Chapter 9. Grid Master Plan

9.1 Preparation Work for Grid Master Plan Development

9.1.1 Simplified Power System Modeling

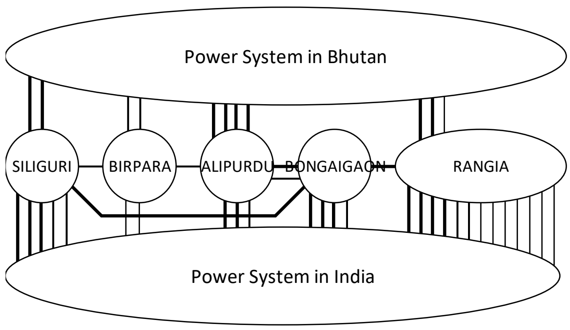
(1) Merits of simplifying the simulation model

Currently, the simulation model for Bhutan is prepared by DHPS, and the simulation model for India is prepared by Indian consultants. The simulation model for Bhutan is integrated with that for India, and DHPS uses the integrated model. When the transmission components and constitution are modified on this model, the calculations may not converge due to its complicated data. If this model undergoes a large change, the calculations may not converge because the difference between the initial values in PSS/E and the solution will become very large. Even if the calculations converge, many iterations will be necessary. However, if the initial values are replaced after convergence, the next calculation will need many fewer iterations. This is because the system data is so big that it becomes difficult to secure convergence. Generally, more nodes and branches increase the possibility of non-convergence. This issue requires too much time for data checking.

To counter this problem, a simplified simulation model is prepared mainly to reduce the influence of the Indian systems. Although a simplified model is not as accurate as a full model, it can become almost as accurate via the adjustment of power flow and fault currents under N-0 conditions. Use of a simplified model provides the advantage of being able to study the future power system in Bhutan separately from that in India.

(2) Topology and Requirements

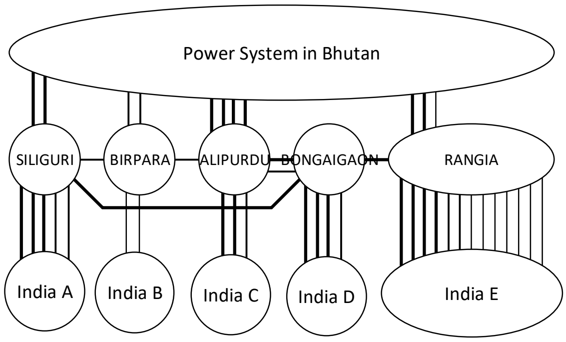
Figure 9-1 shows the current interconnections between Bhutan and India.



(Source: JICA Survey Team)

Figure 9-1 Interconnections between Bhutan and India

As Bhutan's systems are connected to the Indian systems through five substations (Siliguri, Birpara, Alipurduar, Bongaigaon, and Rangia), a simplified model using these substations can be realized as follows.



(Source: JICA Survey Team)

Figure 9-2 Illustration of simplifying the Indian systems

To create the simplified model, the following network requirements are necessary.

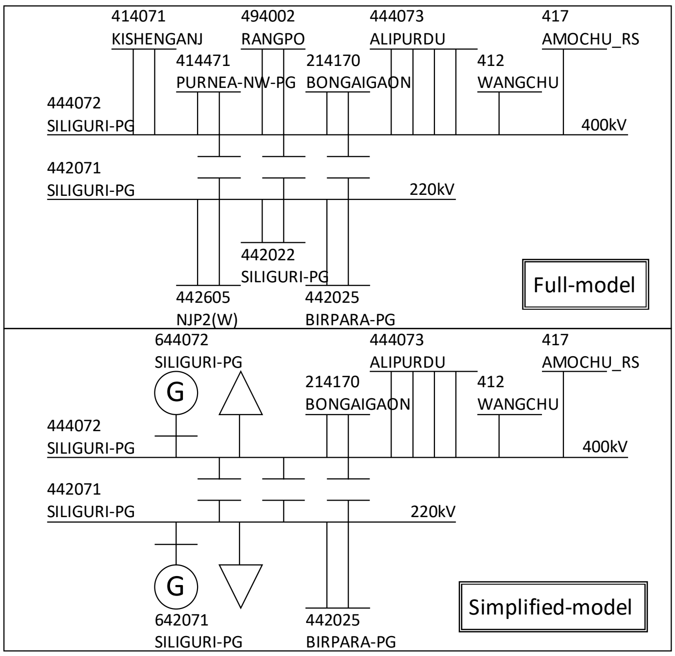
- ✓ The power flow situation at the interconnection transmission lines does not change after the simplification.
- ✓ Fault currents from the inter-ties are not changed.

(3) Simplification at substations

Based on the network requirements, the simplification is realized as follows:

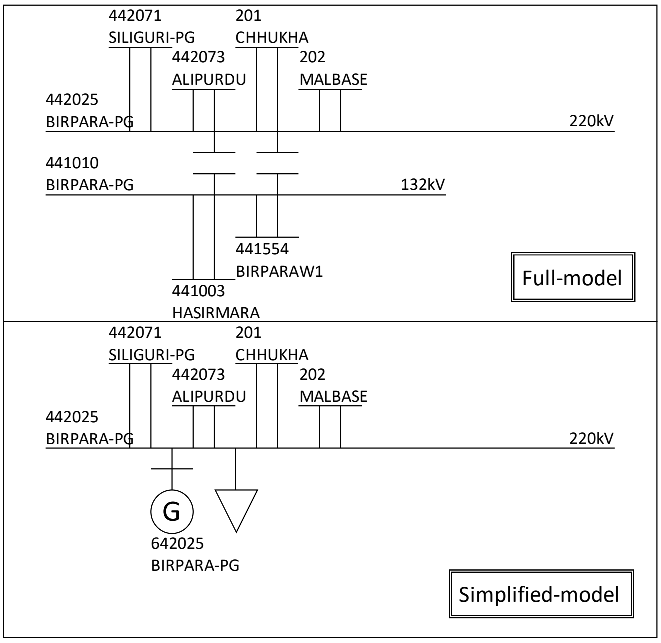
- ✓ Power flow requirement: Load is used as the power flow on the inter-ties.
- ✓ Fault current requirement: Fault current is provided by generators with adjusted back impedance.

The concrete methods are shown in the following figures. (Figure 9-3 - Figure 9-7)



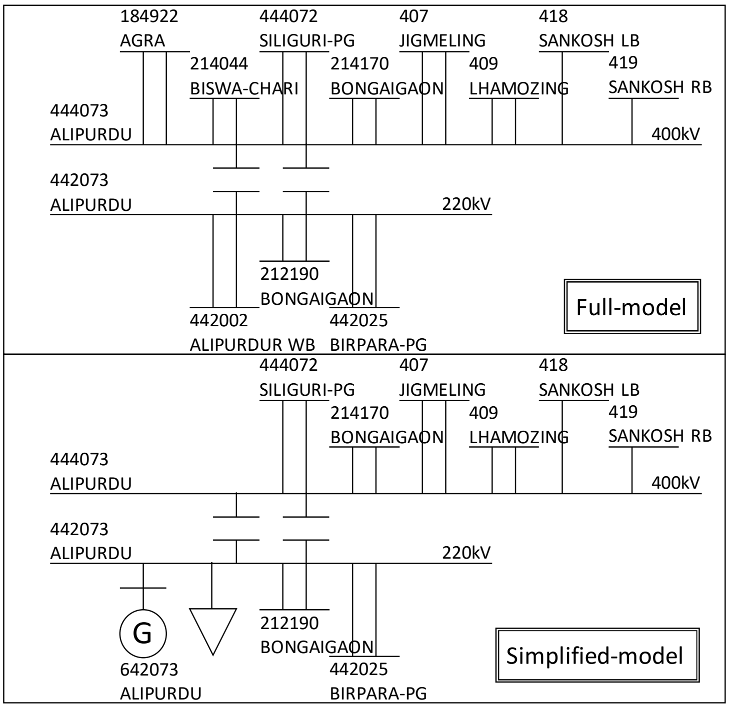
(Source: JICA Survey Team)

Figure 9-3 Simplification at Siliguri Substation



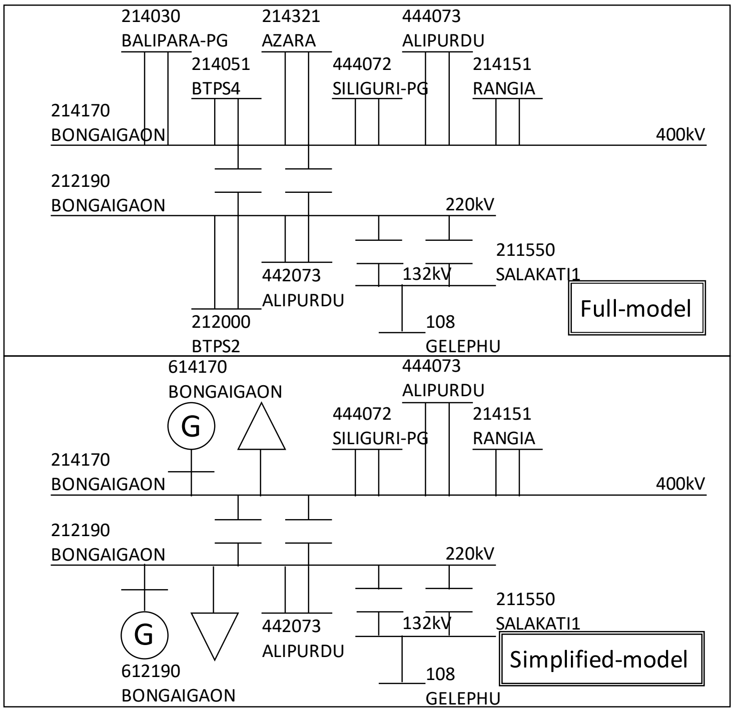
(Source: JICA Survey Team)

Figure 9-4　Simplification at Birpara Substation



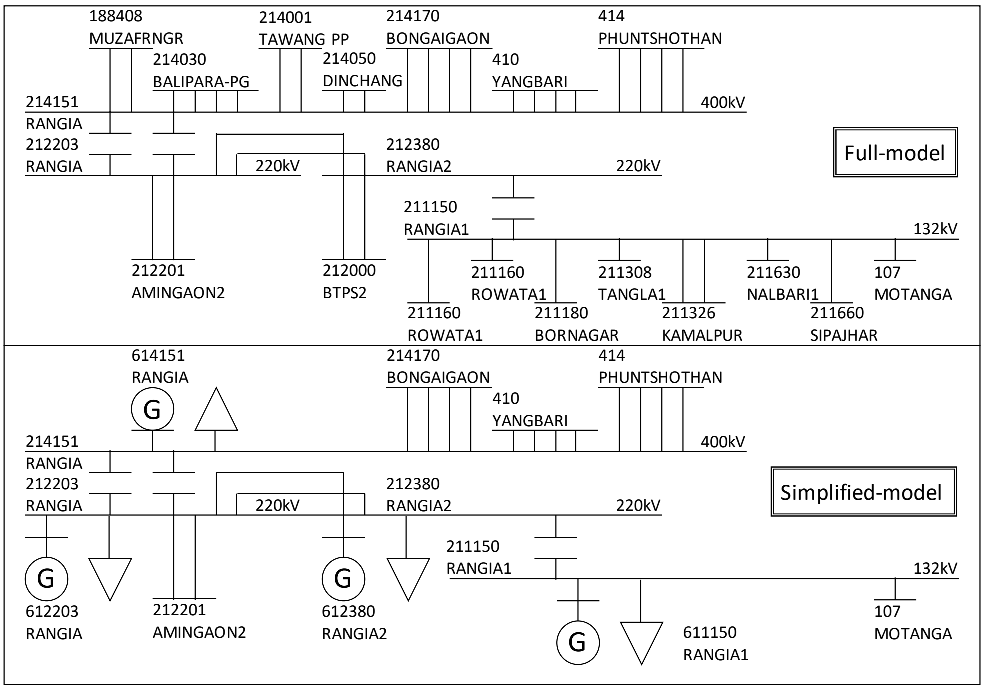
(Source: JICA Survey Team)

Figure 9-5　Simplification at Alipurduar Substation



(Source: JICA Survey Team)

Figure 9-6 Simplification at Bongaigaon Substation



(Source: JICA Survey Team)

Figure 9-7 Simplification at Rangia Substation

The slack bus should be a 400kV bus at Siliguri S/S due to the following reasons.

- The slack bus in the full model is in the Indian power system and nearer to Siliguri S/S than to the other 4 substations, such as Birpara S/S.
- The main power system in India is interconnecting to Siliguri S/S.
- The fault current from the virtual generator connecting to the 400kV bus at Siliguri S/S is larger than at the other 4 substations, such as Birpara S/S. This means that the 400kV bus at Siliguri S/S has the largest virtual generator.

System analyses such as power flow and fault current will be implemented using the simplified model to formulate future system plans.
In this study, the simplified model in 2035 is used for other years, because the full model is only available for 2035. However, because the power flows in Bhutan's power system and the interconnection lines between Bhutan and India are adjusted via the changing of loads at 5 substations in the Indian power system, and the effects of power flow and fault currents between Bhutan's eastern area and western area interact via the transmission lines between the 5 substations in each study year, the accuracy is improved.

9.1.2 Estimated Load for each Substation

Estimated load for each substation is shown in Table 9-1. For the load from 2025 to 2040, the values of NTGMP 2018 were basically used and reviewed according to the modeling of the substation. In addition, the load of each substation in 2050 was calculated based on the total load in 2050 and the allocation rate of each substation in 2040.
This estimation method is decided in advance in consultation with DHPS.

Table 9-1 Estimated Load for each Substation

Bus No	Bus Name	Voltage (kV)	2025		2030		2035		2040		2050	
			MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar
206	Jigmeling	220	79	38	147	71	181	87	181	87	229	110
209	Samtse	220	15	7	36	17	56	27	63	31	80	39
102	Kilikhar	132	9	4	11	5	14	7	26	12	33	15
103	Kanglung	132	16	8	22	11	29	14	39	19	49	24
104	Nangkor	132	3	2	4	2	4	2	4	2	5	3
105	Nganglam	132	33	16	33	16	33	16	33	16	42	20
106	Deothang	132	34	16	40	19	47	23	56	27	71	34
107	Motanga	132	57	28	118	57	148	72	148	72	187	91
109	Tingtibi	132	2	1	2	1	2	1	3	1	4	1
110	Yurmo	132	8	4	9	4	9	5	10	5	13	6
603	Watsa	66	3	2	3	2	3	2	3	2	4	3
605	Paro	66	11	6	15	7	19	9	24	12	30	15
606	Haa	66	4	2	5	2	6	3	7	3	9	4
607	Gedu	66	6	3	6	3	7	3	7	3	9	4
608	Jemina	66	15	7	17	8	19	9	22	11	28	14
609	Olakha	66	40	19	52	25	66	32	76	37	98	48
610	Semtokha	66	25	12	30	14	35	17	41	20	52	25
611	Dechencholing	66	17	8	19	9	22	10	24	12	30	15
612	Lobeysa	66	23	11	27	13	33	16	39	19	49	24
616	Dhajay/Tsirang	66	10	5	13	6	16	8	21	10	27	13
617	Phuentsholing	66	11	5	13	6	15	7	18	9	23	11
618	Malbase	66	133	64	135	66	138	67	141	68	178	86
619	Gomtu	66	19	9	21	10	24	12	27	13	34	16
621	Singhigaon	66	67	33	69	34	71	35	73	36	92	46

(Source: JICA Survey Team)

In general, load forecasting for each substation is a very important theme when formulating a grid MP. However, the amount of electricity exported to India is much larger than the electricity supplied to the domestic demand in Bhutan. For this reason, in the formulation of the grid MP, the main focus is on examining transmission methods for exporting the large amount of surplus power generated due to the progress of hydropower development to neighboring countries. Considering the special characteristics of Bhutan, domestic load forecasting is a positioning for reference in this MP, and the load forecasts of each substation basically use the values forecasted in NTGMP 2018.

As mentioned in the section on demand forecasting (Chapter 4), the power demand at each substation varies greatly depending on the increase in bulk customers (HV Industries), which account for more than 70% of the total demand. In the future, it is assumed that along with the progress in hydropower development, industrial parks will be created and new demand will increase through the attraction of large-scale factories. It is necessary to accurately ascertain to which substation such new demand will be connected and to carry out demand forecasts for each substation.

9.2 Current System Expansion Plan

The power analyses were conducted to verify the current power transmission system plan for 2020, 2025 and 2030. Demand forecast, a generation expansion plan and the power transmission system plan for the system analyses have been based on the latest master plan "National Transmission Grid Master Plan (NTGMP) of Bhutan - 2018" provided by DHPS.
The analyses have been conducted using PSS/E, which is software for system analysis. The system analyses were conducted not only under sound system equipment conditions (N-0 conditions) but also under conditions with a single contingency of equipment, such as a single transmission line circuit outage and single transformer outage (N-1 conditions).

9.2.1 Criteria for Verification

(1) Operational conditions of generators and shunt reactors

(a) Generator terminal voltage

As described later in a power flow analysis under N-1 conditions, it was confirmed that some power flow calculations don't converge due to shortage of reactive power supply for reactive power consumption in loads and reactive power loss in the power grid. Thus, to enable generators to supply more reactive power, the terminal voltage of generators has been set to 1.02 p.u.[12], higher than the rated voltage of 1.0 p.u., not only under N-1 conditions but also under N-0 conditions. Since the system under these conditions has insufficient reactive power, it is necessary to increase the reactive power supplied from the generators by increasing their terminal voltage. If the reactive power is sufficient under some conditions, such as high power factor of the load, the terminal voltage may be lowered. The terminal voltage of the generator should inherently be used within the allowable range of each generator.

(b) Reactors

As with the generator terminal voltage noted above, to alleviate the problem of a shortage of reactive power supply under N-1 conditions, the existing and planned reactors have been disconnected for power flow calculations not only under N-1 conditions but also under N-0 conditions.
For the calculation under heavy load conditions, the reactor that consumes the reactive power should be opened since the reactive power is insufficient in the system. On the other hand, if the power flow is small, the reactive power loss is small and, consequently, the reactive power is excessive, it is necessary to connect reactors to consume the excess. The reactive power status changes depending on the load and generator operating status. When it is insufficient, suitable reactors should be opened. When it is at an adverse surplus, suitable ones should be connected with the grid.

(c) Output power of power station

- Basic conditions: output power of power stations is set to 100% as a severe condition in terms of equipment overloading.
- The studies have been conducted under the N-0 and N-1 conditions for 100% output from generators, and the N-0 condition for 110% output. Although it is possible to examine them under the N-0 and N-1 conditions at 110% output, the equipment measure costs would increase excessively. Considering the probability of N-1 contingencies, studying the system under N-0 and N-1 at 100% output conditions and N-0 condition at 110% seems to be more reasonable.
- Output cases in which the power of power stations is set to 20% considering the dry season were also studied. The number of generators in each power station is set to one or two units. If possible,

[12] p.u.: Unit in PU method. Expressed in p.u., pu, or %. The PU method (Per Unit method or percent method) expresses various quantitative values of practical units as a ratio to a predetermined reference value (base amount). Since there is no need to spend much time on handling the practical units constantly, this convenient percent method (unit dimensionless method) is used in any areas. (Source: Yoshihide Hase (2004). Practical theory handbook of power system technology. Maruzen)

one generator is in operation to maintain higher power generation efficiency. Demand in Indian substations is decreased proportionally to maintain the supply and demand balance.

(2) Criteria for results evaluations

(a) Power flow loading criterion

Power flow loading shall be less than each capacity (MVA) under both N-0 and N-1 conditions. The transmission line capacity is considered to be calculated with an ambient temperature of 40°C, a maximum wire temperature of 75°C for existing transmission lines and 85°C for transmission lines to be newly constructed, and a power factor of 0.9. Calculations have basically been conducted with the PSS/E data provided. The temperature of each transmission line is based on PSS/E data submitted by DHPS. The temperature of each transmission line constructed in the future is used 85 degrees to ensure larger transmission capacity.

Table 9-2 Transmission Line Capacity

	Ampacity (A)		Capacity (MVA)		Thermal loading (MW)	
	75°C	85°C	75°C	85°C	75°C	85°C
400kV, Moose, Twin	700	850	970	1,178	873	1,060
220kV, Zebra, Single	620	750	236	286	212	257
132kV, Panther, Single	415	490	95	112	86	101
66kV, Dog, Single	345	410	39	47	35	42

(b) Voltage criterion

N-0 conditions: ±5%
N-1 conditions: ±10%

(c) Stability criterion

If the angle difference between the terminals of a branch (transmission line or transformer) given by power flow calculation results is less than 20 degrees, it is judged to be stable.

(d) Fault current criterion

The following fault current level, which is the same as the one in India, is adopted.

Table 9-3 Fault Current Level

Voltage Level (kV)	Rated Breaking Capacity (kA)
132	25
220	31.5
400	50

(3) Scope of N-1 contingency

Power flow analyses have been performed for 2020, 2025 and 2030. Stability and fault current analyses have been performed for 2030, as a more severe condition.

(a) Power Flow Analysis

The contingency for the power system analysis is assumed to be a single facility of 132kV and higher voltage systems under N-1 conditions, and power flows and voltages are basically checked on 66kV and higher voltage systems (in particular, the 33kV system in Thimphu and its neighboring areas is also checked).

(b) Stability evaluation

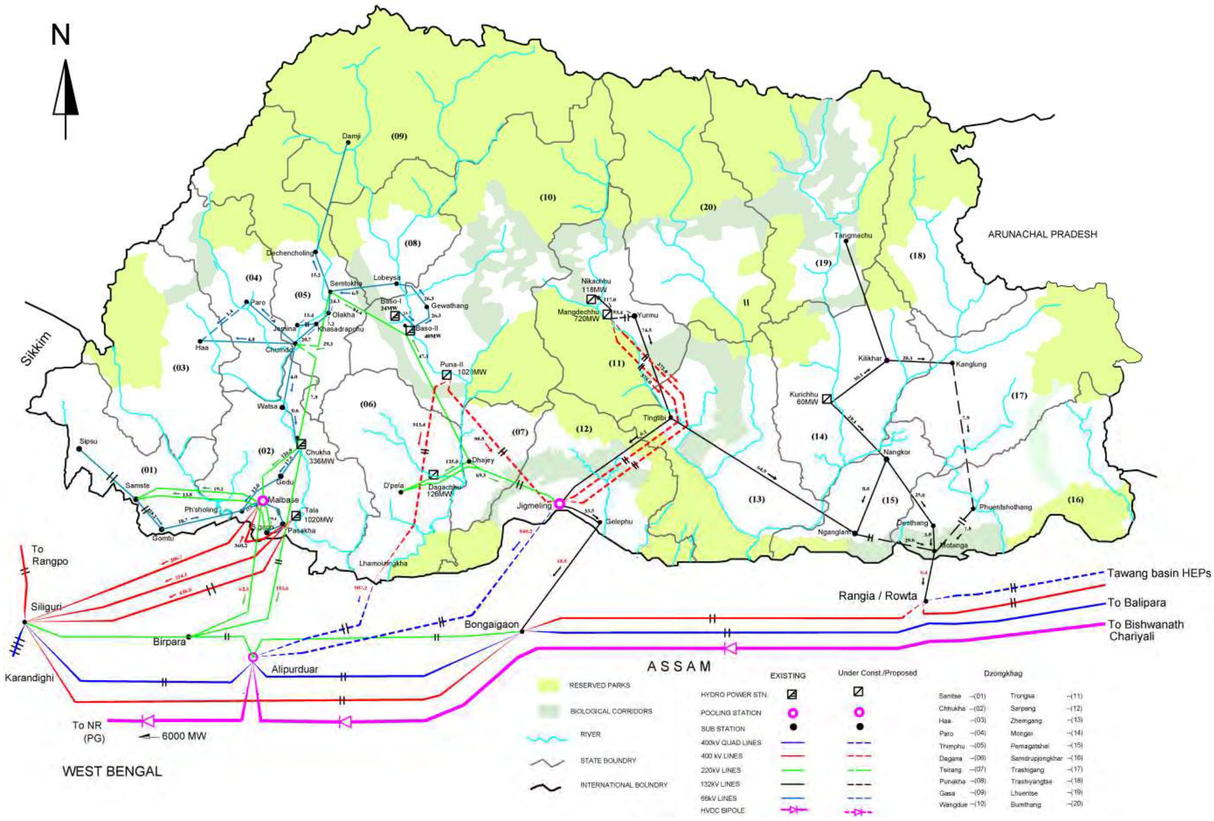
With regard to the power flow analysis to evaluate the stability, a single circuit outage of a transmission line or a single transformer outage at a substation which is connected with a power station is treated as a contingency.

(c) Fault current analysis

Fault location: 132, 220 or 400kV bus
Fault type: Three phase short circuit

9.2.2 National Grid by 2020

The power system diagram for 2020 according to the current plan is shown below.



(Source: NTGMP of Bhutan - 2018)

Figure 9-8 Power System Diagram for 2020

(1) National Grid by 2020

(a) Generation developments planned by 2020

Mangdechhu (MHEP) power station started commercial operation on June 2019, so these generators and relevant transmission system equipment are included in the model for the analytic study. Their equipment augmentations are listed in the table below.

Table 9-4 Equipment to be constructed by 2020

Generation equipment

Location	Power output	Rated power of a unit and quantity
Mangdechhu	720MW	(180MW x 4)

Transmission line

Voltage	From	To	Main specifications
400kV	PHEP-II	Jigmeling	1 x 2 circuits, Moose x 2 conductors, 65.0km
400kV	MHEP	Jigmeling	2 x 2 circuits, Moose x 2 conductors, 85.1km, 84.7km
400kV	Jigmeling	Alipurduar	1 x 2 circuits, Moose x 4 conductors, 167.0km
132kV	MHEP	Yurmo	1 x 2 circuits, Panther x 1 conductor, 5km

Substation equipment

Voltage	Location	Main specifications
400/220kV	Jigmeling	Transformer, 3 x 167 MVA
400/132kV	MHEP	Transformer, 3 x 167 MVA
400kV	MHEP	Step-up transformer, 4 x 225MVA

(Source: NTGMP of Bhutan - 2018)

(b) Shunt capacitors

The table below shows shunt capacitors which will be required to maintain the voltage within the allowable range for 2025 in the NTGMP of Bhutan - 2018, and those that were modeled in a power flow calculation for 2020 in this Survey.

Table 9-5 Shunt Capacitors

Substation Name	Voltage (kV)	B-Shunt for 2025 (MVAR)	B-Shunt for 2020 (MVAR)
Olakha	66	10	10
Semtokha	66	20	20
Dechencholing	66	15	15
Lobeysa	66	5	5
Pasakha	66	50	0
Malbase	66	0	50
Singhigaon	66	30	30
Gelephu	66	5	5
Motanga	132	25	0
Nganglam	132	20	0
Total		180	135

Source of “B-Shunt for 2025”: NTGMP - 2018 (p36)

(Source：Created by JICA survey team referring NTGMP - 2018)

Pasakha substation is not modeled in the PSS/E data set, but the corresponding load is modeled as the one connected with Malbase substation. Since the distance between Malbase and Pasakha substations is 3.4km and relatively short, there is no problem with this model in PSS/E.

(2) Power flow analysis results for 2020 under the N-0 conditions

The following shows the power flow analysis results calculated under N-0 conditions.

(a) Power flow check

There are no overloaded facilities. The table below shows some heavily-loaded facilities for reference. The whole power flow diagram is shown in the appendixes.

Table 9-6 Power Flow Analysis Results under the N-0 Conditions: Relatively heavily-loaded Facilities

TL (1)	From			To			CCT	Loading	Rating	Percent
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.	(MVA)	(MVA)	(%)
1	109	Tingtibi	132	110	Yurmo	132	1	74.9	95	78.8
1	105	Nganglam	132	109	Tingtibi	132	1	67.9	95	71.4
0	202	Malbase	220	402	Malbase	400	1	154.4	200	77.2
0	208	Singhigaon	220	621	Singhigaon	66	1	40.4	50	80.8

TL(1): Transmission Line, TF(0): Transformer

(Source: JICA Survey Team)

(b) Voltage check

The voltage of all buses is within the allowable range.

(3) Power flow analysis for 2020 under the N-1 conditions

(a) Power flow analysis results for 2020 under the N-1 conditions

The following shows the power flow analysis results calculated under N-1 conditions.

1) Power flow check

a) Overloaded facility list

The table below shows overloaded facilities under the N-1 conditions

Table 9-7 Power Flow Analysis Results under the N-1 Conditions: Overloaded Facilities

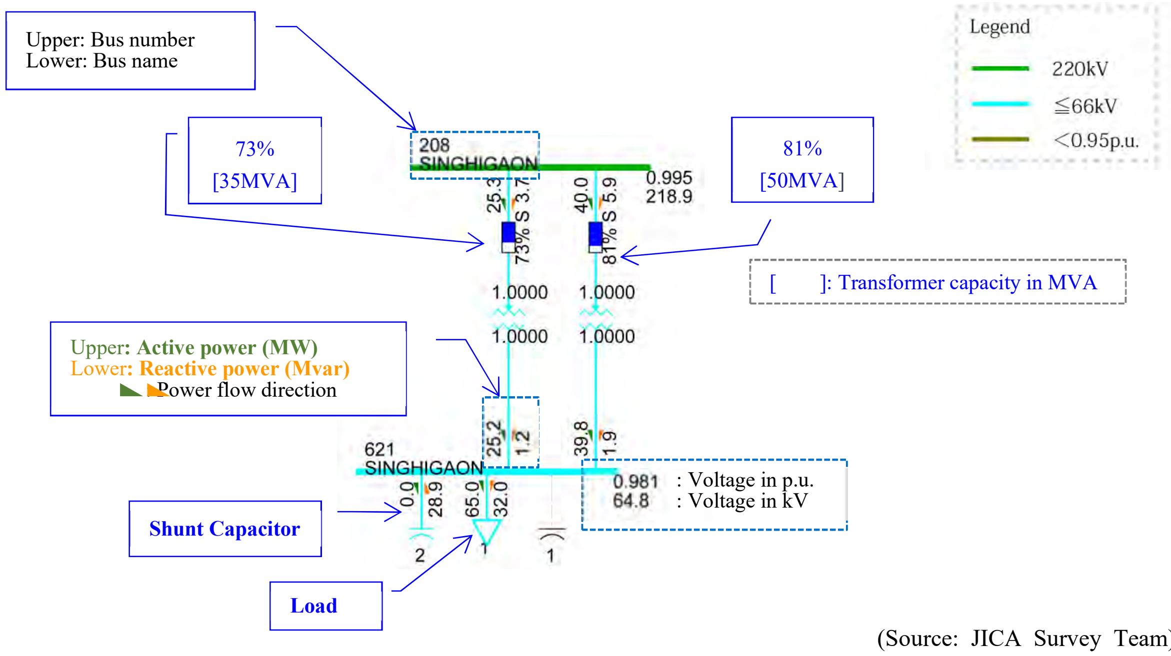
Contingency								Overloaded facility	Load factor (%)
TL (1)	From			To			CCT		
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.		
1	604	Chumdo	66	623	Khasadrapchu	66	1	609 Olakha 66 610 Semtokha 66 2	102.0
0	208	Singhigaon	220	621	Singhigaon	66	1	208 Singhigaon 220 621 Singhigaon 66 2	201.8
0	208	Singhigaon	220	621	Singhigaon	66	2	208 Singhigaon 220 621 Singhigaon 66 1	134.3

TL(1): Transmission Line, TF(0): Transformer

(Source: JICA Survey Team)

b) Transformer outage case at Singhigaon substation

The highest overloaded ratio case in the table above is the one with a transformer outage at Singhigaon substation. The figure below shows the power flow calculation results under N-0 conditions (before the contingency).



(Source: JICA Survey Team)

Figure 9-9 Power Flow in Singhigaon Substation for 2020 under the N-0 Condition

The power flows in the two transformers are unbalanced (impedances of the 50MVA and 35MVA transformers are 12.0% and 13.3% respectively) due to the difference in impedance. In the case of a 50MVA transformer outage, all power flow for both transformers flows into the 35MVA transformer, and consequently the loading ratio reaches 202%. If overloading such as over 200% occurs, it is proper to trip the overloaded facility automatically via an OLR (Over Load Relay) rather than trip manually by an operator. Installing a new 50MVA transformer cannot be a measure for 2020 to prevent the transformer from overloading, even under N-1 conditions, due to the tight schedule. If the existing 50MVA transformer becomes persistently out of order, some consumers will suffer blackouts. In that event, electricity will be delivered via properly selected 66kV transmission line feeders from the remaining 35MVA transformer. It may also be worth considering rolling power outages.

2) Voltage Check

The voltages of all buses are within the allowable range (±10%).

(b) Power flow analysis result with insufficient reactive power supply under N-1 conditions

In the previous analyses in this report, terminal voltage settings of all generators are 1.02 p.u. to enable generators to supply enough reactive power. When a power flow calculation is performed with all generator terminal voltages set at 1.0 p.u. under N-1 conditions, the power flow calculation did not converge under N-1 conditions with an outage of a 400kV transmission line circuit between Jigmeling and Alipurduar substations. Since a similar calculation converges with all generator terminal voltages set at 1.02 p.u. under the same N-1 conditions, the problem in convergence with the voltages set at 1.0 p.u. is obviously due to the insufficient reactive power supply from the generators. The non-convergence implies that the power system can fall into a voltage collapse and consequently suffer a wide area blackout for a long time. It is recommended that generator terminal voltage should be set at 1.0 p.u. for the long term planning, and margin to increase the generator terminal voltage should be prepared as a countermeasure against unexpected delays in constructing equipment and so forth.

(4) Power flow analysis for 2020 dry season

A power flow calculation for the 2020 dry season under N-0 conditions was performed. Output power from each power plant is 20% of the rated power as previously noted, and the supply and demand balance is maintained by adjusting loads in India.

(a) Power flow check

There are no overloaded facilities. The table below shows some heavily-loaded facilities as a reference. The whole power flow diagram is shown in the appendixes.

Table 9-8 Power Flow Analysis Result under the N-0 Conditions: Relatively heavily loaded Facilities

TL (1)	From			To			CCT	Loading	Rating	Percent
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.	(MVA)	(MVA)	(%)
1	107	Motanga	132	211150	Rangia1	132	1	59.4	95	62.5
1	105	Nganglam	132	109	Tingtibi	132	1	54.8	95	57.7
0	208	Singhigaon	220	621	Singhigaon	66	1	40.5	50	80.9
0	208	Singhigaon	220	621	Singhigaon	66	2	25.6	35	73.1

TL(1): Transmission Line, TF(0): Transformer

(Source: JICA Survey Team)

(b) Voltage check

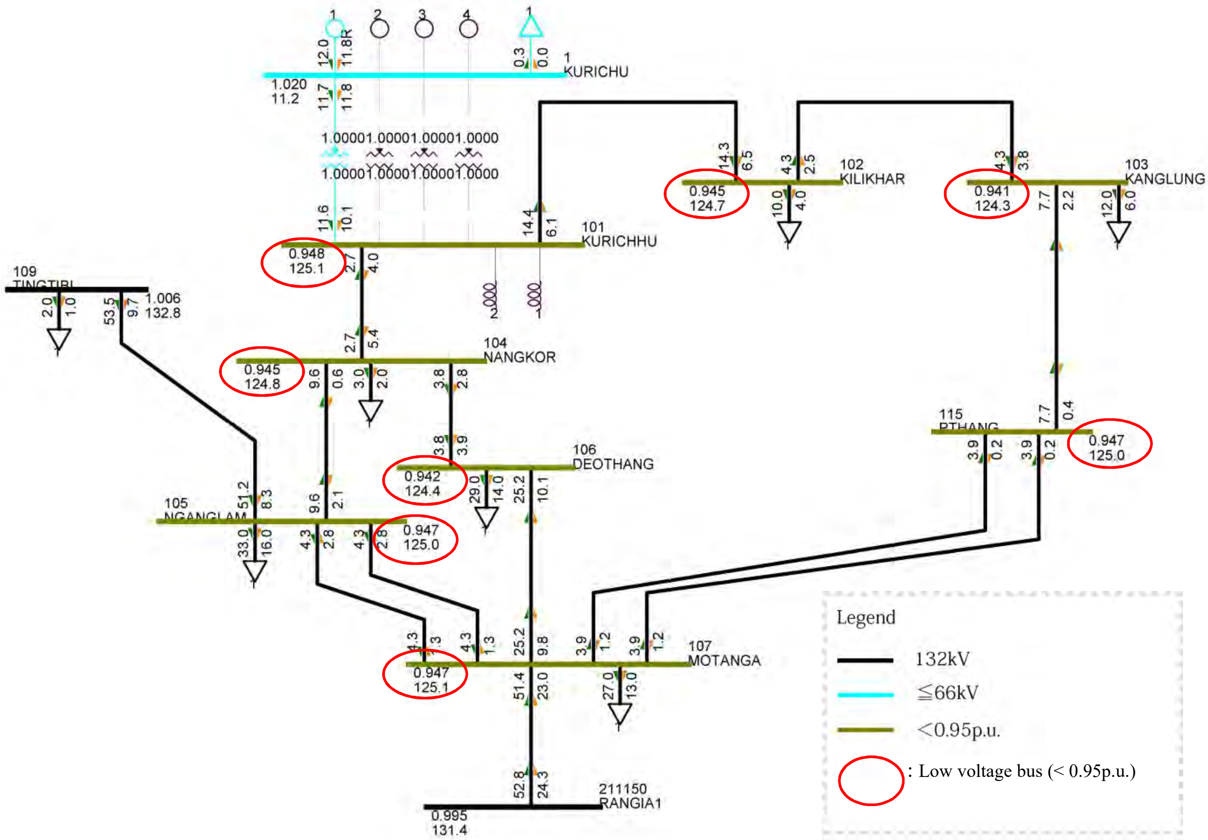
The voltages of some buses in the southeast 132kV system are lower than the allowable lower voltage limit, 0.95 p.u. The table below lists buses where voltages are lower than the lower voltage limit.

Table 9-9 Power Flow Analysis Results under the N-0 Conditions: Bus Voltage

Bus Number	Bus Name	Base kV	Voltage (p.u.)
101	Kurichhu	132	0.95
102	Kilikhar	132	0.94
103	Kanglung	132	0.94
104	Nangkor	132	0.95
105	Nganglam	132	0.95
106	Deothang	132	0.94
107	Motanga	132	0.95
115	Phuentshothang	132	0.95

(Source: JICA Survey Team)

The figure below shows the power flow calculation results for a 132kV system in the southeast area.



(Source: JICA Survey Team)

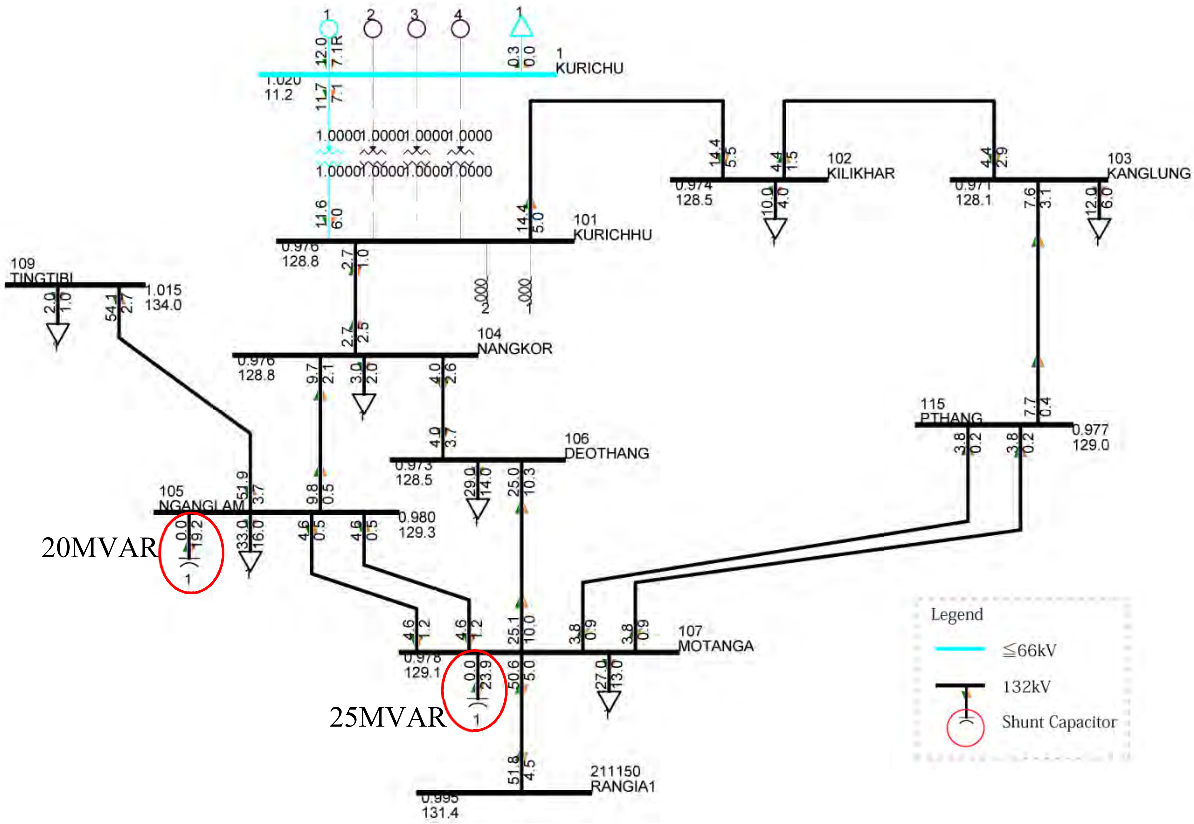
Figure 9-10 Power Flow Analysis Results for 2020 Dry Season under the N-0 Conditions

The low voltages shown above are due to insufficient reactive supply:

- Only one unit is in operation,
- Consequently, reactive power supply from Kurichhu power station is limited (about 10MVAR in total).

(c) Measures for low voltage

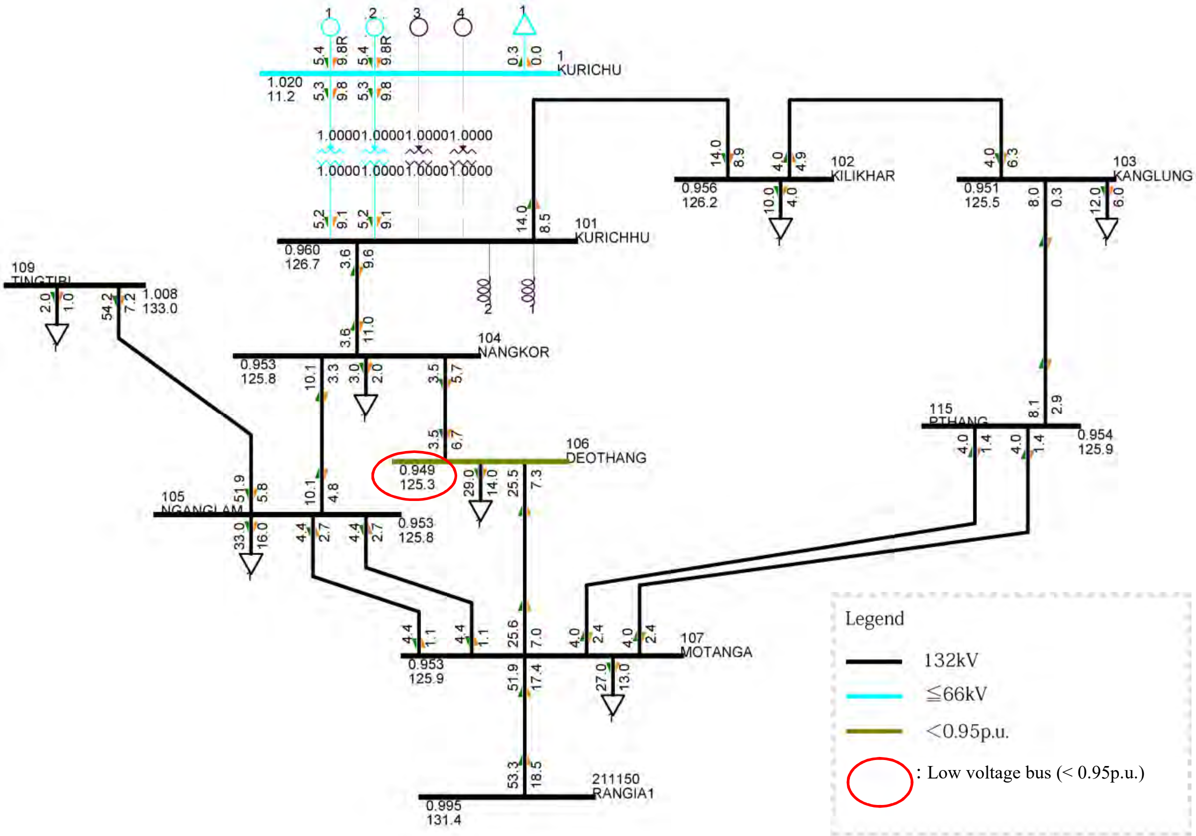
Installing a shunt capacitor bank is an effective measure against low voltage in general. The figure below shows the power flow calculation results with 25MVAR and 20MVAR shunt capacitor banks installed in Motanga and Nganglam substations respectively.



(Source: JICA Survey Team)

Figure 9-11 Power Flow Analysis Results for 132kV System in the Southeast Area for 2020 Dry Season: with Shunt Capacitor Banks

As shown above, the lowest bus voltage is 0.97 p.u. at Deothang substation and the low voltage problem is solved. However, shunt capacitor banks in Motanga and Nganglam substations would, in fact, probably not be installed by 2020 due to the schedule being too tight. In that case, more generators in operation at Kurichhu power station can increase the reactive power supply from the power station and consequently contribute to solving the low voltage problem to some extent. The figure below shows the power flow calculation results under the assumption that two generators are in operation and total power output is 10% less than the previous case, as a reference.



(Source: JICA Survey Team)

Figure 9-12 Power Flow Analysis Results for 132kV System in the Southeast Area for 2020 Dry Season: Two Generators in Operation

Reactive power supply from Kurichhu power station is about 18MVAR in total, and this reactive power helps to ease the low voltage to some extent.

(5) Power flow analysis for 2020 with 110% generator output

A power flow calculation for the 2020 under N-0 conditions with 110% generator output was performed.

(a) Power flow check

There are no overloaded facilities. The table below shows some heavily-loaded facilities for reference.

Table 9-10 Power Flow Analysis Result under the N-0 Conditions with 110% generator output: Relatively heavily loaded Facilities

TL (1)	From			To			CCT	Loading	Rating	Percent
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.	(MVA)	(MVA)	(%)
1	109	Tingtibi	132	110	Yurmo	132	1	78.4	95	82.6
1	105	Nganglam	132	109	Tingtibi	132	1	68.1	95	71.7
0	208	Singhigaon	220	621	Singhigaon	66	1	40.4	50	80.8
0	208	Singhigaon	220	621	Singhigaon	66	2	25.5	35	73.0

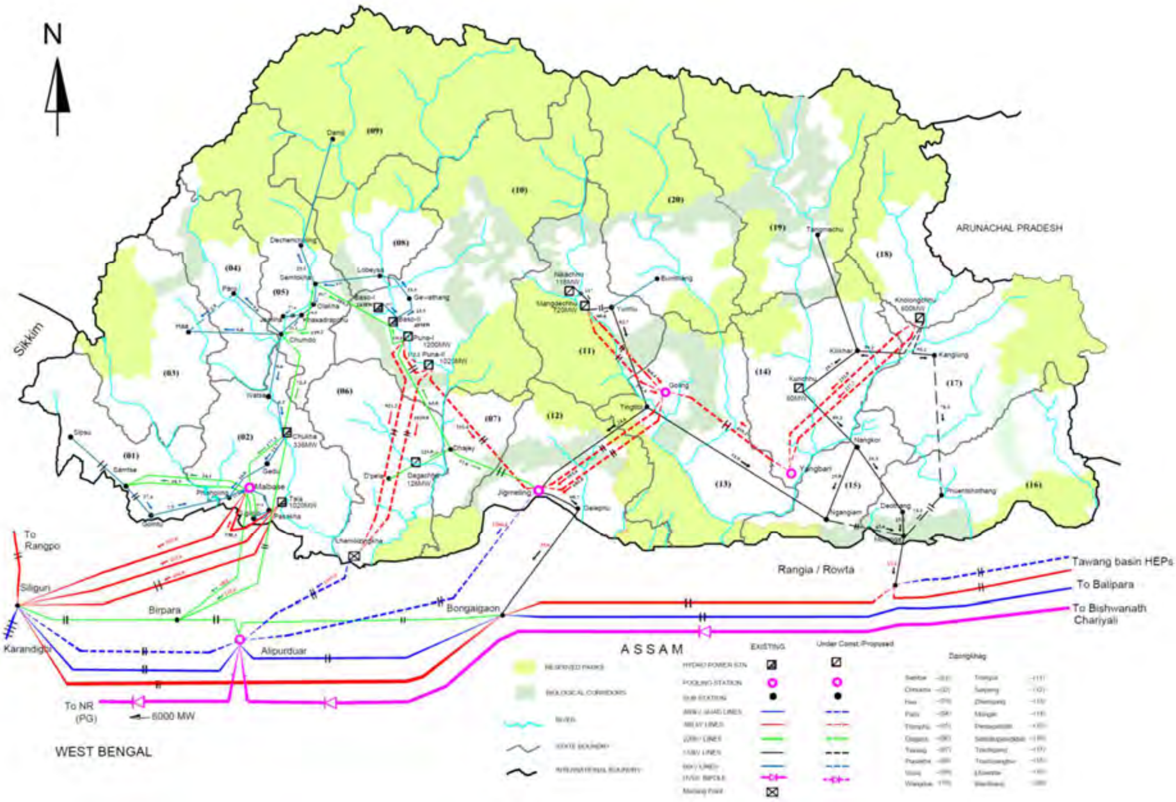
(Source: JICA Survey Team)

(b) Voltage check

The voltage of all buses is within the allowable range.

9.2.3 National Grid by 2025

The power system diagram for 2025 according to the current plan is shown below.



(Source: NTGMP of Bhutan - 2018)

Figure 9-13 Power System Diagram for 2025

(1) Development plan for 2025

(a) Generation developments planned by 2025

Nikachhu, Punatsangchhu-II (PHEP-II), Punatsangchhu-I (PHEP-I) and Kholongchhu power stations are planned to operate by 2025, so these generators and relevant transmission system equipment are included in the model for the analytic study. Their equipment augmentations for 2025 are listed in the table below.

Table 9-11 Equipment to be constructed by 2025

Generation equipment

Location	Power output	Rated power of a unit and quantity
Nikachhu	118MW	(59MW x 2)
PHEP-II	1,020MW	(170MW x 6)
PHEP-I	1,200MW	(200MW x 6)
Kholongchhu	600MW	(150MW x 4)

Transmission line

Voltage	From	To	Main specifications
400kV	PHEP-II	Lhamoizingkha	1 x 2 circuits, Moose x 2 conductors, 80.5km
400kV	Lhamoizingkha	Alipurduar	1 x 2 circuits, Moose x 4 conductors, 64.0km
400kV	PHEP-I	Lhamoizingkha	1 x 2 circuits, Moose x2 conductors, 92.9km
400kV	PHEP-I	PHEP-II	1 x 2 circuits, Moose x2 conductors, 13.0km
400kV	Kholongchhu	Yangbari	2 x 1 circuits, Moose x2 conductors, 68.3km, 69.7km
400kV	Goling	Yangbari	1 x 2 circuits, Moose x2 conductors, 60.0km
400kV	Mangdechhu	Jigmeling	LILO of 2 x 2 circuits at Goling substation
132kV	Nikachhu	MHEP	1 x 2 circuits, Panther x 1 conductor, 10km
132kV	Kholongchhu	Kilikhar	1 x 1 circuits, Panther x 1 conductor, 34.7km
132kV	Kholongchhu	Kanglung	1 x 1 circuits, Panther x 1 conductor, 23.0km
132kV	Kilikhar	Kanglung	LILO of 1 x 1 circuits at Kholongchhu HEP

Substation equipment

Voltage	Location	Main specifications
132kV	Nikachhu	Step-up transformer, 2 x 72MVA
400/220kV	PHEP-I	Transformer, 3 x 105 MVA
400kV	PHEP-II	Step-up transformer, 6 x 210MVA
400kV	PHEP-I	Step-up transformer, 6 x 225MVA
400/132kV	Kholongchhu	Transformer, 3 x 67 MVA
400kV	Kholongchhu	Step-up transformer,4 x 189MVA

(Source: NTGMP of Bhutan - 2018)

(b) Shunt capacitors

The shunt capacitors which were determined to be necessary to maintain the voltages for 2025 in the NTGMP of Bhutan-2018 was adopted as the base case conditions. (See Table 9-5)

(2) Power flow analysis for 2025 under the N-0 conditions

(a) Power flow analysis results for 2025 under the N-0 condition

The following shows power flow analysis results calculated under N-0 conditions.

1) Power flow check

There are no overloaded facilities. The table below shows some heavily-loaded facilities as a reference. The whole power flow diagram is shown in the appendixes.

Table 9-12 Power Flow Analysis Results under the N-0 Conditions: Relatively heavily loaded Facilities

TL (1)	From			To			CCT	Loading	Rating	Percent
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.	(MVA)	(MVA)	(%)
1	101	Kurichhu	132	104	Nangkor	132	1	92	95	96.8
1	107	Motanga	132	211150	Rangia1	132	1	90.9	95	95.6
0	208	Singhigaon	220	621	Singhigaon	66	1	41.8	50	83.7
0	208	Singhigaon	220	621	Singhigaon	66	2	26.4	35	75.5

TL(1): Transmission Line, TF(0): Transformer

(Source: JICA Survey Team)

2) Voltage check

The voltages of all buses are within the allowable range.

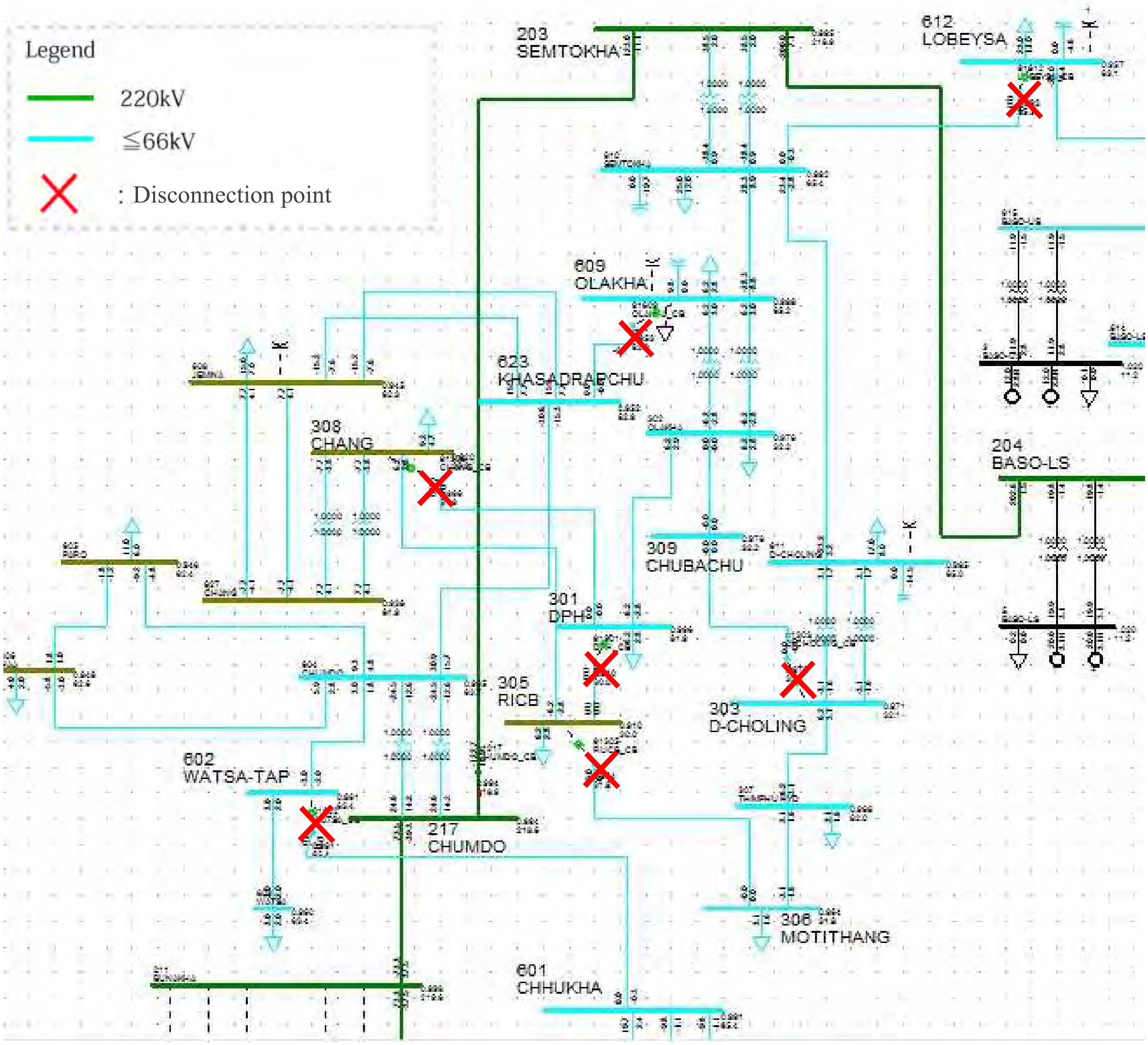
(b) Power flow analysis results for 2025 under the N-0 conditions with a radial system configuration in the northwest area

A system analysis to be hereinafter described gives the suggestion that 66kV and 33kV systems should be separated at proper points, and the system configuration should be changed from loop to radial to predict easily power flows changed by switching operations, including ones due to fault clearing protective relaying. The table and figure below show the transmission lines to be open.

Table 9-13 Disconnected Transmission Lines for the Radial System Configuration in the Northwest Area

From Bus No.	From Bus Name	To Bus No.	To Bus Name
601	Chhukha 66	602	Watsa 66
610	Semtokha 66	612	Lobeysa 66
609	Olakha 66	623	Khasadrapchu 66
301	DPH 33	308	Changidapuchu 33
301	DPH 33	305	RICB 33
303	Dechencholing 33	309	Chubachu 33
305	RICB 33	308	Changidapuchu 33

(Source: JICA Survey Team)



(Source: JICA Survey Team)

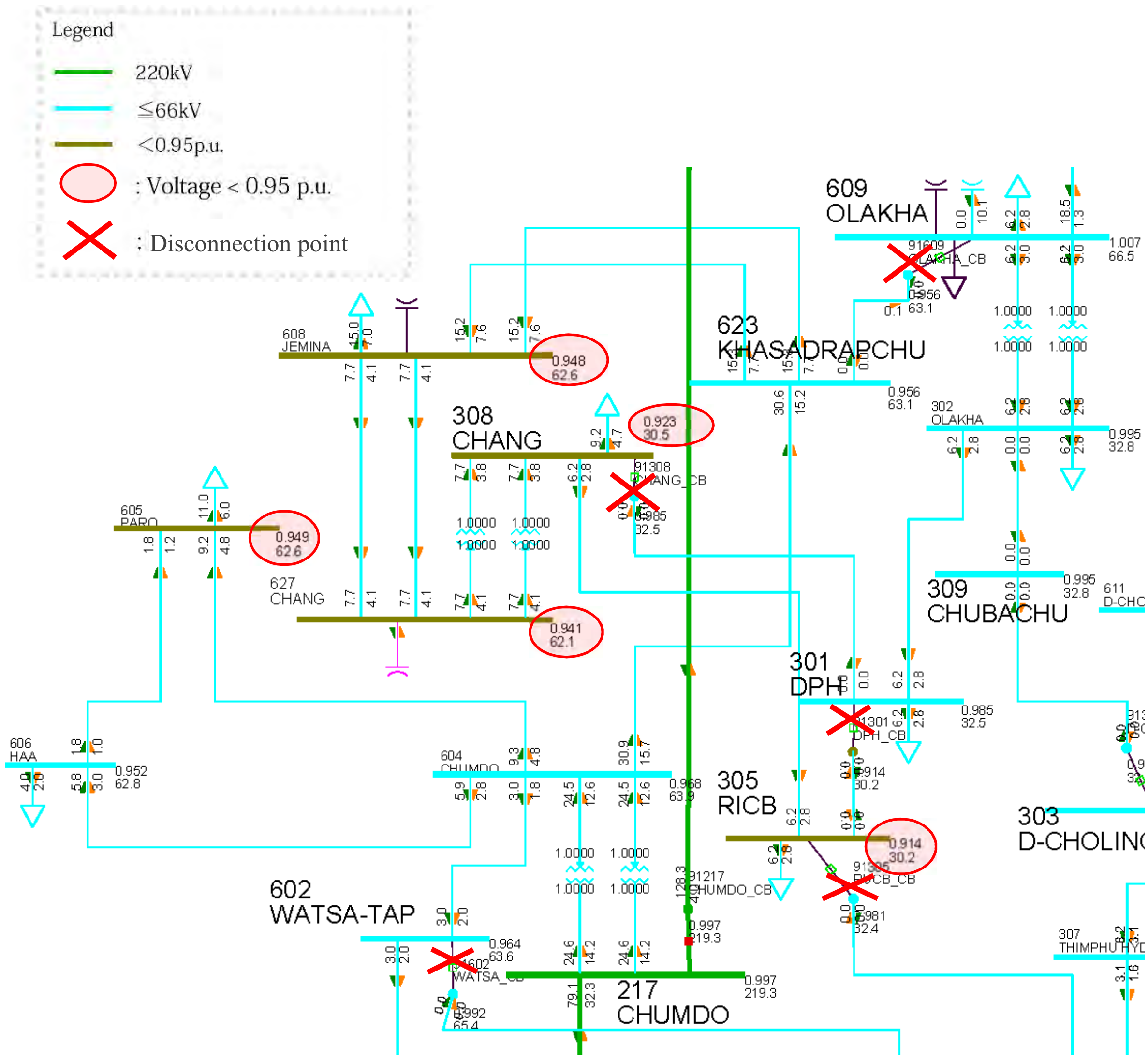
Figure 9-14 Split Points for the Radial System Configuration in Northwest Area

1) Power flow check

There are no overloaded facilities. The whole power flow diagram is shown in the appendixes.

2) Voltage check

Since the resultant reactance of the 66kV and 33kV systems in the northwest area increases due to the system splits, reactive power loss increases. Furthermore, reactive power cannot be delivered to some areas because of the system splits. For these reasons, the voltages at five substations are lower than 0.95p.u.

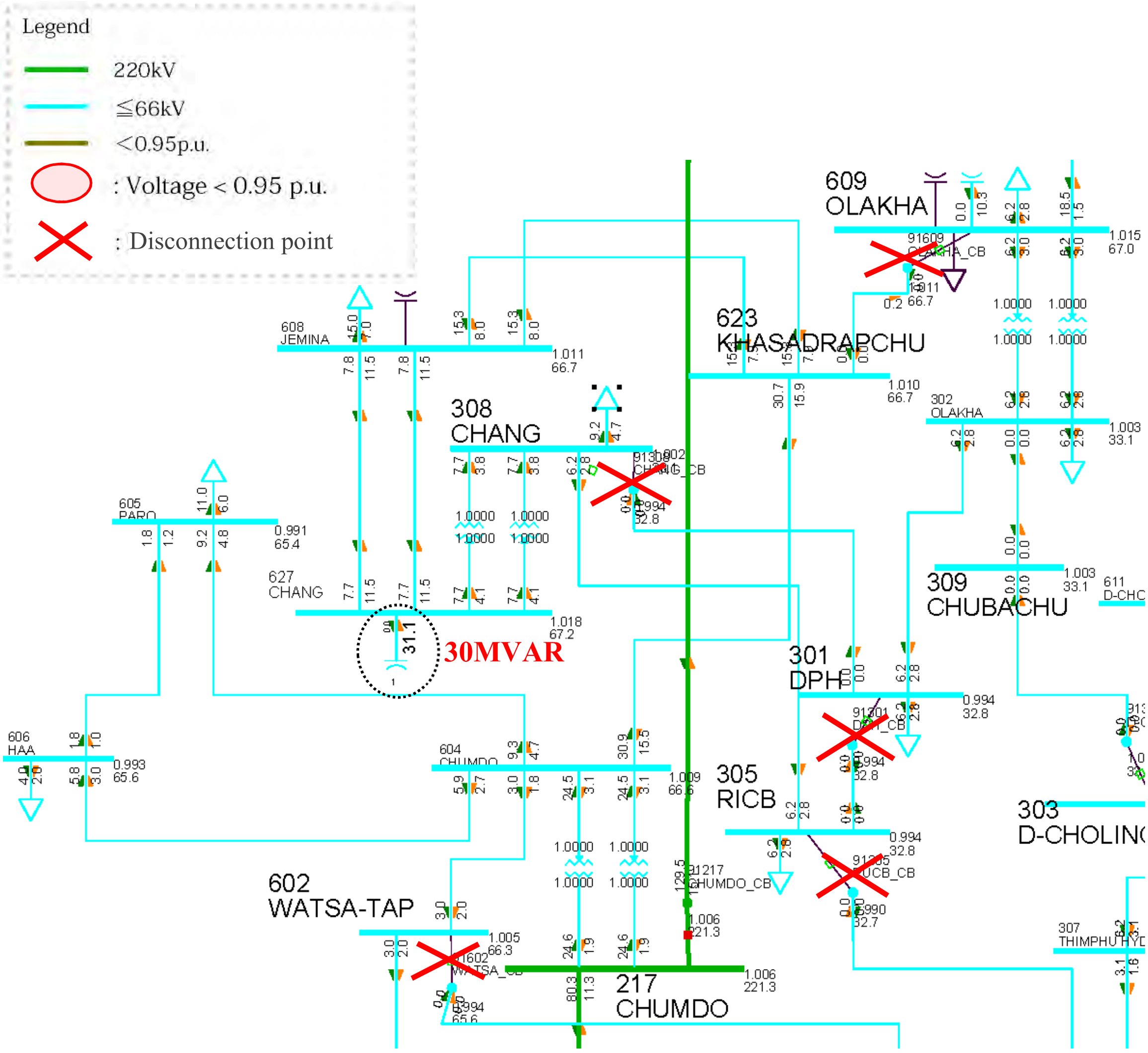


(Source: JICA Survey Team)

Figure 9-15 Low Voltages due to the Radial Configuration under N-0 Conditions

3) Countermeasures for low voltages due to the radial configuration in northwest system

Generally, installing shunt capacitors is an effective measure for the low voltage problem. The figure below shows the power flow calculation results with 30MVAR installed at Changidapuchu substation.



(Source: JICA Survey Team)

Figure 9-16 Countermeasures for Low Voltages due to the Radial Configuration in Northwest System

The table below shows that the installation of shunt capacitors at Changidapuchu substation remedies the low bus voltages.

Table 9-14 Effect of the Installation of the Shunt Capacitors for Low Voltages in Northwest Radial System

Bus Number	Bus Name	Base kV	Voltage (p.u.)	
			Without Capacitor	With Capacitor
305	RICB	33	0.91	0.99
308	Changidapuchu	33	0.92	1.00
627	Changidapuchu	66	0.94	1.02
608	Jemina	66	0.95	1.01
605	Paro	66	0.95	0.99

(Source: JICA Survey Team)

(3) Power flow analysis for 2025 under the N-1 conditions

(a) Loop configuration in the northwest system

The following shows the power flow analysis results calculated under N-1 conditions with the loop configuration in the northwest system.

1) Power flow check

The table below shows overloaded facilities under N-1 conditions.

Table 9-15 Power Flow Analysis Result under N-1 Conditions for 2025: Overloaded Facilities

Contingency								Overloaded facility	Load factor (%)
TL (1)	From			To			CCT		
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.		
	Base case								0.0
1	203	Semtokha	220	217	Chumdo	220	1	609 Olakha 66 610 Semtokha 66 2	153.6
1	203	Semtokha	220	204	Baso-LS	220	1	613 Gaywathang 66 614 Baso-LS 66 1	141.0
								612 Lobeysa 66 613 Gaywathang 66 1	140.5
								204 Baso-LS 220 614 Baso-LS 66 1	105.0
1	103	Kanglung	132	114	Kholongchhu	132	1	101 Kurichhu 132 104 Nangkor 132 1	139.0
								109 Tingtibi 132 110 Yurmo 132 1	101.7
1	101	Kurichhu	132	104	Nangkor	132	1	103 Kanglung 132 114 Kholongchhu 132 1	134.7
								109 Tingtibi 132 110 Yurmo 132 1	105.8
1	103	Kanglung	132	115	Phuentshothang	132	2	101 Kurichhu 132 104 Nangkor 132 1	130.5
1	105	Nganglam	132	109	Tingtibi	132	1	101 Kurichhu 132 104 Nangkor 132 1	116.0
								103 Kanglung 132 114 Kholongchhu 132 1	104.5
1	102	Kilikhar	132	114	Kholongchhu	132	1	103 Kanglung 132 114 Kholongchhu 132 1	111.8
1	407	Jigmeling	400	444073	Alipurduar	400	1	107 Motanga 132 211150 Rangia1 132 1	111.4
								101 Kurichhu 132 104 Nangkor 132 1	102.4
1	407	Jigmeling	400	444073	Alipurduar	400	2	107 Motanga 132 211150 Rangia1 132 1	111.4
								101 Kurichhu 132 104 Nangkor 132 1	102.4
1	109	Tingtibi	132	110	Yurmo	132	1	101 Kurichhu 132 104 Nangkor 132 1	107.3
1	409	Lhamoizingkha	400	444073	Alipurduar	400	1	107 Motanga 132 211150 Rangia1 132 1	105.9
								101 Kurichhu 132 104 Nangkor 132 1	100.1
1	409	Lhamoizingkha	400	444073	Alipurduar	400	2	107 Motanga 132 211150 Rangia1 132 1	105.9
								101 Kurichhu 132 104 Nangkor 132 1	100.1
1	112	Mangdechhu	132	113	Nikachhu	132	1	112 Mangdechhu 132 113 Nikachhu 132 2	105.5
1	112	Mangdechhu	132	113	Nikachhu	132	2	112 Mangdechhu 132 113 Nikachhu 132 1	105.5
1	101	Kurichhu	132	102	Kilikhar	132	1	103 Kanglung 132 114 Kholongchhu 132 1	104.7
1	403	Kholongchhu	400	410	Yangbari	400	2	101 Kurichhu 132 104 Nangkor 132 1	101.5
								107 Motanga 132 211150 Rangia1 132 1	101.3
1	403	Kholongchhu	400	410	Yangbari	400	1	101 Kurichhu 132 104 Nangkor 132 1	101.3
								107 Motanga 132 211150 Rangia1 132 1	101.1
1	408	Goling	400	410	Yangbari	400	1	101 Kurichhu 132 104 Nangkor 132 1	100.9
								107 Motanga 132 211150 Rangia1 132 1	100.3
1	408	Goling	400	410	Yangbari	400	2	101 Kurichhu 132 104 Nangkor 132 1	100.9
								107 Motanga 132 211150 Rangia1 132 1	100.3
1	108	Gelephu	132	111	Jigmeling	132	1	107 Motanga 132 211150 Rangia1 132 1	100.1
0	208	Singhigaon	220	621	Singhigaon	66	1	208 Singhigaon 220 621 Singhigaon 66 2	212.7
0	208	Singhigaon	220	621	Singhigaon	66	2	208 Singhigaon 220 621 Singhigaon 66 1	139.5
0	403	Kholongchhu	400	114	Kholongchhu	132	1,2,3	109 Tingtibi 132 110 Yurmo 132 1	128.4
								105 Nganglam 132 109 Tingtibi 132 1	124.2
0	404	Mangdechhu	400	112	Mangdechhu	132	1,2,3	109 Tingtibi 132 110 Yurmo 132 1	115.6
0	205	Tsirang	220	616	Tsirang	66	1	205 Tsirang 220 616 Tsirang 66 2	115.6
0	205	Tsirang	220	616	Tsirang	66	2	205 Tsirang 220 616 Tsirang 66 1	115.6

TL(1): Transmission Line, TF(0): Transformer

(Source: JICA Survey Team)

a) Transformer outage at Singhigaon substation

The heaviest overloading is caused by a 50MVA transformer outage at Singhigaon substation, as per the results for 2020. Installing another new 50MVA transformer at Singhigaon substation is deemed to be an option to take. If the installation of another transformer at Singhigaon substation is delayed, and if the existing 50MVA transformer becomes persistently out of order, electricity will be delivered via properly selected 66kV transmission line feeders from the remaining 35MVA transformer, as per the 2020 case.

b) Transformer outage at Kholongchhu power station

For overload of 132kV transmission line between Yurmo and Nganglam via Tingtibi occurring at 400kV/132kV transformer accident at Kholongchhu power station, open operation of 132kV transmission line between Yurmo and Tingtibi by OLR or operator may be effective as an operational measure.

c) Transformer outage at Mangdechhu power station

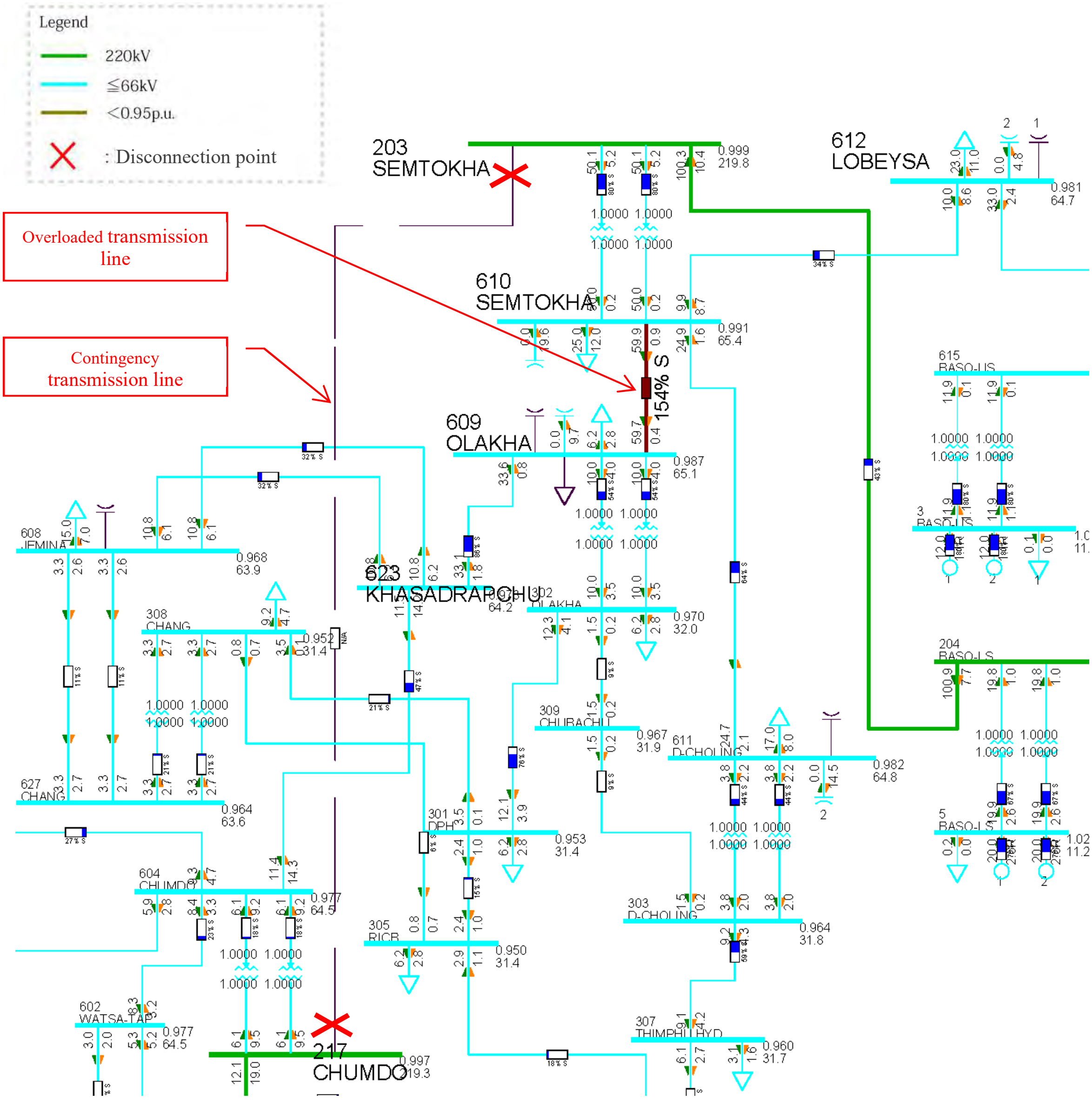
For overload of 132kV transmission line between Yurmo and Tingtibi occurring at 400kV/132kV transformer accident at Mangdechhu power station, output suppression of the Nikachhu power station may be effective as an operational measure.

d) Transformer outage at Tsirang substation

Installing the same capacity transformer as the existing one is an option to take.

e) 220kV transmission line outage between Semtokha and Chumdo substations

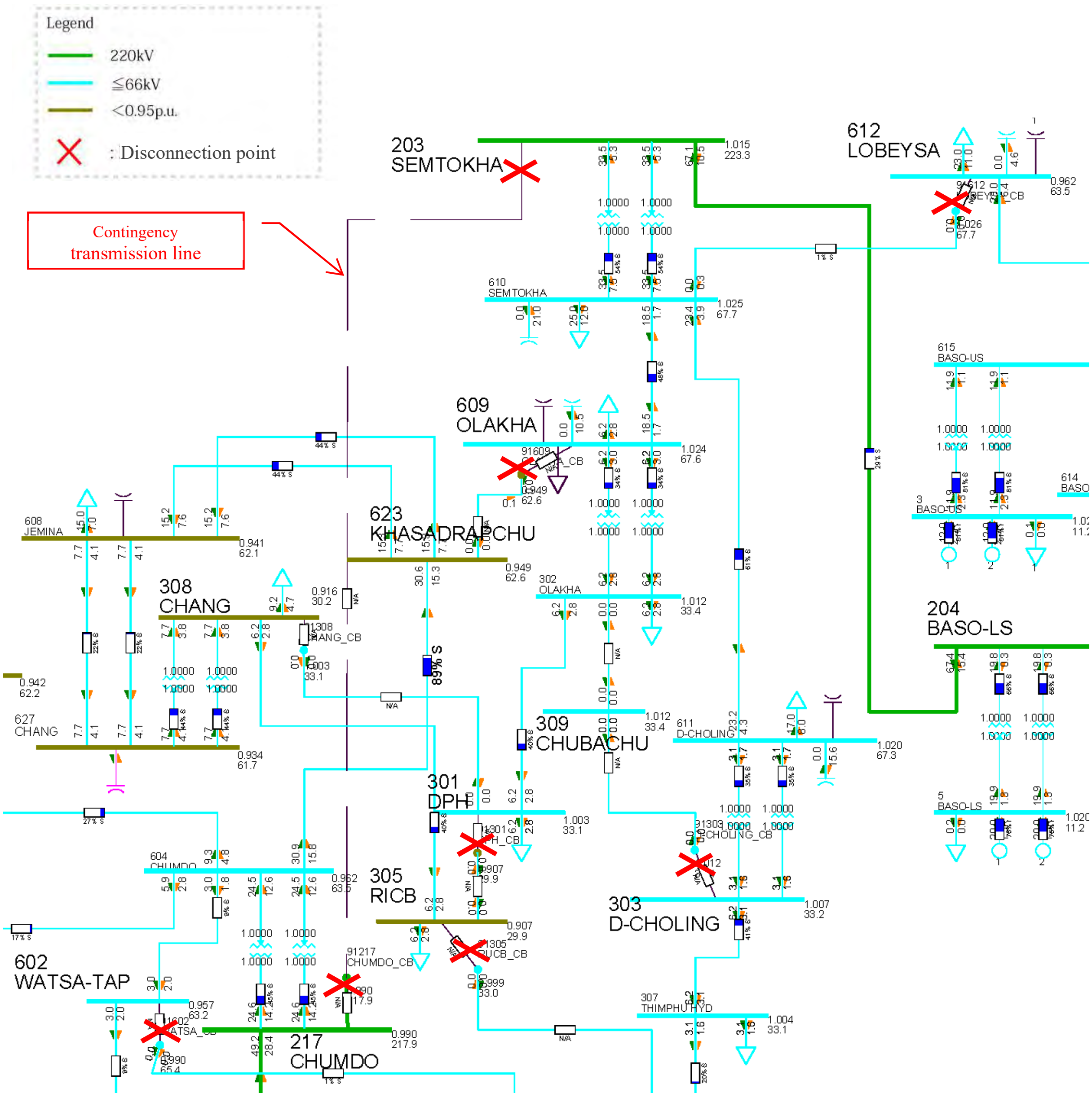
The heaviest overloaded facility among the transmission lines is the 66kV transmission line between Olakha and Semtokha (Loading ratio: 154%), caused by a 220kV transmission line outage between Semtokha and Chumdo substations. If it occurs, the overloaded transmission line should be tripped via an OLR or an operator's decision.



