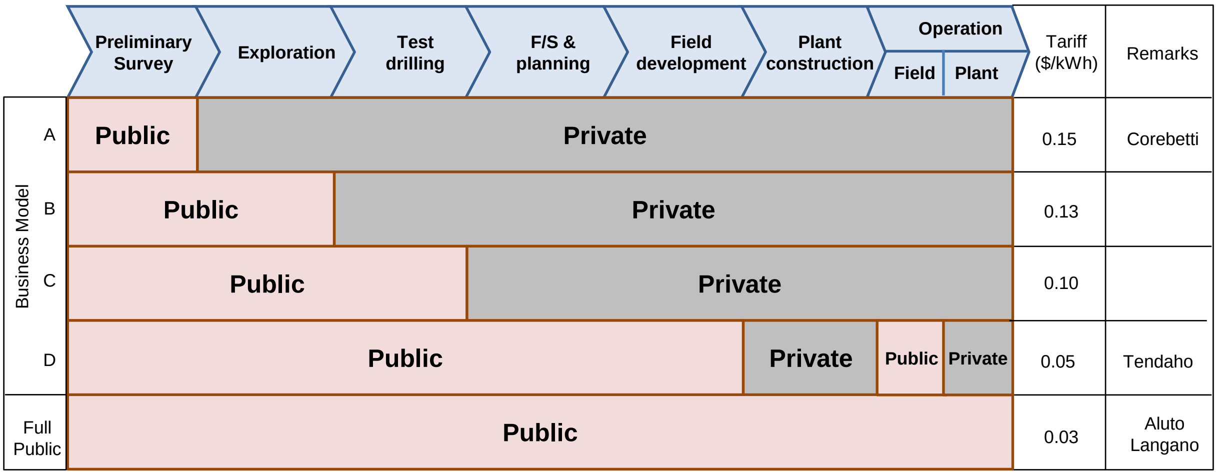
(1) Energy cost and Structural Body

As stated in Chapter 5.4 above, the energy cost in Ethiopia ranges from US$ 0.07-0.08/kWh, whereas the retail electricity price ranges from US$ 0.015-0.04/kWh (average US$ 0.03/kWh). The GoE presently subsidizes this gap. For export, the price is set at US$ 0.07/kWh according to the PPA with Djibouti. Thus, the energy cost of geothermal power generation shall be below the presently adopted electricity retail tariffs under the conditions of the present energy price policy.

IFC conducted a case study where four value chain models for geothermal power generation were assumed, and presented a tariff variation for each case. Tariffs here are defined as the sales tariffs charged for the electricity generated by the geothermal power plant at the delivery point to off-takers (Figure 5.5.1). For the four cases, it was assumed that the private sector will construct and conduct operation and maintenance (O&M) of the power plant, except for the case of the fully public model.

- For the US$ 0.15/kWh tariff level, a full private model (except for pre-survey) may be used,
- For the US$ 0.12-13/kWh levels, the private sector may enter at the test drilling stage,
- For the US$ 0.10/kWh level, private entry after the test drilling stage may be possible,
- For the US$ 0.05/kWh level, all the upstream activities should be undertaken by the government, leaving the power plant construction and operation to the private sector, and
- For the US$ 0.03/kWh level, only the fully public model may be used.

With the current tariff levels, possible and sustainable options are a fully public model for the domestic supply project, and Models C or D for the export supply project. However, it will be a reasonable option wherein geothermal power plants will be used for domestic use rather than hydropower, which is susceptible to seasonal fluctuations. Therefore, fully public model may be the best option for geothermal energy development.



(Source) IFC

Figure 5.5.1 PPP Model Options and Tariff

(2) Pros/Cons Analysis of GSE and EEP and Proposal of New Organization

The Business Models C or D and fully public model will only be sustainable under the present national electricity price policy. Under these models, public entities shall conduct work up to at least the test well drilling stage. Presently, GSE and EEP are the only public entities that could undertake the mandate. The IFC (International Finance Cooperation) of a World Bank Group presented a pros/cons analysis of these entities. The analysis also assumes a new entity. A summary of the analysis is as follows:

1) Pros/Cons Analysis of GSE and EEP

Pros/cons analysis for surface survey and test drilling are as follows:

- The existing GSE has legal mandate to undertake geotechnical investigation and exploration activities. The GSE geothermal directorate is especially dedicated to geothermal development. They have limited experience and/or insufficient resources in terms of manpower and equipment.
- The existing EEP is presently involved in Aluto and Tendaho projects. They have no legal mandate for geothermal development. The commercially operating EEP might be unmatched with high risk exploration works.
- A new, special purpose entity (presently non-existing) with mandate to focus on geothermal resources may address all the shortcomings of the two existing entities and accelerate rapid geothermal development, although it requires new laws and regulations that may take time to set up.

Pros/cons analysis for field development:

- The existing GSE has test drilling experience although manpower and financial capabilities are limited.
- The existing EEP is willing to do field development in Aluto-Langano and may be able to raise funding easily, although they do not have sufficient manpower, equipment, and technical

experience.

- A new, special entity (presently non-existing) may rapidly accelerate geothermal development.

2) Restrictions of Existing Organizations and Proposal of New Special Purpose Entity

Figure 5.5.2 summarizes various options of models C, D, and fully public model. Figure 5.5.2 includes the case where one unified entity undertakes production and sale of steam as well as power generation because there are similar cases all over the world including GDC in neighboring Kenya. Examples were explained in the latter part of this section as reference. On the other hand, a fully private model such as the one that is being operated in Corbetti is not included because the overall business model is not clearly announced at this stage.

An analysis is described below in accordance with Figure 5.5.2.

- Since the existing GSE is responsible only for geoscientific research activities, GSE may not undertake production well construction and the work thereafter. Therefore, an amendment of the existing laws and/or regulations shall be necessary for Option D-1 and Option FPc-1. Similarly, since the existing EEP is responsible for generation, transmission, and distribution of electricity, they may not undertake geoscientific survey in Option D-3 and Option FPc-3 without amendment of existing laws and/or regulations. However, even if the relevant laws and/or regulations were to be amended, the following issues shall be addressed.

- Even though it is not necessary to get a mandate from the Ministry of Water, Irrigation and Energy, EEP is undertaking confirmation well drilling in Aluto-Langano. This corresponds to Models D-2 or FPc-2. In the Project, the actual drilling works are conducted by GSE in the field under the project manager from EEP. Possibly due to insufficient EEP experience in geothermal development management, the project tended to be behind schedule. Therefore, it is indispensable that EEP capacity shall be enhanced for geothermal development if these options are to proceed.

- However, such capacity enhancement will result in competing or duplicating mandate against GSE under the Ministry of Mines. Therefore, coordination or cooperation will be indispensable between the two public entities. That being said, however, coordination/cooperation of two entities, each under different ministries, will usually be difficult. Thus, it is recommended that geothermal-related sections of those two entities shall be merged into one public entity.

- Such new entity shall be formed under the Ministry of Water, Irrigation and Energy because the main purpose of geothermal development is for electricity development. There will be two options: the first option is to merge them under EEP and the other is to establish a new entity outside EEP. The first option may not be suitable because: (i) EEP is presently undertaking large-scale hydropower projects so vigorously that geothermal development priority will be kept low, and (ii) the commercially operating EEP might be unmatched with high risk exploration works, which may render management complicated. All of these may hinder smooth development of geothermal energy.

- From the above analysis, it is recommended to establish a new special purpose entity that undertakes geothermal energy development-related services, under the Ministry of Water, Irrigation and Energy.

Development Stage		Early: Preliminary Survey	Early: Exploration	Early: Test Drilling	Early: F/S, Planning	Middle: Field Development	Late: Power Plant Construction	Late: Operation	Off-taker: EEP	Notes
Business Model-C	C1	GSE (or New Enterprise)			Private		Power Plant: Private Steam: Private		EEP	-
	C2	GSE (or New Enterprise)			Private		Power Plant: EEP Steam: Private		EEP	-
Business Model-D	D1	GSE			GSE(*)		Power Plant: Private Steam: GSE(*)		EEP	(*)GSE is not in charge of Field development and/or Steam sales
	D2	GSE			EEP		Power Plant: Private Steam: EEP		EEP	-
	D3	EEP(*)			EEP		Power Plant: Private Steam: EEP		EEP	(*) EEP is not in charge of exploration
	D4	New Enterprise					Power Plant: Private Steam: New E.		EEP	-
Fully Public Model	FPc-1	GSE			GSE(*)		Power Plant: EEP Steam: GSE(*)		EEP	(*)GSE is not in charge of Field development and/or Steam sales
	FPc-2	GSE			EEP		Power Plant: EEP Steam: EEP		EEP	*Present Aluto Langano Project*
	FPc-3	EEP(*)			EEP		Power Plant: EEP Steam: EEP		EEP	(*) EEP is not in charge of exploration.
	FPc-4	New Enterprise					Power Plant: EEP Steam: New E.		EEP	-
	FPc-5	New Enterprise					Power Plant: New Steam: New E.		EEP	-

D1, D3, FPc1, FPc3: Amendment of regulations for GSE and EEP is required (D1, D3, FPc-1, FPc-3)
D2, FPc3: EEP Capacity for geothermal development shall be enhanced, GSE and EEP shall be well coordinated (D2, FPc-2)
D4, FPc-4, FPc-5: In Model-D, FPc-4 and FPc-5, the New Enterprise will undertake steam prodution and sales.
C1, C2: In Model C1 and C2, the New Enterprise may handle the work upto Test Drilling

Source: JICA Project Team

Figure 5.5.2 PPP Models for Geothermal Development in Ethiopia

5.5.2 Special Purpose Public Entity (Enterprise)

(1) Establishment of Special Purpose Public Entity (Enterprise)

The recommended new special purpose entity is temporarily named as Ethiopian Enterprise for Geothermal Energy Development (EEGeD). The business models of EEGeD are the Models D-4, FPc-4, and FPc-5. EEGeD could deal with the Model C-1 and C-2, if the private sector will undertake the operation from the start of field development. As can be seen from the figure, the mandates of EEGeD may be as follows:

- To undertake the geothermal resource surface survey and test drilling,
- To undertake project feasibility study when necessary for future business of EEGeD,
- To undertake field development wherever possible, and

- To operate steam production and sales wherever possible.

However, the current move to privatization will likely become more evident in the future with various financial and/or regulation arrangements. Therefore, the establishment of EEGeD shall not hinder the private sector from participating in geothermal development at any stage.

There may be a possibility that EEGeD may extend its operation to power generation. However, it may be prudent that the mandate of EEGeD should be concentrated to geothermal-related matters since even this mandate necessitates highly specialized knowledge and experience.

The merits of forming EEGeD are as follows:

- EEGeD will be able to concentrate its efforts to geothermal development mainly for the purpose of electricity generation;
- EEGeD will also be able to accumulate its knowledge and experiences within the organization, which will accelerate geothermal development; and
- EEGeD, as the single focal point for geothermal development in Ethiopia, will be able to attract donors' attention, which will make financial arrangement much easier.

