III GEOTHERMAL POWER DEVELOPMENT PLAN

In order to assist in planning the future development by GDC in the target fields of this JICA project, preliminary plans for geothermal power development were developed based on the results of the reevaluation of the resource potential described in the previous chapter. In this chapter, after describing the current status of the construction of infrastructure for resource development, the preliminary plan of geothermal power development and estimated development costs are presented for the five target geothermal fields, for which the resource potential was re-estimated. In addition, there is discussion about the planning of construction of regional power transmission lines according to the development plan for the each of the fields.

III-1 Infrastracture around the Geothermal Prospects

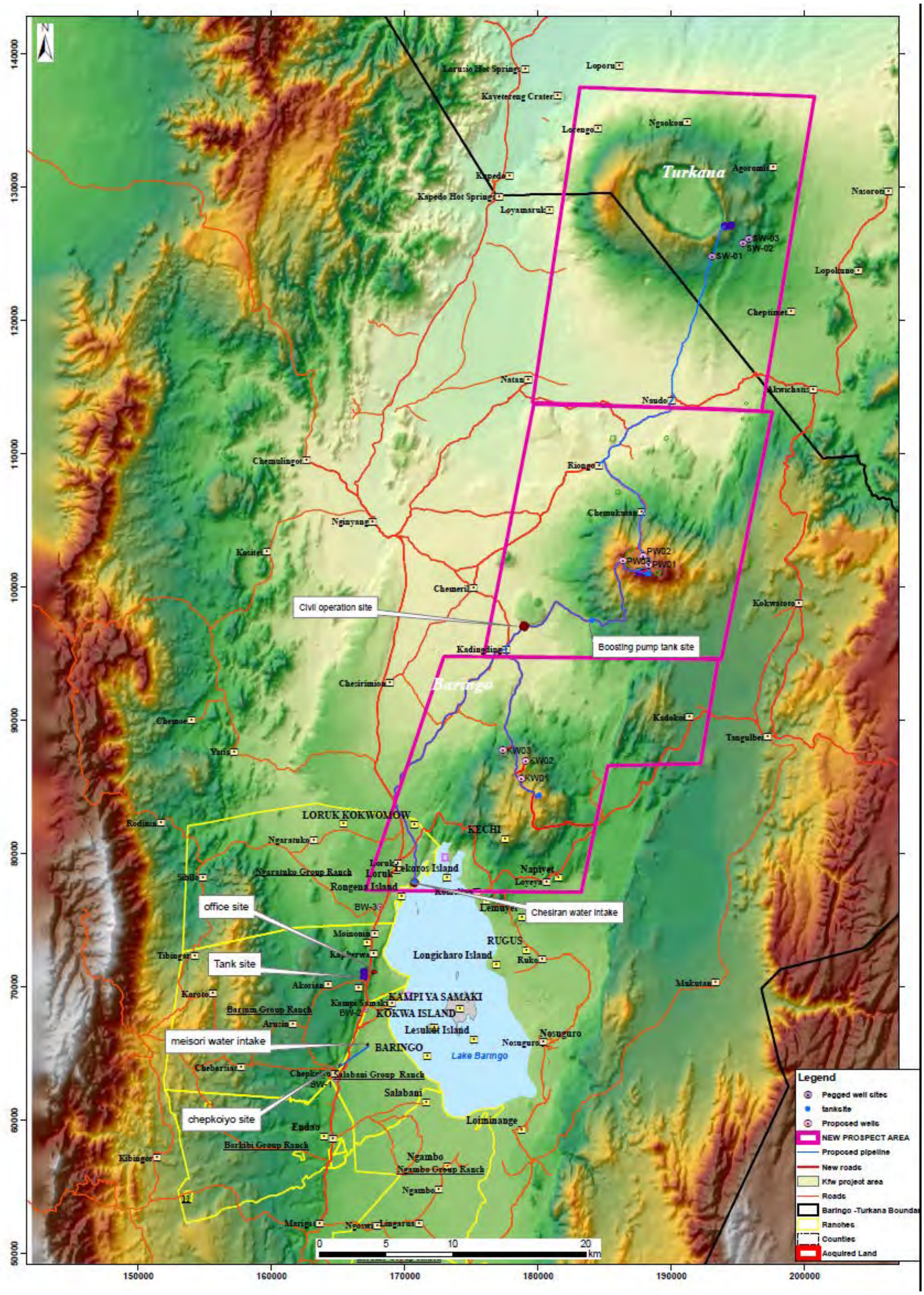
In general, the target geothermal prospects of this project are remote and far from developed areas, and require significant preparation regarding roads and water supply. The information in Table III-1.1 presented by KenGen (2002) shows the distances from each of the targeted prospects to existing transmission lines, main roads and water supplies. Although details on Baringo and Chepchuk are not shown in the table, Baringo has the best accessibility because there is already a primary route across the area. On the other hand, the prospects to the north of Baringo are poor regarding water sources, so a water supply system from the Lake Baringo to each of the more northern prospects will be required to secure the water necessary for the development.

Table III-1.1 Location of geothermal areas (2002)

	Distance to named 132KV Line	Distance to named 11KV Line	Distance to all weather road	Distance to paved (Tarmac) road	Distance (Direct) to named major shopping center	Distance to nearest water source (Lake/River/borehole)
L. Bogoria and Arus	Nakuru: 50 km	Nakuru:	< 2km	<2 km	Nakuru: 40 km	R. Molo: <5km
Korosi	Nakuru: 113 km	Loruk: 10 km	3km	10 km	Kampi Ya Samaki: 18km	L. Baringo: 5 km
Paka	Nakuru: 130 km	Loruk: 30 km	11 km	30 km	Kampi Ya Samaki: 38km	L. Baringo: 50 km
Silali	Lessos: 97 km	Loruk: 52 km	1-8 km	52 km	Loruk: 52 km	L. Baringo: 150 km

GDC is currently implementing a project to construct accessible roads and sufficient water distribution from Lake Baringo to Silali to support the exploratory and development well drilling. The map of this of the facilities under construction, or to be constructed within the said project is shown in Fig. III-1.1. According to the plan, access roads and a water supply system will be constructed to Korosi, Paka and Silali from Lake Baringo. The water supplied to each of the areas is to be pumped up to the point of highest elevation within each site to be distributed from this point to the supply areas with the least of the pumping requirements.

In the Baringo field, a drilling pad had been already completed as of May 2015 when the JICA project team visited there (Fig. III-1.2). The location of the drilling pad is close to the Chepkoiyo well in the southern part of the Baringo field. According to the information from the GDC management, the access road up to Silali was completed by the end of 2016.



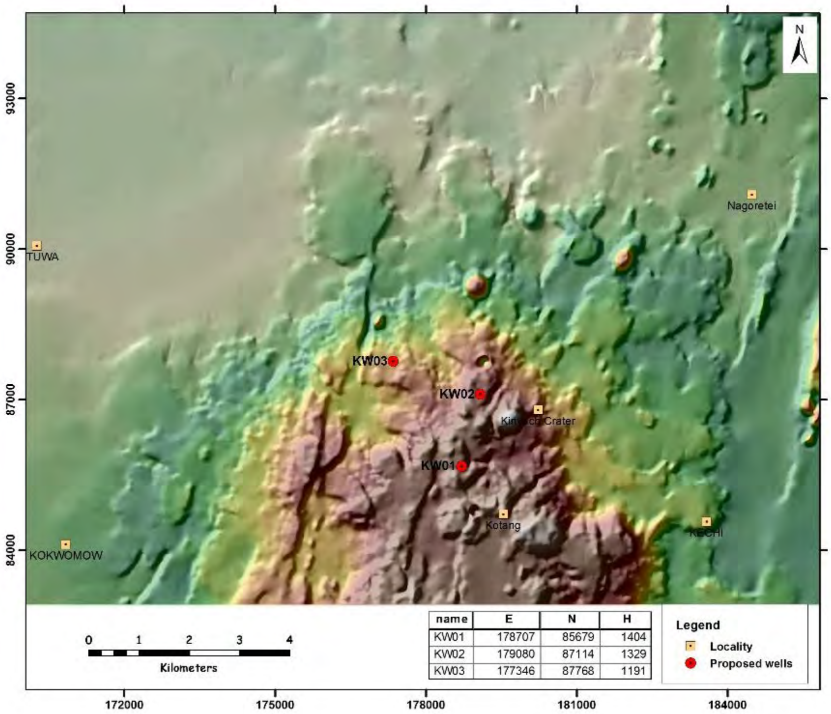
Source: GDC (November 2015)

Fig. III-1.1 Infrastructure construction plan in Baringo - Silali area by GDC

Source: JICA Study Team (May 2015)

Fig. III-1.2 Drilling pad in the south of Baringo

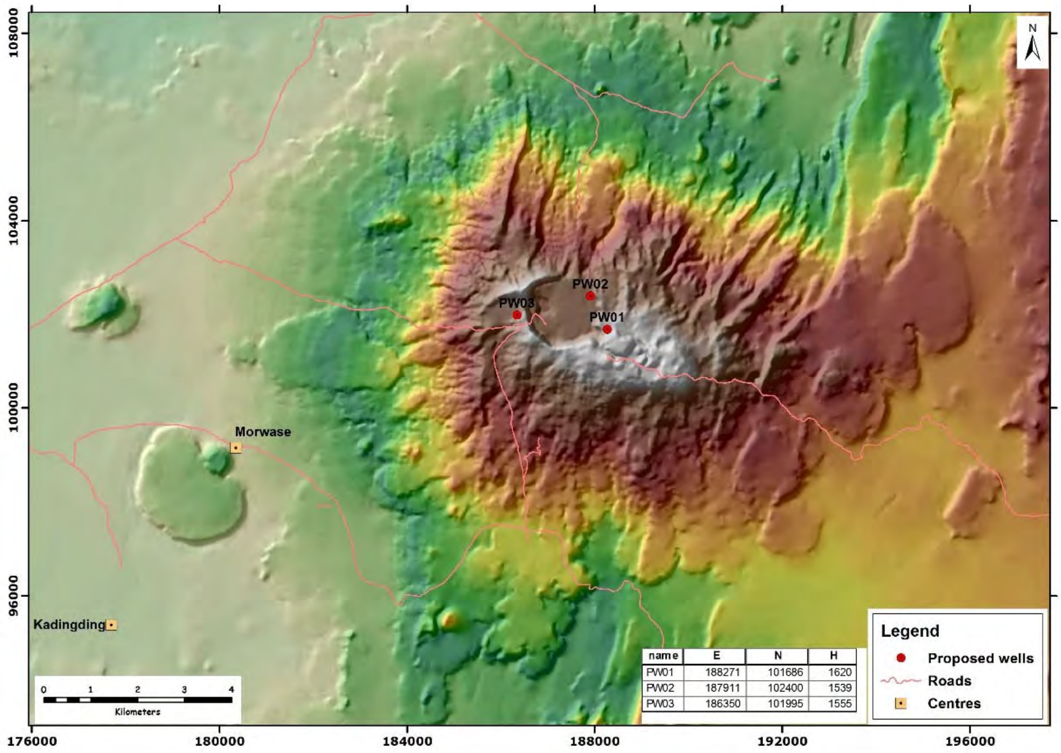
In Korosi and Paka, three drilling pads have already been built in each field. The location maps of drilling pads are shown in Figs. III-1.3 and Fig. III-1.4. However, the construction of water pipelines from Baringo to those fields has not been completed yet.



name	E	N	H
KW01	178707	85679	1404
KW02	179080	87114	1329
KW03	177346	87768	1191

Source: GDC

Fig. III-1.3 Location map of drilling pads in Korosi



name	E	N	H
PW01	188271	101686	1620
PW02	187911	102400	1539
PW03	186350	101995	1555

Source: GDC

Fig. III-1.4 Location map of drilling pads in Paka

The conceptual design of the water supply system consists of three crude water-pumping stations with high-lift booster pumps and storage tanks; the first of the pumping stations will located on the shores of Baringo Lake, a second near the Paka volcano and another near the Silali caldera, as are found depicted in Fig III-1.5. Ten-inch diameter Victaulic-type pipelines are envisioned to connect the pumping stations. From the pumping stations, feeder lines would be constructed up to the prospect fields for the development work. The project also foresees branching additional feeder pipelines in order to supply water to several local communities dispersed in the region north of Baringo Lake, in some cases, far away from the passing main pipeline; which would minimize the possibility of cattle herds being attracted to the vicinity of the water storage tanks. Diesel generators will supply power for the operation of the pumps.

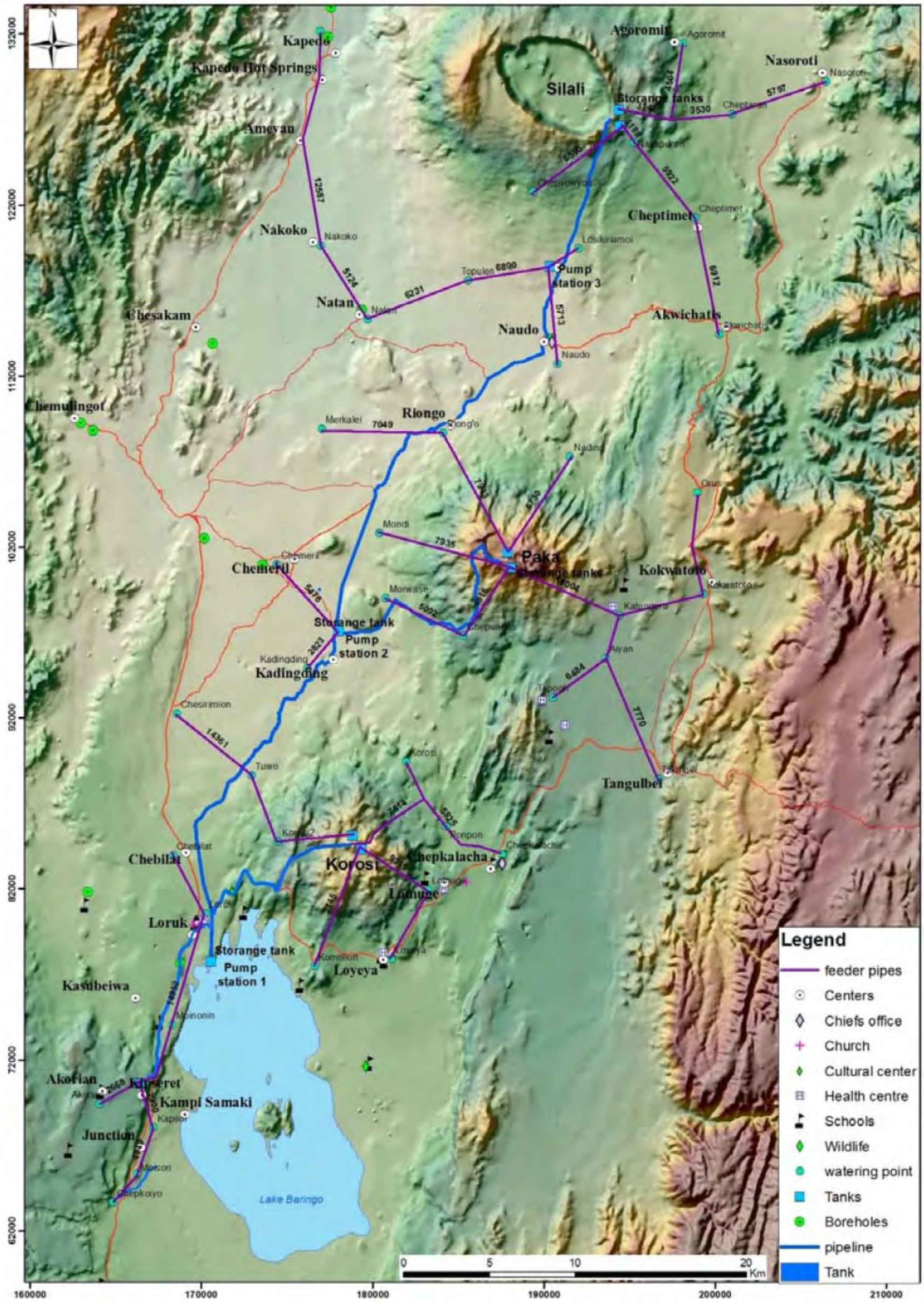


Fig. III-1.5 Overview of the plan for water supply to the north of Baringo Lake

III-2 Development Plan for the Arus Field

III-2.1 Development scale and main facilities

The development scale (the output capacity of the geothermal power plant) for Arus field is proposed based on the estimated resource potential. The type of power plant was selected to be a conventional flash steam cycle (condensing type). The required number of geothermal wells is estimated according to the results of the evaluation of productivity (and injectivity) of wells. The main specifications regarding the possible power development of the Arus field are shown in Table III-2.1.

Based upon the possible power development plan stated above, to exploit a field installing a 100MW flash type geothermal power generation, ten production wells and nine reinjection wells are estimated to be required for start-up. In consideration of the drilling success ratio (which is assumed to be 50% for exploration wells and 80-100% for appraisal/operation wells), thirteen production wells and ten reinjection wells should be drilled. Regarding the number of exploratory wells, two wells are tentatively planned in this study because of the plan of relatively small-scale development in the Arus field. However, if the budget permits, drilling of three or more wells is recommendable to ascertain the existence and extension of the exploitable geothermal reservoir.

Table III-2.1 Main specifications for the possible power development in the Arus field

Field	Planned Capacity	Average Productivity	Total Reinjection Brine	Assumed Injection Capacity	Required Wells for operation	
	(MW-gross)	(MW/well)	(t/h)	(t/h/well)	Production	Reinjection
Arus 50MW x 2	100	10	2600	300	**10**	**9**

Field		Exploration Stage		Appraisal Stage		Development Stage		Total	
		P-well	R-well	P-well	R-well	P-well	R-well	P-well	R-well
Arus 50MW x 2	Drilled wells	2	0	5	1	6	9	**13**	**10**
	Successful Wells (for operation)	1	0	4	1	5	8	**10**	**9**

III-2.2 Resource development plan

According to the conceptual model of the geothermal system, total drilling depth will vary from 1,800m to 2,300m for both production wells and reinjection wells. In order to minimize the number of required drilling pads and to allow multiple targets to be drilled from the same pad, directional drilling should be adopted. To avoid interference among wells, the targets are located at intervals of around 300m. In addition, detailed drilling depths and well profiles for the development production/reinjection wells should be planned based on the up-date geothermal conceptual model reflecting the results of exploration/appraisal wells drilling and testing.

Drilling rigs owned by GDC with a 2,000HP output capability will be available to drill directionally to 1,800-2,300m in depth, with a final completion diameter of 8.5 inches. Fig. III-2.1 shows an example of a possible well casing program and Fig. III-2.2 shows an example of a possible well directional drilling program.

The number of drilling pads is tentatively assumed to be two pads for production wells and two pads for reinjection wells. Approximately eight wells can be drilled from one pad of dimensions of 100m x 150m, including water/mud pits and pipe storage yard, etc. Furthermore, constructed pads will be available for future drilling of make-up wells during the power plant operation.

Fresh water for well drilling and power plant operation can be supplied from the river flowing through the project site by utilizing a steel pipeline for water transportation. In addition, fresh water should be distributed to pads from water tanks with around 4,000 cubic meters capacity, which will be installed close to power plant.

Drilling pads for reinjection wells should be situated at elevations lower than the separator stations to transport the brine to the reinjection wells by gravity. The drilling targets for reinjection wells should be separated from the production zone at least 1 km to avoid the breakthrough of reinjected water that could cause cooling of the high temperature reservoir. The planned layout is shown in Fig. III-2.3.

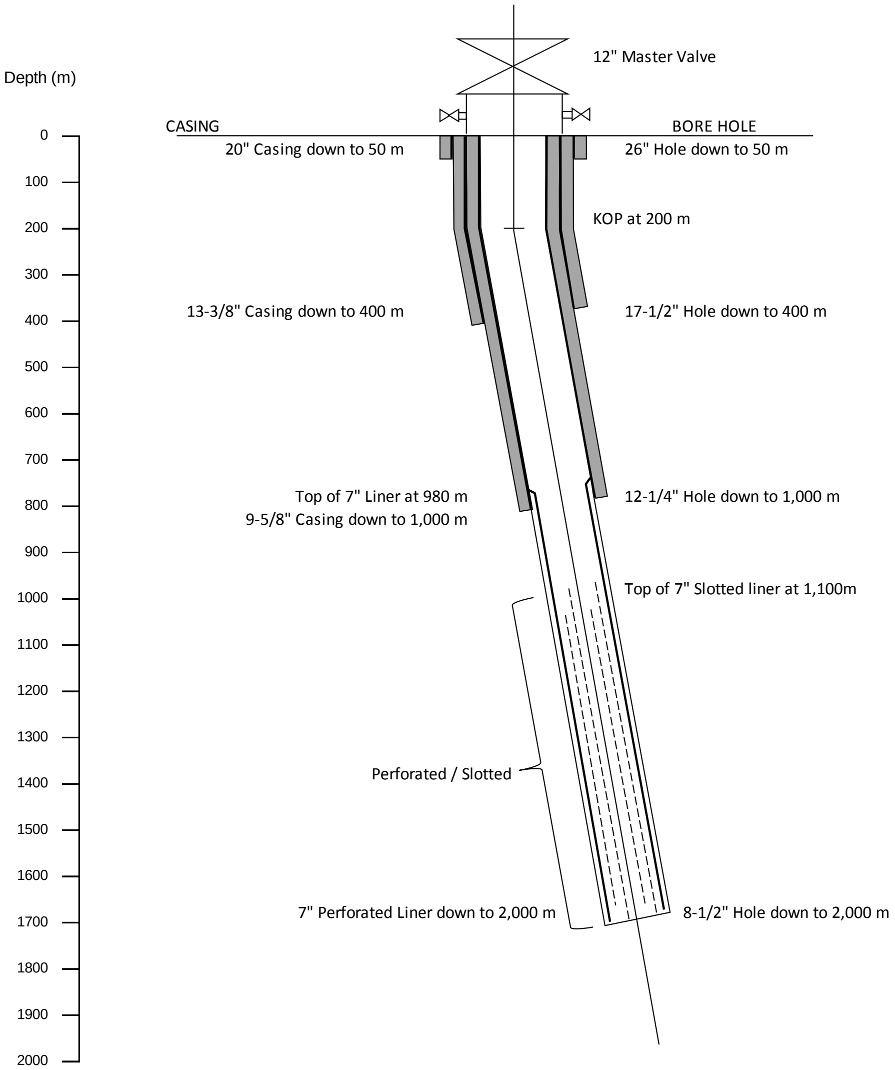


Fig. III-2.1 An example of well casing program (TD2,000m, Directional)

WELL NAME	Production/Reinjection

(m)

KOP	RKB ELEVATION	GROUND ELEVATION
200.00	1010.00	1000.00

Note: Directional Angle from True North

Planned

Survey Calculation Method : Minimum Curvature

	Measured Depth (m)	Inclination (deg)	Azimuth (deg)	Vertical Depth (m)	Elevation (a.s.l) (m)	+N/-S (m)	-W/+E (m)	Deviation (m)	Dog-leg Rate (deg/100ft)
1	0.00	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00
2	200.00	0.00	120.00	200.00	800.00	0.00	0.00	0.00	0.00
3	215.00	1.00	120.00	215.00	785.00	-0.07	0.11	0.13	2.03
4	230.00	2.00	120.00	229.99	770.01	-0.26	0.45	0.52	2.03
5	245.00	3.00	120.00	244.98	755.02	-0.59	1.02	1.18	2.03
6	260.00	4.00	120.00	259.95	740.05	-1.05	1.81	2.09	2.03
7	275.00	5.00	120.00	274.90	725.10	-1.64	2.83	3.27	2.03
8	290.00	6.00	120.00	289.84	710.16	-2.35	4.08	4.71	2.03
9	305.00	7.00	120.00	304.74	695.26	-3.20	5.55	6.41	2.03
10	320.00	8.00	120.00	319.61	680.39	-4.18	7.24	8.36	2.03
11	335.00	9.00	120.00	334.45	665.55	-5.29	9.16	10.58	2.03
12	350.00	10.00	120.00	349.24	650.76	-6.53	11.31	13.06	2.03
13	365.00	11.00	120.00	363.99	636.01	-7.90	13.67	15.79	2.03
14	380.00	12.00	120.00	378.69	621.31	-9.39	16.26	18.78	2.03
15	395.00	13.00	120.00	393.33	606.67	-11.01	19.08	22.03	2.03
16	410.00	14.00	120.00	407.92	592.08	-12.76	22.11	25.53	2.03
17	425.00	15.00	120.00	422.44	577.56	-14.64	25.36	29.28	2.03
18	440.00	16.00	120.00	436.89	563.11	-16.65	28.83	33.29	2.03
19	455.00	17.00	120.00	451.27	548.73	-18.78	32.52	37.55	2.03
20	470.00	18.00	120.00	465.58	534.42	-21.03	36.43	42.06	2.03
21	485.00	19.00	120.00	479.81	520.19	-23.41	40.55	46.82	2.03
22	500.00	20.00	120.00	493.94	506.06	-25.92	44.89	51.83	2.03
23	515.00	21.00	120.00	507.99	492.01	-28.54	49.44	57.08	2.03
24	530.00	22.00	120.00	521.95	478.05	-31.29	54.20	62.58	2.03
25	545.00	23.00	120.00	535.81	464.19	-34.16	59.17	68.32	2.03
26	560.00	24.00	120.00	549.56	450.44	-37.15	64.35	74.30	2.03
27	575.00	25.00	120.00	563.21	436.79	-40.26	69.73	80.52	2.03
28	590.00	26.00	120.00	576.75	423.25	-43.49	75.33	86.98	2.03
29	605.00	27.00	120.00	590.18	409.82	-46.84	81.12	93.67	2.03
30	620.00	28.00	120.00	603.48	396.52	-50.30	87.12	100.60	2.03
31	635.00	29.00	120.00	616.66	383.34	-53.88	93.32	107.76	2.03
32	650.00	30.00	120.00	629.72	370.28	-57.57	99.72	115.14	2.03
33	665.00	31.00	120.00	642.64	357.36	-61.38	106.31	122.76	2.03
34	680.00	32.00	120.00	655.43	344.57	-65.30	113.10	130.59	2.03
35	695.00	33.00	120.00	668.08	331.92	-69.33	120.08	138.65	2.03
36	710.00	34.00	120.00	680.59	319.41	-73.47	127.25	146.93	2.03
37	725.00	35.00	120.00	692.95	307.05	-77.71	134.60	155.43	2.03
38	800.00	35.00	120.00	754.39	245.61	-99.22	171.86	198.45	0.00
39	900.00	35.00	120.00	836.30	163.70	-127.90	221.53	255.80	0.00
40	1000.00	35.00	120.00	918.22	81.78	-156.58	271.21	313.16	0.00
41	1100.00	35.00	120.00	1000.13	-0.13	-185.26	320.88	370.52	0.00
42	1200.00	35.00	120.00	1082.05	-82.05	-213.94	370.55	427.88	0.00
43	1300.00	35.00	120.00	1163.97	-163.97	-242.62	420.22	485.23	0.00
44	1400.00	35.00	120.00	1245.88	-245.88	-271.30	469.90	542.59	0.00
45	1500.00	35.00	120.00	1327.80	-327.80	-299.97	519.57	599.95	0.00
46	1600.00	35.00	120.00	1409.71	-409.71	-328.65	569.24	657.31	0.00
47	1700.00	35.00	120.00	1491.63	-491.63	-357.33	618.92	714.66	0.00
48	1800.00	35.00	120.00	1573.54	-573.54	-386.01	668.59	772.02	0.00
49	1900.00	35.00	120.00	1655.46	-655.46	-414.69	718.26	829.38	0.00
50	2000.00	35.00	120.00	1737.37	-737.37	-443.37	767.94	886.74	0.00

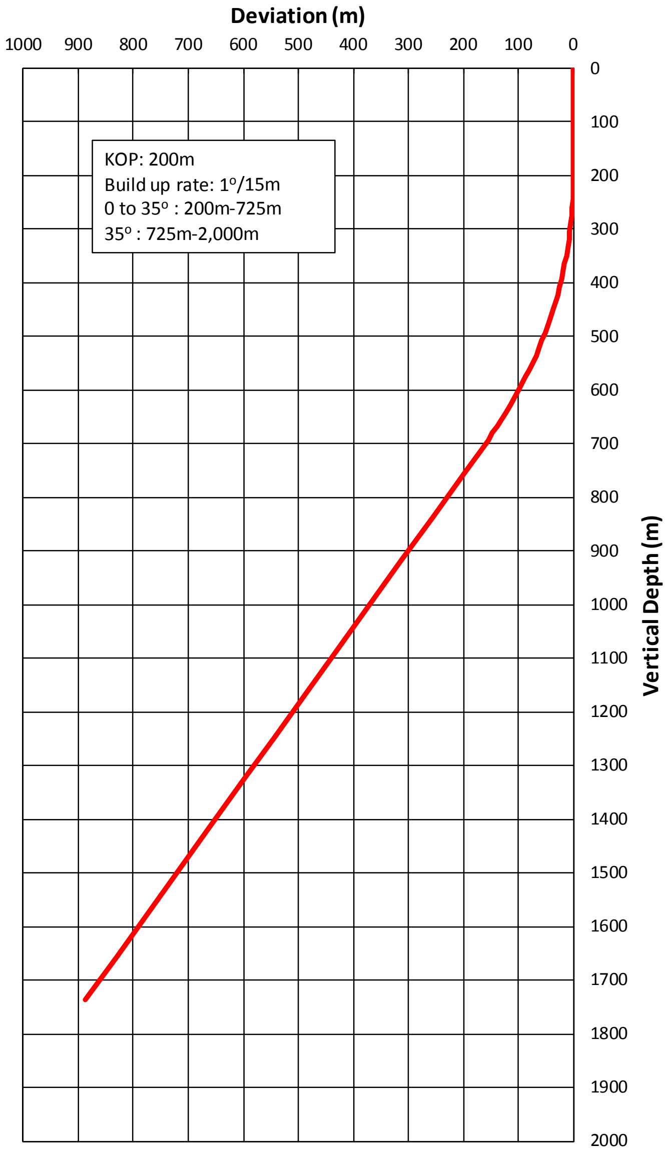


Fig. III-2.2 An example of well directional drilling program (KOP; 200m, Max angle; 35 deg.)

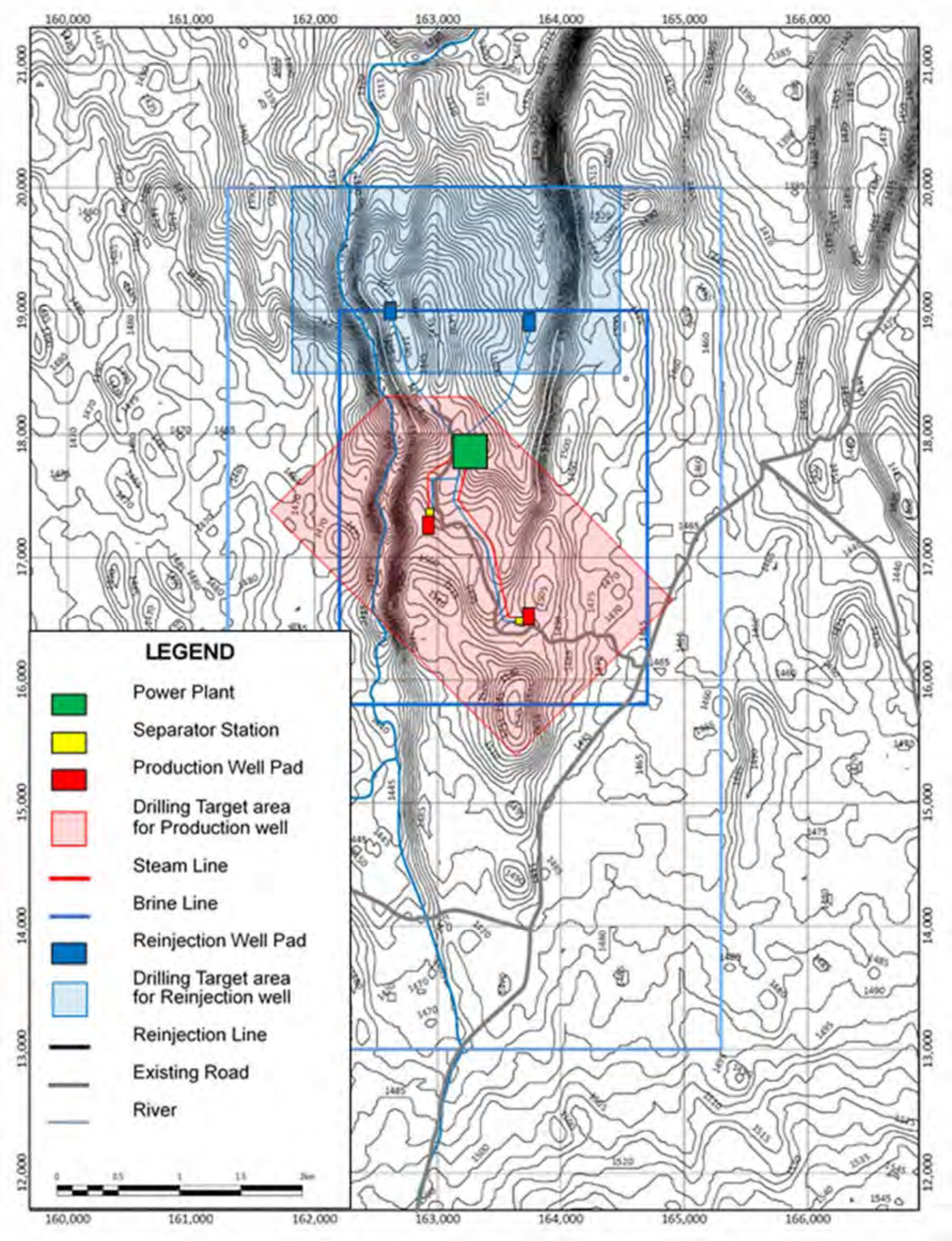


Fig. III-2.3 Preliminary layout for the development of Arus

III-2.3 Development plan for the power plant and substation

A geothermal plant consisting of two single-flash condensing 50MW units is envisioned to be constructed in the Arus field. Further studies on the available resource may lead to different unit size or energy conversion technology.

Power generated at the Arus geothermal power plant will be evacuated to the 400/220kV Arus substation through 220kV transmission line (single Canary x 2 circuits) to connect with the Kenyan National Grid.

The 400kV transmission line, 400/220kV substations and 220kV transmission line from the power plants to substation will be constructed by KETRACO.

The flow diagram, including the power plant and fluid transportation system are depicted in Fig. III-2.4; the one line diagram of the energy evacuation system is shown in Fig. III-2.5 and the substation layout in Fig. III-2.6.