(Source: JICA Survey Team)

Figure 9-17 Power Flow Calculation Results after Clearance of a Fault on 220kV T/L between Semtokha and Chumdo

If it takes a long time to recover from the fault on the 220kV transmission line between Semtokha and Chumdo, or if the fault is persistent, electricity can be delivered to the tentatively unsupplied loads by properly splitting the 66kV and 33kV systems in the northwest area into radial systems. The figure below shows the power flow calculation results with the radial configuration. Although the voltage of Changidapuchu substation is slightly low, it is higher than 0.9 p.u., the lowest allowable voltage under N-1 conditions, and there are no overloaded facilities.

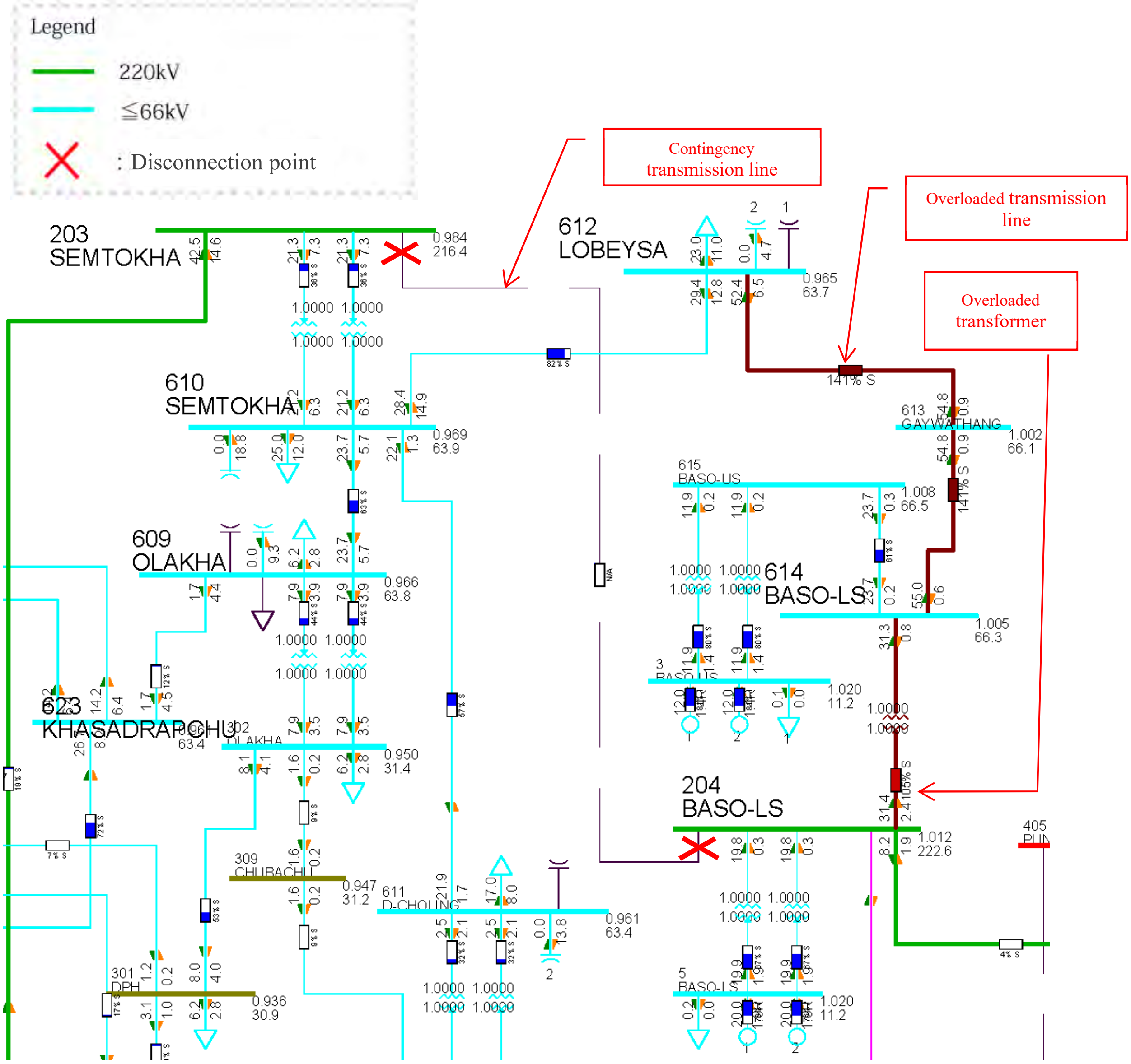


(Source: JICA Survey Team)

Figure 9-18 System Configuration to eliminate Overload after a Fault on 220kV T/L between Semtokha and Chumdo

f) 220kV transmission line outage between Semtokha substation and Basochhu power station

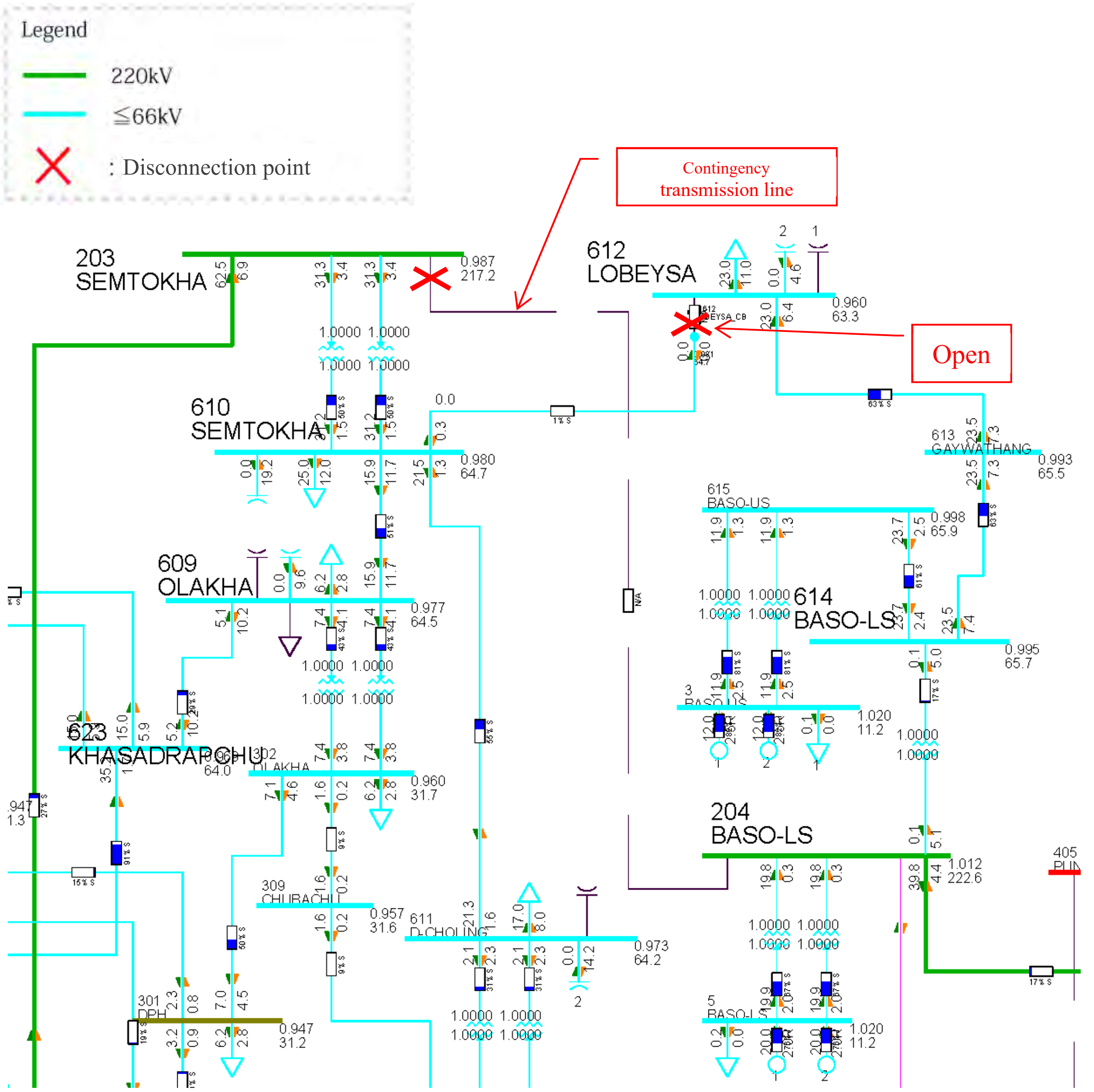
The next heaviest overloaded facility among the transmission lines is the 66kV transmission line between Basochhu power station and Lobeysa substation (Loading ratio: 141%), caused by a 220kV transmission line outage between Semtokha substation and Basochhu power station. In addition, a 220kV/66kV transformer at Basochhu power plant is overloaded.



(Source: JICA Survey Team)

Figure 9-19 Power Flow Calculation Results after a Fault on 220kV T/L between Semtokha and Chumdo and Fault Clearance

If it takes a long time to recover from the fault on the 220kV transmission line between Semtokha and Basochhu, or if the fault is persistent, electricity can be delivered to the tentatively unsupplied loads by switching operations in the system. As shown in the figure below, if a 66kV transmission line between Semtokha and Lobeysa is disconnected, the electricity can be delivered to the unsupplied loads without any problem.



(Source: JICA Survey Team)

Figure 9-20 System Configuration to eliminate Overload after a Fault on 220kV T/L between Semtokha S/S and Basochhu P/S

g) 132kV transmission line outage between Kanglung substation and Kholongchhu power station

The third heaviest overloaded facility among the transmission lines is the 132kV transmission line between Kurichhu and Nangkor substations (Loading ratio: 139%), caused by a 132kV transmission line outage between Kanglung substation and Kholongchhu power station. The overload under N-1 conditions in the 132kV southeast area system including this case has a common problem, and this problem is dealt with if the 66kV and 33kV systems in the northwest area are a radial configuration, as described later.

h) 132kV transmission line outage between Nikachhu and Mangdechhu power stations

When this transmission line suffers an outage, the output power of Nikachhu power station should be reduced as a practical measure.

2) Voltage check

The table below shows the contingency case in which a bus voltage is lower than the minimum allowable level.

Table 9-16 Power Flow Analysis Results under N-1 Conditions: Bus Voltage

Contingency								Out of the allowable range	
TL (1)	From			To			CCT	Low voltage bus	Voltage
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.		(p.u.)
0	208	Singhigaon	220	621	Singhigaon	66	1	621 Singhigaon 66	0.90

(Source: JICA Survey Team)

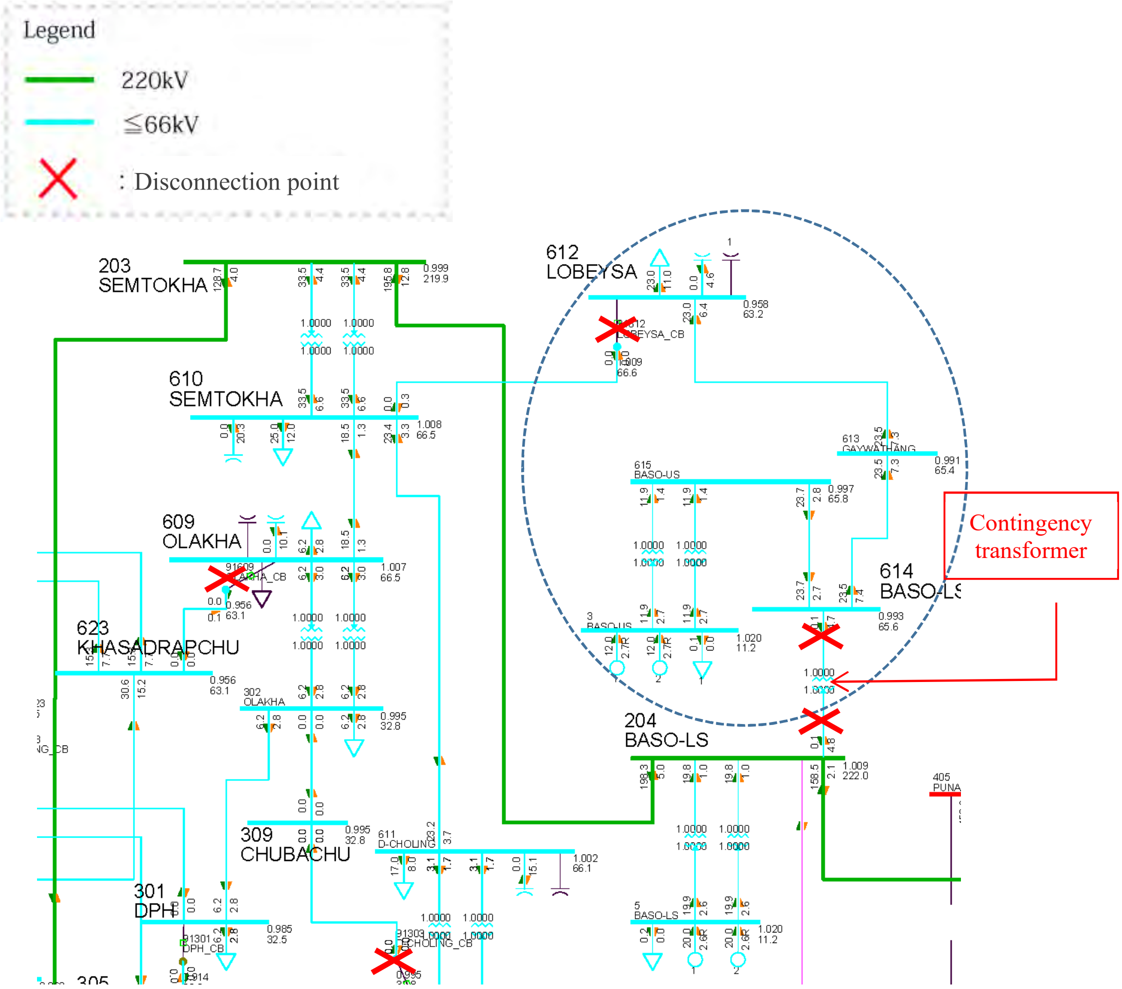
A 66kV bus voltage at Singhigaon substation is lower than the minimum allowable voltage, but this does not mean that measures for the voltage problem are definitely required.

(b) Radial configuration in the northwest system

The power flow calculations were performed under N-0 conditions with a radial system configuration in the northwest area. The calculation results are shown below.

1) System separation case

Since the system is split between Semtokha and Lobeysa substations, if a 220kV/66kV transformer in Basochhu suffers an outage, the local system including Basochhu-LS power station and Lobeysa substation will be separated from the main system, and a blackout will occur in the local system (Unsupplied power: 23.0MW). However, even if the outage is persistent, electricity can be delivered to the tentatively unsupplied loads by connecting Semtokha and Lobeysa substations with the existing 66kV transmission line.



(Source: JICA Survey Team)

Figure 9-21 Radial System Configuration: Power Flow Diagram around Basochhu P/S

2) Power flow check

a) Overloaded facility list

The table below lists overloaded facilities under N-1 conditions.

Table 9-17 Power Flow Analysis Results under N-1 Conditions: Overloaded Facilities (Radial Configuration in the Northwest System)

Contingency								Overloaded facility	Load factor (%)
TL (1)	From			To			CCT		
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.		
1	103	Kanglung	132	114	Kholongchhu	132	1	101 Kurichhu 132 104 Nangkor 132 1	139.0
								109 Tingtibi 132 110 Yurmo 132 1	101.7
1	101	Kurichhu	132	104	Nangkor	132	1	103 Kanglung 132 114 Kholongchhu 132 1	134.7
								109 Tingtibi 132 110 Yurmo 132 1	105.7
1	103	Kanglung	132	115	Phuentshothang	132	2	101 Kurichhu 132 104 Nangkor 132 1	130.5
1	105	Nganglam	132	109	Tingtibi	132	1	101 Kurichhu 132 104 Nangkor 132 1	116.0
								103 Kanglung 132 114 Kholongchhu 132 1	104.5
1	102	Kilikhar	132	114	Kholongchhu	132	1	103 Kanglung 132 114 Kholongchhu 132 1	111.8
1	407	Jigmeling	400	444073	Alipurduar	400	1	107 Motanga 132 11150 Rangia1 132 1	111.6
								101 Kurichhu 132 104 Nangkor 132 1	102.4
1	407	Jigmeling	400	444073	Alipurduar	400	2	107 Motanga 132 211150 Rangia1 132 1	111.6
								101 Kurichhu 132 104 Nangkor 132 1	102.4
1	109	Tingtibi	132	110	Yurmo	132	1	101 Kurichhu 132 104 Nangkor 132 1	107.3
1	409	Lhamoizingkha	400	444073	Alipurduar	400	1	107 Motanga 132 211150 Rangia1 132 1	106.0
								101 Kurichhu 132 104 Nangkor 132 1	100.1
1	409	Lhamoizingkha	400	444073	Alipurduar	400	2	107 Motanga 132 211150 Rangia1 132 1	106.0
								101 Kurichhu 132 104 Nangkor 132 1	100.1
1	112	Mangdechhu	132	113	Nikachhu	132	1	112 Mangdechhu 132 113 Nikachhu 132 2	105.5
1	112	Mangdechhu	132	113	Nikachhu	132	2	112 Mangdechhu 132 113 Nikachhu 132 1	105.5
1	101	Kurichhu	132	102	Kilikhar	132	1	103 Kanglung 132 114 Kholongchhu 132 1	104.7
1	403	Kholongchhu	400	410	Yangbari	400	2	101 Kurichhu 132 104 Nangkor 132 1	101.5
								107 Motanga 132 211150 Rangia1 132 1	101.4
1	403	Kholongchhu	400	410	Yangbari	400	1	101 Kurichhu 132 104 Nangkor 132 1	101.3
								107 Motanga 132 211150 Rangia1 132 1	101.2
1	408	Goling	400	410	Yangbari	400	1	101 Kurichhu 132 104 Nangkor 132 1	101.0
								107 Motanga 132 211150 Rangia1 132 1	100.4
1	408	Goling	400	410	Yangbari	400	2	101 Kurichhu 132 104 Nangkor 132 1	101.0
								107 Motanga 132 211150 Rangia1 132 1	100.4
1	108	Gelephu	132	111	Jigmeling	132	1	107 Motanga 132 211150 Rangia1 132 1	100.2
0	208	Singhigaon	220	621	Singhigaon	66	1	208 Singhigaon 220 621 Singhigaon 66 2	212.6
0	208	Singhigaon	220	621	Singhigaon	66	2	208 Singhigaon 220 621 Singhigaon 66 1	139.5
0	403	Kholongchhu	400	114	Kholongchhu	132	1,2,3	109 Tingtibi 132 110 Yurmo 132 1	128.4
								105 Nganglam 132 109 Tingtibi 132 1	124.3
0	404	Mangdechhu	400	112	Mangdechhu	132	1,2,3	109 Tingtibi 132 110 Yurmo 132 1	115.6
0	205	Tsirang	220	616	Tsirang	66	1	205 Tsirang 220 616 Tsirang 66 2	115.6
0	205	Tsirang	220	616	Tsirang	66	2	205 Tsirang 220 616 Tsirang 66 1	115.6
0	203	Semtokha	220	610	Semtokha	66	1	203 Semtokha 220 610 Semtokha 66 2	108.4
0	203	Semtokha	220	610	Semtokha	66	2	203 Semtokha 220 610 Semtokha 66 1	108.4

TL(1): Transmission Line, TF(0): Transformer

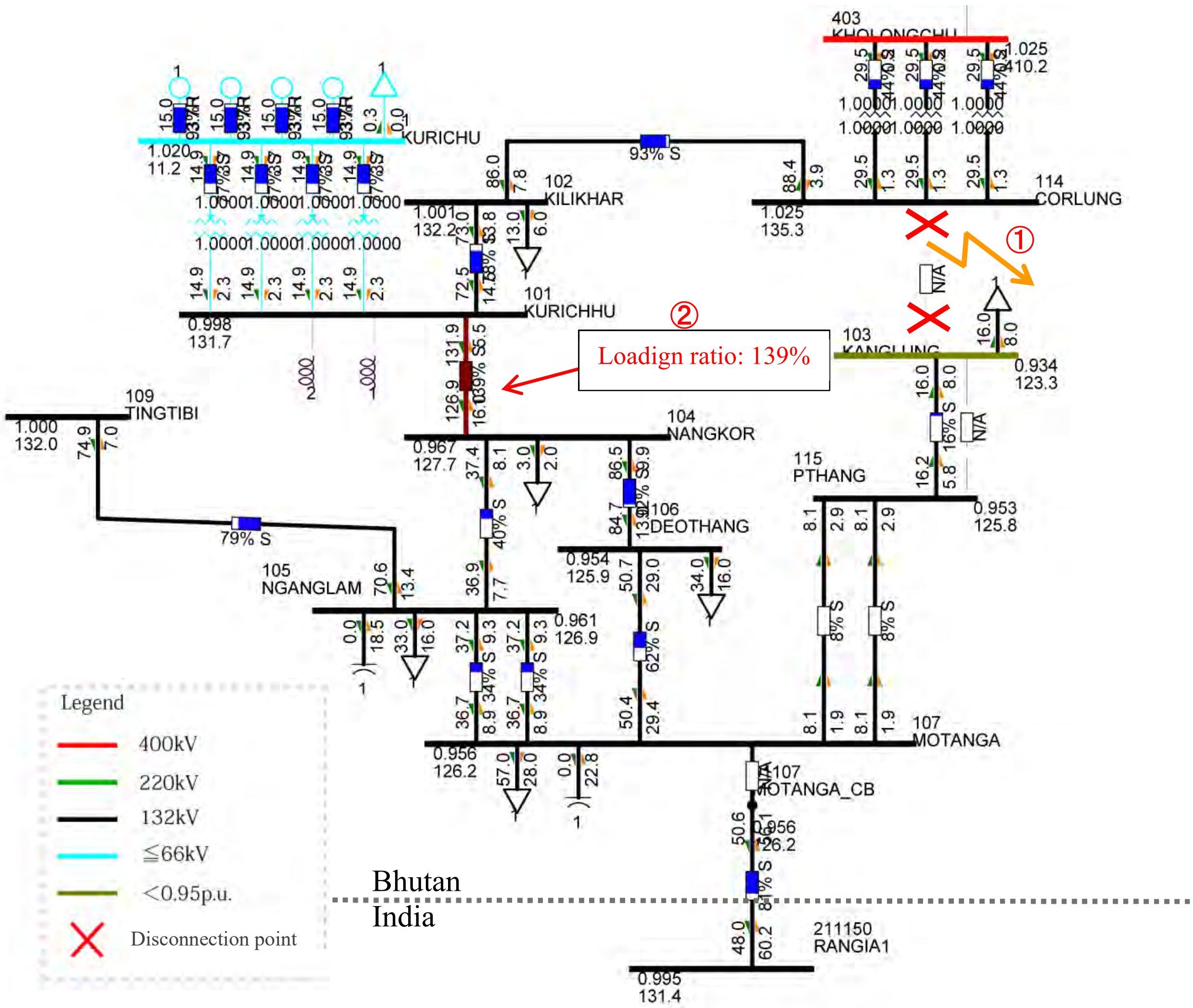
(Source: JICA Survey Team)

Comparing the above results to those in Table 9-15, which is given by the calculation with the loop configuration of 66kV and 33kV systems, there are no overloaded transmission lines in the northwest area under N-1 conditions, with overloaded ones only in southeast 132kV systems.

b) 132kV transmission line outage between Kanglung substation and Kholongchhu power station

■ Step-1

The most heavily overloaded facility among the transmission lines is the 132kV transmission line between Kurichhu power station and Nangkor substation (Loading ratio: 139%), caused by a 132kV transmission line outage between Kanglung substation and Kholongchhu power station.



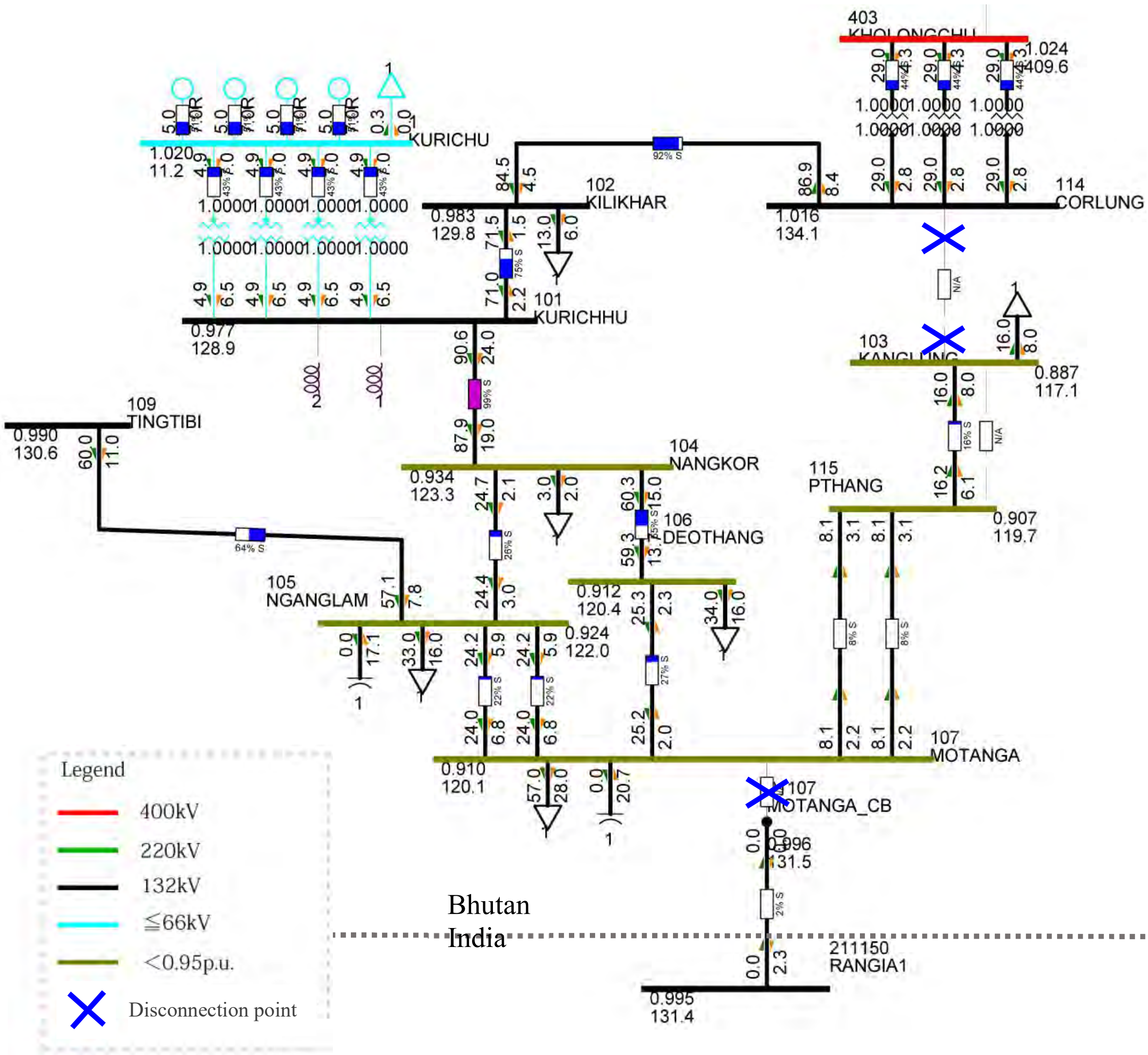
(Source: JICA Survey Team)

Figure 9-22 Power Flow Calculation Results after a Fault on 132kV T/L between Kanglung S/S and Kholongchhu P/S and Fault Clearance

- Step-2
  If the overloaded transmission line between Kurichhu power station and Nangkor substation is tripped via an OLR or an operator's decision, then another 132kV transmission line between Tingtibi and Nganglam substations becomes overloaded (Loading ratio: 139%).

- Step-3
  If the overloaded transmission line between Tingtibi and Nganglam substations is tripped, then another 132kV transmission line between Motanga and Rangia substations becomes overloaded (Loading ratio: 173%). If the overloaded transmission line between Motanga and Rangia substations trips, then the 132kV system in the southeast area, including Motanga substation, experiences a blackout.

- Step-4
  The figure below shows an example system configuration for recovering from a blackout if the 132kV Kanglung-Kholongchhu transmission line outage is persistent.



(Source: JICA Survey Team)

Figure 9-23 System Configuration for recovering from Blackout with Persistent 132kV T/L Outage between Kanglung S/S and Kholongchhu P/S

An international tie line with India has to be stopped by opening the 132kV transmission line between Motanga and Rangia substations. The output of Kurichhu power station has to be controlled so as not to cause related 132kV transmission lines to become overloaded. Moreover, voltage at the 132kV bus of Kanglung substation is 0.89 p.u., which is a little low.

- Option
  Power export to India via the 132kV tie line is likely to cause an overload of the related 132 kV transmission lines. If there is a rule in place to disconnect the tie line with India immediately after a fault on the 132kV transmission line between Kanglung substation and Kholongchhu power station, or if the tie line is kept open from the beginning, there is a high possibility of avoiding the said blackout.

3) Voltage check

The power flow calculations were performed under N-1 conditions. The table below shows cases where bus voltages are lower than the minimum allowable voltage.

Table 9-18 Power Flow Analysis Results under N-1 Conditions: Bus Voltage

Contingency									Out of the allowable range	
TL (1)	From			To			CCT	Low voltage bus	Voltage
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.		(p.u.)
0	217	Chumdo	220	604	Chumdo	66	1	305 RICB 33	0.88
								308 Changidapuchu 33	0.89
0	217	Chumdo	220	604	Chumdo	66	2	305 RICB 33	0.88
								308 Changidapuchu 33	0.89
0	208	Singhigaon	220	621	Singhigaon	66	1	621 Singhigaon 66	0.90

(Source: JICA Survey Team)

66kV bus voltages of the above substations are lower than the minimum allowable voltage, but this does not mean that facility measures for the voltage problem are definitely required.

(4) Power flow analysis result for 2025 dry season

A power flow calculation was performed for the 2025 dry season under N-0 conditions with a radial configuration of 66kV and 33kV systems in the northwest area. Output power from each power plant is 20% of the rated power as noted previously, and the supply and demand balance is maintained by adjusting loads in India.

(a) Power flow check

There are no overloaded facilities. The table below shows some relatively heavily-loaded facilities as a reference. The whole power flow diagram is shown in the appendixes.

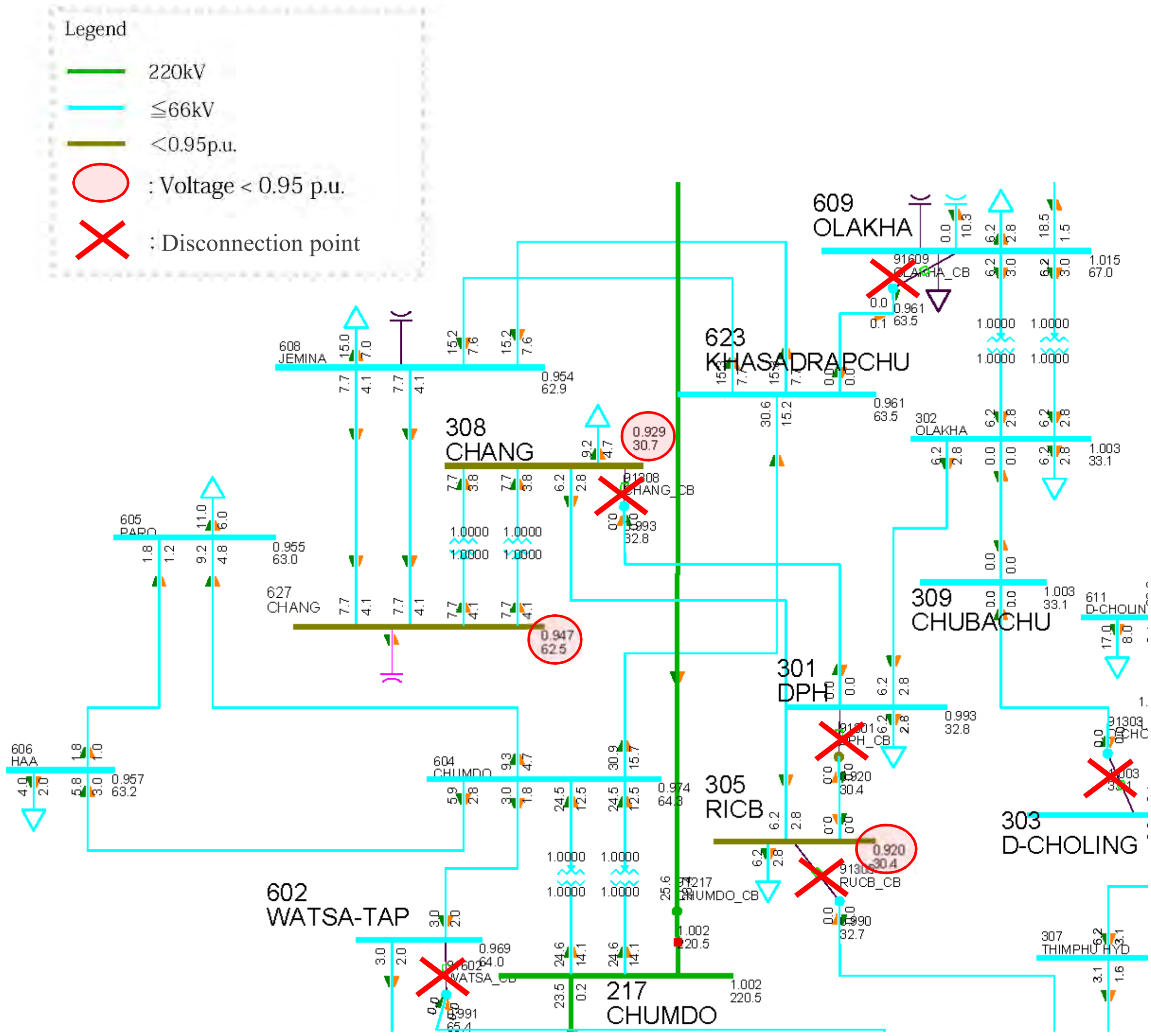
Table 9-19 Power Flow Analysis Results under N-0 Conditions: Relatively heavily loaded Facilities

TL (1)	From			To			CCT	Loading	Rating	Percent
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.	(MVA)	(MVA)	(%)
1	604	Chumdo	66	623	Khasadrapchu	66	1	34.6	39	88.8
1	613	Gaywathang	66	614	Baso-LS	66	1	24.6	39	63.2
0	208	Singhigaon	220	621	Singhigaon	66	1	41.8	50	83.6
0	208	Singhigaon	220	621	Singhigaon	66	2	26.4	35	75.5

(Source: JICA Survey Team)

(b) Voltage check

The figure below shows the power flow calculation results for the northwest system. Voltages in part of the northwest area are lower than 0.95 p.u., the minimum allowable voltage.

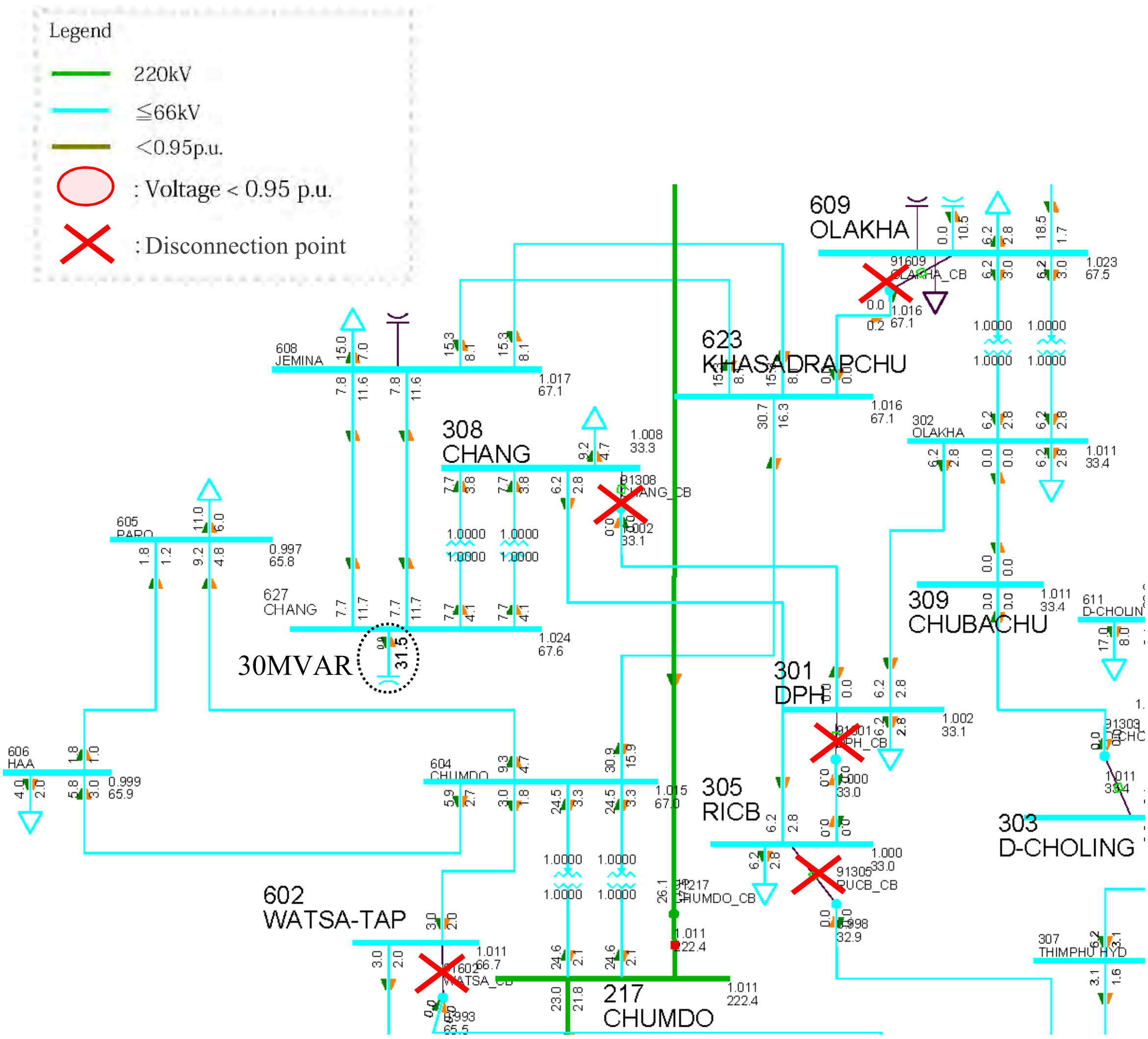


(Source: JICA Survey Team)

Figure 9-24 Power Flow Calculation Results in the Northwest System for 2025 Dry Season

(c) Measures for low voltage problem

The figure below shows the power flow calculation results with 30MVAR installed at Changidapuchu substation, the same as the low voltage measure in 9.2.3(2)(b)3).



(Source: JICA Survey Team)

Figure 9-25 Shunt Capacitor Installation as a Measure against Low Voltages in Northwest System

A 30MVAR Shunt capacitor installation can eliminate the low voltage problem as shown in the table below.

Table 9-20 Effect of the Installation of the Shunt Capacitors for Low Voltages

Bus Number	Bus Name	Base kV	Voltage (p.u.)	
			Without Capacitor	With Capacitor
305	RICB	33	0.92	1.00
308	Changidapuchu	33	0.93	1.01
627	Changidapuchu	66	0.95	1.02

(Source: JICA Survey Team)

(5) Power flow analysis for 2025 with 110% generator output

(a) Without countermeasures

The power flow analysis for the rainy season with 110% generator output was conducted under the following conditions.

- Radial configuration in the north west power system
- 30MVAR shunt capacitor at Changidapuchu substation
- N-0

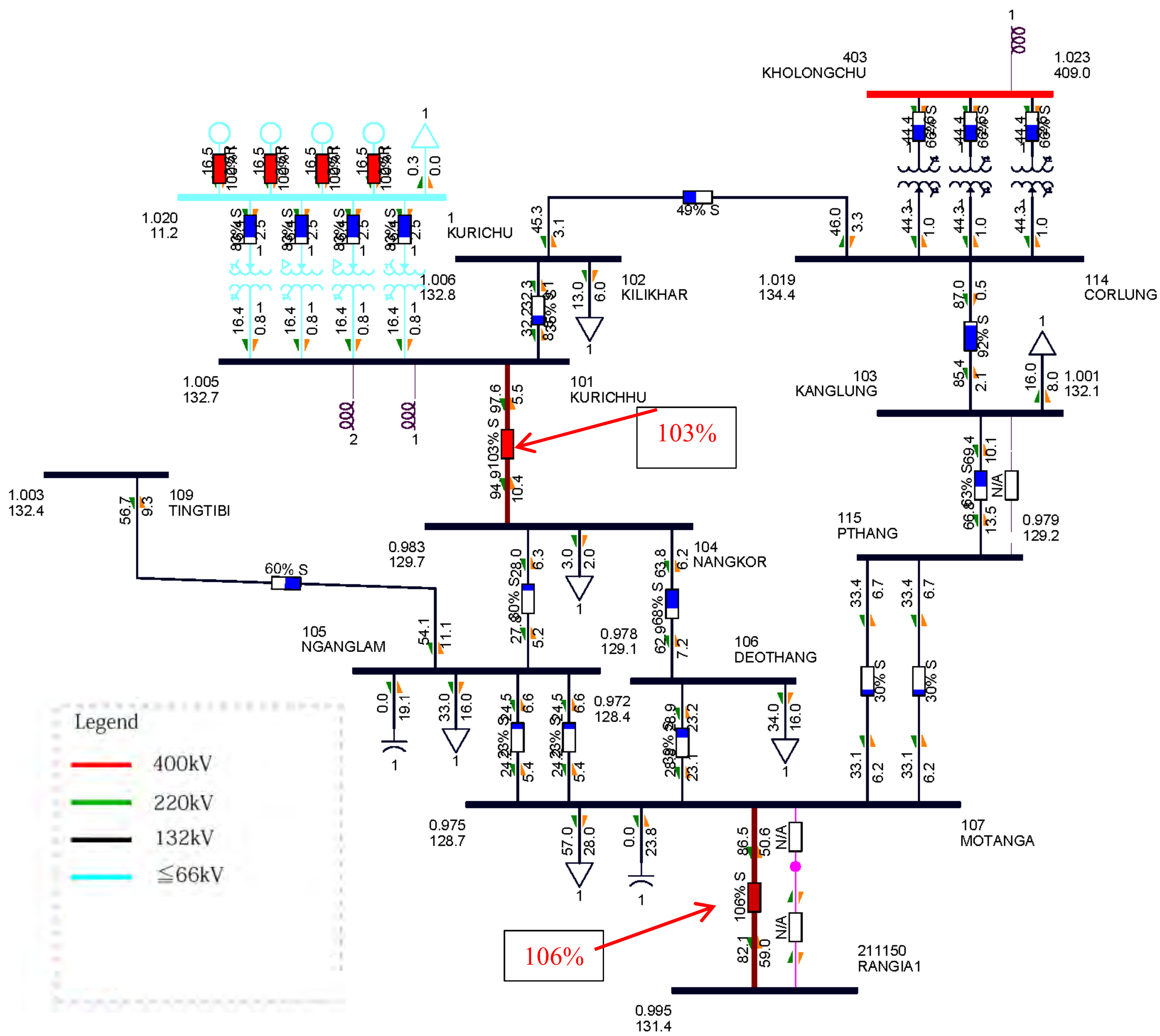
1) Power flow check

As shown in the table and figure below, some 132kV transmission lines are overloaded in the southeast power system with 110% generator output.

Table 9-21 Power Flow Analysis Results for 2025 under N-0 Conditions with 110% Generator Output: Overloaded Facilities

TL (1)	From			To			CCT	Loading	Rating	Percent
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.	(MVA)	(MVA)	(%)
1	107	Motanga	132	211150	Rangia1	132	1	101.1	95	106.4
1	101	Kurichhu	132	104	Nangkor	132	1	97.8	95	102.9

(Source: JICA Survey Team)



(Source: JICA Survey Team)

Figure 9-26 Power Flow Diagram for 2025 with 110% Generator Output in Southeast System

2) Voltage check

The voltage of all buses is within the allowable range.

(b) International tie line open with Indian system in the southeast area

The figure below shows the power flow calculation results under conditions whereby the 132kV international tie line is open with the Indian system in the southeast area.

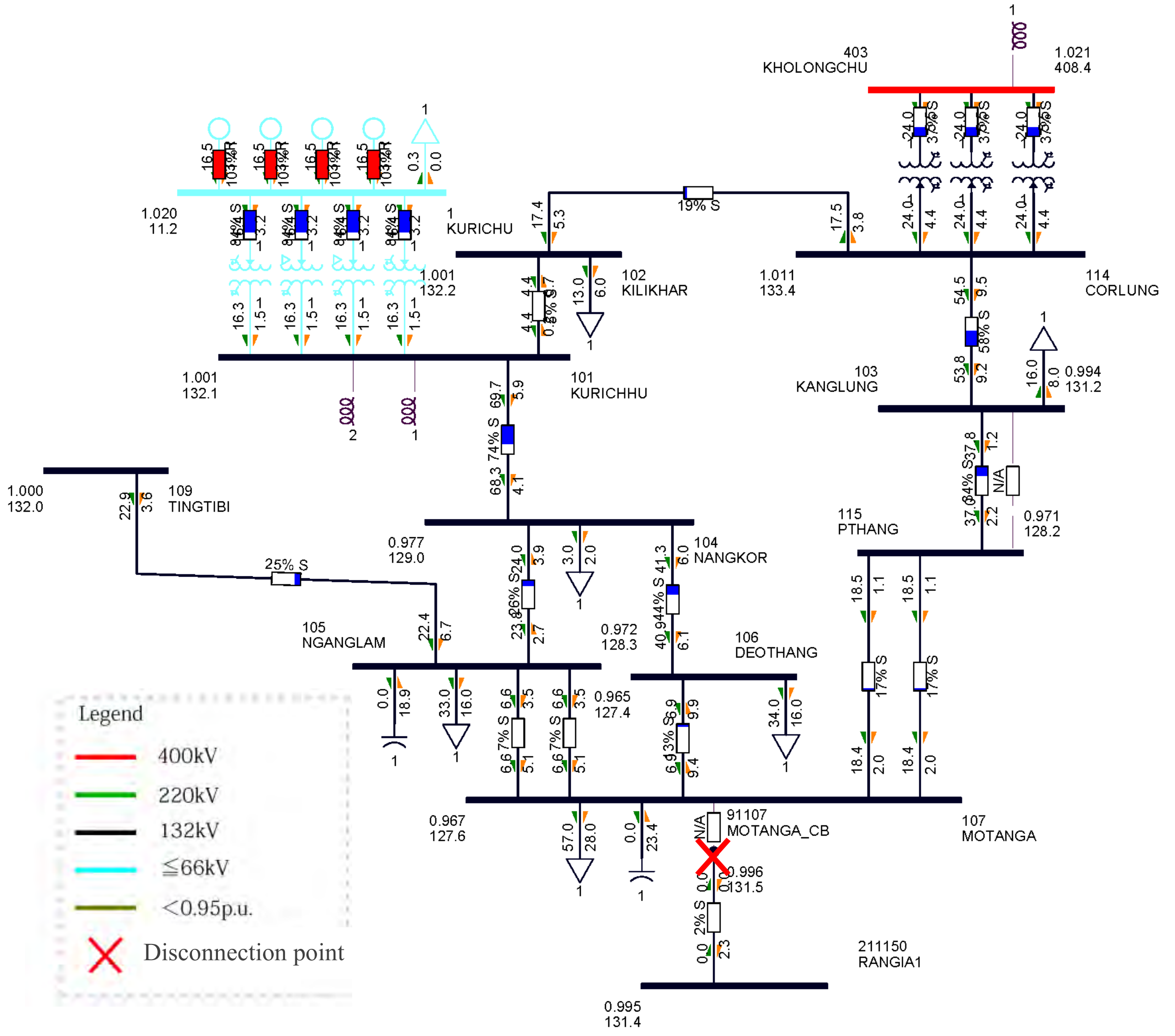


Figure 9-27 Power Flow Diagram for 2025 with 110% Generator Output and international tie line Open with Indian System in Southeast 132kV System

1) Power flow check

There are no overloaded facilities across the entire Bhutan system. The table below shows some heavily-loaded facilities for reference.

Table 9-22 Power Flow Analysis Results for 2025 under N-0 Conditions with 110% Generator Output and International Tie Line Open with Indian System in Southeast 132kV System: Relatively Heavily Loaded Facilities

TL (1)	From			To			CCT	Loading	Rating	Percent
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.	(MVA)	(MVA)	(%)
1	203	Semtokha	220	204	Baso-ls	220	1	219.4	236	93.0
1	604	Chumdo	66	623	Khasadrapchu	66	1	34.5	39	88.5
0	208	Singhigaon	220	621	Singhigaon	66	1	41.8	50	83.6
0	208	Singhigaon	220	621	Singhigaon	66	2	26.4	35	75.5

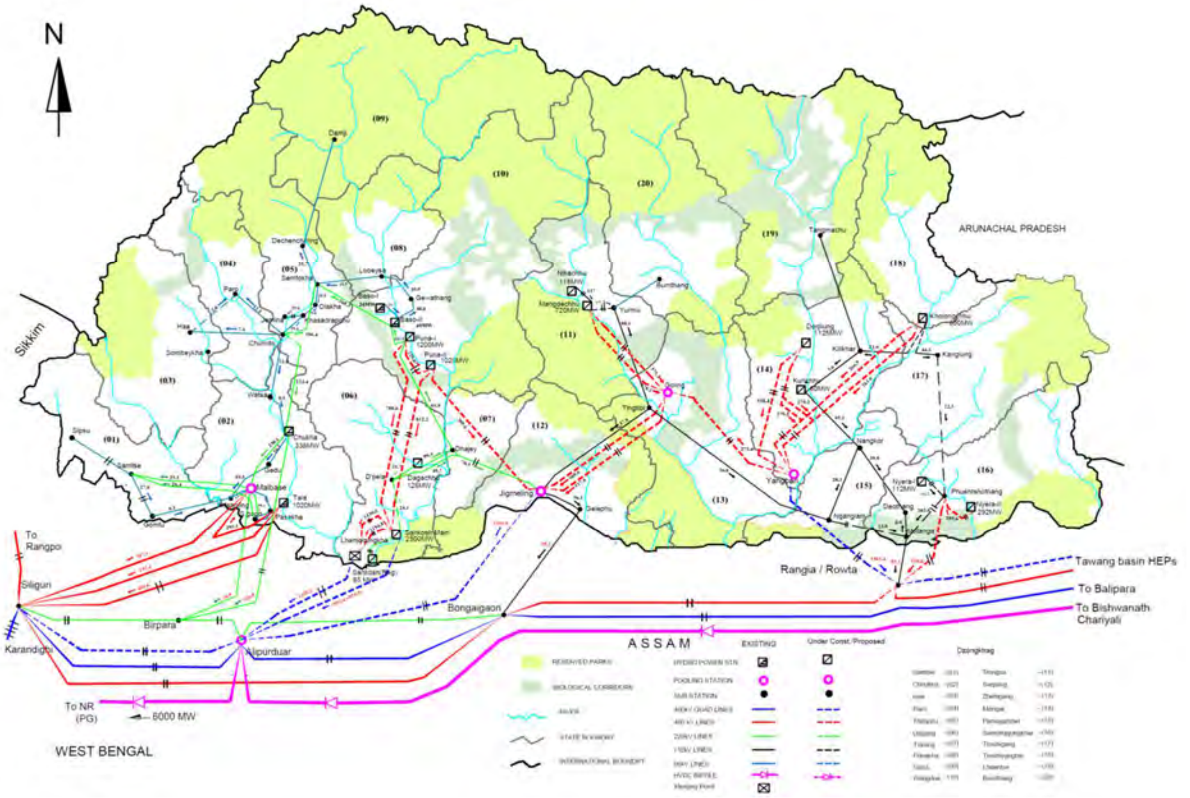
(Source: JICA Survey Team)

2) Voltage check

The voltage of all buses is within the allowable range.

9.2.4 National Grid by 2030

The power system diagram for 2030 according to the current plan is shown below.



(Source: NTGMP of Bhutan - 2018)

Figure 9-28 Power System Diagram for 2030

(1) Development plan for 2030

(a) Generation developments planned by 2030

Dorjilung, Sankosh, and Nyera Amari I & II power stations are planned to operate by 2030, so these generators and relevant transmission system equipment are included in the model for the analytic study. Their equipment augmentations for 2030 are listed in the table below.

Table 9-23 Equipment to be constructed by 2030

Generation equipment

Location	Power output	Rated power of a unit and quantity
Sankosh	2,585MW	(312.5MW x 8, 28.3MW x 3)
Dorjilung	600MW	(150MW x 4)
Nyera Amari-I	112MW	(56MW x 2)
Nyera Amari-II	292MW	(97.3MW x 3)

Transmission line

Voltage	From	To	Main specifications
400kV	PHEP-I	Sankosh RB	1 x 2 circuits, Moose x 2, 82.9km
400kV	PHEP-II	Sankosh LB	1 x 2 circuits, Moose x 2, 70.5km
400kV	Sankosh RB	Lhamoizingkha	1 x 2 circuits, Moose x 2, 20.0km
400kV	Sankosh LB	Lhamoizingkha	1 x 2 circuits, Moose x 2, 20.0km
400kV	Sankosh RB, LB	Alipurduar	1 x 2 circuits, Moose x 4, 79.0km
220kV	Sankosh	Sankosh (Regulation)	1 x 2 circuits, Zebra x 1, 13.0km
220kV	Dagapela	Sankosh	1 x 1 circuits, Zebra x 1, 28.0km
400kV	Dorjilung	Yangbari	2 x 2 circuits, Moose x 2, 38.0km
400kV	Yangbari	Rangia	1 x 2 circuits, Moose x 4, 40.0km
132kV	Nyera Amari-I	Phuentshothang	1 x 2 circuits, Panther x 1, 5.0km
400kV	Nyera Amari-II	Phuentshothang	1 x 2 circuit, Moose x 2, 5.0km

Substation equipment

Voltage	Location	Main specifications
400/220kV	Sankosh	Transformer, 2 x 104 MVA
400kV	Sankosh RB, LB	Step-up transformer, 8 x 382MVA
220kV	Sankosh (Regulation)	Step-up transformer, 3 x 35MVA
400kV	Dorjilung	Step-up transformer, 6 x 240MVA
132kV	Nyera Amari-I	Step-up transformer, 2 x 78MVA
400kV/132kV	Phuentshothang	Transformer, 3 x 67 MVA
400kV	Nyera Amari-II	Step-up transformer, 3 x 135MVA

(Source: NTGMP of Bhutan - 2018)

(b) Shunt capacitors

The shunt capacitors which were determined to be necessary to maintain the voltages for 2025 in the NTGMP of Bhutan - 2018 were adopted as the base case conditions. (See Table 9-5.)

(2) System configuration in northwest area

The system configuration in the northwest region is based on radial systems for 2030. The difference from the system configuration for 2025 (see Table 9-13) is that the 220kV transmission line between Semtokha and Chumdo substations is also disconnected. The reason for opening the 220 kV transmission line between Semtokha and Chumdo substations will be described later.

(3) Power flow analysis for 2030 under N-0 conditions

(a) Power flow analysis for 2030 under the N-0 conditions in the base case

The following shows the power flow analysis results calculated under N-0 condition.

1) Power flow check

There are no overloaded facilities. The table below shows some heavily-loaded facilities as a reference. The whole power flow diagram is shown in the appendixes.

Table 9-24 Power Flow Analysis Results under N-0 Conditions: Relatively heavily-loaded Facilities

TL (1)	From			To			CCT	Loading	Rating	Percent
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.	(MVA)	(MVA)	(%)
1	623	Khasadrapchu	66	91604	Chumdo_CB2	66	1	38.8	39	99.5
1	107	Motanga	132	211150	Rangia1	132	1	86.5	95	91.1
0	208	Singhigaon	220	621	Singhigaon	66	1	43.3	50	86.5
0	208	Singhigaon	220	621	Singhigaon	66	2	27.3	35	78.1

TL(1): Transmission Line, TF(0): Transformer

(Source: JICA Survey Team)

2) Voltage check

The table below lists buses of which voltages are lower than the minimum allowable voltage (0.95p.u.).

Table 9-25 Power Flow Analysis Results under N-0 Conditions: Buses with Lower Voltages than the Minimum Allowable Value

Bus Number	Bus Name	Base kV	Voltage (p.u.)
612	Lobeysa	66	0.94
305	RICB	33	0.95

(Source: JICA Survey Team

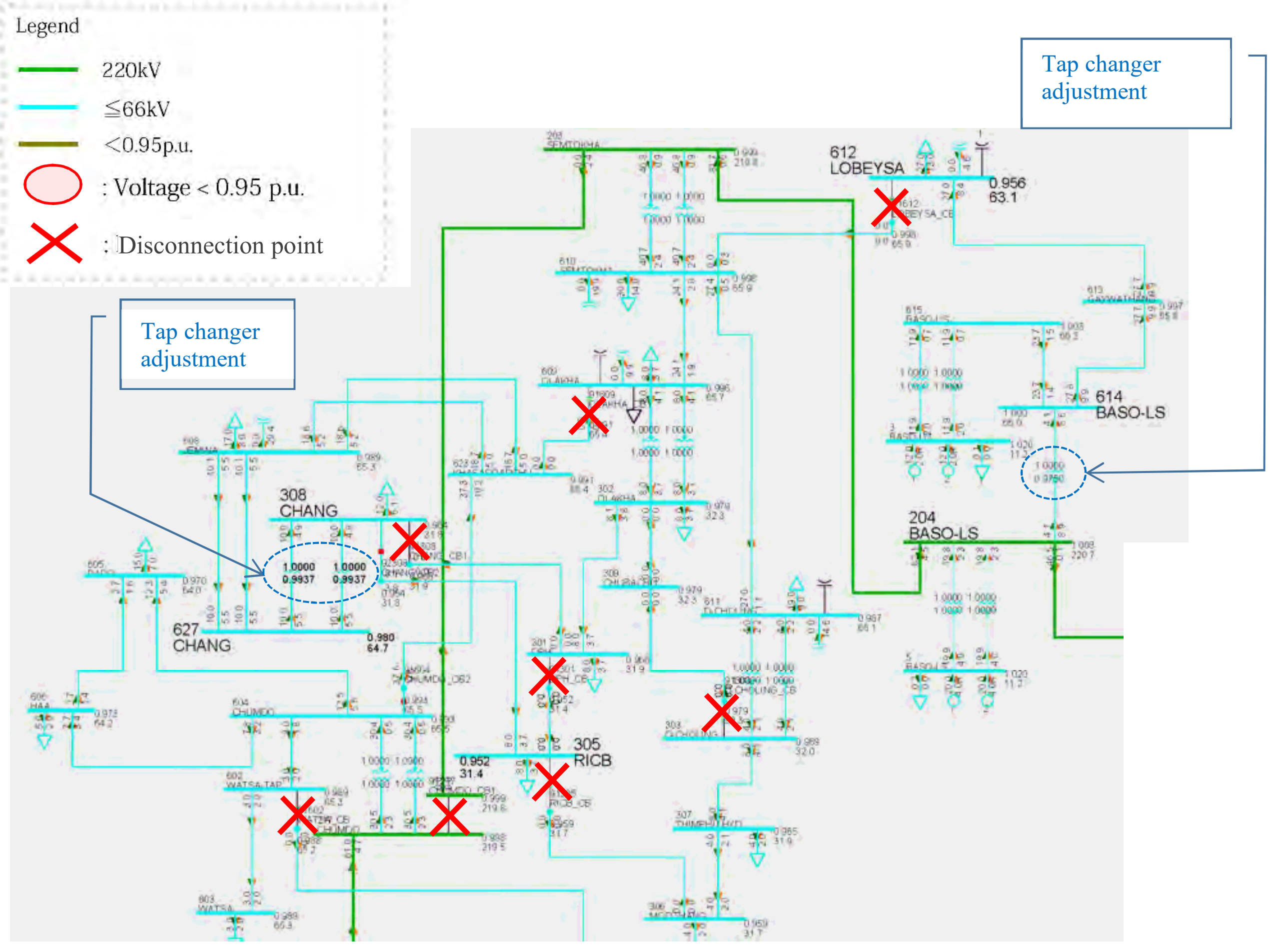
The 66kV bus voltages of Lobeysa and RICB substations are lower than the minimum allowable voltage, but this does not mean that measures to combat voltage problems, such as facility augmentations, are definitely required.

3) Measures for low voltage

As noted above, measures to combat voltage problems, such as facility augmentations, are not definitely required. Adjusting the transformer tap ratio may also mitigate the low voltage. The following adjustments was confirmed as measures against the said low voltages.

- Low voltage at Lobeysa substation: Tap changer ratio adjustment for the transformer at Basochhu power station
- Low voltage at RICB substation: Tap changer ratio adjustments for the transformers at Changidapuchu substation

The figure below shows a power flow diagram after the tap adjustments.



(Source: JICA Survey Team)

Figure 9-29 Elimination of the Low Voltage Problem in Northwest System via Tap changer Adjustments for 2030

The table below shows the low voltage problem remedied via tap changer adjustments.

Table 9-26 Comparison of the Voltages before and after the Tap changer Adjustments for 2030

Bus Number	Bus Name	Base kV	Voltage (p.u.)	
			Before	After
612	Lobeysa	66	0.940	0.956
305	RICB	33	0.946	0.952

(Source: JICA Survey Team)

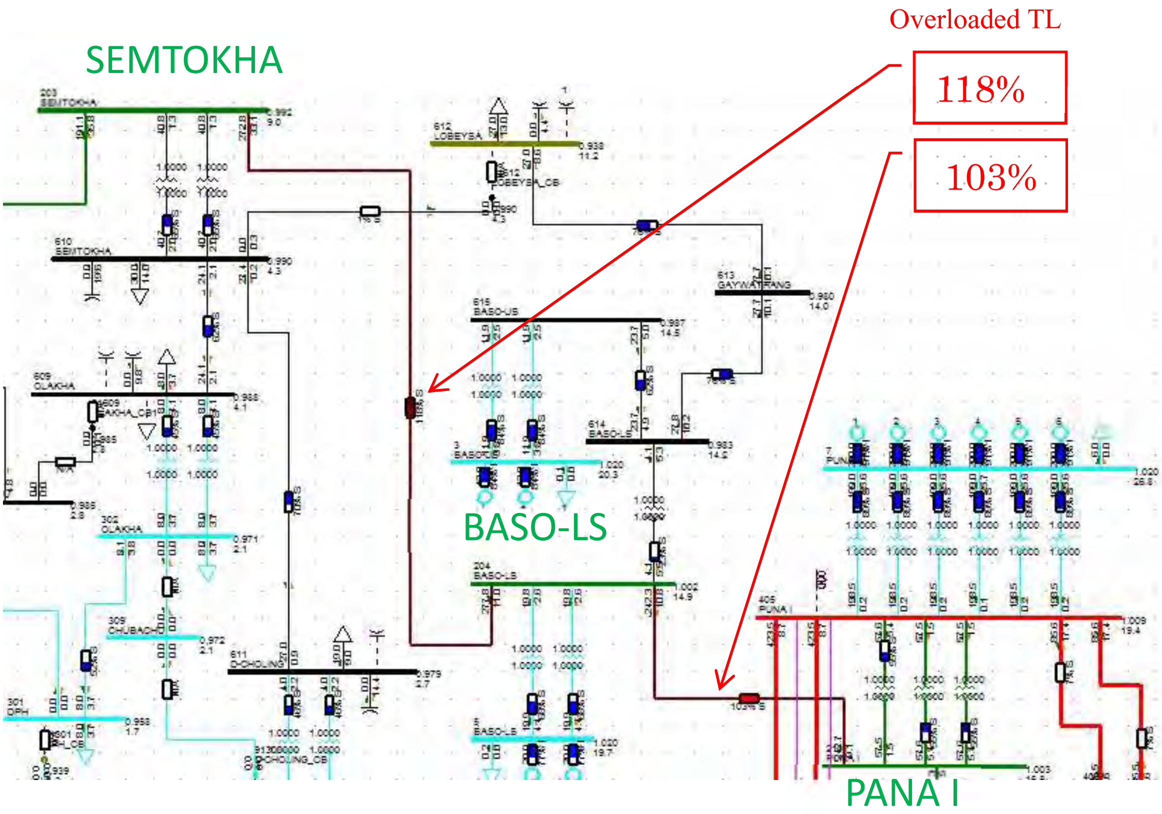
(b) Power flow analysis for 2030 under the N-0 conditions with loop configuration in 220kV northwest system

1) Power flow calculation results for 2030 under the N-0 conditions

The following shows the power flow calculation results for 2030 under the N-0 conditions with a loop configuration in the 220kV northwest system.

a) Power flow check

As shown in the figure below, since the 220kV transmission lines between Punatsangchhu power station and Semtokha substation are overloaded even under N-0 conditions, some measures are necessary for these problems.



(Source: JICA Survey Team)

Figure 9-30 Power Flow Calculation Results for 2030 with 220kV Radial Configuration System in the Northwest Area

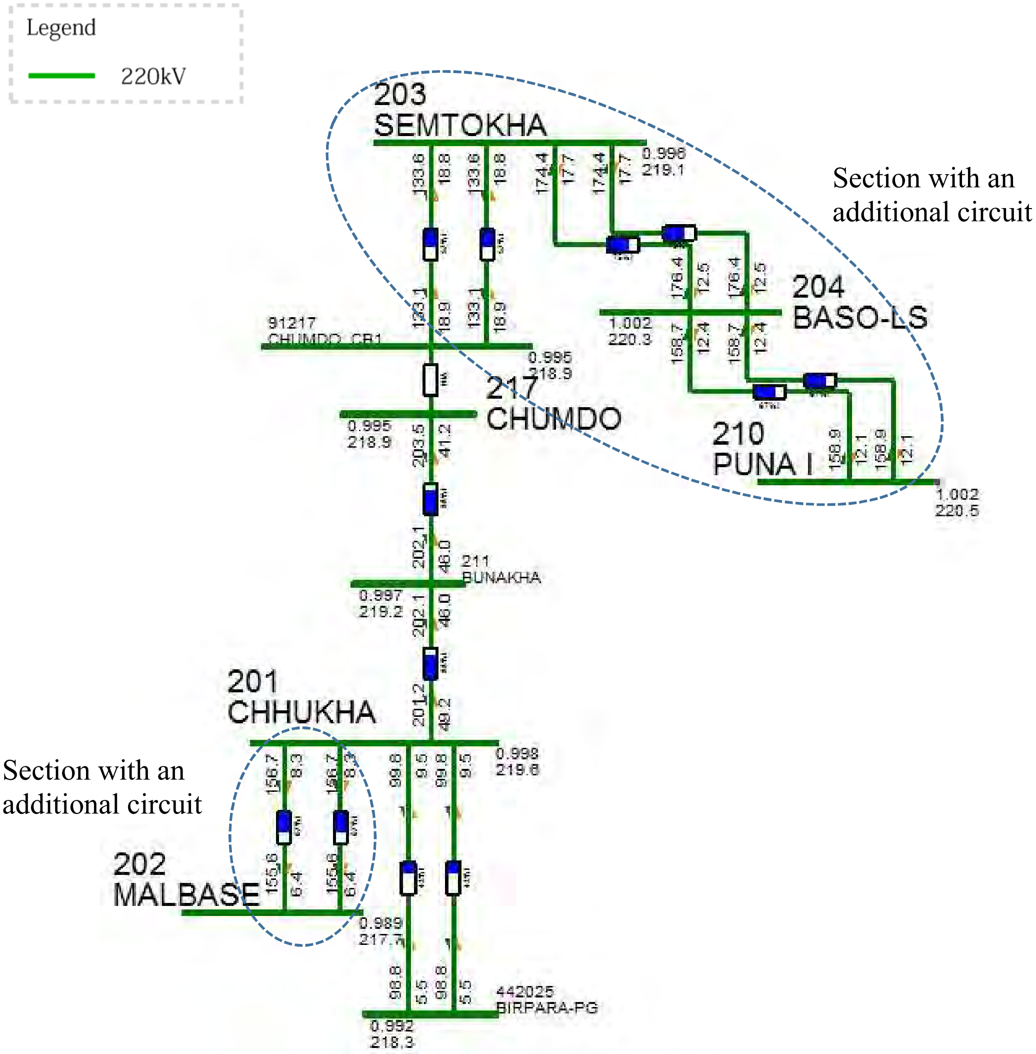
The following two kinds of measures can be considered for the overload.

- Split the 220kV system at a proper point and
- Augment the 220kV system

2) Augmentation of 220kV system in northwest area with the loop configuration for the 220kV northwest system

A power flow calculation with an augmentation of a circuit of additional transmission line between Punatsangchhu power station and Semtokha substation was performed as a measure to combat overloading of the existing transmission line on the same section. The result was an overloading of other 220kV transmission line sections, between Semtokha and Chumdo (Loading ratio: 102%) and between Chhukha and Malbase (Loading ratio: 106%), due to the reduction in impedance of the said augmented transmission line section.

The figure below shows a simple power flow diagram with additional transmission lines for the same existing overloaded transmission line sections.



(Source: JICA Survey Team)

Figure 9-31 Power Flow Calculation Results for 2030: 220kV Loop Configuration System in the Northwest Area with additional 220kV T/L between Punatsangchhu and Chumdo and between Chhukha and Malbase

This system configuration plan is also an option to take. Since the 220kV transmission line between Punatsangchhu power station and Chumdo substation delivers power to the capital city Thimphu and its outskirts, and is a very important route for that reason, reduplicating the route has advantages. However, according to the latest generation plan, a double circuit 220kV transmission line between Bunakha power station and Malbase substation will have been constructed in line with operation commencement of Bunakha power station in 2035, and power flow through the 220kV transmission line between Chhukha and Malbase will decrease in future. Thus, the advantages of reduplication of this route for 2030 are insignificant.

To reduplicate the 220kV transmission line between Punatsangchhu and Chumdo and avoid reduplicating the 220kV transmission line between Chhukha and Malbase as well, it is reasonable to wait until operation commencement of the double circuit 220kV transmission line between Bunakha and Malbase.

(4) Power flow analysis for 2030 under N-1 conditions

(a) Power flow analysis results for 2030 under N-1 conditions with a 220kV radial system configuration in the northwest area

The power flow calculations were conducted under N-1 conditions with a 220kV radial system configuration in the northwest area,

1) Separated system case

a) List of separated system cases

The table below shows cases where the system is separated due to a contingency under N-1 conditions, and the islanded part of the system falls into a blackout. The case in which blackout load power is the largest is the one with a contingency of the 220kV transmission line between Basochhu and Punatsangchhu-I power stations, whereby 108MW loads are not supplied.

Table 9-27 Power Flow Analysis Results under N-1 Conditions: Case with System Separation

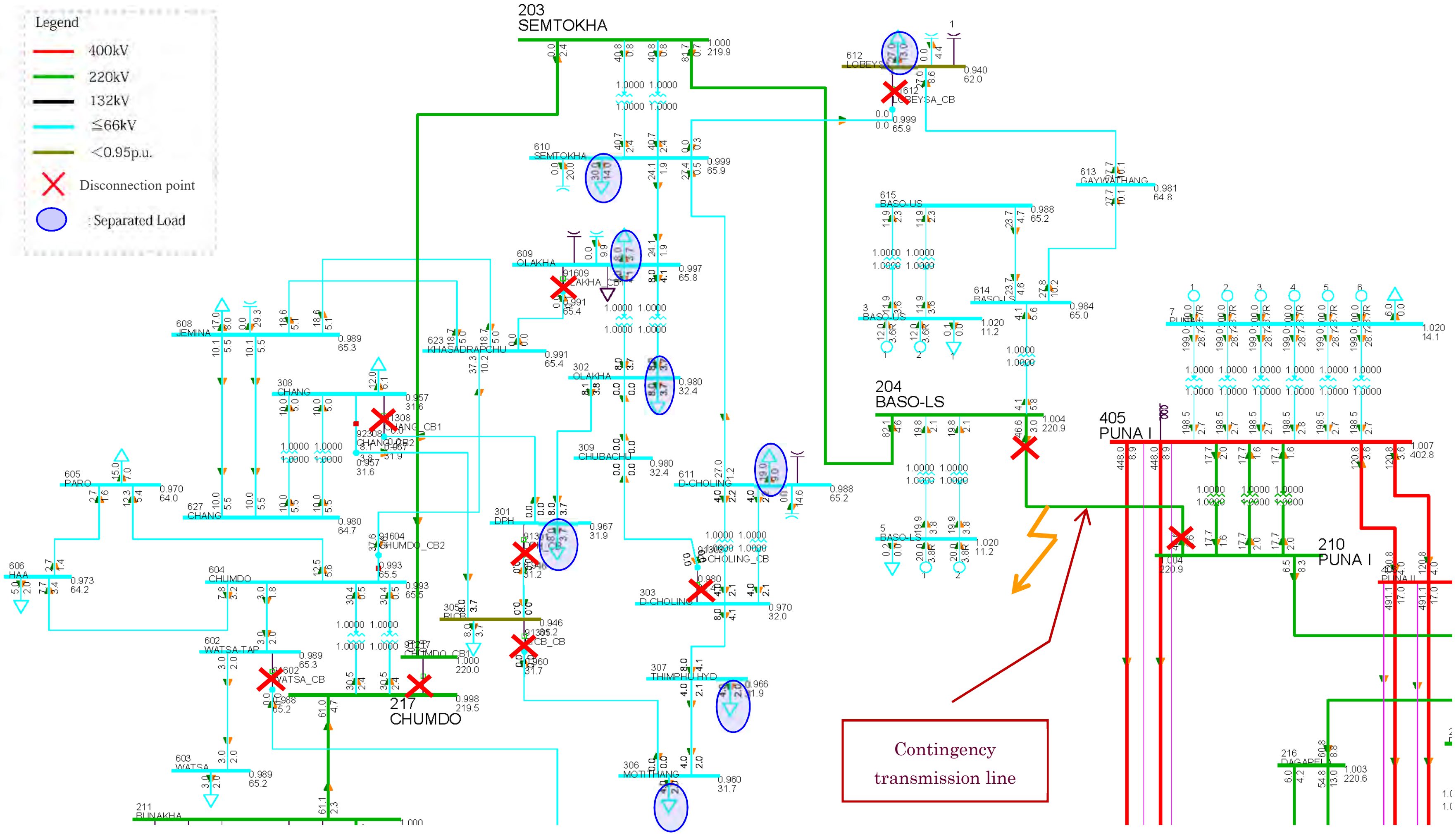
Contingency								Islanding Bus #	Unsupplied power (MW)
TL (1)	From			To			CCT		
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.		
1	204	Baso-LS	220	210	Punatsangchhu Ii	220	1	22	108
1	203	Semtokha	220	204	Baso-LS	220	1	15	81
1	201	Chhukha	220	217	Chumdo	220	1	15	60
1	623	Khasadrapchu	66	91604	Chumdo_CB2	66	1	8	37
1	610	Semtokha	66	611	Dechencholing	66	1	5	27
1	612	Lobeysa	66	614	Baso-LS	66	1	2	27
1	609	Olakha	66	610	Semtokha	66	2	6	24
1	602	Watsa-tap	66	604	Chumdo	66	2	2	3
1	602	Watsa-tap	66	603	Watsa	66	1	1	3
0	204	Baso-LS	220	614	Baso-LS	66	1	5	27

TL(1): Transmission Line, TF(0): Transformer

(Source: JICA Survey Team)

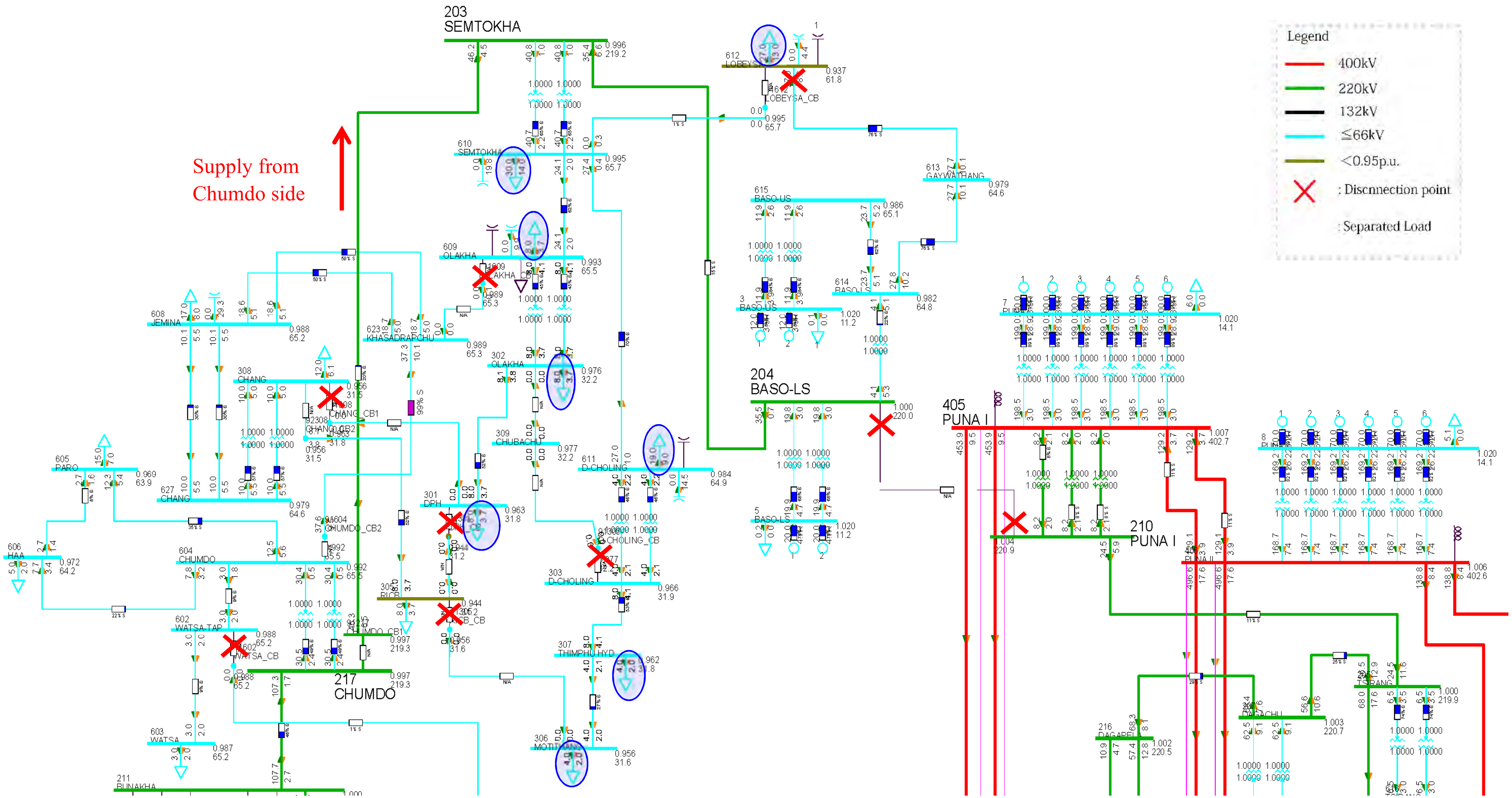
b) Contingency of 220kV transmission line between Basochhu and Punatsangchhu power stations

The figure below shows unsupplied loads after a separation from the main system due to a contingency of the transmission line between Basochhu and Punatsangchhu power stations. Even if the contingency is persistent, it is possible to deliver electricity to the tentatively unsupplied loads via the 220kV transmission line between Semtokha and Chumdo substations. Figure 9-33 shows a power flow diagram for supplying power from the Chumdo side.