(2) Establishment of EEGeD

The new geothermal-specialized public entity EEGeD shall be financially sustainable once it becomes a fully-fledged operation. It is for this reason that EEGeD shall undertake steam production and sales, thereby ensuring stable revenue. It is understood that a public entity in Ethiopia named "Enterprise" is defined to be financially sustainable.

Designing of a proper institutional and regulation framework and formulation of implementation plan of the new enterprise EEGeD will be necessary. A master plan project will be proposed in Chapter 9 in this report.

5.6 On Direct Use of Geothermal Resources

5.6.1 Present Status of Geothermal Resource

(1) Direct Uses of Geothermal Resources in the World and in Japan

Table 5.6.1 shows the present status of direct uses of geothermal resources in the world and in Japan

Geothermal resources are widely used for bathing/pools, indoor heating, and greenhouses in the world whereas there are only nominal uses for others. On the other hand, it is used in Japan largely for bathing – Onsen bathing followed by snow melting.

Table 5.6.1 Present Status of Geothermal Direct Uses in the World and in Japan

Geothermal Direct Uses	World (15,346 MW)	Japan (2,100 MW)
Bathing/swimming pool	44%	87%
Heating	35%	4%
Greenhouses	10%	2%
Fish farming	4%	0%
Industrial utilization	4%	0%
Space cooling/snow melting	2%	7%
Agricultural drying	1%	0%

Source：Lund et al. (2010)

(2) Direct Uses of Geothermal Resources in Ethiopia

In Ethiopia, geothermal resources are used by local people mainly for hot spring or steam bathing. In Sodole, there is are large-scale state operating recreational facilities; and hot spring bathing facilities are available in Addis Ababa and in the southern part of Ethiopia. In Nazareth (Boku), there is a state operating sanitarium facility, and there are local steam bathing locations in the surveyed area.

Table 5.6.2 Geothermal Direst Use

	Sites	Direct User
1	Gedemsa (Hippo Pool)	There are bathing facilities that draw water from nearby hot springs. Local residents use them for hot spring curing and washing as well.
2	Nazareth (Boku)	There are small rooms above the fumaroles for vapor bathing and cure. There is a state operating accommodation. The whole area is prepared as recreation area or sanitarium facility.
3	Nazareth (Sodole)	The whole area, including hot springs, is utilized as a recreation center and tourist attraction, where swimming pool and bathing facilities are equipped with restaurants and accommodations.
4	Boseti (Kintano)	The fumaroles are covered by rock fences. They are utilized as steam baths.
5	Meteka	There are bathing facilities utilizing nearby hot springs. Local residents use them for hot spring curing.
6	Bobessa (Gebiba)	People gather water by covering the fumarole with tree branches for cooling the vapor into water.

Source: JICA Project Team

	
Gedemsa (Hippo Pool)	Nazareth (Boku)
	
Nazareth (Sodole)	Boseti (Kintano)
	
Meteka	Aluto-2 (Bobessa: Gebiba)

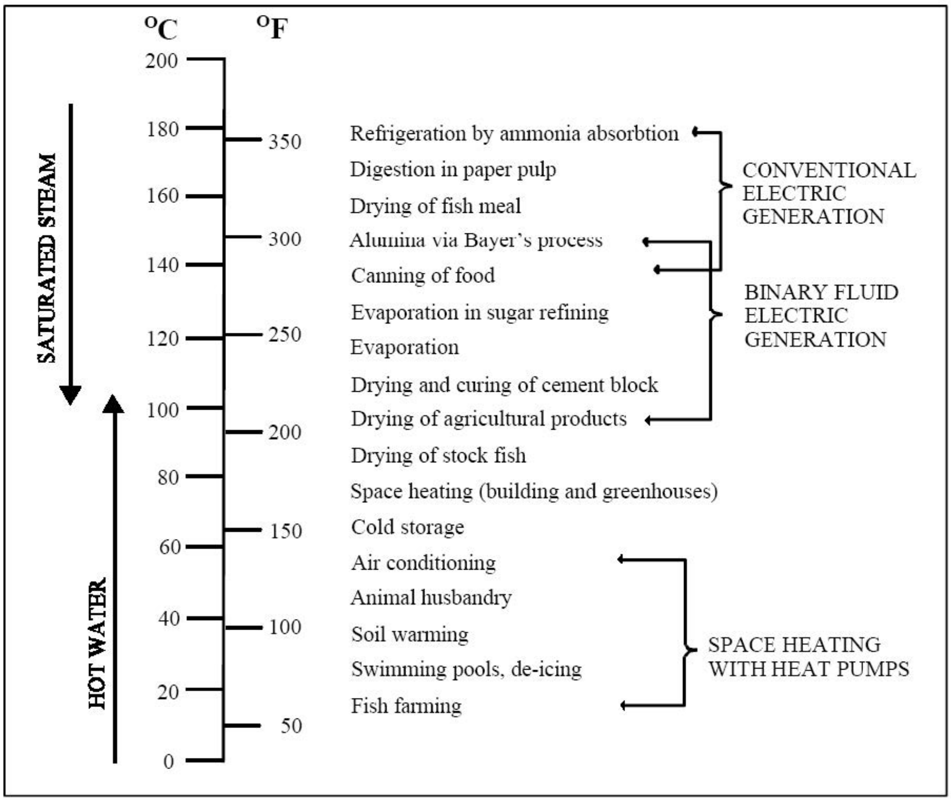
Source: JICA Project Team

Figure 5.6.1 Geothermal Resource Direct Use in Ethiopia

5.6.2 Proposals for Direct Uses of Geothermal Resources in Ethiopia

(1) Lindal Diagram

The general application guidelines for direct uses of geothermal resources are systematized as Lindal Diagram (Jon S. Gudmundsson, etc., 1985). Hot spring not hotter than the body temperature is used for fish farming and swimming pools. Temperatures between the body temperature and 100 ℃ are used for space heating including greenhouse and drying of agricultural products and stock fish. Vapor above 100 ℃ can be used for various applications such as drying of industrial products like cement and agricultural products like sugarcanes.



Source : Jon S. Gudmundsson, others (1985)

Figure 5.6.2 Lindal Diagram

(2) Proposal of Direct Use in Ethiopia

The following table shows the proposals for direct uses of geothermal resources in Ethiopia based on the consideration of the existing geothermal site conditions and the current utilization of geothermal resources.

Table 5.6.3 Proposals for Direct Uses of Geothermal Resources in Ethiopia

Direct uses items	Contents	Conditions	Areas
Gardening Greenhouses	Greenhouse flower growing (export)	Suitable water available (effect: constant temperature, sterilization, photosynthesis)	Ziway lake (Aluto-Langano, Tulu Moye)
Fish farming	Farming of prawns and fresh water fish (export)	Suitable water available	Ziway Lake (Aluto-Langano, Tulu Moye)
Agriculture	Fruits growing (export) Vegetable growing （domestic）	Suitable water available Near large market	Ziway Lake (Aluto-Langano, Tulu Moye) Nazareth
Leisure and recreation	Hot spa, pool, steam bath	Easily accessible	Geothermal site
Food processing	Dry fruits	Close to fruit production area	Geothermal sites in Oromia, Southern Nation
	Yogurt	Close to milk production area Near large market	Nazareth Boseti
	Coffee beans drying	Close to coffee plantation	Geothermal sites
	Sugarcane drying	Close to sugarcane plantation	Geothermal site Tendaho

Source: JICA Project Team

In addition, cascade utilization will be applicable if the geothermal source is sufficiently hot.

5.7 [REFERENCE] Models of Geothermal Power Development in International Practice

5.7.1 International Practice

Figure 5.7.1 (R.1) shows models of geothermal power development in international practice. In many cases, public financing is applied up to field development stage. After confirmation of geothermal resources, private firms participate in the value chain. However, the following characteristics are commonly observed in countries where private firms have participated in the chain (ESMAP 2012).

- Open market has successfully been implemented in power generation businesses other than geothermal power generation. Parts of or all power generation businesses have been privatized.
- Country investment risks are commonly evaluated low and sufficient returns can be ensured.
- Central government of local governments promote private investment.

In general, the countries in this group are mostly middle- and high-income countries or countries with well-understood geothermal resources and established track record in developing them.

	1	2	3	4	5	6	Note
	Preliminary Survey	Surface Exploration	Test Drilling, F/S	Field Development	Power Plant Construction	O&M	
	Early Stage			Middle Stage	Late Stage		
1	A Fully integrated single national public entity						Kenya(KenGen at Olkaria), Costa Rica (ICE), etc
2	Multi national public entities (Early stage by one entity and subsequent stage by other/s for an example)						Indonesia (before), New Zealand, Ethiopia (Aluto Langano) etc
2'	Public entity (CFE)				Private Contractor	CFE	Mexico (OPF model)
3	National and municipal public entities						Iceland (before the crisis)
4	Fully integrated JV partially owned by the government						El Salvador (LaGeo + Enel Green Power), Japan(recent)
5	Public entities			Private Developers			Japan（before)
5'	Public entity (PNOC EDC)				Private Developer	NPC	Philippines BOT model;
5"	Public entities (GDC in Kenya, Purutamina in Indonesia)				Public entities (Steam production) Private Developers (power generation)		Kenya (KenGen+GDC), Indonesia (before), Philippines (before)
6	Public entities			Private Developers			US; new IPP Project in Turkey, New Zealand, Guatemala and others
7	Public entities		Private Developers				US, Nicaragua and recently Chile; Public entities perform limited exploration. IPPs share the risks of further exploration and construction
8	Private Developers						New Philippines (Chevron project), Australia and Italy (Enel Green Power), New Indonesia with Geothermal Fund Facility, Ethiopia (Corbetti), Japan (recent)

ICE: Instituto Costarricense de Electricidad, Costa Rica; CFE: Federal Commission for Energy, Mexico; PNOC EDC: Philippines National Oil Co.,-Energy Development Corporation, Philippines; NPC: National Power Corporation, Philippines; GDC: Geothermal Development Company, Kenya;

(Original Source: ESMAP 2012, modified by JICA Team)

Figure 5.7.1 (R.1) Models of Geothermal Power Development in International Practice

5.7.2 Example of Kenya

Since 2006, segregation of power generating sector has been implemented into various specialized organizations for achieving efficient operations in Kenya. Power generation is being conducted by

Kenya Electricity Generating Company (KenGen) that owns 72% of installed capacity (as of 2012) and other IPPs whereas the off-taker is Kenya Power and Lighting Company (KPLC). As for geothermal development, the Geothermal Development Company (GDC) was established in 2008 as a governmental special purpose vehicle that undertakes exploration and steam production as well. GDC was separated from KenGen and was given the mandate to undertake the specialized but high-risk task of geothermal development, whereas KenGen should concentrate its effort on power generation only so that the electric sector itself could be more efficient.

GDC has been designed so that it gains revenue through steam production and sales. Figure 5.7.2 (R.2) shows the general operational model of GDC. Option K-1 of GDC corresponds to the Business Models D-4 and/or FPc-4; Option K-3 corresponds to the Business Model C-1 and/or C-2. At present, field development is being undertaken in Menengai Geothermal Field of Kenya with Options K-1 and K-2. It is understood GDC has already entered steam supply agreement with three IPPs (Quantum Power East Africa, Orpower Twenty Two, and Socian Energy) and scheduled to commence steam supply by the end of 2015.