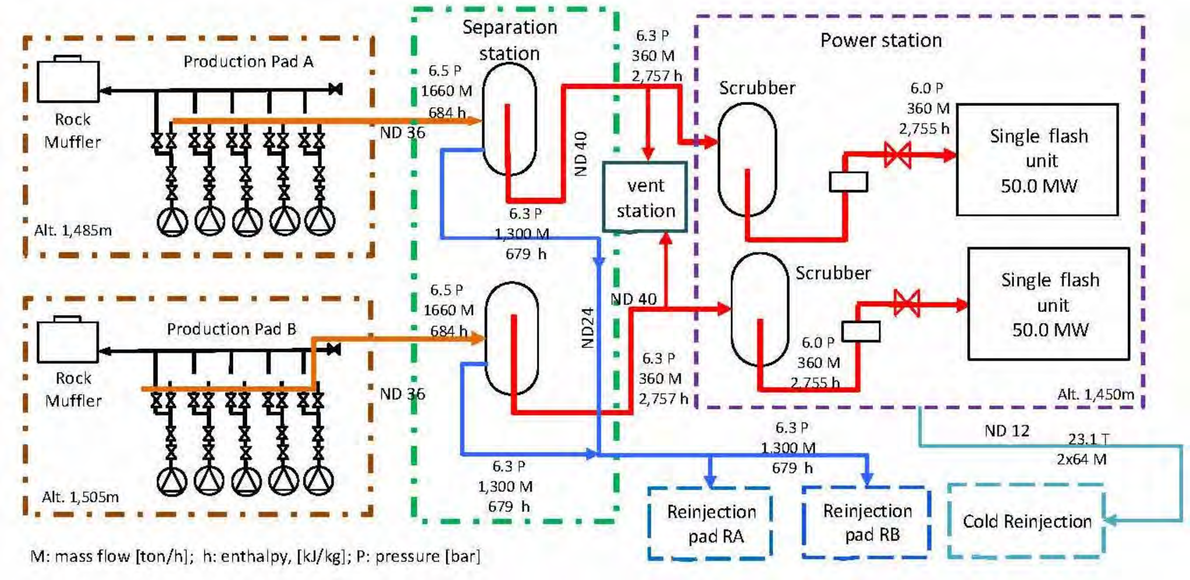


Fig. III-2.4 Arus geothermal field steam gathering system flow diagram

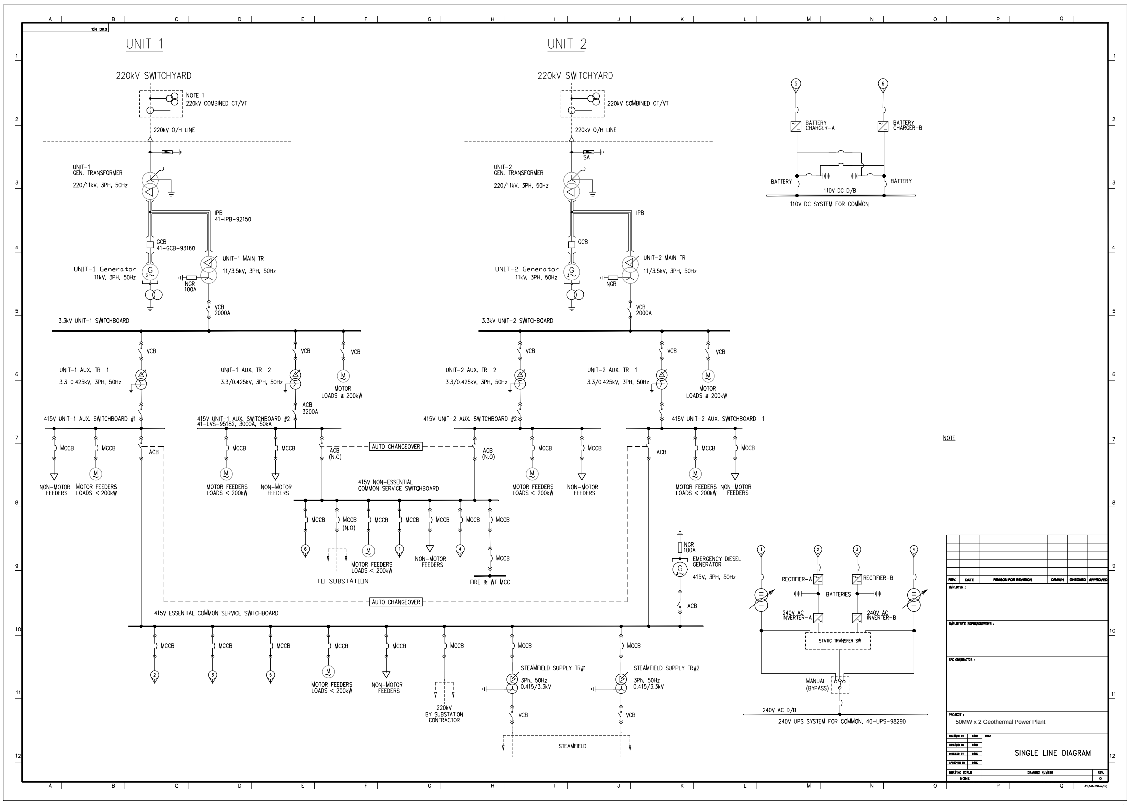


Fig. III-2.5 Typical single line diagram for Arus power plant

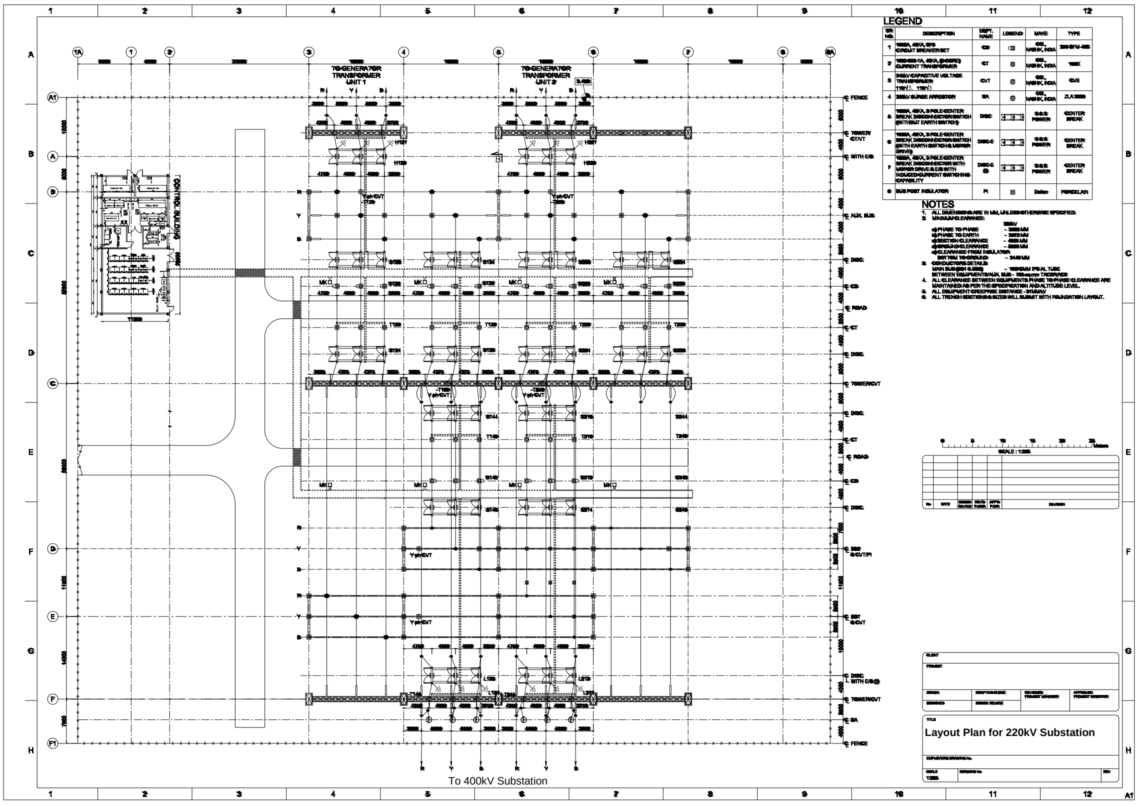


Fig. III-2.6 Arus Substation layout

III-2.4 Development schedule and cost estimation

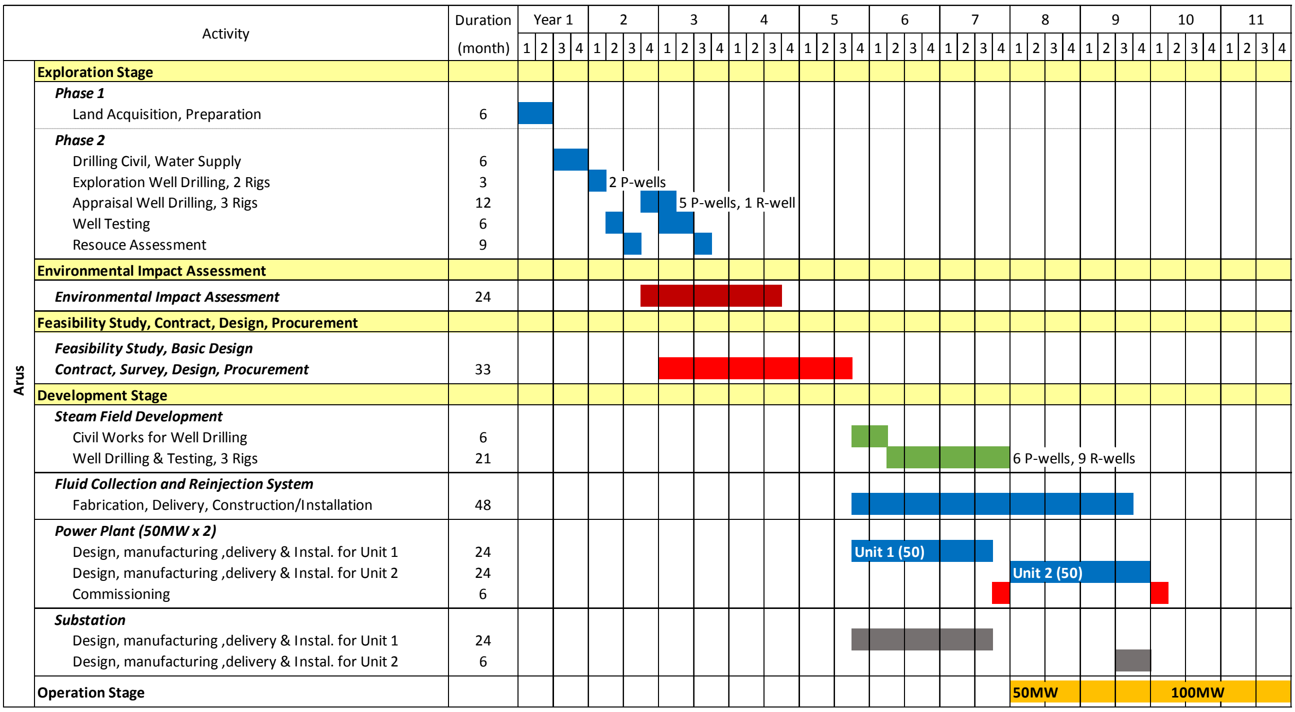
Table III-2.2 shows a tentative development schedule and Table III-2.3 shows cost estimation for a 100MW power plant development at Arus field.

In regards to make-up wells, the decline rates of productivity and the injection capacity due to silica or other scaling of each well are not predictable at present. Therefore, the number of make-up wells required to maintain the rated power output and reinjection capacity over 30 years of plant operation was determined assuming the following usual annual rate of decline for power output of production wells and the injection capacity of reinjection wells.

- Power output of production wells : 3% per year decline
- Injection capacity of injection wells : 3% per year decline

Accordingly, it is estimated that nine production wells and eight reinjection wells will be required as make-up wells over 30 years of plant operation in this study. Depending on the results of well drilling, testing, and the capabilities during operation, consideration should be given to the construction of additional pads or the expansion of existing pads for make-up well drilling.

Table III-2.2 Development schedule



	Activity	Duration (month)
Arus	**Exploration Stage**	
	Phase 1	
	Land Acquisition, Preparation	6
	Phase 2	
	Drilling Civil, Water Supply	6
	Exploration Well Drilling, 2 Rigs	3
	Appraisal Well Drilling, 3 Rigs	12
	Well Testing	6
	Resouce Assessment	9
	Environmental Impact Assessment	
	Environmental Impact Assessment	24
	Feasibility Study, Contract, Design, Procurement	
	Feasibility Study, Basic Design	
	Contract, Survey, Design, Procurement	33
	Development Stage	
	Steam Field Development	
	Civil Works for Well Drilling	6
	Well Drilling & Testing, 3 Rigs	21
	Fluid Collection and Reinjection System	
	Fabrication, Delivery, Construction/Installation	48
	Power Plant (50MW x 2)	
	Design, manufacturing ,delivery & Instal. for Unit 1	24
	Design, manufacturing ,delivery & Instal. for Unit 2	24
	Commissioning	6
	Substation	
	Design, manufacturing ,delivery & Instal. for Unit 1	24
	Design, manufacturing ,delivery & Instal. for Unit 2	6
	Operation Stage	

Table III-2.3 Cost estimation

Exploration Stage

Unit:US$

Item		Unit	Quantity	Unit Price	Price	Remarks
Exploration/Appraisal Well Drilling		**L.S.**	**1**		**40,330,000**	
	Well Pad	Lot	2	600,000	1,200,000	Size: 100m x 150m x 2
	Lay Down/Operation Center	Lot	1	250,000	250,000	
	Access Road	km	2	40,000	80,000	Width: 6-8m
	Water Supply Sysytem	L.S.	1	2,400,000	2,400,000	Tanks, booster pumps, power supply, etc.
	Production Well Drilling	Well	7	4,000,000	28,000,000	±2,000mTD, Directional, 7" liner completion
	Reinjection Well Drilling	Well	1	4,000,000	4,000,000	±2,000mTD, Directional, 7" liner completion
	Water Supply Operation	Well	8	50,000	400,000	Power/water domestic supply
	Well Testing	Well	8	500,000	4,000,000	
Environmental Impact Assessment		**L.S.**	**1**		**300,000**	
Feasibility Study		**L.S.**	**1**		**1,000,000**	
Total Exploration Stage Cost		**L.S.**	**1**		**41,630,000**	

Development Stage (Steam Field)

Unit:US$

Item		Unit	Quantity	Unit Price	Price	Remarks
Start-up Well Drilling		**L.S.**	**1**		**69,740,000**	
	Well Pad	Lot	2	600,000	1,200,000	Size: 100m x 150m x 2
	Lay Down/Operation Center	Lot	1	250,000	250,000	
	Access Road	km	1	40,000	40,000	Width: 6-8m
	Production Well Drilling	Well	6	4,000,000	24,000,000	±2,000mTD, Directional, 7" liner completion
	Reinjection Well Drilling	Well	9	4,000,000	36,000,000	±2,000mTD, Directional, 7" liner completion
	Water Supply Operation	Well	15	50,000	750,000	Power/water domestic supply
	Well Testing	Well	15	500,000	7,500,000	
FCRS Construction		**L.S.**	**1**		**26,950,000**	
	Separator Station	L.S.	2	3,750,000	7,500,000	80m x 80 each
	FCRS Piping	L.S.	2	9,725,000	19,450,000	including civil works, instrument, etc.
Total Steam Field Cost		**L.S.**	**1**		**96,690,000**	

Development Stage (Power Plant)

Unit:US$

Item		Unit	Quantity	Unit Price	Price	Remarks
Power Plant		**L.S.**	**1**		**169,000,000**	
	Site Preparation	L.S.	1	4,000,000	4,000,000	200m x 180m
	Power Plant	L.S.	2	82,500,000	165,000,000	50MW x 2
Switchyard		**L.S.**	**1**		**5,692,000**	
	Site Preparation	m2	14,300	40	572,000	110m x 130m
	Switchyard	L.S.	1	5,120,000	5,120,000	Initial Stage: 3,840,000 and 2nd Stage: 1,280,000
Total Power Plant Cost		**L.S.**	**1**		**174,692,000**	

Operation Stage

Unit:US$

Item		Unit	Quantity	Unit Price	Price	Remarks
Make-up Well Drilling		**L.S.**	**1**		**68,850,000**	
	Production Well Drilling	Well	9	4,000,000	36,000,000	±2,000mTD, Directional, 7" liner completion
	Reinjection Well Drilling	Well	8	4,000,000	32,000,000	±2,000mTD, Directional, 7" liner completion
	Water Supply Operation	Well	17	50,000	850,000	Power/water domestic supply

III-2.5 Economic evaluation of the development plan

a. Financial evaluation

Based on the above-mentioned technical estimation, this section discusses the economic aspects of the development plan. First, financial evaluation is carried out to estimate development cost. In the financial evaluation, it is assumed that a certain entity builds and operates a geothermal power plant, and the profitability of the business is estimated using anticipated financial reports including income statements and cash flow statements of the business. From these financial reports, the return on the equity can be calculated under various energy/steam sales prices. The energy/steam sales price that satisfies the expected rate of return of the business entity is the minimum energy/steam sales price. The thus-calculated minimum energy/steam sales price is defined as the Levelized Energy Cost (LEC) or Levelized Steam Cost (LSC) over the operation period of the power plant. The LEC can be considered as the development cost of Arus geothermal field. In this report, three kinds of development formation is examined; (i) private sector's total project, (ii) GDC and private sector's joint project, and (iii) GDC's total project.

<Assumptions of the financial evaluation>

The following assumptions are used:

a. Evaluation is performed in terms of the US dollar real price (2016 US$) that does not take into account any price/cost inflation, energy/steam sales price hike or the foreign exchange fluctuations.
b. As for the expected rate of return of the business entity, 10% is used for GDC and 20% is used for the private sector.
c. Ten percent (10%) of total cost is added, as the administration cost and consultant fee, to the construction cost of Table III-2.3.
d. During the exploration stage and the appraisal stage, all expense is funded by the business entity's own equity. In the construction stage, 70% of the expense is financed by commercial banks while 30% is funded by the equity. The interest rate of the commercial finance is assumed as 8.0% and the repayment period is assumed as 13 years, of which 3 years are grace period.
e. Auxiliary rate of geothermal power plant is assumed to be 6%. The maintenance and operation (O&M) cost is assumed as 1.0 US¢/kWh.
f. Annual capacity factor of geothermal power plant is 90%.
g. Operating period of unit-1 of the geothermal power plant is 30 years and that of unit- 2 is 28 years.
h. Corporate tax rate is 30% and royalties are 1% of gross sales.
i. Depreciation period is 25 years for both the steam field equipment and the power plant. Calculation is performed using the straight-line method.

Table III-2.4 Basic conditions for the financial evaluation

Stage		Resource exploration	Resource appraisal	Construction of steam facilities	Construction of power plant
Ratio of equity		100%	100%	30%	30%
Ratio of borrowings		-	-	70%	70%
Borrowing conditions	Interest rate	-	-	8%	8%
	Grace period (years)	-	-	3	3
	Repayment period (years)	-	-	10	10
Administration cost and consultants fee		10% of the total construction cost			
Auxiliary rate of plant		6% of gross generation			
O&M cost		1.0 US¢/kWh			
Annual capacity factor		90%			
Operation period		30 years for Unit-1, 28 years for unit-2			
Corporate tax rate		30%			
Royalty of resource		1% of gross sales			
Depreciation period		25 years			
Depreciation method		Straight line method			

<Result of financial evaluation>

Construction costs of the geothermal power plant in the Arus field are as shown in Table III-2.5 (Note: values in this table include 10% to cover the consultant fee and administration cost). In addition, the LEC and the LSC in each development formation has been estimated as shown in Table III-2.6 and Fig. III-2.7.

Table III-2.5 Construction costs of a geothermal power plant in Arus field

Item	Steam field (million US$)	Power plant (million US$)	Total (million US$)	Unit cost (US$/kW)
Construction costs	152	192	344	3,440
IDC	9	14	23	-
Construction costs with IDC	161	206	367	3,670

(Note) IDC: Interest during construction

Table III-2.6 Arus LEC and LSC per development scheme in (US¢/kWh)

Development formation	IPP total PJ	GDC/IPP joint PJ	GDC total PJ
Levelized steam cost (LSC)	9.6	4.7	4.7
Levelized generation cost	5.7	5.7	3.9
Levelized energy cost (LEC)	15.2	10.3	8.6

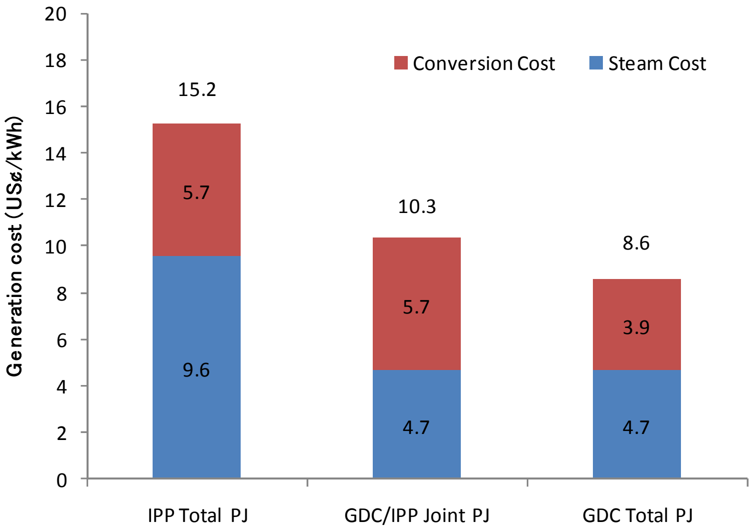


Fig. III-2.7 The LEC and LSC by development formation in Arus field

b. Economic evaluation

Next, economic evaluation is carried out to examine whether geothermal development in Arus field has a social-economic significance compared with the development of other types of power plants. In the economic evaluation, the construction-and-operation costs of other power plants which would be avoided by the geothermal power plant are examined using an internal rate of return method. Specifically, the internal rate of return of the avoided costs (Economic IRR) is evaluated by whether it exceeds 12% which is assumed as the socio-economic opportunity cost of Kenya. As for the alternative power plants, three kinds of power plant are considered; (i) coal-fired power plant, (ii) LNG combined-cycle power plant, and (iii) diesel power plant.

<Assumptions of economic evaluation>

The following assumptions are used:

a. Evaluation is performed in terms of the US dollar real price (2016 US$) that does not take into account any price/cost inflation or the foreign exchange fluctuations.

b. The specifications of each plant and fuel cost estimations are as shown in Table III-2.7:

Table III-2.7 Specifications and fuel cost estimation of alternative power plants

Item	Coal-fired plant	LNG CC plant	Diesel plant
Output capacity	300 MW	300 MW	100 MW
Construction cost（w/o IDC）	2,000 US$/kW	1,160 US$/kW	1,390 US$/kW
Development period	4 years	3 years	2 years
Fuel	Coal	LNG	HSD
Calorific value of fuel	6,000 kcal/kg	1,027 BTU/cubic feet	9,800 kcal/liter
Fuel price	115 US$/ton	12 US$/million BTU	130 US$/bbl
Thermal efficiency of plant	35%	45%	38%

(Note） Fuel prices referred to are the 2030 forecast price in the IEA's World Energy Outlook (2015)

<Result of economic evaluation>

Calculation results of the economic evaluation for each alternative power plant are shown in Table III-2.8. Since all EIRR results exceed 12% which is assumed as the socio-economic opportunity cost of Kenya, the geothermal development in Arus field is justified with the socio-economic significance.

Table III-2.8 Cost competitiveness of geothermal development in Arus field vs. alternative thermal power plants

Alternative plants	Coal-fired plant	LNG CC plant	Diesel plant
Economic Internal Rate of Return	15.6%	18.8%	31.6%

c. Sensitivity analysis

The construction cost of geothermal power plants in the Arus field is estimated to be US $ 368 million with the unit construction cost of 3,670 US$/kW. The sensitivity analysis of the LEC/LSC and the economic evaluation on the change of the estimated construction cost is done. The results are shown in Figs. III -2.8 and III-2.9. When the construction cost changes by ± 20% from the estimated one, the LEC and LSC in the case of joint project between GDC and IPP changes in the range from 8.6 US¢/kWh (-16.8%) to 12.1 US¢/kWh (+16.9%). Regarding the economic evaluation, a geothermal power plant remains competitive against a coal-fired plant, an LNG combined cycle plant and a diesel power plant even if the construction cost rises by 15%. However, when the construction cost rises by 20%, geothermal loses competitiveness and becomes almost equal economic value to that of a coal-fired plant.

In addition, the average output of the production well in Arus field is estimated to be 10 MW per well. The sensitivity analysis of the LEC/LSC and the economic evaluation on the change of the average production well output is also done and the result is shown in Figs. III-2.10 and III-2.11. If the average production well output decreases to 5 MW/well, the LEC will rise by 15.4% to 11.9 US¢/kWh, and the geothermal project in Arus will lose cost competitiveness against coal-fired project. Therefore, great attention is needed to the average production well output in this field.

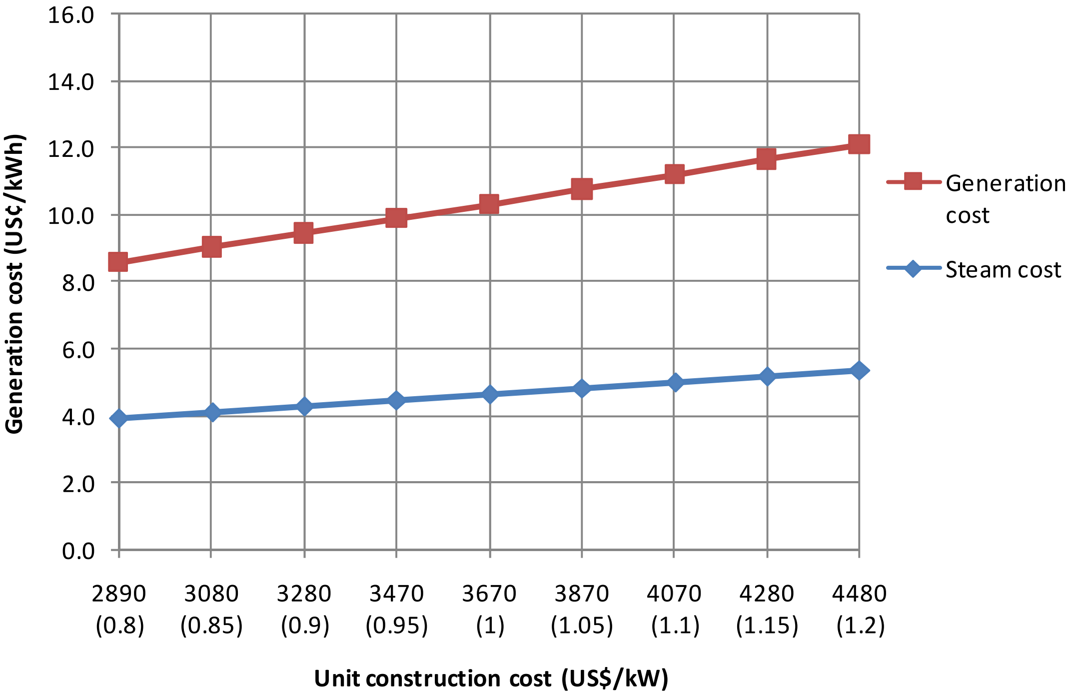


Fig. III-2.8 Sensitivity analysis of the LEC and LSC to changes in the construction cost (Arus)

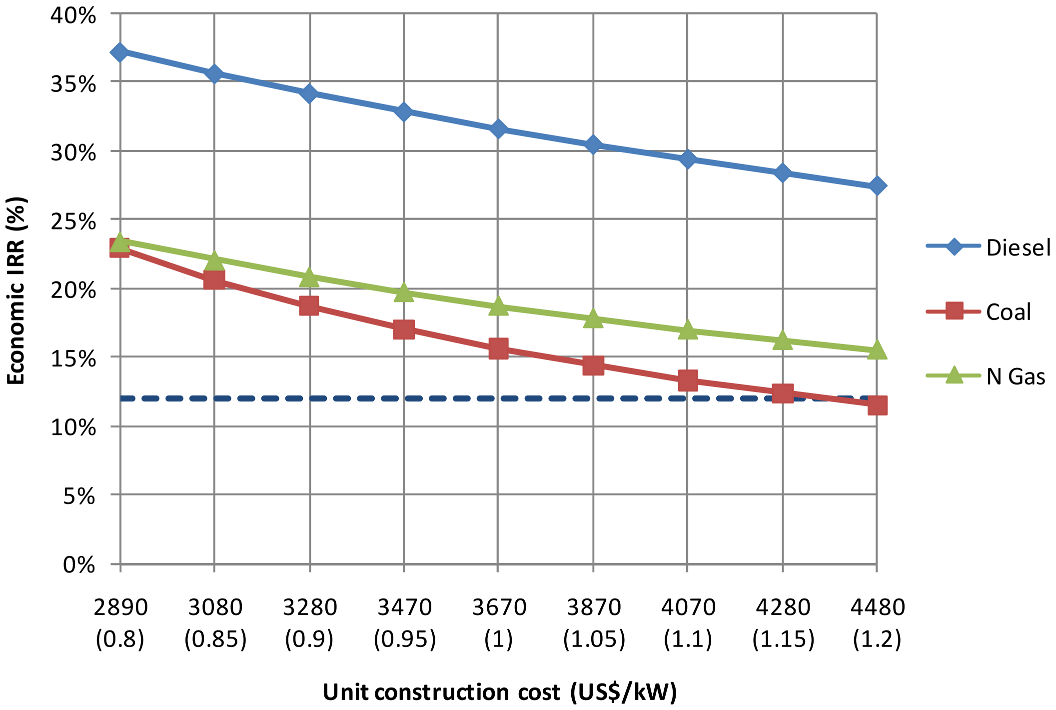


Fig. III-2.9 Sensitivity analysis of the EIRRs to changes in the construction cost (Arus)

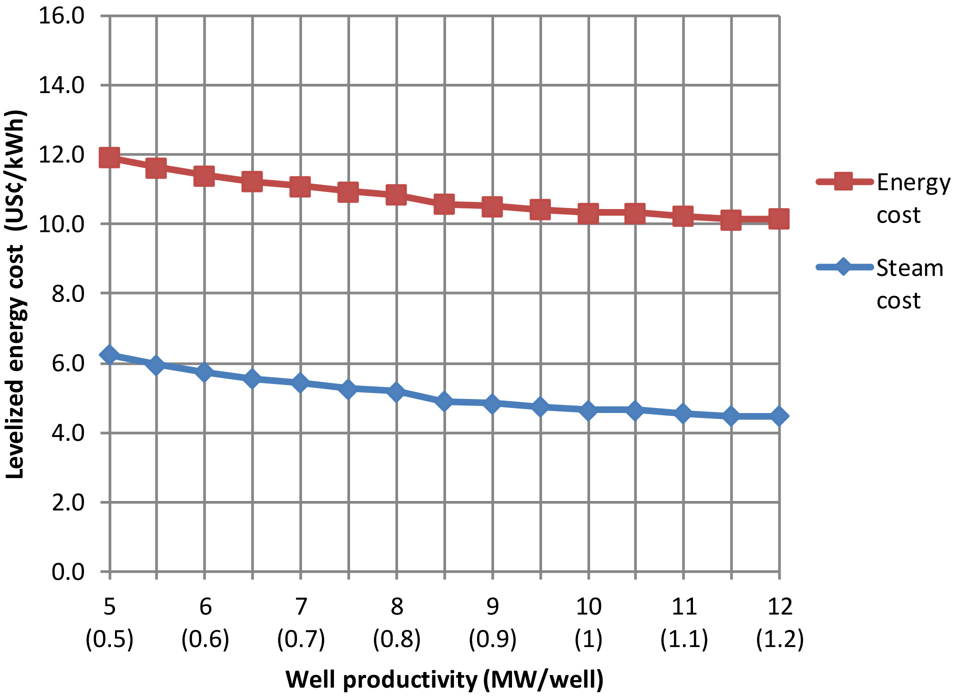


Fig. III-2.10 Sensitivity analysis of the LEC and LSC to changes in the average production well output (Arus)

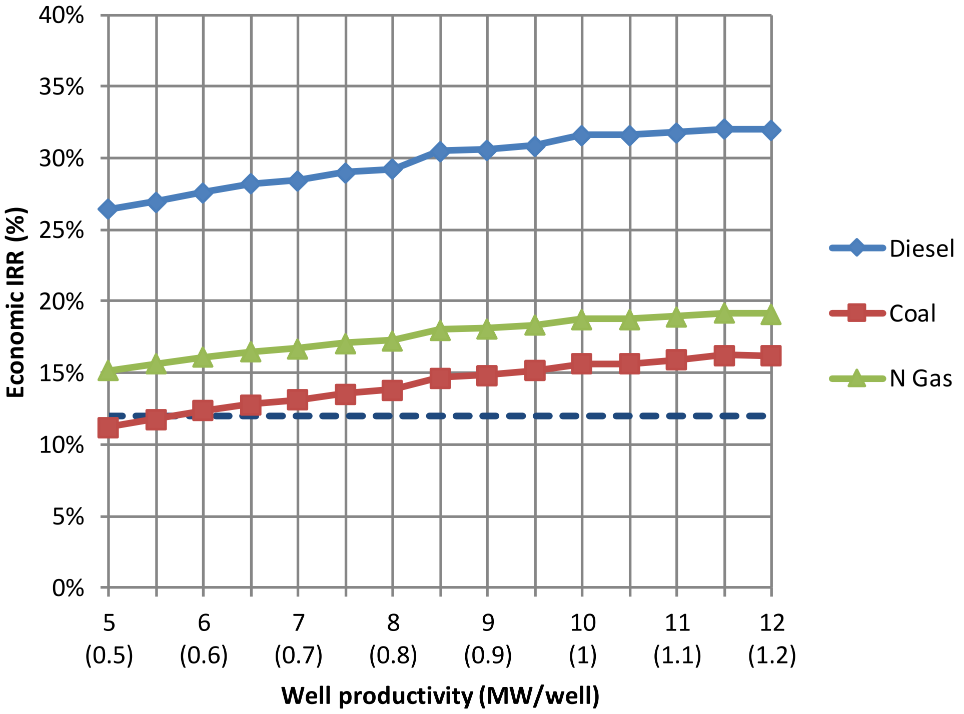


Fig. III-2.11 Sensitivity analysis of the EIRRs to changes in the average production well output (Arus)

III-3 Development Plan for the Baringo (South & North) Field

III-3.1 Development scale and main facilities

The development scale (the output capacity of the geothermal power plant for the Baringo field) is proposed based on the estimated resource potential. The type of power plant was selected to be a conventional flash steam cycle (condensing type). The required number of wells is estimated according to the results of the evaluation of productivity (and injectivity) of wells. The main specifications regarding the possible power development of the Baringo field are shown in Table III-3.1.

Based upon the possible power development plan stated above, to exploit a field installing a 100MW flash type at Baringo South, seventeen production wells and thirteen reinjection wells are estimated to be required for start-up. In consideration of the drilling success ratio (which is assumed to be 50% for exploration wells and 80-100% for appraisal/operation wells), twenty-one production wells and fourteen reinjection wells should be drilled. Regarding the power development plan for 100MW geothermal power generation at Baringo North, ten production wells and nine reinjection wells are estimated to be required for start-up. In consideration of the drilling success ratio, thirteen production wells and ten reinjection wells should be drilled. Regarding the number of exploratory wells, two wells are tentatively planned in this study because of the plan of relatively small-scale development in the Baringo South and North fields. However, if the budget permits, drilling of three or more wells is recommendable to ascertain the existence and extension of the exploitable geothermal reservoir.

Table III-3.1 Main specifications for the possible power development in the Baringo field

Field	Planned Capacity	Average Productivity	Total Reinjection Brine	Assumed Injection Capacity	Required Wells for operation	
	(MW-gross)	(MW/well)	(t/h)	(t/h/well)	Production	Reinjection
Baringo South 50MW x 2	100	6	3740	300	**17**	**13**
Baringo North 50MW x 2	100	10	2600	300	**10**	**9**

Field		Exploration Stage		Appraisal Stage		Development Stage		Total	
		P-well	R-well	P-well	R-well	P-well	R-well	P-well	R-well
Baringo South 50MW x 2	Drilled wells	2	0	5	1	14	13	**21**	**14**
	Successful Wells (for operation)	1	0	4	1	12	12	**17**	**13**
Baringo North 50MW x 2	Drilled wells	2	0	5	1	6	9	**13**	**10**
	Successful Wells (for operation)	1	0	4	1	5	8	**10**	**9**

III-3.2 Resource development plan

According to the conceptual model of the geothermal system, total drilling depth will vary from 1,800m to 2,300m in depth for both production wells and reinjection wells. In order to minimize the number of required drilling pads and to allow multiple targets to be drilled from the same pad, directional drilling should be adopted. To avoid interference among wells, the targets are located at intervals of around 300m. Detailed drilling depth and well profiles for the development production/reinjection wells should be planned based on the up-date geothermal conceptual model reflecting the results of exploration/appraisal wells drilling and testing.