(Source: JICA Survey Team)

Figure 9-32 Power Flow Calculation Results for 2030 with a 220kV T/L Contingency between Basochhu and Punatsangchhu: Part of the System is separated from the Main System and falls into Blackout



(Source: JICA Survey Team)

Figure 9-33 Power Flow Calculation Results for 2030 after the 220kV T/L Contingency between Basochhu and Punatsangchhu: System Configuration for recovering the Unsupplied Loads

c) Contingency of 220kV transmission line between Basochhu and Semtokha

The second largest unsupplied power case is the 220kV transmission line contingency between Basochhu and Semtokha in Table 9-27. Even if the contingency is persistent, it is possible to deliver electricity to the tentatively unsupplied loads via the 220kV transmission line between Semtokha and Chumdo substations, which was open before the outage.

d) Contingency of 220kV transmission line between Chhukha and Chumdo

Even if the contingency is persistent, it is possible to deliver electricity to the tentatively unsupplied loads via the 220kV transmission line between Semtokha and Chumdo substations, which was open before the outage.

From the above, it is possible to deliver electricity to the tentatively unsupplied loads under a disconnection of any 220kV transmission line section between Punatsangchhu-I and Chhukha without any serious problem.

2) Power flow check

a) List of overloaded facilities

The table below shows overloaded facilities under N-1 conditions

Table 9-28 Power Flow Calculation Results under N-1 Conditions for 2030: Overloaded Facilities

Contingency								Overloaded facility	Load factor (%))
TL (1)	From			To			CCT		
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.		
1	107	Motanga	132	115	Phuentshothang	132	1	107 Motanga 132 115 Phuentshothang 132 2	144.6
1	107	Motanga	132	115	Phuentshothang	132	2	107 Motanga 132 115 Phuentshothang 132 1	144.6
1	101	Kurichhu	132	104	Nangkor	132	1	107 Motanga 132 115 Phuentshothang 132 1	105.0
								107 Motanga 132 115 Phuentshothang 132 2	105.0
1	112	Mangdechhu	132	113	Nikachhu	132	1	112 Mangdechhu 132 113 Nikachhu 132 2	104.8
1	112	Mangdechhu	132	113	Nikachhu	132	2	112 Mangdechhu 132 113 Nikachhu 132 1	104.8
0	208	Singhigaon	220	621	Singhigaon	66	1	208 Singhigaon 220 621 Singhigaon 66 2	221.9
0	205	Tsirang	220	616	Tsirang	66	1	205 Tsirang 220 616 Tsirang 66 2	149.4
0	205	Tsirang	220	616	Tsirang	66	2	205 Tsirang 220 616 Tsirang 66 1	149.4
0	208	Singhigaon	220	621	Singhigaon	66	2	208 Singhigaon 220 621 Singhigaon 66 1	144.7
0	203	Semtokha	220	610	Semtokha	66	1	203 Semtokha 220 610 Semtokha 66 2	131.0
0	203	Semtokha	220	610	Semtokha	66	2	203 Semtokha 220 610 Semtokha 66 1	131.0
0	108	Gelephu	132	622	Gelephu	66	1	108 Gelephu 132 622 Gelephu 66 2	125.5
0	108	Gelephu	132	622	Gelephu	66	2	108 Gelephu 132 622 Gelephu 66 1	125.5
0	404	Mangdechhu	400	112	Mangdechhu	132	1,2,3	109 Tingtibi 132 110 Yurmo 132 1	113.9
0	202	Malbase	220	618	Malbase	66	1	202 Malbase 220 618 Malbase 66 2	100.5
								202 Malbase 220 618 Malbase 66 3	100.5
0	202	Malbase	220	618	Malbase	66	2	202 Malbase 220 618 Malbase 66 1	100.5
								202 Malbase 220 618 Malbase 66 3	100.5
0	202	Malbase	220	618	Malbase	66	3	202 Malbase 220 618 Malbase 66 2	100.5
								202 Malbase 220 618 Malbase 66 1	100.5

TL(1): Transmission Line, TF(0): Transformer

(Source: JICA Survey Team)

b) Transformer outage at Singhigaon substation

The highest overloaded ratio for 2030 is caused by a transformer outage at Singhigaon substation, as per 2020 and 2030. Installing another new 50MVA transformer at Singhigaon substation is deemed to be an option to take. If the installation of another transformer at Singhigaon substation is delayed, and if the existing 50MVA transformer becomes persistently out of order, electricity will be delivered via properly selected 66kV transmission line feeders from the remaining 35MVA transformer, as per the cases for 2020 and 2025.

c) Transformer outage at other substations

Installing the same capacity transformer as the existing one is an option to take.

d) Overloading of 132kV transmission lines in southeast area

Since 400kV international tie lines with Rangia substation in the Indian system are augmented in 2030 (a new double circuit transmission line from Phuentshothang substation and a new double circuit transmission line from Yangbari substation), there is possibly no problem in disconnecting the existing 132kV transmission line between Motanga and Rangia substations. The table below shows the power flow calculation results for transmission lines under N-1 conditions with the 132kV transmission line between Motanga and Rangia substations kept open.

Table 9-29 Power Flow Calculation Results under N-1 Conditions for 2030: 132kV T/L between Motanga and Rangia substations kept open

Contingency								Overloaded facility	Over loaded ratio (%)
TL (1)	From			To			CCT		
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.		
1	107	Motanga	132	115	Phuentshothang	132	1	107 Motanga 132 115 Phuentshothang 132 2	110.0
1	107	Motanga	132	115	Phuentshothang	132	2	107 Motanga 132 115 Phuentshothang 132 1	110.0
1	112	Mangdechhu	132	113	Nikachhu	132	1	112 Mangdechhu 132 113 Nikachhu 132 2	104.9
1	112	Mangdechhu	132	113	Nikachhu	132	2	112 Mangdechhu 132 113 Nikachhu 132 1	104.9

(Source: JICA Survey Team)

The overloaded ratio of a 132kV transmission line between Motanga and Phuentshothang is 110%. As the overload can be eliminated via output power reductions of properly selected generators, the overload is not critical.

3) Voltage check

A power flow calculation was performed under N-1 conditions with a radial configuration in the northwest system and the disconnection of the 132kV tie line with the Indian system in the southeast system. The table below shows the case in which bus voltage is lower than the minimum allowable voltage.

Table 9-30 Power Flow Analysis Results under N-1 Conditions: Bus Voltage

Contingency								Out of the allowable range	
TL (1)	From			To			CCT	Low voltage bus	Voltage
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.		(p.u.)
0	208	Singhigaon	220	621	Singhigaon	66	1	621 Singhigaon 66	0.88

(Source: JICA Survey Team)

The 66kV bus voltage of Singhigaon substation is lower than the minimum allowable voltage, but this does not mean that facility measures for the voltage problem are definitely required.

(5) Fault current analysis

A fault current calculation was performed for 2030 under relatively severe conditions as shown below.

(a) Conditions for the fault current calculation

The generation plan is based on the NTGMP of Bhutan - 2018. Planned system configurations are also based on the said NTGMP, and the following revisions are taken into account.

- 66kV and 33kV systems in the northwest area are radial
- 220kV west system configuration is a loop one, as a severe condition. To enable this loop configuration, the transmission line between Punatsangchhu-I power station and Chhukha substation is reduplicated. The conductor type for the transmission line is Zebra, which is necessary as of 2050.

- With regard to overloading of the transmission line between Chhukha and Malbase substations, reconductoring with high temperature low sag conductors is assumed. Therefore, the same impedance as the original one is used.

(b) Fault current calculation results

Short circuit currents at busses are shown in the table below.

Table 9-31 Fault Current Calculation Results

400kV			220kV			132kV		
Bus No.	Bus name	Fault Current (kA)	Bus No.	Bus name	Fault Current (kA)	Bus No.	Bus name	Fault Current (kA)
444073	Alipurduar	45.9	442071	Siliguri-PG	30.7	115	Phuentshothang	19.4
444072	Siliguri-PG	45.8	212190	Bongaigaon	29.9	611150	Rangia1	16.9
644072	Siliguri-PG	45.4	642071	Siliguri-PG	29.5	211150	Rangia1	16.8
409	Lhamoizingkha	39.1	612190	Bongaigaon	29.5	116	Nyera Amari-I	16.2
406	Punatsangchhu II	38.1	442073	Alipurduar	25.6	107	Motanga	13.8
418	Sankosh LB	38.0	212203	Rangia	21.5	112	Mangdechhu	10.5
214170	Bongaigaon	38.0	442025	Birpara-PG	21.3	110	Yurmo	9.8
214151	Rangia	37.8	201	Chhukha	16.6	114	Kholongchhu	9.7
419	Sankosh RB	37.4	212380	Rangia2	16.5	113	Nikachhu	9.1
614170	Bongaigaon	37.1	206	Jigmeling	15.5	106	Deothang	9.1
614151	Rangia	36.6	210	Punatsangchhu I	14.4	105	Nganglam	8.6
405	Punatsangchhu I	35.9	211	Bunakha	14.0	111	Jigmeling	8.0
410	Yangbari	35.6	204	Baso-LS	13.9	104	Nangkor	7.7
407	Jigmeling	33.1	202	Malbase	13.4	109	Tingtibi	7.3
408	Goling	31.7	612380	Rangia2	13.4	101	Kurichhu	6.6
411	Dorjilung	28.2	205	Tsirang	13.0	103	Kanglung	6.5
404	Mangdechhu	25.1	217	Chumdo	12.3	102	Kilikhar	6.4
401	Tala	20.5	208	Singhigaon	12.1	108	Gelephu	5.5
414	Phuentshothang	17.9	207	Dagachhu	12.1	211550	Salakati1	5.1
403	Kholongchhu	17.1	216	Dagapela	12.1			
413	Nyera-Amari II	17.1	612203	Rangia	11.8			
402	Malbase	16.1	203	Semtokha	11.8			
				Sankosh RB	9.5			
				Birpara-PG	9.3			
				Sankosh (reg.)	8.2			
				Samtse	7.2			
				Sankosh LB	7.1			
				Alipurduar	3.6			

(Source: JICA Survey Team)

Since the fault current at each bus is under the corresponding current breaking capacity, there are no problems.

(6) Power flow analysis results for 2030 dry season

A power flow calculation was performed for the 2030 dry season under N-0 conditions with a radial configuration for the 66kV and 33kV systems in the northwest area and disconnection of the 132kV tie line with the Indian system in the southeast system. As previously described, output power from each power plant is 20% of the rated power, and the supply and demand balance is maintained by adjusting loads in India.

(a) Power flow check

There are no overloaded facilities. The table below shows some relatively heavily-loaded facilities as a reference. The whole power flow diagram is shown in the appendixes.

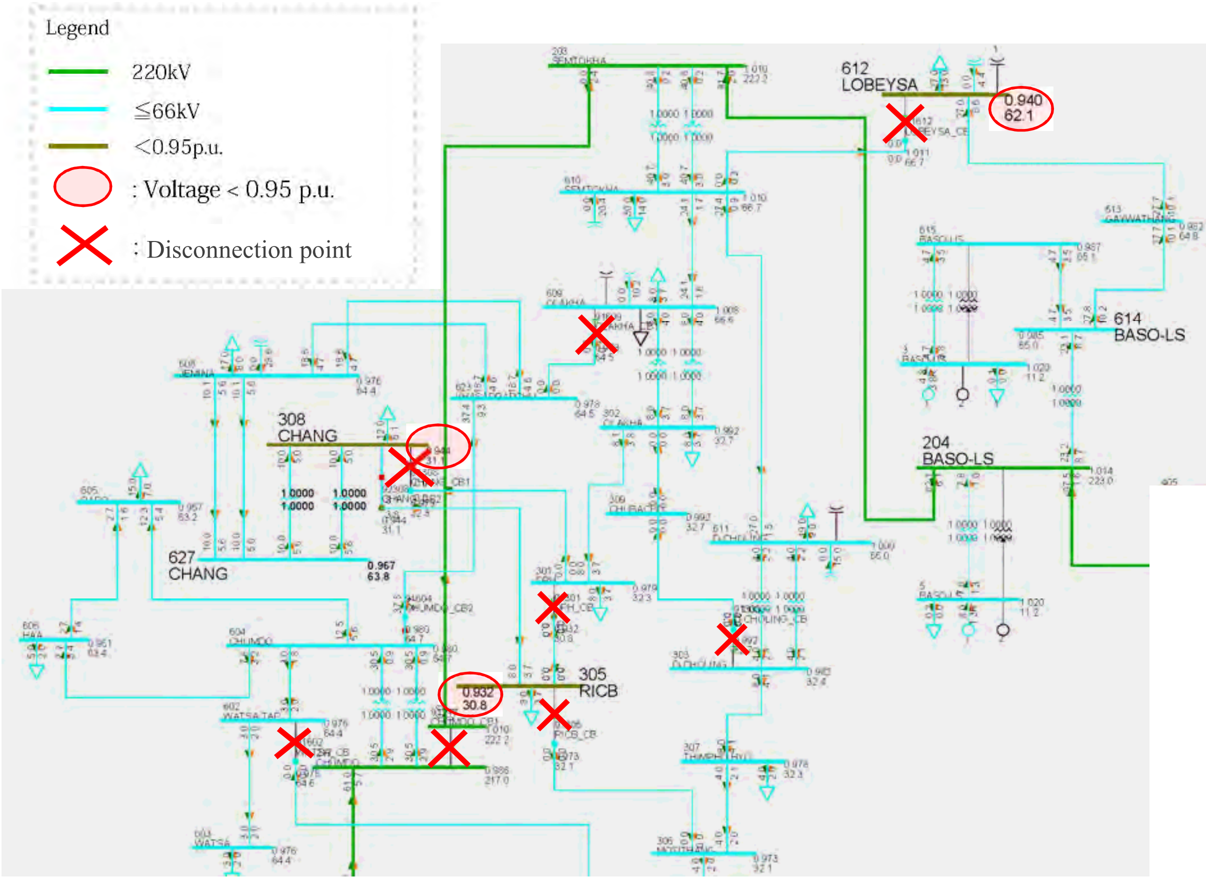
Table 9-32 Power Flow Analysis Results under N-0 Conditions: Relatively heavily-loaded Facilities

TL (1)	From			To			CCT	Loading	Rating	Percent
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.	(MVA)	(MVA)	(%)
1	623	Khasadrapchu	66	91604	Chumdo_CB2	66	1	38.6	39	99.0
1	613	Gaywathang	66	614	Baso-LS	66	1	29.6	39	75.9
0	208	Singhigaon	220	621	Singhigaon	66	1	43.3	50	86.6
0	204	Baso-LS	220	614	Baso-LS	66	1	24.8	30	82.6

(Source: JICA Survey Team)

(b) Voltage check

The figure below shows the power flow calculation results for the northwest system. Voltages in part of the northwest area are lower than 0.95 p.u., the minimum allowable voltage.



(Source: JICA Survey Team)

Figure 9-34 Power Flow Calculation Results in the Northwest System for 2030 Dry Season

(c) Measures for low voltage problem

Tap ratios of transformers in Changidapuchu substation and Basochhu power station are adjusted as measures for low voltages, as per the rainy season. The table below shows the effect of tap ratio adjustments comparing the situation before and after adjustments.

Table 9-33 Power Flow Calculation Results in the Northwest System for 2030 Dry Season. Comparison of Voltages before and after the Tap Ratio Adjustments

Bus Number	Bus Name	Base kV	Voltage (p.u.)	
			Before	After
305	RICB	33	0.93	0.95
612	Lobeysa	66	0.94	0.95
308	Changidapuchu	33	0.94	0.96

(Source: JICA Survey Team)

Adjusting tap ratios can remedy the low bus voltages and keep them within the allowable range.

(7) Power flow analysis for 2030 with 110% generator output

The power flow analysis for 2030 for the rainy season with 110% generator output was conducted under the following conditions.

- Radial configuration in the northwest power system
- N-0

1) Power flow check

There are no overloaded facilities. The table below shows some heavily-loaded facilities for reference.

Table 9-34 Power Flow Analysis Results for 2030 under N-0 Conditions with 110% generator output: Relatively Heavily-Loaded Facilities

L (1)	From			To			CCT	Loading	Rating	Percent
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.	(MVA)	(MVA)	(%)
1	623	Khasadrapchu	66	91604	Chumdo_cb2	66	1	38.8	39	99.5
1	107	Motanga	132	211150	Rangia1	132	1	89.4	95	94.1
0	208	Singhigaon	220	621	Singhigaon	66	1	43.2	50	86.5
0	208	Singhigaon	220	621	Singhigaon	66	2	27.3	35	78.1

(Source: JICA Survey Team)

2) Voltage check

Although the voltage at the 66kV bus of Gelephu substation (the Bhutan side of the 132kV international tie line with the Indian system) is slightly low, new facility measures are not necessary. The issue can be addressed by adjusting the tap ratio of transformers in the substation. The table below shows voltages at the 66kV bus of Gelephu substation before and after the tap ratio adjustment.

Table 9-35 Power Flow Analysis Result for 2030 under the N-0 Conditions with 110% generator output: Voltage Comparison before and after Tap Ratio Adjustment

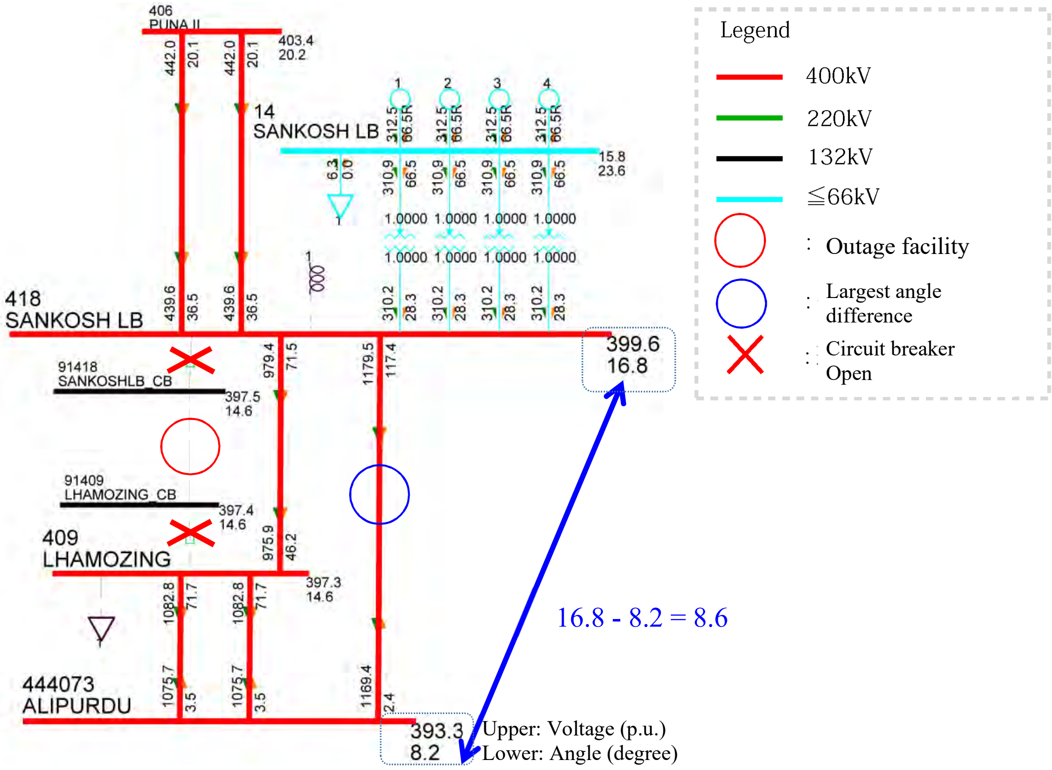
Bus Number	Bus Name	Base kV	Voltage (pu)	
			Tap ratio adjustment	
			Before	After
622	Gelephu	66	0.949	0.968

(Source: JICA Survey Team)

(8) Stability evaluation

To confirm whether the transient stability analysis is necessary or not, the power flow calculations were conducted under N-1 conditions and has calculated the angle differences of both terminals of a facility (transmission line and transformer). The configuration in the northwest system, including 220kV transmission lines, is assumed to be radial as a severe condition for stability.

The largest angle difference is 8.6 degrees, which is between both terminals of the Sankosh-LB side circuit at 2 circuits of the transmission line between Sankosh power station and Alipurduar substation, under the contingency of a circuit of the 400kV transmission line between Sankosh LB power station and Lhamoizingkha substation (400kV buses of Sankosh LB and Sankosh RB power stations are assumed to be split).



(Source: JICA Survey Team)

Figure 9-35 Power Flow Calculation Results for 2030: Case with the Largest Angle Difference

Since the largest angle difference shown above is sufficiently smaller than 20 degrees, the judgment threshold angle difference in the stability criterion, there is no problem at this angle difference level.

9.3 Transmission Plan for Short-listed Power Plants

The transmission plans for18 short-listed hydropower plant candidate sites are as follows.
All the new transmission lines are double-circuit transmission lines, and the voltage is selected on the condition that power can be stably transmitted without curtailment of the generated output, even in the event of a single-circuit accident.
Among these transmission plans, the plan at the Minjey site crosses a biological corridor (about 3km), but there are no other sites that cross protected areas.

Table 9-36 Transmission Plans for Short-listed Hydropower Plants

Project code	Voltage	From	To	Length (km)
A-5	400kV	Tingma	Amochhu Reservoir	48.7
A-8	400kV	Dorokha	Amochhu reservoir	26.6
P-15	220kV	Tseykha	Punatsangchhu-I	37.9
P-26	400kV	Thasa	LILO	2.3
P-29	132kV	Kago	Punatsangchhu-II	9.3
P-30	220kV	Pinsa	Punatsangchhu-II	5.2
P-34	220kV	Darachhu	Dagachhu II	2.3
P-35	220kV	Dagachhu II	Dagapela	18.0
M-6	400kV	Jongthang	Mangdechhu	23.6
M-11	400kV	Wangdigang	LILO	4.4
M-17	132kV	Buli	Goling	10.5
C-7	400kV	Chamkharchhu-IV	Mangdechhu	53.9
C-10	400kV	Chamkharchhu-II	Chamkharchhu-I	35.9
K-13	400kV	Minjey	Dorjilung	35.0
G-10	220kV	Gamrichhu-2	Gamrichhu-1	22.2
G-11	220kV	Gamrichhu-1	Uzorong	27.1
G-14	400kV	Uzorong	Dorjilung	25.9
N-1	132kV	Nyera Amari Kangpara	Phuentshothang	55.6

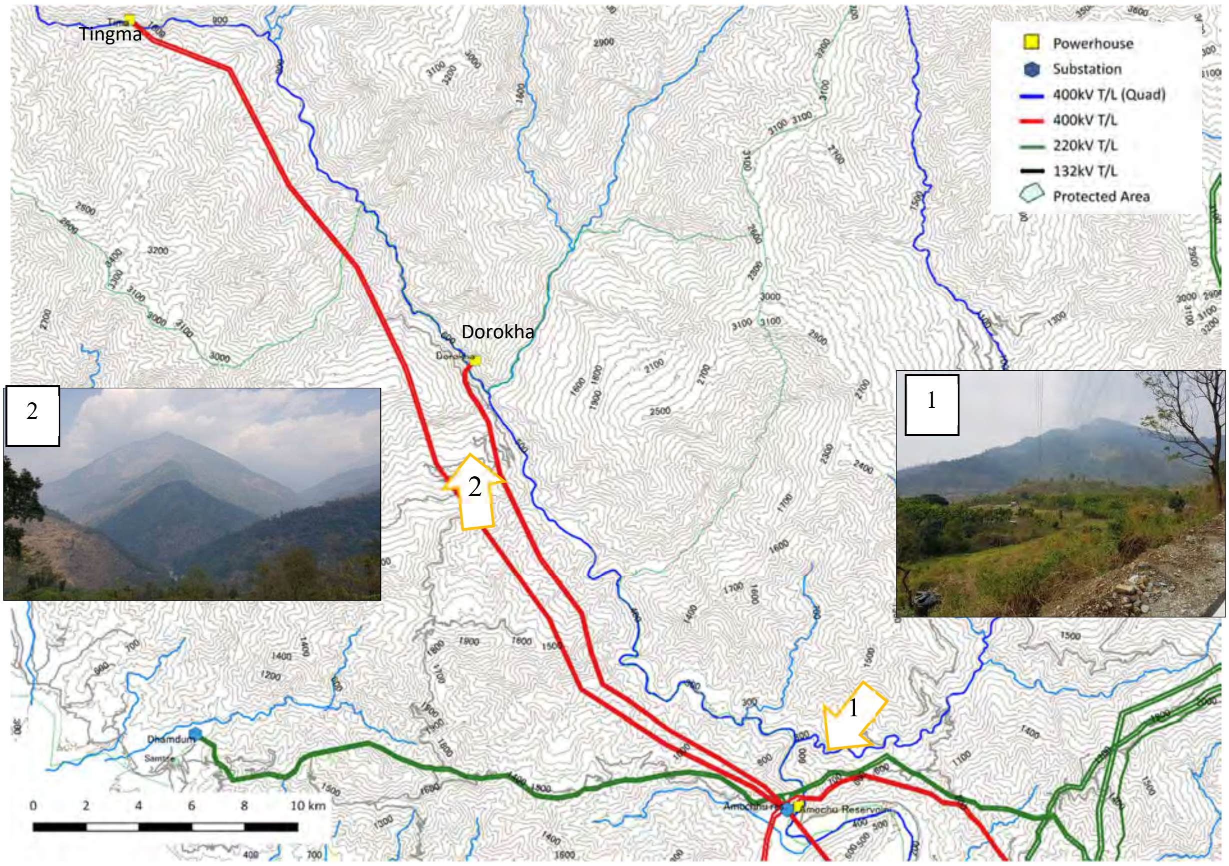
Among the transmission plans in Table 9-36, field surveys were conducted on the following power transmission lines and pooling stations. The validity of the routes and location points, and the necessity of route changes, etc. were confirmed.

- Dorokha line
- Pinsa line
- Chamkharchhu II line
- Chamkharchhu IV line
- Jongthang line
- Uzorong line
- Gamrichhu 2 line
- Goling Pooling Station
- Yangbari Pooling Station

(1) Tingma site (783MW), Dorokha site (550MW)

Since both sites are planned to connect to Amochhu Substation via a 400kV transmission line, two transmission line routes are necessary, from near the Dorokha site to the Amochhu Substation. Because the topography is steep around the Dorokha site, it is difficult to secure a large area for a switching station. However, it is possible to connect the Tingma site to Amochhu Substation via the Dorokha site by using only one transmission line if the land area for this can be secured. In this case, since it is necessary to apply 4 bundle conductors for the transmission line between Dorokha and Amochhu substation, when developing the Dorokha site it is necessary to formulate an appropriate transmission plan based on the development plans for both sites.

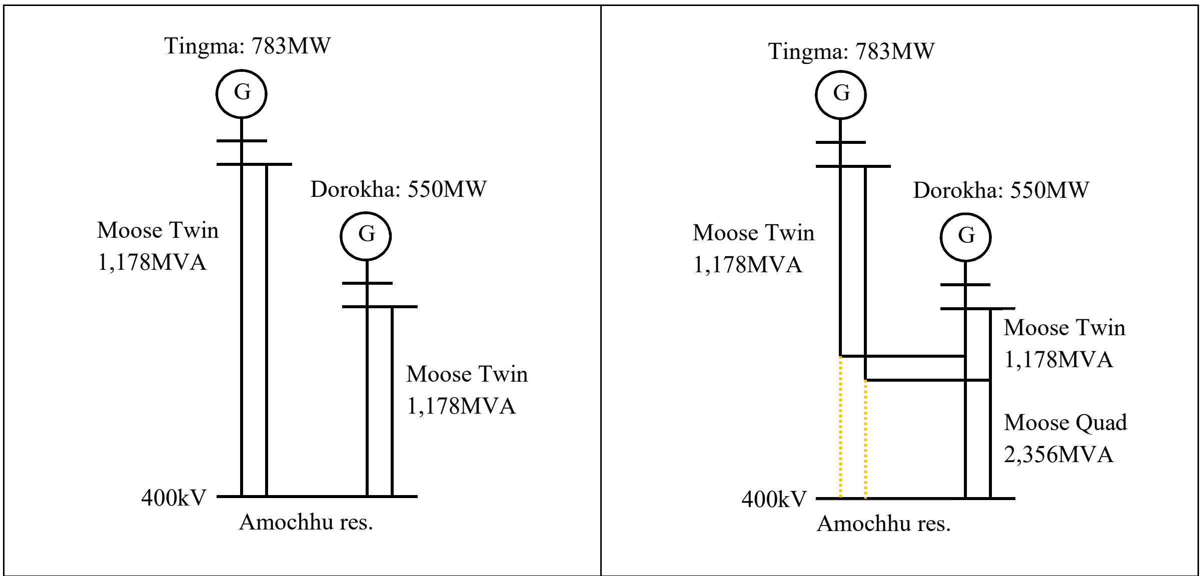
The Amochhu substation was originally planned to be constructed on the riverbank, but due to concerns about the river flooding, it is recommended to change the location to high ground/a hill near the existing 400kV transmission line, which is on the west side of the initial location point.



(Source: JICA Survey Team)

Figure 9-36 Transmission Line Routes for Tingma Site and Dorokha Site

Two transmission lines are required from around the Dorokha site to the Amochhu substation. By adopting T-connection technology as shown in the figure below, the transmission route distance, number of routes, and amount of substation equipment can be reduced.



Original: Current Plan	Proposal: Application of T-Connection Technology

(Source: JICA Survey Team)

Figure 9-37 Single Line Diagram after Application of T-Connection Technology

Table 9-37 Comparison between Current Plan and Plan after Application of T-Connection Technology

(Unit: million Nu.)

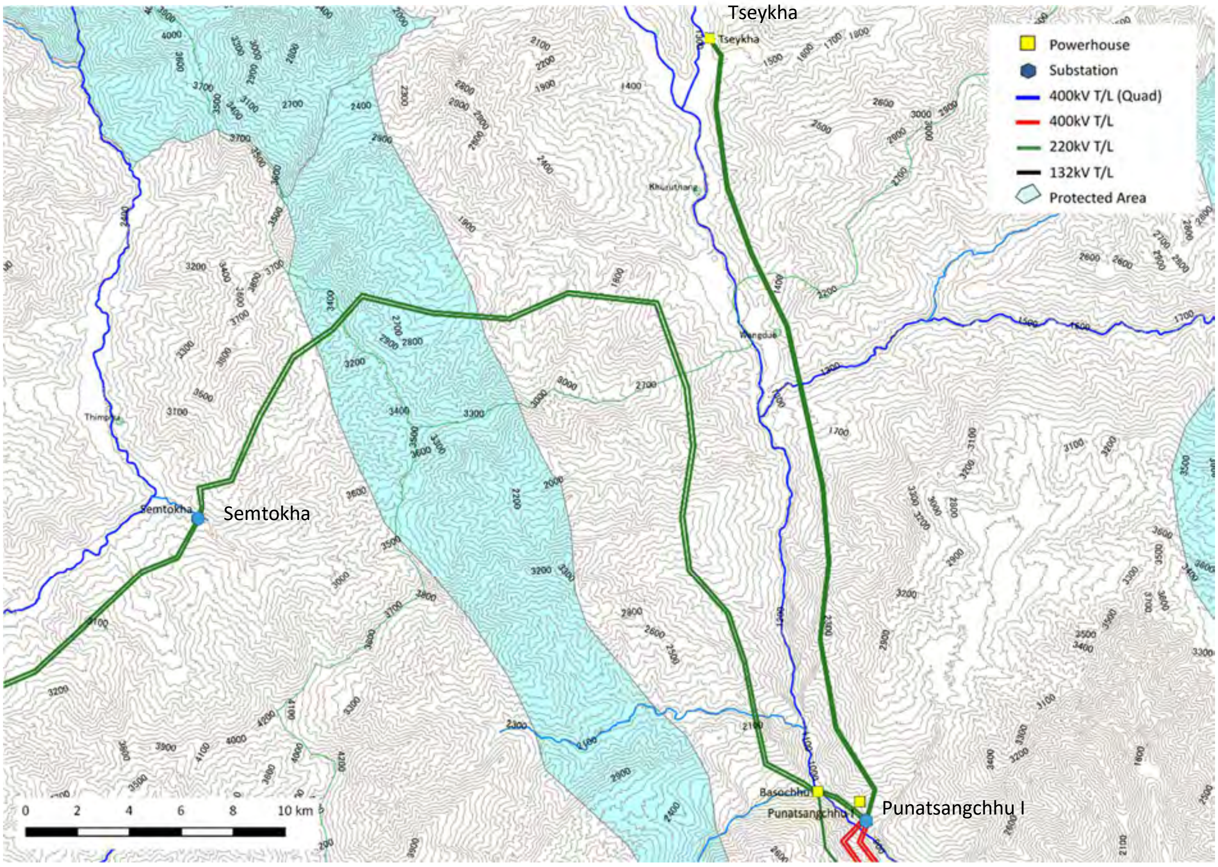
		Unit price (million Nu.)	Original		Proposal		Cost reduction
			Unit	Cost	Unit	Cost	
Tingma	T/L (Twin)	49.0	48.7km	2,386	25.1km	1,230	1,156
	CB	160.8	2	322	2	322	0
Dorokha	T/L (Twin)	49.0	26.6km	1,303	1.0km	49	1,254
	T/L (Quad)	65.2		0	25.6km	1,669	-1,669
	CB	160.8	2	322	2	322	0
Amochhu res	CB	160.8	4	643	2	322	322
Total				4,976		3,913	1,063

(Source: JICA Survey Team)

When 4 bundle conductors are applied, enough tower strength is necessary and the tower weight has to increase especially for dead end towers at substations. Moreover, the application of 4 bundle spacer is necessary and the installation work becomes more difficult than that of spacer of double conductors, because of increasing the weight and the number of attaching parts on the conductor.

(2) Tseykha site (215MW)

A new 220kV transmission line is connected to Punatsangchhu-I power station.



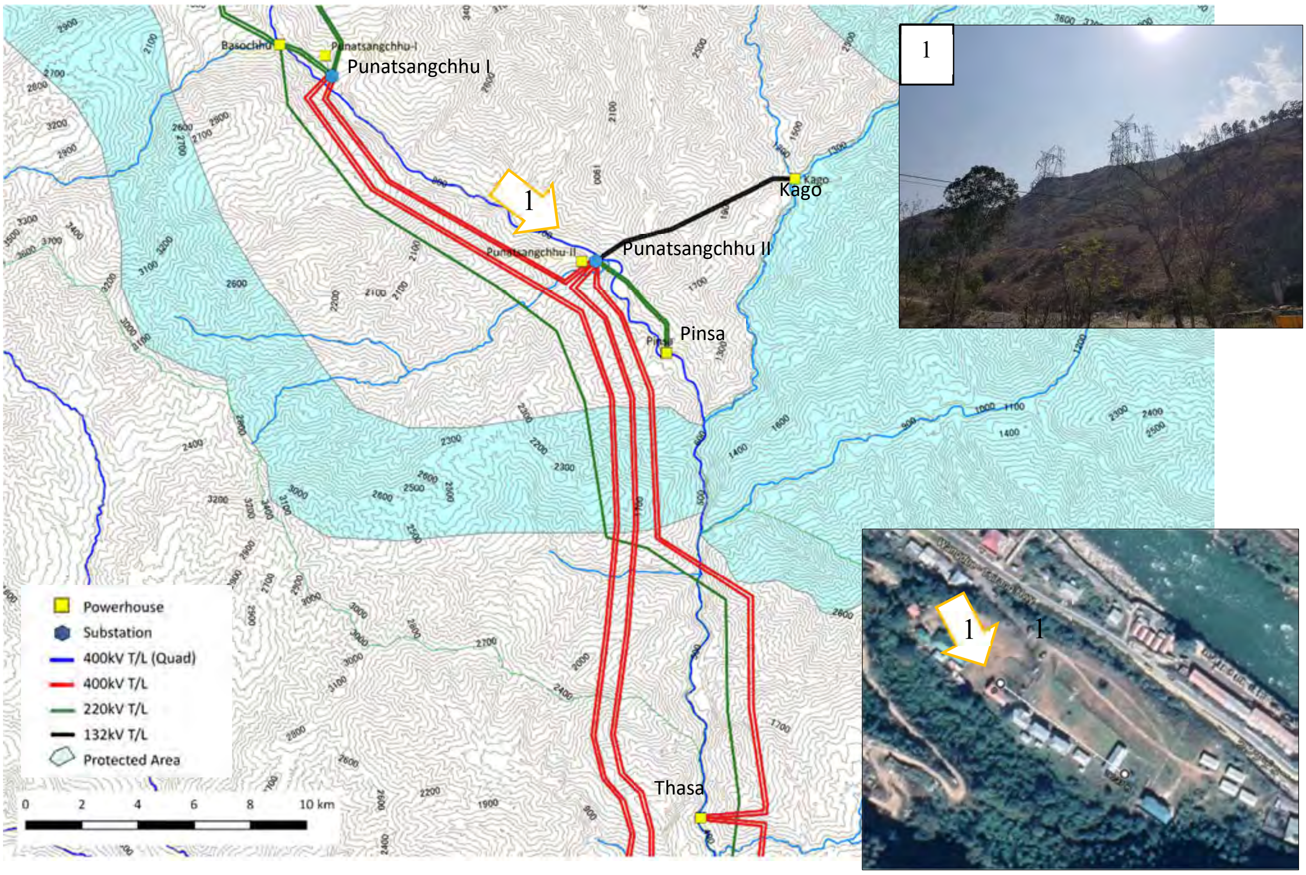
(Source: JICA Survey Team)

Figure 9-38 Transmission Line Routes for Tseykha Site

The transmission distance between the Tseykha site and Punatsangchhu I power station is as long as 37.9km. Therefore, as an optional plan, one of the 220kV transmission lines between Semtokha and Basochhu might be drawn into the Tseykha site as LILO connection.

(3) Pinsa site (153MW), Kago site (58MW), Thasa site (706MW)

Transmission line routes for the Pinsa site, Kago site and Thasa site are as follows.



(Source: JICA Survey Team)

Figure 9-39 Transmission Line Routes for Pinsa Site, Kago Site and Thasa Site

(a) Pinsa site

At the Pinsa site, the 220kV transmission line will be connected to the 400kV Punatsangchhu II switching station, which is currently under construction, and the voltage will be stepped-up to 400kV. However, if the switching station site is too small and it is difficult to install a transformer and construct a new bay for the line, the following options are possible.

Option 1 The existing Basochhu-Dhajey 220kV transmission line is drawn into the Pinsa site as LILO connection.

Option 2 The 220kV transmission line will be constructed to the Punatsangchhu I substation and connect to its 220kV bus.

Option 3 One of the 400 kV transmission lines between Punatsangchhu II and Jigmeling passing through the neighborhood is drawn into Pinsa as LILO connection.

(b) Kago site

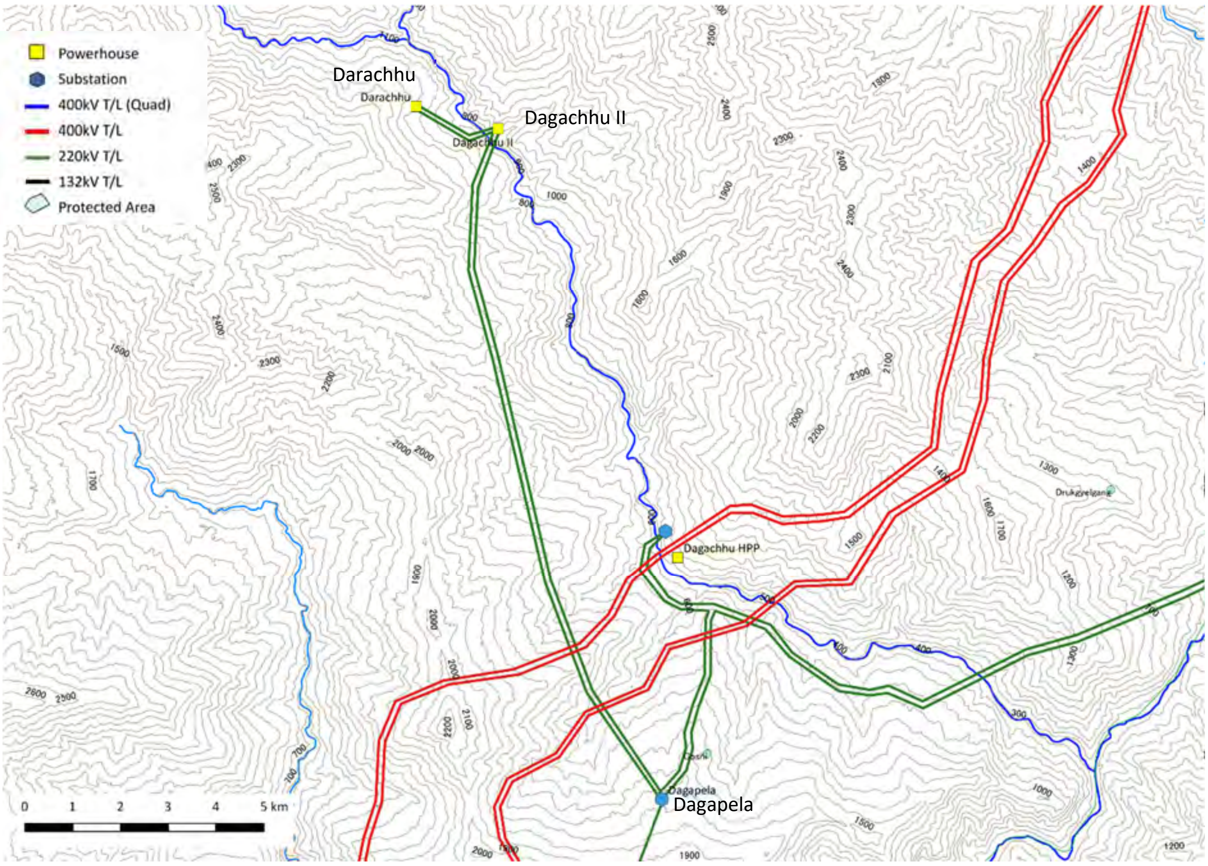
The installed capacity at the Kago site is 58MW, and it is difficult to transmit the power via standard 66kV lines, so a 132kV transmission line is selected and this is connected to the Punatsangchhu II switching station currently under construction. However, in the western region of Bhutan, the voltage class of 132kV is not used, so it is necessary to consider transmitting via 66kV line. In that case, since the capacity of the standard wire is insufficient, it will be necessary to use a thicker wire or a twin-conductor. If it is difficult to connect the line to the Punatsangchhu II switching station due to land issues, the line will be connected to the Pinsa power plant.

(c) Thasa site

For the Thasa site, a new 400kV Punatsangchhu II – Jigmeling transmission line is connected to the site via a π configuration connection for both circuits.

(4) Dagachhu II site (71MW), Darachhu site (89MW)

The Darachhu site is connected to the Darachhu-II site by a new 220kV transmission line; the power from both sites is then combined and transmitted to Dagapela substation. Although the transmission distance would be shorter if connected to the existing Dagachhu power plant, the total power output of the three power plants reaches 286MW, and if an accident happens on one of the circuits between Dagachhu and Dagapela, another circuit will be overloaded. Therefore, it is more economical to connect to the Dagapela substation, as additional equipment measures will not be needed.



(Source: JICA Survey Team)

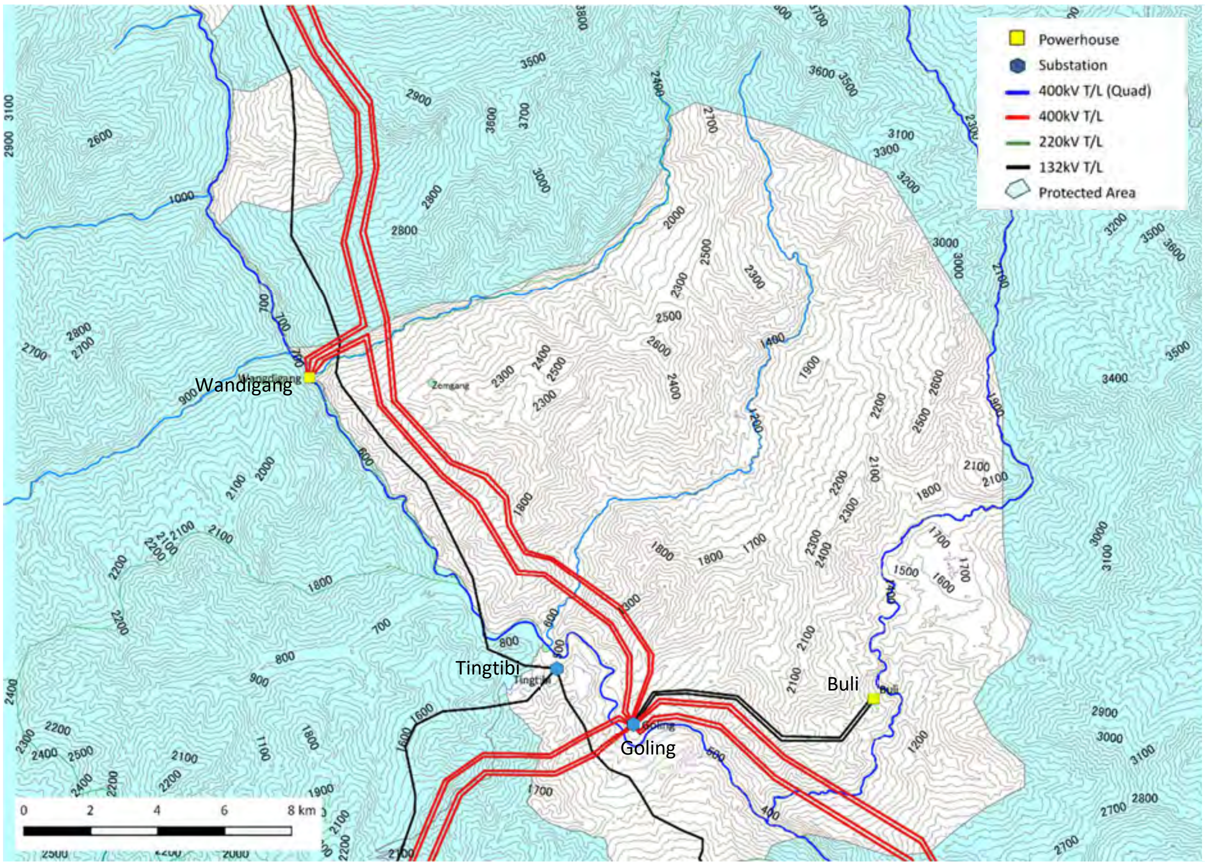
Figure 9-40 Transmission Line Routes for Dagachhu II Site and Darachhu Site

There is a possibility that the Dagapela substation will not have enough space on-site, and additional transmission lines cannot be connected. In such case, a connection will be made to the 220kV transmission line between Dagachhu and Dagapela in the shape of LILO.

(5) Wangdigang site (502MW), Buli site (69MW)

For the Wangdigang site, a new 400kV Mangdechhu – Goling transmission line is connected to the site via a π configuration connection for both circuits.

For the Buli site, a new 132kV transmission line is connected to Goling pooling station. If Goling PS does not have enough space to install a 400/132kV transformer, it can be connected to the Tingtibi substation or to the 132kV transmission line between Tingtibi and Nganglam in the shape of LILO. However, both plans require the crossing of 400kV transmission lines.



(Source: JICA Survey Team)

Figure 9-41 Transmission Line Routes for Wangdigang Site and Buli Site

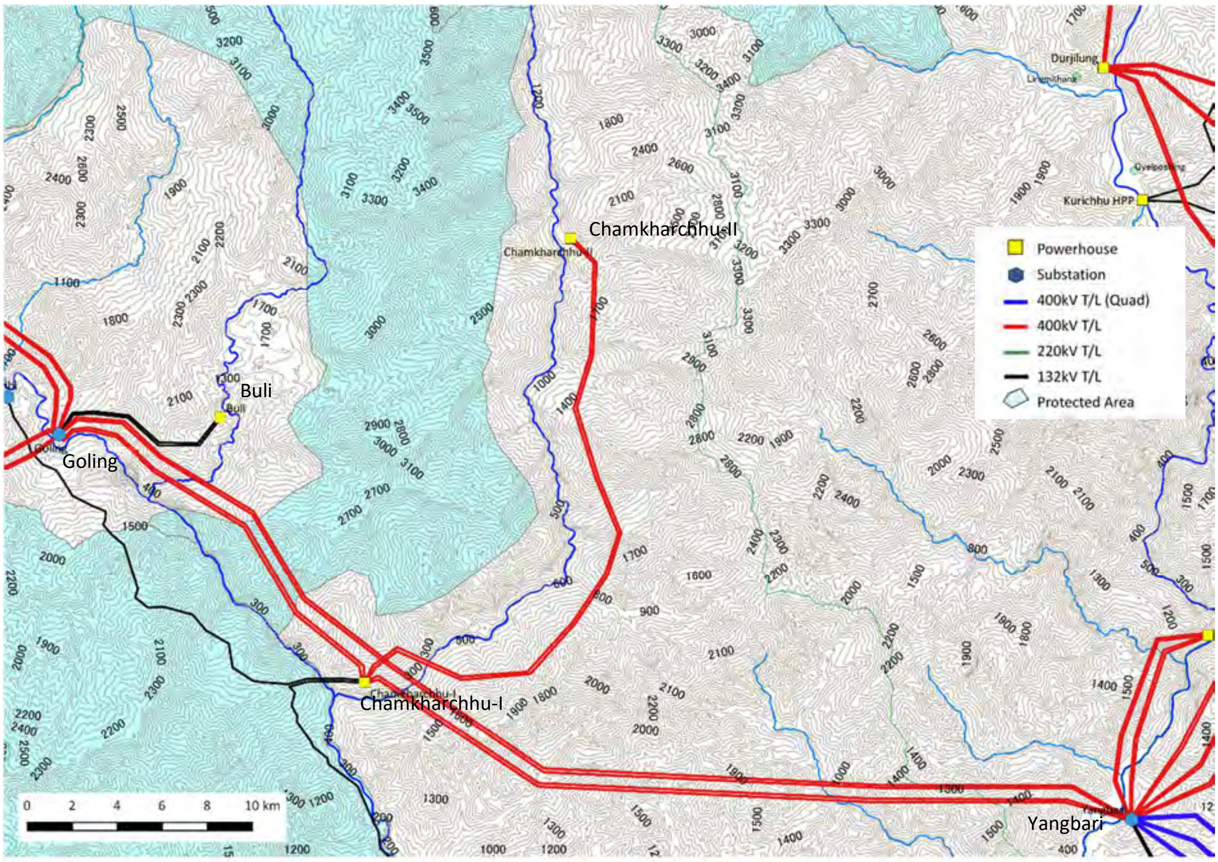
(6) Chamkharchhu II site (414MW)

The following three methods are proposed for power supply to the Chamkharchhu II site.

Table 9-38 Comparison of Power Supply Methods at Chamkharchhu II

Sl.	Proposed Method	Line length (km)	Remarks
1	Connection to Goling PS	30.0	This route was proposed in NTGMP 2018, but it needs to pass through natural conservation areas.
2	Connection to Yangbari PS	44.4	The number of circuit connections to Yangbari PS increases. The length of the route is too long.
3	Connection to Chamkharchhu I HPP	35.9	Crossing of another 400kV transmission line is necessary. No reinforcements are needed for Chamkharchhu I-related lines.

Chamkharchhu II transmission line was connected to Goling Pooling Station in NTGMP 2018. However, the Study Team proposes an alternative route - connecting to Chamkharchhu I power station - which can avoid natural conservation areas. Although the alternative route distance becomes slightly longer and it requires crossing another 400kV line, the length also becomes slightly shorter in comparison with the connection route to Yangbari PS, so this is proposed as the priority plan.

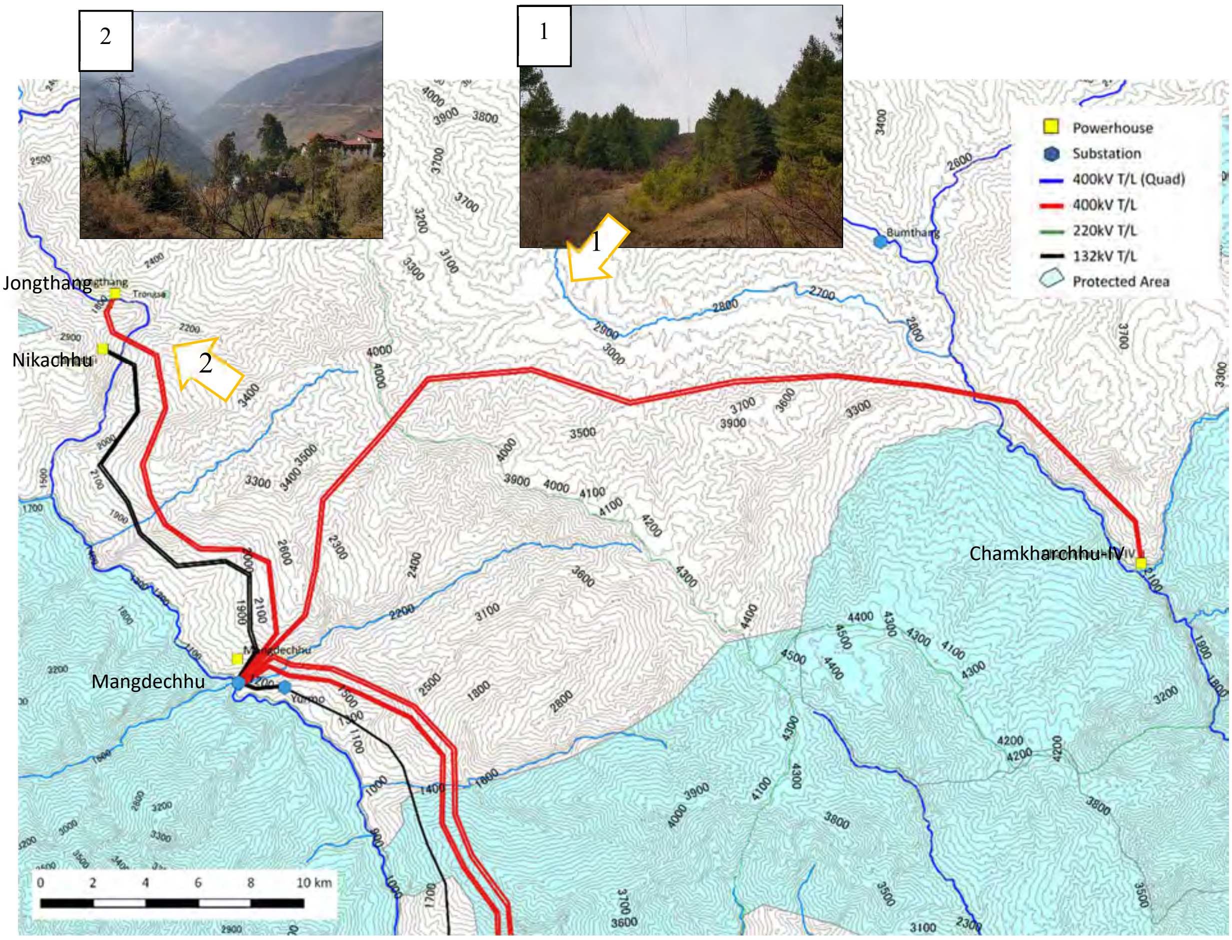


(Source: JICA Survey Team)

Figure 9-42 Transmission Line Route for Chamkharchhu II Site

(7) Chamkharchhu IV site (451MW), Jongthang site (227MW)

Although both transmission lines are connected to the Mangdechhu power plant, difficulties in connection may occur due to land restriction at the switching station in the power plant. In such case, it is necessary to consider a method of connecting directly to the existing 400kV transmission line (between Mangdechhu and Goling).



(Source: JICA Survey Team)

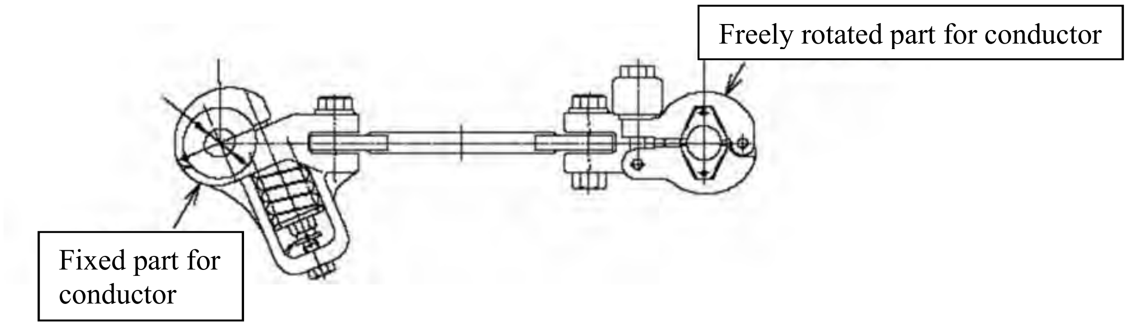
Figure 9-43 Transmission Line Routes for Chamkharchhu IV Site and Jongthang Site

(a) Chamkharchhu IV site

Chamkharchhu IV is planned to be connected to the Chamkharchhu II power plant, based on the NTGMP 2018. However, the Study Team proposes an alternative route - connecting to the Mangdechhu power plant - because this avoids passing through natural conservation areas. The proposed route will, however, be slightly longer. Half of the transmission line route runs parallel to the existing 66kV and passes through an over 4000m class mountain area.

It is necessary to increase the number of insulators in consideration of the decrease in insulation strength in the 4,000m mountainous area, since the air density is reduced there. If the load from ice and snow becomes large at the site, it will be necessary to select conductors and ground wires whose diameters are bigger than those of wires at low elevation. Furthermore, increasing the strength of the steel towers and the arms is needed when severe vibrations (galloping phenomenon) occur due to ice and snow on the conductors.

Since appropriate tower design and conductor design are conducted, it often measures snow and icing loads by installing conductor samplers and monitoring systems at the high elevation sites for few years in Japan. Moreover, since galloping phenomenon are prevented, “Loose Spacer” that has a structure in which the grip portion of one of the conductors is freely rotated is applied in Japan and the effects has already been confirmed. This spacer can prevent the galloping phenomenon, because the direction of snow clinging on the conductor is not constant when the conductor is freely rotated.



(Source: National Convention Conference of I.E.E. Japan in 2003)

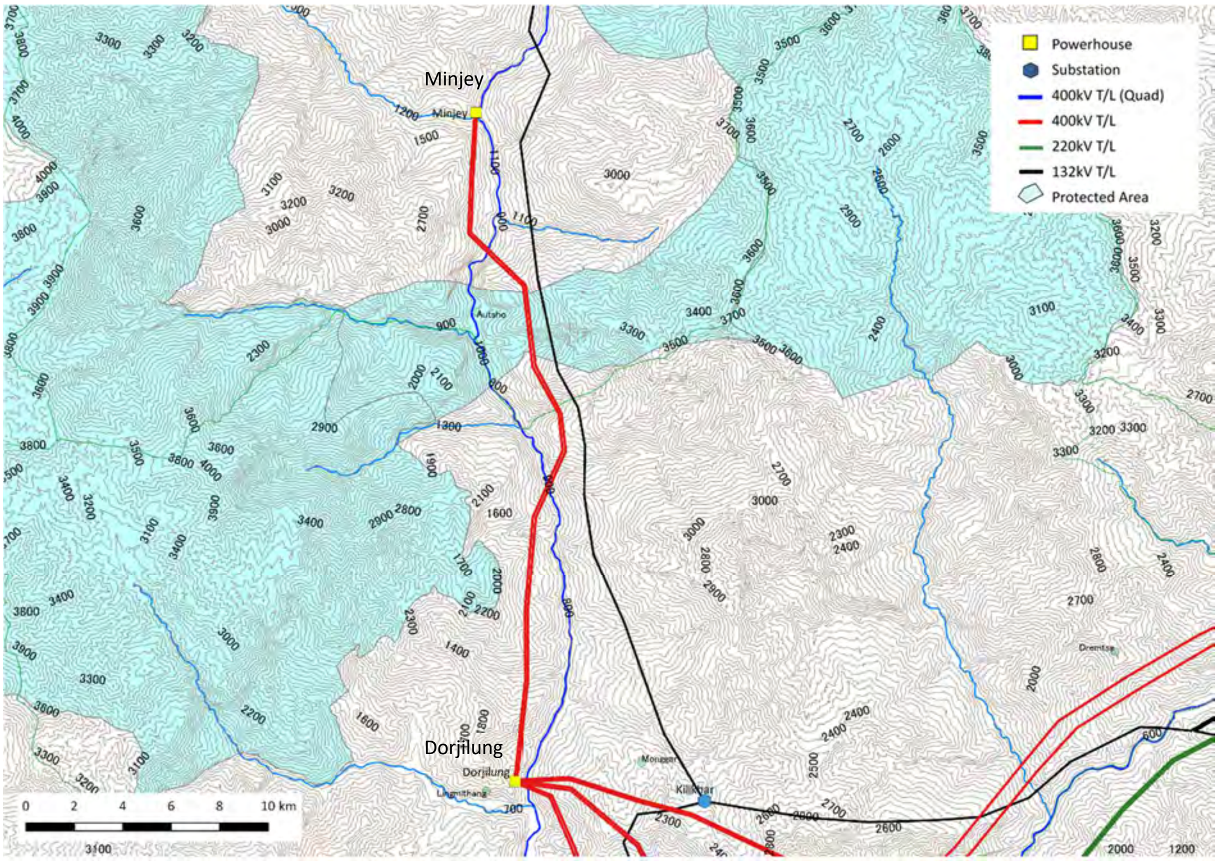
Figure 9-44 Structure of Loose Spacer for double bundles

(b) Jongthang site

For the transmission line at the Jongthang site, from the two options of the route avoiding passing through the city of Trongsa, and the route with the shortest distance, the route with the shortest distance was selected. In this route, it is necessary to take into consideration the visual influence of the towers and lines as viewed from Trongsa city.

(8) Minjey site (673MW)

It connects to Dorjilung power station with a 400kV transmission line. This power plant is surrounded by protected areas, so crossing the protected areas will be inevitable when formulating a transmission plan. Therefore, the transmission line crosses the biological corridor via the shortest route (about 3km).



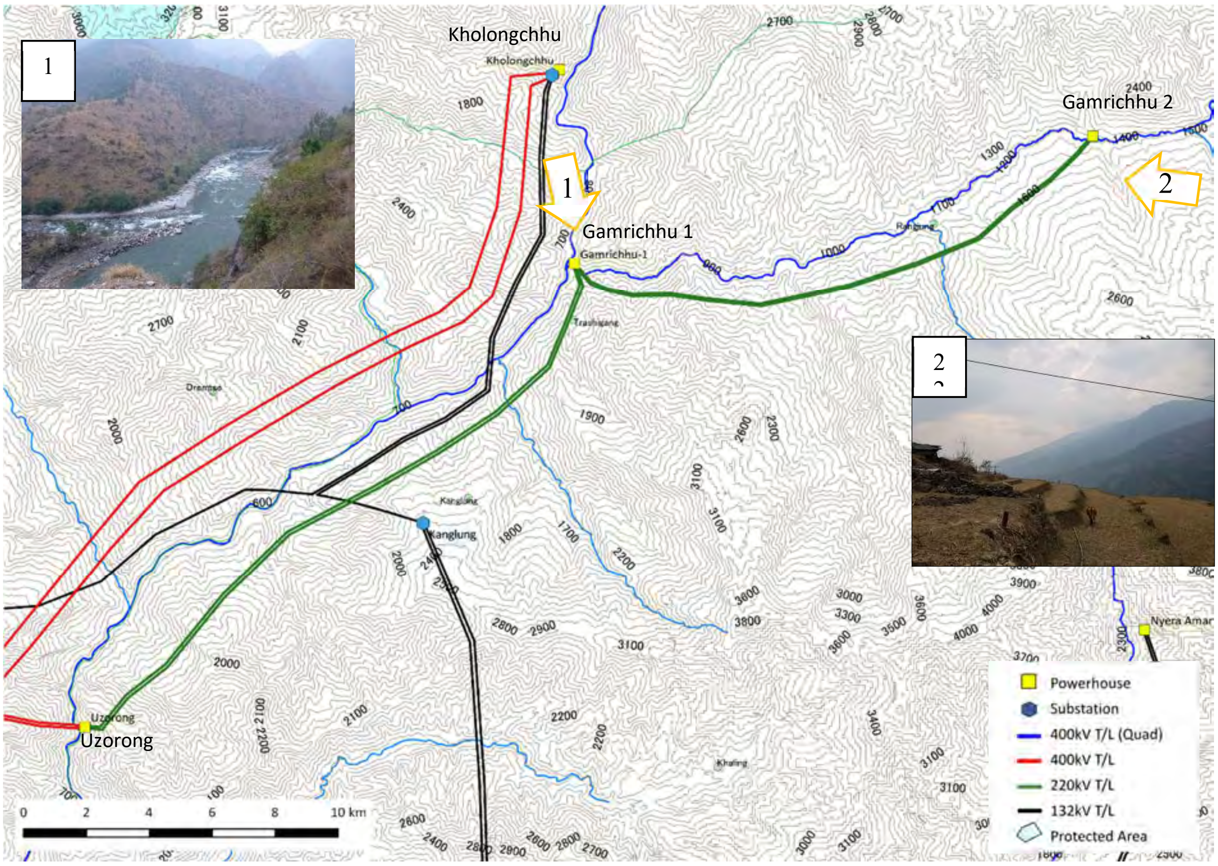
(Source: JICA Survey Team)

Figure 9-45 Transmission Line Routes for Minjey Site

(9) Gamrichhu 1 site (150MW), Gamrichhu 2 site (108MW)

The Gamrichhu 2 site is connected to the Gamrichhu 1 site by a new 220kV transmission line and the power from both sites will be integrated and transmitted to Uzorong power plant. The Gamrichhu 2 transmission line will pass through the southern side (leaf bank side) of the river and connect to Gamrichhu 1 power plant, because a general road is in the vicinity and the mountain slopes of the southern bank are not steep.

When the power from both sites is integrated and transmitted to the Uzorong power plant (840MW), the total capacity of the three power plants will become 1098MW. As the power capacity is within the allowable capacity of the 400kV transmission line to be built for Uzorong power plant, no additional equipment upgrades are required.



(Source: JICA Survey Team)

Figure 9-46 Transmission Line Route for Gamrichhu 2 Site and Gamrichhu 1 Site

Because the installed capacity of the Gamrichhu 1 site is 150MW, it cannot transmit the full output via standard 132kV transmission lines. However, it is conceivable to connect it to the 132kV bus of the Kholongchhu power plant by using a thicker wire or twin conductor of 132kV transmission line. Gamrichhu 2 has an installed capacity of 108MW and power can be transmitted with 132kV transmission lines. Even if these two sites are connected to the 132kV bus of the Kholongchhu power plant, the 400kV transmission line from the Kholongchhu power plant has sufficient transmission capacity, and no additional facility reinforcement is required.

(10) Uzorong site (840MW)

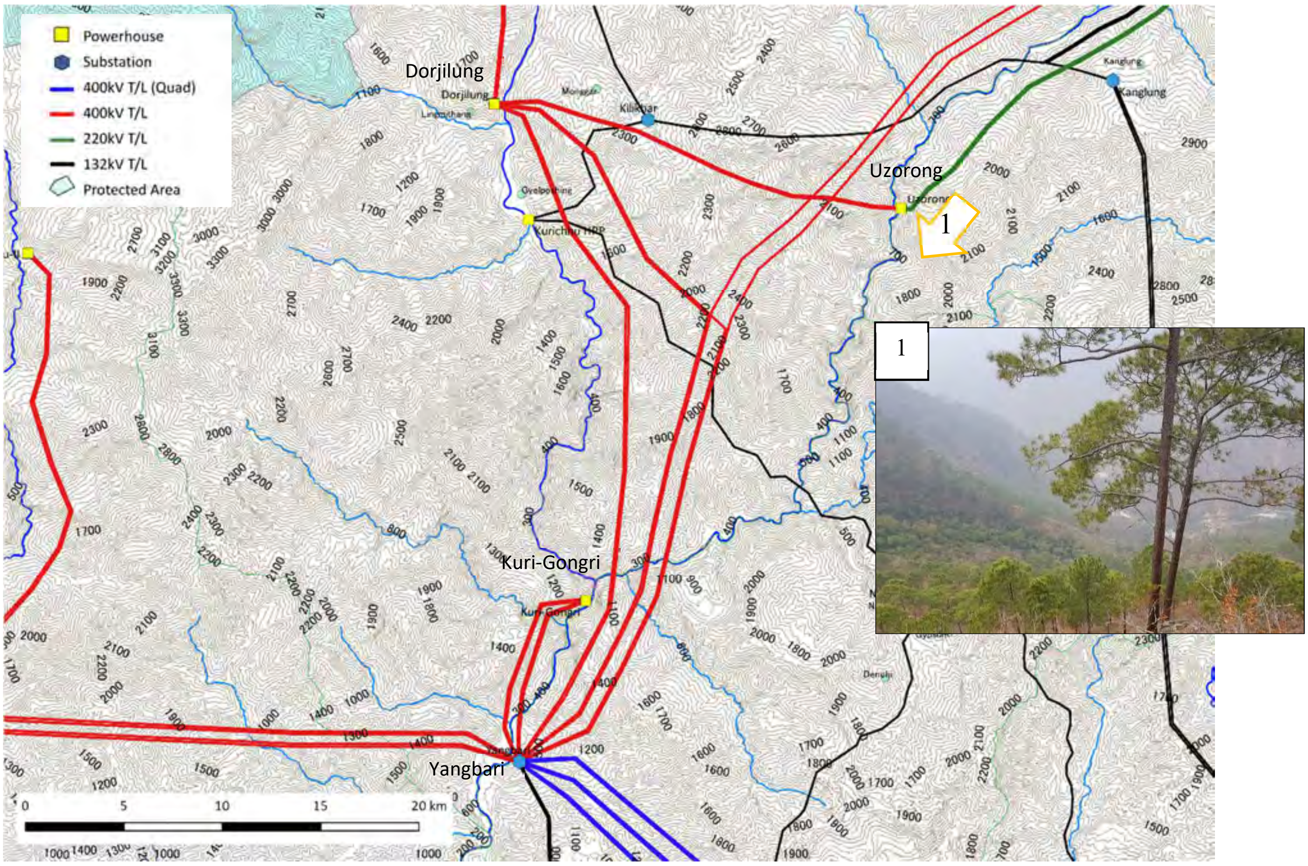
As Gamrichhu 1 and 2 are also connected to Uzorong power plant, it is necessary to transmit a total power of 1,098MW from Uzorong power plant. The following four connection methods are proposed to transmit this amount of power.

Table 9-39 Comparison of Connection Method for Uzorong Site

Sl.	Proposed method	Line length (km)	Remarks
1	Connection to Yangbari PS	47.7	The number of circuit connections to Yangbari PS increases. Long transmission distance.
2	Connection to Kuri-Gongri HPP	39.7	Kuri-Gongri - Yangbari will be overloaded when one circuit line is stopped.
3	Connection to Dorjilung HPP	25.9	Power supply is possible, because there are two routes planned to be constructed between Dorjilung and Yangbari.
4	Pulling into line between Kholongchhu and Yangbari	5.6	The Uzorong -Yangbari section needs to be 4 bundle conductors, but since the plan has already been completed, the conductors need to be replaced in the future.

(Source: JICA Survey Team)

As shown in the table above, the method of pulling into the line between Kholongchhu and Yangbari has the shortest transmission distance. Since it is necessary to change the type of conductors, for which the planning is already in progress, it is assumed that it would be difficult to change the plan. Therefore, the Study Team proposed connection to Dorjilung HPP, which has a shorter distance and fewer problematic issues.

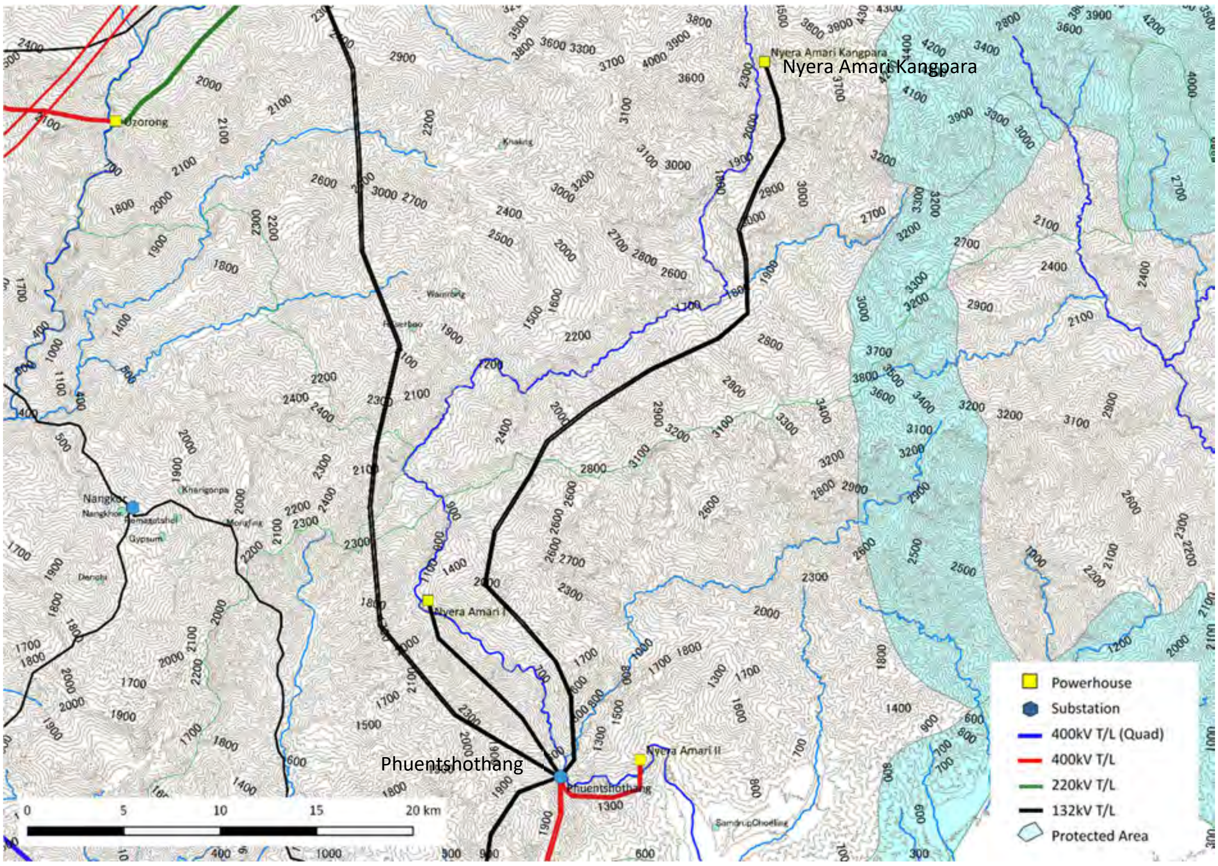


(Source: JICA Survey Team)

Figure 9-47 Transmission Line Route for Uzorong Site

(11) Nyera Amari Kangpara site (71MW)

A new 132kV line is connected to Phuentshothang substation.