GDC PUBLIC PRIVATE PARTNERSHIP - OPTIONS

<table>
<tr><td colspan="2" rowspan="3">IPP INPUT
DEVELOPMENT STAGE</td><td>K-1</td><td colspan="2">K-2</td><td>K-3</td><td>K-4</td><td>K-5</td></tr>
<tr><td colspan="3">In operation at Menengai</td><td colspan="3">Optional</td></tr>
<tr><td>POWER GENERATION</td><td colspan="2">JOINT STEAM DEVELOPMENT</td><td>PRODUCTION DRILLING AND POWER</td><td>STEAM DEVELOPMENT AND</td><td>FULL CONCESSION</td></tr>
<tr><td rowspan="5">VIABILITY ANALYSIS</td><td>DETAILED SURFACE STUDIES</td><td rowspan="7">GDC</td><td colspan="2" rowspan="2">GDC</td><td rowspan="5">GDC</td><td rowspan="3">GDC</td><td rowspan="9">IPP</td></tr>
<tr><td>INFRASTRUCTURE DEVELOPMENT</td></tr>
<tr><td>EXPLORATION DRILLING</td><td rowspan="5">GDC</td><td rowspan="5">IPP</td></tr>
<tr><td>APPRAISAL DRILLING</td><td rowspan="6">IPP</td></tr>
<tr><td>FEASIBILITY STUDY</td></tr>
<tr><td rowspan="3">IMPLEMENTATI</td><td>PRODUCTION DRILLING</td><td rowspan="4">IPP</td></tr>
<tr><td>STEAM GATHERING</td></tr>
<tr><td>POWER PLANT CONSTRUCTION</td><td rowspan="2">IPP</td><td colspan="2" rowspan="2">IPP</td></tr>
<tr><td rowspan="2">INCOME</td><td>OPERATION AND MAINTENANCE</td></tr>
<tr><td>STEAM FIELD MANAGEMENT</td><td colspan="6">GDC</td></tr>
</table>

GDC: Geothermal Development Company; IPP: Independent Power Provider (Source: GDC 2014, slightly modified by the JICA Project Team)

Figure 5.7.2 (R.2) Operation Option of GDC, Kenya

5.7.3 Example of Geothermal Development in the Philippines

Geothermal development in the Philippines dates back to 1967 when small-scale geothermal power stations were constructed in Barrio Cale, Tiwi, and Albay. Full-fledged development was implemented in Tiwi and Makban (660 MW, 1979-1984) in Luzon, which the National Power Corporation (NPC) constructed through the then Philippine Geothermal Incorporated. Since then, geothermal power stations were constructed mainly by the Philippine National Oil Company–Energy Development Corporation (PNOC-EDC), i.e., Palinpinon I (112.5 MW, 1983), Tongonan （112.5 MW, 1983), Bacon-Manito (150 MW, 1994), and Palinpinon II (80 MW, 1992). In principle, PNOC–EDC undertook the development from initial surface survey to steam production and sales whereas NPC undertook power generation, except a few cases where PNOC–EDC also generated electricity.

In 2001, "The Electric Power Industry Reform Act" was enacted, whereby NPC was then privatized, followed by the step-by-step privatization of PNOC–EDC from 2006. As a result, all the geothermal power stations including Tiwi-Makban, were sold to private firms. However, the separate operational model, i.e., steam production and sales business and power generation business have been maintained in many geothermal power stations. The last power stations developed by the government-owned PNOC–EDC was Mindanao II (54 MW, 1999) and Northern Negros (49.4 MW, 2007). At the former power station, the privatized EDC continues to supply steam to a build-operate-transfer (BOT) power generation company, and the latter has been closed down due to insufficient geothermal resource.

After privatization, there have been no particular geothermal development activities for a long time until 2014, when the Maibarara Geothermal Power Station (20 MW) in Luzon was put into operation. A power station (40 MW) in Mindoro is also reported to be operational in 2015[3].

In conclusion, PNOC-EDC, before privatization, had largely contributed to the geothermal development in the Philippines.

Hereunder, the operation mode of PNOC–EDC and NPC before privatization is introduced, since business circumstances in Ethiopia may be similar to that of the Philippines when geothermal power stations were constructed[4].

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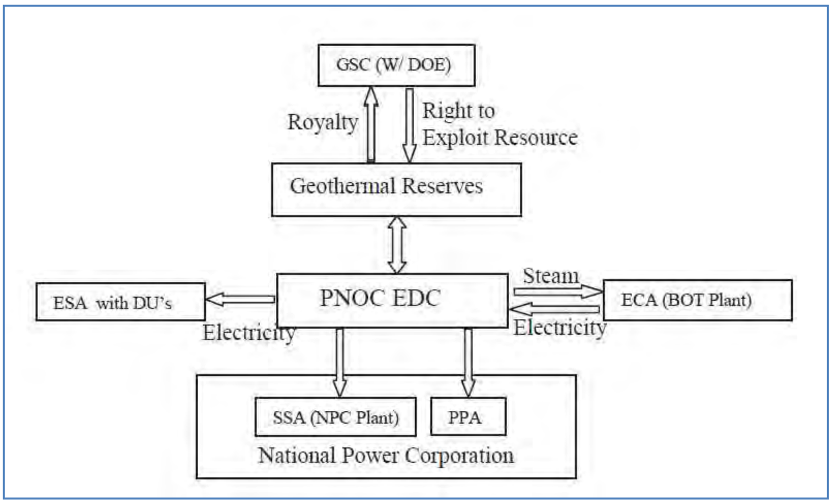
[3] Newspaper of IEE JPAN, 5th December, 2014

[4] Danilo C. Catigtig (2008), Geothermal Energy Development in the Philippines with the energy development corporation embarking into power generation, UNU-GTP 30th Anniversary Workshop



Source: Danilo C. Catigtig 2008

Figure 5.7.3 (R.3) Operation Mode of PNOC EDC in the Philippines

The operation mode in the Philippines is explained by Danilo C. Catigtig (2008) as follows:

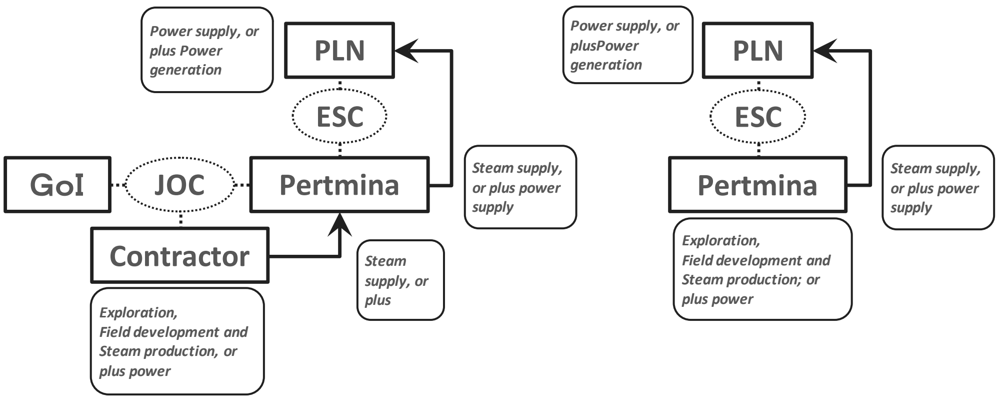
The company's steam field and power plant operations are based on a framework that covers four types of contracts, from which its financial position is practically hinged:

- Geothermal Service Contracts (GSC) with the Department of Energy (DOE) - give EDC the right to explore, develop, and utilize geothermal resources in a certain contract area and in turn remits to the government taxes and royalties from the net proceeds;
- Steam Sales Agreements (SSA) with NPC - EDC delivers and sells steam to NPC power plants for conversion to electricity with a minimum take or pay provision;
- Power Purchase Agreements (PPA) with NPC - EDC sells to NPC electricity with a minimum energy off-take level provision;
- Energy Conversion Agreements (ECA) with BOT contractors - EDC delivers steam to the BOT power plant and pays the contractor for the conversion of steam to electricity at a nominated capacity; and
- Energy Sales Agreement with cooperatives and DU's - EDC sells electricity from its own merchant plant.

5.7.4 Example - Indonesia

Geothermal development in Indonesia has been developed in accordance with Presidential Decree 45 (PD-45, 1991) in principle, followed by various amendments of laws/regulations. Geothermal power generation is being conducted in ten sites out of 58 geothermal areas designated by the Ministry of Energy and Mines, as of 2014. All major sites, except for a remote island, were initiated under the framework enacted by the decree. PD-45 (1991) is illustrated in the figure below:

1. PERTAMINA and its joint operations contractors to develop and operate the steam field only, selling the steam to PLN or other parties for electricity.
2. PERTAMINA or its contractors to generate electricity as well as develop and operate the steam field, with the electricity produced sold to either PLN or other consumers.



Source: JICA Project Team

Figure 5.7.4 (R.4) Geothermal Development Model before Privatization in Indonesia

The principal characteristic of the operations model is that steam development is undertaken by PERTAMINA or a contractor who entered into a Joint Operation Contract (JOC) with PERTAMINA. Although PERTAMINA was privatized in 2003, the presently operating geothermal power stations in Indonesia were initiated by the then nationally-owned PERTAMINA through resource confirmation. This is obvious in Table 5.7.1 (R.1), which shows that steam production of all the power plants that are presently operational or to be operational are PERTAMINA-related companies except for two small power stations in the remote island of Flores. In other words, no private firms other than PERTAMINA-related firms have participated in test wells and steam development.

In 2011, the Government of Indonesia set up the Geothermal Fund Facility to attract private investment for test well drilling activities. By 2013, geothermal survey license for 32 prospects was given to developers. However, no report has reached the JICA Project Team if any test well has been drilled in any of the 32 geothermal prospects.

From the above, it is obvious that the nationally-owned PERTAMINA played a very important role in the development of geothermal energy in Indonesia.

Table 5.7.1 (R.1) Geothermal Power Stations Operational in Indonesia (as of 2015)

No.	Name	Province	Capacity (MW)	DOC	Steam Production	Power Generation	JOC/ESC
1	Kw. Kamojang,	West Java	30	1983	PT. PGE	PLN	JOC, ESC
			55x2	1988			
			60	2008	PT. PGE		(PPA)
2	Kw. Darajat	West Java	55	1994	PT. Chevron	PLN	JOC, ESC
			90	2000	PT. Chevron		JOC, ESC
			110	2007	PT. Chevron		(PPA)
3	G. Wayang Windu	West Java	110	2000	PT. Star Energy		JOC, ESC
			117	2009	PT. Star Energy		(PPA)
4	G. Salak	West Java	60x3	1994	PT. Chevron		JOC, ESC
			65	1997			
5	G. Dieng	Central Java	60	1999	PT. Geodipa		JOC, ESC
6	G. Sibayak	North Sumatra	2	1996	PT. PGE		ESC
			5	2007	PT. PGE		(PPA)
			6	2007			
7	Sarulla	North Sumatra	(330MW)	(2016)	Consortium		JOC, ESC
8	Kw. Ulubelu	Lampung	55x2	2012	PT.PGE	PLN	ESC
			55	(2016)	PT.PGE	PLN	(PPA)
			55	(2017)			
9	Kw. Lahendon	North Sulawesi	20	2001	PT. PGE	PLN	ESC
			20	2007	PT. PGE	PLN	(PPA)
			20	2009			
10	Kw. Ulumbu	West Flores	5	2014	PT. PLN		-
11	Kw. Mataloko	Central Flores	1.8	2011	PT. PLN		-

Source: Based on Asnawir Nasutionm and Endro Supriyanto (2011), edited by the JICA Project Team with information of "Geothermal Power Generation in the World 2010-2014 Update Report" (Ruggero Bertani 2015) and others. Shaded: after privatization of PERTAMINA;
DOC: Date of Commencement

CHAPTER 6 GEOPHYSICAL SURVEY

6.1 Objectives

The Project Team conducted geophysical survey at two selected sites in order to provide information for selecting test well targets.