Drilling rigs owned by GDC with a 2,000HP output capability will be available to drill directionally to 1,800-2,300m in depth, with a final completion diameter of 8.5 inches. Fig. III-2.1 shows an example of a possible well casing program and Fig. III-2.2 shows an example of a possible well directional drilling program.

The number of drilling pads in Baringo South is tentatively assumed to be two pads for production wells and two pads for reinjection wells. The number of drilling pads in Baringo North is assumed to be three for production wells and two for reinjection wells.

Approximately eight wells can be drilled from one pad of dimensions 100m x 150m, including water/mud pits and pipe storage yard, etc. Furthermore, constructed pads will be available for future drilling of make-up wells during the power plant operation.

Fresh water for well drilling and power plant operation can be supplied from Lake Baringo and/or the river flowing through the project site by utilizing steel pipeline for water transportation. In addition, fresh water should be distributed to pads from water tanks with around 4,000 cubic meters capacity, which will be installed close to the power plant.

Drilling pads for reinjection wells should be situated at elevations lower than the separator stations to transport the brine to the reinjection wells by gravity. The drilling targets for reinjection wells should be separated from the production zone at least 1 km to avoid the breakthrough of reinjected water that could cause cooling of the high temperature reservoir. The planned layout of Baringo South and Baringo North are shown in Figs. III-3.1 and III-3.2.

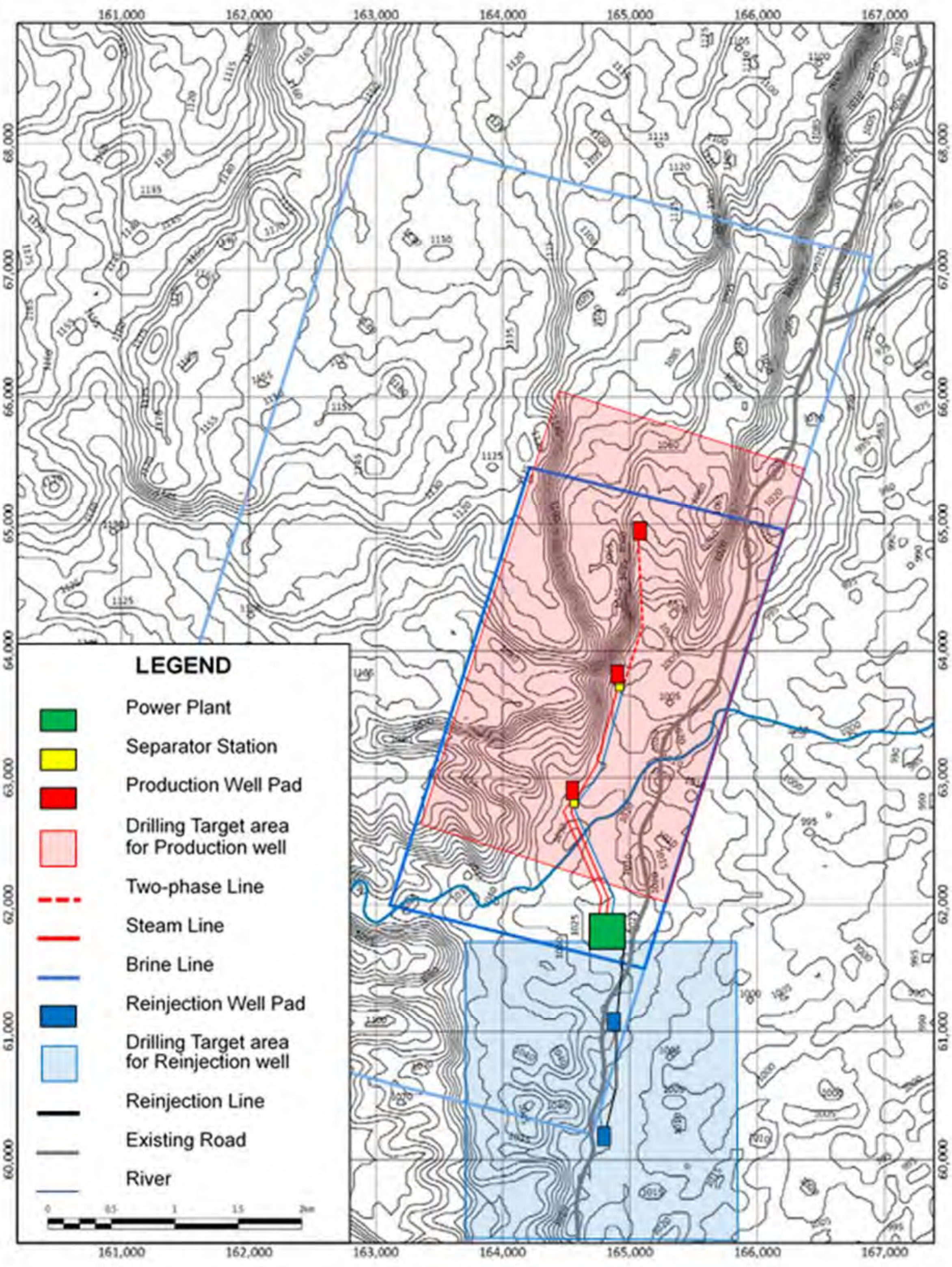


Fig. III-3.1 Preliminary layout for the development of Baringo (South)

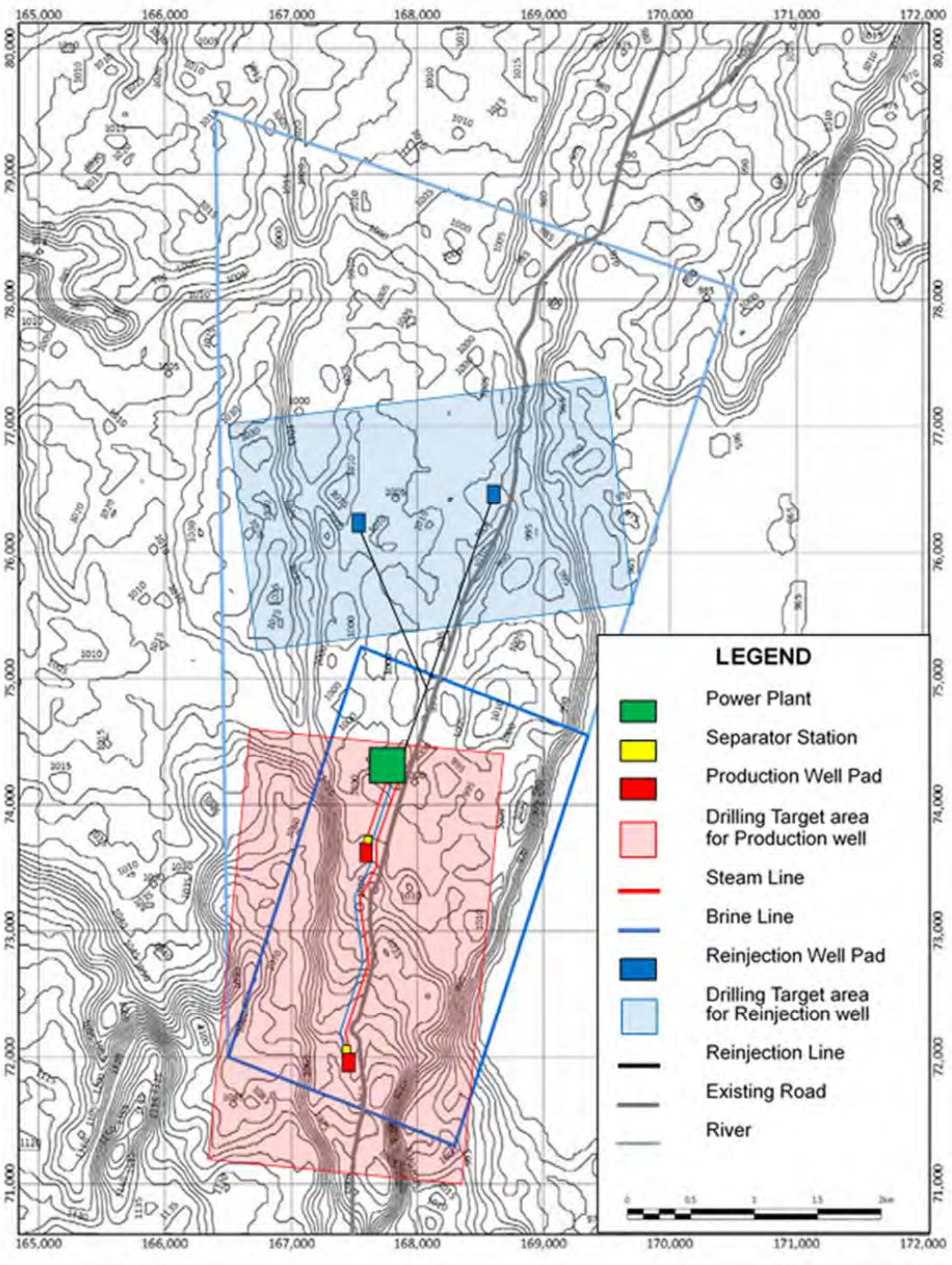


Fig. III-3.2 Preliminary layout for the development of Baringo (North)

III-3.3 Development plan for power plant and substation

Two geothermal plants each consisting of two single-flash condensing 50MW units are envisioned to be constructed in the Baringo North and Baringo South fields respectively. Further studies on the available resource may lead to different unit size or energy conversion technology.

Power generated power by the Baringo South geothermal power plant will be evacuated to the 220kV substation of Baringo North geothermal power plant. The 220kV substation for Baringo North will be connected to the 400/220kV Paka substation through a 220kV transmission line (single Canary x 2 circuits), which will be constructed by KETRACO to connect with the Kenyan National Grid.

The flow diagram, including the power plant and fluid transportation system are depicted in Figs. III-3.3 and III-3.4; the one line diagram of the energy evacuation system is shown in Figs. III-3.5, III-3.6 and III-3.7 below.

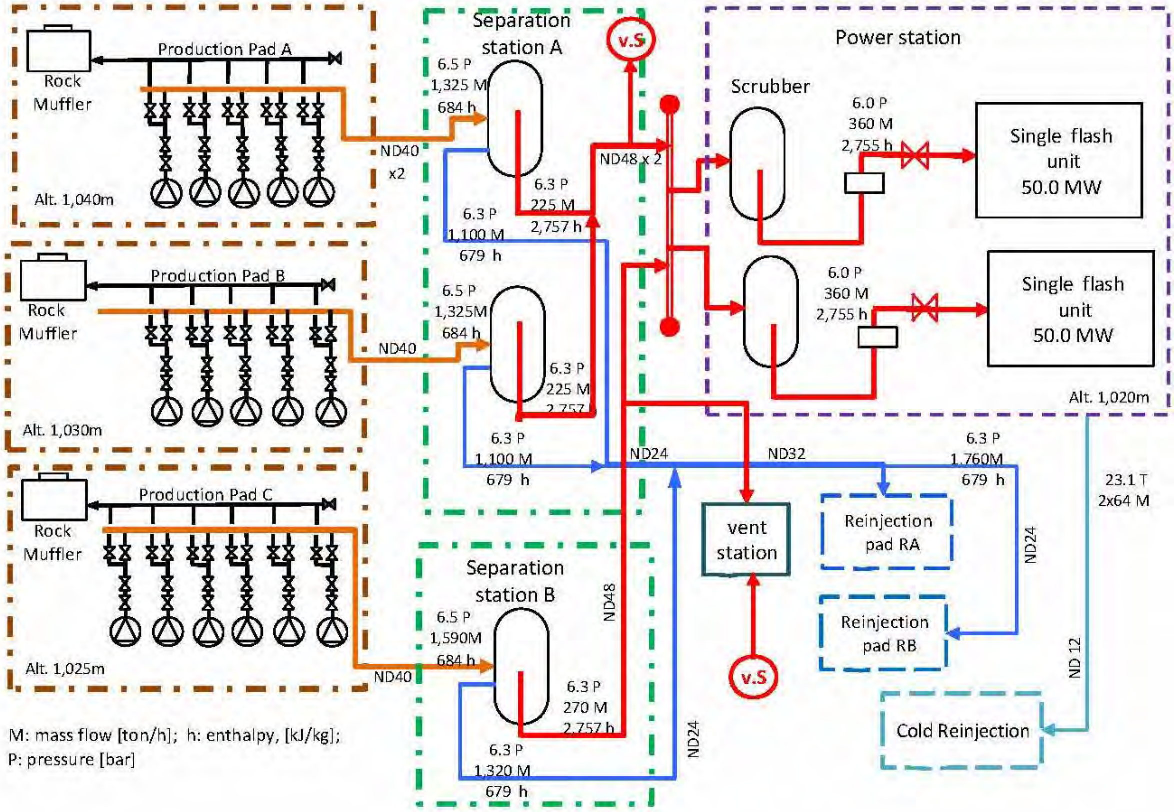


Fig. III-3.3 Baringo South steam gathering system flow diagram

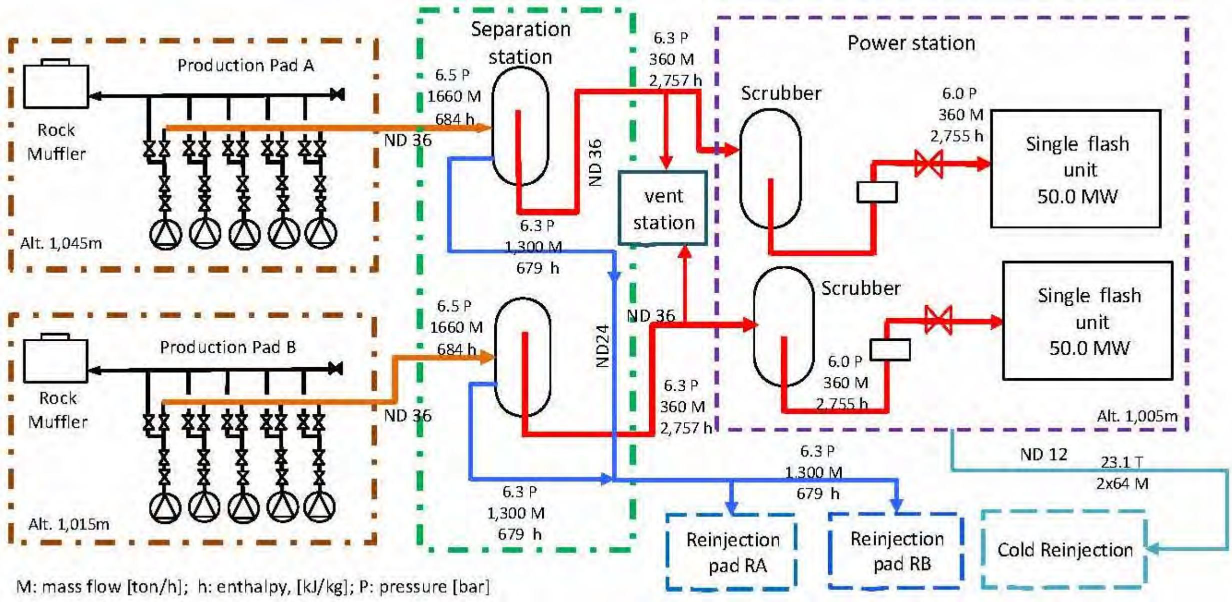


Fig. III-3.4 Baringo North steam gathering system flow diagram

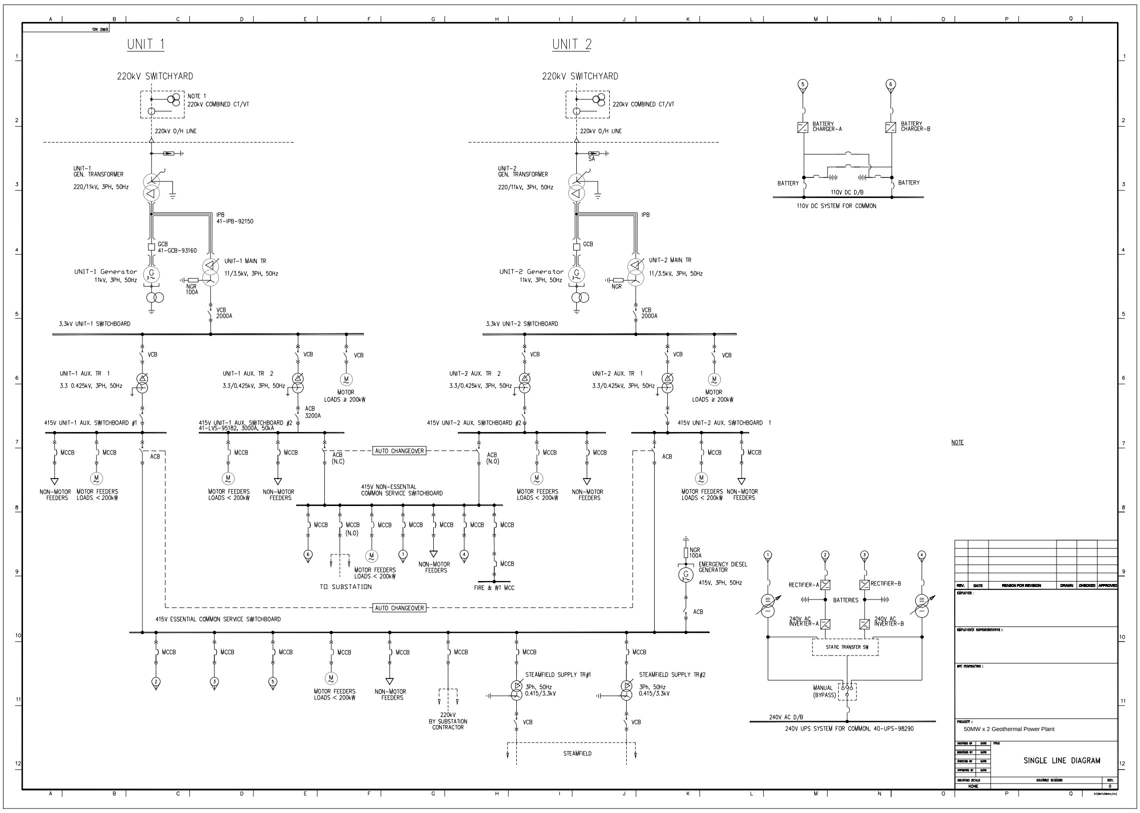


Fig. III-3.5 Single line diagram for Baringo South and North power plants

During the initial development stage, the Baringo South Power Plant 1st unit (50MW) will be constructed. The generated power by the Baringo South power plant (50MW) will be evacuated to the 400/220kV Paka substation through the 220kV x 30km x 2 circuit Single Canary transmission line.

During the next stage, Baringo North 1st unit will be constructed. Further, Baringo South 2nd unit and Baringo North 2nd unit will be constructed. The substation for Baringo North will have bays for Baringo

South (220kV x 2 circuits) and for the Paka substation (220kV x 2 circuits) to connect to the Kenyan National Grid through the 400/220kV Paka substation.

The 400kV transmission line, 400/220kV substations and 220kV transmission line from the power plants to the substation will be constructed by KETRACO.

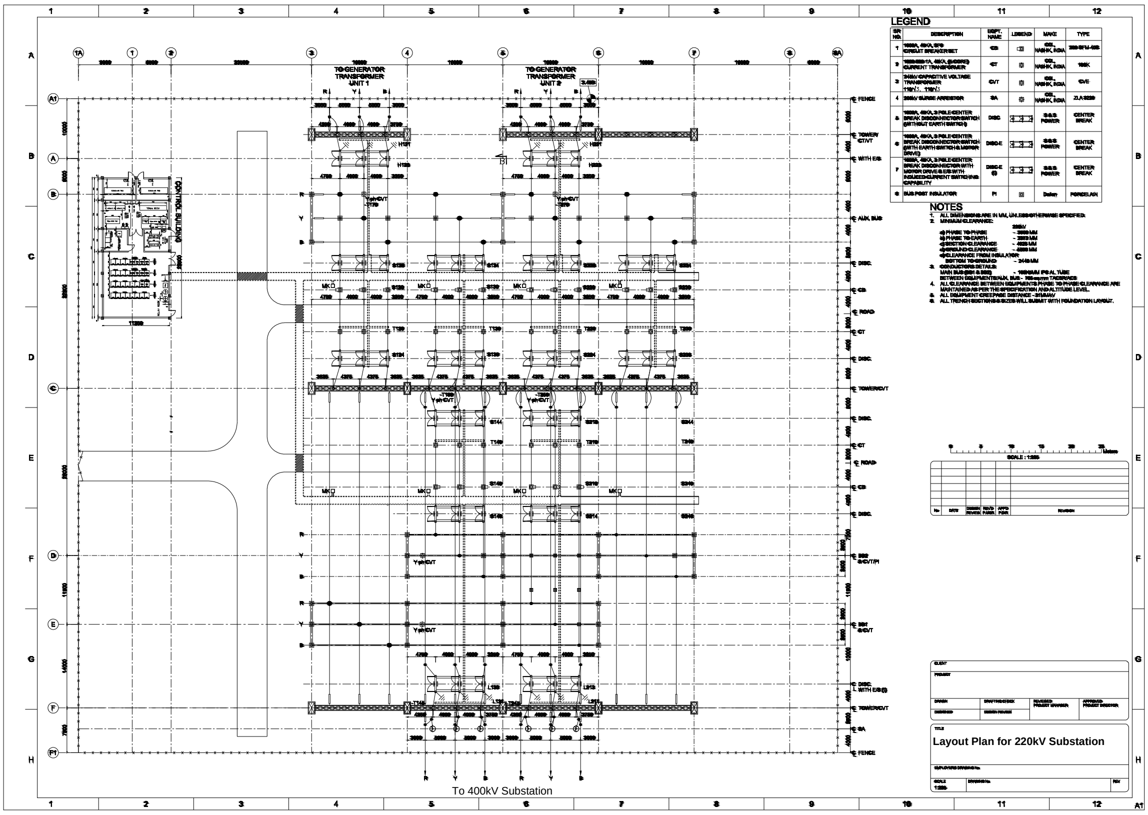


Fig. III-3.6 Baringo South substation layout

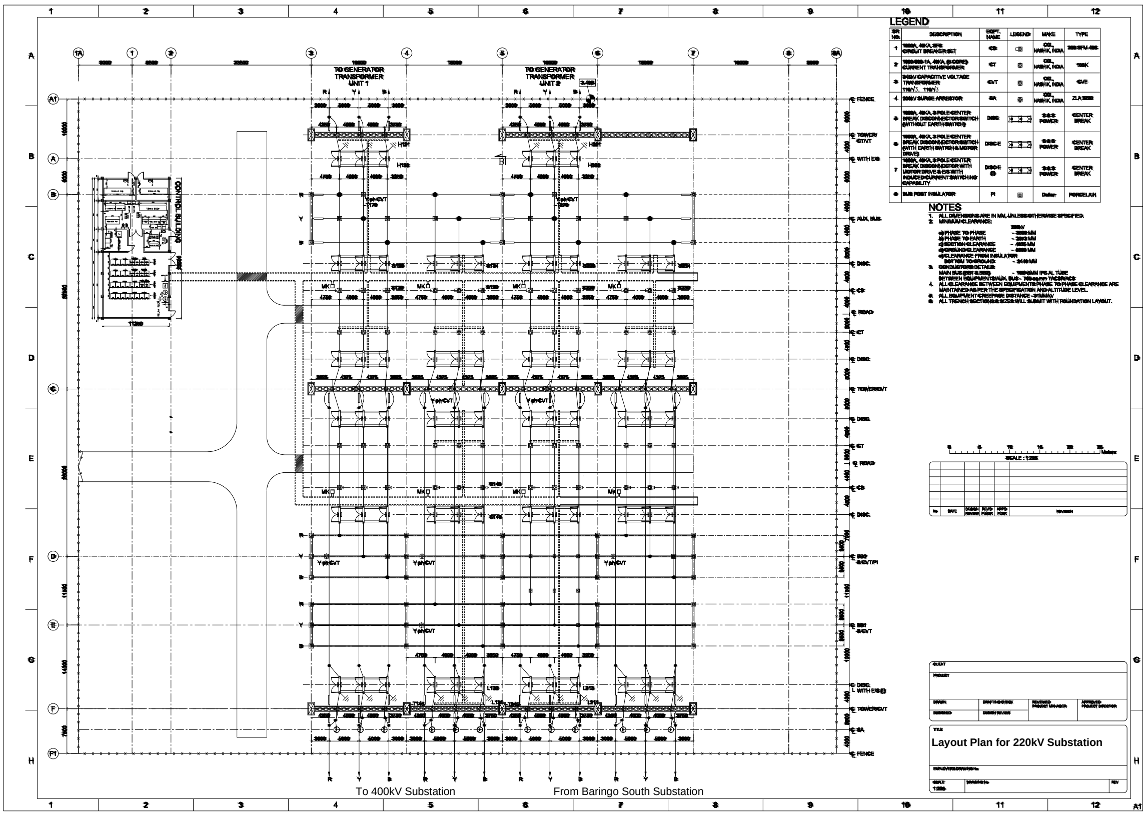


Fig. III-3.7 Baringo North substation layout

III-3.4 Development schedule and cost estimation

Table III-3.2 shows a tentative development schedule of both projects; Table III-3.3 and Table III-3.4 shows a cost estimation for 100MW power plant development at Baringo, South and North respectively.

In regards to make-up wells, the decline rates of productivity and injection capacity due to silica or other scaling of each well are not predictable at present. Therefore, the number of make-up wells required to maintain the rated power output and reinjection capacity over 30 years of plant operation was determined assuming the following usual annual rate of decline for power output of production wells and the injection capacity of reinjection wells.

- Power output of production wells : 3% per year decline
- Injection capacity of injection wells : 3% per year decline

Accordingly, it is estimated that nine production wells and eight reinjection wells in Baringo North and fourteen production wells and eleven reinjection wells in Baringo South will be required as the make-up wells over 30 years of plant operation in this study. Depending on the results of well drilling, testing, and the capabilities during operation, consideration should be given to the construction of additional pads or the expansion of existing pads for make-up well drilling.

Table III-3.2 Development schedule of the Baringo North and South projects

	Activity	Duration	Year 1				2				3				4				5				6				7				8				9				10				11			
		(month)	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
South part of Baringo	**Exploration Stage**																																													
	Phase 1																																													
	Land Acquisition, Preparation	6	■	■																																								
	Phase 2																																													
	Drilling Civil, Water Supply	6			■	■																																						
	Exploration Well Drilling, 2 Rigs	3					■	2 P-wells																																				
	Appraisal Well Drilling, 3 Rigs	12								■	■	5 P-wells, 1 R-well																																
	Well Testing	6						■			■	■																																
	Resource Assessment	9							■				■																															
	Environmental Impact Assessment																																													
	Environmental Impact Assessment	24								■	■	■	■	■	■	■	■																											
	Feasibility Study, Contract, Design, Procurement																																													
	Feasibility Study, Basic Design																																													
	Contract, Survey, Design, Procurement	33									■	■	■	■	■	■	■	■	■	■	■																								
	Development Stage																																													
	Steam Field Development																																													
	Civil Works for Well Drilling	6																			■	■																						
	Well Drilling & Testing, 3 Rigs	33																					■	■	■	■	■	■	■	■	■	■	■	14 P-wells, 13 R-wells											
	Fluid Collection and Reinjection System																																													
	Fabrication, Delivery, Construction/Installation	48																			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■									
	Power Plant (50MW x 2)																																													
	Design, manufacturing ,delivery & Instal. of Unit 1	24																			Unit 1 (50)	■	■	■	■	■	■	■																
	Design, manufacturing ,delivery & Instal. of Unit 2	24																												Unit 2 (50)	■	■	■	■	■	■	■								
	Commissioning activities	6																											■									■							
	Substation																																													
	Design, manufacturing ,delivery & Instal. for Unit 1	24																			■	■	■	■	■	■	■	■																
	Design, manufacturing ,delivery & Instal. for Unit 2	6																																			■	■							
	Operation Stage																													50MW	■	■	■	■	■	■	■	■	100MW	■	■	■	■	■	■
North part of Baringo	**Exploration Stage**																																													
	Phase 1																																													
	Land Acquisition, Preparation	6					■	■																																				
	Phase 2																																													
	Drilling Civil, Water Supply	6							■	■																																		
	Exploration Well Drilling, 2 Rigs	3									■	2 P-wells																																
	Appraisal Well Drilling, 3 Rigs	12												■	■	5 P-wells, 1 R-well																												
	Well Testing	6										■			■	■																												
	Resource Assessment	9											■				■																											
	Environmental Impact Assessment																																													
	Environmental Impact Assessment	24												■	■	■	■	■	■	■	■																							
	Feasibility Study, Contract, Design, Procurement																																													
	Feasibility Study, Basic Design																																													
	Contract, Survey, Design, Procurement	33													■	■	■	■	■	■	■	■	■	■	■																				
	Development Stage																																													
	Steam Field Development																																													
	Civil Works for Well Drilling	6																							■	■																		
	Well Drilling & Testing, 3 Rigs	21																									■	■	■	■	■	■	■	6 P-wells, 9 R-wells											
	Fluid Collection and Reinjection System																																													
	Fabrication, Delivery, Construction/Installation	48																							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
	Power Plant (50MW x 2)																																													
	Design, manufacturing ,delivery & Instal. of Unit 1	24																							Unit 1 (50)	■	■	■	■	■	■	■												
	Design, manufacturing ,delivery & Instal. of Unit 2	24																																Unit 2 (50)	■	■	■	■	■	■	■				
	Commissioning activities	6																															■									■			
	Substation																																													
	Design, manufacturing ,delivery & Instal. for Unit 1	24																							■	■	■	■	■	■	■	■												
	Design, manufacturing ,delivery & Instal. for Unit 2	6																																						■	■				
	Operation Stage																																	50MW	■	■	■	■	■	■	■	■	100MW	■	■

Table III-3.3 Cost estimation (Baringo South)

Exploration Stage

Unit:US$

Item		Unit	Quantity	Unit Price	Price	Remarks
Exploration/Appraisal Well Drilling		**L.S.**	**1**		**40,330,000**	
	Well Pad	Lot	2	600,000	1,200,000	Size: 100m x 150m x 2
	Lay Down/Operation Center	Lot	1	250,000	250,000	
	Access Road	km	2	40,000	80,000	Width: 6-8m
	Water Supply Sysytem	L.S.	1	2,400,000	2,400,000	Tanks, booster pumps, power supply, etc.
	Production Well Drilling	Well	7	4,000,000	28,000,000	±2,000mTD, Directional, 7" liner completion
	Reinjection Well Drilling	Well	1	4,000,000	4,000,000	±2,000mTD, Directional, 7" liner completion
	Water Supply Operation	Well	8	50,000	400,000	Power/water domestic supply
	Well Testing	Well	8	500,000	4,000,000	
Environmental Impact Assessment		**L.S.**	**1**		**300,000**	
Feasibility Study		**L.S.**	**1**		**1,000,000**	
Total Exploration Stage Cost		**L.S.**	**1**		**41,630,000**	

Development Stage (Steam Field)

Unit:US$

Item		Unit	Quantity	Unit Price	Price	Remarks
Start-up Well Drilling		**L.S.**	**1**		**124,340,000**	
	Well Pad	Lot	2	600,000	1,200,000	Size: 100m x 150m x 2
	Lay Down/Operation Center	Lot	1	250,000	250,000	
	Access Road	km	1	40,000	40,000	Width: 6-8m
	Production Well Drilling	Well	14	4,000,000	56,000,000	±2,000mTD, Directional, 7" liner completion
	Reinjection Well Drilling	Well	13	4,000,000	52,000,000	±2,000mTD, Directional, 7" liner completion
	Water Supply Operation	Well	27	50,000	1,350,000	Power/water domestic supply
	Well Testing	Well	27	500,000	13,500,000	
FCRS Construction		**L.S.**	**1**		**32,110,000**	
	Separator Station	L.S.	2	3,750,000	7,500,000	100m x 80m each
	FCRS Piping	L.S.	2	12,305,000	24,610,000	including civil works, instrument, etc.
Total Steam Field Cost		**L.S.**	**1**		**156,450,000**	

Development Stage (Power Plant)

Unit:US$

Item		Unit	Quantity	Unit Price	Price	Remarks
Power Plant		**L.S.**	**1**		**169,000,000**	
	Site Preparation	L.S.	1	4,000,000	4,000,000	200m x 180m
	Power Plant	L.S.	2	82,500,000	165,000,000	50MW x 2
Switchyard		**L.S.**	**1**		**5,692,000**	
	Site Preparation	m2	14,300	40	572,000	110m x 130m
	Switchyard	L.S.	1	5,120,000	5,120,000	Initial Stage: 3,840,000 and 2nd Stage: 1,280,000
Total Power Plant Cost		**L.S.**	**1**		**174,692,000**	

Operation Stage

Unit:US$

Item		Unit	Quantity	Unit Price	Price	Remarks
Make-up Well Drilling		**L.S.**	**1**		**101,250,000**	
	Production Well Drilling	Well	14	4,000,000	56,000,000	±2,000mTD, Directional, 7" liner completion
	Reinjection Well Drilling	Well	11	4,000,000	44,000,000	±2,000mTD, Directional, 7" liner completion
	Water Supply Operation	Well	25	50,000	1,250,000	Power/water domestic supply

Table III-3.4 Cost Estimation (Baringo North)

Exploration Stage

Unit:US$

Item	Unit	Quantity	Unit Price	Price	Remarks
Exploration/Appraisal Well Drilling	**L.S.**	**1**		**40,330,000**	
Well Pad	Lot	2	600,000	1,200,000	Size: 100m x 150m x 2
Lay Down/Operation Center	Lot	1	250,000	250,000	
Access Road	km	2	40,000	80,000	Width: 6-8m
Water Supply Sysytem	L.S.	1	2,400,000	2,400,000	Tanks, booster pumps, power supply, etc.
Production Well Drilling	Well	7	4,000,000	28,000,000	±2,000mTD, Directional, 7" liner completion
Reinjection Well Drilling	Well	1	4,000,000	4,000,000	±2,000mTD, Directional, 7" liner completion
Water Supply Operation	Well	8	50,000	400,000	Power/water domestic supply
Well Testing	Well	8	500,000	4,000,000	
Environmental Impact Assessment	**L.S.**	**1**		**300,000**	
Feasibility Study	**L.S.**	**1**		**1,000,000**	
Total Exploration Stage Cost	**L.S.**	**1**		**41,630,000**	

Development Stage (Steam Field)

Unit:US$

Item	Unit	Quantity	Unit Price	Price	Remarks
Start-up Well Drilling	**L.S.**	**1**		**69,740,000**	
Well Pad	Lot	2	600,000	1,200,000	Size: 100m x 150m x 2
Lay Down/Operation Center	Lot	1	250,000	250,000	
Access Road	km	1	40,000	40,000	Width: 6-8m
Production Well Drilling	Well	6	4,000,000	24,000,000	±2,000mTD, Directional, 7" liner completion
Reinjection Well Drilling	Well	9	4,000,000	36,000,000	±2,000mTD, Directional, 7" liner completion
Water Supply Operation	Well	15	50,000	750,000	Power/water domestic supply
Well Testing	Well	15	500,000	7,500,000	
FCRS Construction	**L.S.**	**1**		**32,110,000**	
Separator Station	L.S.	2	3,750,000	7,500,000	100m x 80m each
FCRS Piping	L.S.	2	12,305,000	24,610,000	including civil works, instrument, etc.
Total Steam Field Cost	**L.S.**	**1**		**101,850,000**	

Development Stage (Power Plant)

Unit:US$

Item	Unit	Quantity	Unit Price	Price	Remarks
Power Plant	**L.S.**	**1**		**169,000,000**	
Site Preparation	L.S.	1	4,000,000	4,000,000	200m x 80m
Power Plant	L.S.	2	82,500,000	165,000,000	50MW x 2
Switchyard	**L.S.**	**1**		**8,252,000**	
Site Preparation	m2	14,300	40	572,000	110m x 130m
Switchyard	L.S.	1	7,680,000	7,680,000	Initial Stage: 6,400,000 and 2nd Stage: 1,280,000
Total Power Plant Cost	**L.S.**	**1**		**177,252,000**	

Operation Stage

Unit:US$

Item	Unit	Quantity	Unit Price	Price	Remarks
Make-up Well Drilling	**L.S.**	**1**		**68,850,000**	
Production Well Drilling	Well	9	4,000,000	36,000,000	±2,000mTD, Directional, 7" liner completion
Reinjection Well Drilling	Well	8	4,000,000	32,000,000	±2,000mTD, Directional, 7" liner completion
Water Supply Operation	Well	17	50,000	850,000	Power/water domestic supply

III-3.5 Economic evaluation of the development plan

a. Financial evaluation

Based on the above-mentioned technical estimation, the financial evaluation was carried out to estimate the development cost of the Baringo field. Similar to the evaluation of Arus field, three kinds of development formations were examined; (i) private sector's total project, (ii) GDC and private sector's joint project, and (iii) GDC's total project. The assumptions of the evaluation are also the same as in the case of Arus field.