(Source: JICA Survey Team)

Figure 9-48 Transmission Line Route for Nyera Amari Kangpara Site

(12) 400kV Goling Pooling Station[13]

There are no significant issues with this location point, but in future the following 12 circuits will be connected to this station. (Refer to Figure 9-41)

- Mangdechhu: 4 circuits
- Yangbari: 4 circuits
- Jigmeling: 4 circuits

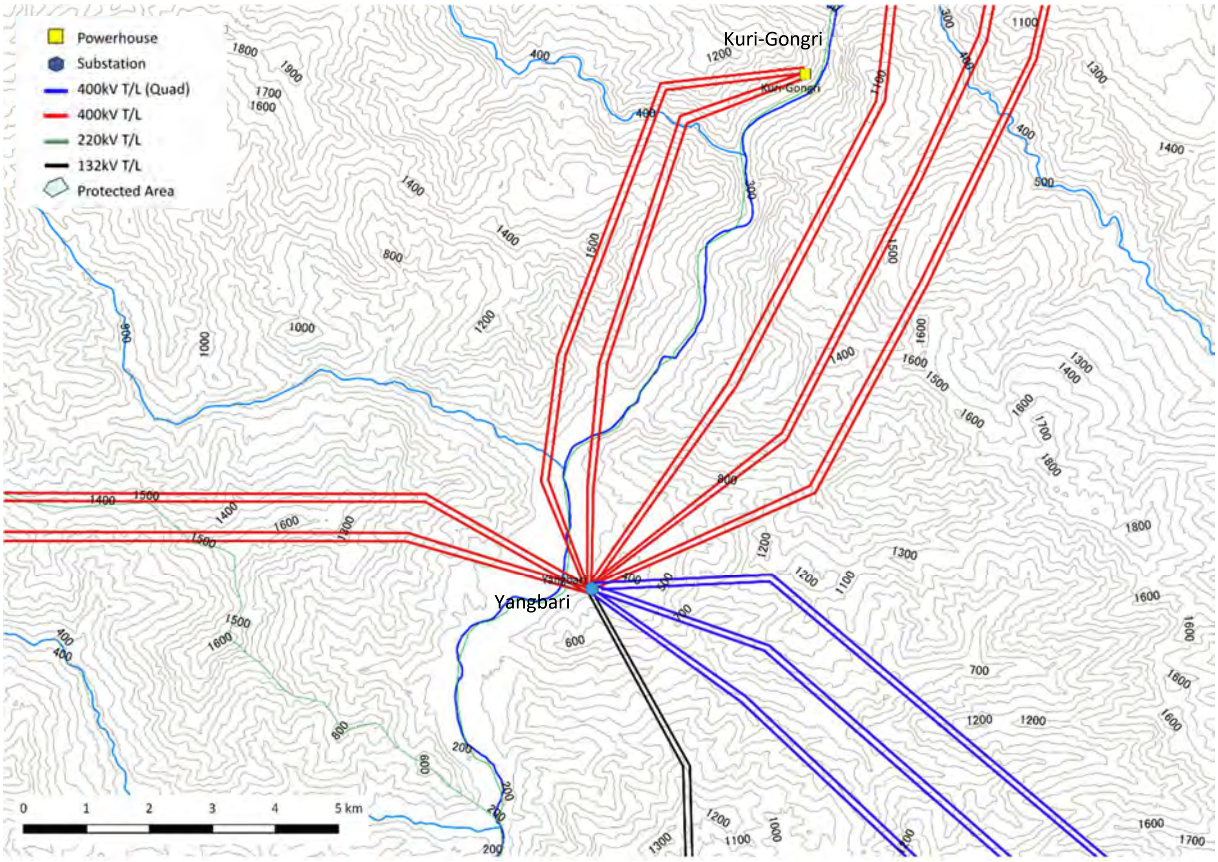
[13] Based on the NTGMP formulated by the CEA of India in 2012, the term "Pooling Station" is used. The aim is to bundle a certain amount of power from hydropower plants in Bhutan when sending to the Indian side.

(13) 400kV Yangbari Pooling Station

Yangbari Pooling Station was originally planned to be built on the right bank, adjacent to the river. However, since the site is privately owned and it is difficult to acquire land, there are plans to change it to a hilly area on the left bank side.

It is planned to connect 20 circuits of the following 400kV transmission lines to this pooling station. (See 9.4.2 (4) for countermeasures against increase in short-circuit current)

- Kuri-Gongri: 4 circuits
- Goling: 4 circuits
- Dorjilung: 4 circuits
- Kholongchhu: 2 circuits
- Rangia/Rowta: 6 circuits



(Source: JICA Survey Team)

Figure 9-49 Location Map for Yangbari Pooling Station

9.4 Future Grid Design

The future grid design is formulated based on the power development plan described in Chapter 8. In this study, the future feasible grid in 2050 is formulated to transmit the power from the 18 promising sites in addition to the candidate power plants for 2035 described in NTGMP 2018.
To realize this feasible grid, necessary system enhancement measures such as installation of new transmission lines and transformers are proposed.

9.4.1 Conditions for developing the Future Grid

The basic requirements are the same as the validation conditions (see 9.2.1). In addition, the followings are modified.

(1) Transmission capacity of transmission lines

Under validation, the transmission line capacity is calculated with an ambient temperature of 40°C, a maximum wire temperature of 75°C, and a power factor of 0.9. However, for a newly constructed transmission line, maximum wire temperature can be up to 85°C. As a result, the transmission capacity changes as follows.

Table 9-40 Modified Transmission Line Capacity

	75°C operation		85°C operation	
	Ampacity (A)	Thermal loading (MW)	Ampacity (A)	Thermal loading (MW)
400kV, Moose, Twin	700	873	850	1,060
220kV, Zebra, Single	620	212	750	257
132kV, Panther, Single	415	86	490	101
66kV, Dog, Single	345	35	410	42

(2) Fault current standards

In the future, since the fault current may increase due to an increase in the number of power plants and the expansion of transmission grids, it is necessary to introduce circuit breakers with a large breaking capacity in the future, referring to the following values.

Table 9-41 Breaking Capacity Reference Values

Voltage Level (kV)	Under validation (kA)	Future grid design (kA)
132	25	31.5
220	31.5	40
400	50	63

9.4.2 Future Grand Grid Design (in 2050)

The future grid should be formulated to meet the final power development plan. In this section, the system requirements in 2050 will be clarified.

(1) Power flow analysis

(a) Power flow in steady state (N-0)

A power flow analysis is conducted in the steady state (N-0). The results are shown in Table 9-42.

Table 9-42 Calculation Results for Power Flow under N-0 Conditions: Overloaded Equipment

TL (1)	From			To			CCT	Loading	Rating	Percent
TF (0)	Bus No.	Bus name	(kV)	Bus No.	Bus name	(kV)	No.	(MVA)	(MVA)	(%)
1	202	Malbase	220	442025	Birpara-PG	220	1	330.5	236	140.0
1	203	Semtokha	220	204	Baso-LS	220	1	454.9	236	192.8
1	203	Semtokha	220	217	Chumdo	220	1	292.9	236	124.1
1	204	Baso-LS	220	210	Puna I	220	1	446.3	236	189.1
1	604	Chumdo	66	623	Khasadrapchu	66	1	79.6	39	204.1
1	609	Olakha	66	610	Semtokha	66	2	53.4	39	136.8
1	610	Semtokha	66	611	Dechencholing	66	1	50.2	39	128.6
1	612	Lobeysa	66	613	Gaywathang	66	1	56.2	39	144.2
1	613	Gaywathang	66	614	Baso-LS	66	1	56.6	39	145.1
0	202	Malbase	220	402	Malbase	400	1	236.9	200	118.5
0	202	Malbase	220	402	Malbase	400	2	76.1	67	113.5
0	202	Malbase	220	402	Malbase	400	3	76.1	67	113.5
0	202	Malbase	220	402	Malbase	400	4	76.1	67	113.5
0	203	Semtokha	220	610	Semtokha	66	1	78.3	63	124.2
0	203	Semtokha	220	610	Semtokha	66	2	78.3	63	124.2
0	204	Baso-LS	220	614	Baso-LS	66	1	32.0	30	106.5
0	205	Tsirang	220	616	Tsirang	66	1	15.9	10	159.4
0	205	Tsirang	220	616	Tsirang	66	2	15.9	10	159.4
0	208	Singhigaon	220	621	Singhigaon	66	1	57.1	50	114.3
0	208	Singhigaon	220	621	Singhigaon	66	2	36.1	35	103.2
0	217	Chumdo	220	604	Chumdo	66	1	70.7	63	112.2
0	217	Chumdo	220	604	Chumdo	66	2	70.7	63	112.2
0	108	Gelephu	132	622	Gelephu	66	1	39.2	25	156.7
0	108	Gelephu	132	622	Gelephu	66	2	39.2	25	156.7

(Source: JICA Survey Team)

The countermeasures for solving the above overloads are shown in Table 9-43. The basic concept is to use two transmission lines per route to prevent transmission line overloading and install an additional transformer to prevent overloading of the transformers, but considering cost-effectiveness, some transmission lines (Bunakha - Chhukha, Punatsangchhu-I - Tsirang) are opened under normal operation.

Table 9-43 Network Countermeasures to solve Overloaded Problems under N-0 Conditions

<Transmission lines>

Transmission line			Voltage(kV)	Countermeasure
Malbase	-	Birpara-PG	220	Zebra 1cct => 2cct
Semtokha	-	Baso-LS	220	Zebra 1cct => 2cct
Semtokha	-	Chumdo	220	Zebra 1cct => 2cct
Baso-LS	-	Punatsangchhu-I	220	Zebra 1cct => 2cct Bunakha - Chhukha: Open Punatsangchhu-I - Tsirang: Open
Chumdo	-	Khasadrapchu	66	Dog 1cct => 2cct
Olakha	-	Semtokha	66	Dog 1cct => 2cct
Semtokha	-	Dechencholing	66	Dog 1cct => 2cct
Lobeysa	-	Gaywathang	66	Dog => Zebra
Gaywathang	-	Baso-LS	66	Dog => Zebra

<Substations>

Substation	Voltage(kV)	Countermeasure
Malbase	400 / 220	5B:200MVA Expansion
Semtokha	220 / 66	3B:50/63MVA Expansion
Baso-LS	220 / 66	2B:50/63MVA Expansion
Tsirang	200 / 66	3B:50/63MVA Expansion
Singhigaon	220 / 66	3B:50/63MVA Expansion
Chumdo	220 / 66	3B:50/63MVA Expansion
Gelephu	132 / 66	3B:50MVA Expansion
Dechencholing	66 / 33	3B:30MVA Expansion
Changidapuchu	66 / 33	3B:30MVA Expansion

(Source: JICA Survey Team)

The power flow calculation results under N-0 with the above measures taken are shown in Table 9-44.

Table 9-44 Results of Power Flow Calculation under N-0 Conditions: After Implementation

TL (1)	From			To			CCT	Loading	Rating	Percent
TF (0)	Bus No.	Bus Name	(kV)	Bus No.	Bus Name	(kV)	No.	(MVA)	(MVA)	(%)
1	202	Malbase	220	442025	Birpara-PG	220	1	291.6	286	102
1	202	Malbase	220	442025	Birpara-PG	220	2	291.6	286	102
1	211	Bunakha	220	217	Chumdo	220	1	243	236	103

(Source: JICA Survey Team)

Since overloads occurred in Malbase - Birpara and Bunakha - Chumdo, the additional measures shown in Table 9-45 are taken.

Table 9-45 Additional Countermeasures to solve Overloading under N-0

Transmission line	Voltage(kV)	Measure
Malbase - Birpara-PG	220	Zebra 2cct => Zebra(Twin) 2cct
Bunakha - Chumdo	220	Zebra 1cct => 2cct

(Source: JICA Survey Team)

By implementing the above measures, overloads under normal conditions are solved.

(b) Power flow under single contingency (N-1)

Table 9-46 shows the results of power flow calculation under N-1.

Table 9-46 Calculation Results under N-1: Overloaded Equipment

Fault equipment								Overloaded equipment							Load factor (%)
TL(1)	From			To			CCT								
TF(0)	No.	Bus name	(kV)	No.	Bus name	(kV)	No.								
1	107	Motanga	132	115	Phuentshothang	132	1	107	Motanga	132	115	Phuentshothang	132	2	114.7
1	107	Motanga	132	115	Phuentshothang	132	2	107	Motanga	132	115	Phuentshothang	132	1	114.7
1	112	Mangdechhu	132	113	Nikachhu	132	1	112	Mangdechhu	132	113	Nikachhu	132	2	105.1
1	112	Mangdechhu	132	113	Nikachhu	132	2	112	Mangdechhu	132	113	Nikachhu	132	1	105.1
1	115	Phuentshothang	132	116	Nyera-I	132	1	115	Phuentshothang	132	116	Nyera-I	132	2	
1	115	Phuentshothang	132	116	Nyera-I	132	2	115	Phuentshothang	132	116	Nyera-I	132	1	
1	202	Malbase	220	211	Bunakha	220	1	202	Malbase	220	211	Bunakha	220	2	163.5
1	202	Malbase	220	211	Bunakha	220	2	202	Malbase	220	211	Bunakha	220	1	163.5
1	203	Semtokha	220	204	Baso-LS	220	1	203	Semtokha	220	204	Baso-LS	220	2	156.7
1	203	Semtokha	220	204	Baso-LS	220	2	203	Semtokha	220	204	Baso-LS	220	1	156.7
1	203	Semtokha	220	217	Chumdo	220	1	203	Semtokha	220	217	Chumdo	220	2	120.5
1	203	Semtokha	220	217	Chumdo	220	2	203	Semtokha	220	217	Chumdo	220	1	120.5
1	204	Baso-LS	220	210	Puna I	220	1	204	Baso-LS	220	210	Puna I	220	2	177.0
1	204	Baso-LS	220	210	Puna I	220	2	204	Baso-LS	220	210	Puna I	220	1	177.0
1	410	Yangbari	400	214151	Rangia	400	1	410	Yangbari	400	214151	Rangia	400	2	109.1
								410	Yangbari	400	214151	Rangia	400	3	109.1
								410	Yangbari	400	214151	Rangia	400	4	109.1
1	410	Yangbari	400	214151	Rangia	400	2	410	Yangbari	400	214151	Rangia	400	1	109.1
								410	Yangbari	400	214151	Rangia	400	3	109.1

Fault equipment								Overloaded equipment							Load factor
TL(1)	From			To			CCT								
TF(0)	No.	Bus name	(kV)	No.	Bus name	(kV)	No.								(%)
								410	Yangbari	400	214151	Rangia	400	4	109.1
1	410	Yangbari	400	214151	Rangia	400	3	410	Yangbari	400	214151	Rangia	400	1	109.1
								410	Yangbari	400	214151	Rangia	400	2	109.1
								410	Yangbari	400	214151	Rangia	400	4	109.1
1	410	Yangbari	400	214151	Rangia	400	4	410	Yangbari	400	214151	Rangia	400	1	109.1
								410	Yangbari	400	214151	Rangia	400	2	109.1
								410	Yangbari	400	214151	Rangia	400	3	109.1
0	108	Gelephu	132	622	Gelephu	66	3	108	Gelephu	132	622	Gelephu	66	1	156.4
								108	Gelephu	132	622	Gelephu	66	2	156.4
0	123	Goling	132	408	Goling	400	1	123	Goling	132	408	Goling	400	2	102.8
0	123	Goling	132	408	Goling	400	2	123	Goling	132	408	Goling	400	1	102.8
0	202	Malbase	220	402	Malbase	400	1	202	Malbase	220	402	Malbase	400	2	114.0
								202	Malbase	220	402	Malbase	400	3	114.0
								202	Malbase	220	402	Malbase	400	4	114.0
								202	Malbase	220	402	Malbase	400	5	119.0
0	202	Malbase	220	402	Malbase	400	2	202	Malbase	220	402	Malbase	400	1	102.0
								202	Malbase	220	402	Malbase	400	5	102.0
0	202	Malbase	220	402	Malbase	400	3	202	Malbase	220	402	Malbase	400	1	102.0
								202	Malbase	220	402	Malbase	400	5	102.0
0	202	Malbase	220	402	Malbase	400	4	202	Malbase	220	402	Malbase	400	1	102.0
								202	Malbase	220	402	Malbase	400	5	102.0
0	202	Malbase	220	402	Malbase	400	5	202	Malbase	220	402	Malbase	400	1	119.0
								202	Malbase	220	402	Malbase	400	2	114.0
								202	Malbase	220	402	Malbase	400	3	114.0
								202	Malbase	220	402	Malbase	400	4	114.0
0	203	Semtokha	220	204	Baso-LS	220	1	202	Malbase	220	402	Malbase	400	1	103.1
								202	Malbase	220	402	Malbase	400	5	103.1
0	203	Semtokha	220	204	Baso-LS	220	2	202	Malbase	220	402	Malbase	400	1	103.1
								202	Malbase	220	402	Malbase	400	5	103.1
0	401	Tala	400	444072	Siliguri-pg	400	3	202	Malbase	220	402	Malbase	400	1	100.9
								202	Malbase	220	402	Malbase	400	5	100.9
0	401	Tala	400	444072	Siliguri-pg	400	4	202	Malbase	220	402	Malbase	400	1	100.9
								202	Malbase	220	402	Malbase	400	5	100.9
0	412	Wangchu	400	444072	Siliguri-pg	400	1	202	Malbase	220	402	Malbase	400	1	100.5
								202	Malbase	220	402	Malbase	400	5	100.5
0	422	Amochhu res	400	444072	Siliguri-pg	400	1	202	Malbase	220	402	Malbase	400	1	100.1
								202	Malbase	220	402	Malbase	400	5	100.1
0	422	Amochhu res	400	444073	Alipurduar	400	1	202	Malbase	220	402	Malbase	400	1	100.4
								202	Malbase	220	402	Malbase	400	5	100.4
0	422	Amochhu res	400	444073	Alipurduar	400	2	202	Malbase	220	402	Malbase	400	1	100.4
								202	Malbase	220	402	Malbase	400	5	100.4
0	201	Chhukha	220	601	Chhukha	66	1	202	Malbase	220	618	Malbase	66	1	100.8
								202	Malbase	220	618	Malbase	66	2	100.8
								202	Malbase	220	618	Malbase	66	3	100.8
0	201	Chhukha	220	601	Chhukha	66	2	202	Malbase	220	618	Malbase	66	1	100.8
								202	Malbase	220	618	Malbase	66	2	100.8
								202	Malbase	220	618	Malbase	66	3	100.8
0	202	Malbase	220	208	Singhigaon	220	1	202	Malbase	220	618	Malbase	66	1	102.6
								202	Malbase	220	618	Malbase	66	2	102.6
								202	Malbase	220	618	Malbase	66	3	102.6
0	202	Malbase	220	209	Samtse	220	1	202	Malbase	220	618	Malbase	66	1	100.6
								202	Malbase	220	618	Malbase	66	2	100.6
								202	Malbase	220	618	Malbase	66	3	100.6
0	202	Malbase	220	618	Malbase	66	1	202	Malbase	220	618	Malbase	66	2	139.6
								202	Malbase	220	618	Malbase	66	3	139.6
0	202	Malbase	220	618	Malbase	66	2	202	Malbase	220	618	Malbase	66	1	139.6
								202	Malbase	220	618	Malbase	66	3	139.6
0	202	Malbase	220	618	Malbase	66	3	202	Malbase	220	618	Malbase	66	1	139.6
								202	Malbase	220	618	Malbase	66	2	139.6
0	208	Singhigaon	220	209	Samtse	220	1	202	Malbase	220	618	Malbase	66	1	100.1
								202	Malbase	220	618	Malbase	66	2	100.1
								202	Malbase	220	618	Malbase	66	3	100.1
0	209	Samtse	220	620	Samtse	66	1	202	Malbase	220	618	Malbase	66	1	101.4
								202	Malbase	220	618	Malbase	66	2	101.4
								202	Malbase	220	618	Malbase	66	3	101.4
0	209	Samtse	220	620	Samtse	66	2	202	Malbase	220	618	Malbase	66	1	101.4
								202	Malbase	220	618	Malbase	66	2	101.4
								202	Malbase	220	618	Malbase	66	3	101.4
0	203	Semtokha	220	610	Semtokha	66	1	203	Semtokha	220	610	Semtokha	66	2	126.7
								203	Semtokha	220	610	Semtokha	66	3	126.7
0	203	Semtokha	220	610	Semtokha	66	2	203	Semtokha	220	610	Semtokha	66	1	126.7
								203	Semtokha	220	610	Semtokha	66	3	126.7
0	203	Semtokha	220	610	Semtokha	66	3	203	Semtokha	220	610	Semtokha	66	1	126.7

Fault equipment								Overloaded equipment							Load factor (%)
TL(1)	From			To			CCT								
TF(0)	No.	Bus name	(kV)	No.	Bus name	(kV)	No.								
								203	Semtokha	220	610	Semtokha	66	2	126.7
0	204	Baso-LS	220	614	Baso-LS	66	2	204	Baso-LS	220	614	Baso-LS	66	1	107.8
0	205	Tsirang	220	616	Tsirang	66	3	205	Tsirang	220	616	Tsirang	66	1	159.3
								205	Tsirang	220	616	Tsirang	66	2	159.3
0	208	Singhigaon	220	621	Singhigaon	66	3	208	Singhigaon	220	621	Singhigaon	66	1	114.2
								208	Singhigaon	220	621	Singhigaon	66	2	103.1
0	202	Malbase	220	402	Malbase	400	1	210	Puna I	220	405	Puna I	400	1	104.7
								210	Puna I	220	405	Puna I	400	2	104.7
								210	Puna I	220	405	Puna I	400	3	104.7
0	202	Malbase	220	402	Malbase	400	5	210	Puna I	220	405	Puna I	400	1	104.7
								210	Puna I	220	405	Puna I	400	2	104.7
								210	Puna I	220	405	Puna I	400	3	104.7
0	210	Puna I	220	405	Puna I	400	1	210	Puna I	220	405	Puna I	400	2	122.7
								210	Puna I	220	405	Puna I	400	3	122.7
0	210	Puna I	220	405	Puna I	400	2	210	Puna I	220	405	Puna I	400	1	122.7
								210	Puna I	220	405	Puna I	400	3	122.7
0	210	Puna I	220	405	Puna I	400	3	210	Puna I	220	405	Puna I	400	1	122.7
								210	Puna I	220	405	Puna I	400	2	122.7
0	402	Malbase	400	422	Amochhu res	400	1	210	Puna I	220	405	Puna I	400	1	106.3
								210	Puna I	220	405	Puna I	400	2	106.3
								210	Puna I	220	405	Puna I	400	3	106.3
0	405	Puna I	400	419	Sankosh RB	400	1	210	Puna I	220	405	Puna I	400	1	102.9
								210	Puna I	220	405	Puna I	400	2	102.9
								210	Puna I	220	405	Puna I	400	3	102.9
0	405	Puna I	400	419	Sankosh RB	400	2	210	Puna I	220	405	Puna I	400	1	102.9
								210	Puna I	220	405	Puna I	400	2	102.9
								210	Puna I	220	405	Puna I	400	3	102.9
0	406	Puna II	400	418	Sankosh lb	400	1	210	Puna I	220	405	Puna I	400	1	102.3
								210	Puna I	220	405	Puna I	400	2	102.3
								210	Puna I	220	405	Puna I	400	3	102.3
0	406	Puna II	400	418	Sankosh lb	400	2	210	Puna I	220	405	Puna I	400	1	102.3
								210	Puna I	220	405	Puna I	400	2	102.3
								210	Puna I	220	405	Puna I	400	3	102.3
0	407	Jigmeling	400	444073	Alipurduar	400	1	210	Puna I	220	405	Puna I	400	1	102.8
								210	Puna I	220	405	Puna I	400	2	102.8
								210	Puna I	220	405	Puna I	400	3	102.8
0	407	Jigmeling	400	444073	Alipurduar	400	2	210	Puna I	220	405	Puna I	400	1	102.8
								210	Puna I	220	405	Puna I	400	2	102.8
								210	Puna I	220	405	Puna I	400	3	102.8
0	409	Lhamoizingkha	400	444073	Alipurduar	400	1	210	Puna I	220	405	Puna I	400	1	105.9
								210	Puna I	220	405	Puna I	400	2	105.9
								210	Puna I	220	405	Puna I	400	3	105.9
0	409	Lhamoizingkha	400	444073	Alipurduar	400	2	210	Puna I	220	405	Puna I	400	1	105.9
								210	Puna I	220	405	Puna I	400	2	105.9
								210	Puna I	220	405	Puna I	400	3	105.9
0	418	Sankosh lb	400	444073	Alipurduar	400	1	210	Puna I	220	405	Puna I	400	1	107.2
								210	Puna I	220	405	Puna I	400	2	107.2
								210	Puna I	220	405	Puna I	400	3	107.2
0	419	Sankosh RB	400	444073	Alipurduar	400	1	210	Puna I	220	405	Puna I	400	1	107.4
								210	Puna I	220	405	Puna I	400	2	107.4
								210	Puna I	220	405	Puna I	400	3	107.4
0	217	Chumdo	220	604	Chumdo	66	1	217	Chumdo	220	604	Chumdo	66	2	105.2
								217	Chumdo	220	604	Chumdo	66	3	105.2
0	217	Chumdo	220	604	Chumdo	66	2	217	Chumdo	220	604	Chumdo	66	1	105.2
								217	Chumdo	220	604	Chumdo	66	3	105.2
0	217	Chumdo	220	604	Chumdo	66	3	217	Chumdo	220	604	Chumdo	66	1	105.2
								217	Chumdo	220	604	Chumdo	66	2	105.2
0	219	Puna II	220	406	Puna II	400	1	219	Puna II	220	406	Puna II	400	2	146.2
0	219	Puna II	220	406	Puna II	400	2	219	Puna II	220	406	Puna II	400	1	146.2

Note) Although Phuentshothang to Nyera Amari-I is not overloaded, it may become overloaded depending on the generator power factor, so countermeasures will be taken.

(Source: JICA Survey Team)

The measures to solve these overloads are shown in Table 9-47.

Table 9-47 Countermeasures to solve Overloading under N-1

<Transmission lines>

Transmission line			Voltage(kV)	Countermeasure
Motanga	-	Phuentshothang	132	Conductor Type: Panther => Zebra
Phuentshothang	-	Nyera-I	132	Conductor Type: Panther => Zebra
Malbase	-	Bunakha	220	Conductor Type: Zebra => Zebra（Twin）
Semtokha	-	Baso-LS	220	Conductor Type: Zebra => Zebra（Twin）
Semtokha	-	Chumdo	220	Conductor Type: Zebra => Zebra（Twin）
Baso-LS	-	Puna I	220	Conductor Type: Zebra => Zebra（Twin）
Yangbari	-	Rangia	400	Conductor No: Moose (Quad) 4cct => 6cct

Note) 132kV Mangdechhu to Nikachhu is an existing power transmission line; it is measured by output suppression of Nikachhu.

<Substations>

Substation	Voltage(kV)			Measure
Gelephu	132	/	66	4B:50MVA Expansion
Goling	400	/	132	1B,2B:67 => 100MVA Replacement
Malbase	400	/	220	6B:200VA Expansion
Malbase	220	/	66	4B:50/63MVA Expansion
Semtokha	220	/	66	4B:50/63MVA Expansion
Baso-LS	220	/	66	3B:50/63MVA Expansion
Tsirang	220	/	66	4B:50/63MVA Expansion
Singhigaon	220	/	66	4B:50/63MVA Expansion
Puna I	400	/	220	1～3B:105 => 150MVA Replacement
Chumdo	220	/	66	4B:50/63MVA Expansion
Puna II	400	/	220	1,2B:105 => 200MVA Replacement

(Source: JICA Survey Team)

By implementing these measures, no overloads in the steady state (N-0) or the N-1 state occur.

In terms of accidents at single phase transformers, an overload occurs in the case of an accident at a 400/220kV single phase transformer in Punatsangchhu-I substation and an accident at a 400/132kV single phase transformer in Mangdechhu substation. To counter this, it is necessary to replace the affected transformer with a spare one. While replacement work is ongoing , the following operational countermeasures may be effective:
Punatsangchhu-I:Transmission line of Punatsangchhu-I – Tsirang, which is usually opened, is closed
Mangdechhu: Output suppression of the Nikachhu Power Station

Table 9-48 Calculation Results under an Accident of a Single Phase Transformer: Overloaded Equipment

Fault equipment								Overloaded equipment							Load factor
TL(1)	From			To			CCT								
TF(0)	No.	Bus name	(kV)	No.	Bus name	(kV)	No.								(%)
0	112	Mangdechhu	132	404	Mangdechhu	400	1,2,3	109	Tingtibi	132	110	Yurmo	132	1	111.4
0	210	Puna I	220	405	Puna I	132	1,2,3	202	Malbase	220	402	Malbase	400	1	101.2
								202	Malbase	220	402	Malbase	400	5	101.2
								202	Malbase	220	402	Malbase	400	6	101.2

(Source: JICA Survey Team)

(2) Voltage check

Table 9-49 shows buses that deviate from the reference voltage (0.95 to 1.05 pu) in the steady state (N-0) after implementing the above overload countermeasures.

Table 9-49 Reference Voltage Deviation Busbars

Bus No.	Name	Voltage (p.u.)	Voltage (kV)
106	Deothang	0.935	123.4
107	Motanga	0.942	124.4
108	Gelephu	0.925	122.0

602	Watsa-Tap	0.948	62.5
603	Watsa	0.947	62.5
605	Paro	0.901	59.4
606	Haa	0.909	60.0
608	Jemina	0.931	61.4
612	Lobeysa	0.890	58.7
619	Gomtu	0.939	62.0
622	Gelephu	0.906	59.8
623	Khasadrapchu	0.943	62.2
627	Changidapuchu	0.910	60.0

(Source: JICA Survey Team)

In order to maintain the proper voltage level at the bus, the following reactive power compensator will be installed in this study.

Table 9-50 Reactive Power Compensator installed

Substation	Voltage(kV)	SC(MVA)
Deothang	132	50
Paro	66	25
Lobeysa	66	30
Gomtu	66	20
Gelephu	66	30
Changidapuchu	66	20

(Source: JICA Survey Team)

By implementing the above measures, it is possible to maintain the proper voltage level in the steady state. Furthermore, the proper voltage (0.90 to 1.10 pu) can be maintained even under N-1 conditions.

(3) Outage of one generator (Optional N-1)

Even when one generator is stopped, there is no overloaded equipment, and proper voltage can be maintained.

(4) Fault current analysis

The fault current at the busbar of each substation is calculated in the system where measures were taken via power flow current analysis. The results are shown below.

Table 9-51 Fault Current Calculation Results

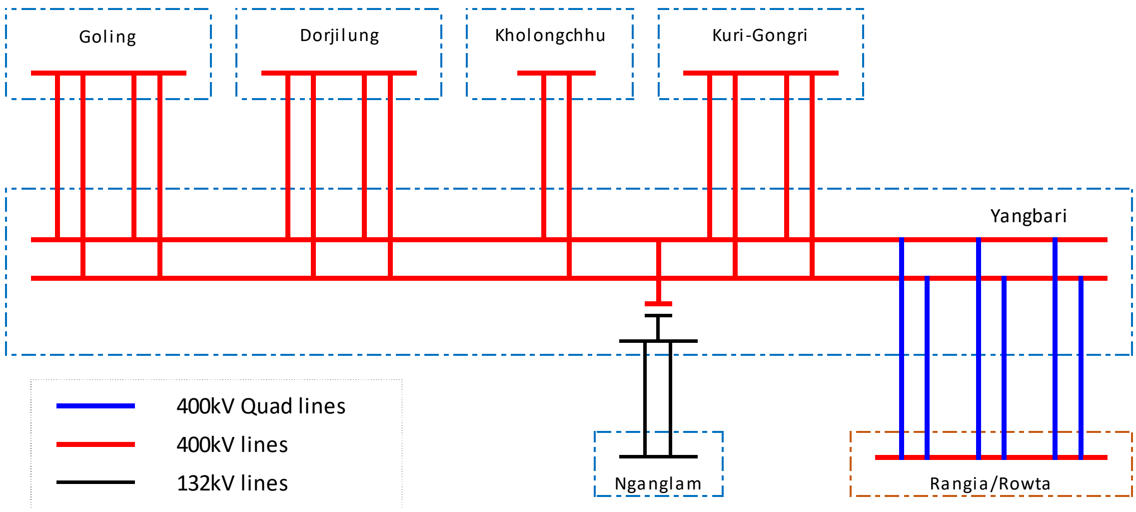
400kV			220kV			132kV		
Bus No.	Bus name	Fault Current (kA)	Bus No.	Bus name	Fault Current (kA)	Bus No.	Bus name	Fault Current (kA)
401	Tala	31.2	201	Chhukha	16.3	101	Kurichhu	6.9
402	Malbase	34.8	202	Malbase	28.1	102	Kilikhar	6.6
403	Kholongchhu	20.7	203	Semtokha	13.1	103	Kanglung	8.6
404	Mangdechhu	38.0	204	Baso-LS	15.0	104	Nangkor	8.5
405	Puna I	41.6	205	Tsirang	10.1	105	Nganglam	12.9
406	Puna II	45.7	206	Jigmeling	14.9	106	Deothang	9.5
407	Jigmeling	45.8	207	Dagachhu	12.2	107	Motanga	14.1
408	Goling	54.7	208	Singhigaon	22.9	108	Gelephu	3.9
409	Lhamoizingkha	45.5	209	Samtse	10.1	109	Tingtibi	9.8
410	Yangbari	70.8	210	Puna I	15.5	110	Yurmo	10.6
411	Dorjilung	49.0	211	Bunakha	17.3	111	Jigmeling	7.0
412	Wangchhu	22.5	212	Sankosh RB	9.8	112	Mangdechhu	11.3

400kV			220kV			132kV		
Bus No.	Bus name	Fault Current (kA)	Bus No.	Bus name	Fault Current (kA)	Bus No.	Bus name	Fault Current (kA)
413	Nyera-II	19.9	213	Sankosh LB	7.2	113	Nikachhu	9.6
414	Phuentshothang	21.0	215	Sankosh (reg.)	8.4	114	Kholongchhu	10.8
415	Kuri-Gongri	48.0	216	Dagapela	13.0	115	Phuentshothang	21.9
416	Chamkharchhu-I	47.0	217	Chumdo	14.0	116	Nyera-I	17.8
418	Sankosh LB	43.6	218	Pinsa	9.9	117	Chamkharchhu-I	20.1
419	Sankosh RB	42.6	219	Puna II	10.3	118	Yangbari	11.6
420	Dorokha	27.9	220	Tseykha	9.7	119	Kago	5.5
421	Chamkharchhu-II	23.9	221	Dagachhu-II	10.9	120	Buli	7.9
422	Amochhu res	46.7	222	Gamri-II	8.7	121	N.A. Kangpara	7.1
423	Tingma	22.4	223	Gamri-I	11.0	122	Puna II	5.9
424	Chamkharchhu-IV	19.1	226	Phuentshothang	5.9	123	Goling	8.8
425	Uzorong	30.8	227	Darachhu	10.6	211150	Rangia1	14.0
426	Thasa	38.5	228	Uzorong	13.8	211550	Salakati1	3.3
427	Jongthang	24.5	9920	Chhukha CB	9.5			
428	Minjey	25.8	9921	Dagapela CB	12.2			
430	Wangdigang	39.5	9922	Tsirang CB	5.1			
214151	Rangia	61.0	212190	Bongaigaon	29.9			
214170	Bongaigaon	42.6	212203	Rangia	23.1			
444072	Siliguri-PG	52.4	212380	Rangia2	17.2			
444073	Alipurduar	61.8	442025	Birpara-PG	25.8			
			442071	Siliguri-PG	31.7			
			442073	Alipurduar	27.0			

(Source: JICA Survey Team)

The fault current exceeds 63kA in the 400kV bus fault at Yangbari Substation. If the fault current does not reach 63kA, it can be solved by adopting a circuit breaker with the rating capacity of 63kA, but generally, a circuit breaker with a rating capacity over 63kA would be special. So, if the fault current exceeds 63kA, measures such as transmission line opening, substation division, and bus separation may be considered. In general, the bus separation method is used due to its cost-effectiveness.

In this study, the effect of using the 400kV busbar separation of Yangbari Substation as shown in the figure is evaluated.



(Source: JICA Survey Team)

Figure 9-50 Yangbari Substation 400kV Bus Division

The calculation results for the fault current before and after the 400kV bus separation of Yangbari Substation are shown in Table 9-52.

Table 9-52 Results of Fault Current Calculation before and after 400kV Bus Separation of Yangbari Substation

Bus Voltage (kV)	Bus No	Substation	Fault current(kA)		Countermeasure
			before	after	
400	410	Yangbari (a)	70.8	59.8	Bus separation
-	-	Yangbari (b)	-	59.6	

(Source: JICA Survey Team)

Since the effectiveness of 400kV separated busbar operation at the Yangbari substation can be expected from these results, it is adopted in this study.
However, since the fault current in the case of a transmission line accident becomes unbalanced with 400kV separated busbar operation, a bus-tie automatic closing device should be installed, and in the case of a transmission line accident, it is recommended to eliminate imbalances in the power flow via automatic connecting of each separated 400kV busbar.

(5) Stability analysis

In order to confirm whether it is necessary to carry out a dynamic stability analysis, power flow calculations were carried out under N-1 conditions, and the phase difference between both ends of the equipment (transmission line and transformer) was calculated.
The maximum phase difference is 10.0 degrees. This is the phase difference of both ends of the 400kV transmission line between Wangchhu Power Station and Siliguri Substation under a single contingency at the Wangchhu - Tala transmission line.
The above result is sufficiently small in comparison with the phase difference of 20 degrees which is regulated in the planning standards.

(6) Study on drought periods

(a) Power flow analysis

1) Power flow analysis in steady state (N-0)

As a result of the power flow analysis in the steady state (N-0), it is confirmed that overloading does not occur.

2) Power flow under single contingency (N-1)

As a result of the power flow analysis under N-1, it is confirmed that overloading does not occur.

In terms of accidents at single phase transformers, an overload occurs in the case of an accident at a 400/132kV single phase transformer in Kholongchhu substation and an accident of a 400/220kV single phase transformer in Jigmeling substation. To counter this, it is necessary to replace the affected transformer with a spare one. While replacement work is ongoing, the following operational countermeasures may be effective:

Kholongchhu: Demand (about 5MW) in Motanga etc. is suppressed.
Jigmeling: Transmission line of Punatsangchhu-I - Tsirang which is usually opened is closed.

Table 9-53 Calculation Results under an Accident of a Single Phase Transformer: Overloaded Equipment

Fault equipment								Overloaded equipment							Load factor (%)
TL(1)	From			To			CCT								
TF(0)	No.	Bus name	(kV)	No.	Bus name	(kV)	No.								
0	114	Kholongchhu	132	403	Kholongchhu	400	1,2,3	115	Phuentshothang	132	414	Phuentshothang	400	2	101.6
								115	Phuentshothang	132	414	Phuentshothang	400	3	101.6
								115	Phuentshothang	132	414	Phuentshothang	400	4	101.6
0	206	Jigmeling	220	407	Jigmeling	400	1,2,3	109	Tingtibi	132	111	Jigmeling	132	1	109.3

(Source: JICA Survey Team)

(b) Voltage check
In the steady state and N-1 state, there were no busbar that deviated from the reference voltage.

(c) Out of one generator (Optional N-1)
Even when one generator is stopped, there is no overloaded equipment, and proper voltage can be maintained.

(7) Study on 110% output of generators
(a) Power flow analysis
As a result of the power flow analysis in the steady state (N-0), it is confirmed that overloading does not occur.

(b) Voltage check
In the steady state, there were no busbar that deviated from the reference voltage.
However, it is expected that Tap change of transformer in Changidapuchu will be necessary.

(8) Proposal of future grid design requirements
To realize the feasible grid in 2050, the following measures are required.

Table 9-54 Grid Requirements in 2050

<Transmission lines>

Transmission line			Voltage (kV)	Countermeasure
Yangbari	-	Rangia	400	Moose (Quad) 4cct => 6cct
Baso-LS	-	Punatsangchhu-I	220	Zebra 1cct => Zebra (Twin) 2cct Bunakha - Chhukha: open Punatsangchhu-I - Tsirang: open
Semtokha	-	Baso-LS	220	Zebra 1cct => Zebra (Twin) 2cct
Semtokha	-	Chumdo	220	Zebra 1cct => Zebra (Twin) 2cct
Bunakha	-	Chumdo	220	Zebra 1cct => 2cct
Malbase	-	Bunakha	220	Zebra 2cct => Zebra (Twin) 2cct
Malbase	-	Birpara-PG	220	Zebra 1cct => Zebra (Twin) 2cct
Motanga	-	Phuentshothang	132	Panther 2cct => Zebra 2cct
Phuentshothang	-	Nyera Amari-I	132	Panther 2cct => Zebra 2cct
Chumdo	-	Khasadrapchu	66	Dog 1cct => 2cct
Olakha	-	Semtokha	66	Dog 1cct => 2cct
Semtokha	-	Dechencholing	66	Dog 1cct => 2cct
Lobeysa	-	Gaywathang	66	Dog 1cct => Zebra 1cct
Gaywathang	-	Baso-LS	66	Dog 1cct => Zebra 1cct

<Substations>

Substation	Voltage(kV)			Countermeasure
Punatsangchhu-I	400	/	220	1～3B:105 => 150MVA Replacement
Punatsangchhu-II	400	/	220	1, 2B:105 => 200MVA Replacement
Goling	400	/	132	1B, 2B:67 => 100MVA Replacement
Malbase	400	/	220	5B:200MVA Expansion
	400	/	220	6B:200MVA Expansion
	220	/	66	4B:50/63MVA Expansion
Semtokha	220	/	66	3B:50/63MVA Expansion
	220	/	66	4B:50/63MVA Expansion
Baso-LS	220	/	66	2B:50/63MVA Expansion
	220	/	66	3B:50/63MVA Expansion
Tsirang	200	/	66	3B:50/63MVA Expansion
	220	/	66	4B:50/63MVA Expansion
Singhigaon	220	/	66	3B:50/63MVA Expansion
	220	/	66	4B:50/63MVA Expansion
Chumdo	220	/	66	3B:50/63MVA Expansion

	220	/	66	4B:50/63MVA Expansion
Gelephu	132	/	66	3B:50MVA Expansion
	132	/	66	4B:50MVA Expansion
Dechencholing	66	/	33	3B:30MVA Expansion
Changidapuchu	66	/	33	3B:30MVA Expansion
Yangbari	400			Bus division

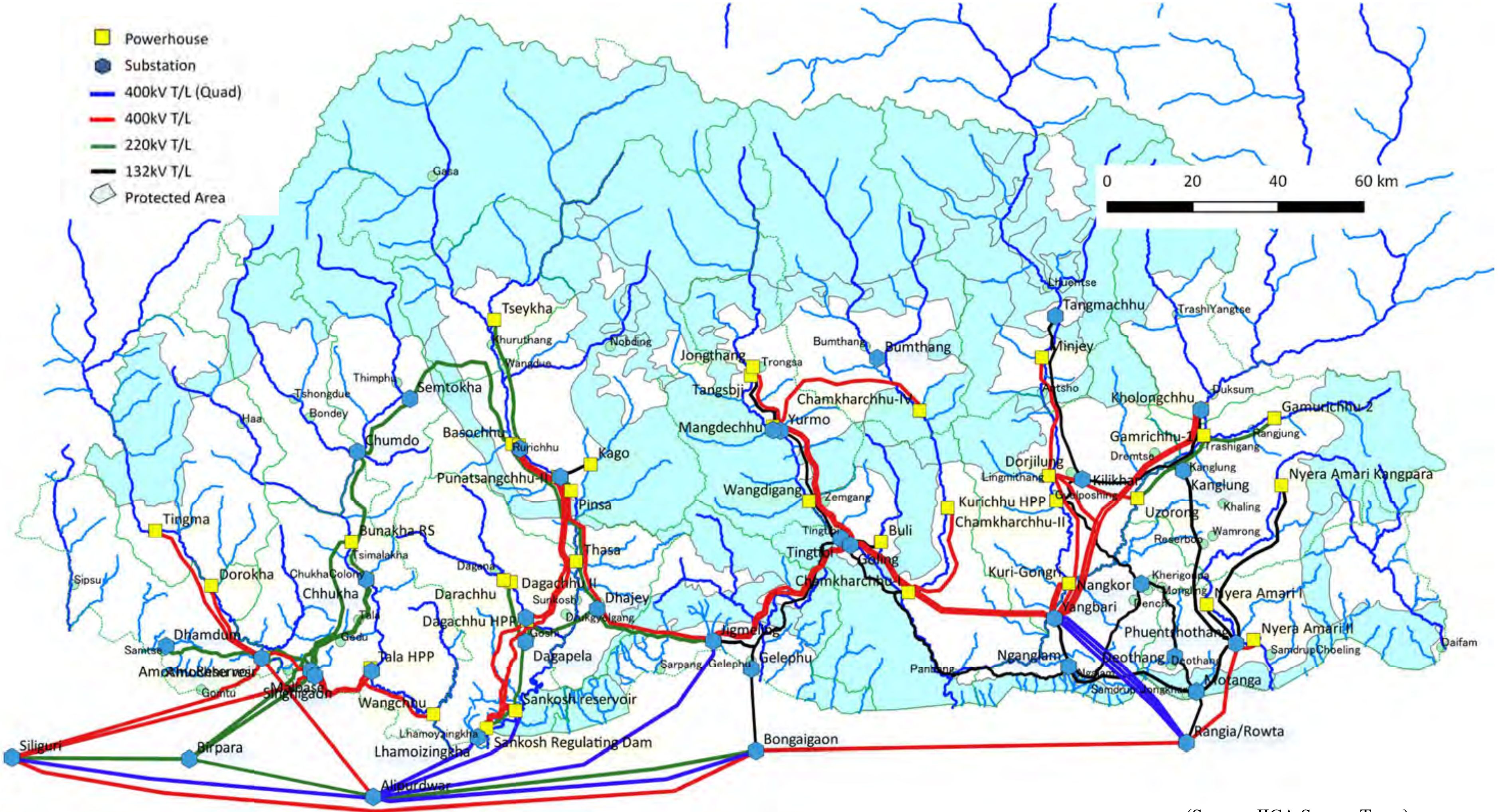
< Reactive power compensator>

Substation	Voltage(kV)	SC[MVA]
Deothang	132	50
Paro	66	25
Lobeysa	66	30
Gomtu	66	20
Gelephu	66	30
Changidapuchu	66	20

(Source: JICA Survey Team)

As a result of implementing these measures, there is no overloaded equipment under N-0 or N-1, and the appropriate voltage can be maintained. In addition, the fault current is also within the allowable value, and transient stability is within the regulated level.

Implementing the above measures, the network system in 2050 will be as shown in Figure 9-51.



(Source: JICA Survey Team)

Figure 9-51 Future Designed Grid (2050)

9.4.3 Grid Plan in 2035

(1) Plans to be developed by 2035

By 2035, in addition to the Kuri-Gongri (2,640 MW), Bunakha (180 MW), Chamkharchhu-I (770 MW) and Wangchhu (570 MW) hydropower plants, development of three sites extracted as promising sites in this MP (Dorokha (550MW), Pinsa (153MW), Chamkharchhu-II (414MW)) is planned to be put into operation, and these generators and corresponding transmission facilities are included in the model for the study. The following shows the modifications from the grid plan in 2030 described in NTGMP 2018.

Table 9-55 Additional Equipment (up to 2035)

Generators

Generator	Output	
Kuri-Gongri	2,640MW	(330MW x 8)
Bunakha	180MW	(60MW x 3)
Chamkharchhu-I	770MW	(192.5MW x 4)
Wangchhu	570MW	(142.5MW x 4)
Dorokha	550MW	
Pinsa	153MW	
Chamkharchhu-II	414MW	

Transmission line

Voltage	From	To	Main specification
400kV	Kuri-Gongri	Yangbari	2 x 2cct, Moose (Twin), 40.0km
400kV	Yangbari	Rangia/Rowta	1 x 2cct, Moose (Quad), 40.0km
132kV	Yangbari	Nganglam	1 x 2cct, Panther, 30.0km
220kV	Bunakha	Malbase	1 x 2cct, Zebra, 30.0km
220kV	Bunakha	LILO	1cct, Zebra, Chhukha-Semtokha
400kV	Yangbari	Goling	2 x 2cct, Moose (Twin) , 60.0km
400kV	Chamkharchhu-I	LILO	2cct, Moose (Twin), Yangbari-Goling
132kV	Chamkharchhu-I	LILO	1cct, Panther, Nganglam-Tingtibi
400kV	Wangchhu	LILO	1cct, Moose (Twin), Tala-Khogla/Pugli-Siliguri
400kV	Dorokha	Amochhu	1 x 2cct, Moose (Twin), 26.6km
220kV	Pinsa	Punatsangchhu-II	1 x 2cct, Zebra, 5.2km
400kV	Chamkharchhu-II	Chamkharchhu-I	1 x 2cct, Moose (Twin), 35.9km

Substation equipment (Excluding boost transformer at power plant)

Voltage	Substation	Main specification
400/132/33kV	Yangbari	Transformer 4 x 67 MVA (1 is spare)
400kV	Yangbari	ShR 2 x 80MVAr
400/220kV	Malbase	Transformer 4 x 67 MVA (1 is spare)
400/132/33kV	Chamkharchhu-I	Transformer 4 x 67 MVA (1 is spare)
400kV	Goling	ShR 2 x 80Mar
400kV	Wangchhu	ShR 1 x 63 MVAr
400/220kV	Punatsangchhu-II	Transformer 2 x 105 MVA (for Pinsa)

(Source: JICA Survey Team)

(2) Power flow analysis

(a) Power flow in steady state (N-0)

A Power flow analysis is conducted in the steady state (N-0). The results are shown in Table 9-56.

Table 9-56 Results of Power Flow Calculation under N-0: Overloaded Equipment

TL (1)	From			To			CCT	Loading	Rating	Percent
TF (0)	Bus No.	Bus name	(kV)	Bus No.	Bus name	(kV)	No.	(MVA)	(MVA)	(%)
1	604	Chumdo	66	623	Khasadrapchu	66	1	45.3	39.0	116.2

(Source: JICA Survey Team)

In order to solve the above overload, the Chumdo-Khasadrapchu 66kV transmission line is doubled as shown in Table 9-57.

Table 9-57 System Measures for Overload Cancellation under N-0 Conditions

Transmission line	Voltage(kV)	Measure
Chumdo - Khasadrapchu	66	Dog 1cct => 2cct

(Source: JICA Survey Team)

(b) Power flow under single contingency (N-1)

The results of the power flow calculation under N-1 are shown in Table 9-58, and the measures to prevent overloading are shown in Table 9-59.

Table 9-58 Calculation Results under N-1: Overloaded Equipment

Fault equipment								Overloaded equipment							Load factor
TL(1)	From			To			CCT								
TF(0)	No.	Bus name	(kV)	No.	Bus name	(kV)	No.								(%)
1	112	Mangdechhu	132	113	Nikachhu	132	1	112	Mangdechhu	132	113	Nikachhu	132	2	105.4
1	112	Mangdechhu	132	113	Nikachhu	132	2	112	Mangdechhu	132	113	Nikachhu	132	1	105.4
1	419	Sankosh RB	400	444073	Alipurduar	400	1	203	Semtokha	220	204	Baso-LS	220	1	100.1
0	108	Gelephu	132	622	Gelephu	66	1	108	Gelephu	132	622	Gelephu	66	2	167.2
0	108	Gelephu	132	622	Gelephu	66	2	108	Gelephu	132	622	Gelephu	66	1	167.2
0	202	Malbase	220	618	Malbase	66	1	202	Malbase	220	618	Malbase	66	2	106.9
0	202	Malbase	220	618	Malbase	66	1	202	Malbase	220	618	Malbase	66	3	106.9
0	202	Malbase	220	618	Malbase	66	2	202	Malbase	220	618	Malbase	66	1	106.9
0	202	Malbase	220	618	Malbase	66	2	202	Malbase	220	618	Malbase	66	3	106.9
0	202	Malbase	220	618	Malbase	66	3	202	Malbase	220	618	Malbase	66	1	106.9
0	202	Malbase	220	618	Malbase	66	3	202	Malbase	220	618	Malbase	66	2	106.9
0	203	Semtokha	220	610	Semtokha	66	1	203	Semtokha	220	610	Semtokha	66	2	210.4
0	203	Semtokha	220	610	Semtokha	66	2	203	Semtokha	220	610	Semtokha	66	1	210.4
0	614	Baso-LS	66	615	Baso-US	66	2	204	Baso-LS	220	614	Baso-LS	66	1	127.0
0	205	Tsirang	220	616	Tsirang	66	1	205	Tsirang	220	616	Tsirang	66	2	189.3
0	205	Tsirang	220	616	Tsirang	66	2	205	Tsirang	220	616	Tsirang	66	1	189.3
0	208	Singhigaon	220	621	Singhigaon	66	1	208	Singhigaon	220	621	Singhigaon	66	2	213.6
0	208	Singhigaon	220	621	Singhigaon	66	2	208	Singhigaon	220	621	Singhigaon	66	1	149.3
0	217	Chumdo	220	604	Chumdo	66	1	217	Chumdo	220	604	Chumdo	66	2	124.2
0	217	Chumdo	220	604	Chumdo	66	2	217	Chumdo	220	604	Chumdo	66	1	124.2
0	219	Puna II	220	406	Puna II	400	1	219	Puna II	220	406	Puna II	400	2	145.9
0	219	Puna II	220	406	Puna II	400	2	219	Puna II	220	406	Puna II	400	1	145.9

(Source: JICA Survey Team)

Table 9-59 Countermeasures to solve Overloading under N-1

<Transmission lines>

Transmission line	Voltage(kV)	Countermeasure
Semtokha - Baso-LS	66	Zebra 1cct => Zebra(Twin) 2cct

Note) 132kV Mangdechhu-Nikachhu is an existing power transmission line; the overload is coped with via output suppression of Nikachhu.

<Substations>

Substation	Voltage(kV)	Countermeasure
Gelephu	132 / 66	3B:50MVA Expansion
Malbase	220 / 66	4B:50/63VA Expansion
Semtokha	220 / 66	3B:50/63MVA Expansion
Baso-LS	220 / 66	2B:50/63MVA Expansion

Tsirang	220 / 66	3B:50/63MVA Expansion
Singhigaon	220 / 66	3B:50/63MVA Expansion
Chumdo	220 / 66	3B:50/63MVA Expansion
Puna II	400 / 220	1,2B:105 => 200MVA Replace

(Source: JICA Survey Team)

Table 9-60 shows the results of the power flow calculation after taking the above measures, and Table 9-61 shows the measures for overloads.

Table 9-60 Results of Power Flow Calculation under N-1: after Implementation of Measures

Fault equipment								Overloaded equipment							Load factor
TL(1)	From			To			CCT								
TF(0)	No.	Bus name	(kV)	No.	Bus name	(kV)	No.								(%)
1	112	Mangdechhu	132	113	Nikachhu	132	1	112	Mangdechhu	132	113	Nikachhu	132	2	105.4
1	112	Mangdechhu	132	113	Nikachhu	132	2	112	Mangdechhu	132	113	Nikachhu	132	1	105.4
0	202	Malbase	220	402	Malbase	400	1	204	Baso-LS	220	210	Puna I	220	1	100.2
0	407	Jigmeling	400	444073	Alipurduar	400	1	204	Baso-LS	220	210	Puna I	220	1	102.4
0	407	Jigmeling	400	444073	Alipurduar	400	2	204	Baso-LS	220	210	Puna I	220	1	102.4
0	409	Lhamoizingkha	400	444073	Alipurduar	400	1	204	Baso-LS	220	210	Puna I	220	1	104.1
0	409	Lhamoizingkha	400	444073	Alipurduar	400	2	204	Baso-LS	220	210	Puna I	220	1	104.1
0	418	Sankosh LB	400	444073	Alipurduar	400	1	204	Baso-LS	220	210	Puna I	220	1	105.3
0	419	Sankosh RB	400	444073	Alipurduar	400	1	204	Baso-LS	220	210	Puna I	220	1	105.5

(Source: JICA Survey Team)

Table 9-61 Countermeasures to solve Overloading under N-1

<Transmission line>

Transmission line	Voltage(kV)	Countermeasure
Baso-LS - Puna I	66	Zebra 1cct => Zebra (Twin) 2cct

Note) 132kV Mangdechhu-Nikachhu is an existing power transmission line, the overload is coped with output suppression of Nikachhu.

(Source: JICA Survey Team)

By implementing these measures, overloading in the steady state (N-0) and the N-1 state is solved.

In terms of accidents at single phase transformers, an overload occurs in the case of an accident at a 400/132kV single phase transformer in Mangdechhu substation. To counter this, it is necessary to replace the affected transformer with a spare one. While replacement work is ongoing, the following operational countermeasures may be effective:
Mangdechhu: Output suppression of the Nikachhu Power Station

Table 9-62 Calculation Results under an Accident of a Single Phase Transformer: Overloaded Equipment

Fault equipment								Overloaded equipment							Load factor
TL(1)	From			To			CCT								
TF(0)	No.	Bus name	(kV)	No.	Bus name	(kV)	No.								(%)
0	112	Mangdechu	132	404	Mangdechu	400	1,2,3	109	Tingtibi	132	110	Yurmo	132	1	115.0

(Source: JICA Survey Team)

(3) Voltage check

Under N-0 and the N-1 conditions, the busbar voltage of each substation can maintain an appropriate voltage. However, it is expected that operational measures (SC40MVA release of Olakha, SC15MVA release of Dechencholing, Tap change of Changidapuchu) will be necessary.

(4) Outage of one generator (Optional N-1)

Even when one generator is stopped, there is no overloaded equipment, and proper voltage can be maintained.

(5) Fault current analysis

As a result of the fault current analysis, it is confirmed that the fault current at the busbar of each substation is within the reference value shown in 9.4.1 (2).

Table 9-63 Fault Current Calculation Results

400kV			220kV			132kV		
Bus No.	Bus name	Fault Current (kA)	Bus No.	Bus name	Fault Current (kA)	Bus No.	Bus name	Fault Current (kA)
401	Tala	29.4	201	Chhukha	18.7	101	Kurichhu	6.9
402	Malbase	30.4	202	Malbase	20.1	102	Kilikhar	6.6
403	Kholongchu	19.8	203	Semtokha	11.0	103	Kanglung	8.5
404	Mangdechhu	31.6	204	Baso-Ls	13.6	104	Nangkor	8.4
405	Puna I	38.9	205	Tsirang	13.0	105	Nganglam	12.7
406	Puna II	42.2	206	Jigmeling	15.6	106	Deothang	9.3
407	Jigmeling	40.8	207	Dagachu	12.2	107	Motanga	13.6
408	Goling	44.9	208	Singhigaon	17.3	108	Gelephu	3.9
409	Lhamoizingkha	42.9	209	Samtse	8.8	109	Tingtibi	9.8
410	Yangbari	59.0	210	Puna I	14.1	110	Yurmo	10.5
411	Dorjilung	38.4	211	Bunakha	18.2	111	Jigmeling	7.0
412	Wangchu	21.7	212	Sankosh RB	9.5	112	Mangdechhu	11.2
413	Nyera-II	18.8	213	Sankosh LB	7.1	113	Nikachhu	9.5
414	Phuentshothang	19.8	215	S.Regulating	8.2	114	Kholongchhu	10.7
415	Kurigongri	43.9	216	Dagapela	12.1	115	Phuentshothang	20.0
416	Chamkharchhu-I	41.7	217	Chumdo	11.6	116	Nyera-I	16.6
418	Sankosh LB	41.3	218	Pinsa	9.8	117	Chamkharchhu-I	19.8
419	Sankosh RB	40.4	219	Puna II	10.3	118	Yangbari	11.4
420	Dorokha	24.7	212190	Bongaigaon	29.6	9908		1.7
421	Chamkharchhu-II	26.4	212203	Rangia	22.6	9909		3.1
422	Amochhu Res	38.1	212380	Rangia2	17.0	211150	Rangia1	14.0
214151	Rangia	51.7	442025	Birpara-PG	22.6	211550	Salakati1	3.3
214170	Bongaigaon	40.9	442071	Siliguri-PG	31.2			
444072	Siliguri-PG	49.8	442073	Alipurduar	26.2			
444073	Alipurduar	55.4						

(Source: JICA Survey Team)

(6) Stability analysis

In order to confirm whether it is necessary to carry out a dynamic stability analysis, power flow calculations were carried out under N-1 conditions, and the phase difference between both ends of the equipment (transmission line and transformer) was calculated.

The maximum phase difference is 9.9 degrees. This is the phase difference of both ends of the 400kV transmission line between Wangchhu Power Station and Siliguri Substation under a single contingency at the Wangchhu - Tala transmission line.

The above result is sufficiently small in comparison with the phase difference of 20 degrees which is regulated in the planning standards.

(7) Study on drought periods

(a) Power flow analysis

1) Power flow analysis in steady state (N-0)

As a result of the power flow analysis in the steady state (N-0), it is confirmed that overloading does not occur.

2) Power flow under single contingency (N-1)

The power flow calculation results under N-1 are shown in Table 9-64.

Table 9-64 Power Flow Calculation Results under N-1: Overloaded Equipment

Fault equipment								Overloaded equipment	Load factor (%)
TL(1)	From			To			CCT		
TF(0)	No.	Bus name	(kV)	No.	Bus name	(kV)	No.		
0	204	Baso-LS	220	614	Baso-LS	66	2	204 Baso-LS 220 614 Baso-LS 66 1	100.5

(Source: JICA Survey Team)

In the case of this single contingency of 220/66kV transformer at Baso-LS, we cope with the overload by closing the opened 220kV Semtokha - Lobeysa transmission line under normal operation.

(b) Voltage check

In the steady state and N-1 state, there were no busbars that deviated from the reference voltage.

(c) Outage of one generator (Optional N-1)

Even when one generator is stopped, there is no overloaded equipment, and proper voltage can be maintained.

(8) Study on 110% output of generators

(a) Power flow analysis

As a result of the power flow analysis in the steady state (N-0), it is confirmed that overloading does not occur.

(b) Voltage check

In the steady state, there were no busbars that deviated from the reference voltage.
However, it is expected that Tap change of transformer in Changidapuchu will be necessary.

9.4.4 Grid Plan in 2040

(1) Plans to be developed by 2040

By 2040, three development prospects (Tingma (783MW), Jongthang (414MW), Uzorong (840MW)) extracted in this MP are planned to start operation, and these generators and the corresponding power transmission equipment are included in the model for the study in 2040. The following shows the modifications from the study model in 2035.

Table 9-65 Additional Equipment (up to 2040)

Generator

Generator	Output	
Tingma	783MW	
Jongthang	227MW	
Uzorong	840MW	

Transmission line

Voltage	From	To	Main specification
400kV	Tingma	Amochhu	1 x 2cct, Moose(Twin), 48.7km
400kV	Jongthang	Mangdechhu	1 x 2 cct, Moose(Twin), 23.6km
400kV	Uzorong	Dorjilung	1 x 2 cct, Moose(Twin), 25.9km

(Source: JICA Survey Team)

(2) Power flow analysis

(a) Power flow analysis in steady state (N-0)

A power flow analysis was conducted in the steady state (N-0). The results are shown below.

Table 9-66 Results of Power Flow Calculation under N-0 Conditions: Overloaded Equipment

TL (1)	From			To			CCT	Loading	Rating	Percent
TF (0)	Bus No.	Bus name	(kV)	Bus No.	Bus name	(kV)	No.	(MVA)	(MVA)	(%)
1	609	Olakha	66	610	Semtokha	66	1	43.8	39	112.3
1	610	Semtokha	66	611	Dechencholing	66	1	43.6	39	111.7
1	612	Lobeysa	66	613	Gaywathang	66	1	41.5	39	106.5
1	613	Gaywathang	66	614	Baso-LS	66	1	41.7	39	106.9

(Source: JICA Survey Team)

In order to solve the above-mentioned overloading, the transmission lines are reinforced as shown in Table 9-67.

Table 9-67 Countermeasures to solve Overloads under N-0

Transmission line			Voltage(kV)	Countermeasure
Olakha	-	Semtokha	66	Dog 1cct => 2cct
Semtokha	-	Dechencholing	66	Dog 1cct => 2cct
Lobeysa	-	Gaywathang	66	Dog 1cct => Zebra 1cct
Gaywathang	-	Baso-LS	66	Dog 1cct => Zebra 1cct

(Source: JICA Survey Team)

(b) Power flow under N-1 condition

Table 9-68 shows the results of the power flow calculation under N-1, and Table 9-69 shows measures against overloading.

Table 9-68 Power Flow Calculation Results under N-1: Overloaded Equipment

Fault equipment								Overloaded equipment							Load factor
TL(1)	From			To			CCT								
TF(0)	No.	Bus name	(kV)	No.	Bus name	(kV)	No.								(%)
1	112	Mangdechhu	132	113	Nikachhu	132	2	112	Mangdechhu	132	113	Nikachhu	132	1	105.3
1	112	Mangdechhu	132	113	Nikachhu	132	1	112	Mangdechhu	132	113	Nikachhu	132	2	105.3
0	203	Semtokha	220	610	Semtokha	66	2	203	Semtokha	220	610	Semtokha	66	1	100.2
0	203	Semtokha	220	610	Semtokha	66	3	203	Semtokha	220	610	Semtokha	66	1	100.2
0	203	Semtokha	220	610	Semtokha	66	1	203	Semtokha	220	610	Semtokha	66	2	100.2
0	203	Semtokha	220	610	Semtokha	66	3	203	Semtokha	220	610	Semtokha	66	2	100.2
0	203	Semtokha	220	610	Semtokha	66	1	203	Semtokha	220	610	Semtokha	66	3	100.2
0	203	Semtokha	220	610	Semtokha	66	2	203	Semtokha	220	610	Semtokha	66	3	100.2
0	205	Tsirang	220	616	Tsirang	66	1	205	Tsirang	220	616	Tsirang	66	3	123.3
0	205	Tsirang	220	616	Tsirang	66	2	205	Tsirang	220	616	Tsirang	66	3	123.3
0	108	Gelephu	132	622	Gelephu	66	1	108	Gelephu	132	622	Gelephu	66	3	116.9
0	108	Gelephu	132	622	Gelephu	66	2	108	Gelephu	132	622	Gelephu	66	3	116.9

(Source: JICA Survey Team)

Table 9-69 Countermeasures to solve Overloads under N-1

Substation	Voltage(kV)	Countermeasure
Gelephu	132 / 66	4B:50MVA Expansion
Semtokha	220 / 66	4B:50/63MVA Expansion
Tsirang	220 / 66	4B:50/63MVA Expansion

Note) 132kV Mangdechhu-Nikachhu is an existing power transmission line; the overload is coped with via output suppression of Nikachhu.

(Source: JICA Survey Team)

By implementing these measures, overloading in the steady state (N-0) and the N-1 state is solved.

In terms of accidents at single phase transformers, an overload occurs in the case of an accident at a 400/132kV single phase transformer in Mangdechhu substation. To counter this, it is necessary to replace the affected transformer with a spare one. While replacement work is ongoing, the following operational countermeasures may be effective:

Mangdechhu: Output suppression of the Nikachhu Power Station

Table 9-70 Calculation Results under an Accident of a Single Phase Transformer: Overloaded Equipment

Fault equipment								Overloaded equipment							Load factor
TL(1)	From			To			CCT								
TF(0)	No.	Bus name	(kV)	No.	Bus name	(kV)	No.								(%)
0	112	Mangdechu	132	404	Mangdechu	400	1,2,3	109	Tingtibi	132	110	Yurmo	132	1	114.8

(Source: JICA Survey Team)

(3) Voltage check

Table 9-71 shows busbars that deviate from the reference voltage (0.95 to 1.05 pu) in the steady state (N-0) after implementing the above overloading countermeasure.

Table 9-71 Reference Voltage Deviation Busbars

Bus No.	Name	Voltage (p.u.)	Voltage (kV)
108	Gelephu	0.947	125.0
606	Haa	0.929	61.3
622	Gelephu	0.936	61.8
605	Paro	0.927	61.2
612	Lobeysa	0.936	61.7
627	Changidapuchu	0.939	62.0

(Source: JICA Survey Team)

In order to maintain the proper voltage at each busbar, the following reactive power compensators will be installed in this study.

Table 9-72 Reactive Power Compensators installed

Substation	Voltage(kV)	SC[MVA]
Gelephu	66	30
Changidapuchu	66	20
Paro	66	25
Lobeysa	66	30

(Source: JICA Survey Team)

By implementing the above measures, it is possible to maintain the proper voltage in the normal state. The proper voltage (0.90 to 1.10 pu) under N-1 conditions can also be maintained.

(4) Outage of one generator (Optional N-1)

Even when one generator is stopped, there is no overloaded equipment, and it is possible to maintain the proper voltage.

(5) Fault current analysis

In the system where measures are taken based on the power flow analysis, a fault current calculation at the busbar of each substation is performed. The results are shown in Table 9-73. From the calculation results, it is confirmed that there are no busbars where the fault current exceeds the reference value.

Table 9-73 Results of Fault Current Calculation

400kV			220kV			132kV		
Bus No.	Bus name	Fault Current (kA)	Bus No.	Bus name	Fault Current (kA)	Bus No.	Bus name	Fault Current (kA)
401	Tala	30.1	201	Chhukha	18.8	101	Kurichhu	6.9
402	Malbase	32.1	202	Malbase	20.2	102	Kilikhar	6.6
403	Kholongchu	20.1	203	Semtokha	11.0	103	Kanglung	8.5
404	Mangdechhu	33.3	204	Baso-Ls	13.6	104	Nangkor	8.4
405	Puna I	39.3	205	Tsirang	13.0	105	Nganglam	12.7
406	Puna II	42.8	206	Jigmeling	15.7	106	Deothang	9.3
407	Jigmeling	42.0	207	Dagachu	12.2	107	Motanga	13.6
408	Goling	47.1	208	Singhigaon	17.4	108	Gelephu	3.9
409	Lhamoizingkha	43.7	209	Samtse	8.8	109	Tingtibi	9.8
410	Yangbari	63.1	210	Puna I	14.2	110	Yurmo	10.5
411	Dorjilung	43.0	211	Bunakha	18.3	111	Jigmeling	7.0
412	Wangchu	22.1	212	Sankosh RB	9.5	112	Mangdechhu	11.3
413	Nyera-II	19.0	213	Sankosh LB	7.1	113	Nikachhu	9.5
414	Phuentshothang	20.0	215	S.Regulating	8.3	114	Kholongchhu	10.7
415	Kurigongri	45.4	216	Dagapela	12.2	115	Phuentshothang	20.1
416	Chamkharchhu-I	43.3	217	Chumdo	11.7	116	Nyera-I	16.7
418	Sankosh LB	41.9	218	Pinsa	9.8	117	Chamkharchhu-I	19.9
419	Sankosh RB	41.1	219	Puna II	10.3	118	Yangbari	11.5
420	Dorokha	26.1	212190	Bongaigaon	29.7	9908		1.7
421	Chamkharchhu-II	26.9	212203	Rangia	22.7	9909		3.1
422	Amochhu Res	42.2	212380	Rangia2	17.1	211150	Rangia1	14.0
423	Tingma	22.2	442025	Birpara-PG	22.7	211550	Salakati1	3.3
425	Uzorong	27.8	442071	Siliguri-PG	31.3			
427	Jongthang	22.8	442073	Alipurduar	26.3			
214151	Rangia	53.7						
214170	Bongaigaon	41.4						
444072	Siliguri-PG	51.0						
444073	Alipurduar	58.1						

(Source: JICA Survey Team)

The fault current exceeds 63kA in the 400kV bus fault at Yangbari Substation. Therefore, 400kV separated busbar operation is adopted at Yangbari Substation as in 2050.

The calculation results for the fault current before and after the 400kV bus separation of Yangbari Substation are shown in Table 9-74.

Table 9-74 Results of Fault Current Calculation before and after 400kV Bus Separation of Yangbari Substation

Bus Voltage (kV)	Bus No	Substation	Fault current(kA)		Countermeasure
			before	after	
400	410	Yangbari (a)	63.1	53.2	Bus separation
-	-	Yangbari (b)	-	53.0	

(Source: JICA Survey Team)

(6) Stability analysis

In order to confirm whether it is necessary to carry out a dynamic stability analysis, power flow calculations were carried out under N-1 conditions, and the phase difference between both ends of the equipment (transmission line and transformer) was calculated.
The maximum phase difference is 10.6 degrees. This is the phase difference of both ends of the 400kV transmission line between Tala Power Station and Siliguri Substation under a single contingency at the Tala - Siliguri transmission line.
The above result is sufficiently small in comparison with the phase difference of 20 degrees which is regulated in the planning standards.

(7) Study on drought periods

(a) Power flow analysis

1) Power flow analysis in steady state (N-0)

As a result of the power flow analysis in the steady state (N-0), it is confirmed that overloading does not occur.

2) Power flow under single contingency (N-1)

The power flow calculation results under N-1 are shown in Table 9-75.

Table 9-75 Power Flow Calculation Results under N-1: Overloaded Equipment

Fault equipment								Overloaded equipment							Load factor (%)
TL(1)	From			To			CCT								
TF(0)	No.	Bus name	(kV)	No.	Bus name	(kV)	No.								
0	204	Baso-LS	220	614	Baso-LS	66	2	204	Baso-LS	220	614	Baso-LS	66	1	120.7

(Source: JICA Survey Team)

In the case of this single contingency of 220/66kV transformer at Baso-LS, we cope with the overload by closing the opened 220kV Semtokha - Lobeysa transmission line under normal operation

(b) Voltage check

In the steady state and N-1 state, there were no busbars that deviated from the reference voltage.
However, it is expected that open operation of 15MVA SC (10MVA + 5MVA) in Lobeysa will be necessary.

(c) Outage of one generator (Optional N-1)

Even when one generator is stopped, there is no overloaded equipment, and proper voltage can be maintained.

(8) Study on 110% output of generators

(a) Power flow analysis

As a result of the power flow analysis in the steady state (N-0), it is confirmed that overloading does not occur.

(b) Voltage check

In the steady state, there were no busbars that deviated from the reference voltage.
However, it is expected that Tap change of transformer in Changidapuchu will be necessary.

9.5 Grid Master Plan

9.5.1 Time Sequence for Transmission Grid Development

Based on the results studied in Sections 9.2 and 9.4, the time sequence for transmission grid development from 2021 to 2050 is shown below.