6.2 Selection of the Target Sites

Two sites for the geophysical survey were selected from the 22 targets sites based on the following criteria. Through the Master Plan formulation in the Chapter 5, Tendaho-2 (Ayrobera), Boseti and Meteka were selected as high priority sites to be developed other than those sites that have been already committed by other donors or a private firm. Among those, we selected Tendaho-2 (Ayrobera) and Boseti for the geophysical survey. We expect GSE to conduct the survey in Meteka using equipment newly provided by JICA for the survey.

6.3 Selection of the Target Sites

The geophysical survey conducted consisted of MT (Magnetotelluric) survey and TEM (Transient Electromagnetics) survey.

・Survey Method

MT method with far remote reference site
TEM method with central loop system （for static correction of MT data）

・Survey Site

Tendaho-2 (Ayrobera) site and Boseti site

・The number of stations

Tendaho-2 (Ayrobera) site: 24 stations, Remote reference station at Mille
Boseti site: 30 stations, Remote reference station at Koka

・Acquired data

MT method: 3 components of magnetic field 3 (Hx, Hy, Hz) and 2 components of electric field (Ex, Ey) in time series data (Measurement time: More than 14 hours per one station)
TEM method: 1 component of magnetic field (Hz) of transient response

・The number of frequency for data processing and analysis

MT method: 80 frequencies in the range of 320Hz ~ 0.00034Hz
TEM method: 3 kinds of repeat rate 237.5Hz, 62.5Hz and 25.0Hz

6.4 Survey Results

The location map and the station map of the MT/TEM survey for each survey area are shown in Figure 6.4.1, Figure 6.4.2, and Figure 6.4.3. The list of coordinates of the stations is shown in Appendix-6.

6.4.1 Tendaho-2 (Ayrobera) Geothermal Field

(1) MT Survey

After the acquired data were processed using the remote reference technique, the apparent resistivity and phase curves were created, and the data quality of each measuring station evaluated. At almost all stations, the data quality from high frequencies to low frequencies was good. Though at some stations the apparent resistivity curve shows a little scattering in local reference data processing, noises were reduced and data quality was improved after remote reference data processing.

After 2D inversion analysis was carried out at eight profiles, as shown in Figure 6.4.2, which consist of two profiles where the MT survey was conducted in the Project and the six existing profiles from past MT surveys, the resistivity structure was obtained and the resistivity cross sections were created. According to the results, the resistivity plan maps and the corresponding panel diagram were created. Figure 6.4.4 shows the panel diagram of the resistivity plan maps. The resistivity cross sections, the resistivity plan maps, and the fit of the observed data and model responses are attached in Appendix-6.

The main resistivity features of Tendaho-2 (Ayrobera) as revealed from the MT survey are as follows:

- About the surveyed site, the resistivity structure is generally composed of three zones, namely, conductive overburden, resistive zone, and conductive zone, from the surface to 5,000 m depth. The resistivity distribution is roughly in the range of 1 ohm-m to 250 ohm-m.
- At 200 m elevation, low resistivity (≤ 16 ohm-m) is widely spread all over the surveyed site. Moreover, very low resistivity (≤ 3 ohm-m) is widely prevalent at the southwest part and southeast part.
- At 0 m elevation, low resistivity is widely spread all over the site, similar to that at 200 m elevation and the resistivity value becomes lower. Resistivity at the southern part is relatively low.
- At -700 m elevation, a low resistivity (≤ 16 ohm-m) belt is at the center of the site. Especially at the center of the belt, the resistivity is lower at less than 6 ohm-m. High resistivity of more than 40 ohm-m can be found outside the conductive belt and high resistivity variation is exhibited around the border of the conductive belt. The almost straight contour lines indicate resistivity discontinuity structure.
- At -1,500 m elevation, the conductive belt of NW-SE strike direction is recognized similar to that at -700 m elevation. Comparing with -700 m elevation, the distribution pattern is similar and the

resistivity values are entirely higher.

- At -2,500 m elevation, similar to that at -700 m and -1,500 m elevations, the conductive belt of NW-SE strike direction is recognized at the center of the site. The difference from that at -1,500 m elevation is that the resistivity value of the conductive belt is more than 40 ohm-m.

- The width of the conductive belt which is distributed from -700 m elevation to the deep zone does not change generally and the conductive belt composes a channel structure of low resistivity to the deep zone. That channel structure of low resistivity is rather narrow in width and shows a little constriction around profile TDO97.

- The NE-SW strike direction is clearly recognized from the shallow zone to the deep zone except for surface ground in each resistivity plan map.

(2) Summary

The characteristics of the resistivity structure in the surveyed site are summarized in Table 6.4.1.

Table 6.4.1 Summary of MT/TEM Survey at Tendaho-2 (Ayrobera)

Item	Descriptions
Resistivity Structure	Composed of three zones, namely, conductive overburden, resistive zone and conductive zone, from the surface to -5,000 m elevation.
Resistivity Value	Ranges from 1 ohm-m to 250 ohm-m
Resistivity Discontinuity	The conductive belt of NW-SE direction is distributed from -700 m elevation to the deep zone and composes the channel structure of low resistivity at the center of the site.
	The resistivity discontinuity structure is indicated by the resistivity variation between the channel structure composed of the distribution of low resistivity and high resistivity.
	The channel structure of low resistivity is rather narrow around the profile of TDO97. This suggests resistivity discontinuity across the channel structure.

Source: JICA Project Team

6.4.2 Boseti Geothermal Field

(1) MT Survey

After the acquired data were processed using the remote reference technique, the apparent resistivity and phase curves were created and the data quality of each measuring station evaluated. At almost all stations, the data quality from high frequencies to low frequencies was good. At BST-501, the acquired data had high scatter in low frequencies and the curve slopes are too large on its apparent resistivity curve, indicating the existence of artificial electromagnetic noise. It seems to be the effect of the power lines at the northern part outside the survey site. Data quality of the other stations is fairly good after noise reduction using remote reference data processing.

After 2D inversion analysis was carried out at four profiles, as shown in Figure 6.4.3, the resistivity structure was obtained and the resistivity cross sections were created. As described below, offset values of static correction obtained from the results of the TEM survey were applied to the MT observed data as input data in the 2D inversion analysis of resistivity structure. Based on the analysis results, the resistivity plan maps and the panel diagram of the resistivity plan map were created. Figure 6.4.5 shows the panel diagram of the resistivity plan map. The resistivity cross sections, the resistivity plan maps and the fit of the observed data and model responses are given at the end of the report.

The main resistivity features of the Boseti site revealed from the MT survey are as follows:

- Generally, the resistivity structure is composed of three zones, namely, resistive overburden, conductive zone, and resistive zone, from the surface to 3,000 m depth. The resistivity distribution is roughly in the range of 1 ohm-m to 600 ohm-m.
- From the surface to 50 m depth, high resistivity (≥ 63 ohm-m) is widely spread all over the survey site. Especially at the northwest part and south part, higher resistivity (≥ 250 ohm-m) is observed.
- At 1,200 m elevation, low resistivity is widely distributed at the south part and the location of its spread coincides with the highlands at the northern slope of Mt. Berecha. The border between the distribution of low resistivity and that of high resistivity at the northern side shows high contrast of resistivity variation, and its contour lines are straight in the WNW-ESE direction and indicate resistivity discontinuity.
- At 500 m elevation, low resistivity is widely spread all over the site. In particular, a low resistivity belt in the NNE-SSW direction can be found at the central part and shows less than 4 ohm-m. From the central part to the north side, the lowest resistivity (≤ 3 ohm-m) is observed. The distribution of low resistivity of the south part at 1,200 m elevation can be seen at this elevation which means there is continuous distribution of low resistivity to the deeper zone.
- At 0 m elevation, the conductive belt is shown similar to that at 500 m elevation, but the value of resistivity is a little higher. The area outside the conductive belt shows high resistivity and high

contrast of resistivity variation is shown around the border of the conductive belt. That contrast indicates resistivity discontinuity structure. The low resistivity distribution observed at 1,200 m elevation cannot be observed at this elevation.

- At -500 m elevation, high resistivity (≥ 25 ohm-m) is widely spread all over the site, and compared with 0 m elevation, relatively high resistivity is observed. More than 63 ohm-m resistivity is distributed locally. The conductive belt can be seen but its resistivity value is higher.

- At -1,000 m elevation, the distribution pattern of resistivity is similar to that of -500 m elevation. Relatively high resistivity (≥ 25 ohm-m) can be found all over the site and the conductive belt in the NNE-SSW direction observed from 500 m elevation to -500 m elevation can be recognized slightly.

- The NNE-SSW strike direction is mainly recognized from the shallow zone to the deep zone in each resistivity plan map.

(2) TEM Survey

The TEM survey was conducted at all stations of MT measurement. About the acquired data quality, though data scatters were observed in a few windows of earlier time and later time at several stations, better quality data applicable to 1D inversion analysis was acquired completely. 1D inversion analysis of resistivity layer was executed using the observed data at each station. Layered resistivity structures, which show resistivity variation of high-low-high from the surface to the deep zone, were obtained at almost all stations. From the results of such, MT responses were calculated and the apparent resistivity and phase curves were created and the offset values for static correction were estimated. After applying the offset values to the apparent resistivity curves observed by MT method, 2D inversion analysis of resistivity structure was executed. The list of offset values for static correction and the results of 1D inversion analysis of resistivity layer are at the end of the report.

(3) Summary

The summarized characteristics of the resistivity structure in the survey site are shown in Table 6.4.1.

Table 6.4.1 Summary of MT/TEM Survey at Boseti

Item	Descriptions
Resistivity Structure	Composed of three zones, namely, conductive overburden, resistive zone, and conductive zone, from the surface to -3,000 m elevation.
Resistivity Value	Ranges from 1 ohm-m to 60 ohm-m
Resistivity Discontinuity	The conductive belt of NNE-SSW direction continues from 500 m elevation to the deep zone and composes the channel structure of low resistivity at the center of the site.
	The resistivity discontinuity structure is observed from the resistivity variation between the channel structure composed of the distribution of low resistivity and high resistivity.
	The low resistivity zone found under the highlands at the northern slope of Mt. Berecha continues from the shallow zone to the deep zone. The resistivity discontinuity is observed at 1,200 m elevation, where the high WNW-ESE contrast is shown between low and high resistivity at the northern part of the survey site.