<Result of financial evaluation>

Construction costs of a geothermal power plant in the south part of Baringo field are as shown in Table III-3.5 (Note: values in this table include 10% to cover the consultant fee and administration cost). Construction costs of a geothermal power plant in the north part of Baringo field are as shown in Table III-3.6.

Table III-3.5 Construction costs of a geothermal power plant in south part of Baringo field

Item	Steam field (million US$)	Power plant (million US$)	Total (million US$)	Unit cost (US$/kW)
Construction costs	218	192	410	4,100
IDC	12	14	27	-
Construction costs with IDC	230	206	437	4,370

Table III-3.6 Construction costs of a geothermal power plant in north part of Baringo field

Item	Steam field (million US$)	Power plant (million US$)	Total (million US$)	Unit cost (US$/kW)
Construction costs	158	195	353	3,530
IDC	9	14	23	-
Construction costs with IDC	167	209	376	3,760

The LEC and the LSC in each development formation in Baringo South has been estimated as shown in Table III-3.7 and Fig. III-3.8. The LEC and the LSC in Baringo North are as shown in Table III-3.8 and Fig. III-3.9.

Table III-3.7 The LEC and LSC by development formation for the Baringo South field (US¢/kWh)

Development formation	IPP total PJ	GDC/IPP joint PJ	GDC total PJ
Levelized steam cost (LSC)	11.2	5.9	5.8
Levelized generation cost	5.7	5.7	3.9
Levelized energy cost (LEC)	16.8	11.5	9.8

Table III-3.8 The LEC and LSC by development formation for the Baringo North field (US¢/kWh)

Development formation	IPP total PJ	GDC/IPP joint PJ	GDC total PJ
Levelized steam cost (LSC)	9.7	4.8	4.7
Levelized generation cost	5.8	5.8	4.0
Levelized energy cost (LEC)	15.5	10.5	8.7

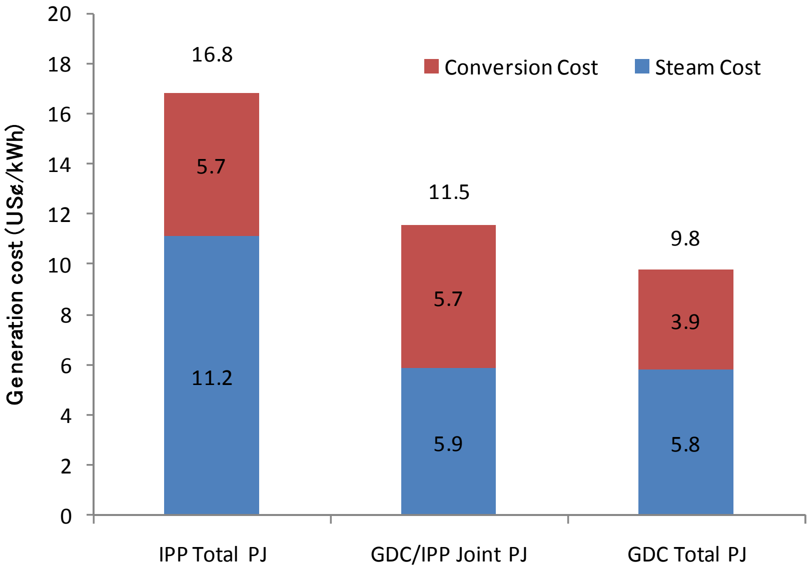


Fig. III-3.8 The LEC and LSC by development formation for the Baringo South field

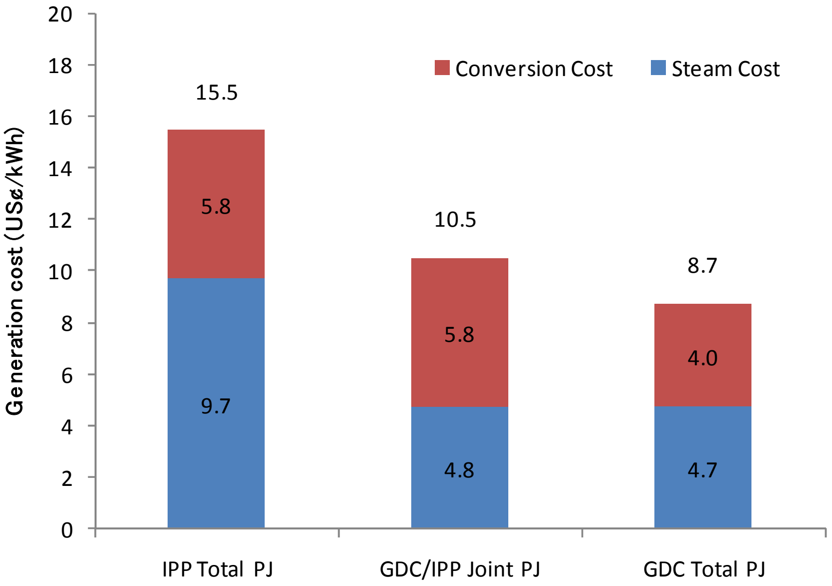


Fig. III-3.9 The LEC and LSC by development formation for the Baringo North field

b. Economic evaluation

An economic evaluation was carried out to examine the social-economic significance of Baringo geothermal field. Similar to the case of Arus field, three kinds of alternative plants are considered; (i) coal-fired power plant, (ii) LNG combined-cycle power plant, and (iii) diesel power plant. The assumptions of the evaluation are also the same as in the case of Arus field.

<Result of economic evaluation>

Results of economic evaluation for the south part of Baringo field are shown in Table III-3.9 and for the north part of Baringo field are shown in Table III-3.10. Since all EIRR results exceed 12% which is assumed as the socio-economic opportunity cost of Kenya, the geothermal development in Baringo field is justified with the socio-economic significance.

Table III-3.9 Cost competitiveness of geothermal development for the Baringo South field vs. alternative thermal power plants

Alternative plants	Coal-fired plant	LNG CC plant	Diesel plant
Economic Internal Rate of Return	12.0%	16.2%	29.1%

Table III-3.10 Cost competitiveness of geothermal development for the Baringo North field vs. alternative thermal power plants

Alternative plants	Coal-fired plant	LNG CC plant	Diesel plant
Economic Internal Rate of Return	15.1%	18.4%	31.2%

c. Sensitivity analysis

The construction cost of geothermal power plants in the Baringo South field is estimated to be US $ 437 million with the unit construction cost of 4,370 US$/kW. The results of the sensitivity analysis of the LEC/LSC and the economic evaluation on the change of the estimated construction cost is shown in Figs. III -3.10 and III-3.11. When the construction cost changes by ± 20% from the estimated one, the LEC and LSC in the case of joint project between GDC and IPP changes in the range from 9.6 US¢/kWh (-17.0%) to 13.5 US¢/kWh (+17.0%). Regarding the economic evaluation, it should be noted that a geothermal power plant loses competitive against a coal-fired plant if the construction cost rises from the estimated cost.

In addition, the average output of the production well in Baringo South field is estimated to be 6 MW per well. The sensitivity analysis of the LEC/LSC and the economic evaluation on the change of the average production well output is also done and the result is shown in Figs. III-3.12 and III-3.13. If the average production well output decreases to 3 MW/well, the LEC will rise by 18.9% to 13.7 US¢/kWh. Figure III-3.13 shows the geothermal power plant will lose cost competitiveness against coal-fired plant if the average production well output becomes less than 6 MW/well. Therefore, great attention is needed to the average production well output in this field.

The construction cost of geothermal power plants in the Baringo North field is estimated to be US $ 376 million with the unit construction cost of 3,760 US$/kW. The results of the sensitivity analysis of the LEC/LSC and the economic evaluation on the change of the estimated construction cost are shown in Figs III -3.14 and III-3.15. When the construction cost changes by ± 20% from the estimated one, the LEC and LSC in the case of joint project between GDC and IPP changes in the range from 8.7 US¢/kWh (-16.8%) to 12.3 US¢/kWh (+17.0%). Regarding the economic evaluation, a geothermal power plant remains competitive against a coal-fired plant, a LNG combined cycle plant and a diesel power plant even if the construction cost rises by 15%. However, when the construction cost rises by 20%, geothermal loses competitiveness and becomes almost equal economic value to that of a coal-fired plant.

In addition, the average output of the production well in Baringo North field is estimated to be 10 MW per well. The sensitivity analysis of the LEC/LSC and the economic evaluation on the change of the average production well output is also done and the result is shown in Figs. III-3.16 and III-3.17. If the average production well output decreases to 5 MW/well, the LGC will rise by 16.4% to 12.2 US¢/kWh. Figure III-3.17 shows the geothermal power plant will lose cost competitiveness against coal-fired plant if the average production well output becomes less than 6 MW/well. Therefore, great attention is needed to the average production well output in this field.

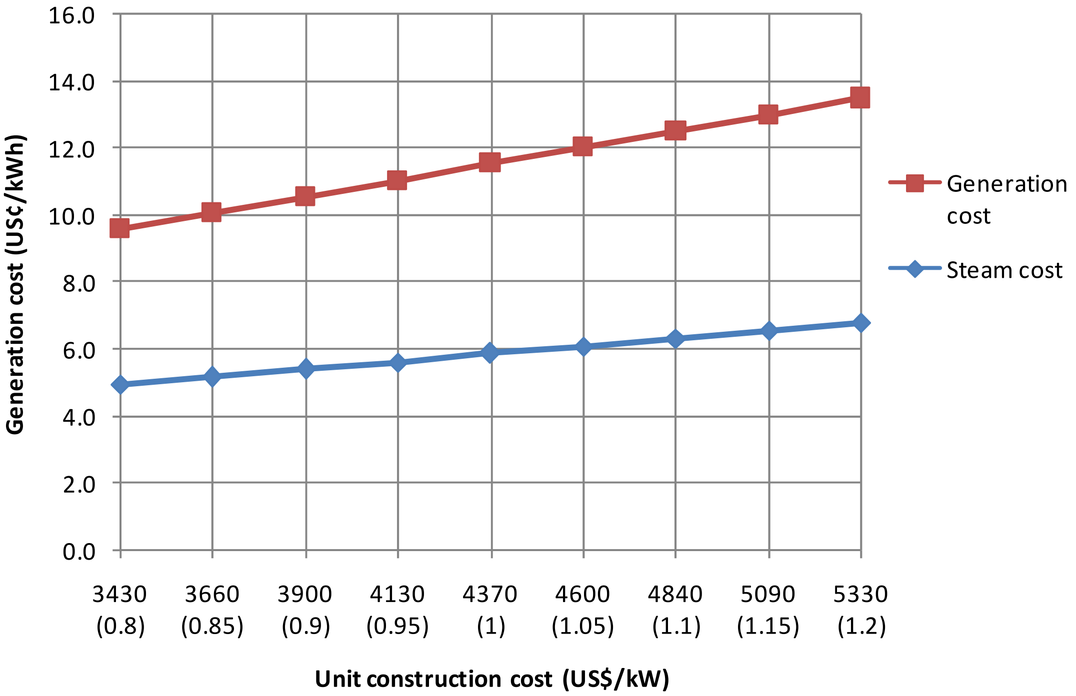


Fig. III-3.10 Sensitivity analysis of the LEC and LSC to changes in the construction cost (Baringo South)

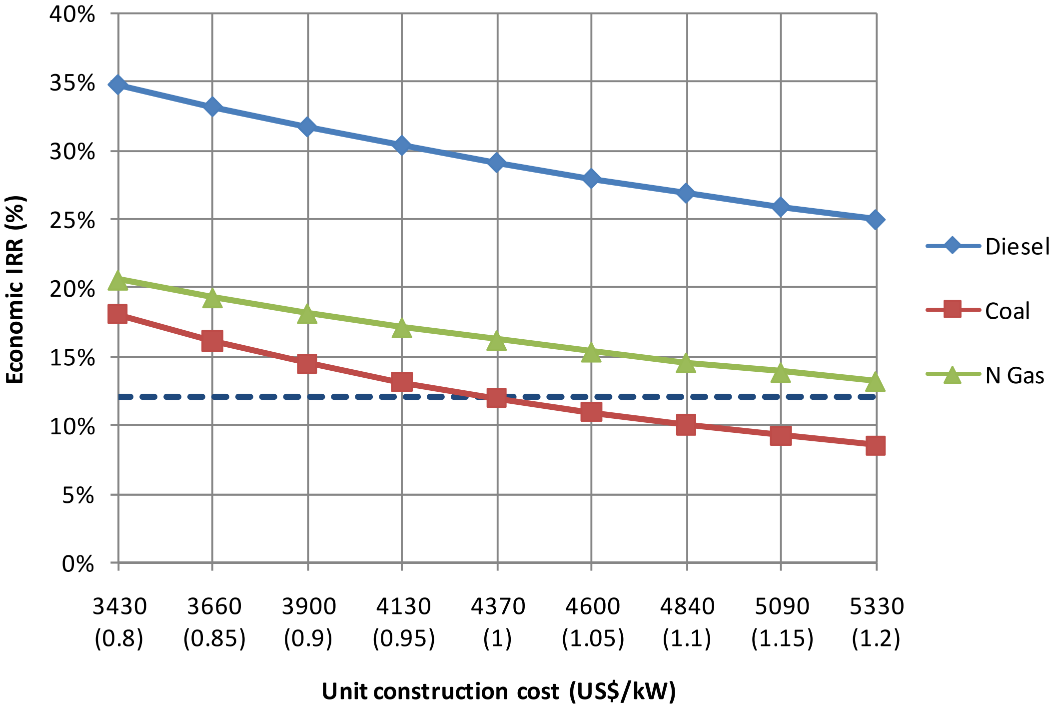


Fig. III-3.11 Sensitivity analysis of the EIRRs to changes in the construction cost (Baringo South)

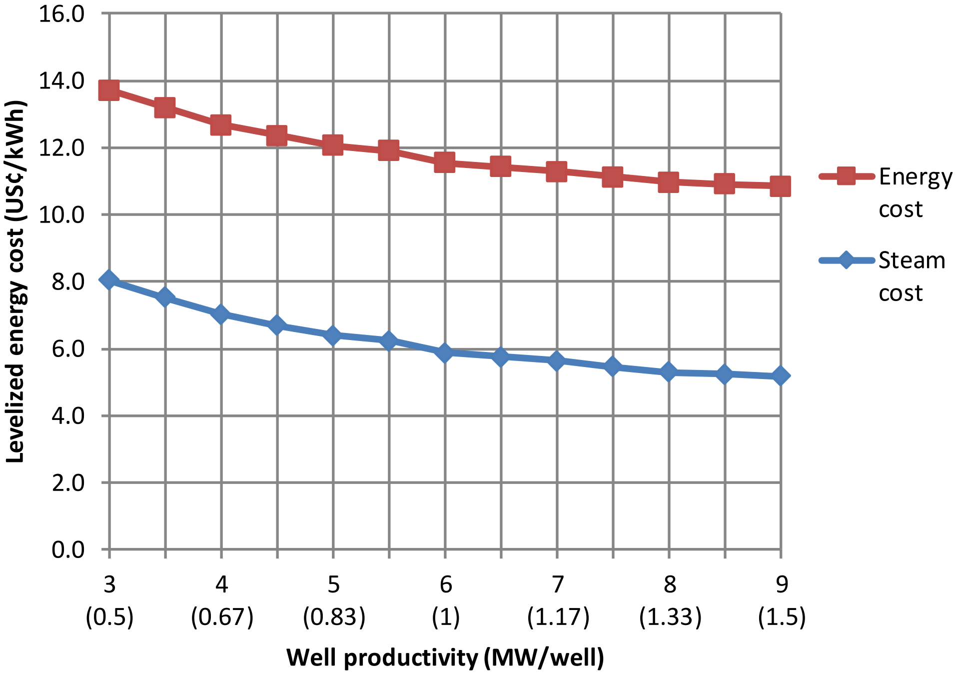


Fig. III-3.12 Sensitivity analysis of the LEC and LSC to changes in the average production well output (Baringo South)

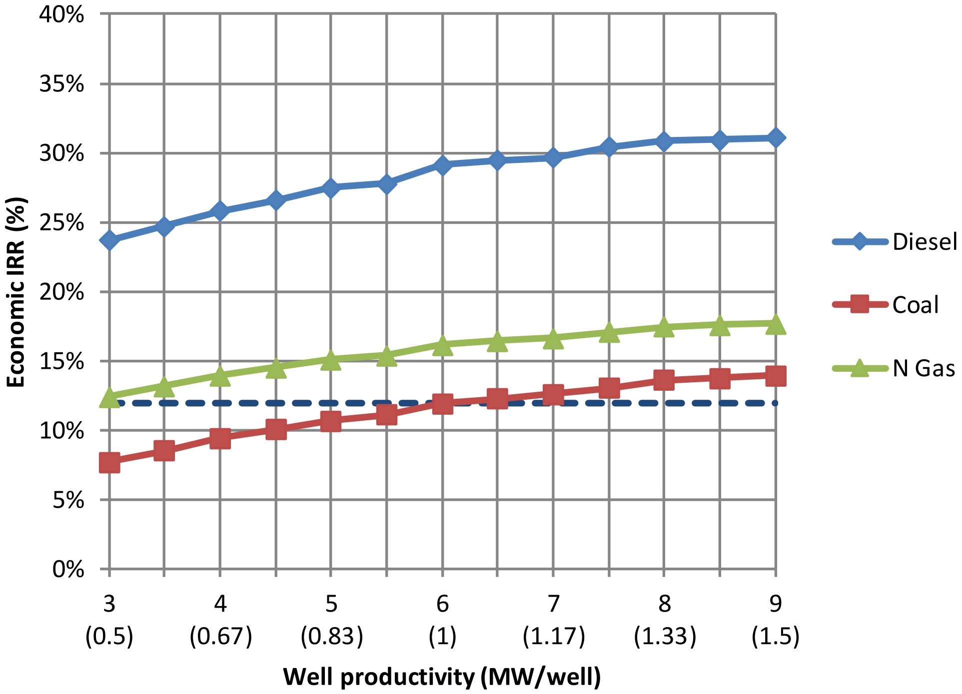


Fig. III-3.13 Sensitivity analysis of the EIRRs to changes in the average production well output (Baringo South)

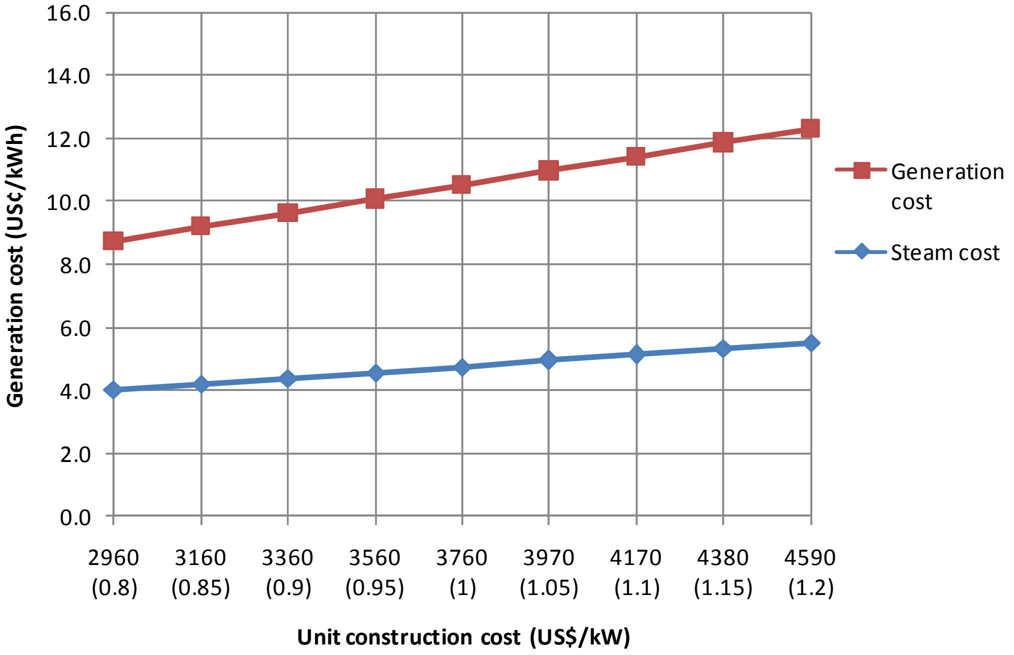


Fig. III-3.14 Sensitivity analysis of the LEC and LSC to changes in the construction cost (Baringo North)

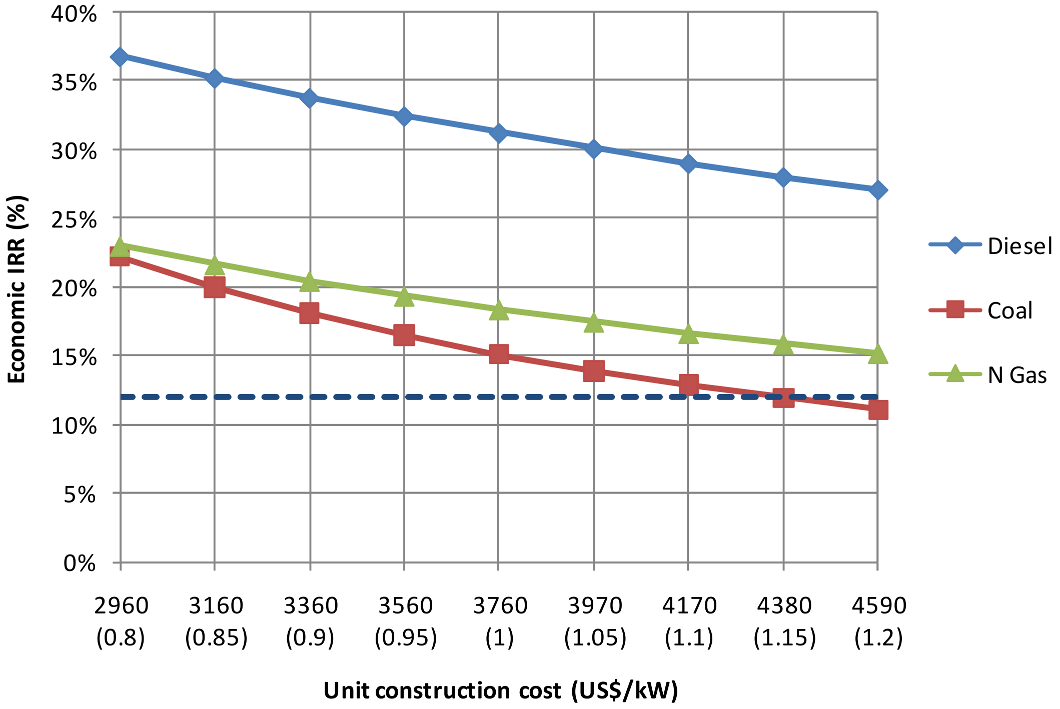


Fig. III-3.15 Sensitivity analysis of the EIRRs to changes in the construction cost (Baringo North)

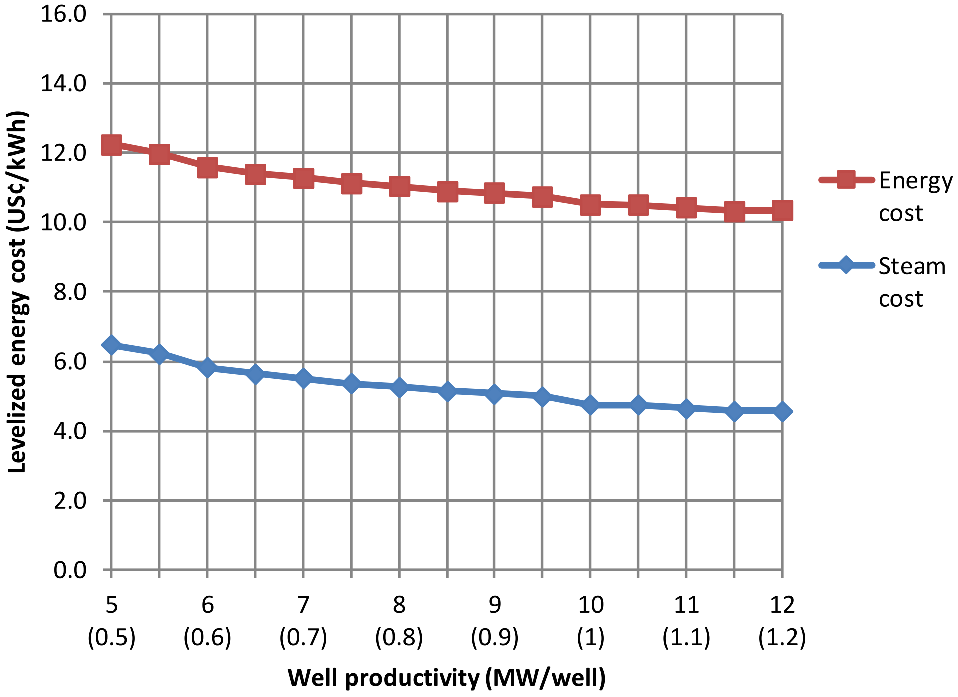


Fig. III-3.16 Sensitivity analysis of the LEC and LSC to changes in the average production well output (Baringo North)

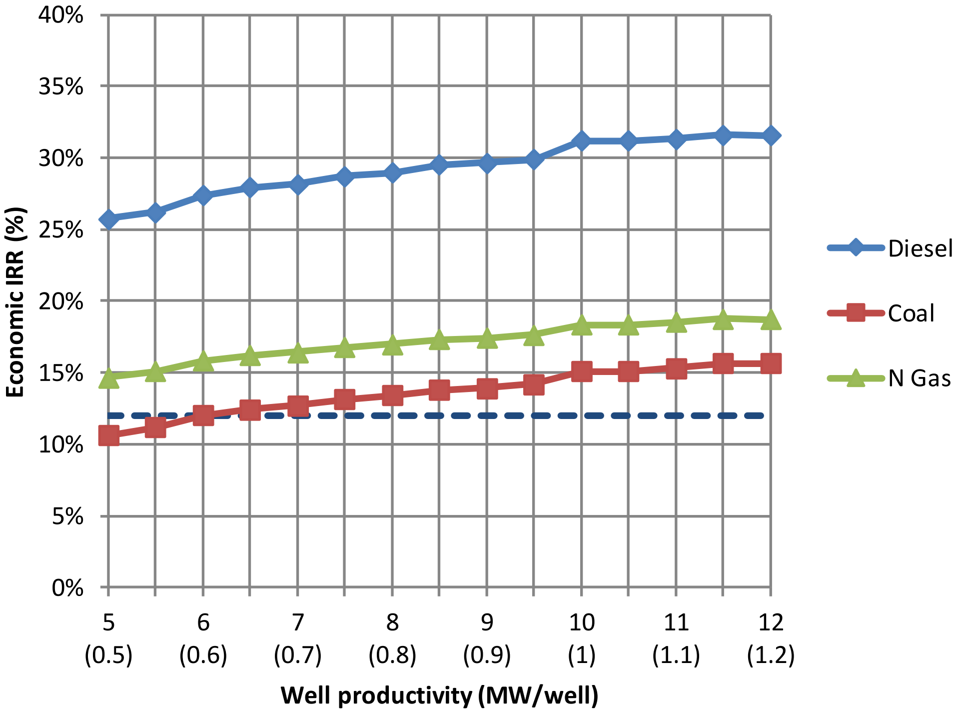


Fig. III-3.17 Sensitivity analysis of the EIRRs to changes in the average production well output (Baringo North)

III-4 Development Plan for the Korosi Field

III-4.1 Development scale and main facilities

The development scale (the output capacity of the geothermal power plant for the Korosi field) is proposed based on the estimated resource potential. The type of power plant was selected to be a conventional flash steam cycle (condensing type) in this study. The required number of geothermal wells is estimated according to the results of the evaluation of productivity (and injectivity) of wells. The main specifications regarding the possible power development of the Korosi field are shown in Table III-4.1.

Based upon the possible power development plan stated above for 210MW flash type geothermal power generation at the Korosi, twenty-three production wells and three reinjection wells are estimated to be required for start-up. In consideration of the drilling success ratio (which is assumed to be 67% for exploration wells and 67-100% for appraisal/operation wells), twenty-eight production wells and four reinjection wells should be drilled.

Table III-4.1 Main specifications for the possible power development in the Korosi field

Field	Planned Capacity	Average Productivity	Total Reinjection Brine	Assumed Injection Capacity	Required Wells for operation	
	(MW-gross)	(MW/well)	(t/h)	(t/h/well)	Production	Reinjection
Korosi 70MW x 3	210	9.5	874	300	**23**	**3**

Field		Exploration Stage		Appraisal Stage		Development Stage		Total	
		P-well	R-well	P-well	R-well	P-well	R-well	P-well	R-well
Korosi 70MW x 3	Drilled wells	3	0	5	1	20	3	**28**	**4**
	Successful Wells (for operation)	2	0	4	1	17	2	**23**	**3**

III-4.2 Resource development plan

According to the conceptual model of the geothermal system, total drilling depth will vary from 1,800m to 2,300m in depth for both production wells and reinjection wells. In order to minimize the number of required drilling pads and to allow multiple targets to be drilled from same pad, directional drilling should be adopted. To avoid interference among wells, the targets are located at intervals of around 300m. In addition, detailed drilling depths and well profiles for the development production/reinjection wells should be planned based on the up-date geothermal conceptual model reflecting the results of exploration/appraisal wells drilling and testing.

Drilling rigs owned by GDC with a 2,000 HP output capability will be available to drill directionally to 1,800-2,300m in depth, with a final completion diameter of 8.5 inches. Fig. III-2.1 shows an example of a possible well casing program and Fig. III-2.2 shows an example of a possible well directional drilling program.

The planned layout of Korosi is shown in Fig. III-4.1. The number of drilling pads is tentatively assumed to be four pads for production wells and one pad for reinjection wells. A total of three existing pads, KW01, KW02 and KW03, which have been constructed by GDC, will be used for production well drilling.

Two-phase fluids from the three production well pads where located east side of candidate power plant location will be transported to the separation station, in which the fluids will be separated into steam and brine. Another separator station at the north of power plant should be located beside the production well pad at the northwest.

Drilling pads for reinjection wells should be situated at lower elevations than the separator stations to transport the brine to the reinjection wells by gravity. The drilling targets for reinjection wells should be separated from the production zone at least 1 km to avoid the breakthrough of reinjected water that could yield cooling of the high temperature reservoir. One reinjection pad is planned to be located on the north side of the production zone.

Approximately eight wells can be drilled from one pad of dimensions of 100m x 150m, including water/mud pits and pipe storage yard, etc. Furthermore, constructed pads will be available for future drilling of make-up wells during the power plant operation.

Fresh water for well drilling and power plant operation can be supplied from Lake Baringo through the project site by utilizing a steel pipe line for water transportation as planned by GDC. In addition, fresh water should be distributed to each pad from water tanks with around 4,000 cubic meters capacity, which will be installed close to the power plant.

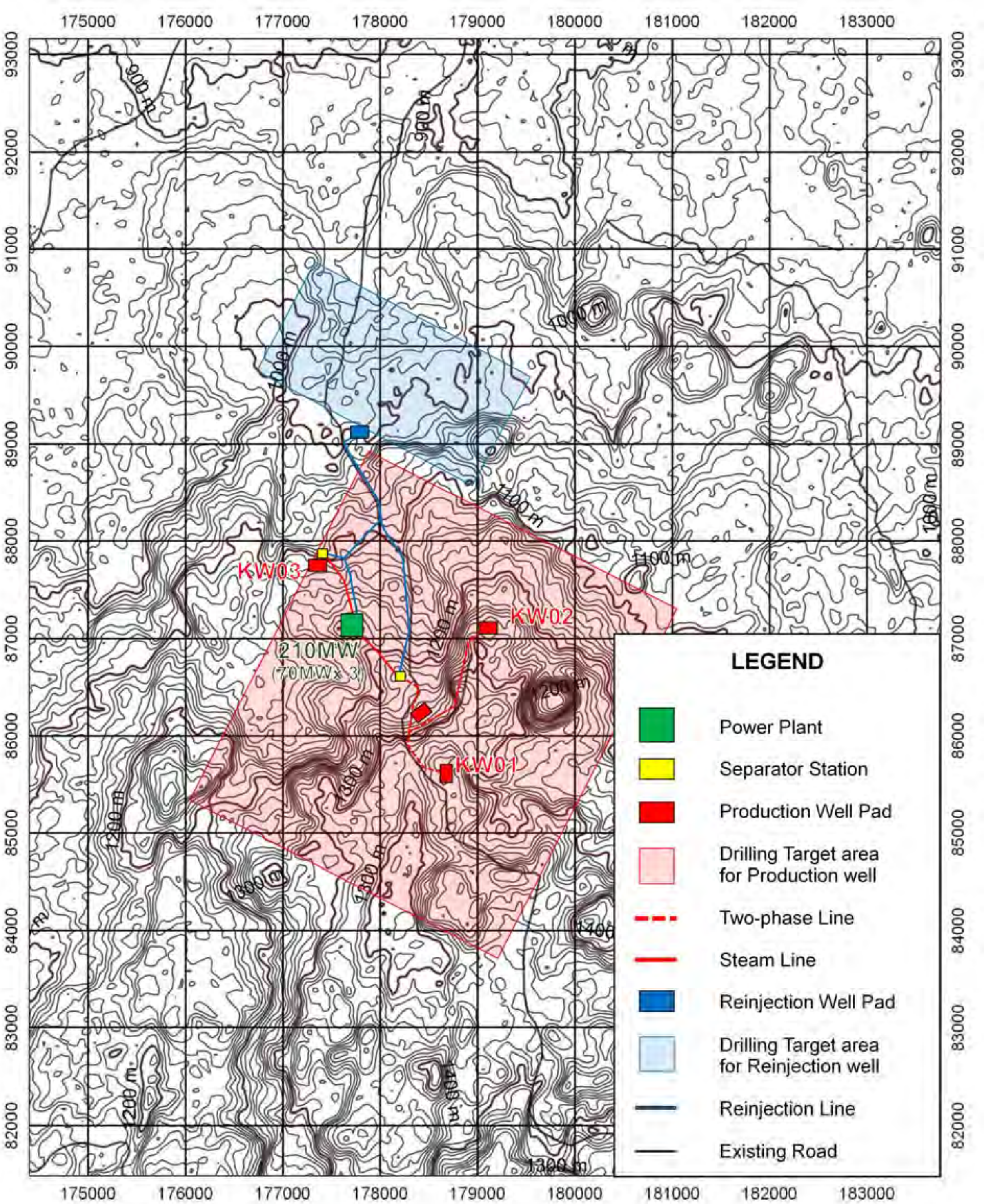


Fig. III-4.1 Possible layout of field development for Korosi

III-4.3 Development plan for power plant and substation

One geothermal power generation plant comprised of three units of 70MW each is envisioned to be constructed at the Korosi geothermal field. In principle, although all units are planned to be of the single flash type, a different plant size or the utilization of other generation technology should not be ruled out until better knowledge of the potential and characteristics of the geothermal fluid is achieved.