Table 9-76 Time Sequence for Transmission Grid Development

<Transmission lines>

Countermeasure			2021 -2025	2026 -2030	2031 -2035	2036 -2040	2041 -2050
Transmission line	Voltage	Main specification					
PHEP-I – Lhamoizingkha	400	1 x 2 cct, Moose (Twin), 92.9km	■				
PHEP-II – Lhamoizingkha	400	1 x 2 cct, Moose (Twin), 80.5km	■				
Lhamoizingkha - Alipurduar	400	1 x 2 cct, Moose (Quad), 64.0km	■				
PHEP-I – PHEP-II	400	1 x 2 cct, Moose (Twin) , 13.0km	■				
Kholongchhu – Yangbari	400	2 x 2 cct, Moose (Twin) , 68.3km, 69.7km	■				
Goling – Yangbari	400	1 x 2 cct, Moose (Twin) , 60.0km	■				
Goling – Jigmeling	400	2 x 2 cct, Moose (Twin) , 37.7km, 38.0km	■				
Mangdechhu – Goling	400	2 x 2 cct, Moose (Twin) , 47.4km, 46.7km	■				
Nikachhu – MHEP	132	1 x 2 cct, Panther, 10km	■				
Kholongchhu – Kilikhar	132	1 x 1 cct, Panther, 34.7km	■				
Kholongchhu – Kanglung	132	1 x 1 cct, Panther, 23.0km	■				
PHEP-I – Sankosh RB	400	1 x 2 cct, Moose (Twin), 82.9km		■			
PHEP-II – Sankosh LB	400	1 x 2 cct, Moose (Twin), 70.5km		■			
Sankosh RB – Lhamoizingkha	400	1 x 2 cct, Moose (Twin), 20.0km		■			
Sankosh LB – Lhamoizingkha	400	1 x 2 cct, Moose (Twin), 20.0km		■			
Sankosh RB, LB – Alipurduar	400	1 x 2 cct, Moose (Quad), 79.0km		■			
Sankosh – Sankosh	220	1 x 2 cct, Zebra, 13.0km		■			
Dorjilung – Yangbari	400	2 x 2 cct, Moose (Twin), 38.0km		■			
Yangbari – Rangia	400	1 x 2 cct, Moose (Quad), 40.0km		■			
Nyera Amari-I – Phuentshothang	132	1 x 2 cct, Panther, 5.0km		■			
Nyera Amari-II – Phuentshothang	400	1 x 2 cct, Moose (Twin), 5.0km			■		
Dorokha – Amochhu reservoir	400	1 x 2 cct, Moose (Twin), 26.6km			■		
Chamkharchhu-II – Chamkharchhu-I	400	1 x 2 cct, Moose (Twin), 35.9km			■		
Pinsa – Punatsangchhu-II	220	1 x 2 cct, Zebra, 5.2km			■		
Kuri-Gongri – Yangbari	400	2 x 2 cct, Moose (Twin), 40.0km			■		
Yangbari – Rangia	400	1 x 2 cct, Moose (Quad), 40.0km			■		
Yangbari – Nganglam	132	1 x 2 cct, Panther, 30.0km			■		
Bunakha – Malbase	220	1 x 2 cct, Zebra, 30.0km			■		
Bunakha	220	Chhukha-Semtokha LILO 1cct, Zebra			■		
Yangbari – Goling	400	1 x 2 cct, Moose (Twin), 60.0km			■		
Chamkharchhu-I	400	Yangbari-Goling LILO 2cct, Moose (Twin)			■		
Chamkharchhu-I	132	Nganglam-Tingtibi LILO 1cct, Panther			■		
Wangchhu	400	Tala-Khogla/Pugli-Siliguri LILO 1cct, Moose(Twin)			■		
Chumdo – Khasadrapchu	66	Dog 1cct => 2cct, 4.8km			■		
Semtokha – Baso-LS	220	Zebra 1cct => Zebra(Twin) 2cct, 44.9km			■		
Baso-LS – Punatsangchhu-I	220	Zebra 1cct => Zebra(Twin) 2cct, 5.0km			■		
Tingma – Amochhu reservoir	400	1 x 2 cct, Moose (Twin), 48.7km				■	
Jongthang – Mangdechhu	400	1 x 2 cct, Moose (Twin), 23.6km				■	
Uzorong – Dorjilung	400	1 x 2 cct, Moose (Twin), 25.9km				■	
Olakha – Semtokha	66	Dog 1cct => 2cct, 1.7km				■	
Semtokha – Dechencholing	66	Dog 1cct => 2cct, 11.5km				■	
Lobeysa – Gaywathang	66	Dog 1cct => Zebra 1cct, 21.8km				■	
Gaywathang – Baso-LS	66	Dog 1cct => Zebra 1cct, 1.5km				■	
Tseykha – Punatsangchhu-I	220	1 x 2 cct, Zebra, 37.9km					■
Kago – Punatsangchhu-II	132	1 x 2 cct, Panther, 9.3km					■
Thasa	400	Punatsangchhu II-Jigmeling LILO 2cct Moose (Twin)					■
Darachhu – Dagachhu-II	220	1 x 2 cct, Zebra, 2.3km					■
Dagachhu-II– Dagapela	220	1 x 2 cct, Zebra, 18.0km					■
Wangdigang	400	Mangdechhu-Goling LILO 2cct Moose (Twin)					■
Buli – Goling	132	1 x 2 cct, Panther, 10.5km					■
Chamkharchhu-IV – Mangdechhu	400	1 x 2 cct, Moose (Twin), 53.9km					■
Minjey – Dorjilung	400	1 x 2 cct, Moose (Twin), 35.0km					■
Gamrichhu-2 – Gamrichhu-1	220	1 x 2 cct, Zebra, 22.2km					■
Gamrichhu-1 – Uzorong	220	1 x 2 cct, Zebra, 27.1km					■
Nyera Amari Kangpara – Phuentshothang	132	1 x 2 cct, Panther, 55.6km					■
Yangbari – Rangia	400	Moose (Quad), 4cct => 6cct					■
Baso-LS – Punatsangchhu-I	220	Bunakha - Chhukha: open Punatsangchhu-I - Tsirang: open					■
Malbase – Birpara-PG	220	Zebra 1cct => Zebra(Twin) 2cct, 40.8km					■
Malbase – Bunakha	220	Zebra 2cct => Zebra(Twin) 2cct, 30km					■
Semtokha – Chumdo	220	Zebra 1cct => Zebra(Twin) 2cct, 17.0km					■
Bunakha – Chumdo	220	Zebra 1cct => 2cct, 22.0km					■
Motanga – Phuentshothang	132	Panther 2cct => Zebra 2cct, 22.0km					■
Phuentshothang – Nyera Amari-I	132	Panther 2cct => Zebra 2cct, 5.0km					■

<Substations>

Countermeasure		2021 -2025	2026 -2030	2031 -2035	2036 -2040	2041 -2050
Substation	Main specification					
Jigmeling	400/220kV 1, 2, 3B: 4 x 167 MVA					
	400/220kV GIS feeder x 4 for 400/220kV Tr					
PHEP-I	400/220kV 1, 2, 3B: 3 x 105 MVA	■				
Kholongchhu	400/132kV 1, 2, 3B: 3 x 67 MVA	■				
Sankosh	400/220kV 1, 2B: 2 x 104 MVA		■			
	400/220kV 1, 2B: 2 x 104 MVA		■			
Phuentshothang	400kV/132kV 1, 2, 3B: 3 x 67 MVA		■			
Yangbari	400/220/33kV 1, 2, 3B: 4 x 67 MVA			■		
	400kV bus division				■	■
Malbase	400/220kV 2, 3, 4B: 4 x 67 MVA			■		
	400/220kV 5B: 200 MVA					■
	400/220kV 6B: 200 MVA					■
	220/66kV 4B: 50/63 MVA			■		
Chamkharchhu-I	400/132/33kV 1, 2, 3B: 4 x 67 MVA			■		
Gelephu	132/66kV 3B: 50 MVA			■		
	132/66kV 4B: 50 MVA				■	
Semtokha	220/66kV 3B: 50/63 MVA			■		
	220/66kV 4B: 50/63 MVA				■	
Tsirang	220/66kV 3B: 50/63 MVA			■		
	220/66kV 4B: 50/63 MVA				■	
Singhigaon	220/66kV 3B: 50/63 MVA			■		
	220/66kV 4B: 50/63 MVA					■
Chumdo	220/66kV 3B: 50/63 MVA			■		
	220/66kV 4B: 50/63 MVA					■
Punatsangchhu-I	400/220kV 1, 2, 3B: 105 => 150 MVA Replacement					■
Punatsangchhu-II	400/220kV 1, 2B: 105 => 200 MVA Replacement			■		
Goling	400/132kV 1B, 2B: 67 => 100 MVA Replacement					■
Baso-LS	220/66kV 2B: 50/63 MVA			■		
	220/66kV 3B: 50/63 MVA					■
Dechencholing	66/33kV 3B: 30 MVA					■
Changidapuchu	66/33kV 3B: 30 MVA					■

<Reactive power compensators>

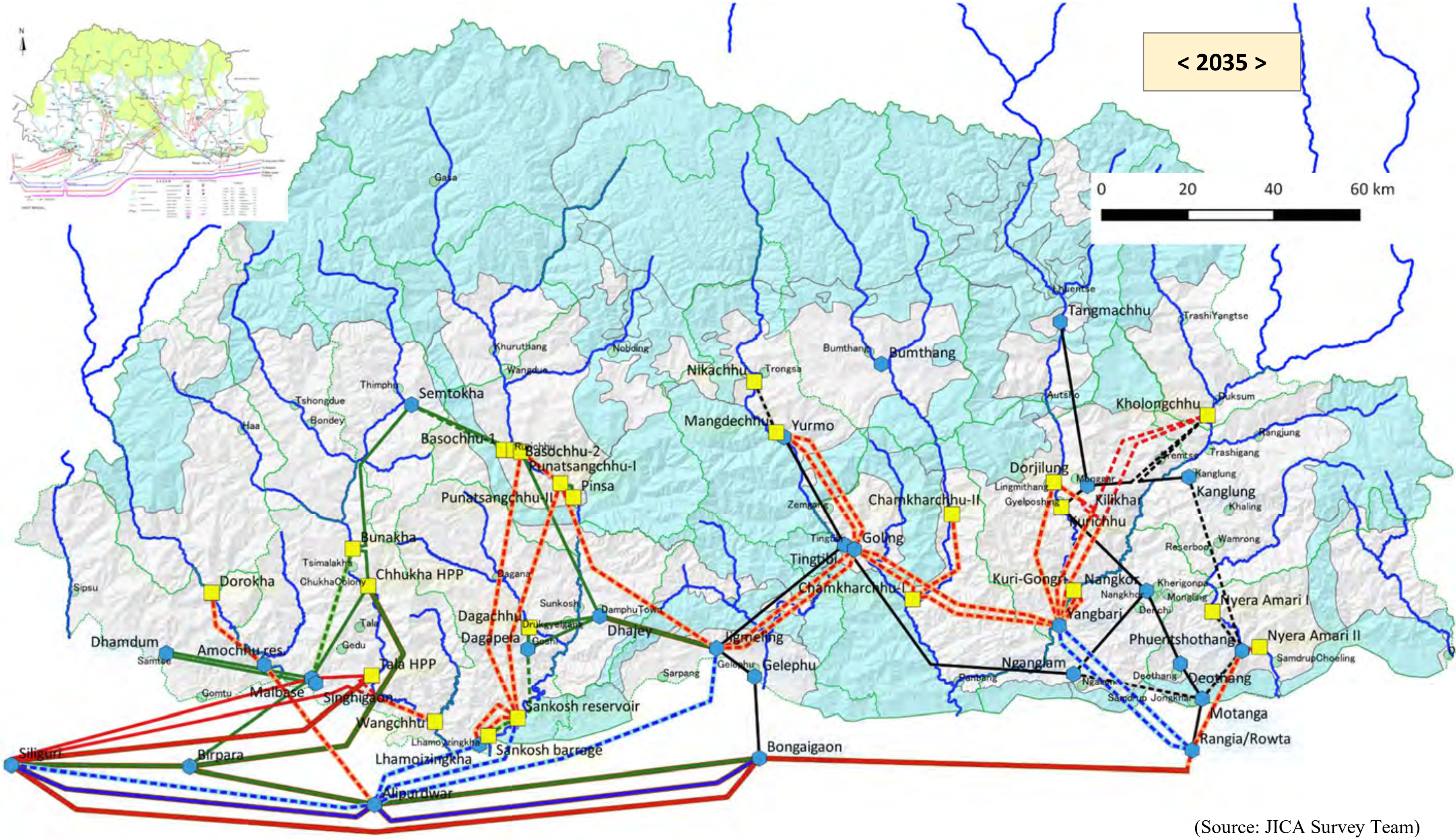
Measure				2021 -2025	2026 -2030	2031 -2035	2036 -2040	2041 -2050
Substation	Voltage	Equipment	Capacity (MVA)					
Yangbari	400	ShR	2 x 80			■		
Goling	400	ShR	2 x 80			■		
Wangchhu	400	ShR	1 x 63			■		
Gelephu	66	ShC	1 x 30				■	
Changidapuchu	66	ShC	1 x 20				■	
Paro	66	ShC	1 x 25				■	
Lobeysa	66	ShC	1 x 30				■	
Deothang	132	ShC	1 x 50					■
Gomtu	66	ShC	1 x 20					■

ShR: Shunt Reactor
ShC: Shunt Capacitor

(Source: JICA Survey Team)

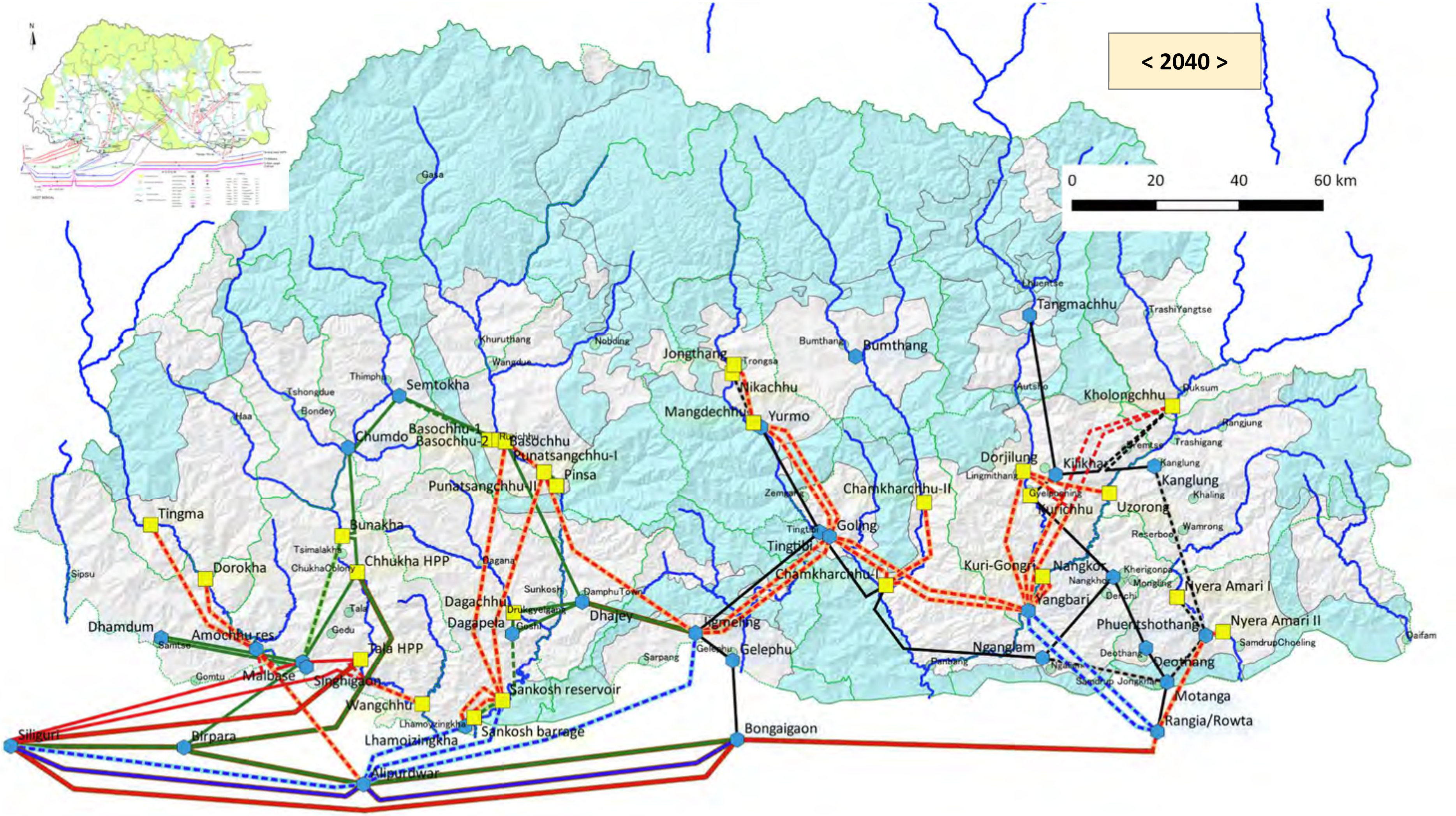
9.5.2 System Maps in Each Year

Based on the above results, system maps for each year are shown below.



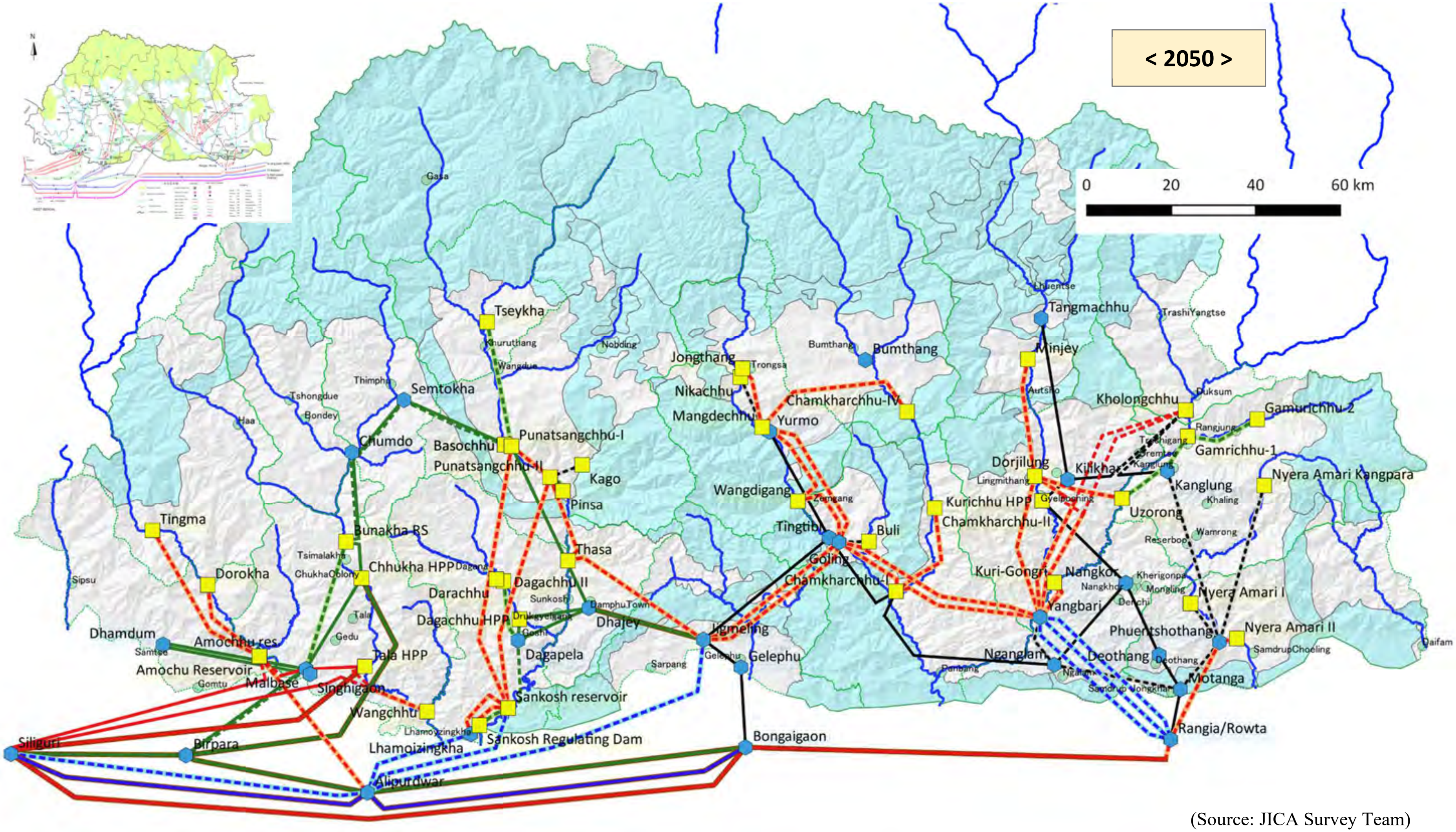
(Source: JICA Survey Team)

Figure 9-52 System Map (in 2035)



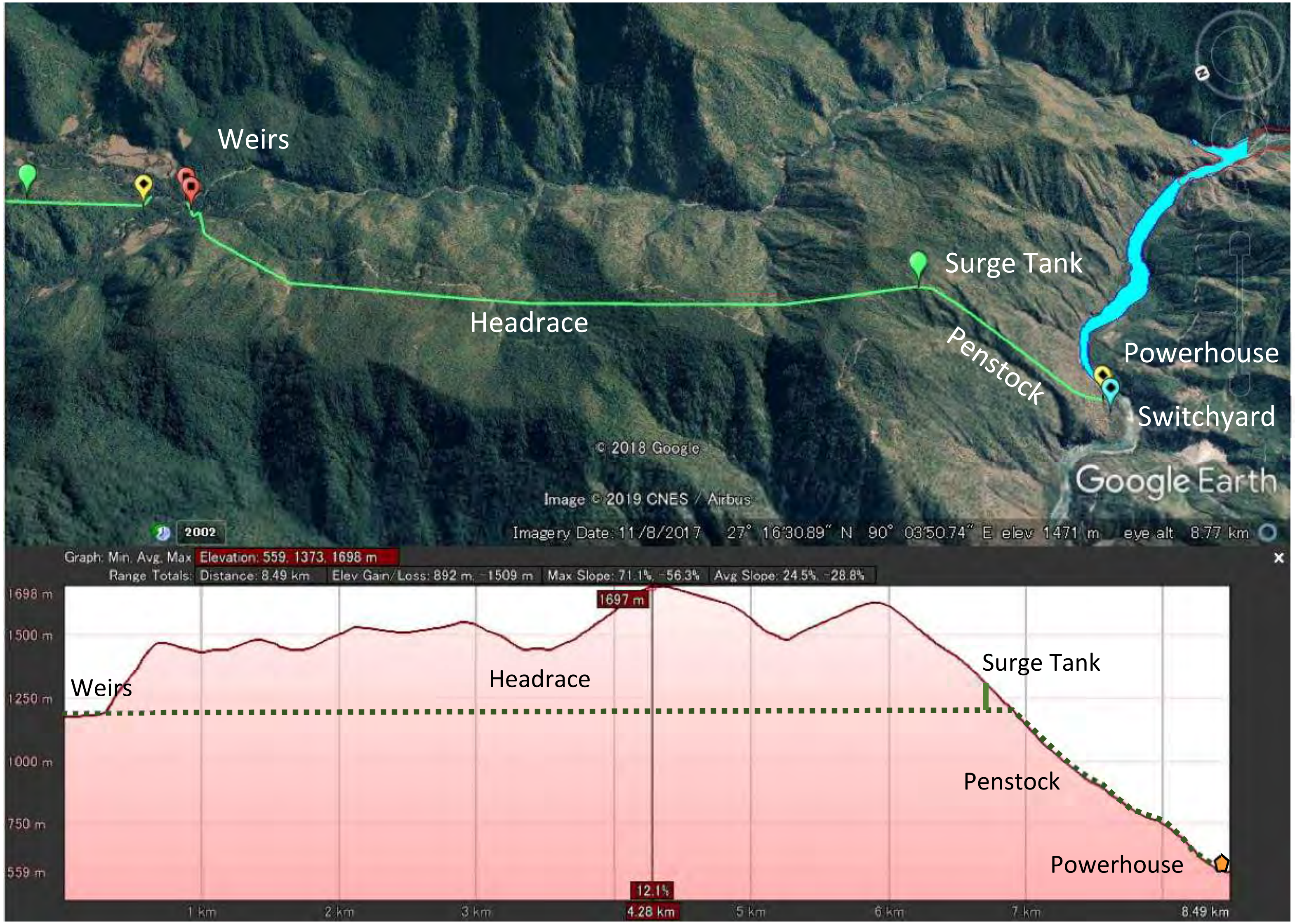
(Source: JICA Survey Team)

Figure 9-53 System Map (in 2040)



(Source: JICA Survey Team)

Figure 9-54 System Map (in 2050)



(Source: JICA Survey Team)

Figure 8-4 Pinsa HPP: Longitudinal Profile

(4) Design of Main Structures and Facilities

(a) Civil structures

1) Intake Weir

An intake dam was originally planned to be constructed at the confluence point of Morichhu and Porichhu. However, it was judged that dam construction would be difficult, since river gradients downstream from the confluence point are steep and a large number of boulders with a major diameter of about 5m were deposited on the riverbed. Therefore, two trench weirs for the main river (Morichhu) and the tributary (Porichhu) were planned to be constructed and their positions were shifted approximately 100m upstream from the original dam site in order to lay out the headrace on the ridge where geological conditions are fair. In addition, since the river width for the new weir sites is quite large at about 300m, a protection wall is to be installed to protect the left and right banks of each weir, the desilting basin and the intake gate.

2) Intake and desilting basin

A ground surface type desilting basin is laid out on the right bank side of the weir on the Porichhu, and an intake gate is installed at the downstream end of the desilting basin. The intake is located at the ridge on the right bank side of the desilting basin.

3) Waterway and powerhouse

The waterway route runs through the right bank of Kisonachhu, according to the geological and topographical conditions, and it should be the shortest route connecting the intake and the outlet.

a) Headrace

The headrace is a pressure tunnel and the inner diameter is determined to be 3.7m (one line) according to the "Guideline & Manual for Hydropower, JICA".

- Lining of the tunnel with reinforced concrete is to be conducted after excavation
- If it is necessary to improve the permeability and deformability of any loosened zone around the tunnel causing by blasting, implementation of consolidation grouting is to be examined.

b) Headrace Surge Tank

The headrace surge tank location is determined so that the top end of the surge tank appears on the ground surface along the ridge, where geological conditions are fair.

c) Penstock

The penstock is planned to have a slope of 10% from the headrace surge tank to the surface. The penstock is bifurcated from 1 line to 2 lines at the lower horizontal part and connects the inlet valve. A ground surface type penstock is advantageous from an economic efficiency aspect. However, since there is a swamp topography which is inferred to be formed along the geological layer border (by intrusion of granite in the bedrock) along the ridge, the alignment of the penstock runs along the ridge of the gneiss on the downstream side avoiding the swamp topography.
The details are as follows:

- The inner diameter of the penstock at the upper horizontal tunnel part and at the ground surface part is determined to be 2.8m (one line) according to the "Guideline & Manual for Hydropower, JICA". The excavation shape of the tunnel part is a horseshoe, of 4.4m in height

d) Powerhouse

A ground surface type powerhouse is selected, since there is plain land on the left bank of Punatsangchhu.
The shape and size of the powerhouse refers to that of Mangdechhu HPP and the "Guideline & Manual for Hydropower, JICA".

e) Tailrace and Outlet

An open channel type is adopted. The inner cross-section dimensions are determined to be 4.4 m wide and 3.5 m high according to the "Guideline & Manual for Hydropower, JICA". In addition, the tail water level (TWL) is set at 540m from the relationship with the full reservoir level (FRL) of Thasa (P-26).

(b) Turbine (Electric facility)
Since the effective head is as large as 600m, a Pelton type turbine is adopted.

(c) Switchyard
Area and alignment of switchyard refer to those of Mangdechhu HPP. The switchyard adjoins the powerhouse on the plain land at the upstream side of the powerhouse.

(d) Layout of access tunnels
The length of the headrace tunnel is 6.0km. In order to make the construction length 2.5km per face or less, one access tunnel at the downstream end of the headrace (at the bottom of the surge tank shaft), and one access tunnel at the middle of the headrace, totally two access tunnels are aligned, so that the headrace can be constructed with four faces at the maximum.

(5) Rough Construction Cost Estimate

Construction costs were estimated roughly by applying the construction cost estimation kits as described in Section 5.5. The rough construction costs estimated are shown in Table 8-9.

Table 8-9 Rough Construction Costs for Pinsa HPP

(10^6Nu)

Cost Items	Cost	Remarks
I. Preparation Work	235	
(1) Access Road	77	
(2) Camp & Facilities	79	(III. Civil Work) x 2%
(3) Compensation & Resettlement	79	(III. Civil Work) x 5%
II. Environmental Mitigation Costs	16	(III. Civil Work) x 2%
III. Civil Work	1,578	
III.1 Intake Dam	26	
III.2 Intake Facilities		
(1) Intake	12	
(2) Desilting Basin	-	
III.3 Headrace Tunnel	914	
III.4 Head Tank/Surge Tank	94	
III.5 Penstock & Side Spillway		
(1) Penstock	-	
(2) Side Spillway	-	
III.7 Powerhouse	303	
III.8 Tailrace		
(1) Tailrace Waterway	26	
(2) Tailrace Outlet	8	
III.9 River Diversions from Neighborhood Basin	121	
III.10 Miscellaneous Work	75	(sum of III.1 to III.9) x 5%
IV. Hydromechanical Work	778	
(1) Gate and Screen	20	Spillway Gate, Intake Gate, Silt Flush Gate, Tailrace Gate
(2) Penstock	687	
(3) Miscellaneous Work (10% of above total)	71	
V. Electrical Work	2,902	
(1) Electro-Mechanical Equipment	2,764	
(2) Miscellaneous work (5% of above total)	138	
VI. Transmission Line		
(1) Transformer, Switchyard, Transmission Line	1,596	
VII. Administration Costs and Engineering Costs	826	(sum of I to V) x 0.15
VIII. Contingency	1,653	(sum of I to V) x 0.3
IX. Interest During Construction	959	(sum of I to VIII) x 0.4 x I x T (Assumed I = 0.05, T = 6 years)
Grand Total	10,543	

(Source: JICA Survey Team)

(6) Construction Schedule

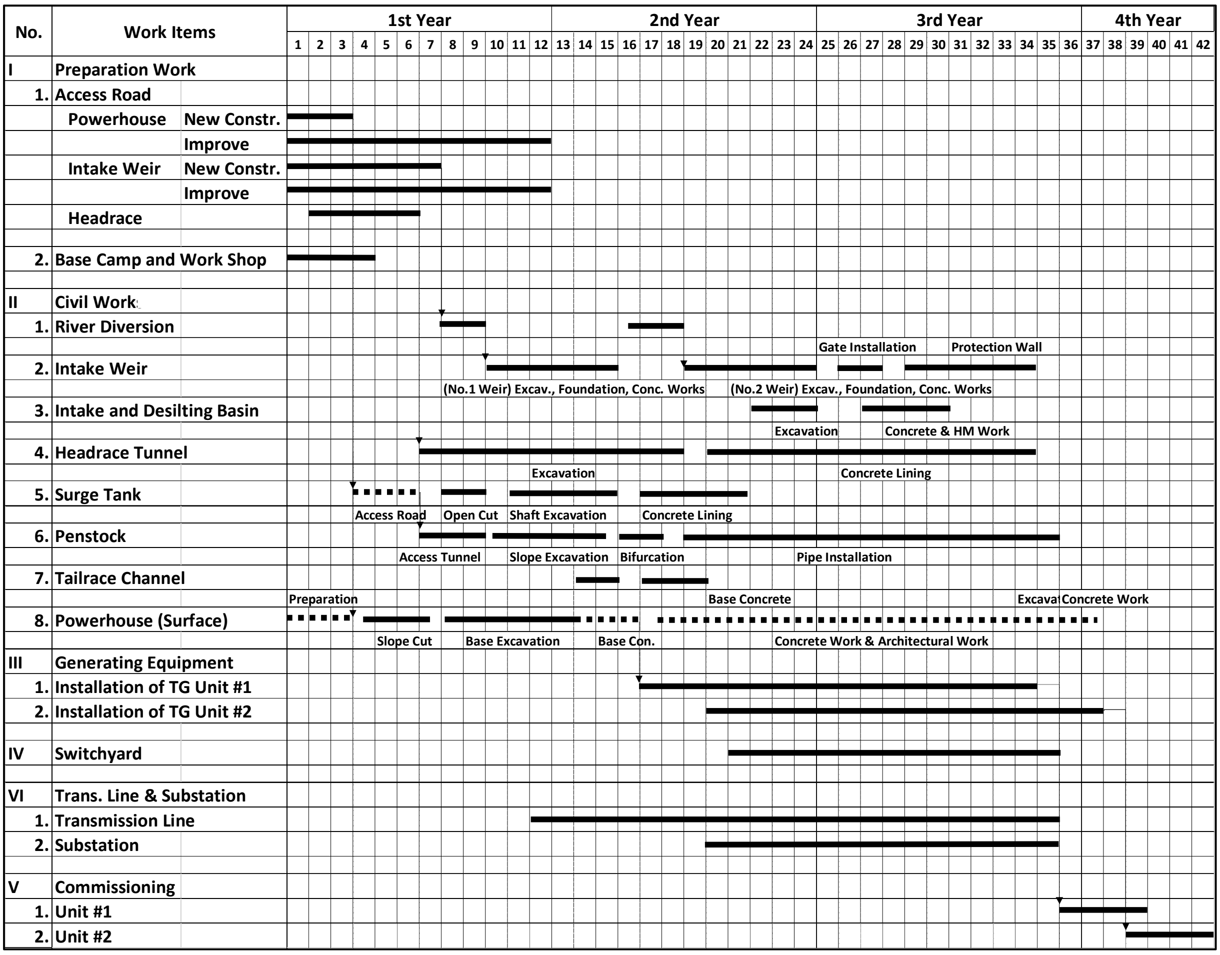
Construction speeds of each component for the construction amount for every main civil structure are set as shown in Table 8-10 based on experiences of construction in Japan.
Since a ground surface type could be adopted for the penstock and powerhouse and both excavation work periods are assumed to be 10 months, the overall construction period is estimated to be 42 months (3 and a half years).
The construction schedule from commencement to commissioning (incl. preparation work) is shown in Table 8-11.

Table 8-10 Construction Speed

No.	Component	Work Item	Construction Speed
1	Access Road	Improvement	1,000 m/month
		New construction	300 m/month
2	Intake Weir	Excavation of Foundation	5,000 m^3/month
		Concrete Placement	1,000 m^3/month
3	Intake and Desilting Basin (Ground surface type)	Excavation	2,000 m^3/month
		Concrete Lining	1,000 m^3/month
4	Headrace/Tailrace Tunnel	Excavation	125 m/month
		Concrete Lining	100 m/month
5	Surge Tank	Excavation (Shaft)	5 months
		Concrete Lining (Shaft)	5 months
6	Penstock (Ground surface type)	Cutting Slope	6 months
		Steel Pipe Installation	100 m/month
7	Powerhouse (Ground surface type)	Cutting Slope	3 months
		Excavation of Foundation	6 months

(Source: JICA Survey Team)

Table 8-11 Construction Schedule (Pinsa HPP)



Note) TG: Turbine generator, HM: Hydro-mechanical

(Source: JICA Survey Team)

8.4.3 Chamkharchhu-II (C-10) HPP

(1) Hydrology

Reliability of hydrological data is of a medium level, since Shingkhar/Bemethang gauging station (Monitoring period: 6 years) is in the vicinity of the dam site and the ratio catchment area at the gauging station and dam site is 0.93. Designed discharge was estimated based on the designed unit discharge of the Chamkharchhu downstream basin, which is described in Table 5-22.

Since the specific sediment yield at Shingkhar/Bemethang gauging station is 56 tons/km^2, the annual sediment volume is estimated to be as little as 0.14 million tons/year.

(2) Topographical and Geological Conditions

The topographical and geological conditions are described in Appendix-1 (26)

(3) Conceptual Design

Primary features were examined as shown in Table 8-12.

Table 8-12 Primary Features of Chamkharchhu-II HPP

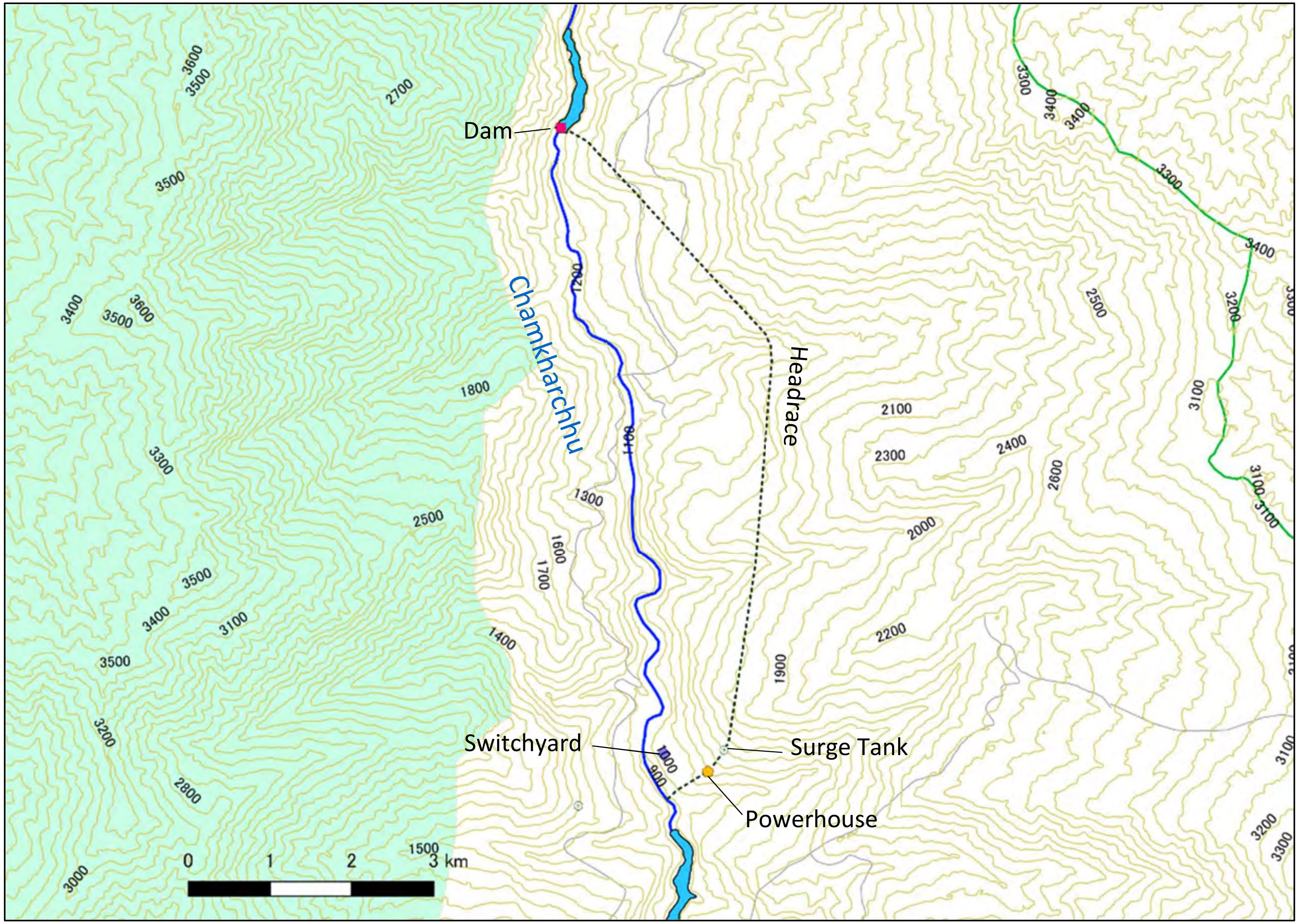
Items			Unit	Description
General	Type			ROR with Pond (II-2)
	Installed Capacity	P	MW	414
	Designed Discharge	Qd	m^3/s	130.4
	Effective Head	Hd	m	368.3
Dam and Reservoir	Type			Concrete Gravity Dam
	Height	H	m	84
	Sediment Depth		m	24
	River Bed Level	RBL	m	1,225
	Crest Length	L	m	180
	Dam Volume	V	m^3	343,000
	Excavation Volume	Ve	m^3	817,000
	Reservoir Area	Ra	ha	15.8
	Catchment Area	Ca	km^2	2,525
	F.R.L. (Full Reservoir Level)		m	1280
	L.W.L. (Low Water Level)		m	1270
	Usable Water Depth		m	10
	Effective Reservoir Capacity		mil.m^3	1.2
Waterway	Intake and Desilting Basin	Ve	m^3	184,000
	Headrace	L(m) x n	m	D=6.5m, 8,630 x 1
	Surge Tank	D(m) x L	m	15 x 100
	Penstock (Vertical shaft)	L(m) x n	m	D=4.8m, 564 x 1, 50 x 2
	Tailrace	L(m) x n	m	D=7.7m, 680 x 1
	Total Length	Lt	m	9,900
Power house	Type			Underground
	Overburden		m	340
	Cavern Volume		m^3	128,000
	T.W.L. (Tail Water Level)		m	884

Turbine	Type			Pelton
	Number		unit	2
	Unit generating capacity		MW	207

(Source: JICA Survey Team)

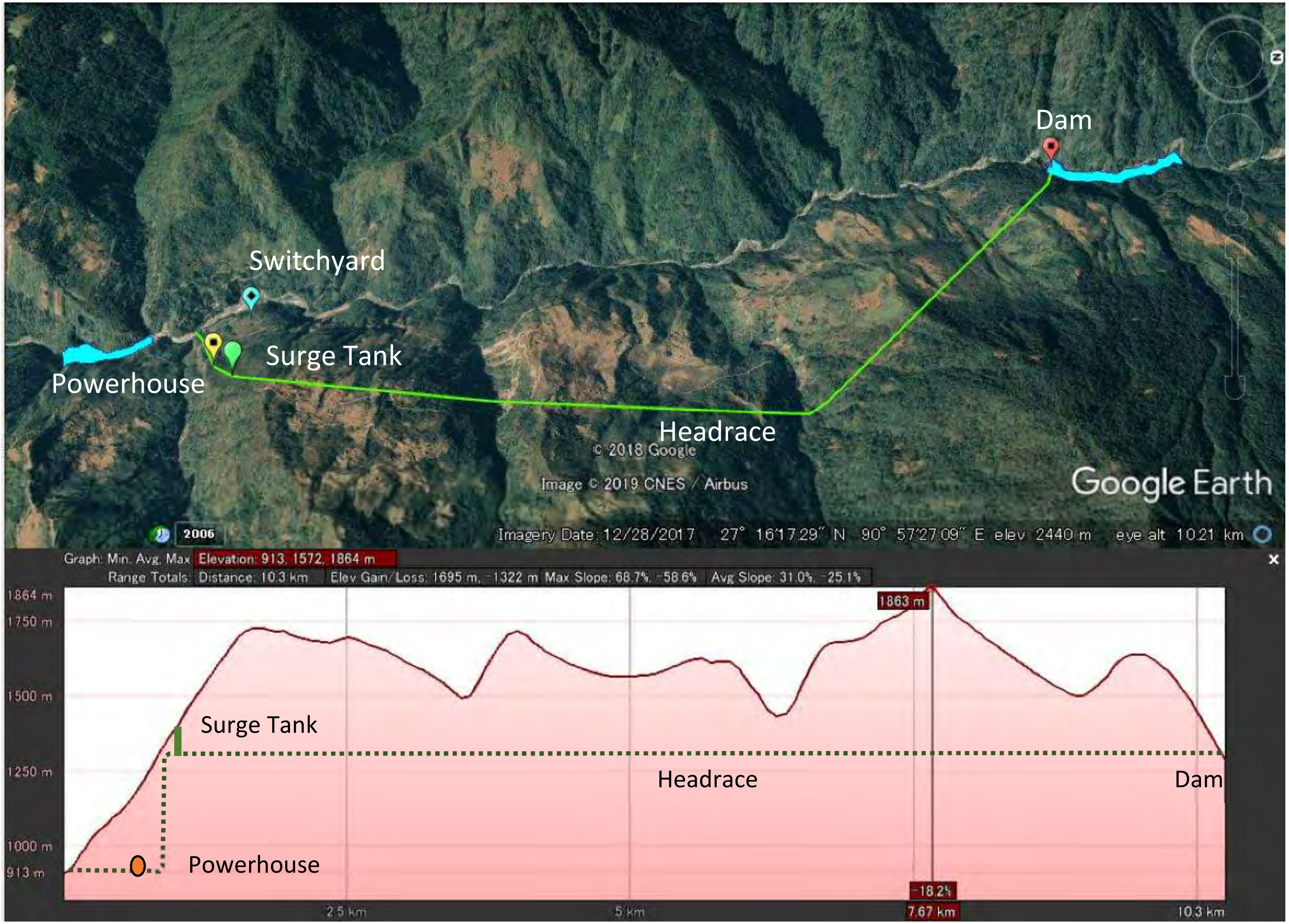
Plot plan and longitudinal profile are illustrated in Figure 8-5 and Figure 8-6, respectively. The following CAD drawings for the general plan and each main civil structure are attached in Appendix – 5 (3).

- General Plan
- Dam and Intake
- Profile of Intake Dam
- Powerhouse and Switchyard



(Source: JICA Survey Team)

Figure 8-5 Chamkharchhu-II HPP: Plot Plan



(Source: JICA Survey Team)

Figure 8-6 Chamkharchhu-II HPP: Longitudinal Profile

(4) Design of Main Structures and Facilities

(a) Civil structures

1) Intake dam and pond

Since the geological conditions are good and a large flood flow of more than 5000m^3/s is anticipated, a concrete gravity dam, for which a spill way can be installed in the dam body, is adopted.

A diversion tunnel and coffer dams are to be constructed during dam construction so that flood flow, for which the probability is once in 10 years, can be diverted. In addition, coffer dams are planned to be built not only upstream but also downstream of the dam in order to excavate and remove the riverbed sediment, the depth of which is assumed to be 24m.

2) Intake and Desilting basin

The intake is planned to be on the right upstream of the dam in parallel with the dam axis on the left bank, where the geological conditions are fair and in order to avoid inflow of earth and sand as much as possible. Although it has a pond, since the active storage capacity is as small as 1.2 million m^3, it is necessary to construct a desilting basin. In addition, since it is topographically difficult to adopt a ground surface type, a pressure tunnel type is adopted.

3) Waterway and Powerhouse

The waterway route runs through the left bank of Chamkharchhu, according to the geological and topographical conditions, and it should be the shortest route connecting the intake and the outlet.

a) Headrace

The headrace is a pressure tunnel and the inner diameter is determined to be 6.5m (one line) according to the "Guideline & Manual for Hydropower, JICA" and excavation shape is a horseshoe, of 7.7m in height.

- Lining of the tunnel with reinforced concrete is to be conducted after excavation
- If it is necessary to improve the permeability and deformability of any loosened zone around the tunnel caused by blasting, implementation of consolidation grouting is to be examined.

b) Headrace Surge Tank

The headrace surge tank location is determined so that the top end of the surge tank appears on the ground surface along the ridge, where geological conditions are fair.

c) Penstock

The penstock is planned to have a slope of 10% from the headrace surge tank to the upper bend, where the overburden does not fall below 50 m, and thereafter, the penstock is a vertical shaft up to the lower bend (the central elevation of the turbine). The penstock is bifurcated from 1 line to 2 lines at the lower horizontal part and connects the inlet valve. In the construction, after excavation is completed, spaces between steel pipes and the bedrock are filled with concrete.

The details are as follows:

- The inner diameter of the penstock at the upper horizontal part is determined to be 4.8m (one line) according to the "Guideline & Manual for Hydropower, JICA". The excavation shape is a horseshoe, of 6.4m in height
- The inner diameter of the penstock at the vertical shaft part is determined to be 4.8m (one line) according to the "Guideline & Manual for Hydropower, JICA". The excavation diameter is 6.0m

d) Powerhouse

Since it is difficult to construct a ground surface type powerhouse in terms of the topography, the powerhouse is to be constructed underground.

In principle, although the location and direction of the underground powerhouse cavern are determined after detailed investigation of the geological conditions via an investigation adit, the location is selected so that the waterway length can be the shortest and the overburden depth does not exceed 500m of the maximum recorded.

The shape and size of the cavern refers to that of Mangdechhu HPP and the "Guideline & Manual for Hydropower, JICA".

In addition, as permanent tunnels necessary for the underground powerhouse, an equipment transportation tunnel, cable tunnel and drainage tunnel were planned based on a 1/25,000 topographical map.

e) Tailrace

The tailrace is a non-pressure tunnel and one line, since the length is as long as about 680m. The inner diameter is determined to be 7.7m according to the "Guideline & Manual for Hydropower, JICA" and the excavation shape is a horseshoe, of 8.8m in height.

4) Outlet

The commonly used lateral type is adopted for the outlet.

(b) Turbine (Electric facility)

Because the effective head is as large as 380m and water discharge varies greatly between the rainy season and the dry season, a Pelton type turbine is adopted, which enables a small discharge to generate electric power.

(c) Switchyard

Area and alignment of switchyard refer to those of Mangdechhu HPP. The plain land on the upstream side of the powerhouse is suitable for the switchyard. However, since the plain land elevation is around EL. 1,040m, which is 150m higher than the powerhouse floor level, the cable tunnel is to be a partially vertical shaft 150m high.

(d) Layout of access tunnels

The length of the headrace tunnel is 8.6km. In order to make the construction length 2.5km per face or less, one access tunnel downstream of the desilting basin, which is diverted to the earth and sand discharge tunnel, one access tunnel at the downstream end of the headrace (at the bottom of the surge tank shaft), and one access tunnel at the mid of the headrace, totally four access tunnels are aligned, so that the headrace can be constructed with four faces at the maximum.

(5) Rough Construction Cost Estimate

Construction costs were estimated roughly by applying the construction cost estimation kits as described in Section 5.5. The rough construction costs estimated are shown in Table 8-13.

Table 8-13 Rough Construction Costs for Chamkharchhu-II HPP

(10^6Nu)

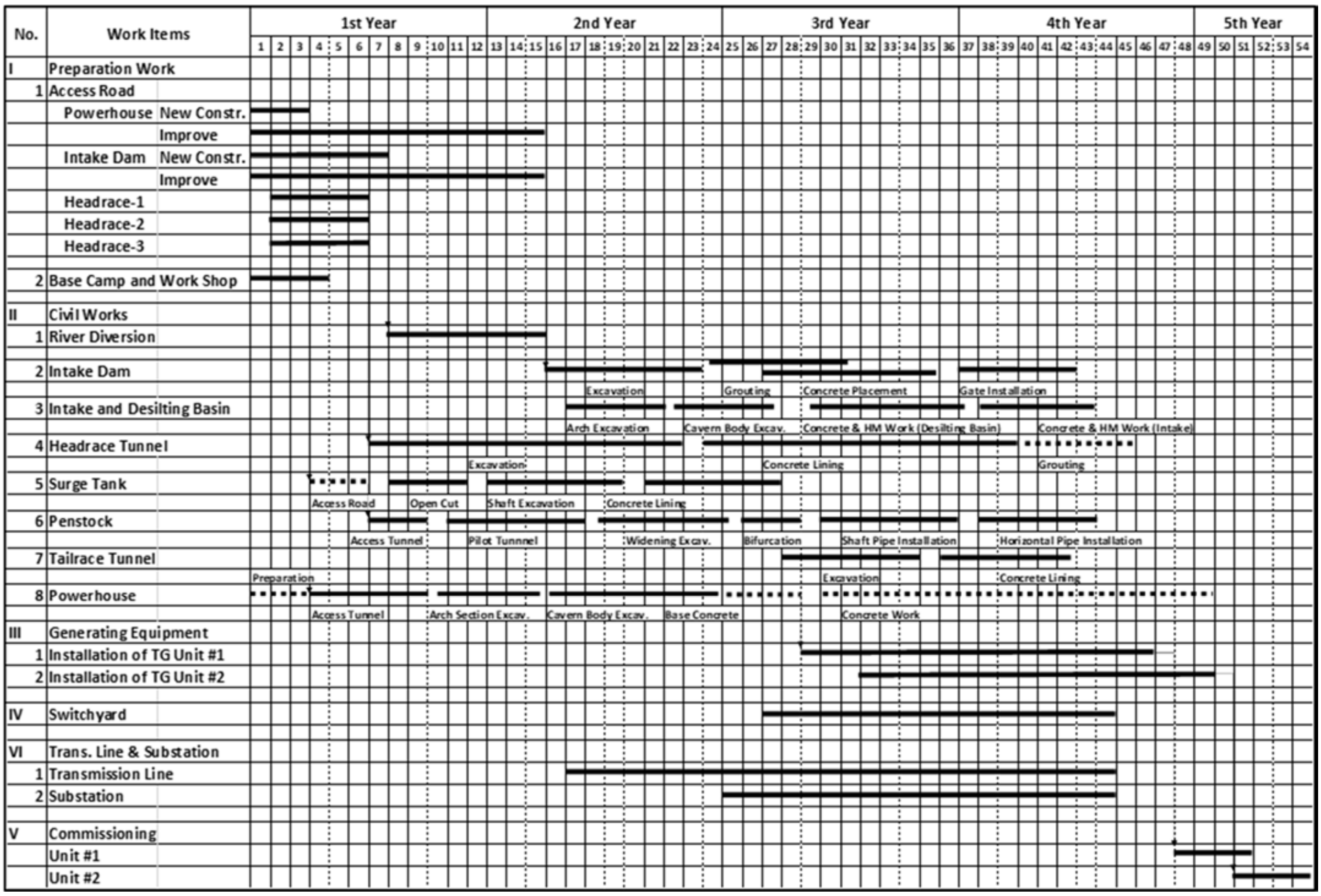
Cost Items	Cost	Remarks
I. Preparation Work	1,394	
(1) Access Road	647	
(2) Camp & Facilities	213	(III. Civil Work) x 2%
(3) Compensation & Resettlement	534	(III. Civil Work) x 5%
II. Environmental Mitigation Costs	320	(III. Civil Work) x 2%
III. Civil Work	10,673	
III.1 Intake Dam	4,359	
III.2 Intake Facilities		
(1) Intake	106	
(2) Desilting Basin	1,018	
III.3 Headrace Tunnel	2,707	
III.4 Head Tank/Surge Tank	502	
III.5 Penstock & Side Spillway		
(1) Penstock	123	
(2) Side Spillway	-	
III.7 Powerhouse	1,050	
III.8 Tailrace		
(1) Tailrace Waterway	272	
(2) Tailrace Outlet	28	
III.9 River Diversions from Neighborhood Basin	-	
III.10 Miscellaneous Work	508	(sum of III.1 to III.9) x 5%
IV. Hydromechanical Work	1,383	
(1) Gate and Screen	726	Spillway Gate, Intake Gate, Silt Flush Gate, Tailrace Gate
(2) Penstock	531	
(3) Miscellaneous Work (10% of above total)	126	
V. Electrical Work	7,397	
(1) Electro-Mechanical Equipment	7,045	
(2) Miscellaneous work (5% of above total)	352	
VI. Transmission Line		
(1) Transformer, Switchyard, Transmission Line	4,251	
VII. Administration Costs and Engineering Costs	3,175	(sum of I to V) x 0.15
VIII. Contingency	6,350	(sum of I to V) x 0.3
IX. Interest During Construction	3,683	(sum of I to VIII) x 0.4 x I x T (Assumed I = 0.05, T = 6 years)
Grand Total	38,628	

(Source: JICA Survey Team)

(6) Construction Schedule

Construction speeds of each component for the construction amount for every main civil structure are set as shown in Table 8-6, as per Dorokha HPP, based on experiences of construction in Japan.
The critical path of the construction schedule is the process of the underground powerhouse. Therefore, the overall construction period is estimated to be 54 months (4 and a half years).
The construction schedule from commencement to commissioning (incl. preparation work) is shown in Table 8-14.

Table 8-14 Construction Schedule (Chamkharchhu-II HPP)



Note) TG: Turbine generator, HM: Hydro-mechanical

(Source: JICA Survey Team)

8.4.4 Uzorong (G-14) HPP

(1) Hydrology

Reliability of hydrological data is of a very high level, since Uzorong gauging station (Monitoring period: 21 years) is in the vicinity of the dam site and the ratio catchment area at the gauging station and dam site is 1.19. Designed discharge was estimated based on the designed unit discharge of the Drangmechhu middle stream basin, which is described in Table 5-22.

Since the specific sediment yield at Uzorong gauging station is 552 tons/km^2, the annual sediment volume is estimated to be relatively large as 0.66 million tons/year.

(2) Topographical and Geological Conditions

The topographical and geological conditions are described in Appendix-1 (35)

(3) Conceptual Design

Primary features were examined as shown in Table 8-15.

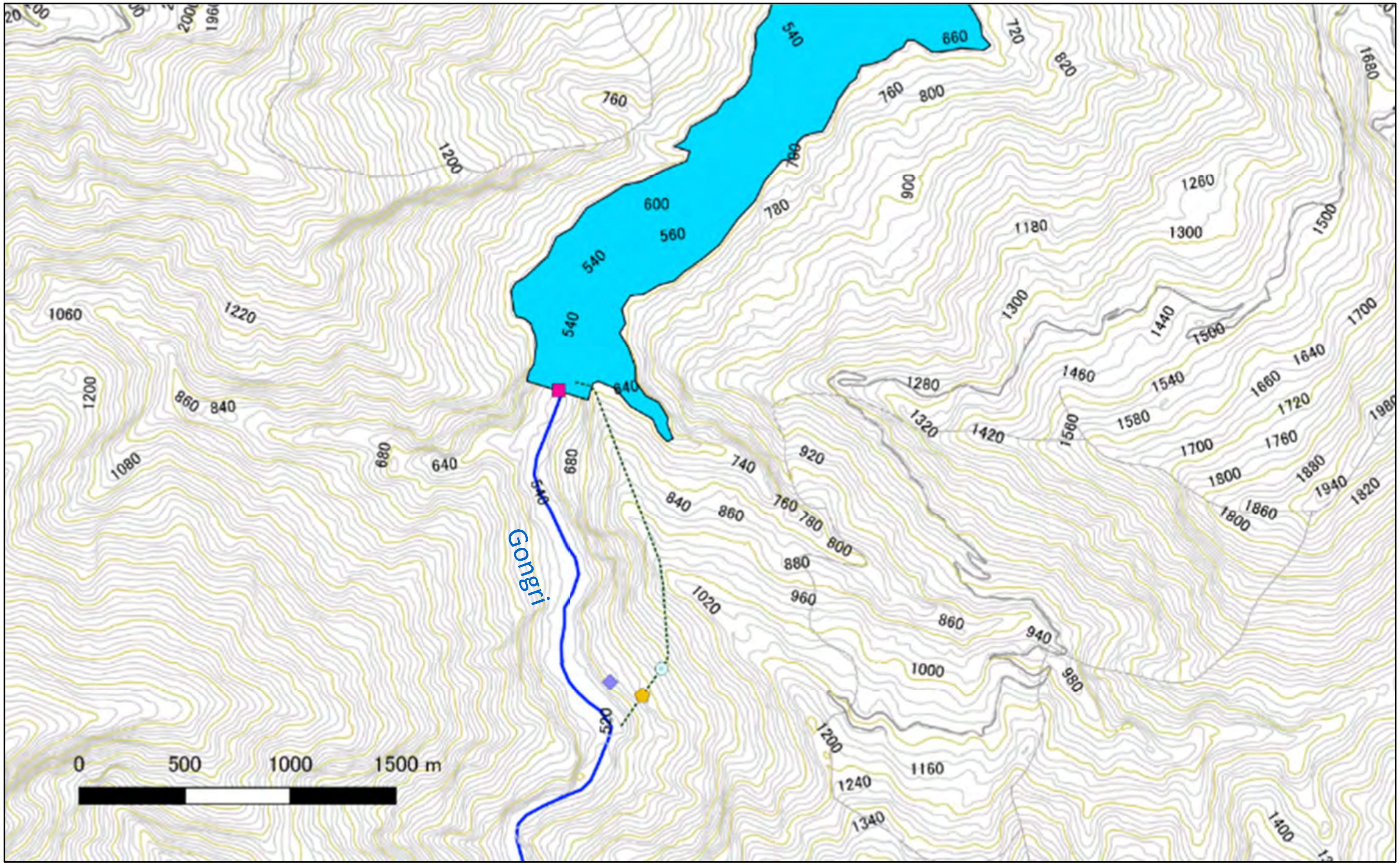
Table 8-15 Primary Features of Uzorong HPP

Items			Unit	Description
General	Type			Pondage (III-2)
	Installed Capacity	P	MW	840
	Designed Discharge	Qd	m^3/s	614.7
	Effective Head	Hd	m	158.4
Dam and Reservoir	Type			Concrete Gravity Dam
	Height	H	m	168
	Sediment Depth		m	23
	River Bed Level	RBL	m	530
	Crest Length	L	m	330
	Dam Volume	V	m^3	1,490,000
	Excavation Volume	Ve	m^3	2,663,000
	Reservoir Area	Ra	ha	686.5
	Catchment Area	Ca	km^2	10,175
	F.R.L. (Full Reservoir Level)		m	670
	L.W.L. (Low Water Level)		m	630
	Usable Water Depth		m	40
	Effective Reservoir Capacity		mil.m^3	217.3
Waterway	Intake and Desilting Basin	Ve	m^3	184,000
	Headrace	L(m) x n	m	D=6.9m, 1,530 x 4
	Surge Tank	D(m) x L	m	15 x 100 x 4
	Penstock (Vertical shaft)	L(m) x n	m	D=5.3m, 265 x 4
	Tailrace	L(m) x n	m	D=8.2m, 180 x 4
	Total Length	Lt	m	1,965
Power house	Type			Underground
	Overburden		m	180
	Cavern Volume		m^3	249,049
	T.W.L. (Tail Water Level)		m	510

Turbine	Type			Vertical Francis
	Number		unit	4
	Unit generating capacity		MW	210

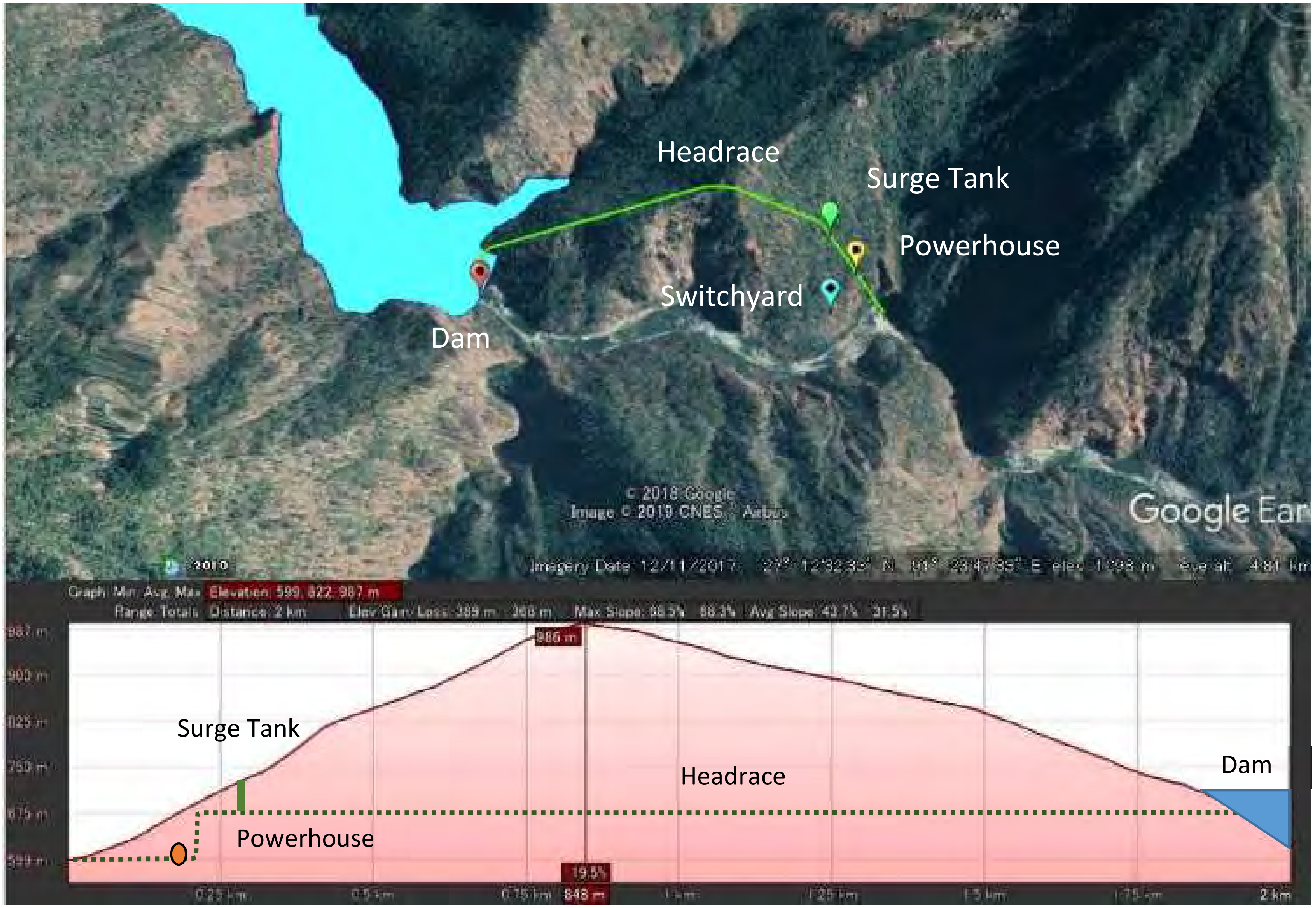
(Source: JICA Survey Team)

Plot plan and longitudinal profile are illustrated in Figure 8-7 and Figure 8-8, respectively.



(Source: JICA Survey Team)

Figure 8-7 Uzorong HPP: Plot Plan



(Source: JICA Survey Team)

Figure 8-8 Uzorong HPP: Longitudinal Profile

(4) Design of Main Structures and Facilities

(a) Civil structures

1) Intake dam and pond

Since the geological conditions are good and a large flood flow of more than 10,000m^3/s is anticipated, a concrete gravity dam, for which a spill way can be installed in the dam body, is adopted.

A diversion tunnel and coffer dams are to be constructed during dam construction so that flood flow, for which the probability is once in 10 years, can be diverted. In addition, coffer dams are planned to be built not only upstream but also downstream of the dam in order to excavate and remove the riverbed sediment, the depth of which is assumed to be 23m.

2) Intake

The intake is planned to be on the right upstream of the dam in parallel with the dam axis on the left bank, where the geological conditions are fair and in order to make waterway length as short as possible. Since it has a large scale reservoir, which active capacity is as large as 217.3 million m^3, it is not necessary to construct desilting chamber. In addition, the annual sediment volume is estimated to be 0.66 million tons/year, and the sum of sediment volume for 100 years will be 66 million ton (50 million m^3).

3) Waterway and Powerhouse

The waterway route runs through the left bank of Manaschhu, according to the geological and topographical conditions, and it should be the shortest route connecting the intake and the outlet.

The tailrace water level was set as EL. 510m, which is FSL. 500m of Kri-Gonri HPP plus margin of 10m, and the dam - waterway type HPP was adopted in this study, however, since RBL at the dam site is EL. 530m, the comparative study with a dam type HPP is to be executed in the next stage.

a) Headrace

The headrace is a pressure tunnel and the inner diameter is determined to be 6.9m (four lines) according to the "Guideline & Manual for Hydropower, JICA" and excavation shape is a horseshoe, of 8.1m in height.

- Lining of the tunnel with reinforced concrete is to be conducted after excavation
- If it is necessary to improve the permeability and deformability of any loosened zone around the tunnel caused by blasting, implementation of consolidation grouting is to be examined.

b) Headrace Surge Tank

The headrace surge tank location is determined so that the top end of the surge tank appears on the ground surface along the ridge, where geological conditions are fair.

c) Penstock

The penstock is planned to have a slope of 10% from the headrace surge tank to the upper bend, where the overburden does not fall below 50 m, and thereafter, the penstock is a vertical shaft up to the lower bend (the central elevation of the turbine). The penstocks connect the inlet valves at the lower horizontal part. In the construction, after excavation is completed, spaces between steel pipes and the bedrock are filled with concrete.

The details are as follows:

- The inner diameter of the penstock at the upper horizontal part is determined to be 5.3m (four lines) according to the "Guideline & Manual for Hydropower, JICA". The excavation shape is a horseshoe, of 6.9m in height
- The inner diameter of the penstock at the vertical shaft part is determined to be 5.3m (one line) according to the "Guideline & Manual for Hydropower, JICA". The excavation diameter is 6.5m

d) Powerhouse

Since it is difficult to construct a ground surface type powerhouse in terms of the topography, the powerhouse is to be constructed underground.

In principle, although the location and direction of the underground powerhouse cavern are determined after detailed investigation of the geological conditions via an investigation adit, the location is selected so that the waterway length can be the shortest and the overburden depth does not exceed 500m of the maximum recorded.

e) Tailrace

The tailrace is a non-pressure tunnel and four lines, since the length is as short as about 180m. The inner diameter is determined to be 8.2m according to the "Guideline & Manual for Hydropower, JICA" and the excavation shape is a horseshoe, of 9.3m in height.

4) Outlet

The commonly used lateral type is adopted for the outlet.

(b) Turbine (Electric facility)

Because the effective head is as small as 180m, vertical Francis type turbine is adopted.

(c) Switchyard

Since the slope around the surface of the powerhouse is too steep to construct switchyard on the ground surface, GIS underground type was selected.

(d) Layout of access tunnels

The length of the headrace tunnel is only 1.5km. an access tunnel at the downstream end of the headrace (at the bottom of the surge tank shaft) is aligned.

(5) Rough Construction Cost Estimate

Construction costs were estimated roughly by applying the construction cost estimation kits as described in Section 5.5. The rough construction costs estimated are shown in Table 8-16.

Table 8-16 Rough Construction Costs for Uzorong HPP

(10^6Nu)

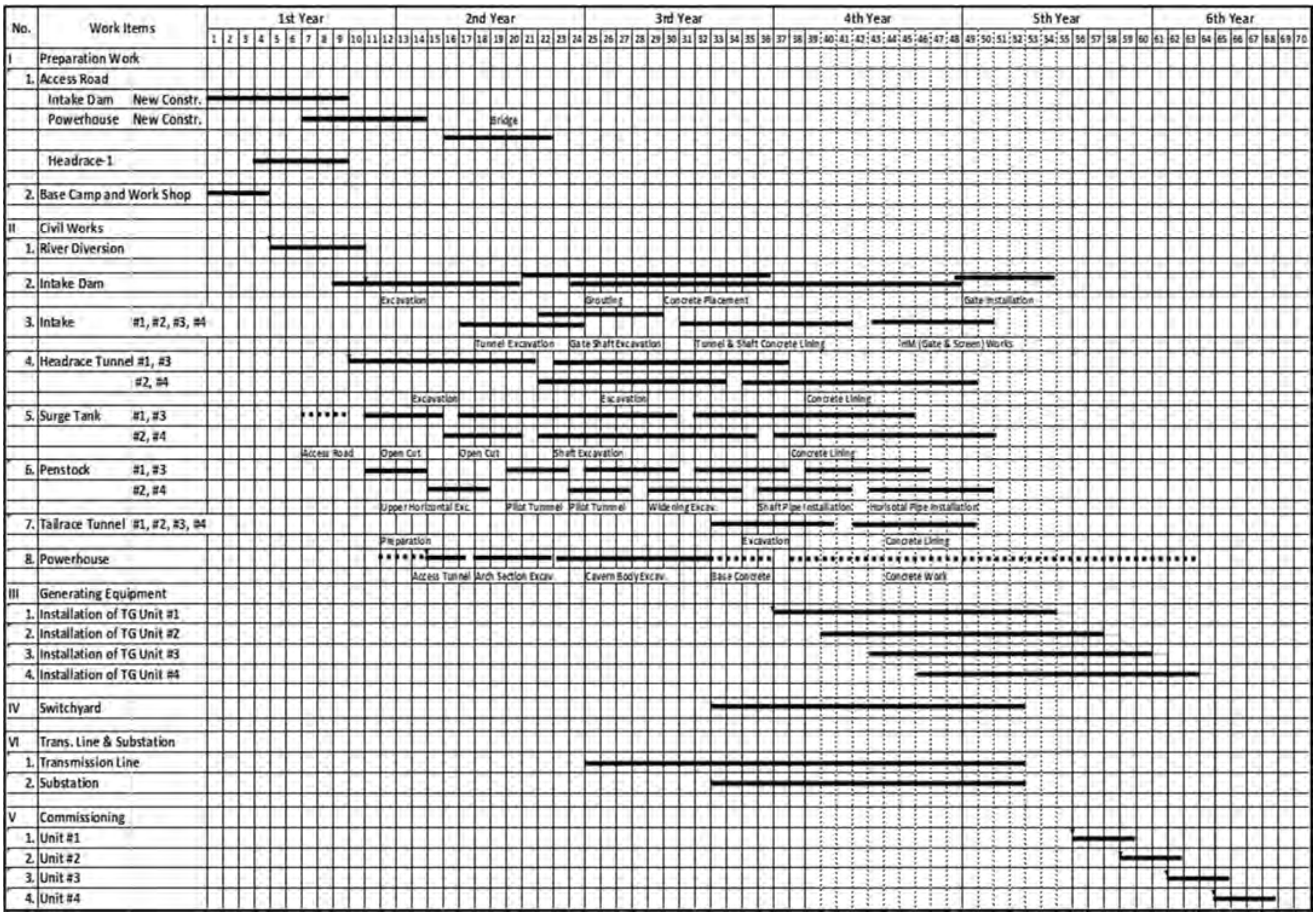
Cost Items	Cost	Remarks
I. Preparation Work	2,453	
(1) Access Road	647	
(2) Camp & Facilities	516	(III. Civil Work) x 2%
(3) Compensation & Resettlement	1,290	(III. Civil Work) x 5%
II. Environmental Mitigation Costs	774	(III. Civil Work) x 2%
III. Civil Work	25,796	
III.1 Intake Dam	18,310	
III.2 Intake Facilities		
(1) Intake	699	
(2) Desilting Basin	-	
III.3 Headrace Tunnel	2,540	
III.4 Head Tank/Surge Tank	404	
III.5 Penstock & Side Spillway		
(1) Penstock	282	
(2) Side Spillway	-	
III.7 Powerhouse	1,895	
III.8 Tailrace		
(1) Tailrace Waterway	316	
(2) Tailrace Outlet	122	
III.9 River Diversions from Neighborhood Basin	-	
III.10 Miscellaneous Work	1,228	(sum of III.1 to III.9) x 5%
IV. Hydromechanical Work	2,773	
(1) Gate and Screen	2,010	Spillway Gate, Intake Gate, Silt Flush Gate, Tailrace Gate
(2) Penstock	511	
(3) Miscellaneous Work (10% of above total)	252	
V. Electrical Work	16,712	
(1) Electro-Mechanical Equipment	15,916	
(2) Miscellaneous work (5% of above total)	796	
VI. Transmission Line	4,382	
(1) Transformer, Switchyard, Transmission Line	4,382	
VII. Administration Costs and Engineering Costs	7,276	(sum of I to V) x 0.15
VIII. Contingency	14,552	(sum of I to V) x 0.3
IX. Interest During Construction	8,440	(sum of I to VIII) x 0.4 x I x T (Assumed I = 0.05, T = 6 years)
Grand Total	83,148	

(Source: JICA Survey Team)

(6) Construction Schedule

Construction speeds of each component for the construction amount for every main civil structure are set as shown in Table 8-6, as per Dorokha HPP, based on experiences of construction in Japan.
Since the dam is as high as 168m, the number of waterway lines and units is four, the critical path of the construction schedule is the process of the dam, the waterway and the underground powerhouse. Therefore, the overall construction period is estimated to be 68 months (5 years and 8 months), meanwhile, the construction period for the first unit is estimated to be 59 months.
The construction schedule from commencement to commissioning (incl. preparation work) is shown in Table 8-17.

Table 8-17 Construction Schedule (Uzorong HPP)



Note) TG: Turbine generator, HM: Hydro-mechanical

(Source: JICA Survey Team)

8.4.5 Jongthang (M-6) HPP

(1) Hydrology

Reliability of hydrological data is of a high level, since Bjizam gauging station (Monitoring period: 21 years) is in the vicinity of the dam site and the ratio catchment area at the gauging station and dam site is 0.85. Designed discharge was estimated based on the designed unit discharge of the Mangdechhu upstream basin, which is described in Table 5-22.

Since the specific sediment yield at Bjizam gauging station is 153 tons/km^2, the annual sediment volume is estimated to be as little as 0.18 million tons/year.

(2) Topographical and Geological Conditions

The topographical and geological conditions are described in Appendix-1 (21)

(3) Conceptual Design

Primary features were examined as shown in Table 8-18.

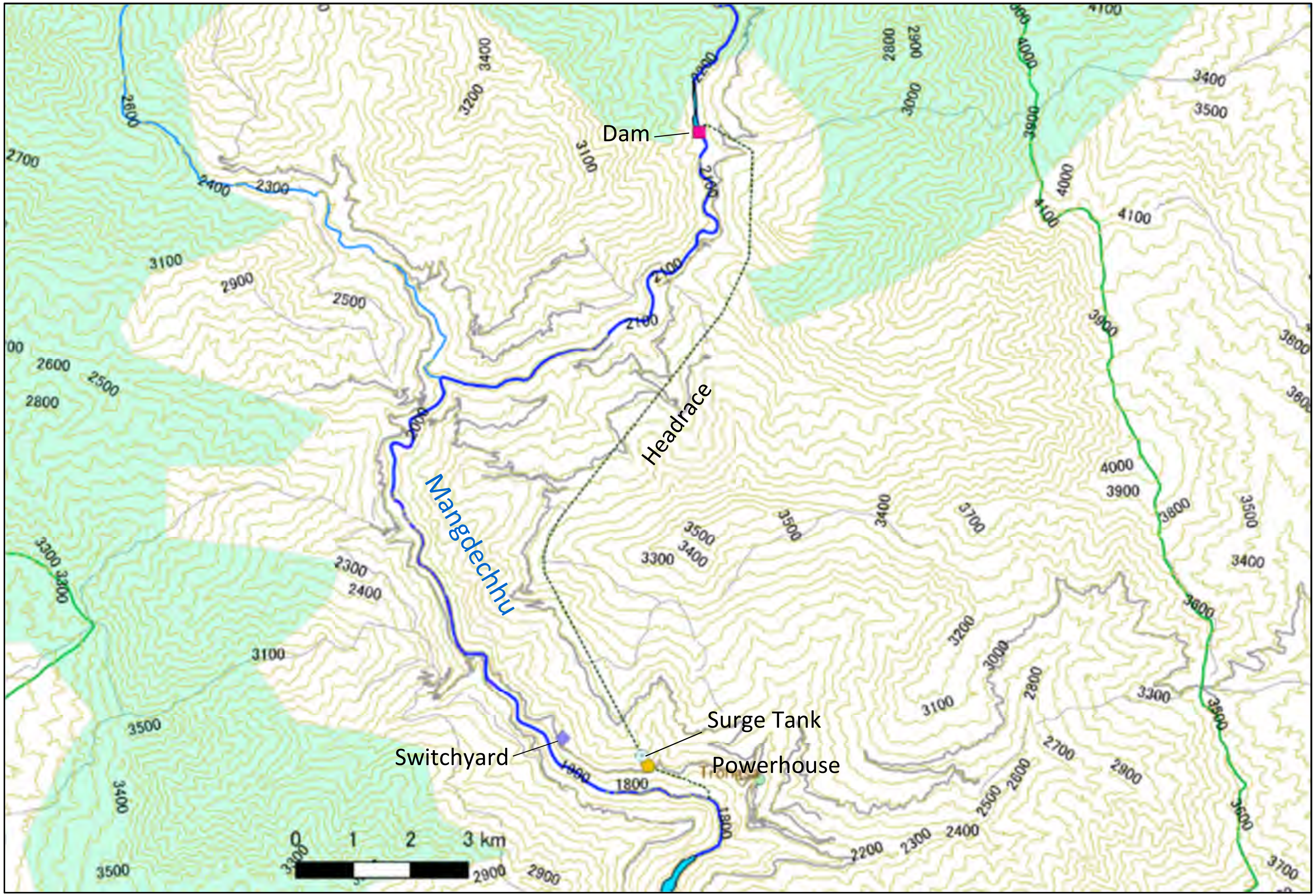
Table 8-18 Primary Features of Jongthang HPP

Items			Unit	Description
General	Type			ROR with Pond (II-2)
	Installed Capacity	P	MW	227
	Designed Discharge	Qd	m^3/s	83.3
	Effective Head	Hd	m	316.2
Dam and Reservoir	Type			Filled or Earth Dam
	Height	H	m	51
	Sediment Depth		m	26
	River Bed Level	RBL	m	2,100
	Crest Length	L	m	140
	Dam Volume	V	m^3	720,000
	Excavation Volume	Ve	m^3	227,000
	Reservoir Area	Ra	ha	4.5
	Catchment Area	Ca	km^2	1,176
	F.R.L. (Full Reservoir Level)		m	2,120
	L.W.L. (Low Water Level)		m	2,110
	Usable Water Depth		m	10
	Effective Reservoir Capacity		mil.m^3	0.3
Waterway	Intake and Desilting Basin	Ve	m^3	110,000
	Headrace	L(m) x n	m	D=5.1m, 13,030 x 1
	Surge Tank	D(m) x L	m	15 x 100
	Penstock (Vertical shaft)	L(m) x n	m	D=4.1m, 501 x 1, 50 x 2
	Tailrace	L(m) x n	m	D=6.5m, 1,390 x 1
	Total Length	Lt	m	15,052
Power house	Type			Underground
	Overburden		m	300
	Cavern Volume		m^3	90,800
	T.W.L. (Tail Water Level)		m	1,780

Turbine	Type			Pelton
	Number		unit	2
	Unit generating capacity		MW	113.5

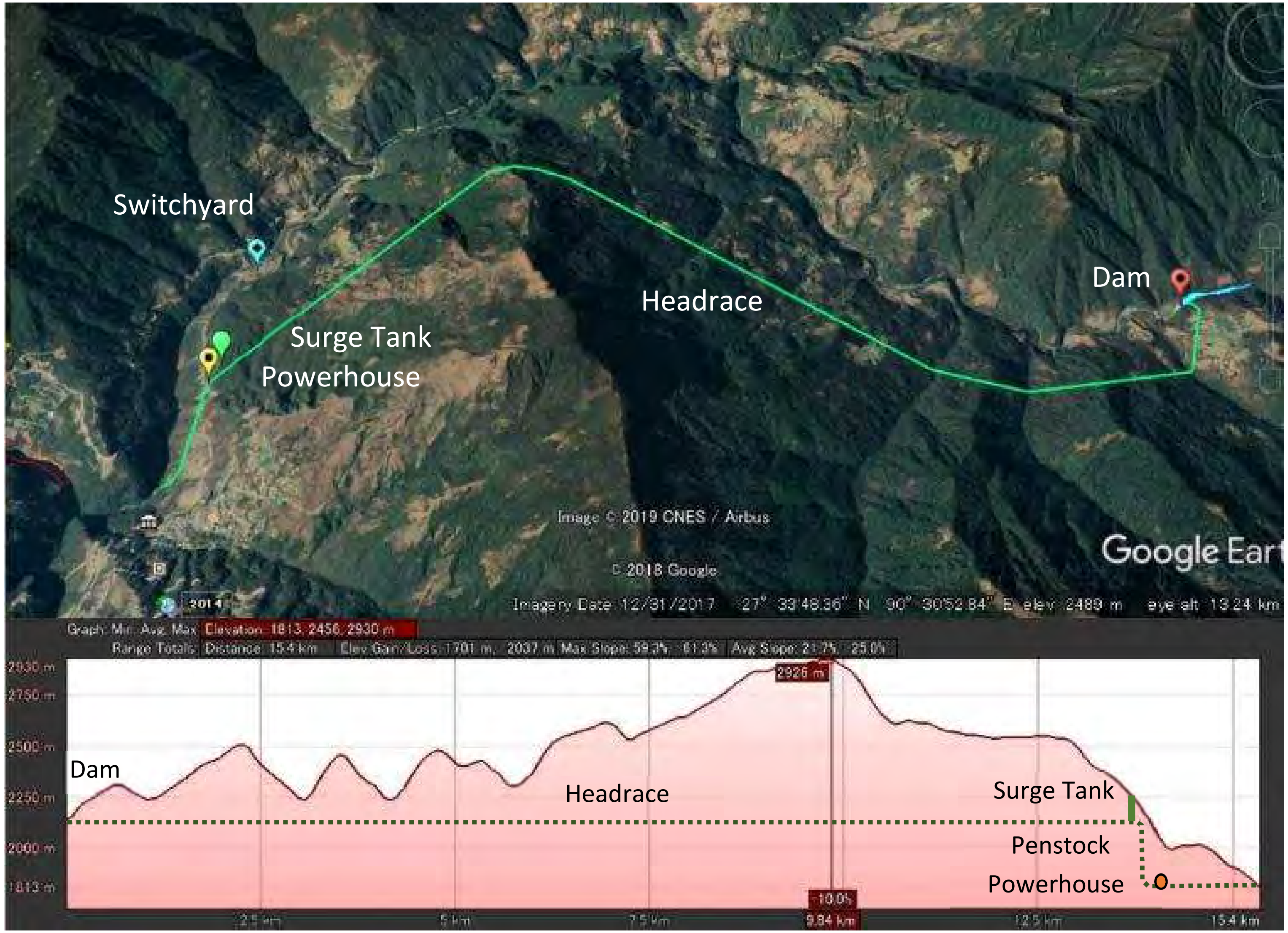
(Source: JICA Survey Team)

Plot plan and longitudinal profile are illustrated in Figure 8-9 and Figure 8-10, respectively.