Source: JICA Project Team

6.4.3 Notes for Reservoir Modelling

Generally, the geological structure is deduced from the resistivity distribution obtained by data analysis in the electromagnetic survey. By knowing the underground resistivity distribution, geology and geological structure, physicality, existence of groundwater, hot spring, and argillation zone, alteration zone can be inferred.

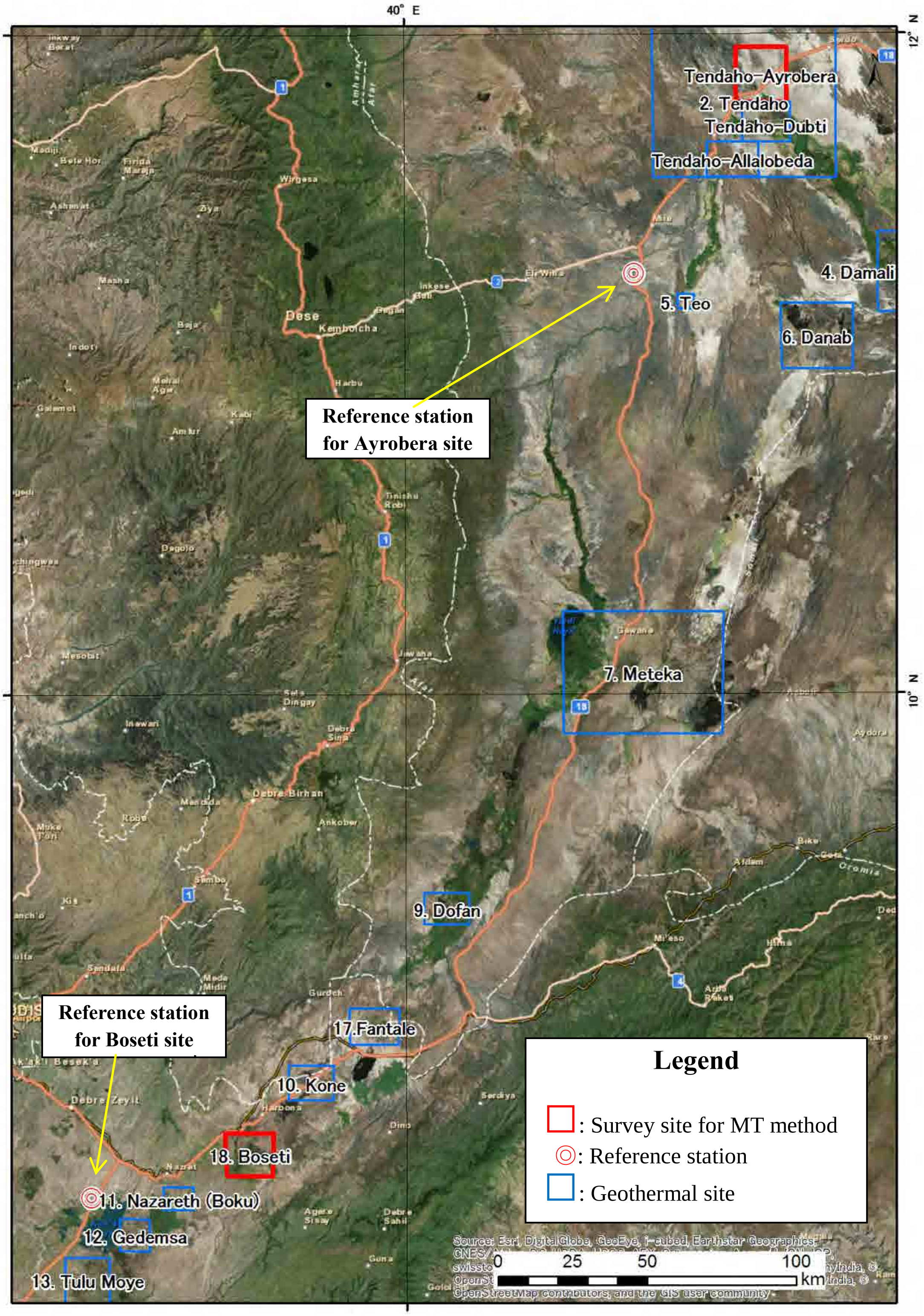
Considering the geothermal reservoirs in volcanic areas, an impermeable zone over the geothermal reservoir is formed by the low resistivity zone regarded as clay minerals and a relatively resistive zone under the impermeable zone is expected as geothermal reservoir. In the resistive zone, there exists a variation of resistivity and generally, a fracture zone has high permeability so that existence of fluid in the fracture zone causes relatively low resistivity. Considering the above, what the resistivity structure of each survey site indicates were inferred.

(1) Tendaho-2 (Ayrobera) Geothermal Field

Considering the characteristics of the resistivity structure obtained from the results of this MT survey and the existing geological information, and the results of the past MT survey, the shallow zone of low resistivity is inferred to be of sediments including saline fluid or hydrothermal alteration zone and the medium zone of high resistivity is inferred to be mainly of basaltic lava rocks. Low resistivity in the deep zone may suggest the existence of fluids related to geothermal resource. Based on the characteristics of the resistivity structure in the survey site, there are channel structures of low resistivity in the NW-SE strike direction and the resistivity discontinuity across the channel structure which shows narrow width around the TDO97 profile. These resistivity discontinuities may be inferred having the possibility to dominate the geothermal reservoir model.

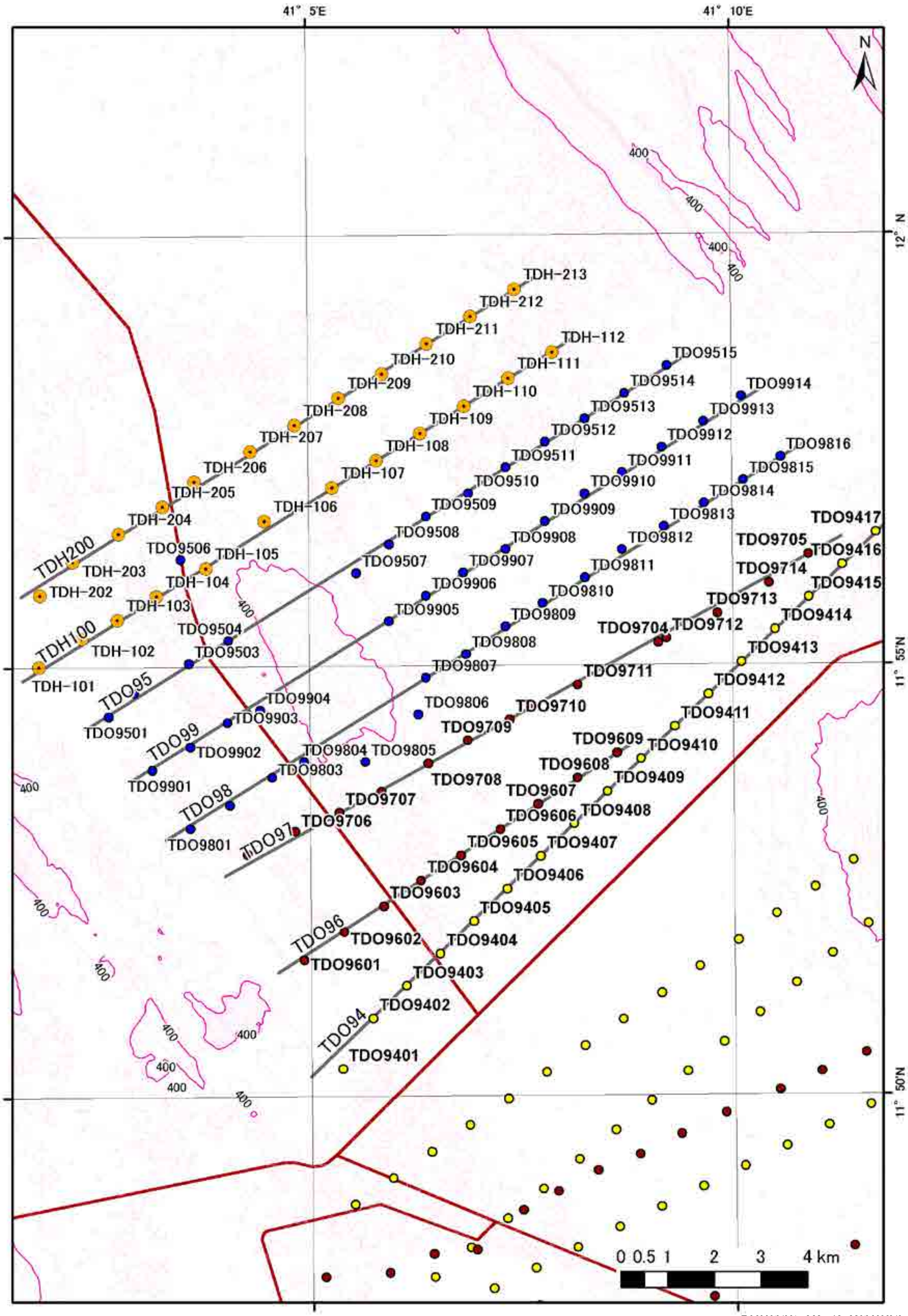
(2) Boseti Geothermal Field

Considering the characteristics of the resistivity structure obtained from the results of this MT survey and the existing geological information, the shallow zone of high resistivity is inferred to be of volcanic lava rocks and the medium zone of low resistivity is inferred to be of hydrothermal alteration zone or aquifer including saline fluid. The deep zone of high resistivity is inferred to be of tuffs. Based on the characteristics of the resistivity structure in the survey site, there are channel structures of NNE-SSW strike direction which show low resistivity and are seen from 500 m elevation, and the distribution of low resistivity which is seen from the shallow zone and continues to the deep zone. These resistivity structures may be inferred having the possibility to dominate the geothermal reservoir model.