The site proposed for power plant construction was selected taking into consideration distances from the production and reinjection wells, ease of pipeline installation, and topographic features. Other issues, such as geologic constraints and/or environmental issues shall be evaluated at the time of the preparation of a feasibility study.

The power generated at the Korosi power units will be evacuated through a dedicated substation to be constructed in the vicinity of the prospect cutting in the 400kV transmission line to be built between Rongai, currently the end of the Kenyan grid, and the Silali prospect.

The flow diagram, of including the power plant and fluid transportation system are depicted in Fig. III-4.2. Figure III-4.3 shows single line diagrams and Fig. III-4.4 shows substation layout.

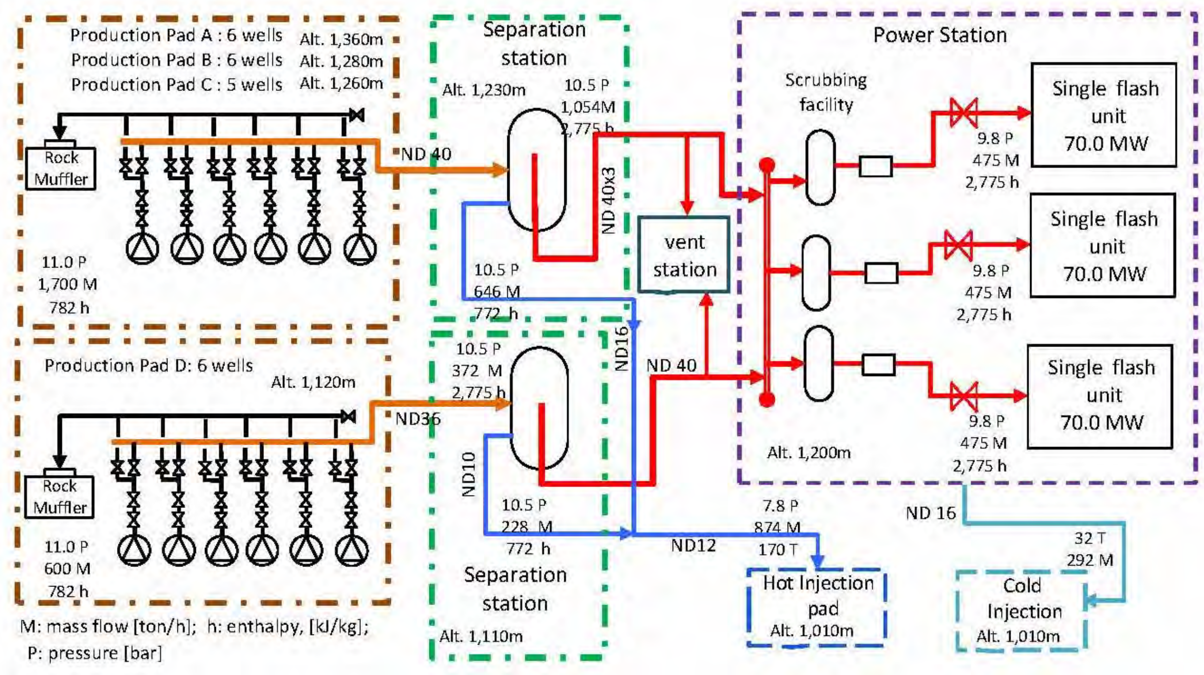


Fig. III-4.2 Korosi steam gathering system flow diagram

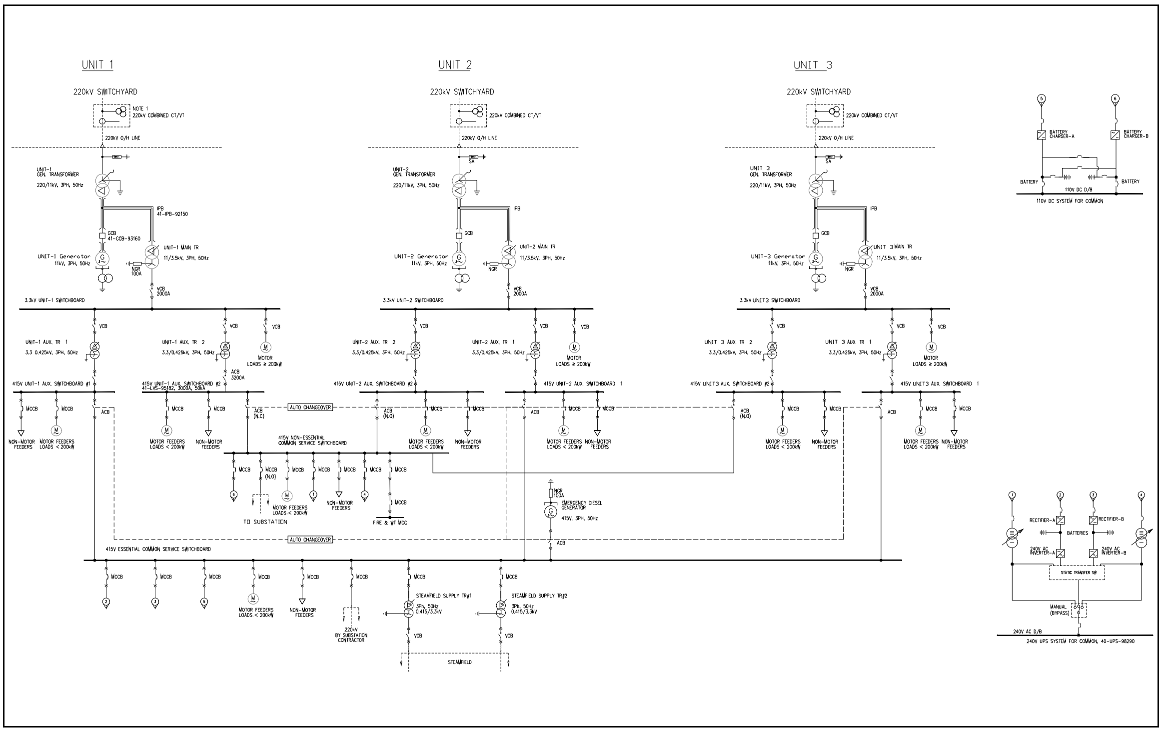


Fig. III-4.3 Single line diagram for Korosi power plant

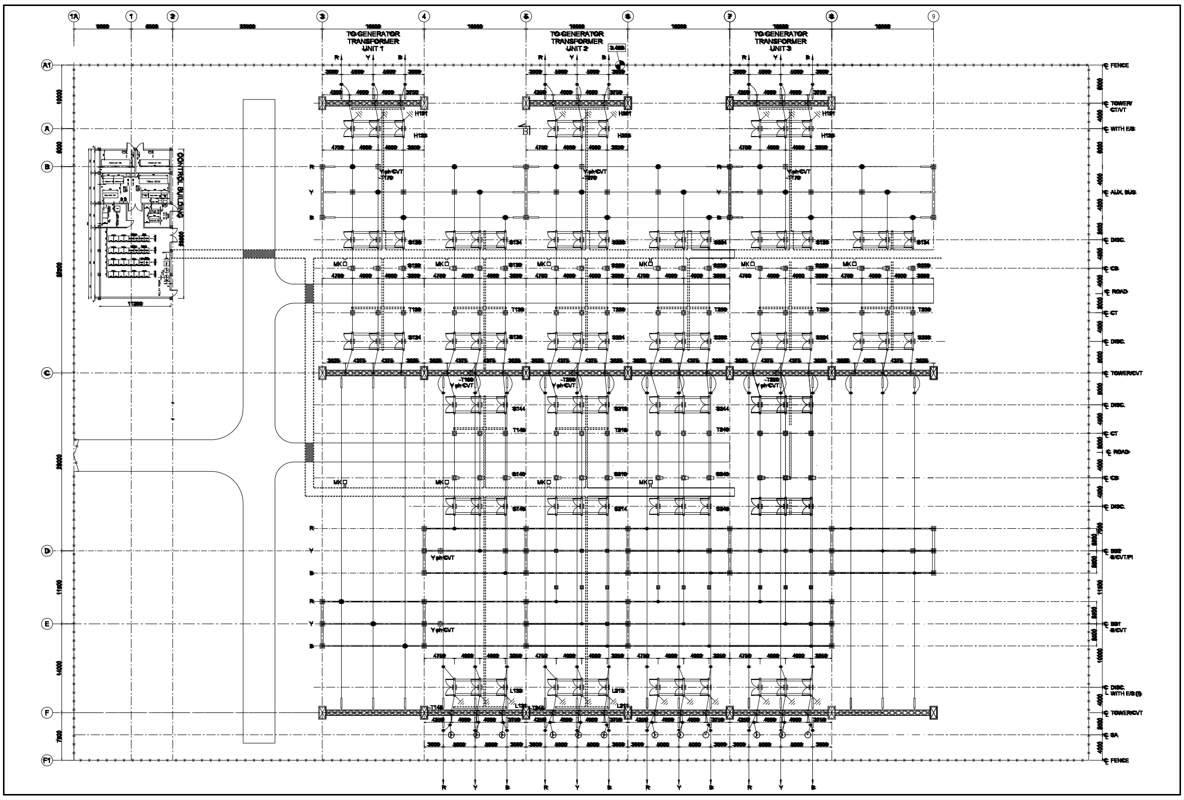


Fig. III-4.4 Korosi substation layout

III-4.4 Development schedule and cost estimation

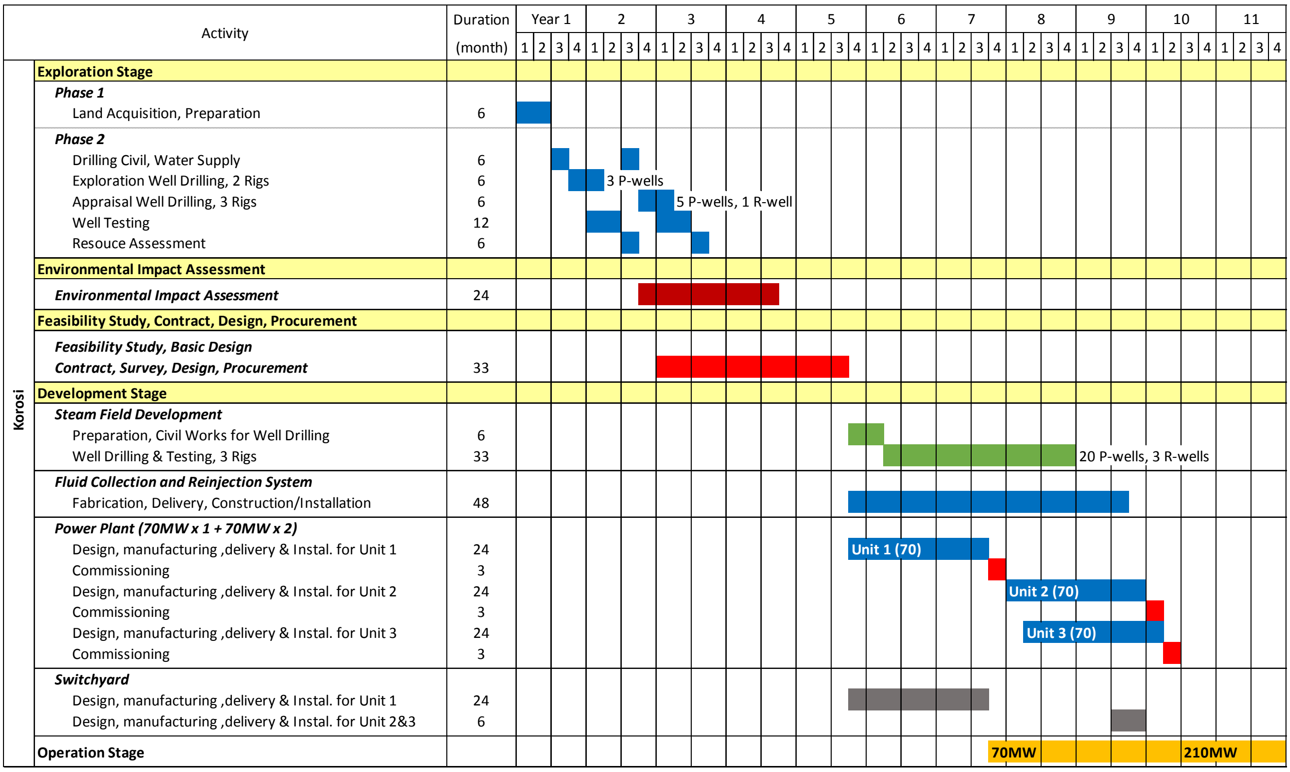
Table III-4.2 shows a tentative development schedule, Table III-4.3 shows cost estimation for 210MW power plant development at the Korosi field.

In regards to make-up wells, the decline rates of productivity and injection capacity due to silica or other scaling of each well are not predictable at present. Therefore, the number of make-up wells required to maintain the rated power output and reinjection capacity over 30 years of plant operation was determined assuming the following usual annual rate of decline for power output of production wells and the injection capacity of reinjection wells.

- Power output of production wells : 3% per year decline
- Injection capacity of injection wells : 3% per year decline

Accordingly, it is estimated that nineteen production wells and three reinjection wells will be required as make-up wells over 30 years of plant operation in this study. Based on this assumption, at least two additional new well pads will be required for production make-up well drilling in the future. Depending on the results of well drilling, testing, and the capabilities during operation, consideration should be given to the construction of additional pads or the expansion of existing pads for make-up well drilling.

Table III-4.2 Development schedule



	Activity	Duration (month)
Korosi	**Exploration Stage**	
	Phase 1	
	Land Acquisition, Preparation	6
	Phase 2	
	Drilling Civil, Water Supply	6
	Exploration Well Drilling, 2 Rigs	6
	Appraisal Well Drilling, 3 Rigs	6
	Well Testing	12
	Resouce Assessment	6
	Environmental Impact Assessment	
	Environmental Impact Assessment	24
	Feasibility Study, Contract, Design, Procurement	
	Feasibility Study, Basic Design ***Contract, Survey, Design, Procurement***	33
	Development Stage	
	Steam Field Development	
	Preparation, Civil Works for Well Drilling	6
	Well Drilling & Testing, 3 Rigs	33
	Fluid Collection and Reinjection System	
	Fabrication, Delivery, Construction/Installation	48
	Power Plant (70MW x 1 + 70MW x 2)	
	Design, manufacturing ,delivery & Instal. for Unit 1	24
	Commissioning	3
	Design, manufacturing ,delivery & Instal. for Unit 2	24
	Commissioning	3
	Design, manufacturing ,delivery & Instal. for Unit 3	24
	Commissioning	3
	Switchyard	
	Design, manufacturing ,delivery & Instal. for Unit 1	24
	Design, manufacturing ,delivery & Instal. for Unit 2&3	6
	Operation Stage	

Table III-4.3 Cost estimation

Exploration Stage

Unit:US$

Item	Unit	Quantity	Unit Price	Price	Remarks
Exploration/Appraisal Well Drilling	**L.S.**	**1**		**43,950,000**	
Well Pad	Lot	1	600,000	600,000	For reinjection well, Size: 100m x 150m
Lay Down/Operation Center	Lot	0	250,000	-	
Access Road	km	0	40,000	-	Width: 6-8m
Water Supply Sysytem	L.S.	1	2,400,000	2,400,000	Tanks, booster pumps, power supply, etc.
Production Well Drilling	Well	8	4,000,000	32,000,000	±2,000mTD, Directional, 7" liner completion
Reinjection Well Drilling	Well	1	4,000,000	4,000,000	±2,000mTD, Directional, 7" liner completion
Water Supply Operation	Well	9	50,000	450,000	Power/water domestic supply
Well Testing	Well	9	500,000	4,500,000	
Environmental Impact Assessment	**L.S.**	**1**		**300,000**	
Feasibility Study	**L.S.**	**1**		**1,000,000**	
Total Exploration Stage Cost	**L.S.**	**1**		**45,250,000**	

Development Stage (Steam Field)

Unit:US$

Item	Unit	Quantity	Unit Price	Price	Remarks
Start-up Well Drilling	**L.S.**	**1**		**105,580,000**	
Well Pad	Lot	1	600,000	600,000	For production wells, Size: 100m x 150m
Lay Down/Operation Center	Lot	1	250,000	250,000	
Access Road	km	2	40,000	80,000	Width: 6-8m
Production Well Drilling	Well	20	4,000,000	80,000,000	±2,000mTD, Directional, 7" liner completion
Reinjection Well Drilling	Well	3	4,000,000	12,000,000	±2,000mTD, Directional, 7" liner completion
Water Supply Operation	Well	23	50,000	1,150,000	Power/water domestic supply
Well Testing	Well	23	500,000	11,500,000	
FCRS Construction	**L.S.**	**1**		**35,000,000**	
Separator Station 1	L.S.	1	7,000,000	7,000,000	80m x 100m
Separator Station 2	L.S.	1	5,000,000	5,000,000	80m x 100m
FCRS Piping	L.S.	1	23,000,000	23,000,000	including civil works, instrument, etc.
Total Steam Field Cost	**L.S.**	**1**		**140,580,000**	

Development Stage (Power Plant)

Unit:US$

Item	Unit	Quantity	Unit Price	Price	Remarks
Power Plant	**L.S.**	**1**		**317,000,000**	
Site Preparation	L.S.	1	5,000,000	5,000,000	300mx 200m
Power Plant	L.S.	3	104,000,000	312,000,000	70MW x 3
Switchyard and Transmission Line	**L.S.**	**1**		**12,045,000**	
Site Preparation	m2	17,600	40	704,000	110m x 160m
Switchyard	L.S.	7	1,463,000	10,241,000	Initial Stage: USD7,315,000 and connection of Chepchuk: USD2,926,000
Transmission Line	km	5	220,000	1,100,000	Korosi PS-Paka SS 220kV x 2circuit (single Canary)
Total Power Plant Cost	**L.S.**	**1**		**329,045,000**	

Operation Stage

Unit:US$

Item	Unit	Quantity	Unit Price	Price	Remarks
Make-up Well Drilling	**L.S.**	**1**		**90,300,000**	
Well Pad	Lot	2	600,000	1,200,000	For production wells, Size: 100m x 150m
Production Well Drilling	Well	19	4,000,000	76,000,000	±2,000mTD, Directional, 7" liner completion
Reinjection Well Drilling	Well	3	4,000,000	12,000,000	±2,000mTD, Directional, 7" liner completion
Water Supply Operation	Well	22	50,000	1,100,000	Power/water domestic supply

III-4.5 Economic evaluation of the development plan

a. Financial evaluation

Based on the above-mentioned technical estimation, the financial evaluation is carried out to estimate the development cost of the Korosi field. Similar to the evaluation of Arus field, three kinds of development formation were examined; (i) private sector's total project, (ii) GDC and private sector's joint project, and (iii) GDC's total project. The assumptions of evaluation are also the same as the case of Arus field.

<Result of financial evaluation>

Construction costs of a geothermal power plant in Korosi field are as shown in Table III-4.4 (Note: values in this table include 10% to cover the consultant fee and administration cost).

Table III-4.4 Construction costs of a geothermal power plant in Korosi field

Item	Steam field (million US$)	Power plant (million US$)	Total (million US$)	Unit cost (US$/kW)
Construction costs	204	362	566	2,700
IDC	11	25	36	-
Construction costs with IDC	215	387	602	2,870

The LEC and the LSC in each development formation in Korosi field have been estimated as shown in Table III-4.5 and Figure III-4.5.

Table III-4.5 The LEC and LSC by development formation in Korosi field (US¢/kWh)

Development formation	IPP total PJ	GDC/IPP joint PJ	GDC total PJ
Levelized steam cost (LSC)	6.5	3.2	3.2
Levelized conversion cost	5.5	5.5	3.8
Levelized generation cost (LEC)	11.9	8.7	7.0

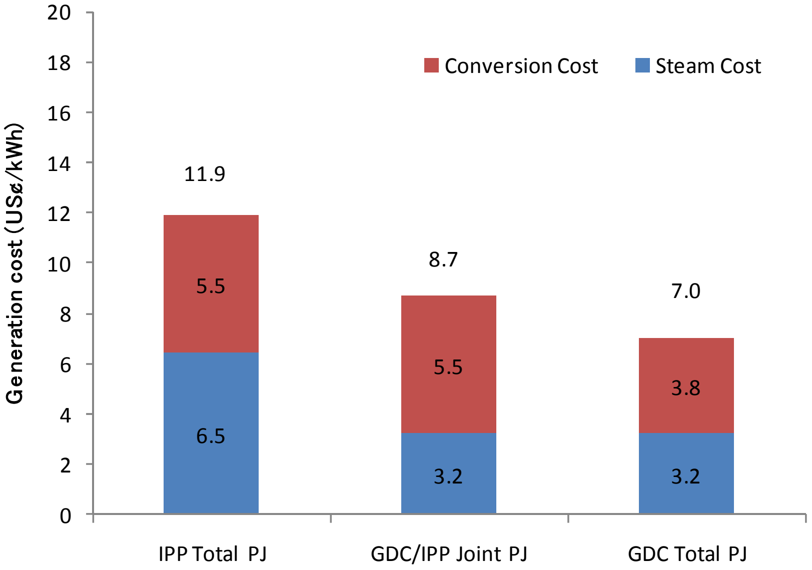


Fig. III-4.5 The LEC and LSC by development formation in Korosi field

a. Economic evaluation

An economic evaluation was carried out to examine the social-economic significance of the development of the Korosi geothermal field. Similar to the case of Arus field, three kinds of alternative plants are considered; (i) coal-fired power plant, (ii) LNG combined-cycle power plant, and (iii) diesel power plant. The assumptions of the evaluation are also the same as the case of Arus field.

<Result of economic evaluation>

Results of the economic evaluation for the Korosi field are shown in Table III-4.6. Since all EIRR results exceed 12%, which is assumed as the socio-economic opportunity cost of Kenya, the geothermal development in Korosi field is justified with the socio-economic significance.

Table III-4.6 Cost competitiveness of the geothermal development in Korosi field vs. alternative thermal power plants

Alternative plants	Coal-fired plant	LNG CC plant	Diesel plant
Economic Internal Rate of Return	22.7%	23.3%	36.7%

b. Sensitivity analysis

The construction cost of geothermal power plants in the Korosi field are estimated to be US $ 602 million with the unit construction cost of 2,870 US$/kW. The results of the sensitivity analysis of the LEC/LSC and the economic evaluation on the change of the estimated construction cost are shown in Figs. III-4.6 and III-4.7. When the construction cost changes by ± 20% from the estimated one, the LEC and LSC in the case of joint project between GDC and IPP changes in the range from 7.3 US¢/kWh (-16.6%) to 10.2 US¢/kWh (+16.8%). Regarding the economic evaluation, a geothermal power plant remains competitive against a coal-fired plant, a LNG combined cycle plant and a diesel power plant even if the construction cost rises by 20%.

In addition, the average output of the production well in Korosi field is estimated to be 9.5 MW per well. The sensitivity analysis of the LEC/LSC and the economic evaluation on the change of the average production well output is also done and the result is shown in Figs. III-4.8 and III-4.9. If the average production well output decreases to 4.5 MW/well, the LEC will rise by 19.7% to 10.4 US¢/kWh. However, Fig. III-4.9 shows the geothermal power plant will keep cost competitiveness against coal-fired plant even if the average production well output decreases to 4.5 MW/well.

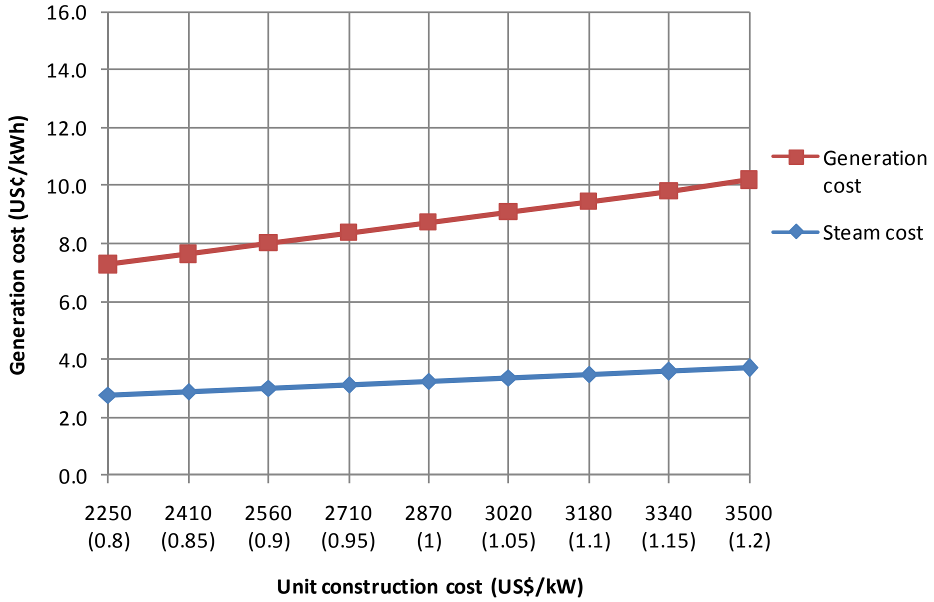


Fig. III-4.6 Sensitivity analysis of the LEC and LSC to changes in the construction cost (Korosi)

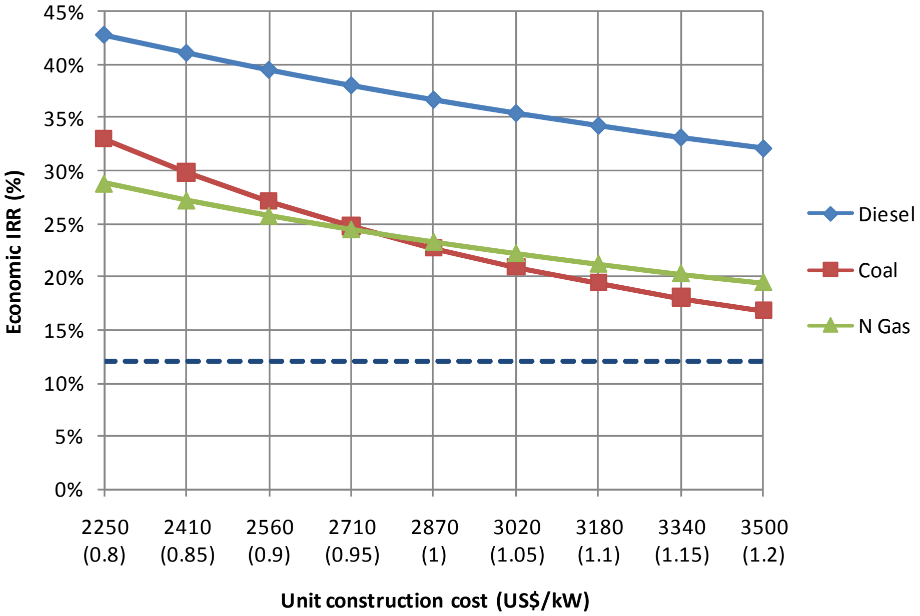


Fig. III-4.7 Sensitivity analysis of the EIRRs to changes in the construction cost (Korosi)

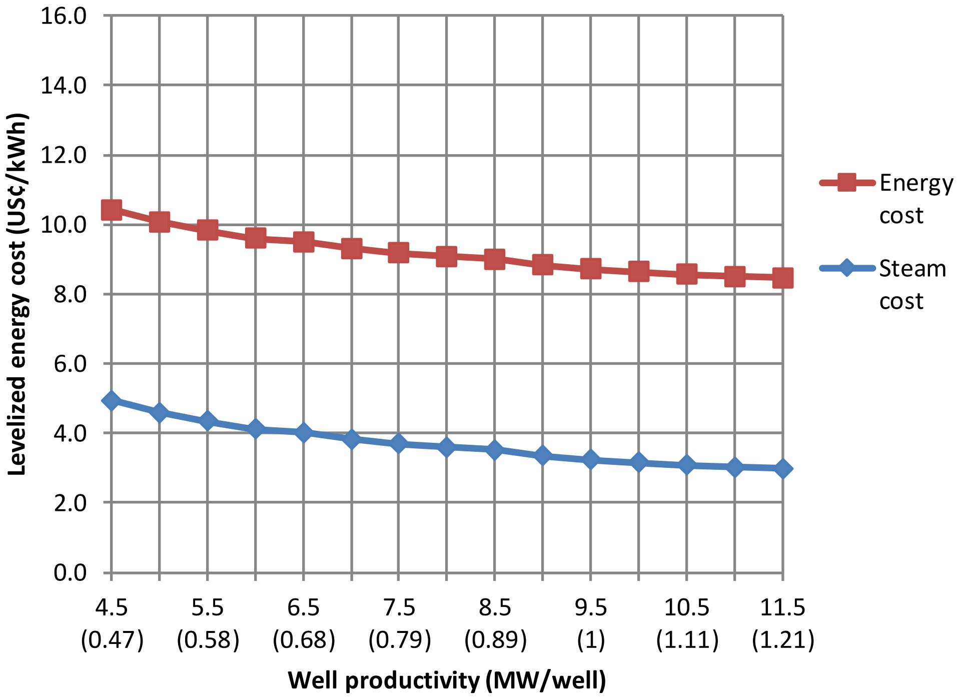


Fig. III-4.8 Sensitivity analysis of the LEC and LSC to changes in the average production well output (Korosi)

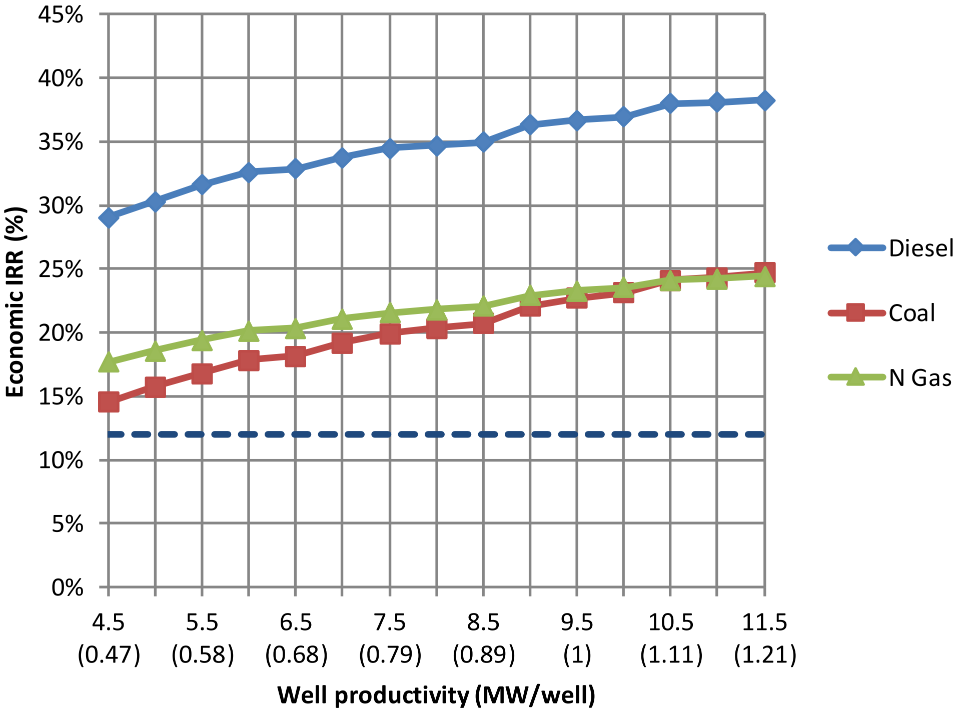


Fig. III-4.9 Sensitivity analysis of the EIRRs to changes in the average production well output (Korosi)

III-5 Development Plan for the Chepchuk Field

III-5.1 Development scale and main facilities

The development scale (the output capacity of the geothermal power plant for the Chepchuk field) is proposed based on the estimated resource potential. The type of power plant was selected to be a conventional flash steam cycle (condensing type) in this study. The required number of geothermal wells is estimated according to the results of the evaluation of productivity (and injectivity) of wells. The main specifications regarding the possible power development of the Chepchuk field is shown in Table III-2.1.

Based upon the possible power development plan stated above for 80MW flash type geothermal power generation at Chepchuk, eight production wells and seven reinjection wells are estimated to be required for start up. In consideration of the drilling success ratio (which is assumed to be 50% for exploration wells and 75-100% for appraisal/operation wells), eleven production wells and eight reinjection wells should be drilled. Regarding the number of exploratory wells, two wells are tentatively planned in this study because of the plan of relatively small-scale development in the Arus field. However, if the budget permits, drilling of three or more wells is recommendable to ascertain the existence and extension of the exploitable geothermal reservoir.

Table III-5.1 Main specifications for the possible power development in the Chepchuk field

Field	Planned Capacity	Average Productivity	Total Reinjection Brine	Assumed Injection Capacity	Required Wells for operation	
	(MW-gross)	(MW/well)	(t/h)	(t/h/well)	Production	Reinjection
Chepchuk 40MW x 2	80	10	2080	300	**8**	**7**

Field		Exploration Stage		Appraisal Stage		Development Stage		Total	
		P-well	R-well	P-well	R-well	P-well	R-well	P-well	R-well
Chepchuk 40MW x 2	Drilled wells	2	0	5	1	4	7	**11**	**8**
	Successful Wells (for operation)	1	0	4	1	3	6	**8**	**7**

III-5.2 Resource development plan

According to the conceptual model of the geothermal system, total drilling depth will vary from 1,800m to 2,300m in depth for both production wells and reinjection wells. In order to minimize the number of required drilling pads and to allow multiple targets to be drilled from the same pad, directional drilling should be adopted. To avoid interference among wells, the targets are located at intervals of around 300m. In addition, detailed drilling depths and well profiles for the development production/reinjection wells should be planned based on the up-date geothermal conceptual model reflecting the results of exploration/appraisal wells drilling and testing.

Drilling rigs owned by GDC with a 2,000 HP output capability will be available to drill directionally to 1,800-2,300m in depth, with a final completion diameter of 8.5 inches. Fig. III-2.1 shows an example of a possible well casing program and Fig. III-2.2 shows an example of a possible well directional drilling program.

The planned layout of Chepchuk is shown in Fig. III-5.1. The number of drilling pads is tentatively assumed to be two pads for production wells and one pad for reinjection wells. These drilling well pads and access roads should be constructed prior to development. A separator station is planned to be located beside each production well pad.

Drilling pads for reinjection wells should be situated at elevations lower than the separator stations to transport the brine to the reinjection wells by gravity. The drilling targets for reinjection wells should be separated from the production zone at least 1 km to avoid the breakthrough of reinjected water that could cause cooling of the high temperature reservoir. One reinjection pad is planned to be located on the north side of the production zone.

Approximately eight wells can be drilled from one pad of dimensions of 100m x 150m, including water/mud pits and pipe storage yard, etc. Furthermore, constructed pads will be available for future drilling of make-up wells during the power plant operation.

Fresh water for well drilling and power plant operation is assumed to be transported from around 5km west of the project site which is planned by GDC that will be supplied from Lake Baringo through pipe line for local residents. In this case, approximately 10km of new water pipe line should be constructed along the local/access road. In addition, fresh water should be distributed to each pad from water tanks with around 4,000 cubic meters capacity, which will be installed close to the power plant.