(Source: JICA Survey Team)

Figure 8-9 Jongthang HPP: Plot Plan



(Source: JICA Survey Team)

Figure 8-10 Jongthang HPP: Longitudinal Profile

(4) Design of Main Structures and Facilities

(a) Civil structures

1) Intake dam and pond

Since the geological conditions are not good, a filled dam or earth dam is adopted. However, since the flood design discharge is estimated to be about 3,000m^3/s, a spill way is to be constructed on the left bank.

A diversion tunnel and a coffer dam are to be constructed during dam construction so that flood flow, for which the probability is once in 30 years, can be diverted. In addition, since it is not necessary to excavate and remove the riverbed sediment the depth of which is assumed to be 24m, a coffer dam downstream is not planned to be built.

2) Intake and Desilting basin

The intake is planned to be on the upstream of the dam. Although it has a pond, since the active storage capacity is as small as 0.3 million m^3, it is necessary to construct a desilting basin. In addition, since it is topographically difficult to adopt a ground surface type, a pressure tunnel type is adopted.

3) Waterway and Powerhouse

The waterway route runs through the left bank of Mangdechhu, according to the geological and topographical conditions. If the shortest route connecting the intake and the outlet is selected, access tunnel length becomes more than 2km and the overburden depth of the tunnel becomes over 1,000m because there exists a 3,500m class high mountain on that way, therefore, the waterway route is to detour the high mountain in view of economic efficiency.

a) Headrace

The headrace is a pressure tunnel and the inner diameter is determined to be 5.1m (one line) according to the "Guideline & Manual for Hydropower, JICA" and excavation shape is a horseshoe, of 6.2m in height.

- Lining of the tunnel with reinforced concrete is to be conducted after excavation
- If it is necessary to improve the permeability and deformability of any loosened zone around the tunnel caused by blasting, implementation of consolidation grouting is to be examined.

b) Headrace Surge Tank

The headrace surge tank location is determined so that the top end of the surge tank appears on the ground surface along the ridge, where geological conditions are fair.

c) Penstock

The penstock is planned to have a slope of 10% from the headrace surge tank to the upper bend, where the overburden does not fall below 50 m, and thereafter, the penstock is a vertical shaft up to the lower bend (the central elevation of the turbine). The penstock is bifurcated from 1 line to 2 lines at the lower horizontal part and connects the inlet valve. In the construction, after excavation is completed, spaces between steel pipes and the bedrock are filled with concrete.

The details are as follows:

- The inner diameter of the penstock at the upper horizontal part is determined to be 4.1m (one line) according to the "Guideline & Manual for Hydropower, JICA". The excavation shape is a horseshoe, of 5.7m in height
- The inner diameter of the penstock at the vertical shaft part is determined to be 4.1m (one line) according to the "Guideline & Manual for Hydropower, JICA". The excavation diameter is 5.3m

d) Powerhouse

Since it is difficult to construct a ground surface type powerhouse in terms of the topography, the powerhouse is to be constructed underground.

In principle, although the location and direction of the underground powerhouse cavern are determined after detailed investigation of the geological conditions via an investigation adit, the location is selected so that the waterway length can be the shortest and the overburden depth does not exceed 500m of the maximum recorded and it can be enough distant from Trongsa Town.

e) Tailrace

The tailrace is a non-pressure tunnel and one line, since the length is as long as about 1,390m. The inner diameter is determined to be 6.5m according to the "Guideline & Manual for Hydropower, JICA" and the excavation shape is a horseshoe, of 7.5m in height.

4) Outlet

The commonly used lateral type is adopted for the outlet.

(b) Turbine (Electric facility)

Because the effective head is as large as 316m and water discharge varies greatly between the rainy season and the dry season, a Pelton type turbine is adopted, which enables a small discharge to generate electric power.

(c) Switchyard

The plain land, where is invisible from Trongsa Town, on the upstream side of the powerhouse is suitable for the switchyard. However, since the plain land elevation is around EL. 2,060m, which is 250m higher than the powerhouse floor level, the cable tunnel is to be a inclined shaft of 30 degrees.

(d) Layout of access tunnels

The length of the headrace tunnel is 13.1km. In order to make the construction length 2.5km per face or less, one access tunnel downstream of the desilting basin, which is diverted to the earth and sand discharge tunnel, one access tunnel at the downstream end of the headrace (at the bottom of the surge tank shaft), and two access tunnels divide three equally between them, totally four access tunnels are aligned, so that the headrace can be constructed with six faces at the maximum.

(5) Rough Construction Cost Estimate

Construction costs were estimated roughly by applying the construction cost estimation kits as described in Section 5.5. The rough construction costs estimated are shown in Table 8-19.

Table 8-19 Rough Construction Costs for Jongthang HPP

(10^6Nu)

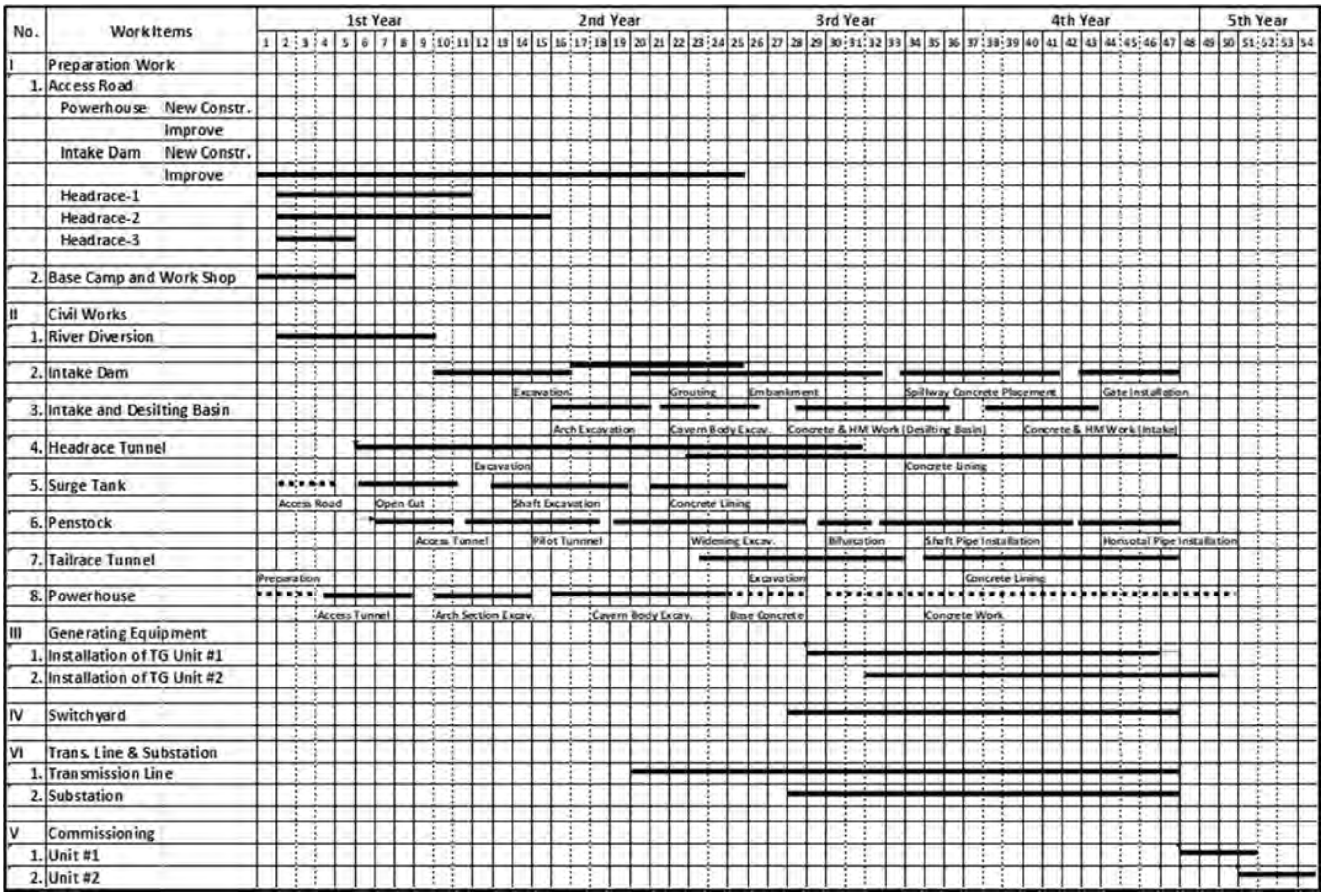
Cost Items	Cost	Remarks
I. Preparation Work	1,181	
(1) Access Road	647	
(2) Camp & Facilities	152	(III. Civil Work) x 2%
(3) Compensation & Resettlement	381	(III. Civil Work) x 5%
II. Environmental Mitigation Costs	229	(III. Civil Work) x 2%
III. Civil Work	7,625	
III.1 Intake Dam	919	
III.2 Intake Facilities		
(1) Intake	58	
(2) Desilting Basin	637	
III.3 Headrace Tunnel	3,268	
III.4 Head Tank/Surge Tank	356	
III.5 Penstock & Side Spillway		
(1) Penstock	89	
(2) Side Spillway	-	
III.7 Powerhouse	766	
III.8 Tailrace		
(1) Tailrace Waterway	405	
(2) Tailrace Outlet	19	
III.9 River Diversions from Neighborhood Basin	-	
III.10 Miscellaneous Work	363	(sum of III.1 to III.9) x 5%
IV. Hydromechanical Work	925	
(1) Gate and Screen	490	Spillway Gate, Intake Gate, Silt Flush Gate, Tailrace Gate
(2) Penstock	351	
(3) Miscellaneous Work (10% of above total)	84	
V. Electrical Work	4,983	
(1) Electro-Mechanical Equipment	4,746	
(2) Miscellaneous work (5% of above total)	237	
VI. Transmission Line	2,913	
(1) Transformer, Switchyard, Transmission Line	2,913	
VII. Administration Costs and Engineering Costs	2,112	(sum of I to V) x 0.15
VIII. Contingency	4,225	(sum of I to V) x 0.3
IX. Interest During Construction	2,450	(sum of I to VIII) x 0.4 x I x T (Assumed I = 0.05, T = 6 years)
Grand Total	25,781	

(Source: JICA Survey Team)

(6) Construction Schedule

Construction speeds of each component for the construction amount for every main civil structure are set as shown in Table 8-6, as per Dorokha HPP, based on experiences of construction in Japan.
The critical path of the construction schedule is the process of the waterway and underground powerhouse. Therefore, the overall construction period is estimated to be 54 months (4 and a half years).
The construction schedule from commencement to commissioning (incl. preparation work) is shown in Table 8-20.

Table 8-20 Construction Schedule (Jongthang HPP)



Note) TG: Turbine generator, HM: Hydro-mechanical

(Source: JICA Survey Team)

8.5 Action Plans for Next Step

8.5.1 Hydrological and Metrological Investigation

- Dorokha HPP
  Hydrological data of Dorokha gauging station are to be arranged and analyzed.
- Pinsa HPP
  A gauging station near the intake weirs should be installed and hydrological data should be analyzed.
- Chamkhachhu II HPP
  Hydrological data of Shingkhar/Bemethang gauging station are to be arranged and analyzed.
- Uzorong HPP
  Hydrological data of Uzorong gauging station are to be arranged and analyzed.
- Jongthang HPP
  Hydrological data of Bjizam gauging station are to be arranged and analyzed.

8.5.2 Geological Investigation

(1) Dorokha HPP, Chamkharchhu II HPP, Uzorong HPP and Jongthang HPP

Items to be clarified in the next step and recommendable geological investigation and laboratory tests for each item are summarized in Table 8-21.

As for the intake dam, in order to figure out the geological structure around the dam site, ground surface reconnaissance should be executed. Besides, a grid of 100m is set throughout the dam site and electric prospecting should be conducted on the grid. Borehole drillings should be conducted on the intersection points of 100m grids. Length of each borehole on the dam axis is set as 60m equivalent to the dam height, and is set 50m up and downstream of the dam center. Lugeon tests are executed for all boreholes to determine the hydrogeological property of the dam foundation.

As for the sites of quarry, intake and outlet, geological conditions are basically investigated by borehole drillings and electric prospecting.

Along the waterway, electric prospecting is conducted for geological interpretation. For the desilting chamber and headrace surge tank, drilling and in-situ test of sonic logging in the borehole will be carried out, and Lugeon tests below the ground water level are executed.

As for the underground powerhouse, in order to figure out the geological structure around the powerhouse, ground surface reconnaissance should be executed. In addition, drilling is conducted from ground surface to the underground powerhouse elevation in order to figure out the surrounding rock condition of the powerhouse cavern. Then, in-situ tests such as sonic logging and Lugeon tests at the range of 100m from the bottom of borehole are executed.

Laboratory testes should be executed for all structure sites. However, XRD (X-Ray Diffraction) analysis is executed only for drilled cores of weathered zone, which have a possibility of including expansive clay minerals.

Meanwhile, exploratory test adits for the dam, the quarry site, and the underground powerhouse (UGPH) and insitu tests in the adits, i.e. rock shearing test, plate loading test, and measurement of initial ground stress of the UGPH will be carried out in the detailed design stage.

Table 8-21 Geological Investigation Work in the F/S Stage for Dorokha HPP, Chamkharchhu II HPP, Uzorong HPP and Jongthang HPP

Structure	Purpose	Investigation item	Notes
Intake Dam	➢ Geological structure ➢ Geotechnical property of dam foundation ➢ Permeability of dam foundation	1. Ground surface survey 2. Electric prospecting 3. Drilling 4. Lugeon test	* Ground surface survey on the whole area of the reservoir

		5. Laboratory tests	
Quarry site	➢ Quality of aggregate for concrete gravity dam.	1. Electric prospecting 2. Drilling 3. Laboratory tests	
Desilting Chamber	➢ Geological property of the desilting chamber and its surrounding area	1. Electric prospecting 2. Drilling (including sonic logging in borehole) 3. Laboratory tests	
Waterway/ Surge tank	➢ Geotechnical feature of the waterway route (possibility of hidden weak zone such as fracture zones and hydrothermal altered zones)	1. Electric prospecting 2. Drilling (including sonic logging in borehole) 3. Lugeon test 4. Laboratory tests	* Electric prospecting intends for only a waterway route * Ground surface survey on surrounding area of the surge tank and the UGPH
Underground Powerhouse	➢ Geological structure ➢ Geotechnical property of the UGPH and neighboring rocks	1. Ground surface survey 2. Drilling (including sonic logging in borehole) 3. Lugeon test 4. Laboratory tests	
Outlet/ Switchyard	➢ Geological structure ➢ Subsurface loosened zone caused by rock creeping ➢ Weathering condition	1. Ground surface survey 2. Electric prospecting 3. Drilling 4. Laboratory tests	*Ground surface survey on surrounding area of the outlet and along the road

(Source: JICA Survey Team)

(2) Pinsa HPP

Items to be clarified in the next step and recommendable geological investigation and laboratory tests for each item are summarized in Table 8-22.

As for the intake weirs, in order to figure out the geological structure around the weir and desilting basin, ground surface reconnaissance should be executed. Electric prospecting on 100m grids is conducted for geological interpretation.

Along the waterway route, electric prospecting is conducted for geological interpretation. For the headrace surge tank, drilling and in-situ test of sonic logging in the borehole will be carried out, and Lugeon tests below the ground water level are executed.

As for the penstock route, in order to figure out the geological structure, ground surface reconnaissance should be executed. Along the penstock route, electric prospecting is conducted for geological interpretation. Borehole drilling and in-situ test of sonic logging in the borehole will be carried out,

As for the switchyard, powerhouse and outlet, in order to figure out the geological structure around the powerhouse, ground surface reconnaissance should be executed. Electric prospecting is conducted on 100m grids for geological interpretation. Borehole drillings of 10m on the intersection points of 100m grids are conducted in order to figure out the foundation condition.

Table 8-22 Proposal of Geological Investigation Work in the F/S Stage for Pinsa HPP

Structure	Purpose	Investigation item	Notes
Intake Weir/ Desilting Basin	➢ Geological structure ➢ Geotechnical property of riverbed	1. Ground surface survey 2. Electric prospecting	* Ground surface survey on the whole area of the reservoir
Waterway/ Surge tank	➢ Geotechnical feature of the waterway route (possibility of hidden weak zone such as fracture zones and hydrothermal altered zones)	1. Electric prospecting 2. Drilling (including sonic logging in borehole) 3. Lugeon test 4. Laboratory tests	* Ground surface survey on surrounding area of the surge tank
Penstock	➢ Geological structure ➢ Geotechnical property of foundation of the penstock ➢ Weathering condition	1. Ground surface survey 2. Electric prospecting 3. Drilling 4. Laboratory tests	* Ground surface survey on surrounding area of the penstock route

Powerhouse/ Switchyard	➢ Geological structure ➢ Geotechnical property of foundation of the powerhouse/ switchyard	1. Ground surface survey 2. Electric prospecting 3. Drilling	*Ground surface survey on surrounding area of the powerhouse, switchyard and outlet

(Source: JICA Survey Team)

8.5.3 Environmental Impact Assessment

According to the screening criteria of JICA and the World Bank, large scale hydropower projects are categorized as "Category A," for which careful EIA procedures are required.

During full-scale EIA procedures, sufficient site investigation should be carried out to fully know the current environmental situation, and consultation with project-affected people (PAPs) and other related people should be done to reflect PAPs' opinion to the resettlement action plan (RAP) and environmental management plan (EMP).

In order to implement EIA procedures, environmental consultants or experts who are familiar with hydropower project will be employed. As for scope of work for EIA, it is necessary that EIA report should be complied with the General Format, which is prescribed in the Bylaws of EIA as well as guidelines of international donor agencies such as JICA.

8.5.4 Feasibility Study

(1) Scope of Work

Items to be studied are as follows:

1. Hydrological, Topographical and Geological Investigations and Comparative Study

1-1 Planning and execution of investigations

1-2 Review of basic plan based on the results of investigations
- To evaluate geological conditions
- To review design flood discharge and capacity of spillway
- To review design sediment volume and sluicing and flushing function

1-3 Comparative study on alternatives
- To review the optimal development scale
- To carry out comparative study of location of UGPH and Waterway / Penstock alinement

2. Basic Design and Construction Planning

2-1 Basic design of civil structure and hydromechanics structure
2-2 Review of design of electro-mechanical equipment
2-3 Evaluation on the possible application of new technologies (TBM)
2-4 Review of construction planning

3. Environmental Impact Assessment

3-1 Review of environmental impact assessment report
3-2 Review of resettlements and land compensations plan

4. Operation and Maintenance (O&M)

4-1 Examination on the optimal O&M structure
4-2 Evaluation on the O&M capability of the developer in terms of technologies and human resources

5. Project Implementation based on above-mentioned Study Results

5-1 Examination on the organizational structure, total cost, financial plan, schedule and procurement of equipment for project implementation
5-2 Economical and financial analysis (IRR, Cash flow)
5-3 Proposal on TOR and Man Month for engineering services

(2) Implementation Schedule of Feasibility Study

Duration of the feasibility study will be two years and duration of project preparation will be two and half years as shown in Table 8-23.

Table 8-23 Draft Schedule from Feasibility Study to Tendering

	1 year				2 year				3 year		4 year		5year	
	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1H	2H	1H	2H	1H	2H
Feasibility Study														
Consultant selection	■													
Hydrological data measurement		■	■	■	■	■	■	■	■	■	■	■	■	■
Geological Investigation		■	■	■										
Basic Design & Cost estimate				■	■	■								
EIA Preparation														
Environment Investigation		■	■	■	■									
Assessment, EIA, EMP, RAP					■	■								
EIA, EMP, RAP Finalization							■							
Financing Plan							■	■						
Project Preparation														
Consultant selection									■					
Detailed Design & Bid document										■	■			
Tendering Procedure													■	■

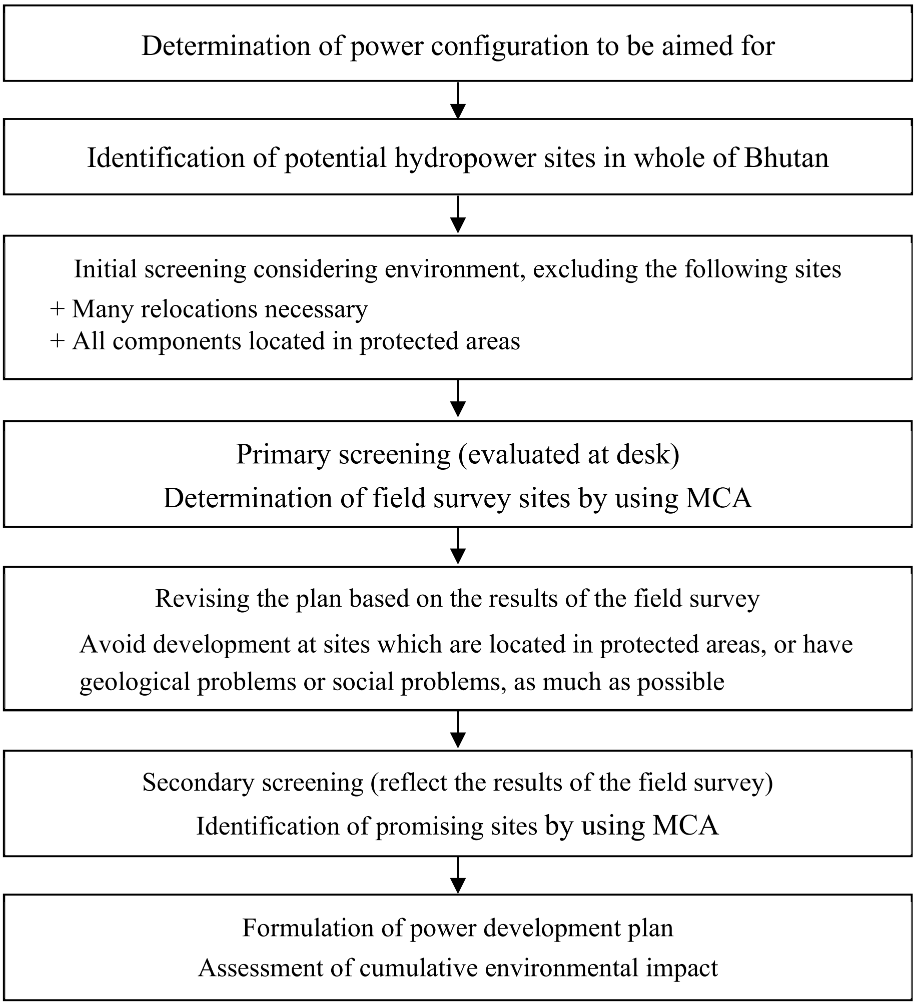
(Source: JICA Survey Team)

Chapter 10. Strategic Environmental Assessment (SEA)

10.1 Overview of this Project Component

10.1.1 Content of this Project Component

The Strategic Environmental Assessment (SEA) has been carried out as a part of the formulation of PSMP-2040, which is a requirement as stipulated in the draft National Guideline of SEA of National Environment Commission (NEC), Bhutan to take cognizant of importance of natural and environmental aspects, taking appropriate actions to avoid, minimize and mitigate the negative impacts induced by implementing the hydropower projects, in addition, to provides a platform to the stakeholders to raise their views and comments during the implementation of SEA and at an early stage in strategic planning. The work flow is as follows.



(Source: JICA Survey Team)

Figure 10-1 Work Flow for this Project

As described in Chapter 3, the future power supply configuration will be almost 100% covered by hydropower, the same as in the present situation. For the power system MP, potential sites for abundant hydro resources will be identified and development priorities will be determined accordingly.

10.1.2 Comparison of Alternatives

In selecting promising sites (Short listed sites) from all potential sites, based on the purpose of an SEA, a comparative evaluation of all sites was conducted in consideration of not only economic efficiency but also environmental aspects. Specifically, using the MCA (Multi Criteria Analysis) method, each site is evaluated multilaterally and compared, and the development priority of each site is determined. As shown below, the criteria for evaluation are divided into five items, which are environmental considerations (natural and social), social development (positive impact), economic aspects, and risks such as geological and hydrological aspects. (Refer to Chapter 7 for the detailed evaluation methods and evaluation results.)

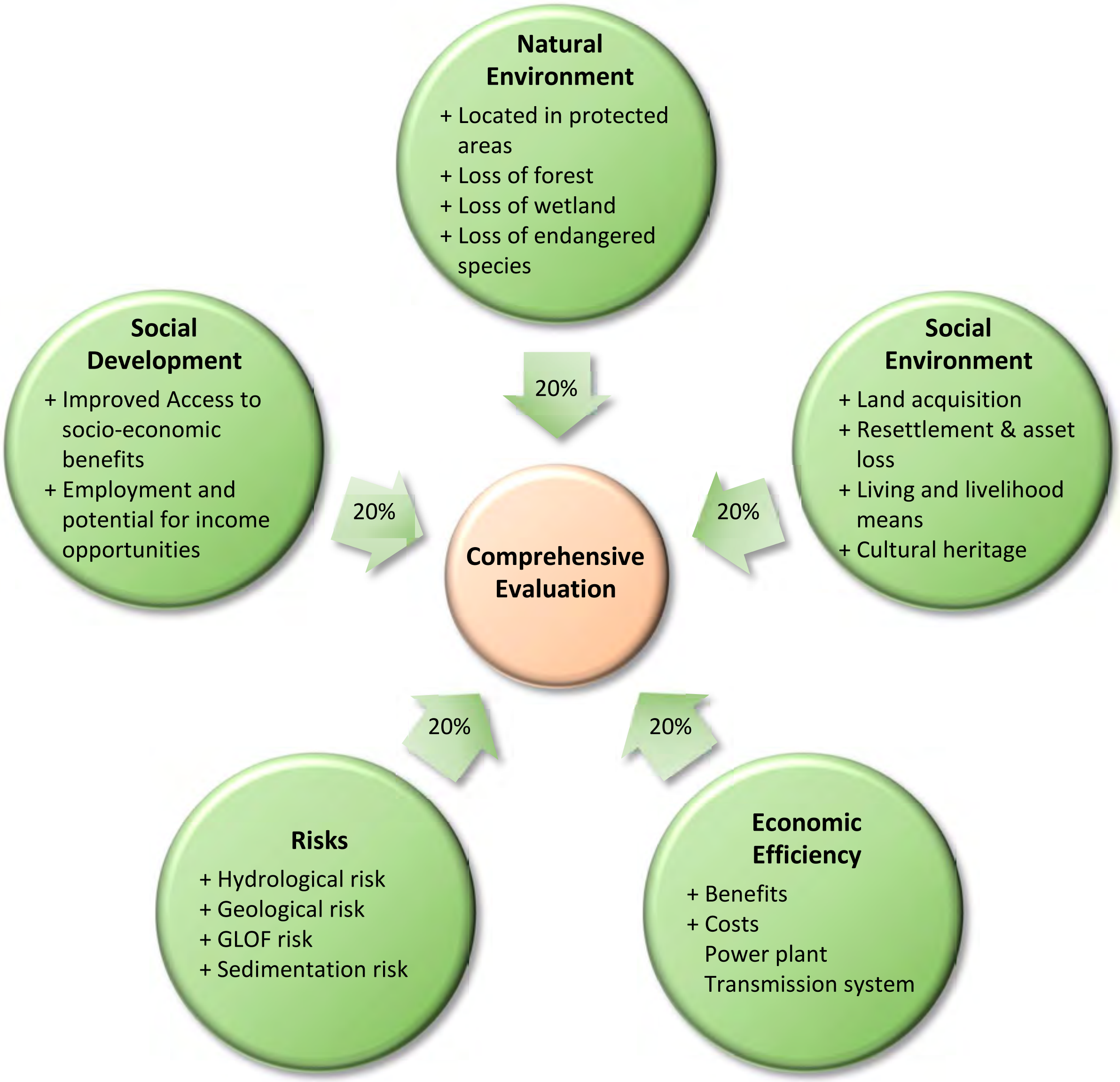


Figure 10-2 Comprehensive Evaluation Method for each site

Specific items and MCA weights finally used for the evaluation of each site are described in Table 7-63.

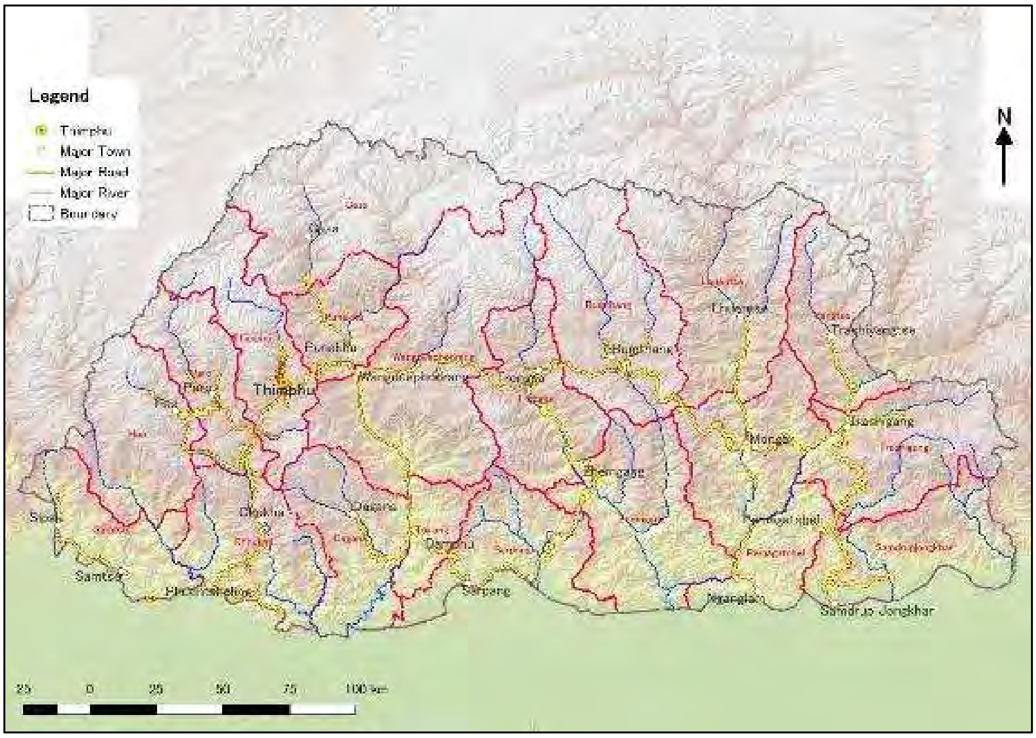
10.2 Environmental and Social Considerations

10.2.1 Present Status of the Environment

(1) Physical environment[14]

(a) Geographical features

Bhutan is a landlocked country, with area of 38,394km^2. It borders China (north: 470km) and India (east, west and south: 605km). It extends approximately 500km from the east to the west and 170km from the north to the south (Figure 10-3).



(Source: JICA Survey Team)

Figure 10-3 Geographic Map of Bhutan

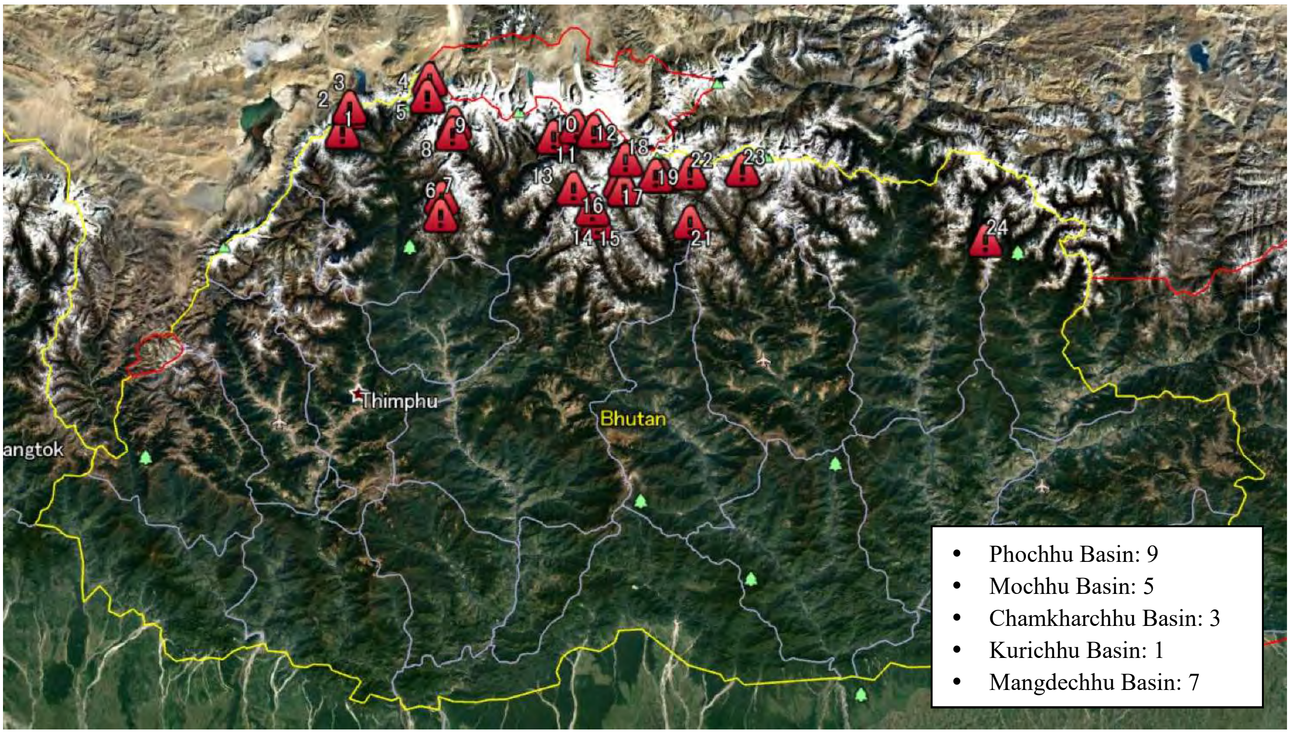
Its land features precipitous terrain, and the altitude is from 160m to over 7,000m. The highest mountain is Gangkhar Puensum, with an altitude of 7,570m. The northern part of Bhutan is in the Himalayan Mountains and is an alpine zone. The central part is a mountainous region extending from the Himalayan Mountains to the southern part. The Black Mountains in the central part are the water sources of the two major rivers, Punatsangchhu and Mangdechhu. The southern Siwalik hill is at the foot of the Himalayan Mountains. It is covered with deciduous forests, and valleys of lowland rivers with alluvial fans have developed. The peaks of the mountains are about 1,500m above sea level, and there are subtropical plains at the foot of the mountains.

The climate zones of Bhutan are divided into alpine, temperate and subtropical, and the climate is affected by monsoons. Spring has less rain, from March to mid-April. After mid-April, the early monsoon climate is observed until June. A full-scale rainy season due to the southwest monsoon continues from late June to late September. The weather is stable from late September or the beginning of October to the end of November, and snowfall is usually observed in the high mountains. Winter is from November to March, and this brings strong winds due to the northeast monsoon.

[14] The Information in this section is from "Statistical Yearbook of Bhutan 2016 (National Statistics Bureau, Royal Government of Bhutan)" unless otherwise noted.

(b) Rivers and glaciers

There are five (5) major river systems in Bhutan, namely Drangmechhu, Mangdechhu, Punatsangchhu, Wangchhu and Amochhu, and they flow into the Brahmaputra River in India.



(Source: JICA Survey Team-created map based on information from http://www.saarc-sadkn.org/)

Figure 10-4 Distribution Map of Glaciers and Glacial Lakes with Risk of Outburst Flood

Glaciers in northern Bhutan cover about 10% of the land area and are an important water source for the country. Luggye Tsho GLOF (Glacial Lake Outburst Flood), which occurred in November 1994, generated a flood height of over 2m at a distance of 200km downstream of the source[15]. When a GLOF occurs, a huge amount of debris piles up in the reservoirs of hydropower plants downstream of the GLOF, so desilting needs to be carried out to maintain stable operation of the plant. There is a risk that O&M costs may increase remarkably due to this.

(2) Natural disasters

The Asian Disaster Reduction Centre summarizes the status of natural disasters in Bhutan as follows:

Geo-physically, Bhutan is located in the young Himalayan Mountains and is considered to be in one of the most seismically active zones in the world. As per the Indian Seismic Code, Bhutan lies in the seismic zones IV and V, which are the most active zones. Considering its location and as proven by past earthquakes, earthquakes are one of the most imminent hazards in Bhutan. As a result of global warming, Glacial Lake Outburst Floods (GLOF) pose another risk to the people of Bhutan. Due to the climatic change, seasonal strong wind is becoming one of the hazards in Bhutan, causing a lot of damage to rural homes. The 2011 and 2013 windstorms caused huge damage to rural homes in Bhutan. Other hazards such as landslides, flash floods and forest/structural fires also sweep across the country causing significant losses to properties and claiming the lives of people[16].

[15] Geoenvironmental Disasters (Deo Raj Gurung et. al., 2017)
[16] http://www.adrc.asia/nationinformation_j.php?NationCode=64&Lang=en&NationNum=33

Table 10-1 summarizes the recent natural disasters in the country.

Table 10-1 Natural disasters in Bhutan

Date	Type	Content
September 2011	Earthquake	An earthquake of **Richter magnitude** scale 6.9 occurred on 18th September 2011. One person died due to a landslide caused by the earthquake, and 14 people were injured. Damage to structures of about 24.5 million US dollars was caused.
June 2013	Flash flood	On 4th June 2013, a flash flood occurred due to heavy rain, and six villages in Punakha Dzongkhag suffered damage. Several acres of land were buried with sediment or washed away. A drainage canal overflowed.
December 2013	Storm	Thirteen Dzongkhags, 53 villages, and one Throm were affected by the storm. 979 houses, 12 schools 50 temples and monasteries, three village stadiums and eight clinics were damaged.

(Source: http://www.adrc.asia/nationinformation_j.php?NationCode=64&Lang=en&NationNum=33)

(3) Biological environment[17]

(a) Vegetation

The Constitution states to maintain the forest coverage rate at over 60%, and the current forest coverage rate is 70.46%. In Bhutan, there are mountains ranging from 150m above sea level to high mountains exceeding 7,000m, and the horizontal distance from south to north is about 170km, and various vegetation has been confirmed accordingly (Table 10-2).

Table 10-2 Climate zones and vegetation

Climate zone	Vegetation
Alpine Zone: 4000 + m above sea level (masl)	Alpine meadows and scrubs dominated by Rhododendron scrubs, Juniper and medicinal plants and herb species
Temperate Zone: 2000 - 4000 masl	Fir Forest: 3000 masl+ Mixed Conifer Forest: 2500 - 3500 masl Blue Pine Forest: 1500 - 3200 masl Broadleaf mixed with Conifer: 2000 - 2500 masl
Sub-Tropical Zone: 150 - 2000 masl	Broadleaf Forest: 1000 - 2000 masl Tropical Lowland Forest: <700 masl

(Source: The Fifth National Report to the Convention of Biological Diversity Secretariat (National Environment Commission, Royal Government of Bhutan, 2016))

(b) Protected areas

51.44%[18] of the country's land is covered with protected areas. The protected area network consists of National Parks, Wildlife Sanctuaries, Strict Nature Reserves, and Biological Corridors. Additionally, there is a botanical garden ($47km^2$), used as a recreational park. There are Core Zones, Buffer Zones and Multiple-use Zones in the protected areas. Local people live in the Multiple-use Zones. Table 10-3 shows the definitions of the protected areas and their zones, Table 10-5 shows the protected areas and Figure 10-5 shows a map of them.

[17] The Information in this section is from "The Fifth National Report to the Convention of Biological Diversity Secretariat (National Environment Commission, Royal Government of Bhutan, 2016)" unless otherwise noted.
[18] National Biodiversity Strategies and Action Plan (2014)

Table 10-3 Protected Areas and its Definitions

Category	Definitions and/or purpose
National Park	A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values (A).
Wildlife Sanctuary	The purpose is the same as that of a national park, but its area is smaller than that of a national park.
Strict Nature Reserve	The purpose is the same as that of a national park. There is only one Strict Nature Reserve. In the Reserve there are no permanent human settlements and human related activities are not permitted, except for regulated research and monitoring programs.
Biological Corridor	It shall mean an area set aside to connect one or more protected areas (B).

(Source: (A): "Guidelines for Zonation in National Parks and Wildlife Sanctuaries in Bhutan (2012)" uses the IUCN's definitions of protected areas. (B): Forest and Nature Conservation Rules of Bhutan (2006) and others are based on information from the Department of Forests and Park Services)

Table 10-4 Zoning Category and its Definitions

Category	Definitions and/or purpose
Core Zone	It shall mean a fully protected zone within a Protected Area, designated in accordance with Technical Regulations, in which human related activities are not permitted, except for regulated research and monitoring programs (B).
Multiple-use Zone	An area set aside within the protected area based on a mutually beneficial relationship between nature conservation and sustainable management of natural resources in relation with the livelihoods of surrounding communities (A).
Buffer Zone	It shall mean an area set aside as a cushion within the Protected Area boundary (B).

(Source: (A): "Guidelines for Zonation in National Parks and Wildlife Sanctuaries in Bhutan (2012)" uses the IUCN's definitions of protected areas. (B): Forest and Nature Conservation Rules of Bhutan (2006) and others are based on information from the Department of Forests and Park Services)

Table 10-5 Protected Areas

Name	Year established	Area in km^2
National Park		
Wangchuck Centennial Park	2008	4,914.00
Jigme Dorji National Park	1993	4,316.00
Jigme Singye Wangchuck National Park	1993	1,730.00
Royal Manas National Park	1993	1,057.00
Phrumsengla National Park	1993	905.05
Wildlife Sanctuary		
Bumdelling Wildlife Sanctuary	1993	1,520.61
Sakten Wildlife Sanctuary	1993	740.60
Phibsoo Wildlife Sanctuary	1993	268.93
Khaling Wildlife Sanctuary	1993	334.73
Strict Nature Reserve		
Jigme Kheser Strict Nature Reserve	1993	609.51
Biological Corridors		
Biological Corridors	1999	2,685.61
Recreation Park		
Royal Botanical Park	2004	47.00
Total area		19,129.04

(Source: Department of Forest & Park Services (DOFPS), MOFA (2013))

(Source: Regulatory Framework for Biological Corridors in Bhutan)

Figure 10-5 Map of the Protected Areas and Biological Corridors

(c) Important areas recognized by an international nature conservation NGO

BirdLife International, an international nature conservation NGO, identifies internationally important bird habitats as Important Bird and Biodiversity Areas (IBAs) and promotes their conservation with local governments and NGOs. There are 23 IBAs and only eight (8) of them are under protection of the government[19].

(d) Status of wildlife species

Table 10-6 shows the number of wildlife species in Bhutan.

Table 10-6 Number of Wildlife Species in Bhutan

Taxon	Number of species
Seed plants	Over 5,600
Freshwater fish	91
Amphibians	61
Reptiles	124
Birds	Approximately 700
Mammals	Approximately 200

(Source: The Fifth National Report to the Convention of Biological Diversity Secretariat (National Environment Commission, Royal Government of Bhutan, 2016))

The direct threats to the biodiversity of the country are land use changes, forest fires, over-logging, firewood collection, over-grazing, illegal forest use, poaching, unsustainable agriculture practices,

[19] Important Bird Areas in Asia: Key sites for conservation (BirdLife International, 2004)

pollution, alien species and human-wildlife conflict. Climate change, population increase, and poverty are recognized as indirect threats. Because of these threats, the extinction of species is also a concern in Bhutan[20]. Table 10-7 shows the number of endangered species in Bhutan (only Critically Endangered, Endangered, and Vulnerable categories. (See Appendix[21] for individual species names))

Table 10-7 Number of endangered species in Bhutan

Taxon	Mammals	Birds	Reptiles	Amphibians	Fishes	Molluscs	Other Inverts	Plants	Fungi & Protists	Total
Number of species	25	19	3	1	3	0	1	43	0	95

(Source: http://cmsdocs.s3.amazonaws.com/summarystats/2017-3_Summary_Stats_Page_Documents/2017_3_RL_Stats_Table_5.pdf (access in March 2018))

(e) Faunal species which may be impacted by the Project

1) Birds

White-bellied Heron *Ardea insignis* is categorized as Critically Endangered in the IUCN/RedList. According to the Royal Society for the Protection of Nature (RSPN), several cases have been reported in which herons became struck in transmission lines in the Punatsangchhu and died, but no similar cases have been reported in other river systems. RSPN has plans to reintroduce the heron to other river systems[22].

2) Freshwater fish

49 fish species were reported in a paper published in 1978. A recent study reveals that there are 91 fish species in Bhutan[23]. Table 10-8 shows endangered fish species (only Critically Endangered, Endangered, and Vulnerable categories).

Table 10-8 Number of endangered fish species in Bhutan

Scientific name	English name	IUCN/RedList category
Tor putitora	Putitor Mahseer (Golden Mahseer)	Endangered
Cyprinion semiplotum	Assamese Kingfish	Vulnerable
Schizothorax richardsonii	na	Vulnerable

(Source: http://www.iucnredlist.org (accessed in March 2018))

Note: Tor putitora is categorized as a protected species in Forest and Nature Conservation Act (1995).

Besides the species shown in Table 10-8, there is one species which needs special attention. *Parachiloglanis bhutanensis* was described in 2014 as a new and endemic species in Bhutan. The species has not yet been reviewed and categorized by the IUCN/RedList because of its recent discovery. The species is only found in Khalingchhu stream and an adjacent, unnamed stream in the headwaters of the Drangmechhu River[24]". It is therefore necessaty to pay special attention to this species when projects in the area are planned and impelented.

[20] https://www.cbd.int/countries/profile/default.shtml?country=bt#facts

[21] Source: https//www.iucnredlist.org/ Advanced => Bhutan access in March 2018

[22] Based on information from RSPN on 15th December 2017.

[23] The Fifth National Report to the Convention of Biological Diversity Secretariat (National Environment Commission, Royal Government of Bhutan, 2016)

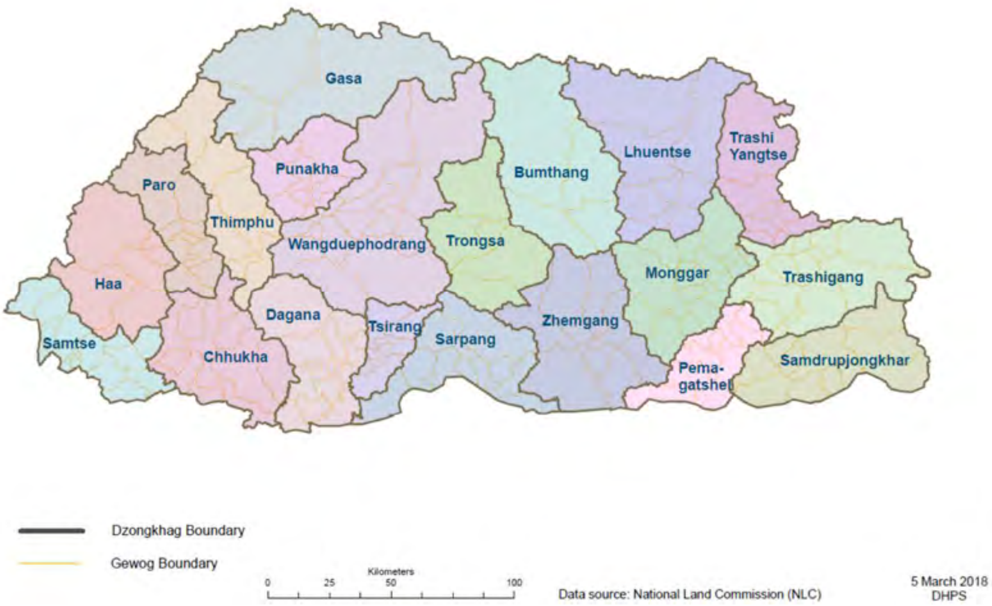
[24] Parachiloglanis bhutanensis, a new species of torrent catfish (Siluriformes: Sisoridae) from Bhutan. Thoni, R.J. & Gurung, D.B. Zootaxa 3869 (3): 306–312.

(4) Social Environment

【General Information】

(a) Administrative Division

In Bhutan, since the 1980s, decentralization has been promoted based on a basic principle of public participation and a local administration system has been established. In this local public administration network, there are 20 administrative divisions or Dzongkhags ("District" in English) and 205 gewogs ("block" in English), as shown in Figure 10-6, in which a Dzongdag in a Dzongkhag and a Gup in a Gewog are assigned as head administrators. Gewogs are composed of several villages (Chiwog) or Thromde, which are the centers of Dzongkhags. In 9 Dzongkhags among a total of 20, there are 16 Dungkhag divisions ("Sub-district" in English), where a Dungpa is assigned as the head.



(Source: Prepared by DHPS, MOEA, as of March 2013)

Figure 10-6 Bhutan Administrative Division Map

A Development Plan was formulated by the Dzongkhag Development Committee (Dzongkhag Tshogdu: DT) which consists of representatives selected by local people and Dzongkhag public administration officers. In the same manner, there is a Gewog Development Committee (Gewog Tshogde: GT), the members of which are Gup, Mangmi (Deputy head of Gewog), Tshogpa (representative of village (s) in Gewog) and a Gewog Administrative Officer (GAO), who has the role of secretary of the GT.

(b) Population

According to the Population and Housing Census of Bhutan (hereinafter referred to as "PHCB2017") by the National Statistics Bureau (NSB), the total population with Bhutanese nationality is 727,145. 62.2% of the total is rural population. Population density is 19 persons/km^2. Population by Dzongkhag is shown in Table 10-9.

Table 10-9 Population by Dzongkhag in Bhutan (2017)

Dzongkhag	Population	Dzongkhag	Population
Bumthang	17,820	Samdrup Jongkhar	35,079
Chhukha	68,966	Samtse	62,590
Dagana	24,965	Sarpang	46,004
Gasa	3,952	Thimphu	138,736

Haa	13,655	Trashigang	45,518
Lhuntse	14,437	Trashiyangtse	17,300
Mongar	37,150	Trongsa	19,960
Paro	46,316	Tsirang	22,376
Pemagatshel	23,632	Wangdue Phodrang	42,186
Punakha	28,740	Zhemgang	17,763

(Source：NSB“2017 Population and Housing Census of Bhutan”)

(c) Religion

Bhutan is a Buddhist country. The religious leader of the Tantrism in India, Padmasambhava, brought Buddhism (Vajrayana) to Bhutan in the 8th century. Later, Phajo Drugom Zhigp from Tibet disseminated the Nyingmapa (the ancient or the older) school of Buddhism in 1222. Zhabdrung Nawang Namgyal came from Tibet in 1616 and brought various Buddhist schools, and unified the country as one whole nation-state, giving it a distinct national identity. Bhutan is referred to as the last Vajrayana Buddhist country; however, animistic traditions and beliefs are still practiced by the people.

In terms of the share compared to the total population, there is a reference document which shows Buddhists at 73.9%, Hindus at 21.9% and people of other religions, including Christians and Muslims, at 4.7%[25].

(d) Language and Ethnicity

Ethnic groups in Bhutan are generally divided into three: Ngalops (Tibetan origin), Tshanglas (or Sharchops; local people living traditionally in the east of Bhutan), and Lhotshampas (Nepalese origin) and 19 languages are in use among them. In some rural areas, there are some small population groups maintaining traditional practices. For example, there are small groups with the nomad custom of keeping yak and sheep, such as Layapas in the northwest and Brokpas, who live in the Merak Sakteng area in the east. Information on current areas of activities and lifestyles in relation to these traditional ethnic groups is limited in existing documents. Therefore, for the baseline information, the latest situation needs to be verified in each site.

【Living Environment Indicators】

(e) Land Ownership and Use

“Land information at a glance” by the National Land Commission Secretariat (NLCS) shows that the total number of registered land ownerships/user certifications (“thram” in Dzongkha, the national language of Bhutan) is 178,179, with a total area of about 468,993 acres (approx. 1,898 km^2), approximately 5% of the total land area in Bhutan. Of total certifications, 86.6% is owned by households, 7.8% by individuals, 3.4% by community, and 2.2% is other. 2.2% of other category occupies a total of 33,685 acres are owned by institutions (government, religious groups, and corporations) and the community, accounting for approximately 0.4 % of the total land. Average land size per thram (land owner or user) is 2.6 acres.

In terms of the use of total registered land, cultivated rain-fed agricultural land (Kamzhing in Dzongkha) is 71.7%, irrigated land (Chhuzhing in Dzongkha) 15.9%, and land for fruit trees (Orchard) 4.8%.

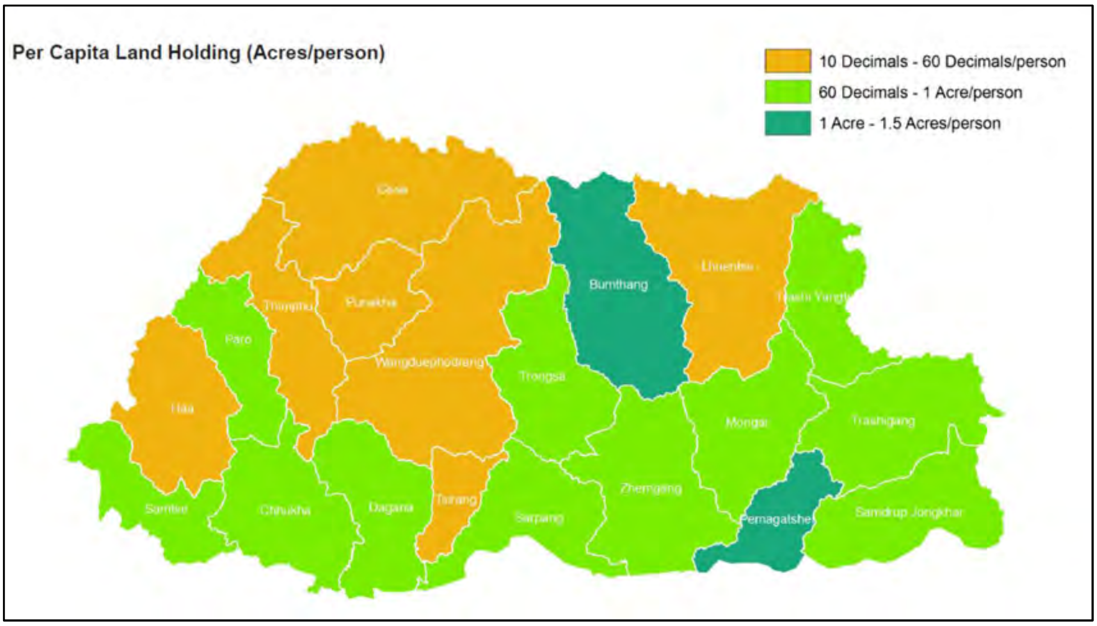
Average land size per thram by Dzongkhag (Table 10-10) ranges from 1.3 to 4.7 acres. Figures in Bumthang and Pemagatshel are over 4 acres and those in Chhukha, Lhuntse, Samdrup Jongkhar, and Zhemgang are over 3 acres. In terms of per capita land holdings (acres/person) in each Dzongkhag (Figure 10-7), only two Dzongkhag (Bumthang and Pemagatshel) reach 1 to 1.5 acres/person, while the average for most Dzongkhag is less than 1 acre/person.

[25] Estimated figure in 2010, from Pew Research Center “The Future of World Religions: Population Growth Projections, 2010-2050”

Table 10-10 Average Land Size per Thram by Dzongkhag in Bhutan

Dzongkhag	Average Land Size per Thram (Acre)	Dzongkhag	Average Land Size per Thram (Acre)
Bumthang	4.7	Samdrup Jongkhar	3.2
Chhukha	3.2	Samtse	2.3
Dagana	2.8	Sarpang	1.8
Gasa	1.3	Thimphu	1.8
Haa	2.8	Trashigang	2.5
Lhuntse	3.5	Trashiyangtse	2.5
Mongar	2.9	Trongsa	3.1
Paro	1.6	Tsirang	2.1
Pemagatshel	4.2	Wangdue Phodrang	1.9
Punakha	2.0	Zhemgang	3.9

(Source: NLC "Land information at a glance"
http://www.nlcs.gov.bt/wp-content/uploads/publications/landinfo.pdf (as of March 2018)



1 decimal = approx. 1/100 acre (40.46 m²)

(Source : NLC "Land information at a glance" (May 2018))

Figure 10-7 Per Capita Land Holding Size

(f) Education and Health

Basic education in Bhutan is free for 11 years. It is common and traditional, in rural areas, to send children to temples for schooling and provide them with literacy education through non-formal programs. The central school system was introduced in 2014 as part of the country's education reform, where boarding facilities, school uniforms, meals and stationery are provided for free, and this attracts parents in rural and remote areas and gives them incentives to send their children to school.

According to the 2017 PHCB, however, the national literacy rate remains at 71.4%. Examining the area-wise indicators, the figure is 63.6% in rural areas, lower than the 84.1% in urban areas. Gender-wise, the male literacy rate is 78.1 whereas the female literacy rate is 63.9%, lower than the male figure. In terms of the age-wise literacy rate, the 10 to 14 years old bracket is the highest, at 98.4%. There is a tendency for the literacy rate to drop with age. The literacy rate of those over 65 years old is very low, at 22.9%.

In terms of health, facilities and networks of health and medical institutions have been expanded to a large extent. Thanks to the government's long-term efforts in improving and modernizing its health and medical care services, a referral system comprised of primary care service facilities (Basic Health Units (BHU), where medical doctors and assistants are deployed), secondary care service facilities (District Hospitals), and tertiary care service facilities (National Referral Hospital in the capital Thimphu and Regional Referral Hospitals in a few major districts) have been well developed. Outreach Clinics (ORCs), which doctors visit periodically, have also been built in areas with poor access to BHUs. As of 2017, 95% of the total population now have access to medical facilities within a three-hour-walking distance[26].

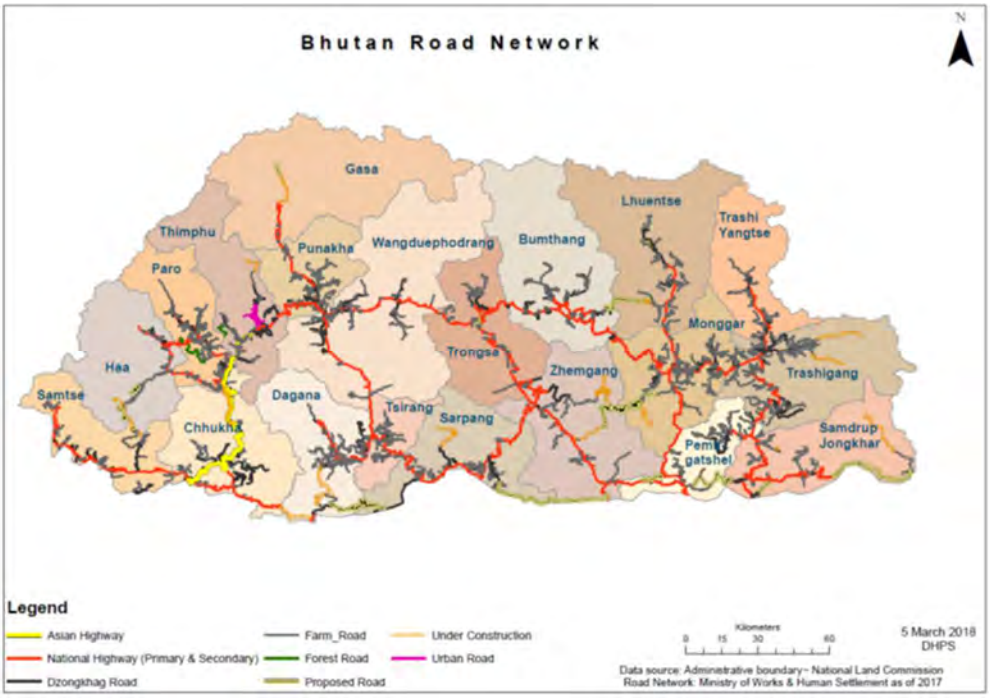
However, the disparity between urban and rural areas remains severe. The infant mortality rate in PHCB 2017 at the national level is 15.1 infants per 1,000, whereas those of urban and rural areas are 12 and 17 respectively. Examining the under-five mortality rate, the difference becomes larger, at 25.3 in urban areas and 40.8 in rural areas. This implies that the difference in health facilities and service quality is large between urban and rural areas.

Though the absolute number is relatively low, HIV infections have been growing in recent years as 38, 32 and 548 cases were detected in 2000, 2013 and 2017 respectively[27]. Of the total number of cases, nearly 50% are concentrated in Thimphu and Phuentscholing, 52% are male, and 34 cases among children below 15 years have been confirmed. UN agencies have analyzed that the increase of HIV incidents in Bhutan has been caused by rapidly expanding economic activities, the growth of tourism and the domestic transportation system, inflow of foreign laborers, and unsafe heterosexual practices[28]. As for tuberculosis (TB), more or less 1,000 people were infected every year from 2013 to 2017, and 929 incidents were confirmed in 2017[29]. Patients have mostly been admitted to the National Referral Hospital (JDWNRH in Thimphu), and District Hospitals in Phuentscholing and Gelephu[30].

(g) Road network

Total road length in Bhutan as of 2016 is approximately 12,000km, of which national road is approximately 2,850km, Dzongkhag road is approximately 2,600km and farm road is approximately 5,000km. The main road network is shown in Figure 10-8.

26 Statistical Yearbook of Bhutan 2018 (National Statistics Bureau)
27 ELEVENTH FIVE YEAR PLAN 2013-2018, UN System Common Country Analysis (Bhutan) 2018.
28 UN Common Country Analysis (Bhutan) 2018.
29 Annual Health Bulleting 2018 (Ministry of Health)
30 Statistical Yearbook of Bhutan 2018 (National Statistics Bureau)



(Source：Prepared by DHPS, as of March, 2018)

Figure 10-8 Main Road Network in Bhutan

【Living Status Statistics】

(h) Poverty Rate and Gini coefficient

The national household poverty rate in 2017 as published by NSB was 5.7%, which decreased dramatically from 23.2% in 2007 over the past 10 years. The urban household poverty rate fell to 0.48% (2017) from 1.4% (2007) and the rural household poverty rate reduced to 8.65% (2017) from 31.1% (2007). It can be considered that this drastic reduction in the poverty rate was attributable to the development of infrastructure such as roads, electricity, communications, water supply, sanitation facilities, etc., and the implementation of poverty countermeasures such as the Rural Economy Advanced Programme (REAP), which grants houses and support for agriculture, and the National Rehabilitation Programme, which grants land.

As shown in Table 10-11, however, there are still regional differences in the household poverty rate. Dagana still registers more than 20% and Dagana, Mongar, Pemagatshel, and Zhemgang more than 10%, relatively higher than the national average. In terms of the distribution of the number of poor people by Dzongkhag, more than 10% in the country are concentrated in Dagana and Mongar. Comparing the Gini coefficient, which shows inequality in income distribution, it has increased slightly to 0.38 (2017) from 0.33 (2007). This implies that inequality in income distribution has advanced.

Table 10-11 Household Rate by Dzongkhag (2017)

Dzongkhag	Poverty Rate (%)	Dzongkhag	Poverty Rate (%)
Bumthang	1.7	Samdrup Jongkhar	4.5
Chhukha	2.2	Samtse	8.5
Dagana	23.7	Sarpang	8.4
Gasa	7.4	Thimphu	0.3
Haa	1.1	Trashigang	7.8
Lhuntse	5.2	Trashiyangtse	8.7
Mongar	14.0	Trongsa	9.6

Dzongkhag	Poverty Rate (%)	Dzongkhag	Poverty Rate (%)
Paro	0.2	Tsirang	2.6
Pemagatshel	10.1	Wangdue Phodrang	3.0
Punakha	1.8	Zhemgang	16.3

(Source: NSB "Poverty analysis Report 2017", p35)

(i) Gross National Happiness (GNH) Index

According to the results of the GNH survey 2015 by the Center for Bhutan Studies & GNH Research (CBS), the National GNH Index[31] is 0.756, which increased from 0.743 in the survey in 2010. Comparing GNH index by Dzongkhag (Table 10-12), Gasa, Bumthang, Thimphu and Paro, which have low household poverty rates, are higher and Dagana and Mongar, which have high poverty rates, and Trashiyangtse and Trongsa, which have relatively high household poverty rates, show a lower GNH Index. However, Pemagatshel, which has a high household poverty rate, shows a relatively high GNH Index and Zhemgang, which has a relatively high household poverty rate, shows a mid-level GNH Index. Thus, correlation of GNH Index with the household poverty rate cannot be identified in general.

Table 10-12 GNH Index by Dzongkhag (2015)

High GNH Index		Middle GNH Index		Low GNH Index	
Gasa	0.858	Punakha	0.758	Wangdue Phodrang	0.721
Bumthang	0.816	Sarpang	0.745	Trashigang	0.716
Thimphu	0.803	Zhemgang	0.745	Dagana	0.715
Paro	0.792	Samtse	0.743	Mongar	0.703
Haa	0.784	Samdrup Jongkhar	0.740	Trashiyangtse	0.702
Pemagatshel	0.777			Trongsa	0.693
Tsirang	0.776				
Lhuntse	0.773				
Chhukha	0.772				

(Source: Center for Bhutan Studies & GNH Research "A Compass towards a Just and Harmonious Society-2015 GNH Survey Report" p.65)

(j) Gender

Assessing the gender inequality index by the United Nations Development Programme (UNDP) 2015, Bhutan has a relatively low rank, at 110th among 188 countries. In the gender indicator ranking by the World Economic Forum[32], Bhutan is 124th among 144 countries. The health, survival, and political empowerment indices are relatively low.

In the GNH Index by gender, the male GNH Index is 0.793, which is higher than the female GNH Index of 0.730. The female GNH Index, however, has improved during the past 5 years, compared to a figure of 0.695 in 2010.

[31] Compound Index which consists of 9 domains in relation to: (1) Psychological Wellbeing, (2) Health, (3) Education, (4) Cultural Diversity and Resilience, (5) Time Use, (6) Good Governance, (7) Community Vitality and Resilience, (8) Ecological Diversity and Resilience, (9) Living Standard

[32] World Economic Forum "Global Gender Gap Report 2017"

10.2.2 Organizations related to the Environment

The main administration organizations for Environmental and Social Considerations and their main roles in Bhutan are shown in the following table, and their outlines are described below.

Table 10-13 Major Government Agencies, NGOs and their Roles related to Environmental and Social Considerations

No.	Field	Name of Administrative Organ/NGO	Main Role
1	Environmental impact assessment	National Environment Commission	Planning and activities concerning environmental conservation. Jurisdiction for EIA/SEA and planning and activities related to climate change
2	Conservation of biodiversity and forests	Department of Forest and Park Services (Ministry of Agriculture and Forests)	Planning and activities related to the management of protected areas
3	Conservation of landscape and traditional culture	Department of Culture (Ministry of Home and Cultural Affairs)	Planning and activities for preservation of cultural heritage
4	Land acquisition and compensation	National Land Commission	Planning and activities concerning land registration and management, leasing and acquisition
5	Conservation of natural environment (general)	Trust Fund for Environmental Conservation	Financial support for nature conservation activities
		NGO: WWF	Ecosystem conservation, planning and activities for wildlife conservation
		NGO: Royal Society for Protection of Nature	Ecosystem conservation, planning and activities for protecting wildlife (especially birds)
6	Social development assistance	NGO: Tarayana Foundation	Social development assistance for poor rural areas

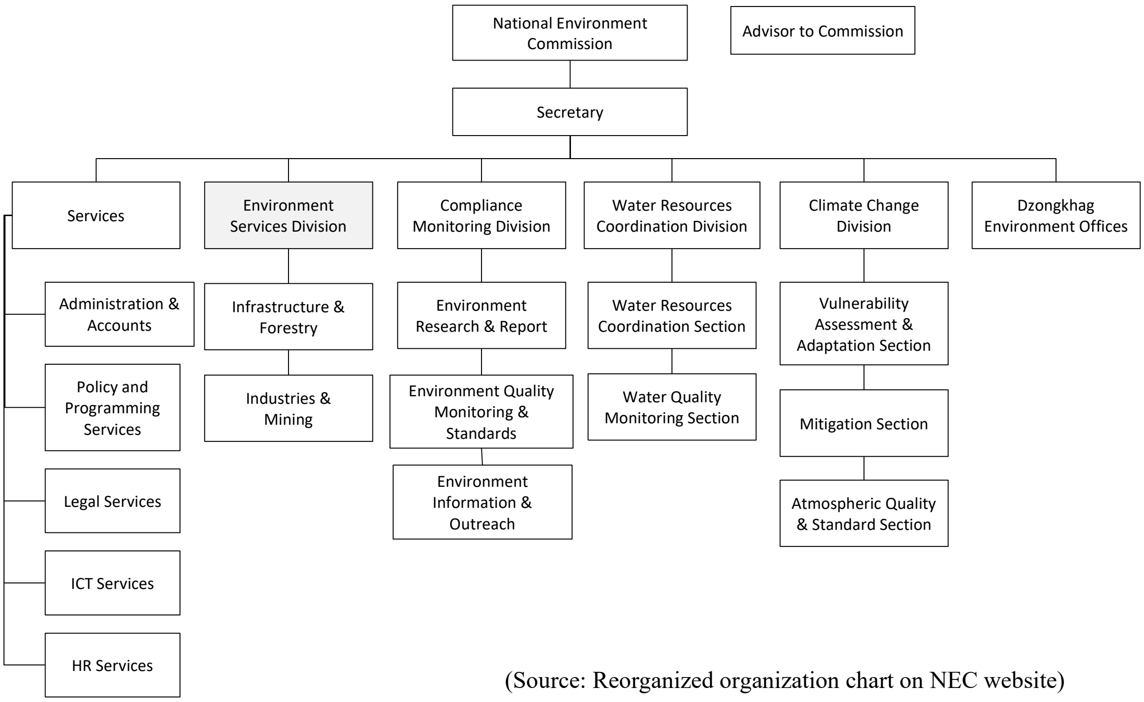
(Source: JICA Survey Team)

(1) Organization related to Environmental Impact Assessment

The National Environment Commission (NEC) has jurisdiction over the implementation of environmental impact assessments (EIA and SEA) in Bhutan. The authority and role of NEC are stipulated by the National Environment Protection Act (2000), which is the nation's highest decision body on environmental management. The outline is as follows.

- Develop policies, plans, and programs
- Raise environmental awareness
- Mainstream the environment into planning processes
- Monitor compliance
- Undertake research and collect data
- Coordinate and facilitate implementation of environmental policies

The organization chart for NEC is shown in the figure below. Environmental impact assessments are handled by the Environment Services Division (shaded in the figure below).



(Source: Reorganized organization chart on NEC website)
(http://www.nec.gov.bt/nec1/index.php/about-nec/organogram/)

Figure 10-9 NEC Organization Chart

(2) Organization related to Biodiversity Conservation/Forest protection

The ministry responsible for biodiversity conservation and forest protection is the Department of Forests and Park Services, Ministry of Agriculture and Forests.

(3) Ministry responsible for Protection of Landscape and Cultural Heritage

The ministry responsible for protection of the landscape and cultural heritage is the Department of Culture, Ministry of Home and Cultural Affairs. DOC has been developing a set of databases for cultural properties, which NLC has plotted into a digital map. However, the number of cultural heritage sites is higher than DOC has calculated since there are numerous sites recognized solely by local communities. DOC is trying to collect all the information through local administration offices, but this process has not been completed as of March 2019.

(4) Organization related to Land Acquisition and Compensation

Issues related to land acquisition, lease and payment of compensation are under the jurisdiction of the National Land Commission (NLC). In the procedure for land acquisition, the Dzongkhag Acquisition and Substitute Land Allotment Committee prepares a report in relation to land acquisition within Dzongkhags other than urban areas. For urban land, the Thromde/Throm Land Acquisition and Allotment Committee is in charge of preparing the report on land acquisition. Notification to land owners about the land acquisition is done by the Dzongkhag committee for areas other than urban land and by the executive secretary of the Thromde/Throm committee for land within urban areas. Valuation of acquired land is done by the Property Assessment and Valuation Agency under the Ministry of Finance. It is mandatory to hold local consultations in order to hear from local people prior to project implementation.

(5) Institutions and roles related to the conservation of the natural environment

Foundations and CSOs are active in conservation activities for the natural environment in Bhutan. The Trust Fund for Environmental Conservation is one body that provides financial support for the conservation of nature. The WWF and the Royal Society for the Protection of Nature, assisted by royal family members, are among those that develop plans and implement activities for ecosystem preservation and the protection of wildlife.

(6) Institutions and their roles related to social development

Foundations and CSOs are also active in social development work in the country. Among them is the Tarayana Foundation, which was established by royal family members in 2003, and registered as a public organization with the Civil Society Organization Authority in 2010. Tarayana is working on the awareness raising of local communities through self-help groups, capacity development, improvement of access to basic needs and housing, and provision of microcredit programs.

(7) Outline of the environmental and social considerations divisions within organizations related to hydroelectric power development

- Division in DHPS
  The Survey, Socio-Environment & Investigation Section conducts affairs to acquire environmental clearance etc. related to hydroelectric power generation.
- Division in DGPC
  Under the Project Department is Druk Green Consultancy, within which there is an Environmental and Social Unit, with 6 people. Its main tasks are: (1) environmental monitoring at power plants in operation, (2) environmental assessment surveys and CDM surveys for power plants at the planning stage, and (3) participation in government-related environmental working groups.
- Division in BPC
  The Environment & GIS Division has 13 people - 10 related to the environment, and 3 in charge of GIS. Its main tasks are: (1) Environmental and Social Impact Studies, and (2) Implementation of environmental monitoring for power transmission lines in operation in line with the environmental management plan.

10.2.3 Legislation Relevant to the Environment

(1) The Constitution, Gross National Happiness, The 11th Five-Year Plan

The Constitution states that Buddhism is the spiritual heritage of Bhutan in Chapter 3 and mentions preserving, protecting and promoting the cultural heritage of the country in Chapter 4. Chapter 5 mentions protecting and conserving the natural resources of Bhutan. It also states that a minimum of 60% of total land shall be maintained under forest cover at all times and that the Parliament may, by law, declare any part of the country to be a protected area. In the second section of the "Basic obligations of the Bhutanese people", in Chapter 8 of the Constitution, it states “to preserve, protect and respect the national natural environment, culture and heritage”.
Regarding environmental social considerations, Gross National Happiness (GNH) stipulates that it is important to consider the impact on nature and the social environment as one of the four pillars. Furthermore, the 11th Five-Year Plan (2013 - 2018) describes the four pillars of GNH, programs to deal with environmental and social considerations, climate change countermeasures, anti-poverty measures, gender-related issues, etc.

(2) National Environment Strategy and National Environment Protection Act

In accordance with the National Environment Strategy formulated in 1998, the National Environment Protection Act, which was the basic environmental law in 2007, was enacted.
An outline of the National Environment Protection Act is as follows.[33]

- Principles of application to environmental protection
- The Constitution, functions, and powers of authority under the National Environment Commission (NEC)

[33] Review and Compendium of Environmental Policies and Laws in Bhutan, ADB 2014.

- Protection of environmental quality by managing hazardous substances, environmental pollutants, and managing waste
- Protection of forests, biodiversity, and ecosystem integrity
- The rights to environmental information and citizen participation
- Procedures for environmental inspections, verification, enforcement, and penalties

(3) Environmental Impact Assessment: EIA

Prior to the National Environmental Protection Act, the Environment Assessment Act was enacted in 2000, prescribing the implementation of environmental assessment and project approval procedures for various projects. Furthermore, the following provisions and guidelines are in place, and Bhutan's Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) processes are being developed.

- Regulation on Environmental Clearance of Projects, 2016.
- Regulation on Strategic Environmental Assessment, 2001.
- Environmental Assessment General Guidelines, 2012. In 2012, guidelines for the seven sectors of forestry, expressway/road projects, hydroelectric power generation, industry, mining, tourism, and power transmission lines were also established.
- National Guidelines for Strategic Environmental Assessment in Bhutan: at the planning stage, to be finalized in 2018.

(4) Environment Clearance Acquisition

When applying for environment clearance for NEC, according to Application for Environmental Clearance: Guidelines for Hydropower 2004, agreement documents (namely the “No Objection Certificate” approval document), as shown in Table 10-14, are to be obtained. There are also some cases which do not require certification.

Table 10-14 No Objection Certificate Necessary for Environmental Clearance (Approval)

Agencies/people to issue NOC Note	Why/When
Dzongkhag/City Corporation	Administrative Approval from Dzongkhag
Department of Forests	If pasture ground (Tsamdo) is damaged or acquired.
Department of Forests	If forest for collecting twigs and leaves for compost is damaged or acquired.
Department of Culture	If project site is located within 50m of cultural or religious facilities.
Nature Conservation Division	If project site is located within boundary of protected areas.
Municipal Authority	If project site is located within 50m of a public park.
Private Land Owner	If project site is located within 50m of a human dwelling.
Private Property Owner	If the project needs to acquire private property.
Department of Health	If project site is located within 50m of a hospital.
Department of Education	If project site is located within 50m of a school.
Department of Energy	If the project requires relocation of power transmission lines.
Bhutan Telecom Authority	If the project requires relocation of telephone lines.
Department of Roads	If the project require access from highway or feeder roads.

Note: It should be noted that titles of agencies are those from 2004; thus, their names may now have changed.