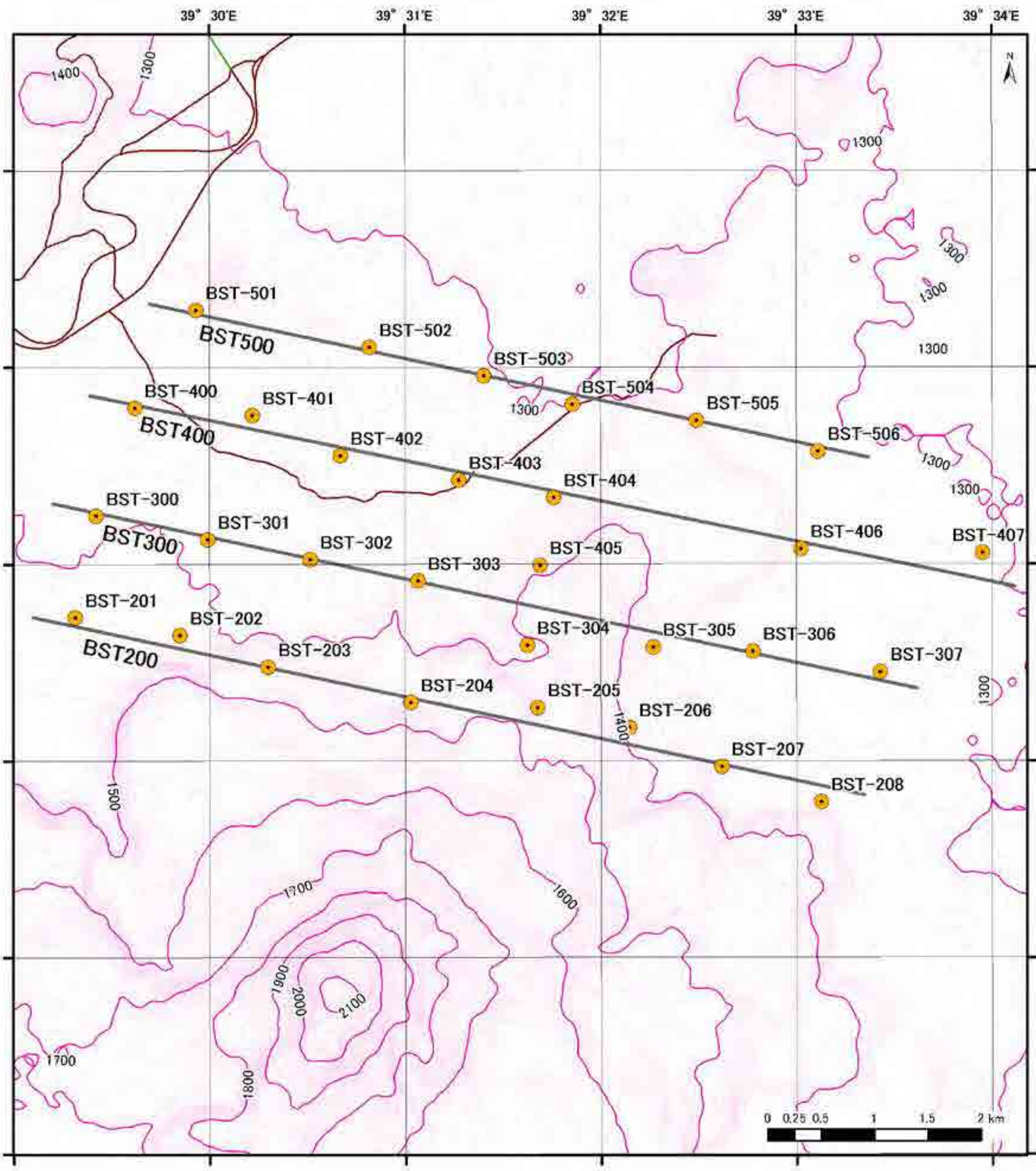
Source: JICA Project Team

Figure 6.4.1 Location map of MT survey



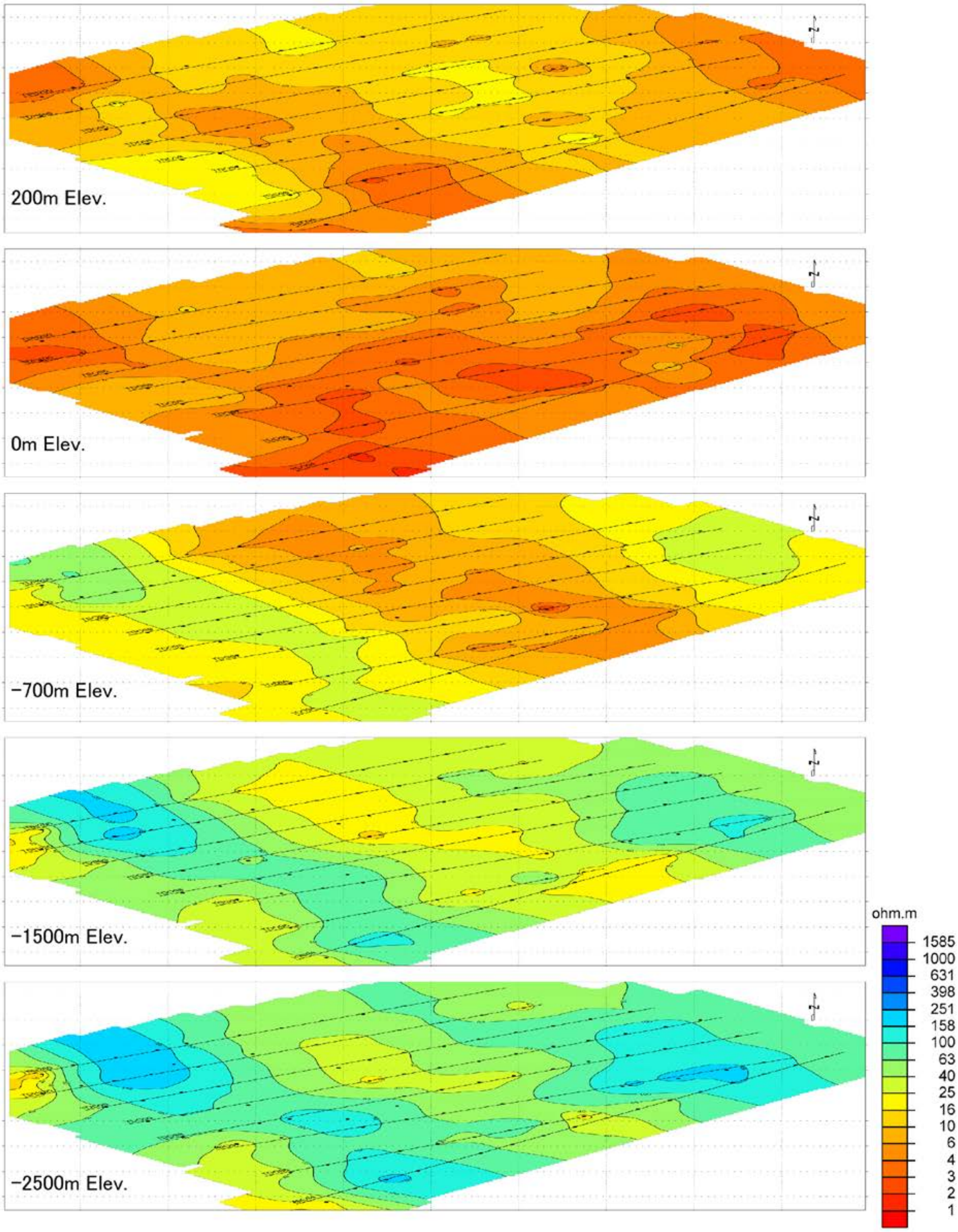
Source: JICA Project Team

Figure 6.4.2 The location map of MT stations (Ayrobera)



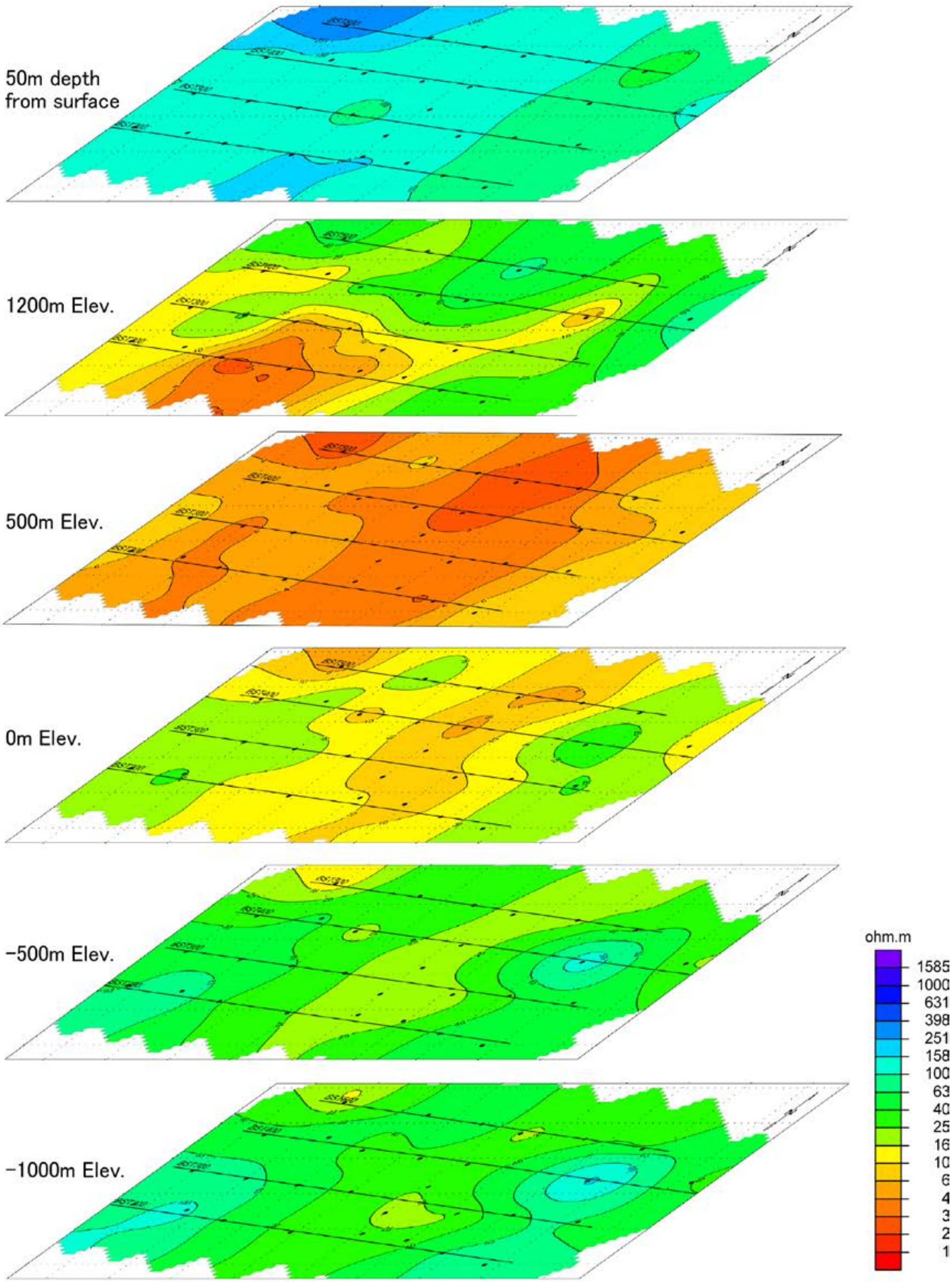
Source: JICA Project Team

Figure 6.4.3 The location map of MT stations (Boseti)



Source: JICA Project Team

Figure 6.4.4 The panel diagram of resistivity plan maps (Ayrobera)



Source: JICA Project Team

Figure 6.4.5 Panel Diagram of Resistivity Maps (Boseti)

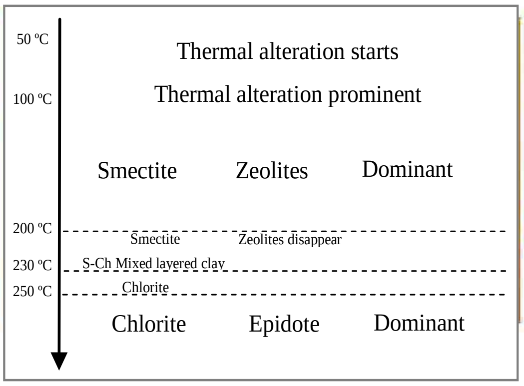
6.5 Interpretation of Resistivity Structure in Geothermal Sites

Underground resistivity structure of a geothermal field is usually divided into three (3) zones (or layers), Characteristics of the three zones in relation with hydrothermal alteration and temperature are shown in Figure 6.5.1 and Table 6.5.1.