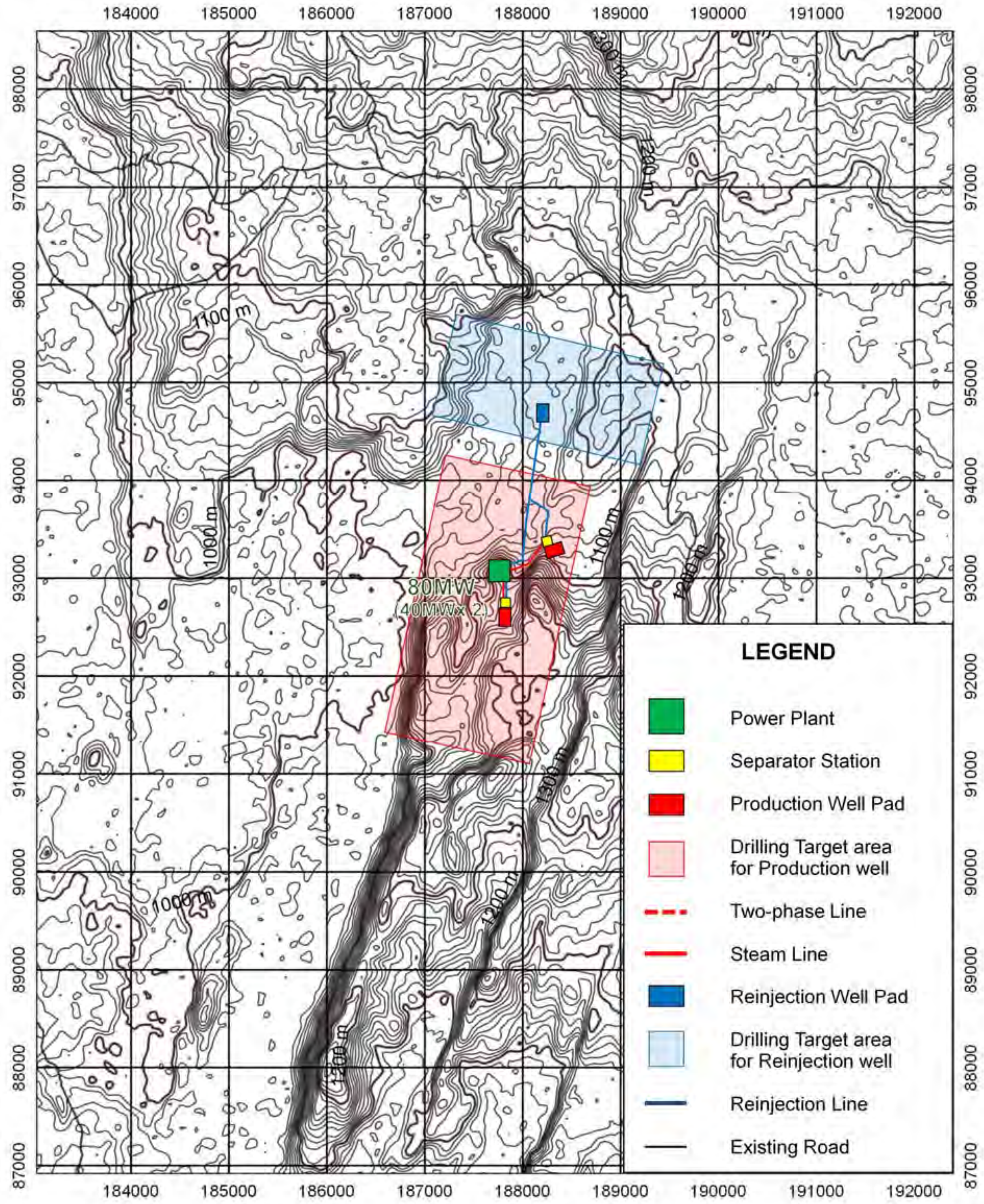


Fig. III-5.1 Possible layout of field development for Chepchuk

III-5.3 Development plan for power plant and substation

One geothermal power generation plant comprised of two units of 40MW each is proposed to be implemented at the Chepchuk geothermal field. In principle, although all units are suggested to be of the single flash type, a different plant size or the utilization of other generation technology should not be ruled out until better knowledge of the potential and characteristics of the geothermal fluid is achieved.

The power generated by the Chepchuk power plant units will be evacuated by connecting the power plant substation to the Paka substation through Korosi substation and a dedicated transmission line.

The flow diagram, of including the power plant and fluid transportation system are depicted in Fig. III-5.2. Figure III-5.3 shows single line diagrams and Fig. III-5.4 shows substation layout.

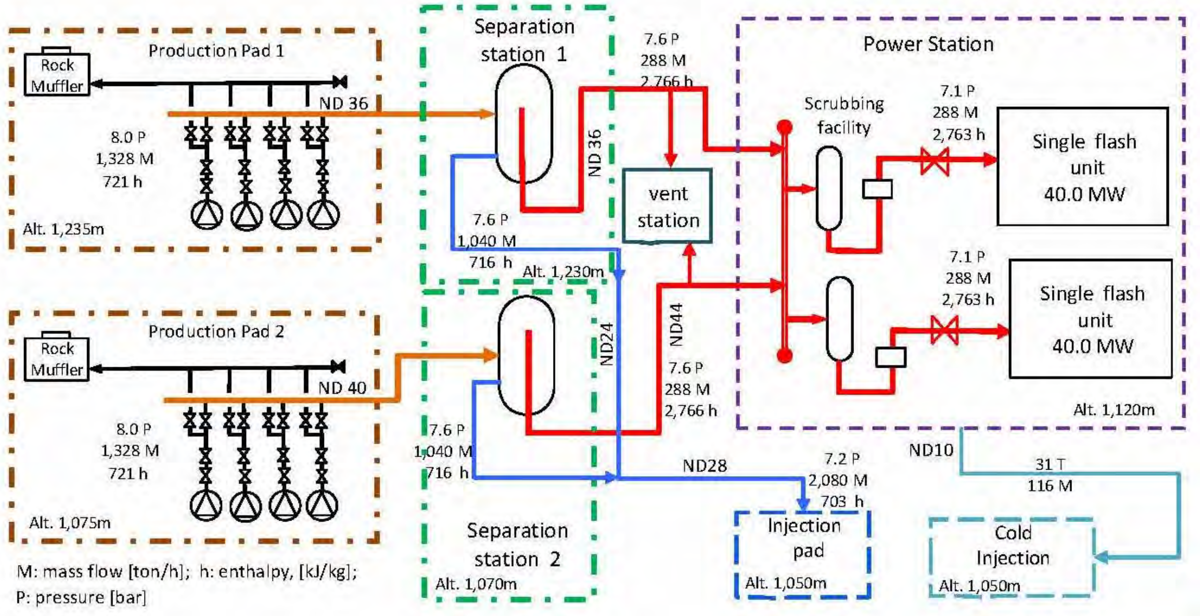


Fig. III-5.2 Chepchuk steam gathering system flow diagram

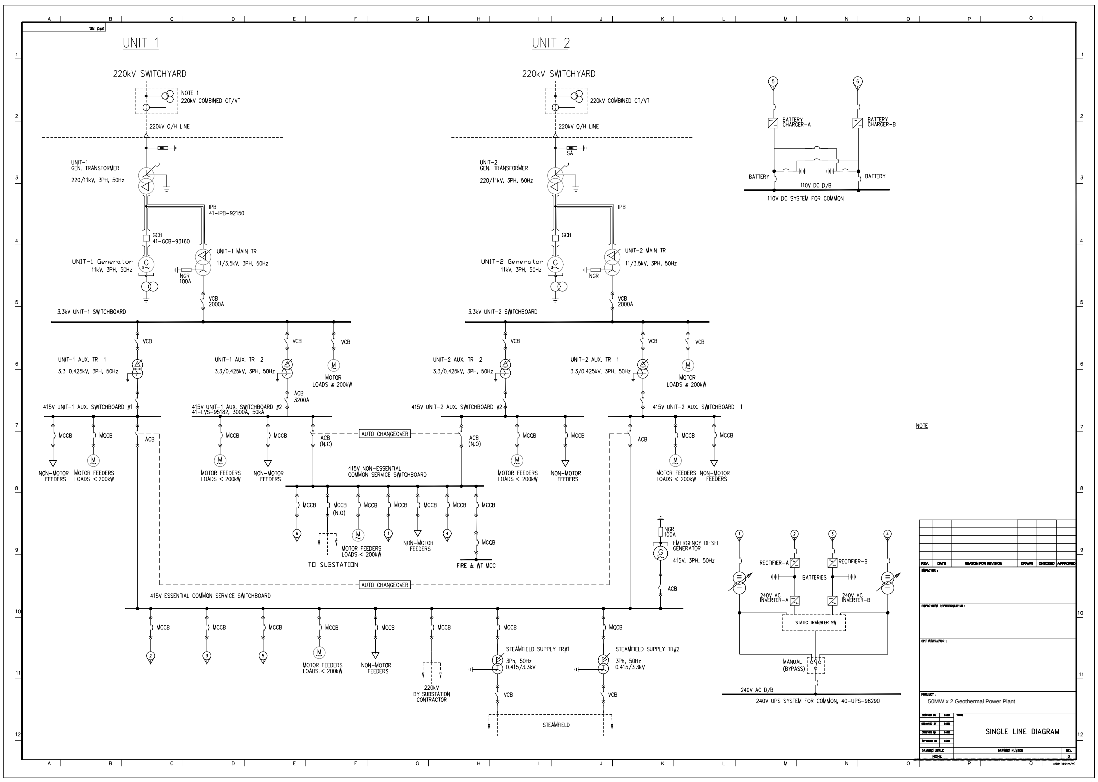


Fig. III-5.3 Single line diagram for Chepchuk power plant

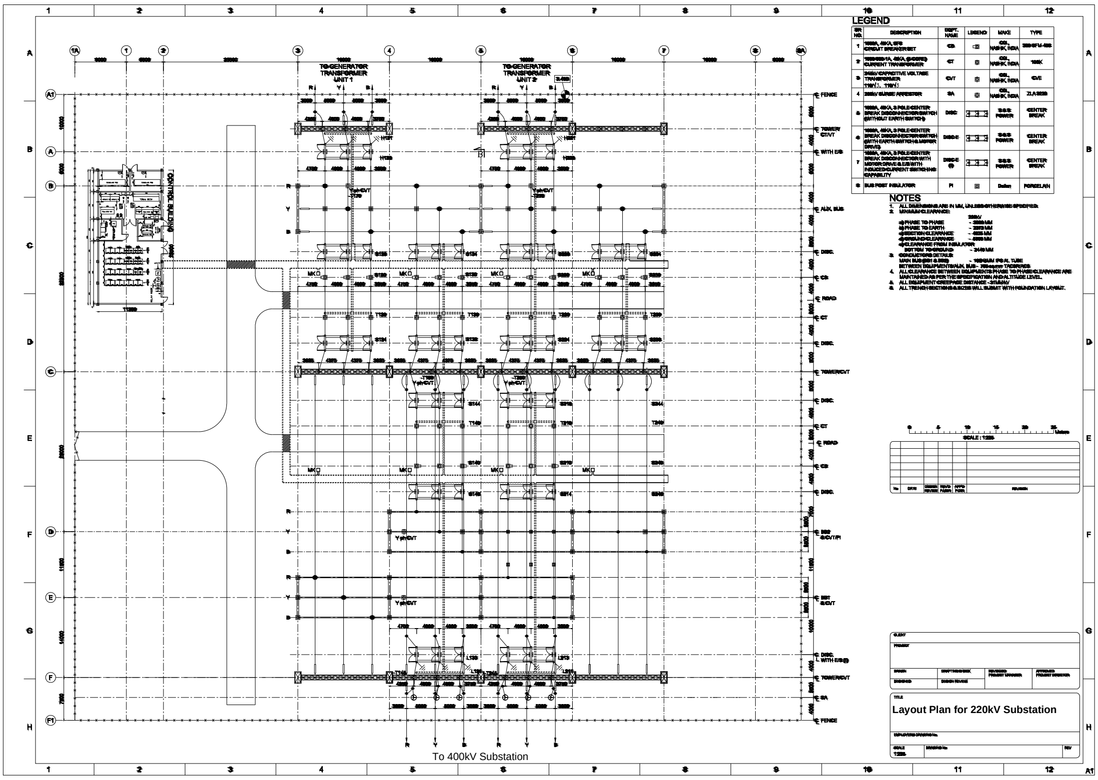


Fig. III-5.4 Chepchuk substation layout

III-5.4 Development schedule and cost estimation

Table III-5.2 shows a tentative development schedule, Table III-5.3 shows cost estimation for 80MW power plant development at the Chepchuk field.

With regards to make-up wells, the decline rates of productivity and injection capacity due to silica or other scaling of each well is not predictable at present. Therefore, the number of make-up wells required to maintain the rated power output and reinjection capacity over 30 years of plant operation was determined assuming the following usual annual rate of decline for power output of production wells and the injection capacity of reinjection wells.

- Power output of production wells : 3% per year decline
- Injection capacity of injection wells : 3% per year decline

Accordingly, it is estimated that seven production wells and six reinjection wells will be required as the make-up wells over 30 years of plant operation in this study. Depending on the results of well drilling, testing, and the capabilities during operation, consideration should be given to the construction of additional pads or the expansion of existing pads for make-up well drilling.

Table III-5.2 Development schedule

Chepchuk

Activity	Duration	Year 1				2				3				4				5				6				7				8				9				10				11			
	(month)	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Exploration Stage																																													
Phase 1																																													
Land Acquisition, Preparation	9	■	■	■																																									
Phase 2																																													
Drilling Civil, Water Supply	12				■	■	■			■																																			
Exploration Well Drilling, 2 Rigs	3							■	2 P-wells																																				
Appraisal Well Drilling, 3 Rigs	6										■	■	5 P-wells, 1 R-well																																
Well Testing	9							■	■			■	■																																
Resouce Assessment	6									■				■																															
Environmental Impact Assessment																																													
Environmental Impact Assessment	24										■	■	■	■	■	■	■	■																											
Feasibility Study, Contract, Design, Procurement																																													
Feasibility Study, Basic Design ***Contract, Survey, Design, Procurement***	33											■	■	■	■	■	■	■	■	■	■	■																							
Development Stage																																													
Steam Field Development																																													
Preparation, Civil Works for Well Drilling	6																						■	■																					
Well Drilling & Testing, 3 Rigs	24																								■	■	■	■	■	■	■	■	4 P-wells, 7 R-wells												
Fluid Collection and Reinjection System																																													
Fabrication, Delivery, Construction/Installation	48																						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
Power Plant (40MW x 2)																																													
Design, manufacturing ,delivery & Instal. of Unit 1	24																						■ Unit 1 (40)	■	■	■	■	■	■	■															
Design, manufacturing ,delivery & Instal. of Unit 2	24																															■ Unit 2 (40)	■	■	■	■	■	■	■						
Commissioning	6																														■									■					
Switchyard																																													
Design, manufacturing ,delivery & Instal. for Unit 1	24																						■	■	■	■	■	■	■	■															
Design, manufacturing ,delivery & Instal. for Unit 2	6																																					■	■						
Operation Stage																																■ 40MW	■	■	■	■	■	■	■	■	■ 80MW	■	■	■	■

Table III-5.3 Cost estimation

Exploration Stage

Unit:US$

Item		Unit	Quantity	Unit Price	Price	Remarks
Exploration/Appraisal Well Drilling		**L.S.**	**1**		**42,010,000**	
	Well Pad	Lot	3	600,000	1,800,000	Size of New Pad: 100m x 150m
	Lay Down/Operation Center	Lot	1	250,000	250,000	
	Access Road	km	4	40,000	160,000	Width: 6-8m
	Water Pipe Line	km	10	100,000	1,000,000	Victaulic pipe
	Water Supply Sysytem	L.S.	1	2,400,000	2,400,000	Tanks, booster pumps, power supply, etc.
	Production Well Drilling	Well	7	4,000,000	28,000,000	±2,000mTD, Directional, 7" liner completion
	Reinjection Well Drilling	Well	1	4,000,000	4,000,000	±2,000mTD, Directional, 7" liner completion
	Water Supply Operation	Well	8	50,000	400,000	Power/water domestic supply
	Well Testing	Well	8	500,000	4,000,000	
Environmental Impact Assessment		**L.S.**	**1**		**300,000**	
Feasibility Study		**L.S.**	**1**		**1,000,000**	
Total Exploration Stage Cost		**L.S.**	**1**		**43,310,000**	

Development Stage (Steam Field)

Unit:US$

Item		Unit	Quantity	Unit Price	Price	Remarks
Start-up Well Drilling		**L.S.**	**1**		**50,050,000**	
	Well Pad	Lot	0	600,000	-	
	Lay Down/Operation Center	Lot	0	250,000	-	
	Access Road	km	0	40,000	-	Width: 6-8m
	Production Well Drilling	Well	4	4,000,000	16,000,000	±2,000mTD, Directional, 7" liner completion
	Reinjection Well Drilling	Well	7	4,000,000	28,000,000	±2,000mTD, Directional, 7" liner completion
	Water Supply Operation	Well	11	50,000	550,000	Power/water domestic supply
	Well Testing	Well	11	500,000	5,500,000	
FCRS Construction		**L.S.**	**1**		**17,500,000**	
	Separator Station 1 & 2	L.S.	2	3,250,000	6,500,000	80m x 80m each
	FCRS Piping	L.S.	1	11,000,000	11,000,000	including civil works, instrument, etc.
Total Steam Field Cost		**L.S.**	**1**		**67,550,000**	

Development Stage (Power Plant)

Unit:US$

Item		Unit	Quantity	Unit Price	Price	Remarks
Power Plant		**L.S.**	**1**		**147,500,000**	
	Site Preparation	L.S.	1	3,500,000	3,500,000	200m x 160m
	Power Plant	L.S.	2	72,000,000	144,000,000	40MW x 2
Switchyard and Transmission Line		**L.S.**	**1**		**9,715,200**	
	Site Preparation	m2	14,080	40	563,200	110m x 128m
	Switchyard	L.S.	4	1,463,000	5,852,000	
	Transmission Line	km	15	220,000	3,300,000	Chepchuk PS-Korosi PS 220kV x 2circuit (single Canary)
Total Power Plant Cost		**L.S.**	**1**		**157,215,200**	

Operation Stage

Unit:US$

Item		Unit	Quantity	Unit Price	Price	Remarks
Make-up Well Drilling		**L.S.**	**1**		**52,650,000**	
	Production Well Drilling	Well	7	4,000,000	28,000,000	±2,000mTD, Directional, 7" liner completion
	Reinjection Well Drilling	Well	6	4,000,000	24,000,000	±2,000mTD, Directional, 7" liner completion
	Water Supply Operation	Well	13	50,000	650,000	Power/water domestic supply

III-5.5 Economic evaluation of the development plan

a. Financial evaluation

Based on the above-mentioned technical estimation, the financial evaluation was carried out to estimate development cost of Chepchuk field. Similar to the evaluation of Arus field, three kinds of development formation were examined; (i) private sector's total project, (ii) GDC and private sector's joint project, and (iii) GDC's total project. The assumptions of the evaluation are also the same as the case of Arus field.

<Result of financial evaluation>

Construction costs of a geothermal power plant in Chepchuk field are as shown in Table III-5.4. (Note: values in this table include 10% to cover the consultant fee and administration cost).

Table III-5.4 Construction costs of a geothermal power plant in Chepchuk field

Item	Steam field (million US$)	Power plant (million US$)	Total (million US$)	Unit cost (US$/kW)
Construction costs	122	173	295	3,690
IDC	6	16	23	-
Construction costs with IDC	128	189	317	3,970

The LGC and the LSC in each development formation in Chepchuk field have been estimated as shown in Table III-5.5 and Fig. III-5.5.

Table III-5.5 The LEC and LSC by development formation in Chepchuk field (US¢/kWh)

Development formation	IPP total PJ	GDC/IPP joint PJ	GDC total PJ
Levelized steam cost (LSC)	11.5	5.1	5.0
Levelized conversion cost	7.3	7.3	4.6
Levelized generation cost (LEC)	18.9	12.4	9.7

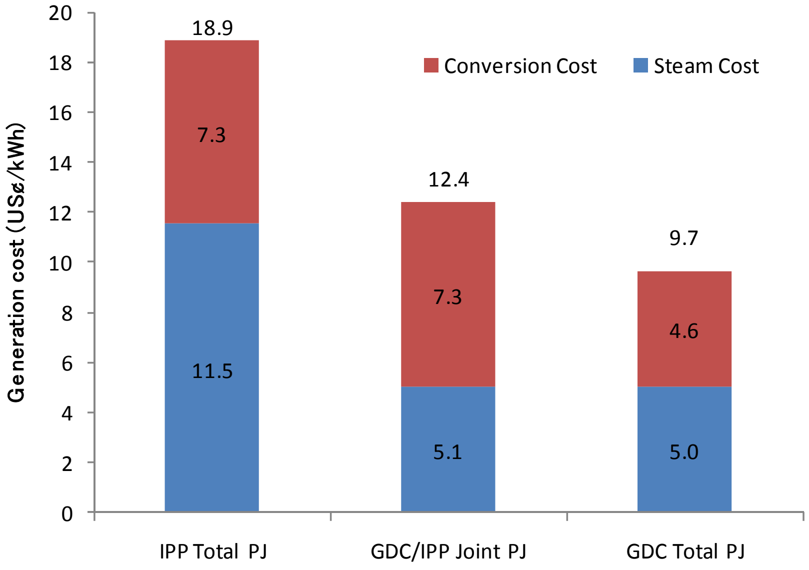


Fig. III-5.5 The LEC and LSC by development formation in Chepchuk field

b. Economic evaluation

An economic evaluation was carried out to examine the social-economic significance the development of the Chepchuk geothermal field. Similar to the case of Arus field, three kinds of alternative plants are considered; (i) coal-fired power plant, (ii) LNG combined-cycle power plant, and (iii) diesel power plant. The assumptions of the evaluation are also the same as the case of Arus field.

<Result of economic evaluation>

Results of the economic evaluation for the Chepchuk field are shown in Table III-5.6. Since all EIRR results exceed 12% which is assumed as the socio-economic opportunity cost of Kenya, the geothermal development in Chepchuk field is justified with the socio-economic significance.

Table III-5.6 Cost competitiveness of the geothermal development in Chepchuk field vs. alternative thermal power plants

Alternative plants	Coal-fired plant	LNG CC plant	Diesel plant
Economic Internal Rate of Return	12.2%	15.7%	26.4%

c. Sensitivity analysis

The construction cost of geothermal power plants in Chepchuk field are estimated to be US $ 317 million with the unit construction cost of 3,970 US$/kW. The results of the sensitivity analysis of the LEC/LSC and the economic evaluation on the change of the estimated construction cost are shown in Figs. III-5.6 and III-5.7. When the construction cost changes by ± 20% from the estimated one, the LEC and LSC in the case of joint project between GDC and IPP changes in the range from 10.2 US¢/kWh (-17.4%) to 14.5 US¢/kWh (+17.4%). Regarding the economic evaluation, it should be noted that a geothermal power plant loses competitive vs. a coal-fired plant if the construction cost rises from the estimated cost.

In addition, the average output of the production well in Chepcuk field is estimated to be 10 MW per well. The sensitivity analysis of the LEC/LSC and the economic evaluation on the change of the average production well output is also done and the result is shown in Figs. III-5.8 and III-5.9. If the average production well output decreases to 5 MW/well, the LEC will rise by 16.0% to 14.4 US¢/kWh. Figure III-5.9 shows the geothermal power plant will lose cost competitiveness against coal-fired plant if the average production well output becomes less than 10 MW/well. Therefore, great attention is needed to the average production well output in this field.

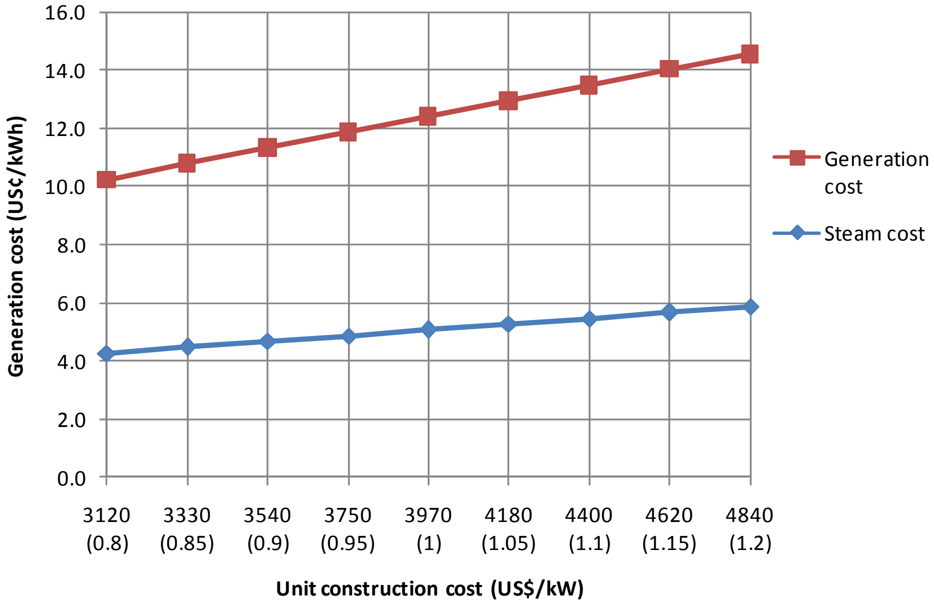


Fig. III-5.6 Sensitivity analysis of the LEC and LSC to changes in the construction cost (Chepchuk)

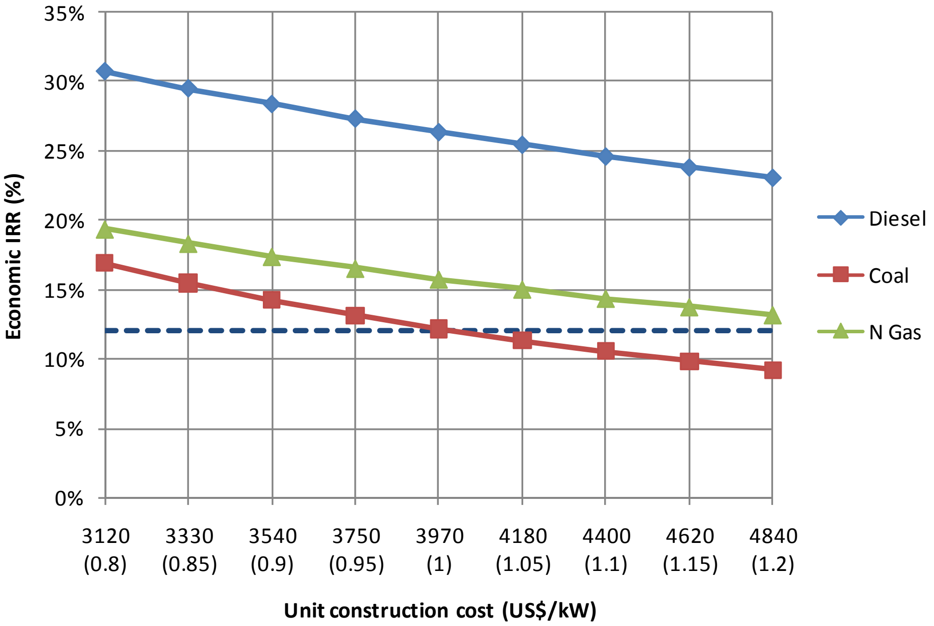


Fig. III-5.7 Sensitivity analysis of the EIRR to changes in the construction cost (Chepchuk)

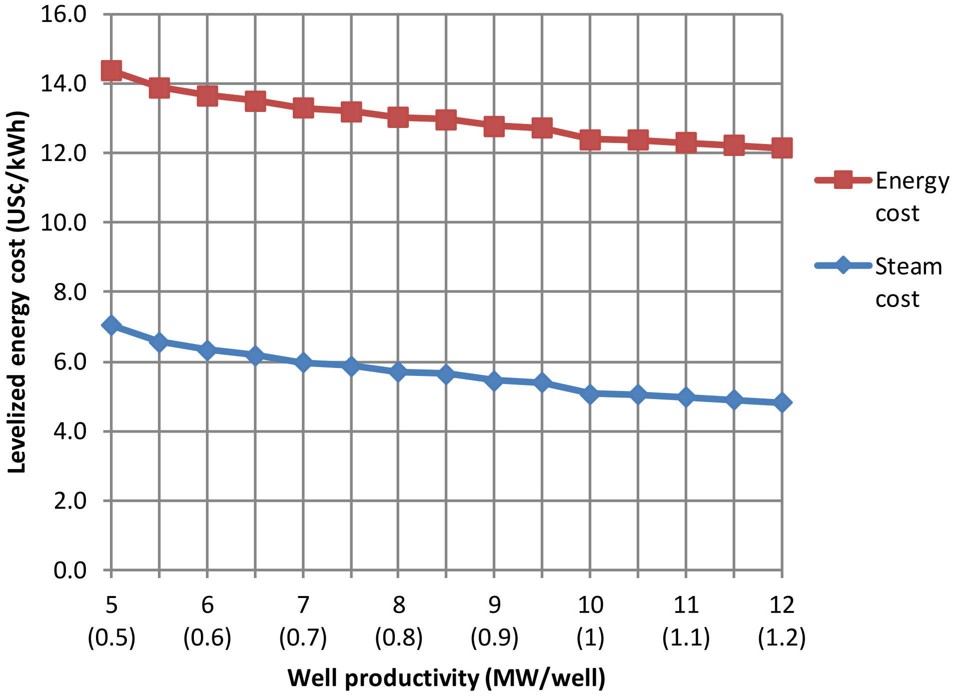


Fig. III-5.8 Sensitivity analysis of the LEC and LSC to changes in the average production well output (Chepchuk)

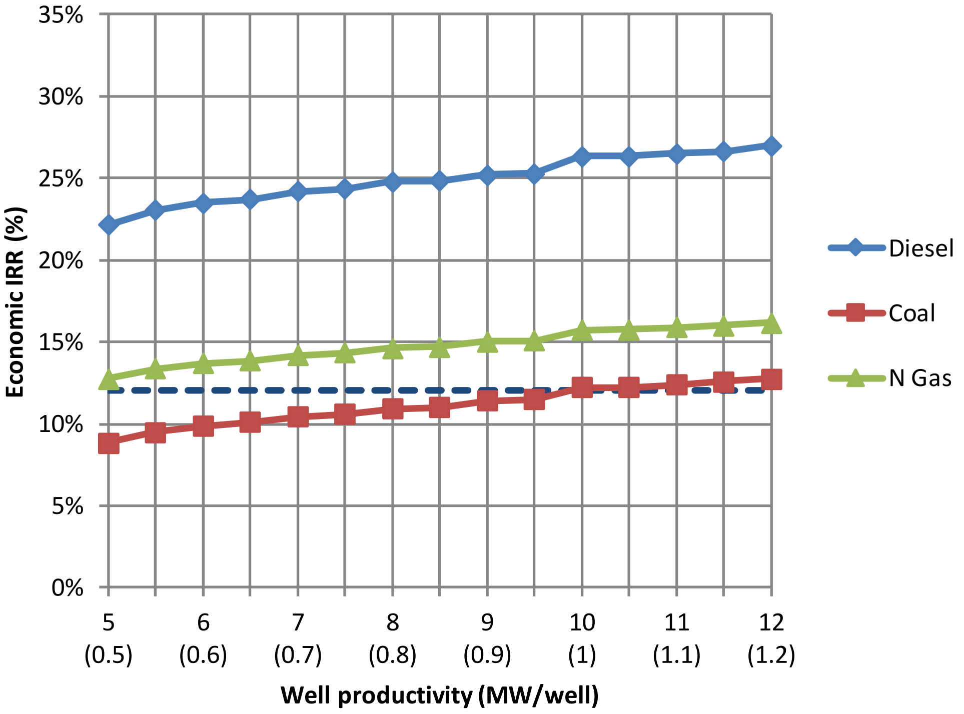


Fig. III-5.9 Sensitivity analysis of the EIRR to changes in the average production well output (Chepchuk)

III-6 Development Plan for the Paka Field

III-6.1 Development scale and main facilities

The development scale (the output capacity of the geothermal power plant for the Paka field) is proposed based on the estimated resource potential. The type of power plant was selected to be a conventional flash steam cycle (condensing type) in this study. The required number of geothermal wells is estimated according to the results of the evaluation of productivity (and injectivity) of wells. The main specifications regarding the possible power development of the Paka field are shown in Table III-6.1.

Based upon the possible power development plan stated above for 320MW flash type geothermal power generation at the Paka, thirty-four production wells and five reinjection wells are estimated to be required for start-up. In consideration of the drilling success ratio, (which is assumed to be 67% for exploration wells and 80-100% for appraisal/operation wells), forty-one production wells and six reinjection wells should be drilled.

Table III-6.1 Main specifications for the possible power development in the Paka field

Field	Planned Capacity	Average Productivity	Total Reinjection Brine	Assumed Injection Capacity	Required Wells for operation	
	(MW-gross)	(MW/well)	(t/h)	(t/h/well)	Production	Reinjection
Paka 70MW x 4 + 40MW x 1	320	9.5	1292	300	**34**	**5**

Field		Exploration Stage		Appraisal Stage		Development Stage		Total	
		P-well	R-well	P-well	R-well	P-well	R-well	P-well	R-well
Paka 70MW x 4 + 40MW x 1	Drilled wells	3	0	5	1	33	5	**41**	**6**
	Successful Wells (for operation)	2	0	4	1	28	4	**34**	**5**

III-6.2 Resource development plan

According to the conceptual model of the geothermal system, total drilling depth will vary from 1,800m to 2,300m in depth for both production wells and reinjection wells. In order to minimize the number of required drilling pads and to allow multiple targets to be drilled from the same pad, directional drilling should be adopted. To avoid interference among wells, the targets are located at intervals of around 300m. In addition, detailed drilling depths and well profiles for the development production/reinjection wells should be planned based on the up-date geothermal conceptual model reflecting the results of exploration/appraisal wells drilling and testing.

Drilling rigs owned by GDC with a 2,000 HP output capability will be available to drill directionally to 1,800-2,300m in depth, with a final completion diameter of 8.5 inches. Fig. III-2.1 shows an example of a possible well casing program and Fig. III-2.2 shows an example of a possible well directional drilling program.

The planned layout of Paka is shown in Fig. III-6.1. The number of drilling pads is tentatively assumed to be six pads for production wells and two pads for reinjection wells. A total of three existing pads, PW01, PW02 and PW03, which have been constructed by GDC will be used for production well drilling. It is assumed that two power plants are separately located on the west side and east side of the Paka field.

In both the west sector and east sector, two-phase fluids from the three production well pads will be transported to the separation stations, in which the fluids will be separated into steam and brine.

Drilling pads for reinjection wells should be situated at elevations lower than the separator stations to transport the brine to the reinjection wells by gravity. The drilling targets for reinjection wells should be separated from the production zone at least 1 km to avoid the breakthrough of reinjected water that could cause cooling of the high temperature reservoir. Two reinjection pads are planned to be located on the north side of the production zone.

Approximately eight wells can be drilled from one pad of dimensions of 100m x 150m, including water/mud pits and pipe storage yard, etc. Furthermore, constructed pads will be available for future drilling of make-up wells during the power plant operation.

Fresh water for well drilling and power plant operation can be supplied from Lake Baringo by utilizing a steel pipe line for water transportation as planned by GDC. In addition, fresh water should be distributed to each pad from water tanks with around 4,000 cubic meters capacity, which will be installed close to the power plants.