(5) Electricity Act enacted in 2001

In the Electricity Act enacted in 2001, the following two of the seven objectives are set as ones for environmental and social considerations.

iii) develop the socio-economic welfare of the people; and,

vi) take environmental considerations into account when developing the electricity supply industry

The Electricity Act is scheduled to be revised at the end of 2017[34].

(6) Environmental standards

NEC established water quality standards, industrial waste water standards, sewage drainage standards, air quality standards, industrial exhaust standards, workplace exhaust standards, vehicle exhaust standards and noise standards in 2010 and water quality standards for drinking water in 2016. (See Appendix)

(7) Regulations for Protection of Landscape and Cultural Heritage

The Constitution stipulates the promotion of protection of traditional culture, "to preserve, protect and respect the nation's natural environment, culture and heritage" as a basic obligation of the people.
There is a law called The Movable Cultural Property Act 2005, which stipulates rules for the registration of movable cultural heritage properties, exhibitions outside of the country, preservation and restoration, etc.
As of March 2019, the draft Cultural Heritage Bill is under appraisal. The contents of the draft bill comprehend the Movable Cultural Property Act 2005 and stipulate registrations and the development of databases for not only movable but immovable properties, cultural landscape impact assessments, management plans, buffer zones and risk mitigation plans for designated heritage sites, and the restriction of work on registered and designated heritage sites. The draft bill also mentions the roles and responsibilities of related organizations such as the Cultural Heritage Committee, and the Cultural Heritage Fund, which are responsible for protecting cultural heritage properties, and Dzongkhag Administration and Gewog Offices. It is however unknown when the draft will pass cabinet approval.

(8) Regulations for Conservation on Biodiversity

In Chapter 8, the Constitution considers "the preservation, protection and respect of the national environment, culture and heritage of the state" a basic obligation of the people. An important point regarding the natural environment in Bhutan is that not only protected areas are subject to conservation - the natural environment outside protected areas is also subject to conservation.
Strategies and regulations concerning conservation of biodiversity include the following.

- National Biodiversity Strategies and Action Plan, 2014: Biodiversity conservation in Bhutan is to be promoted with 20 national goals set. The following two items can be cited as targets (Targets) related to this project - (1) National Target 7: Areas under agriculture and forestry, including rangeland are managed through the adoption of sustainable management practices, ensuring conservation of biological diversity; (2) National Target 11: The current Protected Area System is maintained with enhanced management effectiveness and financial sustainability.
- Biodiversity Act of Bhutan, 2003: Conservation of all biodiversity is prescribed.
- National Forest Policy, 2010: Forest conservation, and management policies for protected areas are prescribed.
- Forest and Nature Conservation Act of Bhutan, 1995: Forest conservation, and management policies for protected areas are prescribed.
- Preservation of natural resources related to forests and wildlife (the provision of natural reserves is also in this Act) is prescribed. Revised in 2006.
- Forest and Nature Conservation Rules of Bhutan, 2006: Regulations of the Forest and Nature Conservation Act (2006).

(9) Other environment-related domestic laws

Other environmental laws, etc. listed in the table below have been developed as domestic laws.

[34] From interview with DHPS

Table 10-15 Other Environment-related Domestic Laws

No.	Name of Law	Related Institution
1	Forest and Nature Conservation Rules and Regulations of Bhutan, 2017	Ministry of Agriculture and Forests
2	Rules on Biological Corridor, 2006	Ministry of Agriculture and Forests
3	Water Act of Bhutan, 2011	National Environment Commission
4	Water Regulation 2014	National Environment Commission
5	Waste Prevention and Management Act, 2009	Ministry of Works and Human Settlement
6	Waste Prevention and Management Regulation, 2012	Ministry of Works and Human Settlement
7	Disaster Management Act, 2013	Ministry of Home and Cultural Affairs

(Source: JICA Survey Team)

(10) Minimum Environmental Flow from dams or weirs

Minimum Environmental Flow is determined by Water Regulations 2014 as follows.

The minimum environmental flow to be maintained in a watercourse to sustain its water ecology and environment will be based on the Environmental Impact Assessment (EIA) report. Where scientific study reports are unable to determine the minimum environmental flow to be maintained in a watercourse, at least 30 % of lean season flow shall be maintained.

However, concerning the maintenance flow rate, NEC is developing maintenance flow guidelines with the support of the Austrian government[35].

(11) Regulations for Land Acquisition and Compensation

There are laws and regulations to be referred to in relation to land acquisition and resettlement, as below:

(a) Land Act 2007

This covers land registration, issuance of land ownership right certificates ("thram"), disputes over land, amendment of land use purposes, and land purchases and sales. Its 7th chapter states that the government is allowed to acquire registered private land for the purpose of public benefits.

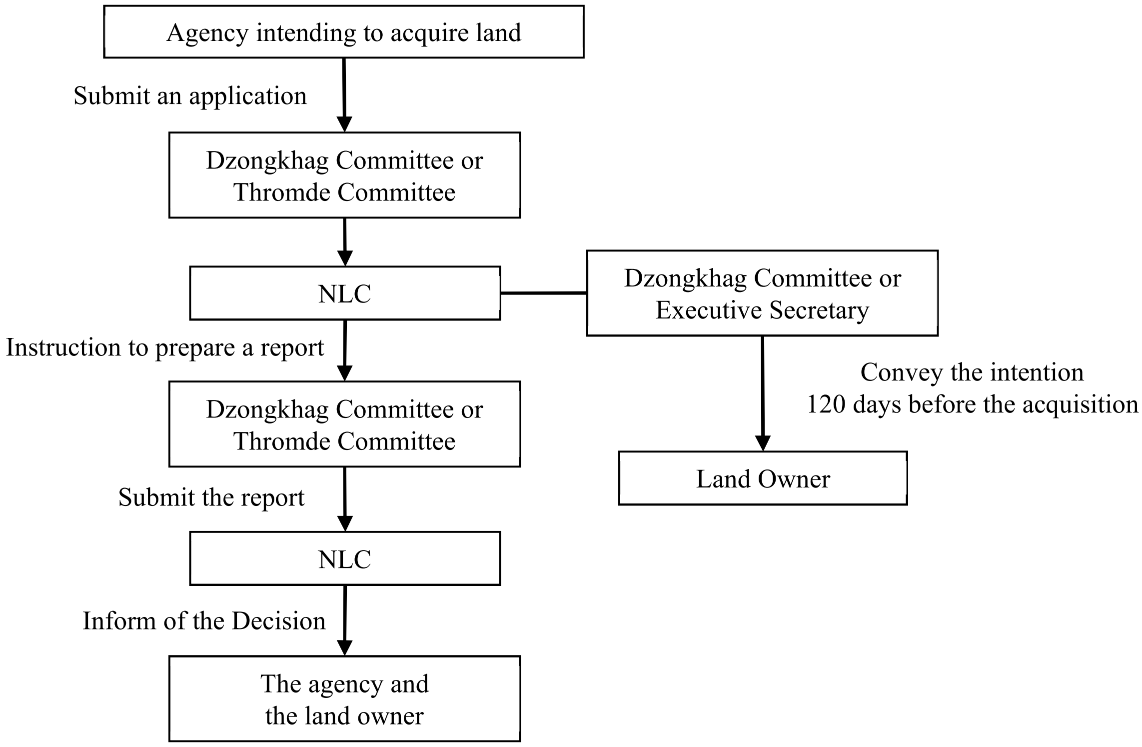
(b) Land Rules and Regulations, 2007

The Rules and Regulations describe procedures for the issues mentioned in the Act 2007, and the roles and duties of relevant organizations. Procedures concerning land acquisition are explained in Chapter 7, "Land Acquisition, Compensation and Allotment". In the procedure for land acquisition, the Dzongkhag Acquisition and Substitute Land Allotment Committee prepares a report in relation to land acquisition within Dzongkhags other than urban areas. As for urban land, the Thromde/Throm Land Acquisition and Allotment Committee is in charge of preparing the report for land acquisition. Notification to land owners about the land acquisition is done by the Dzongkhag committee for areas other than urban land and by the executive secretary of the Thromde/Throm committee for land within urban areas. Land acquisition is conducted based on Article 158 of the Land Act 2007 after completing the compensation procedure for land owners. The Land Acquisition Procedure flow is shown in Figure 10-10.

During the land acquisition procedure, if there are any claims from local people, the aforementioned Dzongkhag or Thromede/Throm Committee attends to them. If local people live in an area unregistered under NLC, these committees conduct a survey and examine whether they can have land ownership or user rights. If they are socially vulnerable people, such as those who are beneath the poverty line under the Kidu system, which is unique to Bhutan, the King of Bhutan can grant them the land.

[35] From interview with NEC on Dec.18, 2017, and http://www.entwicklung.at/en/projects/detail-en/project/show/study-on-minimum-on-environmental-flow-for-hydro-power-projects-in-bhutan/

Regarding compensation, for planned land acquisition sizes under 0.1 acre, it is done via cash, not by provision of substitute land. For planned land acquisition sizes more than 0.1 acre, compensation is via provision of substitute land or cash. In the case of substitute land, in general it is to be within the same Gewog. If there is no appropriate land for substitution, other Gewog within the same Dzongkhag are investigated. The compensation rate is the official one determined by the Property Assessment and Valuation Agency (PAVA). Currently, PAVA refers to Land Compensation Rates 2017 and the market transaction rate is not used.



(Source: prepared by JICA survey team in reference to Land Rules and Regulation (2007))

Figure 10-10 Procedure for Land Acquisition

(c) Land Compensation Rates 2007

This stipulates the compensation rates for dry land (*kamzhing*) and wet land (*chhuzhing*) in urban and rural areas, cash crop land (*ngultho durmra*) and farm land. It also refers to issues for consideration during valuation and provides a guideline on compensation rates for buildings.

(d) Land Lease Rules and Regulations 2018

This provides rules and regulations for temporary, short-term and long-term land leases, organizational structures for valuation, and conditions by lease purpose. It also allows them to lease out a plot of state reserve forest land for leaf litter production and collection. Among the projects mentioned in these Rules and Regulations are hydropower facilities, renewable energy projects and associated transmission systems. Land leases for such power and energy projects shall be done through Dzongkhag Land Lease Committees, and the project proponents are required to conclude an agreement with the Dzongkhag Administration.

There is no particular act regarding resettlement in Bhutan. Instead, the above acts and regulations related to land, and others such as the Environmental Assessment Act (2000), stipulate that discussion with local residents is obligated upon land acquisition and resettlement for project implementation, and thus the government agencies attempt to implement land acquisition and resettlement through consultation with local people as much as possible.

Based on the above acts and regulations, the land ownership is summarized in the table below.

Table 10-16 Land Ownership in Bhutan

Land Ownership	Modality	Conditions
Private	Freehold (thram)	Land owned by individuals that is mentioned as private registered land in the Land Act 2007. Once the land is registered, it can be owned perpetually. However, it can be targeted for land acquisition for public projects as mentioned in Chapter 7 of the Act 2007.
Government	Leasehold	Land leased out to individuals and corporations, etc. Lease period is up to 30 years, but this can be renewed. Land for power stations is often in the form of "leasehold".
	Use-right	Land provided with a use-right. This form is applied to land for government agency buildings. There is no limitation on the period of use-right, but if the entity with the use-right does not actually use the land, the use-right can be transferred to another entity.
	State Forest Land	All land other than private, "leasehold" and "use-right" land. This is mentioned as "Government Reserved Forest" in the Land Act 2007.

(Source: Land Act 2007, and interview with NLC (7 April 2017))

(12) Other social considerations-related domestic laws

Other social considerations-related domestic laws include the Child Care and Protection Act, 2011 (Related Institution: National Commission on Women and Children) and Labour and Employment Act, 2007 (Related Institution: Ministry of Labour and Human Resources).

(13) International Convention on Environmental Protection

Table 10-17 shows the main international environmental conventions to which Bhutan is a member.

Table 10-17 International Conventions on Environmental Protection

No.	Name of Convention	Year of Ratification
1	Convention on Wetlands of International Importance especially as Waterfowl Habitat	2012
2	Convention Concerning the Protection of World Cultural and Natural Heritage	2001
3	Convention on International Trade in Endangered Species of Wild Fauna and Flora	2002
4	Convention on Biological Diversity	1995
5	United Nations Framework Convention on Climate Change	1995
6	Convention on the Elimination of All Forms of Discrimination against Women	1981
7	United Nations Convention on the Rights of the Child	1990
8	Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal	2002

(Source: Website of each convention)

- Three locations are registered as Ramsar site wetlands[36].
  - ✧ Bumdeling
  - ✧ Gangtey-Phobji
  - ✧ Khotokha

- Bhutan is a member of the World Cultural and Natural Heritage Convention, but there is no registered World Natural Heritage yet. The provisional list submitted to UNESCO by the country includes the following eight places[37].

[36] "List of Wetlands of International Importance: Published August 6, 2018"
[37] http://whc.unesco.org/en/states parties/bt, accessed on August 13, 2018

<Cultural Heritage>

- ✧ Ancient Ruin of Drukgyel Dzong (2012)
- ✧ Dzongs: the centre of temporal and religious authorities (Punakha Dzong, Wangdue Phodrang Dzong, Paro Dzong, Trongsa Dzong and Dagana Dzong) (2012)
- ✧ Sacred Sites associated with Phajo Drugom Zhigpo and his descendants (2012)
- ✧ Tamzhing Monastery (2012)

<Natural Heritage>

- ✧ Royal Manas National Park
- ✧ Jigme Dorji National Park
- ✧ Bumdeling Wildlife Sanctuary
- ✧ Sakteng Wildlife Sanctuary

- In relation to the United Nations Framework Convention on Climate Change, Bhutan made the following commitments in the INDC (Intended Nationally Determined Contribution) submitted to the United Nations in 2015: “In order to maintain carbon positive measures and maintain forest areas covering approximately 70% of the state, endeavoring to manage forest resources, strengthen the law on forest protection, prevent land degradation, soil improvement, and disseminate organic agriculture.”

10.3 Legislative background for implementation of SEA

10.3.1 Legislation on Environmental Impact Assessment (SEA, IEEand EIA)

(1) Approval Procedures for Strategic Environmental Assessment (SEA)

The Environmental Assessment Act (2000) and the Regulation for the Strategic Environmental Assessment (2001) provide for the implementation of strategic environmental assessment (SEA) on policies, plans and programs and procedures for approval. However, detailed procedures like the EIA ones are not stated in the Regulation.

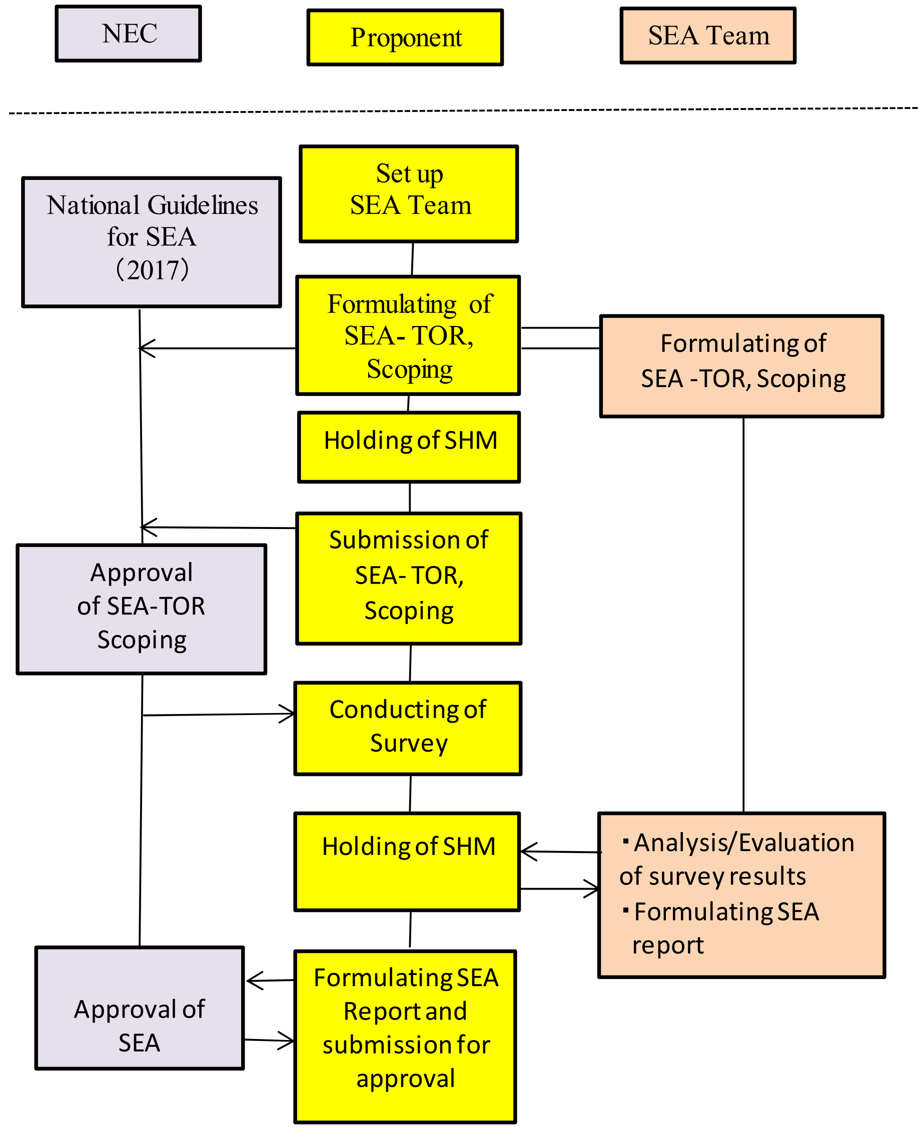
A draft of the National Guidelines for SEA (2017) describing detailed procedures has been formulated and is awaiting promulgation. However, even before the promulgation, the government has agreed to implement SEA for large-scale national projects[38], based on which implementation of SEA at the Master Plan formulation stage is required, with approval from NEC also required.

The Regulation on Strategic Environmental Assessment 2001 does not provide detailed procedures, such as those for EIA, but the process for receiving approval from NEC on the SEA is shown in the National Guideline for Strategic Environmental Assessment in Bhutan 2017.

The concrete procedures for receiving SEA approval from NEC are as follows.

(1) Organizations seeking to obtain NEC's approval on SEA shall establish an "SEA team" consisting of organizations related to environmental and social considerations, and shall formulate a "Terms of Reference" and "Scoping" (hereinafter referred to as SEA-TOR). (2) With regard to the SEA-TOR formulated, the opinions of stakeholders, which includes participants such as relevant residents, are reflected in this SEA-TOR, and approval is applied for from NEC. (3) After NEC's approval of the SEA-TOR, the proponent conducts the necessary natural and social environmental survey. (4) After explaining the results of the survey, forecast and evaluation to the Stakeholders, an SEA report reflecting the opinions of the Stakeholders will be used for application to NEC for SEA approval (see Figure 10-11).

[38] National Guidelines for Strategic Environmental Assessment in Bhutan (2017), 2.2.4 Regulation on Strategic Environmental Assessment, 2002



(Source: JICA survey team-created based on National Guideline for Strategic Environmental Assessment in Bhutan 2017)

Figure 10-11 SEA formulation Flow

(2) Procedures for Environmental Impact Assessment (EIA)

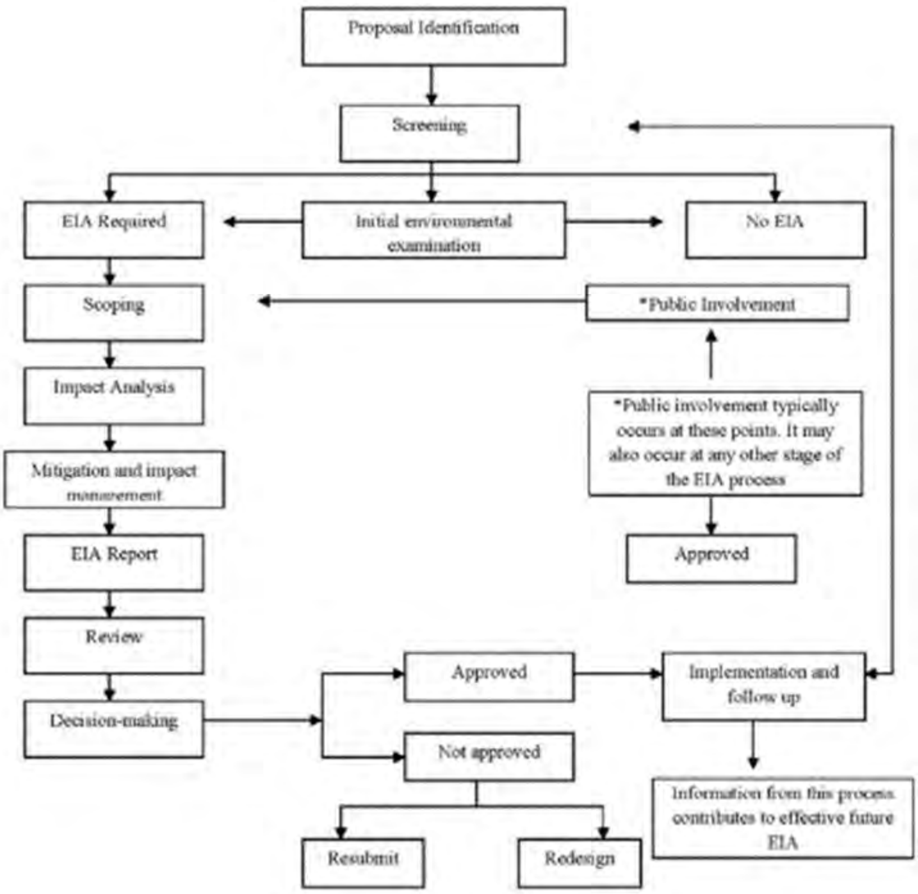
(a) Legislation

The Environmental Assessment Act (2000) and the Regulation for Environmental Clearance of Projects (2016) stipulate the implementation of EIA and its approval procedures for various projects[39].

(b) Procedures for implementation of EIA

The actions concerning EIA are carried out under the flow shown in Figure 10-12 based on the Environmental Assessment General Guidelines (2012).

39 In the Environment Assessment Act (2002), all actions are stated as "Environment Assessment (EA)" and there are no clear definitions of "Environmental Impact Assessment (EIA)" and "Initial Environmental Examination (IEE)". However, the Environmental Assessment General Guidelines (2012) describes them separately. In this report, all assessments are described as "EIA".



(Source: Environmental Assessment General Guidelines (2012))

Figure 10-12 Procedures for the Implementation of EIA

Table 10-18 shows the periods required for various actions for EIA until approval.

Table 10-18 Periods required for various Actions for EIA

Action	Time Limit
Registration and acknowledgement of an application by Secretariat/Competent Authority	Within 2 days from the receipt of an application
Competent Authority forwards application to Secretariat for non-listed projects	Within 7 days from the date of completion of assessment of adequacy of the application
Screening of a project to determine the level of environmental assessment required	Within 1 month
Decision making • Whether Environmental Impact Assessment (EIA) is required or not • Additional information required or not • Issuance or denial of Environmental Clearance if EIA is not required	Within 2 months after completion of screening
If screening determines that an Environmental Impact Assessment is required, the level and time frame for the assessment will be determined through negotiation between the relevant parties and approved by the Secretariat	Time frame to be negotiated
Submission of additional information sought for projects requiring Environmental Impact Assessment	Within 1 year from the date of request for additional information

Action	Time Limit
Submission of additional information sought for projects not requiring Environmental Impact Assessment	Within 3 months from the date of request for additional information
On approval of the clearance, a legal undertaking with the proponent of new projects to comply with the EA Act, 2000	Within 7 days from the date of decision
Response on the environmental clearance decision	Within 7 days from the date of decision
Public notification on the decision by the Secretariat/Competent Authority	Within one month from the date of decision
Appeal on the decision	Within 10 days from the date of publication of public notification
Preparation of monitoring program by Secretariat and Competent Authority	Quarterly
Preparation of monitoring program (along with detailed implementation Plan) by Holder	Within 3 months from the issuance of Environmental Clearance
Submission of application for renewal of Environmental Clearance	Before 3 months prior to its expiry date
Renewal of Environmental Clearance	Prior to expiry of Environmental Clearance
Report on the implementation of the EA Act, 2000 and its regulation to the National Environment Commission by the Secretariat and Report on the implementation of the EA Act, 2000 and its regulation to the Secretariat by the Competent Authorities	Annually

(Source: Regulation for Environmental Clearance of Projects (2016))

10.3.2 Differences between domestic laws in Bhutan and JICA guidelines on SEA

The table below shows the differences between the domestic laws of Bhutan and the JICA guidelines for environmental and land acquisition and resettlement, and the proposed implementation policy for this SEA.

Table 10-19 Differences between JICA Guidelines and Bhutanese Laws and Regulations concerning Land Acquisition

<table>
<tr><th>No.</th><th>JICA Guideline</th><th>Difference from the Bhutanese Laws and Regulations</th><th>SEA Implementation Policy for this Project</th></tr>
<tr><td>1</td><td>Involuntary resettlement and loss of means of livelihood are to be avoided when feasible by exploring all viable alternatives. (JICA GL)</td><td rowspan="3">National Land Commission prioritizes avoiding land owned by individuals.

According to the Environment Assessment Act Law (2000) and other laws, impacts caused by involuntary resettlement are to be minimized.

Targets for compensation are land ownership, buildings, fruit trees/trees, etc.</td><td rowspan="4">Purpose of this project is to formulate the master plan; so land acquisition does not occur during the process.

Respective candidate power development project sites listed in the master plan may require the acquisition of land from private individual owners (further details are uncertain in this project; EIA for each project development site discusses them and proposes countermeasures.)

As described above-left, the Bhutanese government (National Land Commission) has indicated a policy of avoiding acquiring land owned by private individuals as much as possible.</td></tr>
<tr><td>2</td><td>When population displacement is unavoidable, effective measures to minimize impact and to compensate for losses should be taken. (JICA GL)</td></tr>
<tr><td>3</td><td>People who must be resettled involuntarily and people whose means of livelihood will be hindered or lost must be sufficiently compensated and supported, so that they can improve or at least restore their standard of living, income opportunities and production levels to pre-project levels. (JICA GL)</td></tr>
<tr><td>4</td><td>Compensation must be based on the full replacement cost as far as possible. (JICA GL)</td><td>In Bhutan, compensation amount is calculated by the land compensation rate (2017), determined by Property Asset and Valuation Agency compensation amount.</td></tr>
</table>

No.	JICA Guideline	Difference from the Bhutanese Laws and Regulations	SEA Implementation Policy for this Project
5	Compensation and other kinds of assistance must be provided prior to displacement. (JICA GL)	Land acquisition is completed after cash compensation and substitute land have been provided for the landowner.	In conclusion, the land acquisition policy for this project is as follows: ➢ When evaluating the respective project development sites, resettlement is to be avoided or minimized and development within national land is to be considered first. ➢ During the field surveys at the respective project development sites (Oct. 2018 to Mar. 2019), relevant local authorities and local residents were interviewed. Their comments are to be reflected in the plan as far as possible. ➢ When evaluating respective development plans, if land acquisition and involuntary resettlement are predicted, a compensation plan is proposed that includes informal residents at sites, based on the JICA guidelines. ➢ When evaluating respective development plans, if land acquisition and involuntary resettlement are predicted, a compensation plan is proposed to assure compensation amounts, including for informal residents at the sites.
6	For projects that entail large-scale involuntary resettlement, resettlement action plans must be prepared and made available to the public. (JICA GL)	There are no laws which stipulate resettlement. Rehabilitation of livelihood is not always adequately followed-up on at present. Thus, NLC considers fair compensation an important issue. Environmental Assessment General Guidelines (2012) propose formulation of a resettlement and rehabilitation plan when resettlement is predicted, as part of preparing mitigation measures and an environment monitoring plan for socio-economic impacts.	
7	In preparing a resettlement action plan, consultations must be held with the affected people and their communities based on sufficient information made available to them in advance. (JICA GL)		
8	When consultations are held, explanations must be given in a form, manner, and language that are understandable to the affected people. (JICA GL)		
9	Appropriate participation of affected people must be promoted in the planning, implementation, and monitoring of resettlement action plans.		
10	Appropriate and accessible grievance mechanisms must be established for the affected people and their communities. (JICA GL)	Generally, the government implements meetings to explain matters sufficiently and brief people on the necessity of land acquisition and compensation. Claims from landowners are admitted. Environmental Assessment General Guidelines (2012) recommend formulating a resettlement and rehabilitation plan, including a grievance mechanism.	
11	Affected people are to be identified and recorded as early as possible in order to establish their eligibility through an initial baseline survey (including population census that serves as an eligibility cut-off date, asset inventory, and socioeconomic survey), preferably at the project identification stage, to prevent a subsequent influx of outside encroachers who wish to take advantage of such benefits. (WB OP 4.12 Para. 6)	The Bhutanese laws and regulations do not stipulate a cut-off date; however, importance is placed on consultation with the local people.	
12	Eligibility for benefits includes the PAPs who have formal legal rights to land (including customary and traditional land rights recognized under law), the PAPs who don't have formal legal rights to the land at the time of the census but have a claim to such land or assets and the PAPs who have no recognizable legal right to the land they are occupying. (WB OP 4.12 Para. 15)	The Bhutanese laws and regulations do not stipulate compensation for informal residents; however, importance is placed on consultation with the local people.	

No.	JICA Guideline	Difference from the Bhutanese Laws and Regulations	SEA Implementation Policy for this Project
13	Preference should be given to land-based resettlement strategies for displaced persons whose livelihoods are land-based. (WB OP 4.12 Para. 11)	With regard to compensation, if the land to be acquired is less than 0.1 acre, it is acquired via cash compensation, not via substitute land. If such land is 0.1 acre and above, land acquisition is conducted via the provision of substitute land or cash compensation. When providing substitute land, in general, land in the same Gewog is to be sought. If there is no appropriate substitute land in the same Gewog, land in another Gewog (within the same Dzongkhag) is sought.	
14	Provide support for the transition period (between displacement and livelihood restoration). (WB OP 4.12 Para. 6)		
15	Particular attention must be paid to the needs of the vulnerable groups among those displaced, especially those below the poverty line, the landless, the elderly, women and children, ethnic minorities etc. (WB OP 4.12 Para. 8)	No regulations stipulate measures for socially vulnerable people; however, the government pays attention to them based on the concept of Gross National Happiness.	
16	For projects that entail land acquisition or involuntary resettlement of fewer than 200 people, abbreviated resettlement plan is to be prepared. (WB OP 4.12 Para. 25)	Formulation of a resettlement plan is not stipulated in the Bhutanese laws and regulations, so no resettlement plan or Abbreviated Resettlement Action Plan (ARAP) is prepared in accordance with the number of resettled residents. However, the Environmental Assessment General Guidelines (2012) propose the formulation of a resettlement and rehabilitation plan in cases where resettlement is predicted, as part of preparing mitigation measures and an environment monitoring plan for socio-economic impacts.	

（Source：JICA Survey Team）

Table 10-20 Differences between JICA guidelines and Bhutanese guidelines concerning SEA

JICA Guideline		Legal System in Bhutan	Policy for SEA
Basic Items	Main contents		
1. Underlying Principles	Environmental impacts that may be caused by projects must be assessed and examined at the earliest possible planning stage.	The Environmental Assessment Act (2000) and the Regulations for Strategic Environmental Assessments (2001) provide for the implementation of strategic environmental assessments (SEA). A draft of the National Guidelines for SEA (2017) has been formulated.	SEA for MP2040 will be formulated based on a draft of the National Guidelines for SEA (2017).
	Alternatives or mitigation measures to avoid or minimize adverse impacts must be examined and incorporated into the project plan.	The Environmental Law clearly states that environmental impacts are to be predicted and evaluated based on scientific research, negative impacts are to be avoided, and technical alternatives and mitigation measures are to be considered.	Consider alternatives and mitigation plans that avoid and minimize environmental and social impacts through field surveys, interviews with stakeholders, and stakeholder meetings.
2. Examination of Measures	1) Multiple alternatives must be examined in order to avoid	The environmental law stipulates that technical	Multiple alternatives will be considered to select the optimum

JICA Guideline		Legal System in Bhutan	Policy for SEA
Basic Items	Main contents		
	or minimize adverse impacts and to choose better project options in terms of environmental and social considerations. In the examination of measures, priority is to be given to the avoidance of environmental impacts; when this is not possible, minimization and reduction of impacts must be considered next. Compensation measures must be examined only when impacts cannot be avoided by any of the aforementioned measures.	alternatives should be considered, even if the project is not implemented.	plan in terms of environmental and social considerations through reviews of existing materials, confirmations during field surveys, and interviews.
	2) Appropriate follow-up plans and systems, such as monitoring plans and environmental management plans, must be prepared; the costs of implementing such plans and systems, and the financial methods to fund such costs, must be determined. Plans for projects with particularly large potential adverse impacts must be accompanied by detailed environmental management plans.	Environmental management plan is required for the purpose of reviewing mitigation measures or compensation for negative impacts.	Appropriate follow-ups, such as environmental management plans and monitoring plans to be considered during the implementation of EIA, will be suggested.
3. Scope of Impacts to Be Assessed	1) The impacts to be assessed with regard to environmental and social considerations include impacts on human health and safety, as well as on the natural environment, which are transmitted through air, water, soil, waste, accidents, water usage, climate change, ecosystems, fauna and flora, including trans-boundary or global scale impacts. 2) In addition to the direct and immediate impacts of projects, their derivative, secondary, and cumulative impacts, as well as the impacts of projects that are indivisible from the project, are also to be examined and assessed to a reasonable extent.	Qualitative and quantitative examination of physical, biological, socioeconomic and cultural impacts is to be implemented based on environmental laws. In particular, it is specified that the impact on the basin (cumulative environmental impact assessment) should be taken into account.	The impacts to be assessed with regard to environmental and social considerations include impacts on human health and safety. In addition to the direct and immediate impacts of projects, their derivative, secondary, and cumulative impacts, as well as the impacts of projects that are indivisible from the project, are also to be examined and assessed to a reasonable extent.
4. Compliance with Laws, Standards, and Plans	1) Projects must comply with the laws, ordinances, and standards related to environmental and social considerations established by the governments that have jurisdiction over project sites (including both national and	Environmental standards concerning water quality, noise, vibrations, etc. are enforced at the level of laws and resolutions, and there is an obligation to comply with these standards.	Comply with environmental standards.

JICA Guideline		Legal System in Bhutan	Policy for SEA
Basic Items	**Main contents**		
	local governments).		
	2) Projects must, in principle, be undertaken outside of protected areas that are specifically designated by laws or ordinances for the conservation of nature or cultural heritage. Projects are also not to impose significant adverse impacts on designated conservation areas.	Development is prohibited in the core zone of protected areas, but other zones allow development based on the degree of environmental impact.	In principle, the core zones of protected areas are excluded from the project sites.
5. Social Acceptability	Projects must be adequately coordinated so that they are accepted in a manner that is socially appropriate to the country and locality in which they are planned.	The environmental law states that a public hearing needs to be held.	Obtain agreement through stakeholder consultations and interviews with stakeholders.
6. Ecosystem and Biota	Projects must not involve significant conversion or significant degradation of critical natural habitats and critical forests.	National parks, wildlife sanctuaries, strict nature reserves, and biological corridors are designated as protected areas. Such areas are divided into three zones (core, buffer, multiple-use) and managed. For the core zone, development is strictly regulated. To protect ecosystems and biota, domestic laws designate precious animals and plants as protected animal and plant species. For these protected animals and plants, the EIA to be conducted at the project implementation stage will predict and evaluate the impact on them due to the project, and appropriate environmental conservation measures will be taken as necessary.	In principle, the core zones of protected areas are excluded from the project sites.
7. Monitoring	After projects begin, project proponents etc. monitor whether any unforeseeable situations occur and whether the performance and effectiveness of mitigation measures are consistent with the assessment's prediction. They then take appropriate measures based on the results of such monitoring.	The Environmental Law clearly mandates the preparation of an environmental management plan to ascertain the implementation status and effects of mitigation measures planned in advance and consider appropriate measures based on the results.	It is proposed to consider appropriate follow-up plans and systems, such as monitoring plans, costs and procurement methods at the EIA implementation stage.

（Source：JICA Survey Team）

10.3.3 "Without Project" Option

In Bhutan, there are already enough power generation facilities, exceeding demand, and there will be no shortages in the domestic power supply even without implementing this project. It is thus not required to consider alternatives such as development of other power generation facilities or the purchasing of power from other countries. However, there are three issues to be taken into consideration if DHPS goes with the “without project” option:

(1) Impact on the National Finances

Hydropower generation is regarded as one of the promising public natural resources in Bhutan, and electricity sale to other countries is the traction of its economic growth. Operation of the prioritized hydropower projects in this Master Plan will be after 2031, when the RGOB shall repay the construction costs by making use of revenue generated over 20 years. In the year 2050 and later, upon completion of repayment, RGOB will receive approximately Nu. 30 billion per year from this project (equivalent to 55% of the 2018 National Budget, on a 2018 real price base). This means the project will create Nu. 40,000 for each person in the country. Without the project, budgets for basic needs (public welfare, education, etc.) and the amount of social capital such as roads and bridges will shrink and living standards will likely be affected.

(2) Impacts on Local Area Development

Hydropower projects are often implemented in areas that have not been developed yet. It is expected that they (particularly large-scale hydropower development projects that require thousands of construction workers’ residing there for years) will be associated with social infrastructure improvements such as access road development and the establishment of medical facilities. Enhancement of the regional economy through the creation of employment opportunities and sales increases in agriculture products are also expected. Delays in local area development are a concern if this project is not implemented, as it is often the case that the development of less-developed areas in Bhutan depends on large-scale infrastructure development.

(3) Impact on Global Environment

The project will not emit CO_2 at all when generating power. Most of the power generated in this project will be transmitted to India, where thermal power generation can be restrained. Without the project, it is estimated that the amount of CO_2 emissions in India will keep increasing by 20 million tons per year (which is equivalent to approximately 1% of the amount in 2015).

10.3.4 Scoping

(1) Environmental Assessment Method of PSMP2003

Since they developed PSMP2003, DHPS has applied Multi Criteria Analysis (MCA), in which sub-criteria are examined from technical, economic, social, environment and development aspects and given weights according to the importance of each aspect to produce comprehensive scores. Candidate project sites are compared with each other to understand the pros and cons of each site and to rank which the best option is in the given context.

This Master Plan survey has followed the same method to assess the environmental and social impacts in the SEA process, since MCA is familiar to the Bhutanese side and its quantitative analysis can ensure objectivity for all stakeholders.

(2) Basic Idea of MCA Evaluation Items

As a result of intensive discussions with Bhutanese counterparts, MCA evaluation items were examined based on the following:

(a) Appropriate and effective evaluation items shall be selected at the SEA stage

The viability of comparison among candidate sites in an effective manner has been examined. Upon analyzing the impact items, the appropriateness of evaluation item selection and considerations from environmental and social aspects have been reviewed in accordance with the safeguard policies of international organizations, including the JICA Guidelines for Environmental and Social Considerations.

(b) Selection of evaluation items reflecting Bhutanese context

The appropriateness of evaluation items has been examined based on the socioeconomic conditions, natural environment and technical capability of Bhutan, and rising awareness on the environment in recent years.

(3) Selection of Environmental and Social Consideration Items for MCA Evaluation

The following process was applied when evaluation items were selected:

(a) Confirmation of environmental and social impact items that shall be examined at Master Plan stage

MCA evaluation criteria were examined by taking into account whether they would make it possible to compare candidate sites in an effective manner, in a Bhutanese context. The impact items described in the JICA Guidelines were also thoroughly reviewed as shown in Table 10-21. For water quality and waste, it was raised in the 2nd SEA Task Force/WG meeting that they were not appropriate as MCA criteria because similar mitigation measures will come out for all projects. They have thus been deleted from the MCA criteria with the stakeholders' consent. Those items which are excluded from this survey shall be examined at the time of EIA.

Table 10-21 Major Scoping Items and Survey Direction

Type	No.	Check Items	To be Surveyed or not and its Reasons	
Pollution Control	1	Air Pollution	To be not surveyed	Measures will be required during the construction period, but same across all projects, so it cannot be said to be effective in comparing candidate sites.
	2	Water Quality	To be not surveyed	Measures will be required during the construction/operation period, but same across all projects, so it cannot be said to be effective in comparing candidate sites.
	3	Waste	To be not surveyed	Ditto
	4	Soil Contamination	To be not surveyed	Ditto
	5	Noise and Vibration	To be not surveyed	Ditto
	6	Land Subsidence	To be not surveyed	It may occur due to the construction of underground structures, but details are unknown at the comparison stage of the candidate sites, and it is difficult to consider measures. Moreover, it cannot be said that it is effective in comparison of a candidate sites.
	7	Odor	To be not surveyed	Measures will be required during the construction period, but same across all projects, so it cannot be said to be effective in comparing candidate sites.
	8	Sediment	To be surveyed	As the project implementation may have a huge impact, it will be evaluated in terms of natural environment together with topography and geology.
Natural Environment	9	Protected Areas	To be surveyed	Since there is a possibility that implementation of the project will have a huge effect, it is important to compare the necessity of protection between the candidate sites during the scoping phase. Therefore, it is evaluated in the natural environment item.
	10	Ecosystem	To be surveyed	Since there is a possibility that it will be seriously affected by the implementation of the project, it is evaluated in the natural environment item.
	11	Hydrology	To be surveyed	Since there is a possibility that it will be seriously affected by the implementation of the project, it is evaluated in the natural environment item.
	12	Topography/ Geology	To be surveyed	Since it is assumed that there will be effects from topographic changes and reduction of sand supply to downstream due to the implementation of the project, and that there will be possibilities to compare the superiority/inferiority of the candidate spots due to the difference in the geological conditions, topography/ geology is evaluated in the natural environment item.

Type	No.	Check Items	To be Surveyed or not and its Reasons	
Social Environment	13	Land Acquisition/ Resettlement	To be surveyed	The land acquisition and its scale, and the possibility of resettlement can be compared among candidate sites. Thus, this item is evaluated in the social environment item.
	14	Poor People	To be surveyed	If negative impacts among local people can occur due to the project's implementation, impacts on the poor, who are economically vulnerable people, can be significant. Thus, this item is evaluated in the social environment impacts items.
	15	Ethnic Minorities/ Indigenous People	To be surveyed	If negative impacts among local people can occur due to the project's implementation, groups living with traditional culture and values can be impacted significantly. Thus, this item is evaluated in the social environment impacts items.
	16	Regional Economy such as local employment and livelihood means	To be surveyed	While there is a possibility of the loss of existing livelihood means, etc., potential for employment and creation of new livelihood means is high. Thus, not only impacts on the social environment, but also regional development effects are evaluated.
	17	Use of the land and local resources	To be surveyed	It is predicted that there will be changes in land use and impacts on the regional economy, so this is evaluated in the social environment items.
	18	Water Use	To be surveyed	There is a possibility that there will be impacts on water use and irrigation water, so this is evaluated in the social environment.
	19	Existing social infrastructure and social services	To be surveyed	It is expected that there will be development of the road network and improved access to other areas from the project area due to the project's implementation.
	20	Social Capital and Local Decision-Making Institutions	To be not surveyed	There is a possibility that there will be impacts on social capital and local institutions through construction and operation periods, but it will not be of difference among projects. Thus, this item is not evaluated as effective for comparison among candidate sites.
	21	Misdistribution of Benefits and Damages	To be not surveyed	There is a possibility that the project may cause misdistribution of benefits and damages through construction and operation periods, but this item is not evaluated as effective for comparison among candidate sites.
	22	Local Conflict of Interests	To be not surveyed	Ditto
	23	Cultural Heritage	To be surveyed	Registered cultural sites and heritage sites can be affected, so this is evaluated in the social environment.
	24	Landscape	To be surveyed	There is a possibility that the local landscape may be damaged due to the project's facilities and it is necessary to pay attention to the scenery along tourist routes. Therefore, this is evaluated in the natural environment item.
	25	Gender	To be not surveyed	There is a possibility that the project may affect through construction and operation periods, but this item is not evaluated as effective for comparison among candidate sites.
	26	Children's Rights	To be not surveyed	Ditto
	27	Infectious Diseases	To be not surveyed	It is required to take countermeasures against infectious diseases during construction period, but the measures are of similar ones in all projects. Thus this item is not evaluated as effective for comparison among candidate sites.
	28	Labor Environment including Occupational Safety	To be not surveyed	Ditto
Others	29	Accidents	To be not surveyed	Ditto
	30	Cross-boundary impact and Climate Change	To be surveyed	Based on the hydropower priority project finally selected, its effect will be calculated when formulating the development plan up to 2040.

(Source: JICA survey team)

(b) Matters of particular concern based on the current situation in Bhutan

1) Protected Area

In Bhutan, the protected area is divided into three zones, ①core, ②buffer, ③multiple-use, and managed in principle from the viewpoint of protection and utilization. In this project, the above three zones are regarded as protected areas in the JICA guideline, and the candidate sites in the core zone are excluded, and for the other zones, the evaluation points in the MCA will be lowered depending on the degree of environmental loads to consider adoption as a candidate site. In addition, since the biological corridor is not classified and managed by zoning, it was uniformly evaluated by MCA. Furthermore, on development in the protected area, it is assumed that all of the five conditions (see 10.6.2, Table 10-32) will be fulfilled based on “Frequently asked questions (July 20, 2011, revised February 5, 2016) on the environmental and social considerations guidelines”.

2) Climate change measures

In INDC (Intended Nationally Determined Contribution) submitted to the UN by Bhutan (September 15, 2015), Bhutan adheres to carbon positive (emission carbon dioxide is less than absorbed carbon dioxide) measures and continues actions such as implementation of forest sink management, prevention of land degradation, soil improvement, spread of organic farming to maintain the forest area covering about 70% of the nation.
In addition, CO_2 emissions can be reduced by transmitting surplus power to neighboring countries such as India. In this study, CO_2 reduction effect is calculated in case all the hydropower priority project sites finally selected were developed. (see 8.3)

3) The Poor and Indigenous People

Potential sites for hydropower plants are likely located in mountainous and forest areas, where local people often drink spring water, collect NTFPs, and use footpaths. The project implementation may cause adverse impacts such as losses of livelihood means for individuals and households, rights to live in forests, or ownership or use-rights of community forests, which severely hit economically vulnerable people represented by the poor. Thus, it has carefully been reviewed whether there were poor people or indigenous people when evaluating socially adverse impacts such as land acquisition, resettlement, and losses of livelihood means.

4) Gross National Happiness

This SEA is putting emphasis on the GNH concept as described in 2.1 (1) and staying coherent with it.

(c) Examination of MCA evaluation criteria examined in this survey

Based on the above (a) and (b), those criteria presently applied by DHPS were examined to carefully choose the ones to be applied in this survey and give them weights. The finalized criteria and weights are shown in Table 7-63. The following table shows a comparison of the MCA criteria presently applied by DHPS, scoping items according to the JICA Guidelines, and those finally applied in this Master Plan survey.

Table 10-22 Comparison of MCA Criteria between Presently Applied Ones and PSMP's

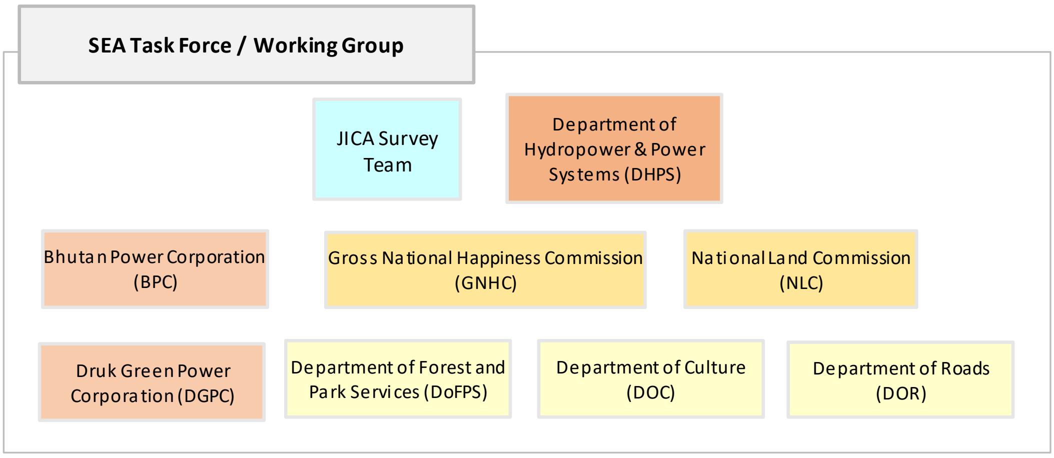
MCA Criteria presently applied by DHPS			Scoping Items in Table 10-21	Scoping Items in the PSMP 2040	
No.	Criteria	Sub-criteria		Sub-criteria	Remarks/Evaluation Items
3.1	Social	Improved access	19. Existing Social Infrastructure and Social Services	Improved access to socioeconomic benefits	・ One of the positive impacts generated by project, which shall be considered in the “Development” criteria.
3.2		Access to reliable power supply	N/A	N/A	・ It shall be excluded considering the recent improvement in electrification rates.

MCA Criteria presently applied by DHPS			Scoping Items in Table 10-21	Scoping Items in the PSMP 2040	
No.	Criteria	Sub-criteria		Sub-criteria	Remarks/Evaluation Items
3.3		Employment benefits	16. Regional Economy such as Local Employment and Livelihood Means	Income opportunities for low-income areas	・ One of the positive impacts generated by project, which shall be considered in the "Development" criteria.
3.4		Rehabilitation & Resettlement	13. Land Acquisition/ Resettlement 14. Poor People 15. Ethnic Minorities /Indigenous People 17. Land Use and Local Resources 18. Water Use	・ Acquisition of private land ・ Resettlement and asset loss ・ Negative impact on lifestyle and livelihood means	・ "Rehabilitation" is one of the countermeasures against negative impacts caused by project, which shall not be among scoping items. ・ Not only resettlement, but land acquisition, loss of assets and livelihood means, and changes in living environment shall be raised as negative social impacts.
3.5		Tourism	N/A	N/A	・ It shall be integrated into other scoping items as socioeconomic benefits such as access improvement, job creation and livelihood; improvements are expected through other activities too.
-	-		23. Heritage	Cultural heritage	・ No. of cultural properties and heritage sites shall be examined, no matter if they are registered or not, when selecting project sites.
-	Environmental		24. Landscape	Impact on Landscape	・ Negative impacts on landscape at tourism spots and routes caused by project facilities including transmission lines.
4.1		Intrusion into protected areas	9. Protected Area	Located in protected areas	・ Affected areas in core zones, buffer zones and multiple-use zones
4.2		Loss of primary forest		Loss of primary forest	・ Loss of forest area and the affected biodiversity
4.3		Dewatering impacts		Loss of wetland	・ Loss of wetland areas, and their importance
			10. Ecosystem 11. Hydrology	Loss of endangered species	・ Loss of habitat areas and number of endangered species
4.4		Access road erosion	12. Topography/ Geology 8. Sediment	Access road/dam site erosion	・ Length of road, geological conditions, etc.
4.5		Fish migration	10. Ecosystem	Fish migration	・ No. of fish species, etc.
5.1	Development	Balanced regional development	N/A	・ Improved access to socio-economic benefits ・ Income opportunities for low-income areas	・ "Well-balanced local area development" has been better specified ・ "Improved access to socio-economic benefits" has taken into consideration road access and network, and access to educational health facilities/services ・ "Income opportunities for low-income areas" considers no. of new jobs generated by project, increased sales of local products, and promotion of local markets ・ "Access to socioeconomic benefits" and "income opportunities for low-income areas" considers distance from dam and power plant.

(Source: JICA survey team)

10.3.5 Setting up of SEA Task Force/Working Group and its role

An SEA Task Force/Working Group (WG), which consists of agencies related to the Master Plan, has been set up. The members are as shown below.



(Source: JICA survey team)

Figure 10-13 SEA Task Force/WG Members

As seen in the following table, there have been SEA Task Force/WG meetings held four times up to January 2019, in which the TOR of SEA, scoping and MCA evaluation criteria were discussed. The discussion results have been reflected in the MCA criteria. The last one is expected in June 2019.

Table 10-23 Summary of SEA Task Force/WG Meetings

Sr.	Date & Time	Participants	Agenda & Discussion Topics
#1	14:30-17:00 March 6, 2018	4 (DHPS) 2 (BPC) 1 (DGPC) 1 (NLCS) 1 (DOFPS) 1 (DOC) 6 (JICA Survey Team)	• Concept of SEA Differences between SEA and EIA were presented from perspectives of planning level and project implementation level • Elaboration of TOR Report regarding SEA Methods to develop TOR for SEA were presented, followed by discussions among participants. <Handouts: SEA concept and experiences in other countries, draft TOR for SEA>
			【Main Topics】 • Timing of technical opinion input during SEA • Relevancy of SEA and MCA for each project • SEA taskforce/WG members excluding NEC
#2	May 16, 2018	3 (DHPS) 1 (BPC) 1 (DGPC) 1 (NLCS) 1 (DOFPS) 1 (DOC) 5 (JICA Survey Team)	• Scoping method • Selection method for site reconnaissance items, survey method, and analysis & evaluation method for site reconnaissance results were explained, followed by discussions among participants. <Handouts: Scoping draft, survey items, methods, schedule, prediction and evaluation method, checklist for site reconnaissance>
			【Main Topics】 • Socio-economic impacts caused by hydropower development projects • MCA items for natural and social environment (revising them to use more appropriate words, deleting indicators of endangered species, adding migratory fish and biological corridor items, discussing forest category items, etc.) • Review of weight of each MCA item • Unsettled boundaries of protected areas and zoning in the protected areas in relation to project sites

#3	10:00-13:00 November 7, 2018	8 (DHPS) 2 (BPC) 1 (DGPC) 1 (NLCS) 1 (GNHC) 1 (DOFPS) 1 (DOC) 5 (JICA Survey Team)	• Project site selection method • MCA scoring standards (for added items) • Site survey items and survey method <Handouts: progress on SEA survey, selection method, conditions for project identification, results of initial screening, screening and evaluation methods, outline of 1st site reconnaissance survey>
			【Main Topics】 • Score by voltage of transmission line for landscape • Important ecological systems outside of protected areas and biological corridors • Definition of wetland • Consideration of cultural landscape and holy sites • Socio-economic indicators at gewog level
#4	14:30-17:00 January 15, 2019	7 (DHPS) 1 (BPC) 1 (DGPC) 1 (NLCS) 1 (DOFPS) 1 (DOC) 4 (JICASurvey Team)	• Method for revising MCA items that reflect site reconnaissance results • MCA scoring standards (for added items) Revisions and additions to the 2nd site reconnaissance survey items and their evaluation methods were explained, based on the results of the 1st site reconnaissance survey (Nov to Dec 2018), followed by discussions among participants. <Handouts: progress on SEA survey, revised scoping items, selection method, results of primary screening, evaluation methods, outline of 2nd site reconnaissance survey>
			【Main Topics】 • Re-inclusion of endangered species indicators • Analysis of cultural heritage sites of national importance • Setting standards for agricultural land areas affected by the project • Consideration of scores for eco-tourism and handicraft production activities, etc. in social development criteria
#5	10:00-12:00 June 10, 2019	4 (DHPS) 1 (BPC) 1 (DGPC) 1 (NLCS) 1 (DOC) 6 (JICA Survey Team)	• Primary and secondary ranking of project candidate sites, short-listed sites and future development plans • MCA for natural and social environment considerations and social development • Examination of alternatives, cumulative impacts, and climate change • Environmental Considerations upon implementing EIA <Handouts: Results of project candidate site ranking, development plan, abstraction of SEA Draft Report>
			【Main Topics】 • Method for determining project candidate sites and their ranking • Information sources for MCA

(Source: JICA survey team)

10.3.6 Preparation of TOR and Scoping report on SEA, and approval by NEC

The TOR on SEA considered at the above SEA Task Force meeting was approved by NEC (approval number: NECS/EACD/SEA/2018/367) on August 15, 2018 (see Attachment 1).
The main items and outline of the TOR report on the SEA that was approved by NEC are as follows (for the full text, see Attachment 1).

(**BOX**)

Terms of Reference (TOR)
for Strategic Environmental Assessment (SEA)
for Project on Power System Master Plan 2040 in Bhutan
(Summary)

1. Introduction

2. Outline of the Project

3. Outline of the SEA for the Project

The objectives are:
-to integrate the Four Pillars of Gross National Happiness into the PSMP 2040;
-to facilitate sustainable harnessing of hydropower resources;
-to avoid, mitigate and minimize adverse environmental impacts and/or cumulative environmental impacts, and to enhance positive impacts; and,
-to strengthen and support implementation of environmental and social considerations at the planning stage.
The benefits are:
-to make the formulation process more effective in terms of better decision-making for evaluation of the PSMP;
-to create an opportunity for the Project Proponent (DHPS) and other stakeholders to experience the SEA process and understand its effectiveness in decision making;
-to consider Hydropower as a Priority Growth Area and to achieve country's theme 'Brand Bhutan'; and,
-to enhance the capacity of DHPS and other related agencies for undertaking the SEA.

4. Methodology and steps for implementation of the SEA

4.2 Scoping

4.2.1.1 Natural environment

(1) Information on protected areas designated by the RGOB, important areas under international treaties, and important areas identified by international NGOs
-National Parks
-Wildlife Sanctuaries
-Strict Nature Reserves
-Biological Corridors
-Ramsar Sites
-World Natural Heritage Sites (including proposed sites)
-Important Bird and Biodiversity Areas
-Other sensitive sites to be protected
(2) Information on Natural Environmental Features
-Flora
・General features of vegetation (e.g. primary forest)
・Habitats of endangered species (designated by IUCN)
・Habitats of endemic/rare species
-Fauna
・General features of fauna habitats (e.g. important habitats)
・Habitats/breeding of endangered species (designated by IUCN)
・Habitats/breeding of endemic/rare species (designated by the country's laws)
・Habitats/breeding of migratory fish species
・Habitats/breeding of migratory bird species (including flying routes on maps)
-Accumulative impacts due to hydro power development on Flora and Fauna for each river system
(3) Collection of existing information/data/reports on Climate Change impact, and on potentiality dangerous glacial lakes will be undertaken.

4.2.1.2 Social Environment

-General features of social environment
-Land use types, types of landownership
-Necessity of resident resettlement
-Numbers and types of cultural and religious heritage sites/remains, graves to be possibly affected including World Cultural Heritage sites (and proposed sites)
-Water-use in downstream area and its type
-Other activities by residents in the project area which are possibly affected by the project

4.3 Selection of project sites

Based on the survey items identified as a result of the scoping, social and environmental surveys will be conducted to collect more information. Project sites (i.e. potential hydropower development sites) will be evaluated and selected by applying Multi Criteria Analysis (MCA).

4.3.2 Multi Criteria Analysis

MCA will be used as a tool for the SEA. The criteria used in the MCA exercise will be well examined based on the results of the scoping and the surveys, and, if necessary, the criteria and other aspects may be modified. Different alternative scenario analyses will be conducted by assigning varying weights to each of the criteria. A scenario evenly weighted between Technical (Technical & Economic) and Social Environmental criteria will be presented as a Base Case, and the priorities of potential sites will be determined. Alternative scenario analyses will be conducted to determine the priorities of potential sites by changing the weights of the Technical and Environmental criteria.

4.3.3 Site Reconnaissance

Before the Secondary Ranking, approximately 30 sites identified by the Primary Ranking will be visited by DHPS and the JICA Survey Team. Two (2) teams of technical and environmental experts will visit the sites to investigate the conditions of each of them.

4.4 Stakeholder Meetings

The tentative schedule and major agenda items for the SHMs are shown in the table below:

Implementation period	Content
1st SHM (Dec.2017)	Explanation of the following issues and Q&A ・Outline of the Project ・Perceptions of environmental and social considerations during the SEA phase
2nd SHM (May2018)	Explanation of the following issues in draft and Q&A ・Outline of the Project & screening method for candidate sites ・Scoping for SEA - Survey items and methods - Evaluation method ・- Criteria for Multi Criteria Analysis
3rd SHM (Oct.2018)	Explanation of the following issues and Q&A ・Outline of the Semi-long List ・Results of Primary Ranking ・Outline of the Site Reconnaissance
4th SHM (Jun.2019)	Explanation of Draft Final Report and Draft SEA report, and Q&A ・Results of the Secondary Ranking ・Outline of the Short List ・Explanation of mitigation measures/monitoring

・・・

6. Work Schedule

The work is expected to start from December 2017 and be completed within 20 months.

(ends)

DHPS will proceed to submission of the SEA application for NEC's approval after all survey results are in hand and their analyses are complete, with NEC's guidance. So far, development of the draft SEA is planned for April 2019, and it is to be explained in the fourth SHM, scheduled for June 2019. Views and opinions collected at the SHM shall be reflected in the SEA Report, which shall be submitted to NEC within the same month.

10.3.7 SEA Report (Executive Summary)

The Executive Summary of the SEA Report submitted to NEC by DHPS is as follows.

Executive Summary

1. Study Purpose and Scope

In the process of formulation of the Power Master Plan 2040 (PSMP 2040) in Bhutan, Strategic Environmental Assessment (SEA) was conducted for potential project sites (69 sites) excluding those which are found difficult to develop in terms of environmental and social considerations, among which development priorities were examined with alternative scenarios.

2. Methodology

SEA in this survey is an environmental assessment that targets higher-level plans that provide a framework for the later planning and implementation of individual projects at EIA Stage. Therefore, at the stage of formulating the MP, the development prioritization of potential hydropower sites was determined with due consideration not only to technical and economic but also to environmental, social and development aspects by adopting multi criteria analysis (MCA) method.

Evaluation criteria were reviewed with different weights in desktop survey (Primary Screening) and field survey (Secondary Screening). Started by the TOR development, the implementation of SEA was carried out in collaboration with the SEA Task Force Team / Working Group consisting of relevant government organizations throughout the MP.

3. Scoping

Scoping items have been examined by taking into account if they could make it possible to compare among candidate sites in an effective manner in Bhutanese context. The scoping items described in the JICA Guidelines for Environmental and Social Considerations issued in April 2010 were also reflected into the survey scoping items as shown in Table-1.

Table-1 Environmental and Social Consideration Items to be Reviewed in the SEA

Type	No.	Items	Survey Item and its Reasons	
Natural Environment	1	Sediment	To be surveyed	As the project implementation may have a huge impact, it will be evaluated in terms of natural environment together with topography and geology.
	2	Protected Areas	To be surveyed	Since there is a possibility that implementation of the project will have a huge effect, it is important to compare the necessity of protection between the candidate sites during the scoping phase. Therefore, it is evaluated in the natural environment item.
	3	Ecosystem	To be surveyed	Since there is a possibility that it will be seriously affected by the implementation of the project, it is evaluated in the natural environment item.
	4	Hydrology	To be surveyed	Since there is a possibility that it will be seriously affected by the implementation of the project, it is evaluated in the natural environment item.
	5	Topography/ Geology	To be surveyed	Since it is assumed that there will be effects from topographic changes and reduction of sand supply to downstream due to the implementation of the project, and that there will be possibilities to compare the superiority/inferiority of the candidate spots due to the difference in the geological conditions, topography/ geology is evaluated in the natural environment item.
Social Environment	1	Land Acquisition/ Resettlement	To be surveyed	The land acquisition and its scale, and the possibility of resettlement can be compared among candidate sites. Thus, this item is evaluated in the social environment.
	2	Poor People	To be surveyed	If negative impacts among local people can occur due to the project's implementation, impacts on the poor, who are economically vulnerable people, can be significant. Thus, this item is evaluated as a social environment impact item.

Type	No.	Items	Survey Item and its Reasons	
	3	Ethnic Minorities/ Indigenous People	To be surveyed	If negative impacts among local people can occur due to the project's implementation, groups living with traditional culture and values can be impacted significantly. Thus, this item is evaluated as a social environment impacts item.
	4	Regional Economy such as local employment and livelihood means	To be surveyed	While there is a possibility of the loss of existing livelihood means, etc., potential for employment and creation of new livelihood means is high. Thus, not only impacts on the social environment, but also regional development effects are evaluated.
	5	Use of the land and local resources	To be surveyed	It is predicted that there will be changes in land use and impacts on the regional economy, so that this is evaluated in the social environment.
	6	Water Use	To be surveyed	There is a possibility that there will be impacts on water use and irrigation water, so that this is evaluated in the social environment.
	7	Existing social infrastructure and social services	To be surveyed	It is expected that there will be development of the road network and improved access to other areas from the project area due to the project's implementation.
	8	Cultural Heritage	To be surveyed	Registered cultural sites and heritage sites can be affected, so this is evaluated in the social environment.
	9	Landscape	To be surveyed	There is a possibility that the local landscape may be damaged due to the project's facilities and it is necessary to pay attention to the scenery along tourist routes. Therefore, this is evaluated in the natural environment item.
	10	Cross-boundary impact and Climate Change	To be surveyed	Based on the hydropower priority project finally selected, its effect will be calculated when formulating the development plan up to 2040.

(Source: JICA Survey Team)

4. Evaluation Criteria and Weights for MCA

MCA evaluation criteria based on scoping items were examined in this survey as shown Table-2. Evaluation Criteria are divided into three areas.

- Technical & Economic

Technical (Technical & Economic) criteria show the economic efficiency of the project as a whole. The "Economic" aspect is evaluated based on total project construction costs (including power transmission facilities), operation and maintenance (O&M) expenses, and electric energy expected to be generated. However, the numerical values, such as construction costs, O&M expenses, and generated electric energy, contain many uncertainties, and the variation risk is evaluated via "Technical" items based on the probability of variation and the impact when variation occurs.

- Impact on environment

When promoting large projects, adverse impacts caused by the development must be minimized as much as possible. If the adverse impacts are large, there is a possibility that the development will have to be abandoned due to residents' opposition to the project. For this reason, with regard to environmental items, impediment factors in promoting hydropower development are evaluated from the viewpoint of the natural and social environment, and projects with fewer impediments are preferentially selected.

- Social Development

In Bhutan, hydropower projects can help promote development of social capital in the target area, which not only directly benefit the region but indirectly benefit the entire country. In the process of selecting the priority projects, such 'development' effect is also an important factor as value addition.

For a base case, the weights of "Technical & Economic" and "Impact on Environment" are evaluated equally, and the weights of the above three items are 40% for "Technical & Economic", 40% for "Impact on Environment", and 20% for "Social Development". Projects to be evaluated include not only hydropower plants but also access roads and related power transmission facilities to be constructed in connection with the construction of power plants.

Table-2 MCA evaluation criteria

No.	Criteria	Sub-criteria		Weights	
1.1	Technical	Hydrological quality	30%	50%	40%
1.2		Geological risk	50%		
1.3		GLOF risk	5%		
1.4		Sedimentation risk	5%		
1.5		Site accessibility	5%		
1.6		Transmission line risk	5%		
2.1	Economic	Economic efficiency		50%	
3.1	Impact on Social environment	Land Acquisition	25%	50%	40%
3.2		Resettlement and Asset Loss	25%		
3.3		Living and Livelihood	20%		
3.4		Cultural Heritage	30%		
4.1	Impact on Natural Environment	Protected areas	40%	50%	
4.2		Loss of primary forest	35%		
4.3		Loss of wetland	10%		
4.4		Aquatic creatures (including Fish migration)	5%		
4.5		Access road/dam site erosion	5%		
4.6		Impact on Landscape	5%		
5.1	Social Development	Improved access to socioeconomic benefits	50%	100%	20%
5.2		Employment and potential for income opportunities	50%		

(Source: JICA Survey Team)

5. Evaluation method (Scoring)

Scoring for each item is evaluated with 5 grades, from 1 to 5, as shown below. In order to avoid different evaluations by different evaluators, evaluation scores are prepared based on numericalized data as much as possible. For items that are difficult to numericalize, standards for each score are expressed in concrete and detailed.For items with an adverse impact, the evaluation score is set to 0 points which leads to abandonment of the site. In such situations, the plan is re-evaluated in an attempt to avoid all 0 point items

Table-3 Evaluation Method (Scoring)

Score	Items with an advantageous impact	General items	Items with an adverse impact
5	Very big impact	Very good	No impact
4	Big impact	Good	Slight impact
3	Some impact	Average	A little impact
2	Slight impact	Bad	Some impact
1	No impact	Very bad	Irreversible impact
0	--	--	Abandon development

(Source: JICA Survey Team)

6. Identification of Sites to be carried out SEA

The total number of potential sites in Bhutan is 155 sites, out of which 39 sites (6 are the existing power plants, 13 are the earmarked projects, and 20 are with an installed capacity of less than 25MW) were excluded, and 116 sites remain.

Furthermore, out of the 116 potential sites 3 potential sites in which many resettlements are required, and 44 potential sites in which all the components of the project are located within a protected area were considered very difficult to realize project were excluded.

In total, development of 86 potential sites these projects was avoided and thus excluded from the list. The SEA was conducted for the 69 remaining candidate sites.

7. Result of Primary Screening

Through the primary screening using MCA, 37 sites were selected as priority development candidate sites and its score shown as below:

Table-4 Priority development candidate sites (Base Case)

Project Code	Name of Project	Installed Capacity (MW)	Annual Energy (GWh)	Technical	Economic	Impact on Social environ-ment	Impact on Natural environ-ment	Social develop-ment	Total	Rank
A-4	Kunzangling	897	3,816	15.3	20.0	20.0	10.6	6.0	71.9	9
A-5	Tingma	567	2,413	15.0	20.0	20.0	15.6	6.0	76.6	6
A-8	Dorokha	573	2,439	15.4	19.2	20.0	15.6	16.0	86.2	1
A-9	Ngatse	44	170	14.5	4.0	20.0	16.0	6.0	60.5	38
A-10	Sanglum	178	779	13.5	4.0	8.6	15.8	16.0	57.9	42
A-11	Dojengkha	25	105	12.9	4.0	20.0	15.8	16.0	68.7	17
A-12	Dolepchen	41	172	11.9	4.0	20.0	16.0	16.0	67.9	22
W-3	Dodennang	61	275	14.1	4.0	20.0	14.0	6.0	58.1	41
W-6	Chuzom	152	645	15.5	7.6	7.0	16.0	6.0	52.1	60
W-7	Getsa	37	152	12.9	4.0	20.0	10.6	16.0	63.5	36
W-8	Zangkhepa	73	305	13.4	8.0	20.0	14.0	16.0	71.4	10
W-13	Singkhar	38	165	14.0	4.0	9.6	17.4	6.0	51.0	65
W-14	Tsendu Goenpa	75	321	14.8	4.0	11.0	17.6	6.0	54.0	56
W-19	Pipingchhu	100	424	13.3	8.0	20.0	16.2	16.0	73.5	8
P-7	Puna Gom	127	543	16.1	4.0	20.0	11.4	6.0	57.5	46
P-15	Tamigdamchu	188	805	14.5	6.4	20.0	11.2	16.0	68.1	20
P-17	Tseykha	170	726	16.2	4.0	16.8	11.4	16.0	64.4	34
P-18	Jarona	43	179	11.6	4.0	20.0	12.8	6.0	54.4	55
P-19	Dangchhu	101	432	14.9	10.0	14.8	11.4	6.0	57.1	48
P-20	Rabuna	33	140	13.8	4.0	16.8	16.2	6.0	56.8	50
P-26	Thasa	680	3,277	15.0	16.8	20.0	16.6	6.0	74.4	7
P-28	Kago-1	102	436	14.6	20.0	20.0	11.8	16.0	82.4	3
P-29	Kago	58	249	13.5	4.4	20.0	12.0	6.0	55.9	54
P-30	Pinsa	151	644	13.2	20.0	20.0	12.0	6.0	71.2	11
P-33	Burichhu	40	170	14.1	4.0	20.0	16.6	16.0	70.7	13
P-34	Darachhu	61	259	13.6	5.2	20.0	16.4	14.0	69.2	16
P-35	Dagachhu-II	94	402	14.0	6.8	14.4	16.6	14.0	65.8	32
P-36	Pelichhu	52	222	13.7	4.0	9.6	16.4	14.0	57.7	45
P-38	Tashiding	81	347	12.0	5.6	20.0	16.4	14.0	68.0	21
M-5	Bemji	333	1,425	15.2	14.8	20.0	12.6	14.0	76.6	5
M-6	Jongthang	170	726	15.6	4.0	15.4	16.0	20.0	71.0	12
M-11	Wangdigang	446	1,907	14.5	12.0	15.4	11.2	14.0	67.1	24
M-14	Tingtibi	181	770	15.1	4.0	20.0	11.2	14.0	64.3	35
M-15	Gomphu	488	2,076	12.5	5.6	5.0	10.8	14.0	47.9	67
M-17	Buli	67	262	15.0	13.6	14.4	12.6	14.0	69.6	14
M-18	Nyekhar	43	183	15.2	4.0	20.0	13.0	14.0	66.2	30
M-19	Sermaling	496	2,171	13.7	7.2	8.0	10.8	20.0	59.7	40
C-3	Kurjey	89	381	14.5	4.0	8.6	14.2	16.0	57.3	47
C-4	Chhutoe	29	126	13.6	4.0	20.0	14.2	6.0	57.8	44
C-7	Chamkharchhu-IV	451	1,928	12.9	18.8	14.4	17.4	6.0	69.5	15
C-10	Chamkharchhu-II	456	1,936	14.7	20.0	14.4	16.0	20.0	85.1	2
K-13	Minjey	490	2,091	12.0	4.0	8.6	10.6	6.0	41.2	69
K-14	Unggarchhu	28	119	13.5	4.0	20.0	13.4	6.0	56.9	49
K-15	Phawan	502	2,185	14.5	4.0	9.6	12.8	6.0	46.9	68
K-19	Shongarchhu	32	138	12.1	4.0	18.4	11.6	14.0	60.1	39
G-3	Tshaling	204	876	14.4	4.0	5.0	9.2	16.0	48.6	66
G-4	Ranya	162	696	15.5	4.0	9.6	16.2	6.0	51.3	64
G-6	Khamdang	494	2,109	16.1	11.2	18.0	16.6	6.0	67.9	23
G-7	Gongri	590	2,515	15.6	4.8	9.6	15.8	6.0	51.8	61

Project Code	Name of Project	Installed Capacity (MW)	Annual Energy (GWh)	Technical	Economic	Impact on Social environ-ment	Impact on Natural environ-ment	Social develop-ment	Total	Rank
G-9	Gamrichhu-3	123	524	12.2	14.4	15.2	8.2	6.0	56.0	53
G-10	Gamrichhu-2	104	446	13.5	9.2	8.0	16.4	6.0	53.1	59
G-11	Gamrichhu-1	108	462	13.0	4.0	8.6	16.2	16.0	57.8	43
G-12	Rotpa	40	172	13.9	5.2	11.6	11.6	14.0	56.3	52
G-13	Sherichhu	53	227	12.2	4.0	20.0	16.6	14.0	66.8	26
G-14	Uzorong	763	3,257	13.1	12.0	11.8	16.0	14.0	66.9	25
G-16	Jerichhu	40	164	13.0	5.2	20.0	16.4	14.0	68.6	18
G-19	Nagor	53	252	11.2	5.6	20.0	15.6	14.0	66.4	29
G-20	Pramaling	29	123	12.3	4.0	20.0	16.2	14.0	66.5	28
G-22	Panbang	1,100	4,640	13.2	14.4	5.0	15.6	20.0	68.2	19
Ai-1	Aiechhu 2	34	146	12.4	4.0	20.0	11.2	6.0	53.6	58
Ai-3	Pelrithang	30	126	10.9	4.0	14.4	11.0	16.0	56.3	51
Ai-4	Ronggangchhu	51	216	10.5	4.0	20.0	11.2	6.0	51.7	62
J-1	Zangtheri	29	121	10.5	4.0	20.0	10.8	6.0	51.3	63
J-2	Jomori-I	82	349	12.4	7.6	15.2	12.6	6.0	53.8	57
J-3	Maenjiwoong	70	296	13.5	4.0	20.0	12.4	16.0	65.9	31
J-4	Jomotsangkha	68	291	12.7	4.0	20.0	10.8	16.0	63.5	37
N-1	NA Kangpara (G)	71	304	12.7	12.4	20.0	15.8	16.0	76.9	4
N-2	Lamai Gonpa	37	156	10.4	4.0	20.0	16.2	16.0	66.6	27
N-3	Paydung-Kangpar	85	364	13.1	4.0	15.4	16.0	16.0	64.5	33

(Source: JICA Survey Team)

8. MCA for Secondary Screening

(1) Site survey

Site survey on the project sites selected through the primary screening was carried out to grasp site status on environment,

1. To verify the location of each major structure (dam, waterway, powerhouse, outlet and switchyard) for the 37 sites selected;
2. To verify access conditions, hydrological conditions, topographical and geological conditions, and natural & social environmental conditions; and
3. To check whether risk avoidance is possible through a review of plot plans/power development plans, and where there are any serious risks (technical and environmental).

(2) Revised MCA for Secondary Screening

In the site reconnaissance, the JICA Survey Team reviewed the MCA formulated via desk study in consideration of the following points:

- Avoiding development in protected areas as much as possible;
- Avoiding places with geological problems as much as possible;
- Avoiding places with social or environmental problems as much as possible; and
- Changing to a plan that can be more economically viable.

The secondary screening was conducted according to the following criteria and weights for MCA.

Table-5 Criteria and Weights for MCA for Secondary Screening

No.	Criteria	Sub-criteria		Weights	
1.1	Technical	Hydrological quality	30%	50%	40%
1.2		Geological risk	50%		
1.3		GLOF risk	5%		
1.4		Sedimentation risk	5%		
1.5		Site accessibility	5%		
1.6		Transmission line risk	5%		
2.1	Economic	Economic efficiency		50%	
3.1	Impact on Social environment	Land Acquisition	25%	50%	40%
3.2		Resettlement and Asset Loss	25%		
3.3		Lifestyle and Livelihood	20%		
3.4		Cultural Heritage	30%		
4.1	Impact on Natural Environment	Located in protected area	35%	50%	
4.2		Loss of primary forest	30%		
4.3		Loss of wetland	10%		
4.4		**Loss of endangered species**	10%		
4.5		Fish migration	5%		
4.6		Access road/dam site erosion	5%		
4.7		Impact on Landscape	5%		
5.1	Social Development	Improved access to socioeconomic benefits	50%	100%	20%
5.2		Employment and potential for income opportunities	50%		

(Source: JICA Survey Team)

There are changes including evaluation method for sub-criteria from primary screening:

(a) Technical

Based on the results of the site reconnaissance, the assessment of the geological aspect was greatly reconsidered.

(b) Economic

The following items were added for the value evaluation.

- Value of providing ancillary services
- Increase in Firm power at downstream power plants

For the minimum flow rate of the river, the average flow rate in February was used in the primary screening, but in the secondary screening the average flow rate in the 4 months from December to March is used for evaluation as per the indication from DHPS.
In addition, for the sites where a review of the plan was carried out, the benefits and costs were also reviewed.

(c) Impact on Social environment

- **Land acquisition**

Based on the discussion with GIS Department of the National Land Commission (NLC) in February 2019, the following were applied to the evaluation in the 2nd MCA:

i) the latest land use information based on the GIS data collected from NLC as of January 2019; and

ii) owners' information obtained through site reconnaissance and local interviews between November 2018 and March 2019.