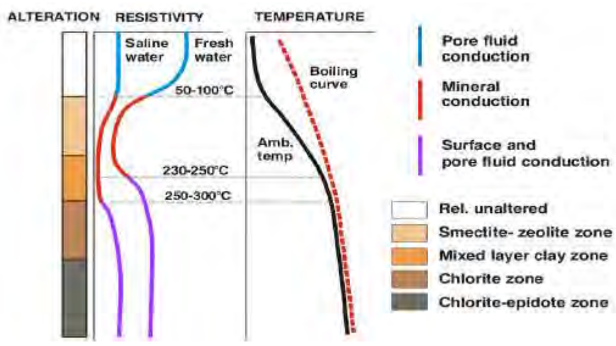
Table 6.5.1 General Interpretation of Resistivity Structure in relation with Alteration Mineral Occurrence and Temperature

Name of Zone	Range of Value	Interpretation of Reservoir	
		Temperature	Alteration/Geology
1) Resistive overburden	Up to several hundred ohm-m or some thousands ohm-m	50-100 ^{o}C	<**Non-Alteration Zone**> Volcanic ash, alluvium, fresh volcanic rocks, etc.
2) Low resistivity zone	Lower than 5 to 10 ohm-m	100-250 ^{o}C	<**Argillized (clay) zone (as cap rock)**> Clay minerals such as smectite and interstratified clay minerals containing smectite layers associated with zeolites
3) Resistive zone	Up to several tens ohm-m to some hundreds ohm-m	250-300 ^{o}C	<**Chlorite –Epidote Zone (as a reservoir)**> High-temperature condition such as chlorite, illite, epidote (and garnet), etc.

Source: JICA Project Team, referred by METI et al. (2010)



a. Alteration mineralogy and temperature



b. Relationship between alteration zone and resistivity

Source: Gylfi et al. (2012)

Figure 6.5.1 General Interpretation of Resistivity Structure in relation with Alteration Minerals Occurrence and Temperature

6.5.1 Tendaho-2 (Ayrobera) Site

Figure 6.5.2 shows the resistivity distribution maps at different elevations, EL+200 m, EL±0 m, EL-700 m, EL-1,500 m, and EL-2,500 m.

In this diagram, low resistivity zones (less than 10 ohm-m) are remarkably dominant at EL 200 m and EL 0 m level; a low resistivity zone extending NW-SE direction becomes apparent at El.-700 m level and downward though the distinctiveness tends to fade out downward. The zone of NW-SE direction that is well in accordance to the general trend of the Tendaho Graben, is considered to be an intensely fractured zone, delineated higher resistive zones (intact rock zones) on both side of the west and the east. The fractured zone could be a reservoir because high permeability would be expected.

For interpreting the cross sectional model, existing information are available here in Tendaho. In Tendaho-1 (Dubti), about 13 km south-east from the site, six (6) test wells were drilled from 1994 to 1998. Among those, TD-1 and TD-2 are useful to refer. The relevant information of the two wells was summarized in Table 6.5.2. According to the table, the depth of the measured resistivity 5 ohm-m ranges from 530 m to 580 m; whereas the depth of the measured temperature 245 – 250 ^{o}C ranges from 450 m to 600 m. From this well corresponding relation between the depths of the resistivity and the temperature, the depth of 5 ohm-m may be considered as the bottom of the cap layer or the top of the reservoir in Tendaho area.

Table 6.5.2 Existing Test Well Data in Tendaho-1 (Dubti)

Name of Zone	TD-1			TD-2		
	Resistivity, (Measured depth)	**Temperature, (Measured depth)**	**Alteration, Inferred Temp., (Measured depth)**	**Resistivity, (Measured depth)**	**Temperature, (Measured depth)**	**Alteration, Inferred Temp., (Measured depth)**
1) Resistive over burden	Resistive	<150 ºC	Non-alteration 50-100 ºC , (95 m)	Resistive	<150 ºC	Non-alteration ,5 0-100 ºC, (50 m)
2) Low resistive zone	<5 ohm-m, (580 m)	150 - 250 ºC, (600 m)	Argillized , 100-250 ºC, (350 m)	<5 ohm-m (530 m)	150 º- 245 ºC (450 m)	Argillized , 100-250 ºC, (280 m)
3) High resistive zone	>5 ohm-m	250 ºC	Chlorite-Epidote, 250-300 ºC	>5 ohm-m	245 ºC	Chlorite-Epidote, 250-300 ºC

Source: Aquator (1994) and Aquator (1995), Compiled by JICA Project Team

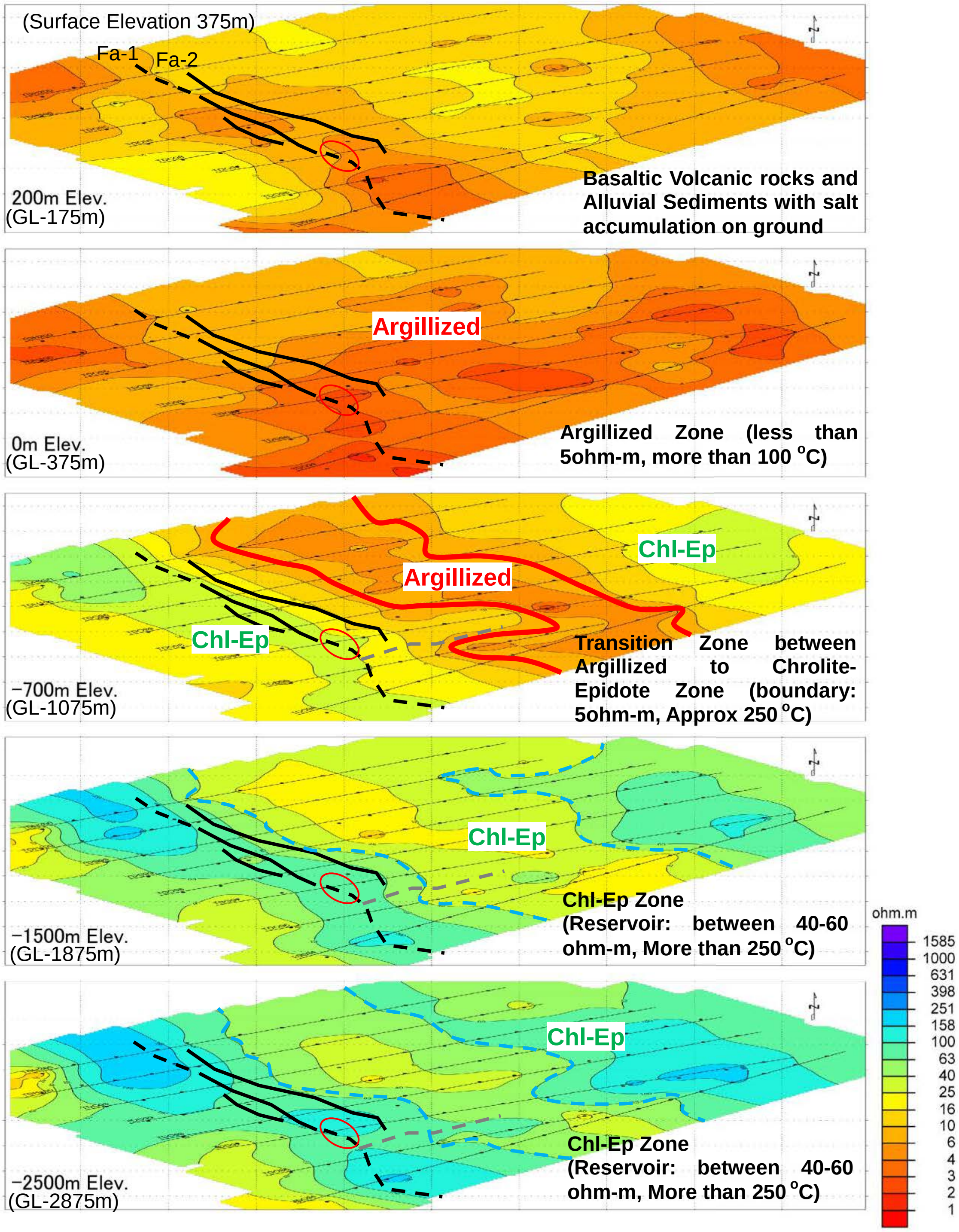
Figure 6.5.3 shows E-W cross section of the resistivity. In the Figure 6.5.3, it is apparent that a zone of low resistivity goes down at the middle part of the analysis section. This low resistivity zone was interpreted as a fault fracture zones that runs NW-SE direction, and the fault zone may be the reservoir. From the Figure 6.5.3, it is apparent that the reservoir is capped by a low resistivity layer, and delineated by high resistivity zones on both sides. As the layer with resistivity lower that 5 ohm-m was interpreted as cap layer (“cap rock”), the bottom depth of the cap layer is estimated to range from 300 m to 1,200 m on the top of the inferred reservoir. Table 6.5.3 summarized the interpretation of the reservoir structure.

It is noted that the fumaroles observed on the surface are not located on the top of the inferred reservoir. This may be interpreted such a way that the top of the reservoir part has been completely sealed by alteration clay and the fumaroles found the pass at a rim part where a set of manor faults outcrops on the surface.