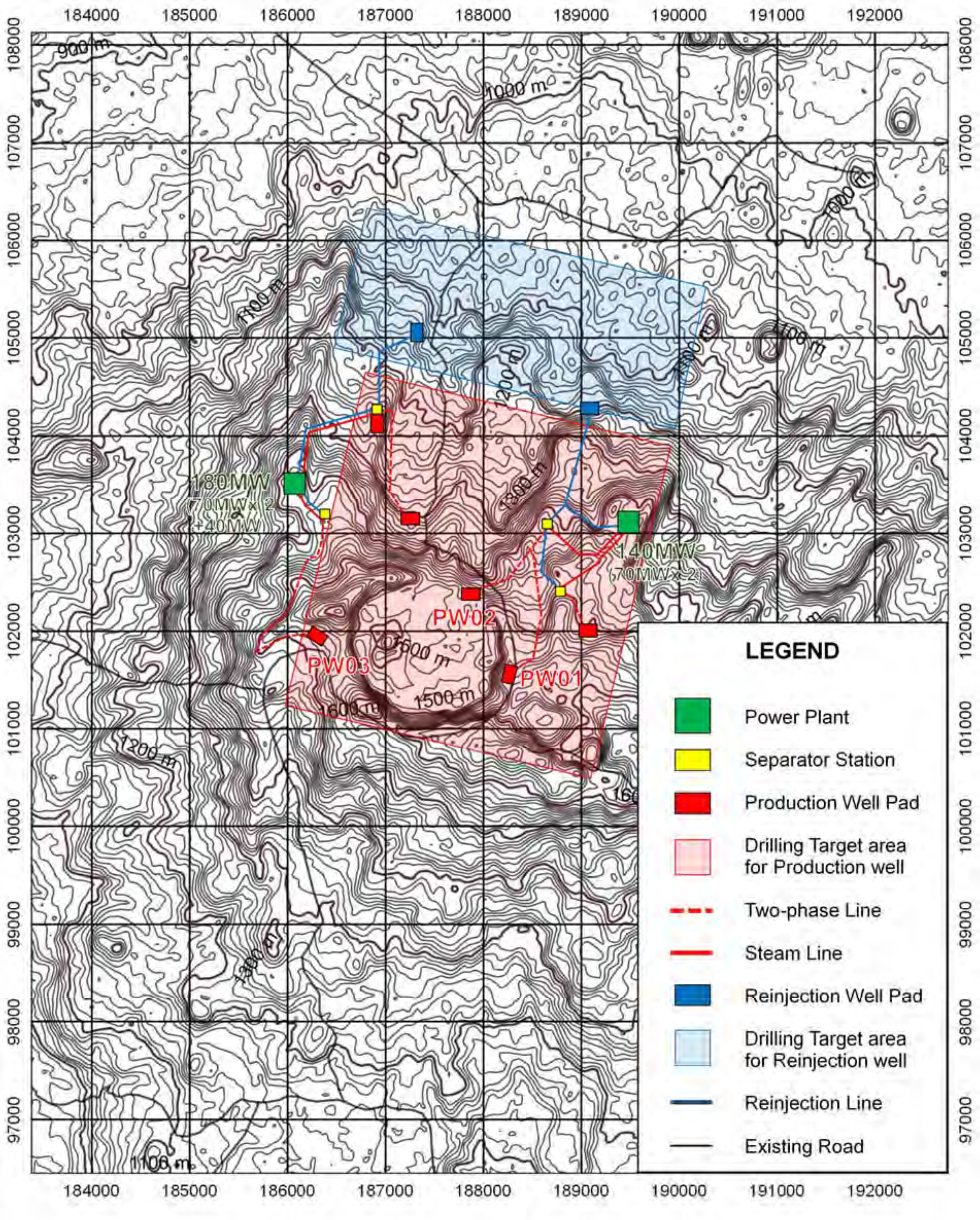


Fig. III-6.1 Possible layout of field development for Paka

III-6.3 Development plan for power plant and substation

Two geothermal power generation plants, hereafter as referred as "West Plant" and "East Plant", are proposed to be implemented at the Paka geothermal prospect. The West Plant would be comprised of two single flash units of 70MW and one unit of 40MW, while the East Plant would be comprised of two units, each of 70 MW. In principle, although all units or both plants are suggested to be of the single flash type, a different plant size or the utilization of other generation technology should not be ruled out until better knowledge of the potential and characteristics of the geothermal fluid is achieved.

The proposed sites for power plant construction were selected taking into consideration distances from the production and reinjection wells, ease of pipeline installation, and topographic features. Other issues such as geologic constraints and/or environmental issues should be evaluated at the time of the preparation of a feasibility study. The possible layout of field development for Paka is shown in Fig. III-6.2 and Fig. III-6.3.

The power generated by the Paka's East Plant units will be evacuated through the Paka West Plant switchyard and a dedicated substation to be constructed in the vicinity of the West Plant, cutting in the 400kV transmission line to be built between Rongai, currently at the end of the Kenyan grid, and the Silali prospect.

The flow diagram, of including the power plant and fluid transportation system are depicted in Figs. III-6.4 and III-6.5. Figures III-6.6 and III-6.7 show single line diagrams. Figures III-6.8 and III-6.9 show substation layout.

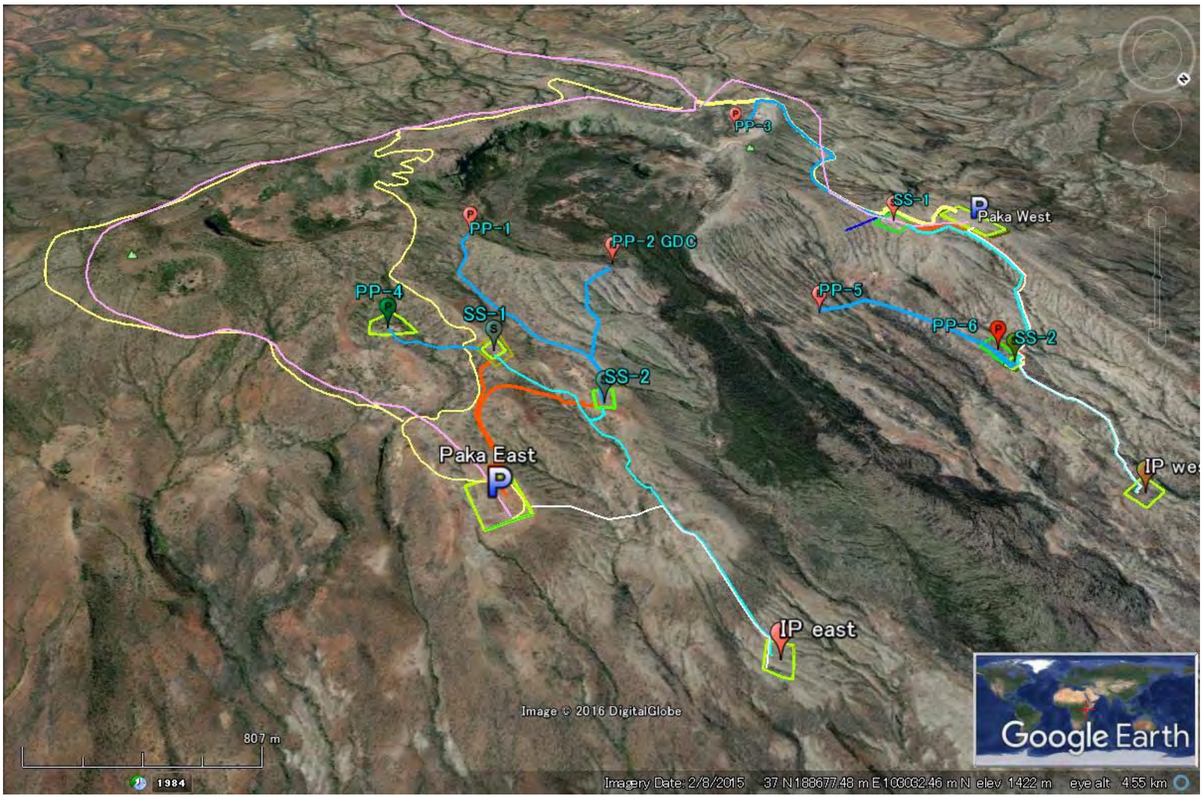


Fig. III-6.2 Possible layout of field development for Paka (View from the northeast)

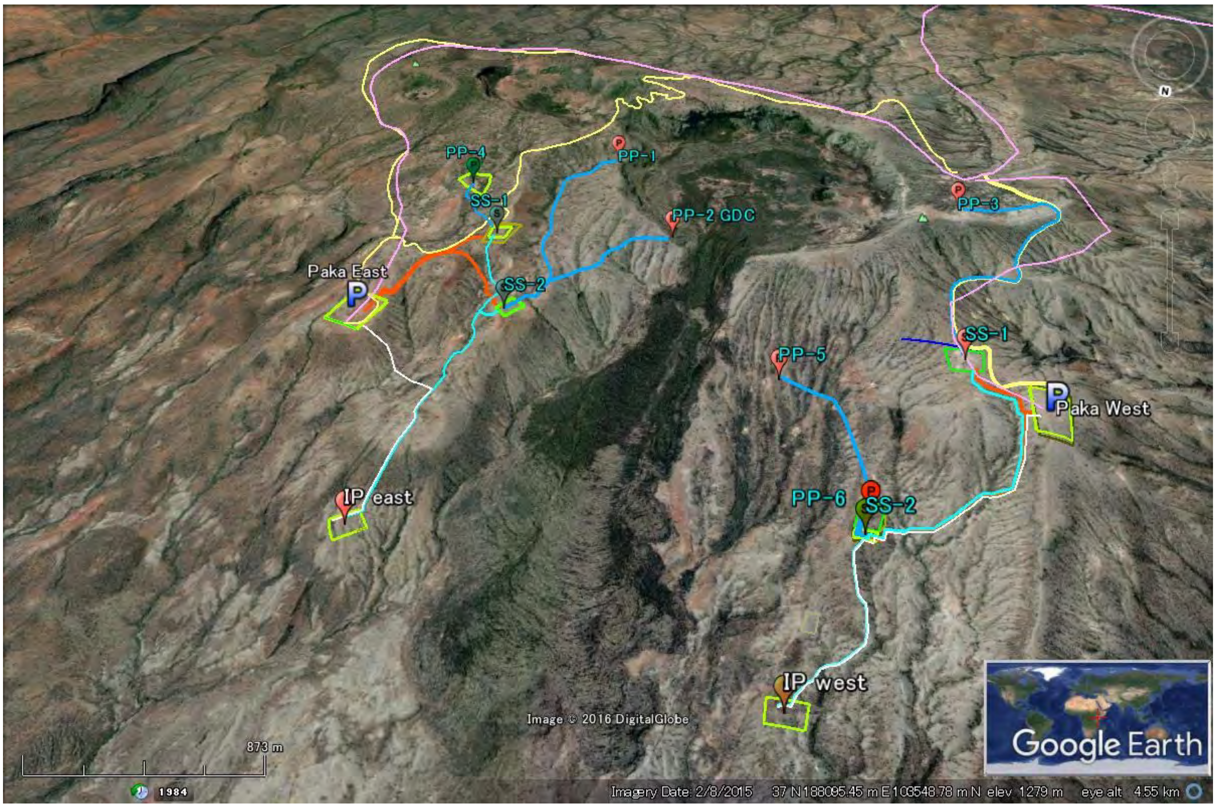


Fig. III-6.3 Possible layout of field development for Paka (View from the North)

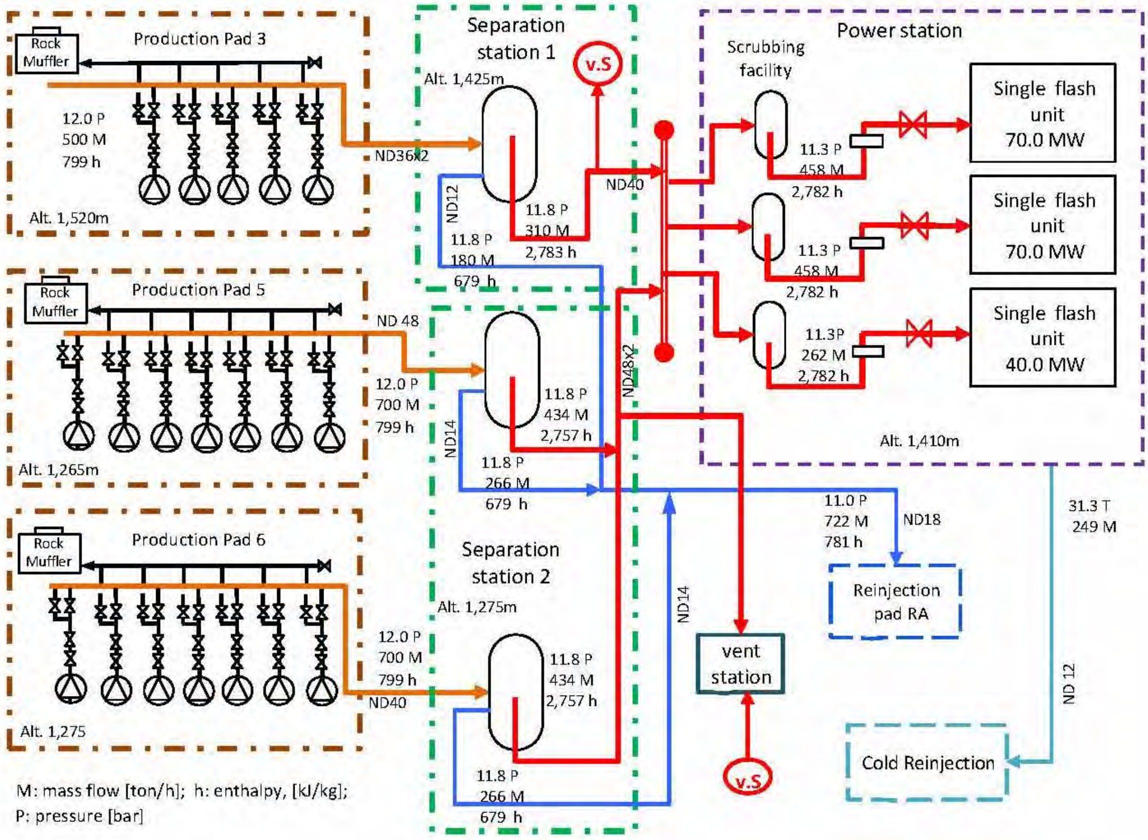


Fig. III-6.4 Paka West Plant steam gathering system flow diagram

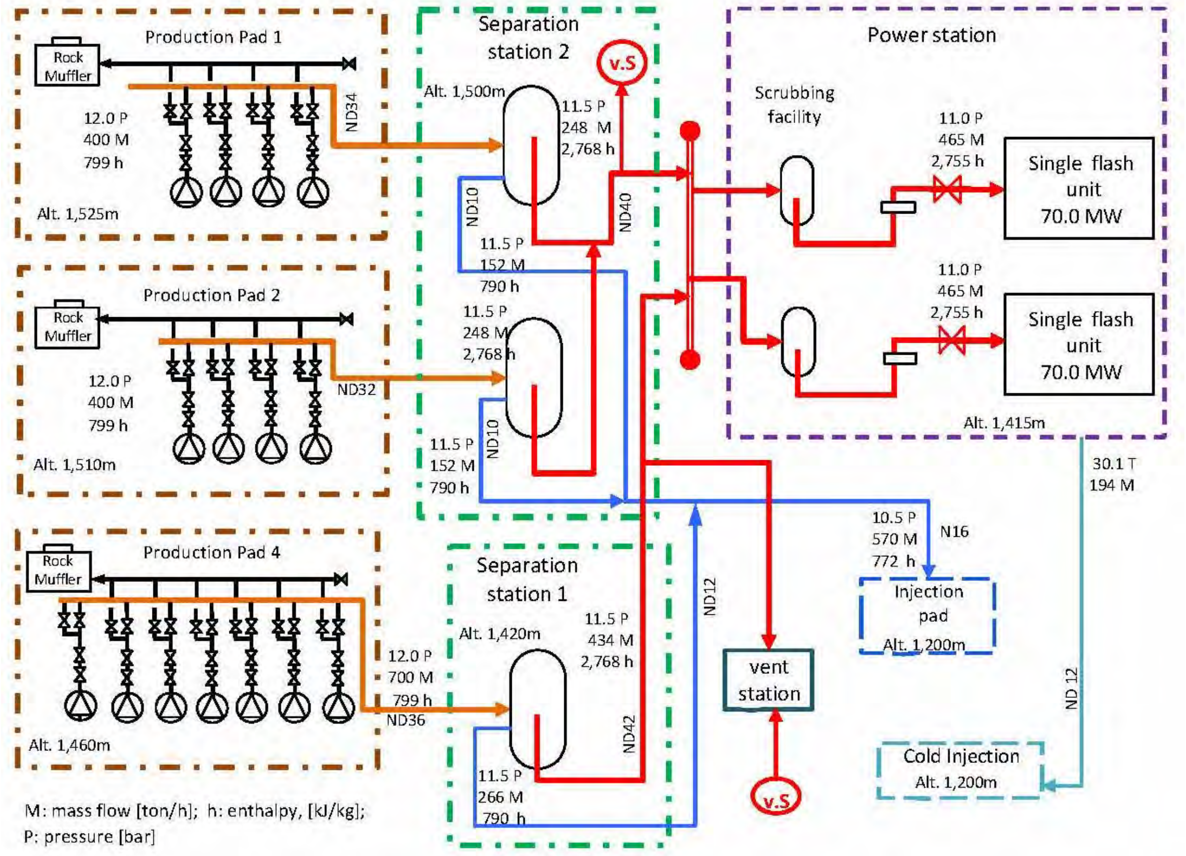


Fig. III-6.5 Paka Eest Plant steam gathering system flow diagram

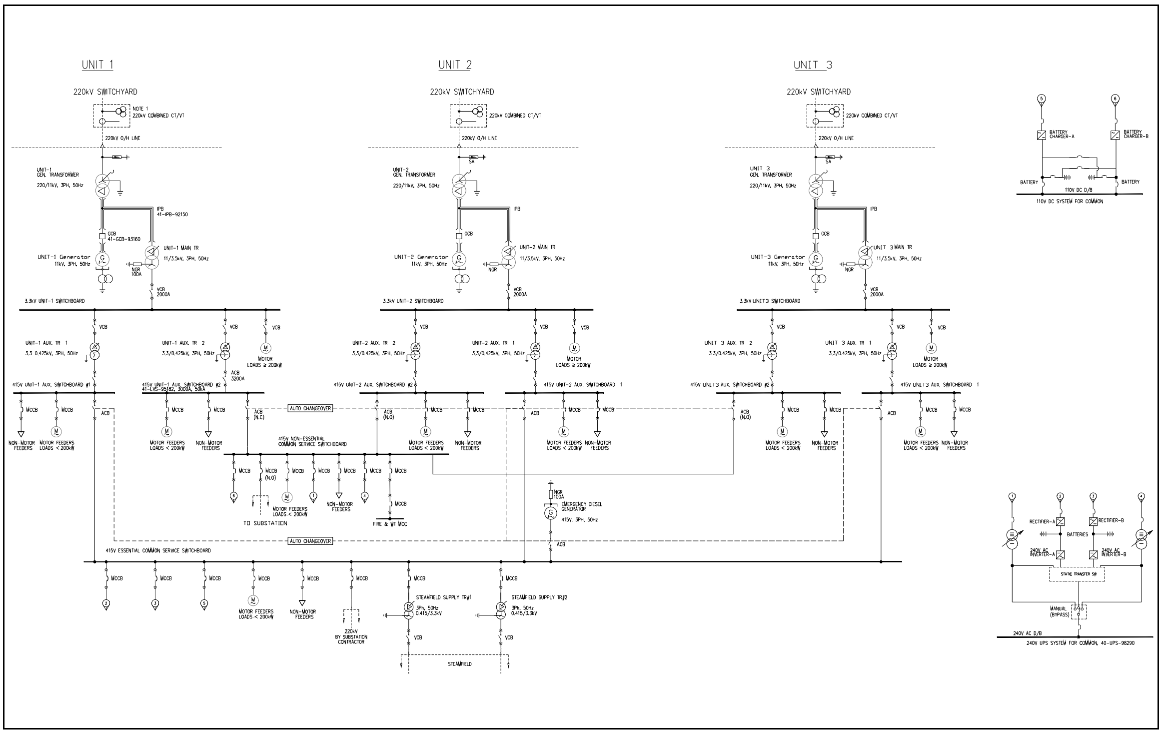


Fig. III-6.6 Single diagram for the Paka power plant (west)

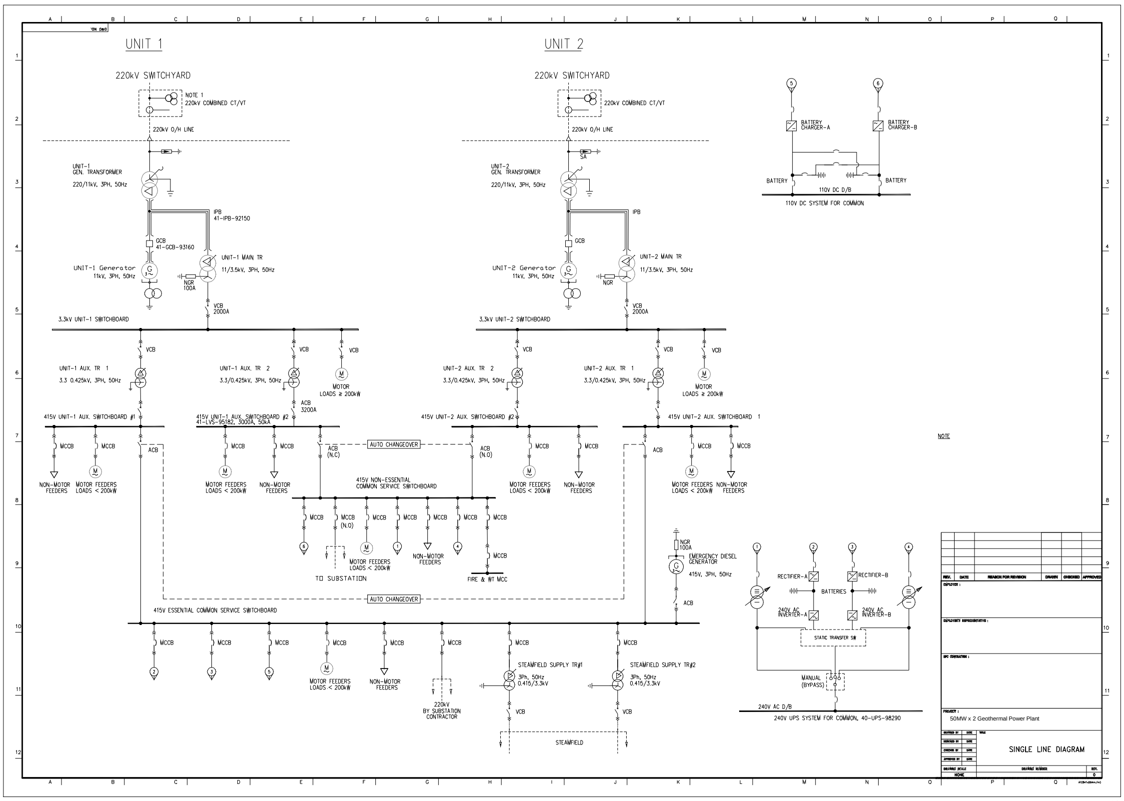


Fig. III-6.7 Single diagram for the Paka power plant (east)

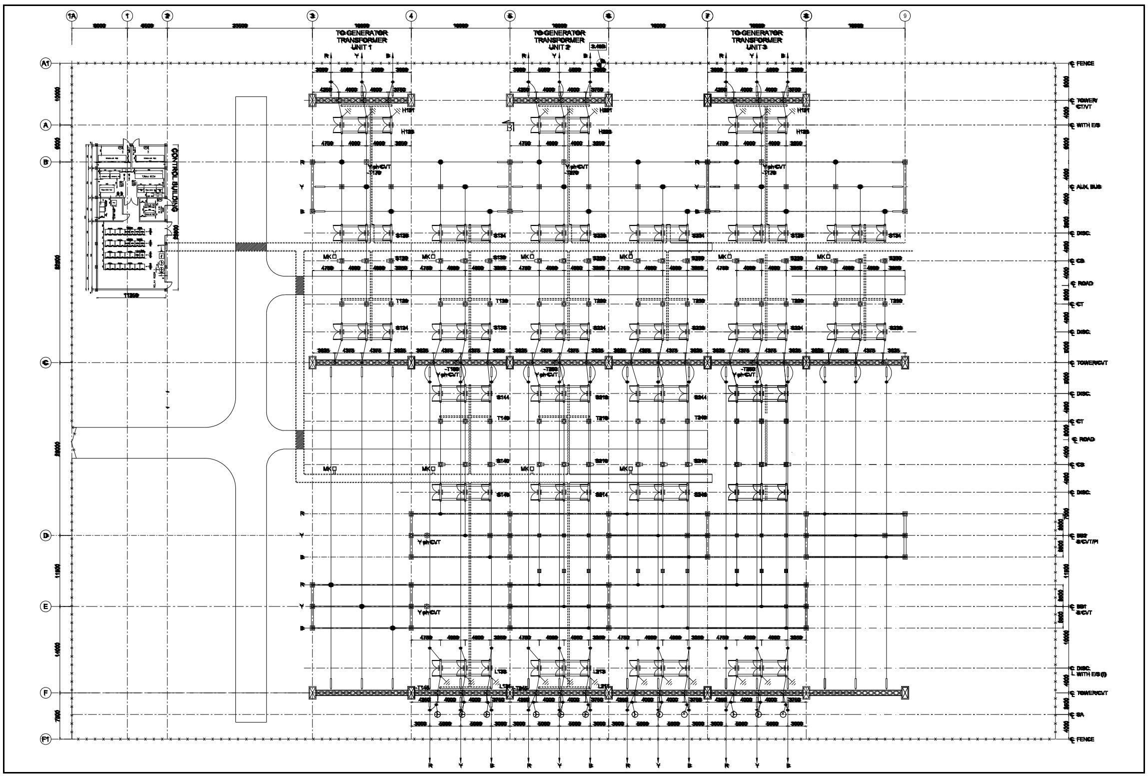


Fig. III-6.8 Paka (west) substation layout

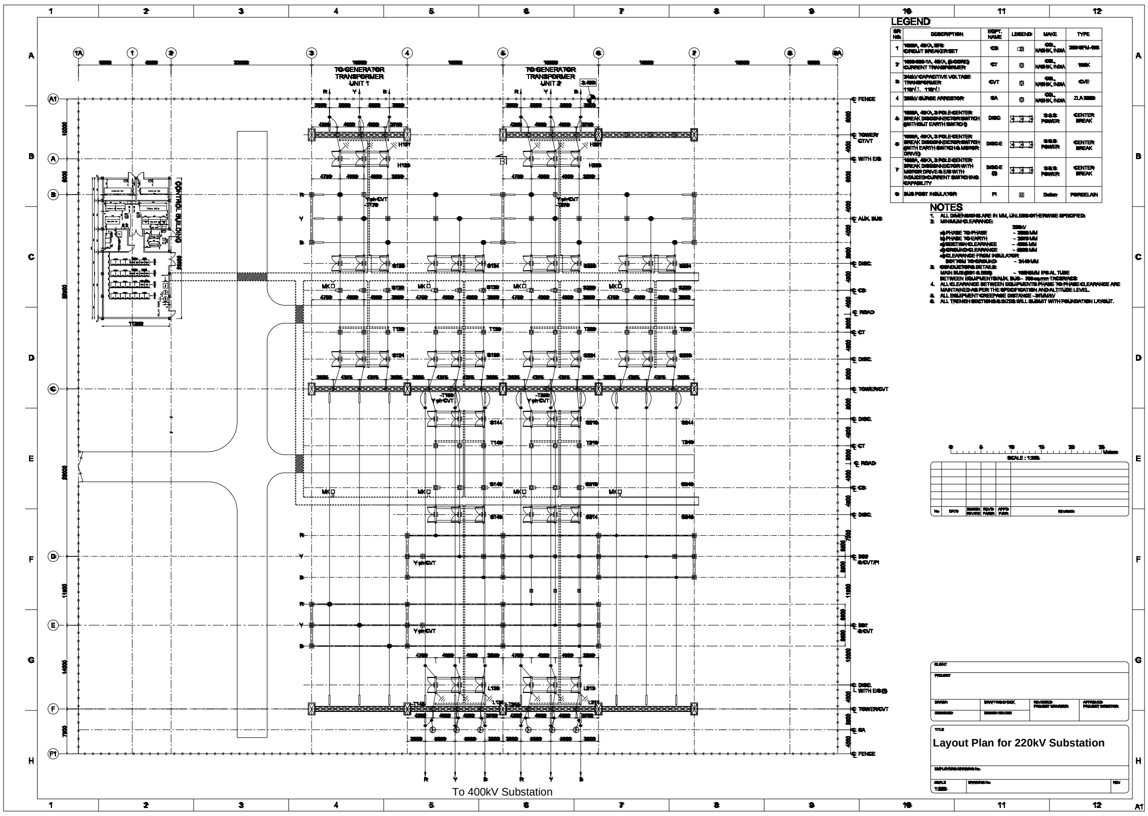


Fig. III-6.9 Paka (east) substation layout

III-6.4 Development schedule and cost estimation

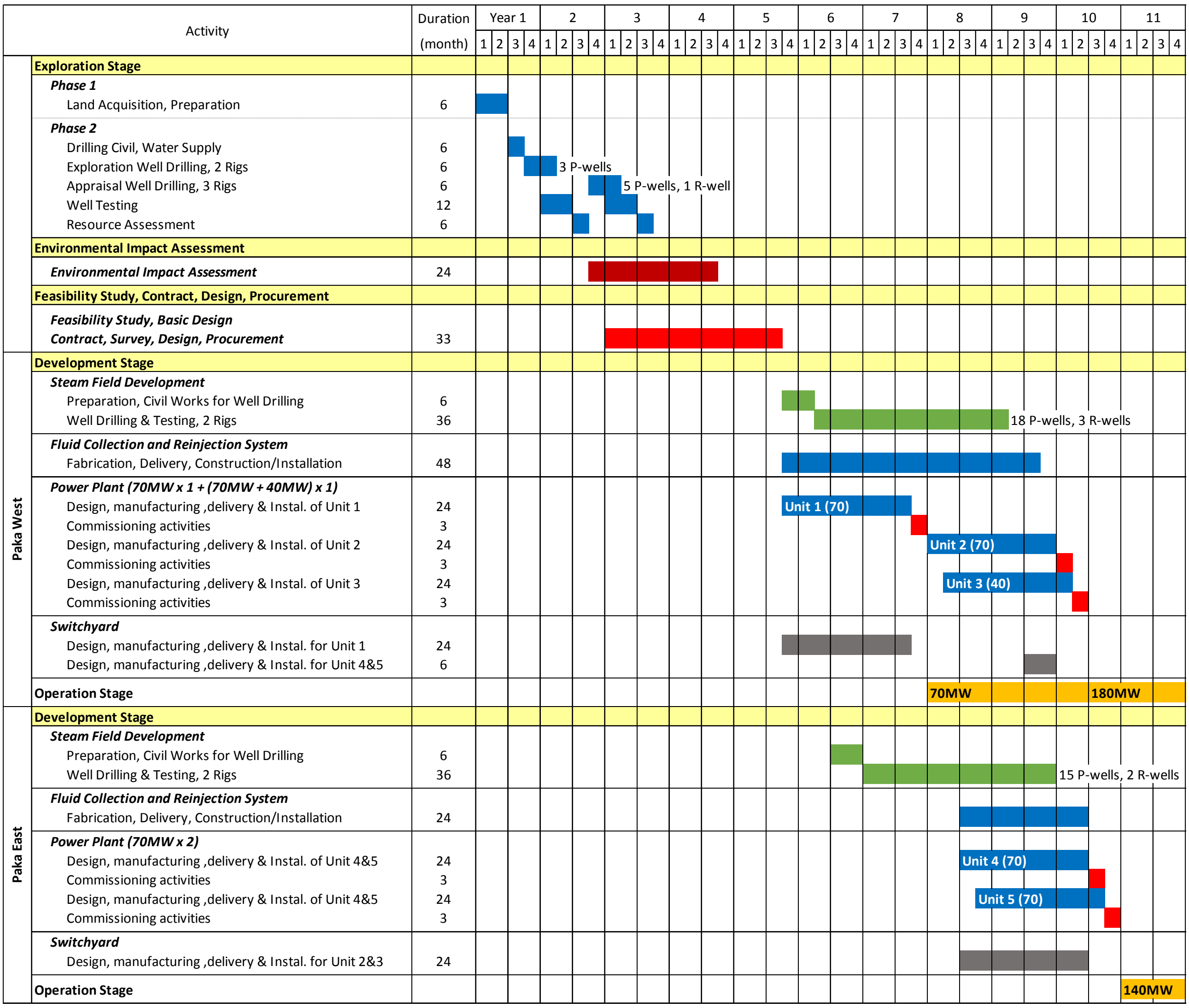
Table III-6.2 shows a tentative development schedule, Table III-6.3 shows cost estimation for 320MW power plant development at the Paka field. It is assumed that the power plant units would be 70MW as Unit 1, then 110MW (70W + 40MW) as Unit 2 & 3 at the West Plant. These units will be followed by 140MW (70W x 2) as Unit 4 & 5 at the East Plant in the tentative development schedule.

With regards to make-up wells, the decline rates of productivity and injection capacity due to silica or other scaling of each well is not predictable at present. Therefore, the number of make-up wells required to maintain the rated power output and reinjection capacity over 30 years of plant operation was determined assuming the following usual annual rate of decline for power output of production wells and the injection capacity of reinjection wells.

- Power output of production wells : 3% per year decline
- Injection capacity of injection wells : 3% per year decline

Accordingly, it is estimated that thirty production wells and three reinjection wells in Paka will be required as make-up wells over 30 years of plant operation in this study. Based on this assumption, at least three additional new well pads will be required for production make-up well drilling in the future. Depending on the results of well drilling, testing, and the capabilities during operation, consideration should be given to the construction of additional pads or the expansion of existing pads for make-up well drilling.