Table 6.5.3 Interpretation of MT/TEM Survey Results with Alteration Mineral Occurrence and Temperature in Tendaho-2 (Ayrobera)

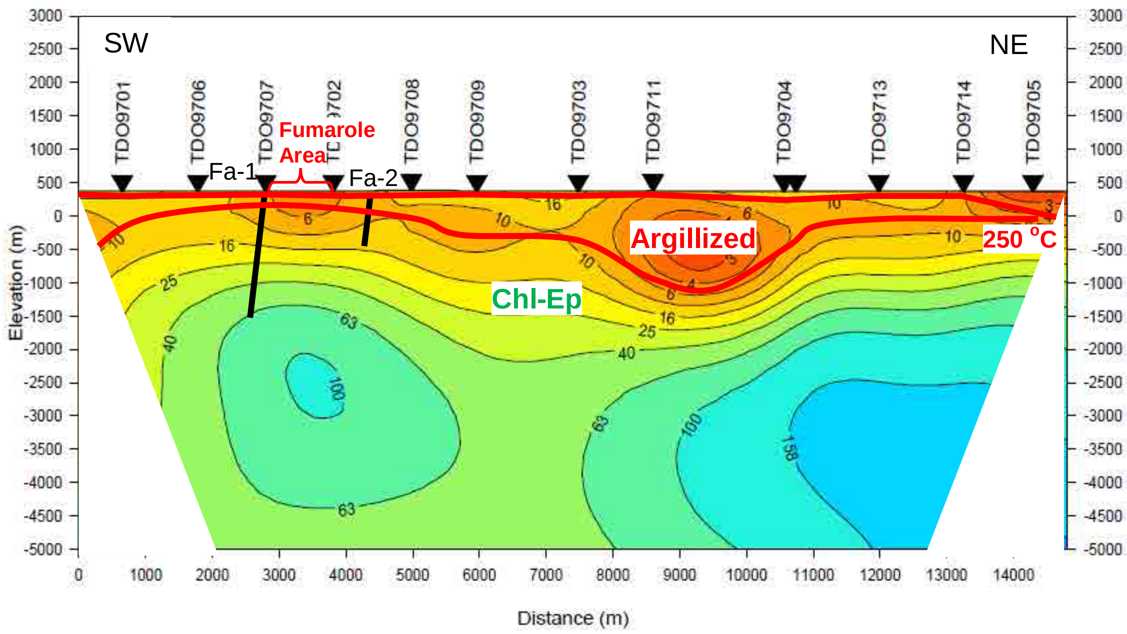
Zone	Interpretation of Reservoir		
	Resistivity	Depth (GL-m)	Interpretation of Temperature
1) Resistive overburden	>10 ohm-m	Less than 100 m	50-100 ^{o}C
2) Low resistivity zone	Less than 5 ohm-m	Approximately 100–500 m	100-250 ^{o}C
3) High resistive zone	>5 ohm-m (40–60 ohm-m)	Deeper than 300–1,200 m	250-300 ^{o}C

Source: JICA Project Team



Source: JICA Project Team

Figure 6.5.2 Schematic Panel Diagram of Resistivity Distribution and Interpretation in Tendaho-2 (Ayrobera)



Source: JICA Project Team

Figure 6.5.3 Schematic Section of Tendaho-2 (Ayrobera)

6.5.2 Boseti Geothermal Site

Figure 6.5.4 shows the resistivity distribution maps at different elevations, EL+1,250 m, EL+1,200 m, EL+50m, EL±0 m, EL-500 m and EL-1,000 m.

In this diagram, resistivity higher than 100 ohm-m observed at surface level is interpreted as a new lava layer. The lower resistivity zones less than 5 ohm-m are remarkably dominant at EL 500 m level: a low resistivity zone extending N-S direction becomes apparent at EL 0 m level and downward though the distinctiveness tends to fade out downwards. The zone is well in accordance to the faults extending to NNE-SSW direction. The low resistivity zone therefore may be interpreted as a fault zone delineated on the both sides by resistive zones.

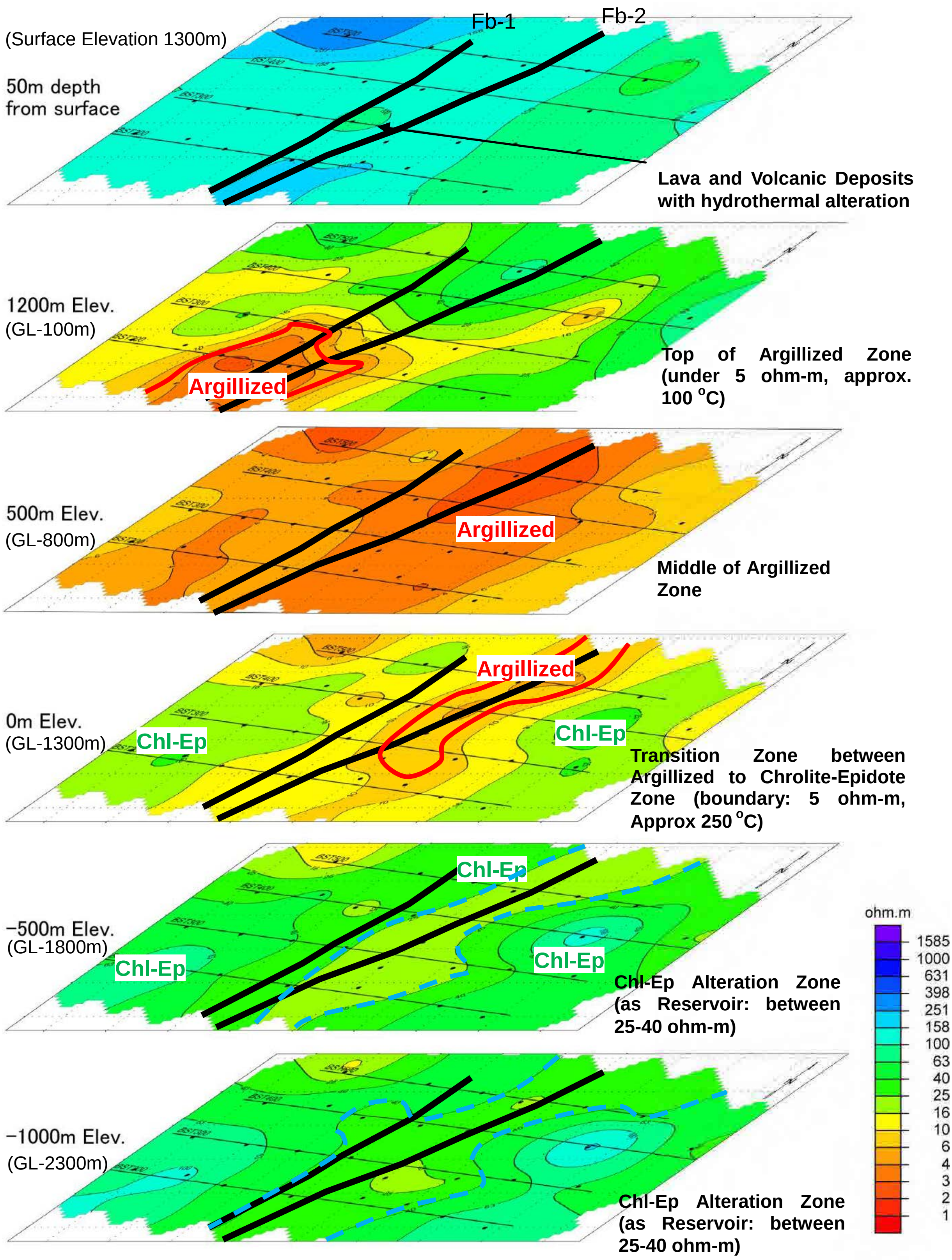
Figure 6.5.5 shows the WNW-ESE cross section of the resistivity. In Figure 6.5.5, it is apparent that a wide zone (channel) of lower resistivity goes down. The low resistivity zone was interpreted in this figure as a fault zone running NNE-SSW direction. It is apparent that the reservoir is capped by a low resistivity layer, and delineated by higher resistivity zones on both side. Therefore, the low resistivity zone could be interpreted as a geothermal reservoir. It was interpreted in Tendaho that the layer of resistivity lower that 5 ohm-m would be a cap layer (cap rock), the bottom depth of the cap layer is estimated to range fromGL- 800 m to GL-900 m as shown in Figure 6.5.5. Table 6.5.4 summarized the interpretation of the inferred reservoir.

Herein Boseti also, the fumaroles observed on the surface are located on a rim part of the inferred reservoir, where a fault was identified.

Table 6.5.4 Interpretation of MT/TEM Survey Results with Alteration Mineral Occurrence and Temperature in Boseti

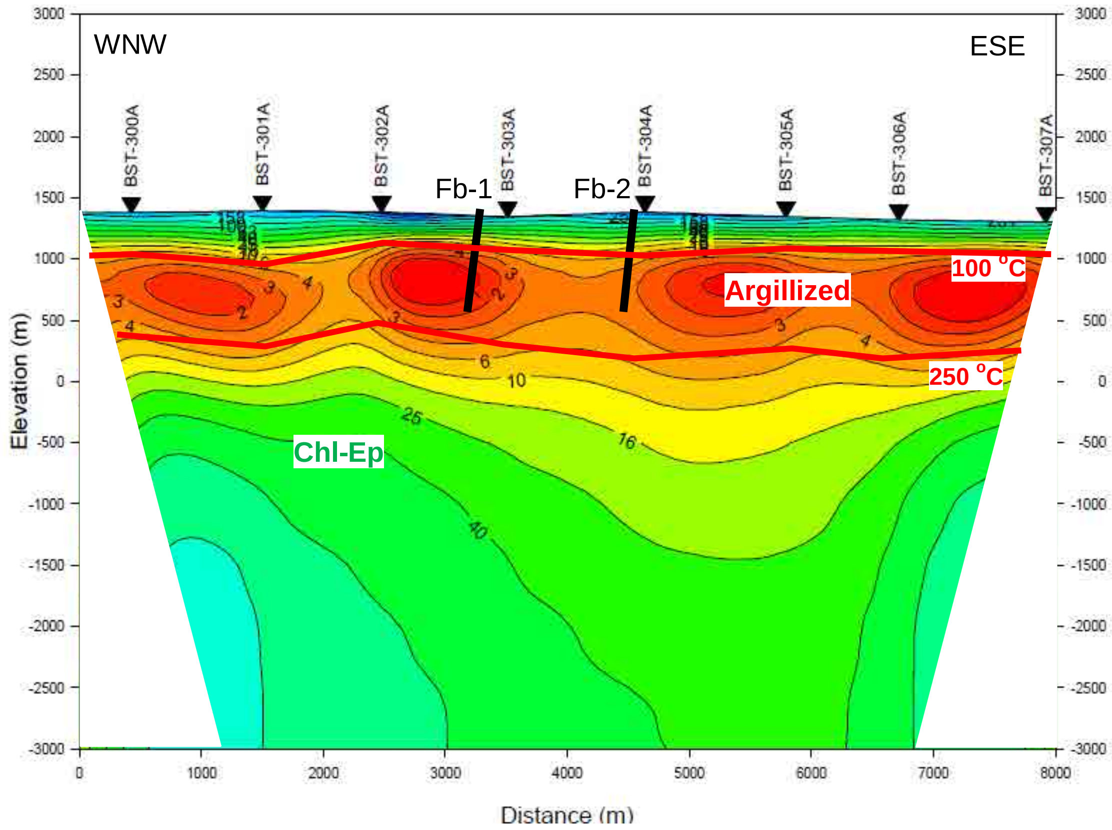
Zone	Interpretation of Reservoir		
	Resistivity	Depth (GL-m)	Interpretation of Temperature
1) Resistive overburden	10–150 ohm-m	Less than 300–500 m	50-100 ^{o}C
2) Low resistivity zone	Less than 5 ohm-m	Approximately 500–900 m	100-250 ^{o}C
3) High resistive zone	>5 ohm-m (25–40 ohm-m)	Deeper than 800– 900 m	250-300 ^{o}C

Source: JICA Project Team



Source: JICA Project Team

Figure 6.5.4 Schematic Panel Diagram of Resistivity Distribution and Interpretation in Boseti



Source: JICA Project Team

Figure 6.5.5 Schematic Section of Boseti Geothermal Site