Table III-6.2 Development schedule



	Activity	Duration (month)
	Exploration Stage	
	Phase 1	
	Land Acquisition, Preparation	6
	Phase 2	
	Drilling Civil, Water Supply	6
	Exploration Well Drilling, 2 Rigs	6
	Appraisal Well Drilling, 3 Rigs	6
	Well Testing	12
	Resource Assessment	6
	Environmental Impact Assessment	
	Environmental Impact Assessment	24
	Feasibility Study, Contract, Design, Procurement	
	Feasibility Study, Basic Design ***Contract, Survey, Design, Procurement***	33
Paka West	**Development Stage**	
	Steam Field Development	
	Preparation, Civil Works for Well Drilling	6
	Well Drilling & Testing, 2 Rigs	36
	Fluid Collection and Reinjection System	
	Fabrication, Delivery, Construction/Installation	48
	Power Plant (70MW x 1 + (70MW + 40MW) x 1)	
	Design, manufacturing ,delivery & Instal. of Unit 1	24
	Commissioning activities	3
	Design, manufacturing ,delivery & Instal. of Unit 2	24
	Commissioning activities	3
	Design, manufacturing ,delivery & Instal. of Unit 3	24
	Commissioning activities	3
	Switchyard	
	Design, manufacturing ,delivery & Instal. for Unit 1	24
	Design, manufacturing ,delivery & Instal. for Unit 4&5	6
	Operation Stage	
Paka East	**Development Stage**	
	Steam Field Development	
	Preparation, Civil Works for Well Drilling	6
	Well Drilling & Testing, 2 Rigs	36
	Fluid Collection and Reinjection System	
	Fabrication, Delivery, Construction/Installation	24
	Power Plant (70MW x 2)	
	Design, manufacturing ,delivery & Instal. of Unit 4&5	24
	Commissioning activities	3
	Design, manufacturing ,delivery & Instal. of Unit 4&5	24
	Commissioning activities	3
	Switchyard	
	Design, manufacturing ,delivery & Instal. for Unit 2&3	24
	Operation Stage	

Table III-6.3 Cost estimation

Exploration Stage

Unit:US$

Item	Unit	Quantity	Unit Price	Price	Remarks
Exploration/Appraisal Well Drilling	**L.S.**	**1**		**43,950,000**	
Well Pad	Lot	1	600,000	600,000	For reinjection well, Size: 100m x 150m
Lay Down/Operation Center	Lot	0	250,000	-	
Access Road	km	0	40,000	-	Width: 6-8m
Water Supply Sysytem	L.S.	1	2,400,000	2,400,000	Tanks, booster pumps, power supply, etc.
Production Well Drilling	Well	8	4,000,000	32,000,000	±2,000mTD, Directional, 7" liner completion
Reinjection Well Drilling	Well	1	4,000,000	4,000,000	±2,000mTD, Directional, 7" liner completion
Water Supply Operation	Well	9	50,000	450,000	Power/water domestic supply
Well Testing	Well	9	500,000	4,500,000	
Environmental Impact Assessment	**L.S.**	**1**		**300,000**	
Feasibility Study	**L.S.**	**1**		**1,000,000**	
Total Exploration Stage Cost	**L.S.**	**1**		**45,250,000**	

Development Stage (Steam Field)

Unit:US$

Item	Unit	Quantity	Unit Price	Price	Remarks
Start-up Well Drilling	**L.S.**	**1**		**175,870,000**	
Well Pad	Lot	4	600,000	2,400,000	3 for production and 1 for reinjection
Lay Down/Operation Center	Lot	1	250,000	250,000	
Access Road	km	8	40,000	320,000	Width: 6-8m
Production Well Drilling	Well	33	4,000,000	132,000,000	±2,000mTD, Directional, 7" liner completion
Reinjection Well Drilling	Well	5	4,000,000	20,000,000	±2,000mTD, Directional, 7" liner completion
Water Supply Operation	Well	38	50,000	1,900,000	Power/water domestic supply
Well Testing	Well	38	500,000	19,000,000	
FCRS Construction	**L.S.**	**1**		**57,000,000**	
Separator Station West 1 & 2	L.S.	2	5,250,000	10,500,000	80m x 100m each
FCRS Piping West (180MW)	L.S.	1	21,000,000	21,000,000	including civil works, instrument, etc.
Separator Station East 1 & 2	L.S.	2	4,500,000	9,000,000	80m x 100m each
FCRS Piping East (140MW)	L.S.	1	16,500,000	16,500,000	including civil works, instrument, etc.
Total Steam Field Cost	**L.S.**	**1**		**232,870,000**	

Development Stage (Power Plant)

Unit:US$

Item	Unit	Quantity	Unit Price	Price	Remarks
Power Plant_West 180MW	**L.S.**	**1**		**284,000,000**	180MW (70MW x 2 + 40MW)
Site Preparation	L.S.	1	4,000,000	4,000,000	360m x 200m
Power Plant	L.S.	2	104,000,000	208,000,000	70MW x 2
Power Plant	L.S.	1	72,000,000	72,000,000	40MW
Power Plant_East 140MW	**L.S.**	**1**		**212,000,000**	140MW (70MW x 2)
Site Preparation	L.S.	1	4,000,000	4,000,000	240m x 200m
Power Plant East	L.S.	2	104,000,000	208,000,000	70MW x 2
Switchyard and Transmission Line	**L.S.**	**1**		**25,720,200**	
Site Preparation	m2	31,680	40	1,267,200	Paka West:110m x 160m, Paka East: 110m x 128m
Switchyard	L.S.	11	1,463,000	16,093,000	Paka West: 10,241,000 and Paka East: 5,852,000
Transmission Line	km	38	220,000	8,360,000	Paka West PS- Paka SS: 28km, Paka East PS-Paka West PS: 10km by 2 circuit of single Canary
Total Power Plant Cost	**L.S.**	**1**		**521,720,200**	

Operation Stage

Unit:US$

Item	Unit	Quantity	Unit Price	Price	Remarks
Make-up Well Drilling	**L.S.**	**1**		**135,450,000**	
Well Pad	Lot	3	600,000	1,800,000	For production wells, Size: 100m x 150m x 3
Production Well Drilling	Well	30	4,000,000	120,000,000	±2,000mTD, Directional, 7" liner completion
Reinjection Well Drilling	Well	3	4,000,000	12,000,000	±2,000mTD, Directional, 7" liner completion
Water Supply Operation	Well	33	50,000	1,650,000	Power/water domestic supply

III-6.5 Economic evaluation of the development plan

a. Financial evaluation

Based on the above-mentioned technical estimation, the financial evaluation was carried out to estimate development cost of Paka field. Similar to the evaluation of Arus field, three kinds of development formation were examined; (i) private sector's total project, (ii) GDC and private sector's joint project, and (iii) GDC's total project. The assumptions of evaluation are also same as the case of Arus field.

<Result of financial evaluation>

Construction costs of the geothermal power plants in Paka field are as shown in Table III-6.4.

Table III-6.4 Construction costs of a geothermal power plant in Paka field

Item	Steam field (million US$)	Power plant (million US$)	Total (million US$)	Unit cost (US$/kW)
Construction costs	290	574	864	2,700
IDC	16	38	54	-
Construction costs with IDC	306	612	918	2,870

The LEC and the LSC in each development formation in Paka field have been estimated as shown in Table III-6.5 and Fig.e III-6.10.

Table III-6.5 The LEC and LSC by development formation in Paka field (US¢/kWh)

Development formation	IPP total PJ	GDC/IPP joint PJ	GDC total PJ
Levelized steam cost (LSC)	5.6	3.0	3.0
Levelized conversion cost	5.8	5.8	4.0
Levelized generation cost (LEC)	11.4	8.8	7.0

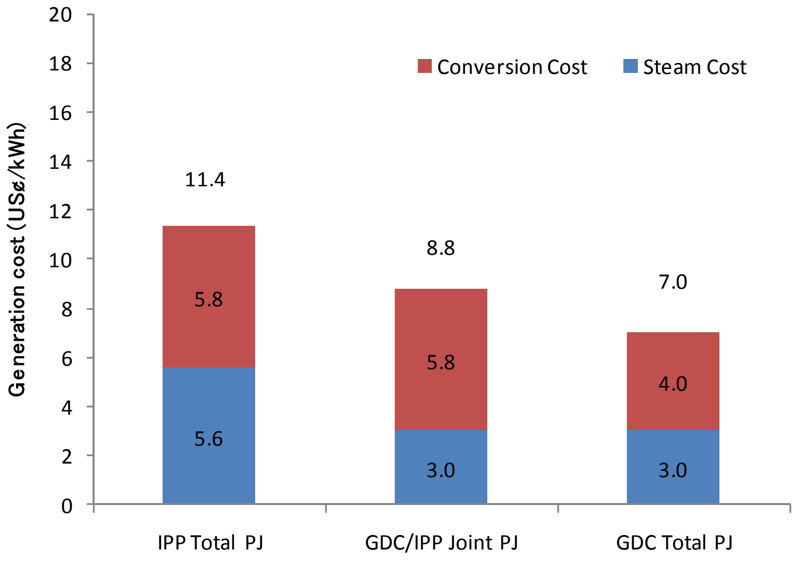


Fig. III-6.10 The LEC and LSC by development formation in Paka field

b. Economic evaluation

An economic evaluation was carried out to examine the social-economic significance of the development of the Paka geothermal field. Similar to the case of Arus field, three kinds of alternative plants are considered; (i) coal-fired power plant, (ii) LNG combined-cycle power plant, and (iii) diesel power plant. The assumptions of the evaluation are also the same as the case of Arus field.

<Result of economic evaluation>

Results of the economic evaluation for the Paka field are shown in Table III-6.6. Since all EIRR results exceed 12%, which is assumed as the socio-economic opportunity cost of Kenya, the geothermal development in Paka field is justified with the socio-economic significance.

Table III-6.6 Cost competitiveness of geothermal development in Paka field against alternative thermal power plants

Alternative plants	Coal-fired plant	LNG CC plant	Diesel plant
Economic Internal Rate of Return	23.5%	23.8%	37.5%

c. Sensitivity analysis

The construction cost of geothermal power plants in Paka field is estimated to be US $ 918 million with the unit construction cost of 2,870 US$/kW. The results of the sensitivity analysis of the LEC/LSC and the economic evaluation on the change of the estimated construction cost are shown in Figs. III-6.11 and III-6.12. When the construction cost changes by ± 20% from the estimated one, the LEC and LSC in the case of joint project between GDC and IPP changes in the range from 7.3 US¢/kWh (-16.7%) to 10.3 US¢/kWh (+16.7%). Regarding the economic evaluation, a geothermal power plant remains competitive vs. a coal-fired plant, an LNG combined cycle plant and a diesel power plant even if the construction cost rises by 20%.

In addition, the average output of the production well in Paka field is estimated to be 9.5 MW per well. The sensitivity analysis of the LEC/LSC and the economic evaluation on the change of the average production well output is also done and the result is shown in Figs. III-6.13 and III-6.14. If the average production well output decreases to 4.5 MW/well, the LEC will rise by 16.2% to 10.2 US¢/kWh. However, Fig. III-6.14 shows the geothermal power plant will keep cost competitiveness against coal-fired plant even if the average production well output decreases to 4.5 MW/well.

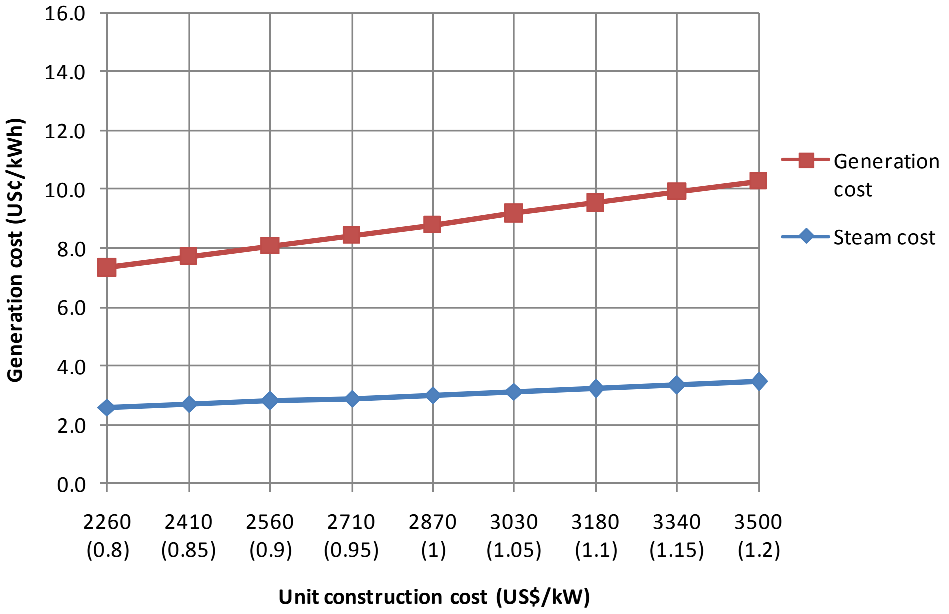


Fig. III-6.11 Sensitivity analysis of the LEC and LSC to changes in the construction cost (Paka)

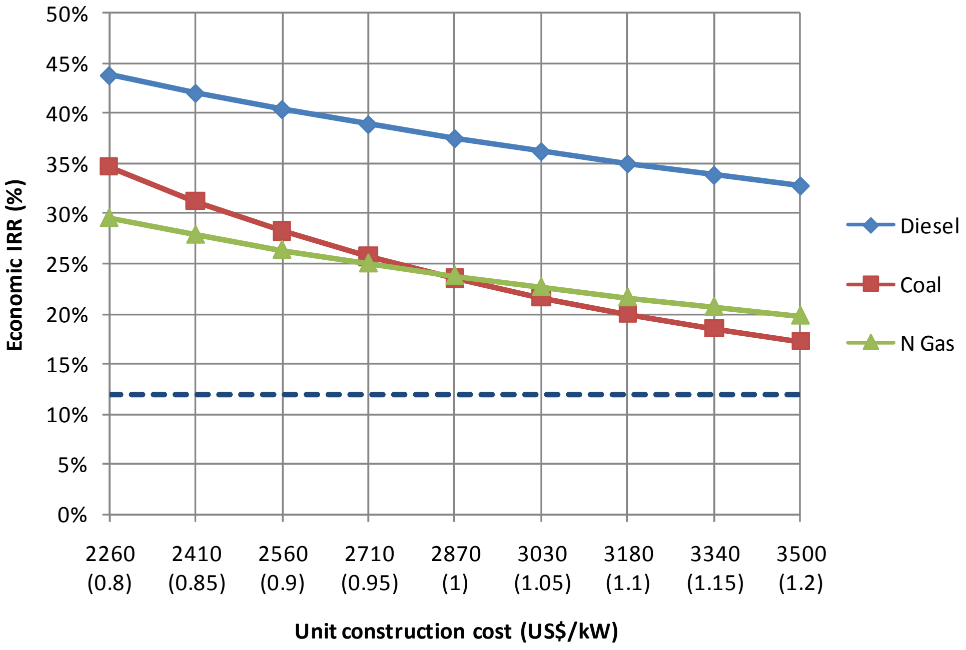


Fig. III-6.12 Sensitivity analysis of the EIRRs to changes in the construction cost (Paka)

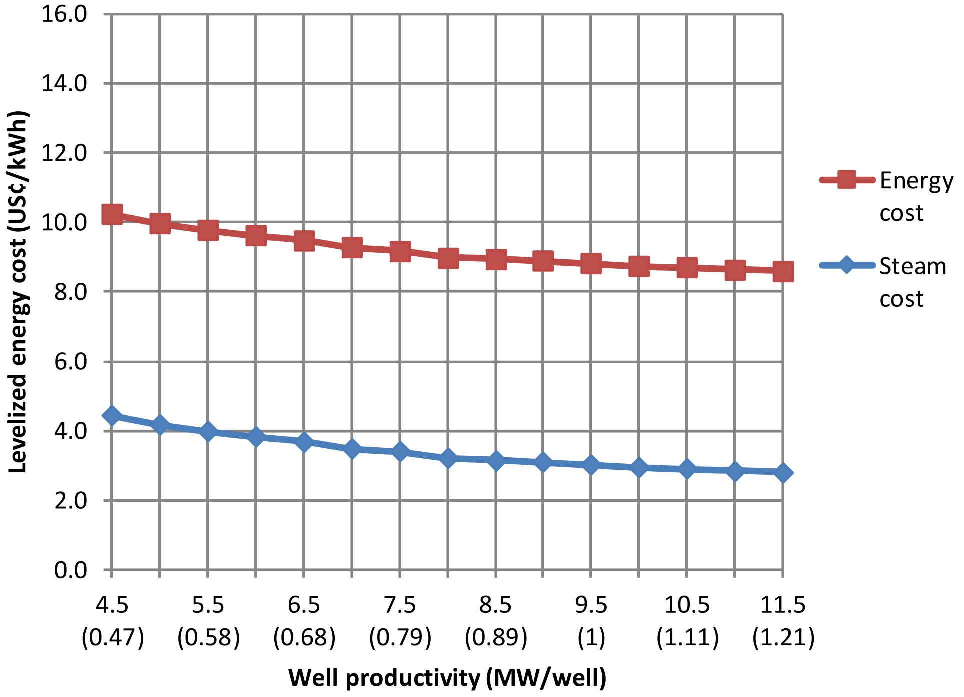


Fig. III-6.13 Sensitivity analysis of the LEC and LSC to changes in the average production well output (Paka)

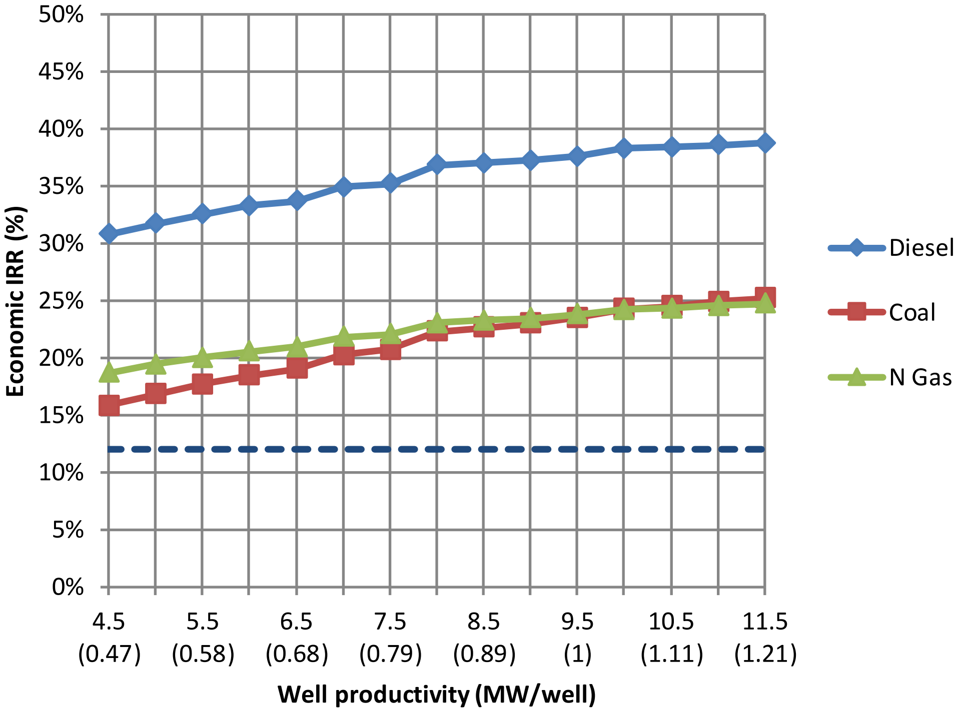


Fig. III-6.14 Sensitivity analysis of the EIRRs to changes in the average production well output (Paka)

III-7 Power Transmission Line

III-7.1 Outline of power transmission line

The Kenyan Transmission Company (KETRACO) is planning to construct a 400kV transmission line along each of the geothermal power generation facilities under development by GDC as it is shown in Fig. III-7.1.

According to the LCPDP 2013, a 400kV x 2 wire transmission line with total length of 150km and connecting the Arus (Bogoria), Korosi, Paka and Silali areas will be built by the year 2020. In addition, a 400kVsubstation will be constructed at each location.

As a result of the hearings held with KETRACO and GDC in November 2015, in reference to the contents of LCPD2013, it was understood that KETRACO will construct 220/4400kV substations at three locations: Arus, Paka and Silali. In addition, KETRACO has planned to construct a 400kV double circuit transmission line of 165km connecting those three locations.

The implementation of this Project, that is, the supply of energy to the area located at one end of the Kenyan electric grid, will help to suppress the voltage drop occurring at that terminal area contributing to the stability of the whole electric grid.

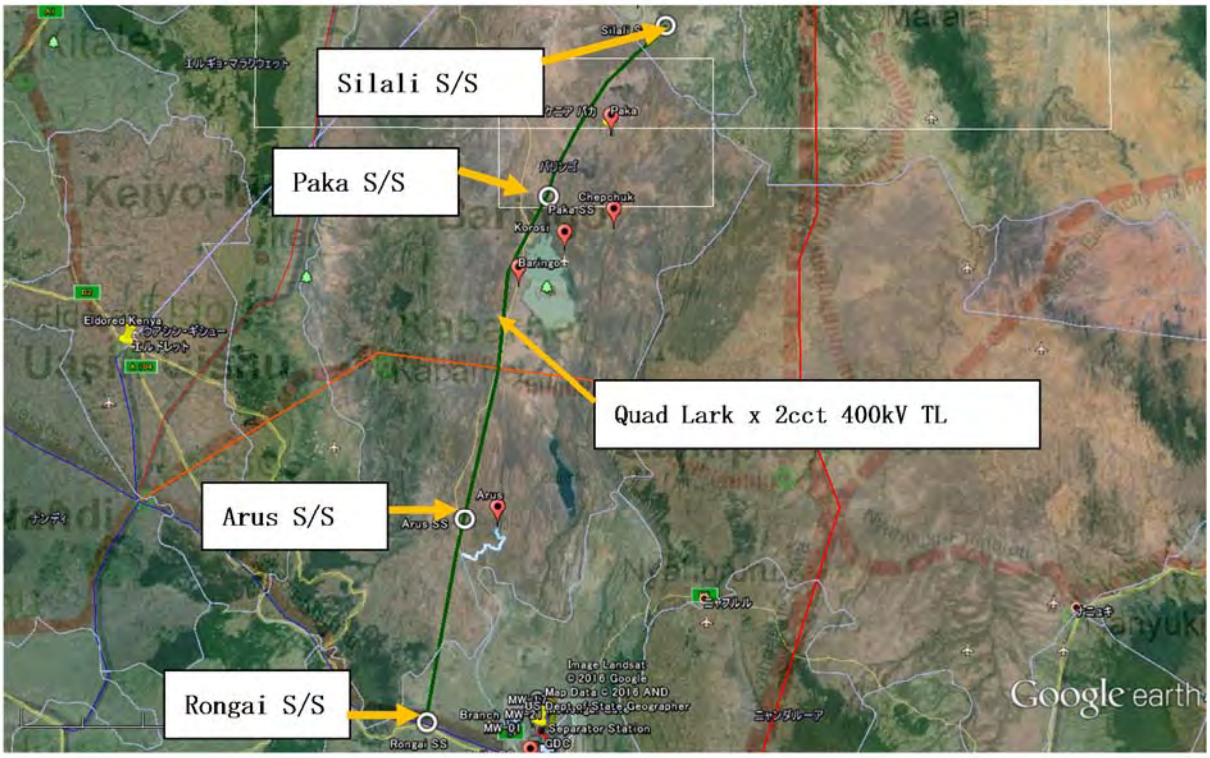
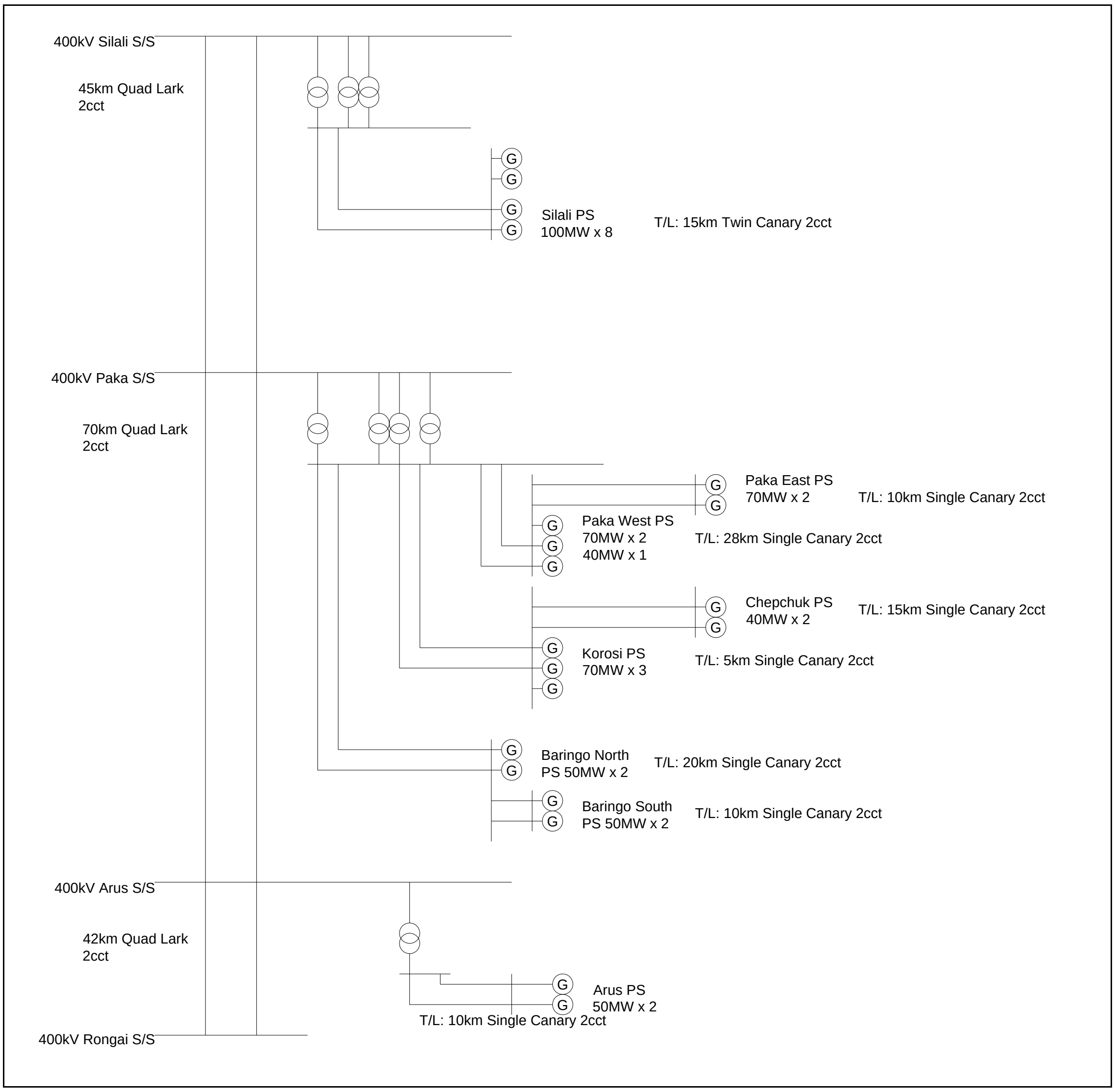


Fig. III-7.1 Route of the 400kV Rongai-Silali Transmission line

The construction of a new substation at the Rongai district is also planned in order to connect the new 400kV transmission line to the existing one.

Figure II-7.2 shows, as per November 2014, the single line connection diagram of the 400kV transmission line, which is based on discussions with KETRACO and GDC, and the single line diagram for connecting the power plant substations, to be built by GDC, to the 400kV substations planned to be constructed by KETRACO.



Prepared by JICA study team

Fig. III-7.2 Single line diagram for 400kV transmission line between Rongai - Silali (Plan)

The Arus power station (50MWx2) will be connected to the 400/220 kV Arus substation through a 220kV 10km long double transmission line (single canary).

In regards to the construction of the Baringo power station, the Baringo South power station (50MWx2) will be connected to the Paka substation through a 30km long 220kV double transmission line (single canary). After that, the switchgear of the Baringo South substation shall be enlarged with one bay in order to connect a 50MWx1 load. Along with the construction of the Baringo North power station (50MWx2), this must be connected to the 220kV transmission line running between the Baringo South power station and the 400/220 kV Paka substation; hence, implementing the transmission of the generated power to this last substation.

The Korosi power station (70MW x3) will be connected to the Paka substation through a 15km long, 220kV double line (single canary) transmission line.

The Chepchuk power station (40MW x2) will be connected through a 15km long, 220kV double line (single canary) transmission line to a switch gear at the above-mentioned Korosi substation, hence, then also to the Paka substation.

The Paka West power station (70MWx2, 40MWx1) will be connected to the 400/220kV Paka substation through a 28km long, 220kV double line (single canary) transmission line. Similarly, the Paka East power station (70MWx2) will be connected to the 400/220kV Paka substation through a 10km long, 220kV double line (single canary) transmission line.

III-7.2 Voltage drop and losses in the transmission line

Table III-7.1 and Table III-7.2 show the estimated voltage drop and transmission losses along the transmission lines as described above are as follows.

Table III-7.1 Estimated voltage drops

No	Transmission Line	Voltage Drop (%)	Specification
1	Arus PS-Arus SS	0.28%	220kV 2cct 10km 100MW (Single Canary)
2	Baringo South PS – Baringo North PS	0.28%	220kV 2cct 10km 100MW (Single Canary)
3	Baringo North – Paka SS	1.12%	220kV 2cct 20km 200MW (Single Canary)
4	Korosi PS-Paka SS	0.30%	220kV 2cct 5km 210MW (Single Canary)
5	Chepchuk PS-Paka SS	0.448%	220kV 2cct 20km 80MW (Single Canary)
6	Paka West PS-Paka SS	1.42%	220kV 2cct 28km 180MW (Single Canary)
7	Paka East PS – Paka SS	1.49%	220kV 2cct 38km 140MW (Single Canary)

Table III-7.2 Estimated transmission losses

No	Transmission Line	Loss (%)	Specification
1	Arus PS-Arus SS	0.31%	220kV 2cct 10km 100MW (Single Canary)
2	Baringo South PS – Baringo North PS	0.31%	220kV 2cct 10km 100MW (Single Canary)
3	Baringo North – Paka SS	1.24%	220kV 2cct 20km 200MW (Single Canary)
4	Korosi PS-Paka SS	0.33%	220kV 2cct 5km 210MW (Single Canary)
5	Chepchuk PS-Paka SS	0.50%	220kV 2cct 20km 80MW (Single Canary)
6	Paka West PS-Paka SS	1.56%	220kV 2cct 28km 180MW (Single Canary)
7	Paka East PS-Paka SS	1.65%	220kV 2cct 38km 140MW (Single Canary)

In addition, the loss along the 70km, 400 kV 4-wire Lark x 2 line transmission line between the 400 kV Paka substation and the 400 kV Arus substation is 0.62%. The loss along the 42km of the 400 kV 4-wire Lark x 2 line between the 400 kV Arus substation and the 400 kV Rongai substation is 0.43%, with a total loss of about 1.05%, which is very small.

III-7.3 Connection method to the 400kV grid

(1) Method for connecting the 400/220kV Arus substation to the 400kV grid

The figure below shows the in-house single line connection diagram when connecting the 220 kV x 2 lines from the Arus power station to the 400/220 kV Arus substation.

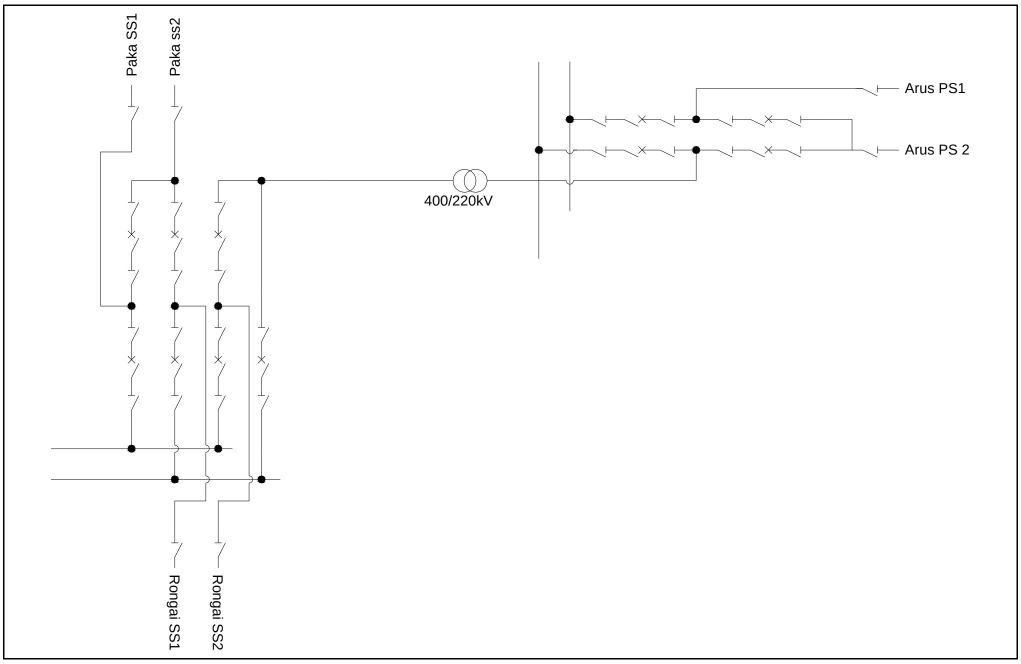


Fig. III-7.3 Single line diagram for the connection of the Arus substation and power station

The specifications of the Arus substation shall be as follows.
- 400 kV x 7 bay (including 2 bay for the Arus power plant)
- 220 kV x 4 bay
- 440 kV / 220 kV 350 MVA Tr

(2) Connection method to the 400/220 kV Paka substation

The figure below shows the in-house single line connection diagram for connecting the 220 kV x 8 lines from the Paka power station, Chepchuk power station, Korosi power station and Baringo South power station to the 400/220 kV Paka substation.

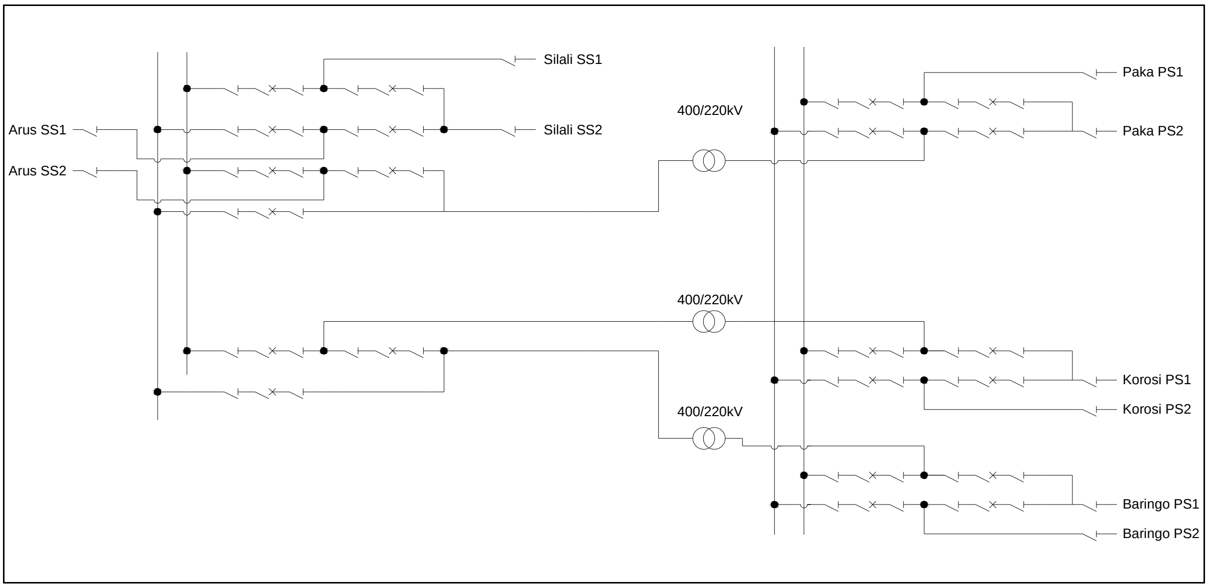


Fig. III-7.4 Single line diagram for connecting the Baringo, Korosi, Chepchuk and Paka power stations with the Paka substation

The specifications of the Paka substation should be as follows.

- 400 kV x 10 bay
- 220 kV x 12 bay
- 440 kV / 220 kV 350 MVA Tr x 3

Table III-7.3 Costs and equipment for connecting the Arus power station and Arus substation

Name	Cost ('000 USD)	Remarks
220kV Bay for Arus PS	5,852	4 bay
400/220kV 350MVA transformer	4,700	1 unit
400kV Bay for Arus PS	4,000	2 bay
Total	**14,552**	

Table III-7.4 Costs and equipment for connecting the Baringo South, Korosi, Chepchuk and Paka to the 400/220kV Paka substation

Name	Cost ('000 USD)	Remarks
220kV Bay for Baringo PS	5,852	4 bay
400/220kV 350MVA transformer	4,700	1 unit
400kV Bay for Baringo PS	4,000	2 bay
220kV Bay for Korosi PS	5,852	4 bay
220kV Bay for Paka PS	5,852	4 bay
400/220kV 350MVA transformer	14,100	3 unit
400kV Bay for Korosi PS	2,000	1 bay
400kV Bay for Paka PS	2,000	1 bay
Total	**44,356**	