Table-6 Evaluation Scores for Land Acquisition (Secondary Screening)

Land size	State	Private
100 acres and more	5	1
50 acres - less than 100 acres		2
25 acres to 50 acres		3
Under 25 acres		4
Nothing (0)		5

(Source: JICA Survey Team)

■ **Resettlement and asset loss**

The numbers of structures in the project sites mentioned in the 2nd MCA represent the structures which the JICA Team and DHPS observed on-site and confirmed through the local interviews with Gewog Offices during the site reconnaissance from November 2018 to March 2019.

Table-7 Evaluation Scores for Resettlement & Asset Loss (Secondary Screening)

No. of Houses	Score
50 and more	1
25 - less than 50	2
Less than 25	3
Nothing (0)	5

(Source: JICA Survey Team)

■ **Living and livelihood means**

Taking into consideration the fact that the livelihoods of rural Bhutanese people heavily rely on agriculture, the evaluation scores for living and livelihood means were thoroughly revised as in the following table.

Table-8 Evaluation Scores for Living and Livelihood Means (Secondary Screening)

Affected activities	Score
Negative impacts on agriculture	1
Negative impacts on forest products (NTFPs) or timber products	3
Negative impacts on livestock	3
Negative impacts on local business*	3
None	5

Note: local business means shop, factory, sand quarry, etc.

(Source: JICA Survey Team)

■ **Cultural heritage**

There are numerous and various cultural, religious and archaeological heritage sites in Bhutan. Discussion with the Department of Culture (DOC) revealed that the Cultural Heritage Bill 2016 is yet to be enacted. The Department of Culture is in a process of inventorying and re-verifying the existing inventory of heritage sites in the country. The Cultural Heritage Bill 2016 mandates registration and classifications of heritage sites according to the significance of Cultural Heritage Value, which have not been completed either as of March 2019. Heritage sites in and around the potential project areas shall be studied site by site. Not only DOC but each District and Gewog shall be contacted to confirm their quality and quantity before concluding the scores, since there can be heritage sites which are recognized only by local communities.

Table-9 Evaluation Scores for Cultural Heritage (Secondary Screening)

No. of Affected Heritage Sites	National importance	Score
3 and more	1	1
2		2
1		3
None	5	5

(Source: JICA Survey Team)

(d) Impact on Natural Environment

■ **Loss of endangered species**

Although there were no major differences from the MCA items used for primary screening, the item "Loss of endangered species" was added as per the request from the SEA Task Team members. If endangered species specified in IUCN are identified around each site, this was evaluated as follows.

Table-10 Evaluation Method for Loss of Endangered Species (Secondary Screening)

Category of Endangered Species (Threatened Species listed in Red Data by IUCN)	Score
Critically Endangered (CR)	1
Endangered (EN)	2
Vulnerable (VU)	3
Nothing	5

(Source: JICA Survey Team)

The weight of "loss of endangered species" was evaluated as 10%. The weight of "Located in protected area" was changed from 40% to 35%, and that of "Loss of primary forest" was changed from 35% to 30% accordingly.

■ **Change of evaluation method for Impact on landscape**

As for Impact on landscape, in the primary screening it was evaluated via the distance of the transmission line, but in response to the indication from DHPS that the height is also a problem, the evaluation method was changed as follows.

Table-11 Evaluation Method for Impact on Landscape (Secondary Screening)

Distance from Nearest Pooling station/Substation	Voltage		
	400kV	220kV	132kV
More than 100 km	1	1	2
From 50 km to 100 km	1	2	3
From 20 km to 50 km	2	3	4
From 10 km to 20 km	3	4	5
Less than 10 km	4	5	5

(Source: JICA Survey Team)

(e) Social development

■ **Improved access to socioeconomic benefits**

It was-examined thoroughly to reach a consensus that the following three issues should be included under the sub-criterion: i) local connectivity, ii) access to education facilities, and iii) access to health facilities, with weights of 40%, 30% and 30% respectively.

Table-12 Evaluation Method for Improved Access to Socioeconomic Benefits (Secondary Screening)

i) Local connectivity evaluated by the travel time from the nearest town (chiwog center /gewog center) (40%)

<Dam> 50%

Sub criteria	Score
Near (Less than 1 hour)	1
Far (1 hour to less than 3 hours)	3
Very Far (3 hours and more)	5

<Power plant> 50%

Sub criteria	Score
Near (Less than 1 hour)	1
Far (1 hour to less than 3 hours)	3
Very Far (3 hours and more)	5

ii) Access to education facilities evaluated by travel time to education facility (30%)

<Dam> 50%

Sub criteria	Score
Near (Less than 1 hour)	1
Far (1 hour to less than 3 hours)	3
Very Far (3 hours and more)	5

<Power plant> 50%

Sub criteria	Score
Near (Less than 1 hour)	1
Far (1 hour to less than 3 hours)	3
Very Far (3 hours and more)	5

ii) Access to health facilities evaluated by travel time to health facility (30%)

<Dam> 50%

Sub criteria	Score
Near (Less than 1 hour)	1
Far (1 hour to less than 3 hours)	3
Very Far (3 hours and more)	5

<Power plant> 50%

Sub criteria	Score
Near (Less than 1 hour)	1
Far (1 hour to less than 3 hours)	3
Very Far (3 hours and more)	5

(Source: JICA Survey Team)

- **Employment and potential for income opportunities (Income improvement in low-income area)**

It was household poverty ratio at Dzongkhag level that was applied in the primary screeningThe scoring thresholds was replaced with the actual amount of per capita income per gewog as shown in the table below, since the Dzongkhag average household poverty ratio does not properly reflect all gewogs' economic condition of the Dzongkhag. The weights are 30% for the dam site and 70% for the PH site, as discussed in the TF/WG.

Table-13 Evaluation Method for Income Improvement in Low-income Areas

Sub-criteria (per capita income at gewog level)	Score
Nu 80000 and more	1
Nu 60,000 to Nu 80,000	2
Nu 40,000 to Nu 60,000	3
Nu 20,000 to Nu 40,000	4
Less than Nu 20,000	5

Note: The data source of per capita income at gewog level is the Bhutan Living Standards Survey Report 2012.

(Source: JICA Survey Team)

(3) Result of Secondary Screening

The comprehensive evaluation results concluded through the 2nd (Secondary) Screening are shown below.

Table-14 Comprehensive Evaluation (Base Case)

Project Code	Name of Project	Installed Capacity (MW)	Annual Energy (GWh)	Technical	Economic	Impact on Social environ -ment	Impact on Natural environ-ment	Social develop-ment	Total	Rank
A-4	Kunzangling	860	3,766	15.3	20.0	20.0	7.0	12.4	74.7	10
A-5	Tingma	783	3,428	15.4	20.0	20.0	14.6	14.0	84.0	2
A-8	Dorokha	550	2,407	15.9	20.0	20.0	14.6	12.4	82.9	3
W-6	Chuzom	152	664	15.5	4.0	4.0	16.4	6.0	45.9	37
W-8	Zangkhepa	54	236	14.3	4.0	15.2	13.8	4.8	52.1	36
W-19	Pipingchhu	100	436	12.1	7.6	16.8	15.4	13.6	65.5	24
P-15	Tamigdamchu	188	824	15.1	6.4	20.0	8.6	11.2	61.3	31
P-17	Tseykha	215	943	16.2	20.0	12.0	11.2	9.6	69.0	20
P-26	Thasa	706	3,094	15.6	14.8	17.0	15.2	11.6	74.2	11
P-28	Kago-1	102	448	15.2	20.0	20.0	8.4	15.6	79.2	5
P-29	Kago	58	255	14.6	14.4	20.0	12.2	14.8	76.0	7
P-30	Pinsa	153	672	15.9	20.0	20.0	11.4	12.0	79.3	4
P-34	Darachhu	89	389	14.1	12.0	16.8	15.2	12.8	70.9	17
P-35	Dagachhu-II	71	311	14.6	10.4	20.0	15.4	11.2	71.6	14
P-38	Tashiding	81	356	10.8	10.8	20.0	15.2	11.8	68.6	21
M-5	Bemji	333	1,458	15.6	17.6	20.0	9.2	10.6	73.0	13
M-6	Jongthang	227	995	15.9	19.2	14.8	15.4	10.8	76.1	6
M-11	Wangdigang	502	2,200	15.3	17.2	9.0	10.4	4.8	56.7	35
M-17	Buli	69	302	15.0	14.8	20.0	12.4	13.6	75.8	8
M-18	Nyekhar	43	188	15.2	4.0	20.0	12.2	14.0	65.4	26
C-7	Chamkharchhu-IV	451	1,974	13.6	20.0	10.0	16.0	9.6	69.2	19
C-10	Chamkharchhu-II	414	1,814	15.0	20.0	20.0	15.0	18.0	88.0	1
K-13	Minjey	673	2,948	13.4	19.6	8.0	10.2	11.2	62.4	30
K-15	Phawan	499	2,185	14.5	6.8	13.4	12.2	12.4	59.3	33
G-6	Khamdang	512	2,242	16.1	14.8	15.8	15.6	10.8	73.1	12
G-7	Gongri	546	2,392	15.6	12.8	7.0	15.2	10.0	60.6	32
G-9	Gamrichhu-3	123	538	12.7	14.0	20.0	8.4	12.2	67.3	23
G-10	Gamrichhu-2	108	471	14.3	14.8	20.0	15.6	10.8	75.5	9
G-11	Gamrichhu-1	150	656	13.7	14.8	17.6	15.4	10.0	71.5	15
G-13	Sherichhu	58	254	12.6	4.0	20.0	16.0	12.2	64.8	27
G-14	Uzorong	840	3,678	14.2	20.0	8.4	15.0	13.0	70.6	18
G-16	Jerichhu	39	169	13.0	5.2	20.0	16.2	11.0	65.4	25
G-19	Nagor	59	258	10.4	5.6	17.6	15.0	15.4	64.0	29
G-22	Panbang	993	4,349	10.7	14.8	6.2	14.6	11.6	57.9	34
N-1	N.A. Kangpara (G)	71	312	13.5	12.8	20.0	15.2	10.0	71.5	16
N-2	Lamai Gonpa	37	161	11.0	4.0	20.0	15.6	13.6	64.2	28
N-3	Paydung-Kangpar	73	319	13.9	10.0	17.6	15.4	11.4	68.3	22

(Source: JICA Survey Team)

Of the 37 sites listed above, it was found very difficult to develop the following 13 sites, which have issues such as major geological risks, major components of the project being in protected areas, and being very close to the International border, which were eventually excluded from the priority development candidate sites. The remaining 24 sites are shown below.

Table-15 Sites that are considered difficult to develop

Project Code	Name of Project	Installed Capacity (MW)	Annual Energy (GWh)	Total	Rank	Reasons why development is difficult
A-4	Kunzangling	860	3,766	74.7	10	Main component is in protected area
W-6	Chuzom	152	664	45.9	37	Many residents need to be resettled
W-19	Pipingchhu	100	436	65.5	24	Geologically difficult
P-15	Tamigdamchu	188	824	61.3	31	Main component is in protected area
P-28	Kago-1	102	448	79.2	5	Main component is in protected area
P-38	Tashiding	81	356	68.6	21	Geologically difficult
M-5	Bemji	333	1,458	73.0	13	Main component is in protected area
G-6	Khamdang	512	2,242	73.1	12	Very close to international border
G-9	Gamrichhu-3	123	538	67.3	23	Main component is in protected area
G-13	Sherichhu	58	254	64.8	27	Geologically difficult
G-19	Nagor	59	258	64.0	29	Geologically difficult
G-22	Panbang	993	4,349	57.9	34	Geologically difficult
N-2	Lamai Gonpa	37	161	64.2	28	Geologically difficult

(Source: JICA Survey Team)

Table-16 Overall Rank (Base Case)

Rank	Project Code	Name of Project	Installed Capacity (MW)	Annual Energy (GWh)	Technical	Economic	Impact on Social environment	Impact on Natural environment	Social development	Total
1	C-10	Chamkharchhu-II	414	1,814	15.0	20.0	20.0	15.0	18.0	88.0
2	A-5	Tingma	783	3,428	15.4	20.0	20.0	14.6	14.0	84.0
3	A-8	Dorokha	550	2,407	15.9	20.0	20.0	14.6	12.4	82.9
4	P-30	Pinsa	153	672	15.9	20.0	20.0	11.4	12.0	79.3
5	M-6	Jongthang	227	995	15.9	19.2	14.8	15.4	10.8	76.1
6	P-29	Kago	58	255	14.6	14.4	20.0	12.2	14.8	76.0
7	M-17	Buli	69	302	15.0	14.8	20.0	12.4	13.6	75.8
8	G-10	Gamrichhu-2	108	471	14.3	14.8	20.0	15.6	10.8	75.5
9	P-26	Thasa	706	3,094	15.6	14.8	17.0	15.2	11.6	74.2
10	P-35	Dagachhu-II	71	311	14.6	10.4	20.0	15.4	11.2	71.6
11	G-11	Gamrichhu-1	150	656	13.7	14.8	17.6	15.4	10.0	71.5
12	N-1	N.A. Kangpara (G)	71	312	13.5	12.8	20.0	15.2	10.0	71.5
13	P-34	Darachhu	89	389	14.1	12.0	16.8	15.2	12.8	70.9
14	G-14	Uzorong	840	3,678	14.2	20.0	8.4	15.0	13.0	70.6
15	C-7	Chamkharchhu-IV	451	1,974	13.6	20.0	10.0	16.0	9.6	69.2
16	P-17	Tseykha	215	943	16.2	20.0	12.0	11.2	9.6	69.0
17	N-3	Paydung-Kangpar	73	319	13.9	10.0	17.6	15.4	11.4	68.3
18	G-16	Jerichhu	39	169	13.0	5.2	20.0	16.2	11.0	65.4
19	M-18	Nyekhar	43	188	15.2	4.0	20.0	12.2	14.0	65.4
20	K-13	Minjey	673	2,948	13.4	19.6	8.0	10.2	11.2	62.4
21	G-7	Gongri	546	2,392	15.6	12.8	7.0	15.2	10.0	60.6
22	K-15	Phawan	499	2,185	14.5	6.8	13.4	12.2	12.4	59.3
23	M-11	Wangdigang	502	2,200	15.3	17.2	9.0	10.4	4.8	56.7
24	W-8	Zangkhepa	54	236	14.3	4.0	15.2	13.8	4.8	52.1

(Source: JICA Survey Team)

9. Alternative Scenarios

For the above 24 sites, the results were reevaluated to show 4 types of alternative scenario of "Basic Case", "Economy Emphasizing Case", "Environment Emphasizing Case", and "Development Emphasizing Case". These are shown below.

Table-17 Four(4) types of alternative scenario

Type of Scenario		Technical	Environmental	Social Development
Scenario A	Base Case	40%	40%	20%
Scenario B	Economy Emphasizing Case	60%	20%	20%
Scenario C	Environment Emphasizing Case	20%	60%	20%
Scenario D	Development Emphasizing Case	30%	30%	40%

(Source: JICA Survey Team)

10. Conclusions

The PSMP 2040 has been formulated with a basic idea of harmonizing environment and development. It initially eliminated those project ideas on the longlist, which would require large-scale acquisition of private lands and resettlement and all hydropower generation facilities of which would be located in protected areas like National Parks. Then a comparative assessment using MCA method among rest of the potential candidate sites was conducted not only from technical, geological and economic, but environmental and social aspects by applying the concept of strategic environment assessment. Site reconnaissance on the semi-longlisted project sites further identified their specific information on protected areas, ecosystems, topography and geology, hydrology, land use, local living and livelihood, indigenous people, cultural heritages and socioeconomic status of each site. Project ideas of each site were technically reviewed and adjusted in a flexible manner to avoid, reduce or minimize environmental and social adverse impacts.

Approximately 80% of the 18 short-listed projects have adopted the run-of-river type generation, not large-scale reservoir type. It makes most use of natural river flow, which helps minimize land inundation and avoid resettlement, losses of livelihood and local conflict of interests. The project is designed to maintain certain water flow in the water reduction section between intake and tail water outlet from powerhouse in order to reduce negative impacts on local water use in downstream areas.

Submersion of land habitat for flora and fauna has been minimized, which reduces adverse impacts on terrestrial ecosystems. With regard to aquatic ecosystems, the project plan technically avoids and reduces impact on fish spawning grounds and loss of their habitats by examination of affects to the hydrostatic environment of river, and fluctuation of water flow condition and level. As is often the case in hydropower projects in Bhutan, this master plan is also expected to bring cumulative positive impacts on local communities through development and improvement of road networks, i.e., better access to education and health facilities, local connectivity and economy.

It is concluded that the PSMP 2040 has taken into considerations of all environmental and social issues at the Strategic Environmental Assessment stage.

The master plan stays at national policy planning level with a broad and long-term view, and it has explored the whole nation in various aspects from global to local. But certain issues at local level may need further investigations at project processing stage. It will require more data and information at ground level to update and refine those collected in this SEA. Project feasibility study being conducted, a comprehensive Environment Impact Assessment will be implemented to predict site- and design-specific environmental and social impacts, both positive and negative, and cumulative impacts, and then appropriate mitigation measures will be planned and implemented.

11. Recommendations

The following issues are essential and should be well considered when projects in the PSMP 2040 are realized. Detailed and reliable data and information should be further collected at local level in project feasibility study and associated environmental impact assessment for updating and refining those collected in the master plan study. Based on the data and information, appropriate countermeasures to these issues should be planned and reflected in the environmental management plan of each project.

■ **Development in protected area**

Hydropower development within protected areas should be avoided to the extent possible. If unavoidable, the project plan should be reexamined. Facility layout and design plan should be reexamined according to the designation objectives of the protected area and its management policy, and mitigation measures should be developed by examining every single aspect for conservation of the protected area.

■ **Consideration for ecosystem**

Hydropower development in areas of rich biodiversity should consider conservation of the ecosystems composed of numerous and various flora and fauna and their conservation on a long-term basis. Facility layout and design plan should be examined to avoid adverse impacts on the ecosystems as much as possible; and appropriate environmental mitigation measures should be planned and implemented. For instance, when hydropower generation plans are to be realized in the river basin of Punatsangchhu (Mochhu, Phochhu, Kamechhu and their tributaries), which is the major habitat of White-Bellied Heron designated as "Critically Endangered" species by IUCN, it is necessary to exclude breeding areas and main feeding areas from the project sites not to give adverse impacts on its habitats. If it is difficult to avoid such areas, alternative habitats in neighboring areas with similar local context need to be provided for the heron (an off-set plan). In case that development affects forest area, such impact as submergence of forest should be minimized. If the particular forest is deemed important for ecosystem conservation, afforestation with same vegetation should be considered in its neighboring area.

■ **Conservation of aquatic habitats: mitigation measures for fish migration between upstream and downstream**

It is recommended to develop such facilities as fish passage, fish ladder and fish elevator that help fish migration, if technically viable. Reduction of impact to juvenile fish migrating to downstream should be carefully considered when designing turbines and spillways. Artificial fish breeding and stocking program, or protection system by capturing and artificially transferring fish between upstream and downstream should be examined and developed if it is impossible to avoid or mitigate adverse impacts by all means. Among the short-listed projects, P-26 Thasa, C-7 Chamkharchhu-IV, K-13 Minjey, and G-14 Uzorong will require careful examination of such artificial protection measures.

■ **Maintenance of water flow**

Water flow maintenance (Environmental flow with scientific verification is recommended to ensure stable water level for sustainance of its water ecology and environment between Dam and TRT. The Water Regulation of Bhutan (2014) stipulates that 30% of lean season flow shall be maintained where scienticfic study reports are unable to determine the minimum environmental flow. However, it is necessary to conduct a river survey to identify fish species which each river accommodates and their specific demands for water flow, and water flow maintenance level should be examined and determined.

■ **Prevention of erosion: prevention of slop erosion and control measures**

Construction of approach roads may cause slope erosion, runoff of earth and sand into rivers and sedimentation in the reservoirs. In order to avoid such negative impacts on the surrounding environment, leveling of steep slope through grading works should be examined, and afforestation plan for the whole river basin can be applied as a mitigation measure. P-26 Thasa, C-7 Chamkharchhu-IV, K-13 Minjey and G-14 Uzorong need to pay special attention to this issue.

■ **Avoidance of negative impacts to cultural heritage**

Department of Culture has been working on identifying and registering all the cultural heritages of national and local importance along with its continuous effort to pass the draft Cultural Heritage bill. Each Dzongkhag also works on the development of its management plan for locally recognized heritages. When projects are processed, it is recommended to confirm the extent to which their works have made progress at national and regional levels, and to ensure their consistency. Avoidance or minimization of adverse impacts on cultural heritages, religious and archaeological sites should be regarded as preconditions for project formulation, and consultations to reflect local views and opinions into the project should be conducted prior to the decision making.

- **Consideration to the affected people**

Run-of-river type power generation design is mainly proposed in the master plan that does not require large-scale land acquisition. Project size, design and location have been continuously examined in the whole survey process to avoid negative impacts on local living and livelihood. However, social impact assessment conducted along with the project feasibility study may detect adverse impacts that are unpredicted in the master plan study. Examining mitigation measures for adverse impacts, it is necessary to assess if there are area losses or damages to settlements, farmland, residential structures and others, cash crops and trees, and livelihood means, and to provide substitute lands, pay compensations, and provide assistance measures according to laws and regulations in Bhutan, donors' safeguard policies and guidelines.

An example is found in Tseza Gewog of Dagana Dzongkhag. A hydropower plant (HPP) was constructed in the past which created large-scale employment opportunities for the local people and provided area development activities. The project not only boosted local economy, the local road network was improved and advanced, and health facilities and schools were upgraded. People in Tseza Gewog, which accommodates P-34 Darachhu and P-35 Dagachhu-II, expect new development works in near future, especially hydropower development, and eager to cooperate. On the other hand, current local government addressed their concerns on hydropower development in case of M-6 Jongthang, M-11Wangdigang, C-7 Chamkharchhu-IV, and C-10 Chamkharchhu-II. Also, as in case of P-22 Thasa, careful and detailed social survey including the consultation with local people will be necessary to identify the impacts on their livelihood, especially if they are economically vulnerable people.

Formulating projects from this mater plan, local consultation should be conducted prior to the finalization of project design, and countermeasures should be examined with understandings and consensus of the local people. Not only the impacts caused by the projects, but also the predicted impacts caused by other current and past development activities should be explained legitimately in both positive and negative aspects.

- **Considerations in power transmission plan**

Power transmission plan in this master plan has identified and proposed those routes which do not pass protected areas. The HPP, emerged from this master plan, will be connected to a substation from which the generated power is transmitted into the existing network, and new transmission lines therefore have to be extended. Doing so, it is important to reduce the numbers of routes and shorten their lengths by using the large capacity transmission lines and streamlining several routes into one. Measures to reduce logging of trees in Right of Way should also be examined. In addition, impacts on tourism and cultural landscape should be avoided, and considerations should be given when selecting the transmission routes and tower locations not to pass private lands.

10.4 Holding of stakeholder meetings

Stakeholders include government agencies, local government agencies, NGOs/CSOs (Civil Society Organizations), academics, academics, related people, etc. SHM will be held in Thimphu, a total of four times. The content of the project, scoping for SEA, evaluation criteria to be used when deciding development priorities, evaluation results, environmental conservation measures and draft SEA Report envisaged will be discussed at the SHM.
The first SHM was conducted during the Inception Workshop with related government organizations. From the Second SHM, DHPS invited further stakeholders, including NGOs, explaining a summary of the survey, answering questions, and collecting comments.

Prior to the second SHM, the stakeholders were identified and, divided into the following groups by the survey team and the environment and social group counterparts from DHPS: (1) relevant governmental agencies (including autonomous and corporate agencies), (2) academics and research centers, and (3) NGOs/CSOs/other funding agencies. As for NGOs/CSOs, the main ones which have experience of providing support for natural environmental conservation or rural poverty reduction efforts in Bhutan, with either national or international support funds, for several years and which are listed as national CSOs are officially registered under the CSO authority in Bhutan. If other stakeholders are to be invited to the meeting, they were added to the SHM invitation list accordingly. Each and every important issue referred to in two SHMs has been reflected in the scoping draft, MCA evaluation criteria and examination process to the extent possible.

The second SHM was held on May 15th, 2018, with stakeholders identified beforehand invited via official DHPS letters to them. A summary of the meeting is given in the table below. The participants' questions were answered, and the issues on the meeting agenda were discussed.

The total number of participants was 51 (39 excluding the JICA-side participants, of which 29 were male and 10 were female) and the numbers from each organization and main comments were as in Table 10-24 below. The main issues commented upon are being reflected in the scoping draft and MCA criteria.

As for the related people in candidate project sites (local government agencies and potentially project affected villages), hearing about possible effects due to the project was planned from representatives from local government and villages during the site surveys.

(a) The First SHM

The first SHM was conducted on Wednesday, December 20, 2017. Participants from government organizations and NGOs such as RSPN and WWF had intensive discussions and a Q&A on the content of this Master Plan survey, and examined how to choose member organizations for SHMs.

(b) The Second SHM

This was held on Tuesday, May 15, 2018. Its agenda is presented in the following table, and included a Q&A and active discussions. The total number of participants was 51 (39 other than JICA people, comprising 29 males and 10 females). A breakdown of participants by organization and their comments is also summarized in the said table.

Table 10-24 Summary of the Second Stakeholders Meeting

Date and time	May 15th (Tue), 2018 09:30 - 13:00
Venue	City Hotel (Thimphu)
Agenda	Project Outline, Scoping List Draft, MCA Criteria Draft
Number of participants from each organization	**DHPS:** 11 **JICA**: Headquarters 1, Bhutan Office 2, Japanese survey team consultants 4, local consultants 5 **Relevant Government Agencies**: NLCS 1, NECS 2, DOA (Department of Agriculture) 1, DoFPS 3, DOC 1, NCHM (National Center for Hydrology and Meteorology) 1, BEA 1, BPC 4, DGPC 2, NBC (National Biodiversity Center) 1, DHPC (Dagachhu Hydro Power Corporation) 1, ThyE (Tangsibji Hydro Energy Limited) 3 **Academics and Research Centers:** UWICER (Ugyen Wangchuck Institute for Conservation and Environmental Research) 1 **NGO/CSO/funding agencies**: WWF 1, RSPN 1, Tarayana Foundation 2, Bhutan Trust Found for Environment 1, BES 1
Main Comments	**Scoping Draft issues** ■ Consideration of New E-flow Guideline Draft upon survey of water usage in the downstream areas ■ Importance of discussion on Climate Change in SEA ■ Consideration of the impacts on the Biological Corridors ■ Provision of data on migratory fish **MCA Issues** ■ Impacts caused by transmission lines on forests and catchment areas ■ Consideration of impacts on community forests in land acquisition ■ Definition of cultural heritage site ■ Expression of "negative" impacts on natural and social environment ■ Concerns regarding cumulative impacts at basin/system level rather than individual project level ■ Perspective on zoning in Protected Areas

(Source: DHPS and JICA Survey Team)

(c) The Third SHM

The Third SHM was held on Monday, November 12, 2018. Active discussions on the topics, questions and answers were observed with 40 participants from various organizations (27 except JICA people, 21 males and 6 females). Number of participants by organization and major comments are summarized as below.

Table 10-25 Outline of the Third Stakeholder Meeting

Date and Time	9:00 - 13:00, Monday, 12 November 2018
Venue	Migmar Hotel (Thimphu)
Topics	a) Progress Status of Survey Work in the Project b) Selection methods for potential project sites, results of initial screening (long list) and primary ranking (semi-long list); and c) Survey sites, survey items under MCA evaluation for second screening, and checklist for site reconnaissance.
Number of Participants by Organization	DHPS: 4 JICA: JICA Bhutan Office 2, JICA Survey Team 5 and Local Consultant 6 Governmental agencies: NECS 2, DLG 1, MoWHS 1, DOR 1, DRE 1, PPD 1, DoFPS 2, DOA 1, DOT 1, DOI 1, NBC 2, NSB 1, BPC 1, DGPC 1, ThyE 1, DHPC 1 Academics and research centers: UWICER 1 and CNRRUB 1 NGOs/CSOs and funding agencies: WWF 1 and Tarayana Foundation 1
Major Q&A / Comments	<Selection methods and potential project sites> ◆ Please share information on the potential sites less than 25MW (DRE) ◆ What does the MCA apply this time that differs from that which DHPS used? =>In the previous MCA, technical & economic score was 70%, and environment and social consideration and development was 30%. In the MCA this time, technical & economic score is

	40%, Environment and Social is 40%, and social development effect is 20%. It places importance on social considerations (Chairperson). <MCA Evaluation Criteria Site Reconnaissance> <Natural Environment> ◆ What is the foundation of the evaluation criteria for forests? Why does it score deciduous broadleaf forest higher than coniferous forest? (USICER) => Biodiversity in the forest is the evaluation criterion. (JICA Survey Team) ◆ What is the background whereby the landscape is evaluated by the route length of transmission lines? (PPD) => Heights of transmission lines and towers will also be examined in addition to the route length. (JICA Survey Team) ◆ Why is the evaluation of soil erosion in two patterns: when mitigation measures can be examined and cannot? (WWF) => It was evaluated based on geographical conditions, but the current scoring is tentative and will be revised after the field survey (JICA Survey Team and Chairperson) ◆ Which occasions allow the installation of fish ladders, although this is considered challenging? (DGPC) => Examination shall be done to find out whether it is technically viable by taking into consideration dam height, natural conditions of dam site, habitats of upstream migrated fish, and so on. (JICA Survey Team) ◆ How will environmental conservation of transmission line routes and ROW be treated? (PPD) => Protection areas and private land shall be avoided to the extent possible. If unavoidable, route length shall be shortened, and compensation shall be considered for private land. Specific mitigation measures will be further examined in the project-level EIA. (JICA Survey Team) <Social Environment> ◆ How are cultural heritage sites targeted in this survey scoped and defined? (PPD) => Scoring at this time basically considers cultural heritage properties of national importance. Currently, there is no list of cultural heritage sites of national importance, thus they are to be identified through discussion with the Department of Culture from now on. (Chairperson and JICA Survey Team) ◆ Study on the gewog level poverty rate is currently being conducted, so it is suggested that people consider its results. (NSB)

(Source: DHPS and JICA Survey Team)

(d) The Fourth SHM

The Fourth SHM was conducted on Tuesday, June 11, 2019. Participants engaged in questions and answers and there was discussion over the topics. The total number of participants was 52 (43 not including people from the JICA side: 32 males and 11 females). The number of participants by organization and major comments are summarized below.

Table 10-26 Outline of the Forth Stakeholder Meeting

Date and Time	June 11th (Tue), 2019 09:30 - 13:00
Venue	Namgay Heritage Hotel (Thimphu)
Topics	● Primary and Secondary Ranking of Project Candidate Sites, Short-listed Sites, Development Plans in the Future ● MCA for Natural and Social Environment, and social development ● Alternative scenarios, cumulative impacts, climate change ● Environmental and social considerations upon implementing EIA
Number of Participants by Organization	◆ **DHPS**:12 ◆ **JICA:** JICA Headquarters: 1, Bhutan Office: 1, JICA Survey Team: 4 and local consultants: 3 ◆ **Governmental agencies:** NECS: 4, NLCS: 1, RMA: 1, BEA: 3, NCHM: 1, DLG: 1, DOR: 1, DoFPS: 1, DOA: 1, DEL: 1, DOL: 1, DMEA: 1, Department of Immigration: 1, NBC: 1, BPC: 1, DGPC: 2, ThyE: 1, DHPC: 1 ◆ **Academics and research centers:** UWICER: 1, CNRRUB: 1, CBS: 1 ◆ **NGOs/CSOs and Funding Agencies**: WWF: 1, BTFEC: 1, Tarayana Foundation: 1, RSPN: 1
Major Q&A / Comments	**Issues concerning Project Candidate Sites' Selection** ◆ For the Chamkharchhu and Dorokha Project Area, the Hydropower Development Committee of the government recommended not to promote development for natural environment and geopolitical reasons; however, PSMP2040 plans to include them as study target areas. (DHPS)

	⇒ We have been aware of their opinion; however, that policy was not determined clearly from the beginning and, during implementation of this study and hydropower development strategy paper, could not be obtained without approval from the cabinet. (JICA Survey Team) ⇒ I agreed with the recommendations by the Hydropower Development Committee. It is desirable that at least one river system is free of dams to protect the natural environment. It is reported that the endemic fish "Masheer" moves up to the upstream of Chamkharchhu for the purpose of spawning, since the dam construction at Mandechhu. (WWF) ◆ How did you attempt to evaluate the transmission line? There is no access to the Dorokha site. (BEA) => It is evaluated from these aspects: economic efficiency, and impacts on the environment and landscape. (JICA Survey Team) ◆ Our foundation has provided support to rural communities for micro hydro projects in the project candidate site area. Can it be connected to the grid and is it possible to sell surplus electricity? (Tarayana Foundation) ⇒ In Bhutan, an electrification rate of 99.97% of households has been achieved and almost all of them are connected to the grid. Electricity tariffs are determined by BEA; however, at this moment, there is not yet a need for a feed-in tariff system. There are technical issues in synchronizing the grid. Small hydro power projects are managed by DRE. (DHPS) **<u>Issues concerning SEA Draft</u>** ◆ Among 18 candidate projects, 6 were commented on from the environment aspect. Does this mean that the other projects have fewer environmental impacts? (DHPS) ⇒ When selecting 25 projects prior to screening 18 candidate projects, the projects were redesigned to minimize the environmental impact and projects for which serious environmental and social impacts could be predicted were excluded from the candidate list during that phase. (JICA Survey Team) ◆ Isn't is necessary to conduct another survey on endangered fish and other species in the upper stream? For example, in the case of the dam in the Uzorong project, which species of fish can be referred to? Have there been any successful cases of constructing fish ladders for a dam height of 200m? (DHPS) ⇒ For Uzorong, if there are migratory fish after dam construction downstream, it is possible to consider that those fish will use the tributaries for spawning. Also, construction of a safe fish ladder will be recommended so that the migratory fish can move to the upstream. (JICA Survey Team) ◆ There are guidelines for setting E-flow which can be referred to in the SEA report. (NECS) ⇒ The standard E-flow is to be sustained. Further detailed study is to be conducted and, at this time, the specific E-flow figure is to be recommended. (JICA Survey Team) ◆ 5% weight for migratory fish seems to be low. (WWF) ⇒ There is only uncertain information about the altitude where the fish can survive, so it is difficult to judge. This weight is determined through discussion with stakeholders; thus, it is difficult to change at this time. (JICA Survey Team) ⇒ It was a challenge to decide the weight for migratory fish among the various criteria. Previously, these criteria were not in the MCA and therefore there was a need to set this item, even though its weight is low. (DHPS) ◆ Are there any existing studies about environmental impacts after dam construction in hydropower projects? There are no symptoms of negative environmental impacts, particularly in the case of the Dagachhu hydropower project. (Dagachhu Hydropower Corporation) ◆ Dam construction on the China side of the border caused concerns regarding hydropower projects in the west, and there is a similar situation in the east along the border area with India. (RSPN) ⇒ There is a neutral opinion on whether or not the future candidate hydropower projects will be implemented. This time, an SEA which includes environmental considerations was implemented and the strategic scope of the catchment area was formulated. Further details should be examined when planning each project. Prior to submission of PSMP2040 to the government, in reviewing it thoroughly DHPS will compile a comprehensive strategic master plan and then will submit it to the cabinet. (DHPS)

10.5 Recommendations by JICA Advisory Committee on "Project on Power System Master Plan 2040"

The first JICA advisory committee on environmental and social considerations was held on April 16, 2018. The scoping items concerning the SEA survey conducted in this case were deliberated and advised upon for the following seven items as items to be noted.

(1) Scoping items deliberated by the JICA Advisory Committee

17 items (Pollution - 3, Natural Environment - 4, Social Environment - 9, Others - 1) in 10.3.4 were discussed and approved. The two items of water quality and waste were excluded from the items with the agreement of all the constituent members.

(2) Recommendations from JICA Environmental and Social Considerations Advisory Committee

The following seven items were recommended.

- The possibility of the development of mini-hydropower plants should be described in the DFR. (See Chapter 3)
- Negative Impacts on potential hydropower resources due to the effects of climate change (Himalayan glaciers, rainfall patterns, floods, forest coverage, etc.) should be studied through existing literature surveys, etc. and be described in the DFR. (See 10.9)
- Evaluation items and their weight in the Multiple Criteria Analysis (MCA) used upon screening the project candidate sites should be described in the DFR, along with the reasons and decision making process. (See Chapter 7)
- Within the protected areas of Bhutan, core zones should be excluded from the candidate sites for hydropower projects. According to the JICA guidelines, one principle is to exclude buffer-zone and multipurpose use zones from the candidate sites for hydropower projects. (See 10.6)
- A Cumulative Environmental Assessment (CEA) should be carried out in a water system unit when the candidate sites are selected, at multiple points in the same river/water system. (See 10.8)
- In the case that serious negative impacts are predicted in an area where economically vulnerable people live, or in mountain and forest areas where people depend on traditional resources, etc., best efforts should be made to exclude those areas from the candidate sites for the hydro power development. (See 10.6.3)
- Participants of stakeholder meetings should include not only representatives of local public administration and governmental entities specialized in the related issues, but also groups that can reflect the voices of people who are potentially affected by the project (such as NGOs). (See 10.4)

10.6 Selection of Potential Project Sites in Protected Areas

10.6.1 Implementation of Hydropower projects in Protected Areas and Environmental and Social Considerations

(1) Implementation sites for hydropower projects in protected areas

(a) Projects excluded from potential hydropower projects because all the components of the project are located in a protected area

Among the 116 sites selected as potential hydropower sites in Bhutan, 44 project sites have all their hydropower facility components (dams, power stations, waterways) located in protected areas and these sites are initially excluded from the hydropower development candidate sites. The candidate sites excluded are shown in the table below.

Table 10-27 Projects excluded from Potential Hydropower Projects due to being located in Protected Areas

Project code	Name	
	Project	Protected area
A-2	Amochhu-2	Jigme Khesar S.N.R.
A-3	Timalumchhu	Jigme Khesar S.N.R.
W-2	Chhanda-gang	Jigme Dorji N.P.
P-1	Taksti Makhang	Jigme Dorji N.P.
P-2	Chhogley	Jigme Dorji N.P.
P-3	Chhuzarkha	Jigme Dorji N.P.
P-4	Rimi	Jigme Dorji N.P.
P-5	Daushing	Jigme Dorji N.P.
P-6	Sechednang	Jigme Dorji N.P.
P-8	Phochhu-2	Jigme Dorji N.P.
P-9	Uesana	Jigme Dorji N.P.
P-10	Wachey	Jigme Dorji N.P.
P-11	Threlga	Jigme Dorji N.P.
P-12	Phochhu-Tr-2	Jigme Dorji N.P.
P-13	Phochhu-1	Jigme Dorji N.P.
P-14	Phochhu-Tr-1	Jigme Dorji N.P.
P-16	Tshachuphu	Jigme Dorji N.P.
P-27	Kago-2	Jigme Singye Wangchuck N.P.
P-32	Rukha	Jigme Singye Wangchuck N.P.
M-1	Mangdechhu-2	Wangchuck C.N.P.
M-2	Duigang chhu	Wangchuck C.N.P.
M-3	Mangdechhu-1	Wangchuck C.N.P.
M-4	Thampochhu	Wangchuck C.N.P.
M-9	Wachichhu	Jigme Singye Wangchuck N.P.
M-12	Rimjigangchhu	Jigme Singye Wangchuck N.P.
M-13	Shergarchhu	Jigme Singye Wangchuck N.P.
C-1	Gumthangchhu	Wangchuck C.N.P.
C-2	Chamkharchhu-V	Wangchuck C.N.P.
C-9	Chamkharchhu-III	Phrumsengla N.P.
K-1	Kurichhu-2	Jigme Singye Wangchuck N.P.
K-2	Kurichhu-1	Wangchuck C.N.P.
K-3	Chagdzom	Wangchuck C.N.P.
K-4	Bazaguruchhu-2	Wangchuck C.N.P.
K-5	Bazaguruchhu-1	Wangchuck C.N.P.
K-6	Nangrigang-2	Wangchuck C.N.P.
K-7	Nangrigang-1	Wangchuck C.N.P.
K-8	Ugenphu	
K-9	Nimshong	

K-10	Khomachhu-1	Bumdeling W.S.
K-11	Khomagang	Bumdeling W.S.
K-12	Khomachhu	Bumdeling W.S.
G-2	Longkhar	Bumdeling W.S.
G-8	Gamrichhu-4	Sakteng W.S.
Mo-2	Aiechhu 1	Corridor
Total	44 sites	

(Source: JICA Survey Team)

Notes: S.N.R. - Strict Nature Reserve, N.P. - National Park,
W.S. - Wildlife Sanctuary, C.N.P. - Centennial National Park

In addition to the above 44 sites, 3 sites which are outside protected areas but which feature large-scale resettlement were added to make a total of 47 sites excluded from the hydropower development candidate sites.

Table 10-28 Project Sites excluded from Candidate Sites due to Large-Scale Resettlement

Project code	Name		Capacity (MW)	Energy (GWh)
	Project	Reservoir		
W-5	Wangchhu	Thimphu Reservoir	46	201
W-10	Parochhu	Paro Reservoir	54	237
C-6	Chamkharchhu	Bumthang	102	447
Total		3 sites	202	884

(Source: JICA Survey Team)

(b) Project candidate sites in which parts of the hydropower components are located in protected areas
The above 47 sites were excluded to avoid their development, and the remaining 69 sites were chosen as candidate sites. Among the 69 remaining candidate sites, there are 29 project candidate sites where some of the components are located in a protected area. The relationship between protected areas (zoning areas) and hydropower facilities is shown in the table below.

Table 10-29 Projects where Some of the Components are located in a Protected Area

Project code	Name		Component in Zoning sites		
	Project	Protected area	Dam	Waterway	Powerhouse
A-4	Kunzangling	Jigme Khesar S.N.R.	Multiple-Use	Multiple-Use	-
W-3	Dodennang	Jigme Dorji N.P.	Multiple-Use	Multiple-Use	-
W-7	Getsa	Jigme Dorji N.P.	Core	Buffer	-
W-8	Zangkhepa	Jigme Dorji N.P.	Multiple-Use	Multiple-Use	-
P-7	Puna Gom	Jigme Dorji N.P.	Multiple-Use	-	-
P-15	Tamigdamchu	Jigme Dorji N.P.	Multiple-Use	Multiple-Use	-
P-17	Tseykha	Jigme Dorji N.P.	Multiple-Use	-	-
P-18	Jarona	Corridor	Corridor	Corridor	-
P-19	Dangchhu	Corridor	Corridor	-	-
P-28	Kago-1	Jigme Singye Wangchuck N.P.	Multiple-Use	Multiple-Use	-
P-29	Kago	Jigme Singye Wangchuck N.P.	Multiple-Use	-	-
P-30	Pinsa	Jigme Singye Wangchuck N.P.	Multiple-Use	-	-
M-5	Bemji	Wangchuck C.P.	Multiple-Use	Multiple-Use	-
M-11	Wangdigang	Jigme Singye Wangchuck N.P.	Multiple-Use	-	-
M-14	Tingtibi	Jigme Singye Wangchuck N.P.	Multiple-Use	-	-
M-15	Gomphu	Manas N.P.	Multiple-Use	Multiple-Use	-

M-19	Sermaling	Manas N.P.	Multiple-Use	Multiple-Use	-
C-3	Kurjey	Wangchuck C.N.P.	Multiple-Use	Multiple-Use	-
C-4	Chhutoe	Wangchuck C.N.P.		Multiple-Use	-
K-13	Minjey	Corridor	Corridor	-	Corridor
K-19	Shongarchhu	Phrumsengla N.P.	Multiple-Use	-	-
G-3	Tshaling	Bumdeling W.S. (Bumdeling Ramsar Site)	Multiple-Use	-	-
G-9	Gamrichu-3	Sakteng W.S	Core	Multiple-Use	-
G-12	Rotpa	Bumdeling W.S.	Multiple-Use	-	-
Mo-1	Aiechhu 2	Corridor	-	Corridor	Corridor
Mo-3	Pelrithang	Corridor	Corridor	Corridor	-
Mo-4	Ronggangchhu	Corridor	-	Corridor	Corridor
J-1	Zangtheri	Sakteng W.S.	Multiple-Use	Multiple-Use	-
J-4	Jomotsangkha	Jomotsangkha W.S.	-	Multiple-Use	Multiple-Use
Total	29 sites				

(Source: JICA Survey Team)

(c) Evaluation and selection of project candidate sites where parts of hydropower components are located in a protected area

The MCA method was used to evaluate 29 project sites where part of the hydropower plant is located in a protected area.

As a result, there are 1) five sites where development is to be abandoned due to their affecting the natural environment at the core of the protected area (core zone etc.), 2) 18 sites that should be excluded as "Out of development prospects sites due to low MCA score", 3) 1 site where the facility construction site was changed outside the protected area, but the MCA overall evaluation score is low, so it should be excluded as a potential development site. A total of 24 sites as above were excluded from the development candidate sites. The remaining 5 sites (P-17, P-29, P-30, M-11 and K-13) were found to have little impact in terms of environmental and social considerations judging by the results of the site reconnaissance, their MCA scores were high and it is difficult to select alternative sites, so they were designated as "a promising site for development due to overall MCA score being high", and adopted as development candidate projects in protected areas (see Table 10-30).

Table 10-30 Selection Results for Projects with Part of Hydropower Plant located in a Protected Area

No.	Name		Results of site reconaisannce and overall MCA evaluation score
	Project	Protected area	
A-4	Kunzangling	Toorsa SNR.	Development is abandoned due to serious impact on the natural environment
W-3	Dodennang	Jigme Dorji N.P.	Inappropriate for development as promising site due to low overall MCA overall score
W-7	Getsa	Jigme Dorji N.P.	Inappropriate for development as promising site due to low overall MCA score
W-8	Zangkhepa	Jigme Dorji N.P.	Change the facility construction site to outside the protected area, however, inappropriate for development as promising site due to low overall MCA score
P-7	Puna Gom	Jigme Dorji N.P.	Inappropriate for development as promising site due to low overall MCA score
P-15	Tamigdamchu	Jigme Dorji N.P.	Development is abandoned due to serious impact on the natural environment
P-17	**Tseykha**	**Jigme Dorji N.P.**	**Promising development site due to high overall MCA score**
P-18	Jarona	Biological Corridor	Inappropriate for development as promising site due to low overall MCA score
P-19	Dangchhu	Biological Corridor	Inappropriate for development as promising site due to low overall MCA score

P-28	Kago-1	Jigme Singye Wangchuck N.P.	Development is abandoned due to serious impact to the natural environment
P-29	**Kago**	**Jigme Singye Wangchuck N.P.**	**Promising development site due to high overall MCA score**
P-30	**Pinsa**	**Jigme Singye Wangchuck N.P.**	**Promising development site due to high overall MCA score**
M-5	Bemji	Wangchuck C.N.P.	Development is abandoned due to serious impact on the natural environment
M-11	**Wangdigang**	**Jigme Singye Wangchuck N.P.**	**Promising development site due to high overall MCA score**
M-14	Tingtibi	Jigme Singye Wangchuck N.P.	Inappropriate for development as promising site due to low overall MCA score
M-15	Gomphu	Manas N.P.	Inappropriate for development as promising site due to low overall MCA score
M-19	Sermaling	Manas N.P.	Inappropriate for development as promising site due to low overall MCA score
C-3	Kurjey	Wangchuck C.N.P.	Inappropriate for development as promising site due to low overall MCA score
C-4	Chhutoe	Wangchuck C.N.P.	Inappropriate for development as promising site due to low overall MCA score
K-13	**Minjey**	**Corridor**	**Promising development site due to high overall MCA score**
K-19	Shongarchhu	Phrumsengla N.P.	Inappropriate for development as promising site due to low overall MCA score
G-3	Tshaling	Bumdeling W.S.	Inappropriate for development as promising site due to low overall MCA score
G-9	Gamrichu-3	Sakteng W.S	Development is abandoned due to serious impact on the natural environment
G-12	Rotpa	Bumdeling W.S.	Inappropriate for development as promising site due to low overall MCA score
Mo-1	Aiechhu 2	Biological Corridor	Inappropriate for development as promising site due to low overall MCA score
Mo-3	Pelrithang	Biological Corridor	Inappropriate for development as promising site due to low overall MCA score
Mo-4	Ronggangchhu	Biological Corridor	Inappropriate for development as promising site due to low overall MCA score
J-1	Zangtheri	Sakteng W.S.	Inappropriate for development as promising site due to low overall MCA score
J-4	Jomotsangkha	Khaling W.S.	Inappropriate for development as promising site due to low overall MCA score
Total	29 sites		

(Source: JICA Survey Team)

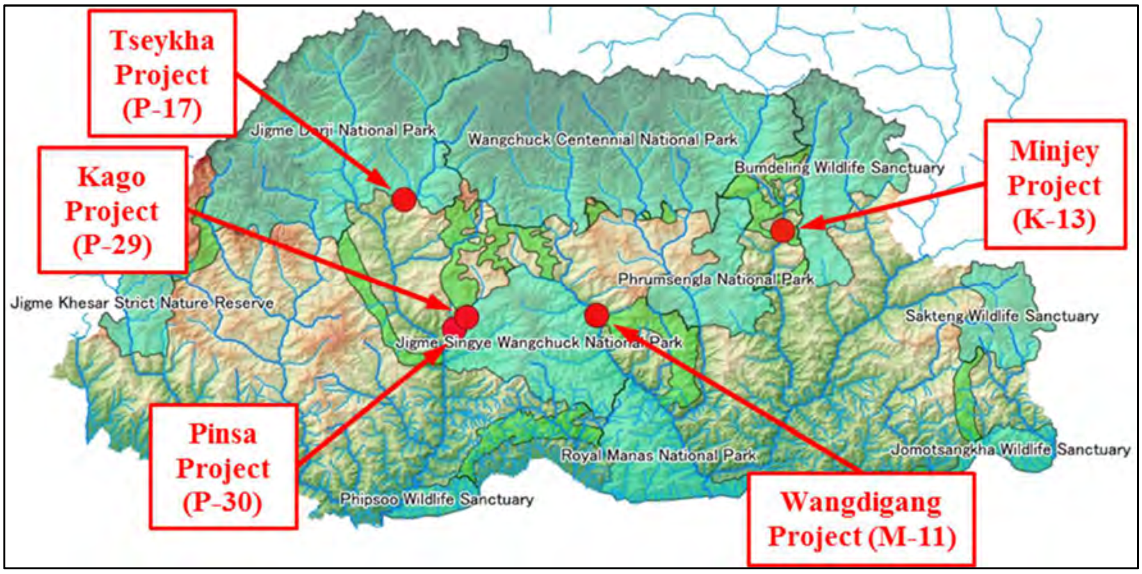
(d) Promising development projects where some of the hydropower facilities are located in protected areas (summary)

Although parts of their hydropower facilities are located in protected areas, the five sites in the table below were narrowed down as promising development candidate projects due to having high overall MCA scores, including for environmental and social considerations, and there being no other alternative areas.

Table 10-31 Projects located in Protected Areas (Summary)

Project code	Name		Results of overall MCA evaluation score
	Project	Protected area	
P-17	Tseykha	Jigme Dorji N.P.	Promising development site due to high overall MCA score
P-29	Kago	Jigme Singye Wangchuck N.P.	Promising development site due to high overall MCA score
P-30	Pinsa	Jigme Singye Wangchuck N.P.	Promising development site due to high overall MCA score
M-11	Wangdigang	Jigme Singye Wangchuck N.P.	Promising development site due to high overall MCA score
K-13	Minjey	Biological Corridor	Promising development site due to high overall MCA score
Total	5 sites		

(Source: JICA Survey Team)



(Source: JICA Survey Team)

Figure 10-14 Distribution of Projects located in Protected Areas

(2) Outline of promising development sites selected in protected areas and countermeasures for these sites

An outline of the environments located in protected areas but narrowed down as promising project sites, and the environmental protection measures examined to minimize the impact on the protected area (examination of alternatives), is given below:

(a) Tseykha (P-17) project site

■ Outline of Protected Area

Name: Jigme Dorji National Park

Year Designated: 1995, Area: 4,316km^2

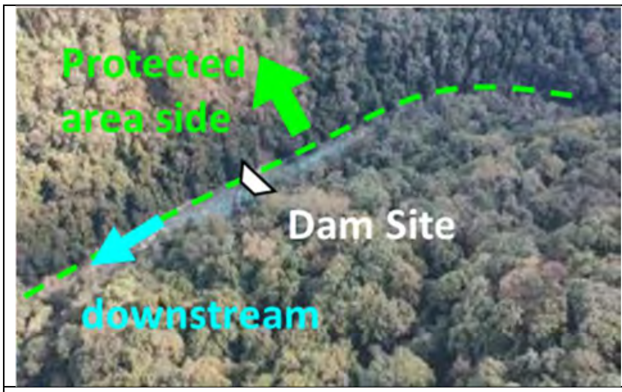
Outline: Located in the northwestern part of Bhutan, the northern and northeastern parts of the park border the Tibet Autonomous Region of China, and the border of the southern part is a river flowing through the valley.

It has a climatic zone that spans a subtropical zone and a 7,000m alpine zone at an altitude of about 1,400m, and it has subtropical broadleaf forest, warm temperate broadleaf forest, cold temperate broadleaf forest, coniferous forest, alpine meadows and various forest zones. It is rich in biodiversity because it has diverse vegetation zones as mentioned.

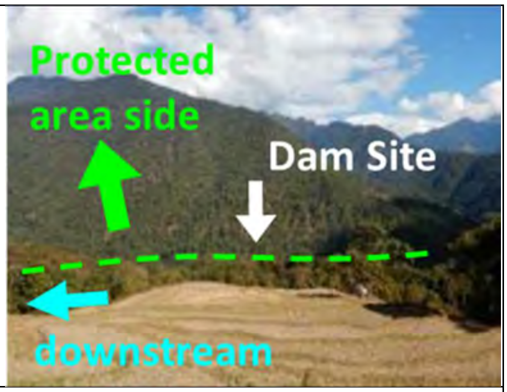
Although systematic environmental surveys covering the entire area have not been conducted, it has been reported that there are 36 species of mammals, 328 species of birds, 5 species of reptiles, 300 species of medicinal plants, and 39 species of butterflies (WWF).
No zoning system has been implemented (as of March 2019).

■ Possible impacts of hydropower project on protected area

Because a river (Pochhu) marks a border line with the protected area, part of the dam embankment to be installed in this river (the river right bank) covers the protected area. Most of the protected area in contact with the dam is native forest of Himalayan pine, but warm temperate evergreen broad-leaved trees grow on the belt on part of the southern slope of the lower bank.
The dam height is 20m, and part of the warm temperate evergreen broadleaf trees and Himalayan pine (about 1.3ha) is submerged.



Vegetation around Dam Site



Vegitation in protected area (Himalayan pine forest overlooked from the other side)

(Source: JICA Survey Team)

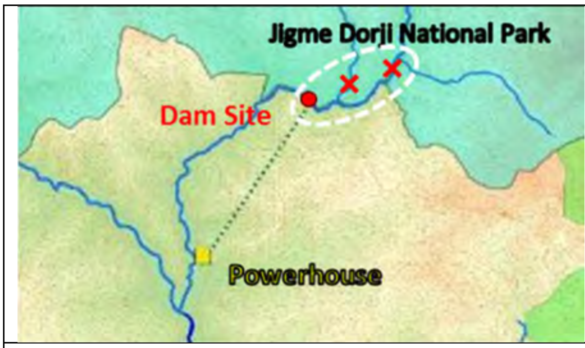
■ Examination of alternatives

a) Initial plan

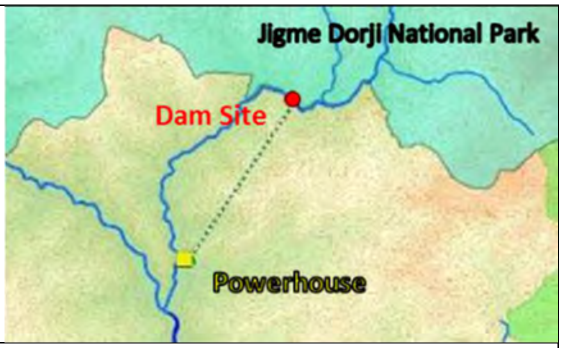
As a result of site reconnaissance for the optimum dam site in the upper stream of the high elevation river (range surrounded by white line: see the initial plan in the figure below), it was found that both sides of the river were covered by the protected area, and there was concern that the protected area around the dam would be submerged.

b) Alternative plan

The dam construction site was moved downstream to a technically feasible position to minimize the impact on the protected area. As a result, it was possible to stop the impact on the protected area only on the right bank of the river and to reduce the flooded area from about 5.2ha to about 1.3ha (25% of the initial plan).



Initial plan
(Search for candidate sites within the white frame)



Alternative plan

(Source: JICA Survey Team)

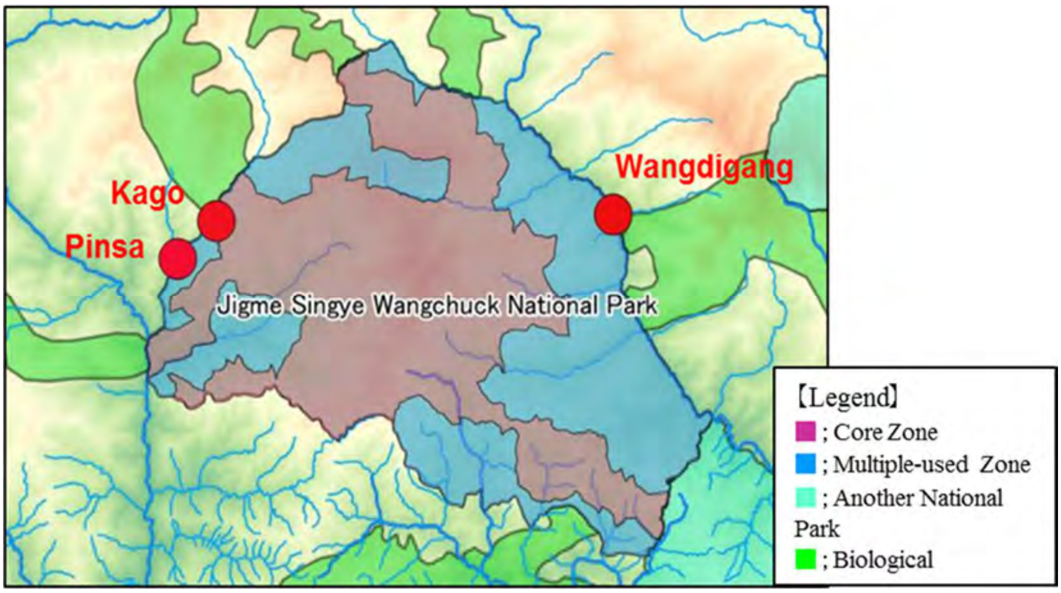
Figure 10-15 Comparison Figures for Initial and Alternative Plans in Tseykha (P-17) Project

(b) Kago (P-29) project site

- Outline of Protected Area

Name : Jigme Singye Wangchuck National Park
Year Designated: 1995, Area: 1,730km^2
Outline : Located in the central part of Bhutan, the south of the park borders the Royal Manas National Park, the north is connected to Jigme Dorji National Park and Wangchuck Centennial National Park and the northeast is connected to Phrumsengla National Park by a biological corridor. It is rich in biodiversity because it has subtropical to alpine meadows and diverse forest zones. Although systematic environmental surveys covering the entire area have not been conducted, it has been reported that there are 39 species of mammals, 270 species of birds, 139 species of butterflies and 16 species of fish. More than 5,000 people (588 families) live in protected areas.
Protected areas are maintained and managed based on zoning classification.
Park management is maintained and managed based on the following basic guidelines.

a) Conserve, protect and maintain the viability of specific ecosystems, and animal and plant communities in a way that will allow natural processes of succession and evolution to continue with minimal human influence.
b) Protect cultural, historical and religious sites
c) Contribute to the socio-economic development of park residents through sustainable use of park natural resources (according to DOFPS materials).



(Source: JICA Survey Team)

Figure 10-16 Jigme Singye Wangchuck National Park and Zoning Classification

- Possible impacts of hydropower project on protected area

Part of the weir installed on this river (left bank side) covers the protected area (designated as a multiple-use zone) as the river (Porichhu) is a boundary line with the protected area.
The reserve bordering the weir is virgin forest covered with warm and temperate evergreen broad-leaved trees. However, since the weir to be built in the riverbed is low (5m) and without water storage, land-change in the protected area due to construction and direct impact on the forest in the protected area due to flooding are not expected.

Vegetation around Weir Site
(the upstream from the weir is the core zone)

Landuse in protected area
(multiple-use zone)

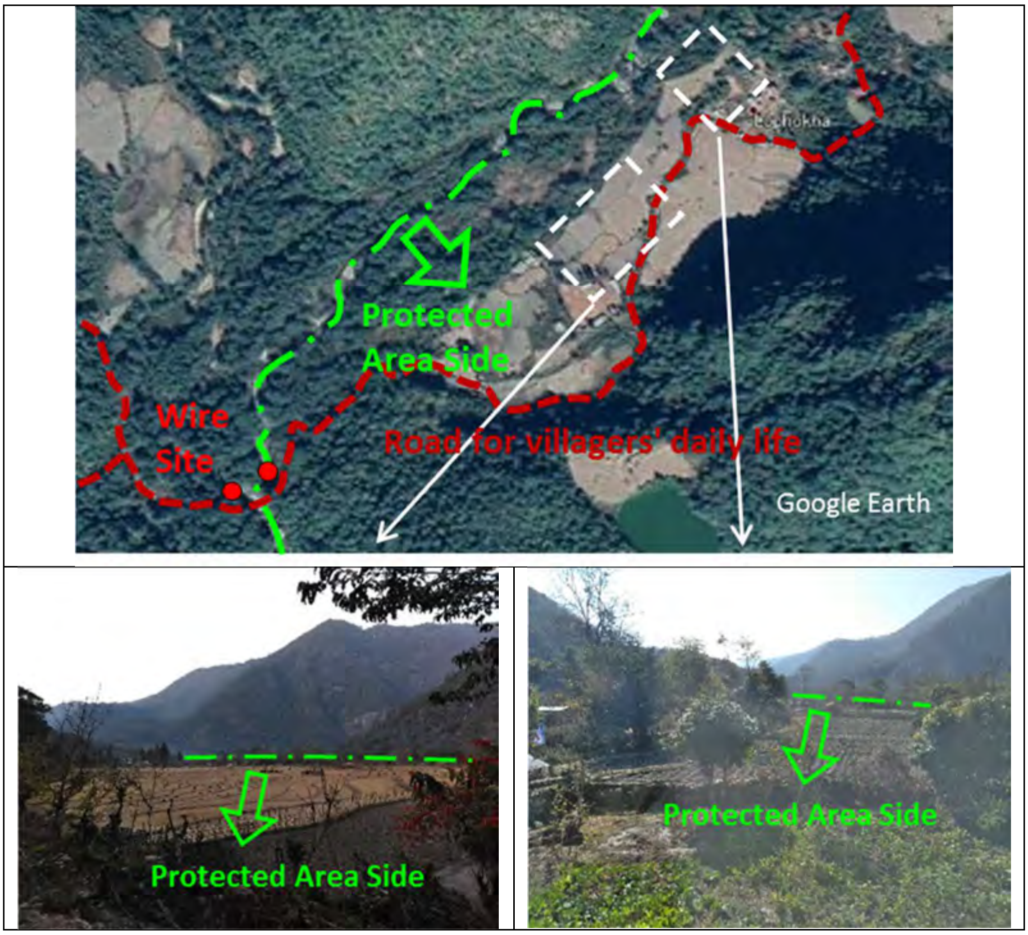
- Examination of alternatives

a) Initial plan

With construction of a 25-meter tall weir, serious impact (submergence) on forests in the protected area (warm and temperate evergreen broad-leaved forests) and land-change in the protected area are concerns.

b) Alternative plan

The height of the weir was changed to 5 m from 25m to avoid impact on the forest in the reserve. As a result, it is possible to avoid inundation of the forest (warm temperate evergreen broad-leaved forest) in the protected area.



(Source: JICA Survey Team)

(c) Pinsa (P-30) Project site

■ Outline of Protected Area

Name: Jigme Singye Wangchuck National Park
Outline: See Kago (P-29) above for the same protected area as Puroject Site

■ Possible impacts of hydropower project on protected area

Part of the weir installed on this river (left bank side) covers the protected area (designated as a multiple use zone) as the river (Porichhu) is a boundary line with the protected area.
The reserve bordering the weir is virgin forest covered with warm and temperate evergreen broad-leaved trees. However, since the weir to be built in the riverbed is low (5m) and without water storage, land-change in the protected area due to construction and direct impact on the forest in the protected area due to flooding are not expected.

Vegetation around Weir Site

(Source: JICA Survey Team)

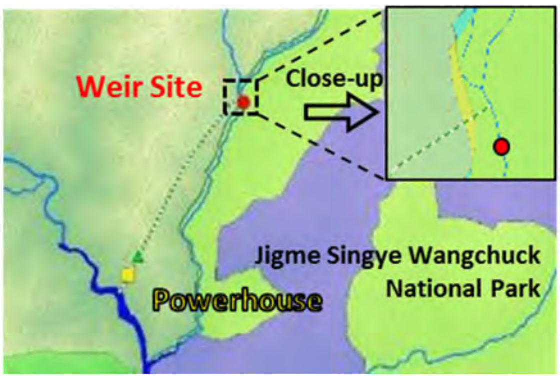
■ Examination of alternatives

a) Initial plan

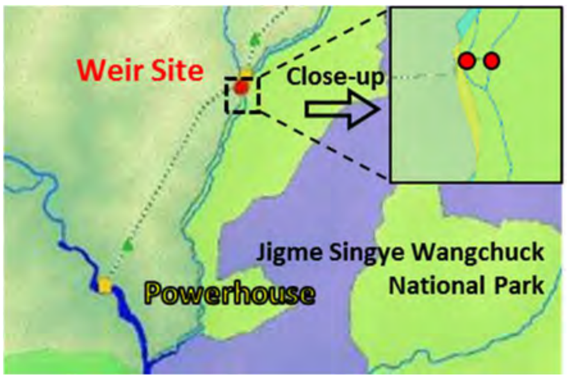
With construction of a 25-meter tall weir downstream where two rivers (Porichhu and Morichhu) join, serious impact (submergence) on forests in the protected area (warm and temperate evergreen broad-leaved forests) and land-change in the protected area due to construction are concerns.

b) Alternative plan

The construction site of the weir is changed to each tributary upstream from the confluence point and the height of the weir is reduced from 25m to 5m due to the change in construction site. Since the weir to be built in the riverbed is low (5m) and without water storage, land-change in the protected area due to construction and direct impact on the forest in the protected area due to flooding are avoided.



Initial plan



Alternative plan

(Source: JICA Survey Team)

Figure 10-17 Comparison Figures for Initial and Alternative Plans in Pinsa (P-30) Project

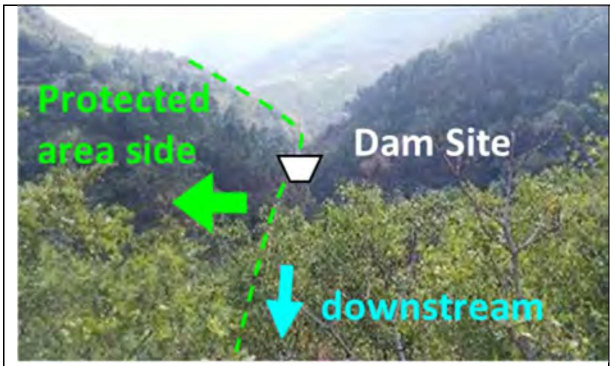
(d) Wangdigang (M-11) project site

■ Outline of Protected Area

Name: Jigme Singye Wangchuck National Park
Outline: See Kago (P-29) above for the same protected area as Puroject Site

■ Possible impacts of hydropower project on protected area

Part of the Dam installed on this river (Right bank side) covers the protected area (designated as a multiple use zone) as the river (Mangdechhu) is a boundary line with the protected area.
Due to the large size of the dam (bank height 100m), there is a concern that the protected area will be submerged (24.9ha) over a wide area.

	
Vegetation around Dam Site	Vegetation around Powerhouse (outside of Protected Area)

(Source: JICA Survey Team)

■ Examination of alternatives

a) Initial plan

Since the power plant is to be built in the biological corridor on the left bank of the river (Mangdechhu), there is concern about land modification of the biological corridor and the logging of trees.

b) Alternative plan

The construction site of the power plant was moved out of the biological corridor to avoid the impact on it.

Initial plan

Alternative plan

(Source: JICA Survey Team)

Figure 10-18 Comparison Figures for Initial and Alternative Plans in Wangdigang (M-11) Project

(e) Minjey (K-13) project site

- Outline of Protected Area

This protected area is a biological corridor connecting the three reserves of Phrumsengla National Park, Wangchuck Centennial National Park and Bumdeling Wildlife Sanctuary.

Biological corridors have been designated and managed based on a Regulation (Forest and Nature Conservation Rules and Regulations of Bhutan, 2017), which states "Biological corridors are areas set aside to connect one or more protected areas and facilitate movement of wildlife".

This biological corridor is mainly used as a transportation route for large mammals such as tigers and black bears. However, in recent years, there has been no evidence of use as an animal movement route due to progress in development inside and outside of the biological corridor (deforestation, cultivation, land development, etc.). For these reasons, the area is being considered for removal from the biological corridor (according to park office).

Vegetation around Dam Site

Vegetation around Powerhouse (underground)


Vegetation and Land-use inside Biological corridor (Mountainous area)
Natural vegetation (Himalayan pine) is cleared for rice and potato fields.


Vegetation inside Biological corridor (River bank)
Himalayan pine grows sparsely on a slope which became bare land.

- Possible impacts of hydropower project on protected area (Biological corridor)

A dam is to be constructed in a river (Kurichhu) that flows dividing a biological corridor about 3,750m wide in the north-south direction. With construction of the dam, part of the biological corridor (northern end) will be submerged for about 1,120m along the river (about 30% of the total length of the biological corridor). However, since a biological corridor of about 2,630m in length will be left along the river, it is assumed that the movement of large mammals, with a wide range of movement, will not be significantly disturbed.

When adverse impacts on the movement behavior of animals is assumed, it is necessary to consider an optimal plan or optimal environmental protection plan, including changing plans to avoid or minimize the adverse impacts, at the time of EIA.

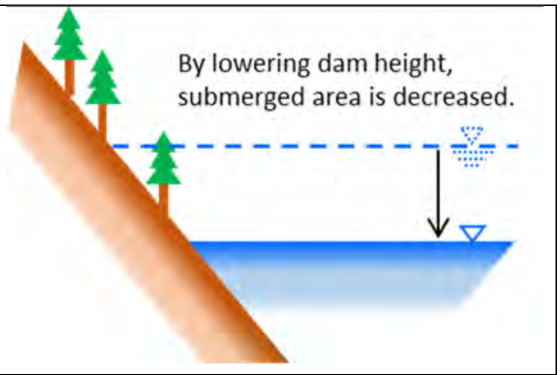
- Examination of alternatives

a) Initial plan

As the dam height is 150m and about 478ha (including outside the protected area) will be submerged, there is concern about the impact on the protected area (biological corridor).

b) Alternative plan

The dam height was lowered to 105m and the submerged area was reduced to about 205ha (including outside the protected area) to minimize the impact on the protected area (biological corridor).



Initial plan	Alternative plan Cross-Sectional view (illustration)

(Source: JICA Survey Team)

Figure 10-19 Comparison Figures for Initial and Alternative Plans in Minjey (K-13) Project

■ Confirmation of characteristics of IBA

At the EIA level, it is necessary to survey whether the IBA site falls under the following items. If applicable, this IBA site must be avoided or appropriate environmental conservation measures must be considered.

➢ The following areas are recognized as extremely important for biodiversity conservation and/or maintenance of the main functions of ecosystems.

- Important habitats for CR, EN, VU, and NT species listed on the International Union for Conservation of Nature (IUCN) Red List
- Important habitats for endemic species and/or species with limited habitat distribution
- Habitats that support globally important aggregates of migratory species and/or species likely making up such groups
- Areas with extremely critical ecosystems and/or unique ecosystems
- Areas associated with significant evolutionary processes

10.6.2 Implementation Requirements and Hydropower Projects within the Protected Area

The JICA Environmental and Social Considerations Guidelines state the following with regard to the implementation of hydropower projects in protected areas: "Projects must, in principle, be undertaken outside protected areas that are specifically designated by the laws or ordinances of the governments for conservation of nature or cultural heritage (excluding projects whose primary objectives are to promote protection or restoration of such designated areas). Projects are also not to impose significant adverse impact on designated conservation areas." Furthermore, project formation and implementation in such areas is limited to cases where all the following conditions are met.

a) There are no other viable alternatives outside protected areas that are specifically designated by the laws or ordinances of the governments for conservation of nature or cultural heritage (hereinafter "the same area").
b) Development activity in the same area is recognized in the domestic law of the governments that have jurisdiction over the project.
c) The implementing agency for the project must comply with the laws, regulations, and protected area management plans concerning the same area.
d) The implementing agency for the project has consulted with the responsible agency in the same area, the surrounding local communities, and other appropriate stakeholders, and an agreement has been reached on the project implementation.
e) The implementing agency for the project implements additional programs, as appropriate, to promote and enhance the conservation aims and effective management of the same area.

As a result of analyzing the adaptability of the above five conditions (see Table 10-32) at five project sites where parts of the hydropower facilities are located in protected areas, it can be judged that all five project sites are adapted to the five conditions.

Table 10-32 Examination Results for Hydropower Project Implementation Requirements in Protected Areas

	Action policy / Implementation requirements [40]	Content examined and confirmed at the SEA level
1	No other viable alternatives outside protected areas that are specifically designated by the laws or ordinances of the governments for conservation of nature or cultural heritage (hereinafter "the same area").	Of the 116 points extracted as potential hydropower development sites, 73 sites, or about 63%, corresponded to protected areas. Therefore, development was abandoned at 44 sites where all of the power generation facilities (dams, waterways and power plants) were located in protected areas. Alternative sites were then examined for the remaining 29 sites where some of the power generation facilities are located in protected areas. As a result of examining alternative sites, no viable alternatives were found for the five locations listed above (see 10.6.1). Since the river where the dam (weir) is to be constructed is used as the boundary of the protected area, four potential hydropower development sites among the five which involved constructing a dam in the river had no alternative sites where hydropower projects could be implemented at any point in the upper or lower river. The other site involves building a dam in rivers flowing north and south in a designated biological corridor, at a certain width in the east and west, and it was not possible to find alternative sites where this could be implemented outside the protected area (biological corridor). With regard to these five places, possible alternatives within protected areas that can avoid and minimize the impact on the protected area have been considered and adopted (see 10.6.1).
2	Development activity in the same area is recognized in the domestic law of the governments that have jurisdiction over the project.	Protected areas are designated and managed (Chapter 3, Article 48) based on "Forest and Nature Conservation Rules and Regulations of Bhutan, 2017" and the "approved protection management plan". The law clearly states that for development activities in a protected area the permission of Department of Forests and Park Services is required (Chapter 2, Article 14, paragraph 9), and states specific development activities, such as "any infrastructure and irrigation channel" (Chapter 7, Article 394, paragraphs 1 and 2). In addition, "deforestation of trees in the core zone" (Article 393, paragraph 1) and "quarrying, mining of minerals" (article 393, paragraph 3) are described as strictly prohibited activities. In Bhutan, there are cases where hydropower development projects in protected areas have been approved after EIA implementation. At the project implementation stage, confirmation is required again based on the specific project plan.
3	The implementing agency for the project must comply with the laws, regulations, and protected area management plans concerning the same area.	The project executing authority (DHPS) is required to implement an EIA based on the Environmental Assessment Act (2000) when implementing a project and to ensure that the content of the EIA is consistent with the protection and management plan for protected areas. At the project implementation stage, confirmation is required again based on the specific project plan.
4	The implementing agency for the project has consulted with the responsible agency in the same area, the surrounding local communities, and other appropriate stakeholders, and an agreement has	The plan for the hydropower project was explained to the local provinces (Dzongkhag), districts (Gewog), villages (Chiwog) and nearby residents gained a broad understanding of the project. Concerning relevant central administrative organizations and NGOs, their understanding of the project has been broadly confirmed through the stakeholder meetings held by law (four times). Agreement on the project is to be reached after

[40] Implementation requirements to be met when implementing a project in an area designated for nature conservation and cultural heritage protection

	been reached on the project implementation.	showing the specific project plan to the related organizations mentioned above once the feasibility study or IEE has been carried out and the feasibility of the project has been confirmed as a result. At the project implementation stage, confirmation is required again based on the specific project plan.
5	The implementing agency for the project implements additional programs, as appropriate, to promote and enhance the conservation aims and effective management of the same area.	In Bhutan, additional programs for environmental protection countermeasures, etc. will be imposed on the project as needed at the EIA level. At present (April 2019), the project executing authority is supporting an aquaculture project for migratory fish (Golden Masheer) and protection and breeding project for endangered species of White-bellied-heron as part of an additional program on power plant construction. As part of an additional program on power plant construction imposed at the EIA level in connection with the hydropower plant project currently under construction (April 2019), DHPS has supported an aquaculture farming program for migratory fish (Golden Masheer) , and the protection and breeding of endangered birds (white-billed heron). Even when the projects listed in this Master Plan are to be implemented, as the SEA emphasizes the need to protect and conserve migratory fish and endangered species, so it is assumed that the same environmental conservation measures should be imposed at the EIA level.

(Source: JICA Survey Team)

10.6.3 Implementation Policy for Hydropower Projects in Socially Vulnerable Areas

During this survey we reviewed whether 37 project sites identified in the primary screening process were located in areas that accommodated economically vulnerable people and/or people who thoroughly relied on traditional resources collected in mountainous areas or forests. The review was based on 1) existing data from the National Statistical Bureau and a literature survey, and 2) interview results with representatives of the Chiwog, Gewog and Dzongkhag Administrations where the project sites are planned.

As a result of the review, it was found that at this moment there are no such sites where local people can be seriously affected in economically and socially vulnerable communities, where they depend on limited traditional resources, in mountain and forest areas.

In addition, in examining the possibility that the project can indirectly affect the lifestyle activities of economically vulnerable groups based on the existing field survey, a minority fishing group was found around the reservoir at the P26 Thasa Project site; however, serious negative impacts could not definitely be confirmed during the survey for this project. Thus, implementation of a detailed social impacts survey is proposed upon conducting the EIA.

Socially vulnerable areas are generally located within and surrounding protected areas, far from urban areas, where local people depend on subsistence farming and there are almost no economic development opportunities. In the case of past hydropower development projects in Bhutan, positive impacts for neighborhood communities were found, such as employment opportunities in construction work, business opportunities in developing canteens or shops for the increased population inflow caused by the formation of colony (workers' camps) for the project's construction, and improved access to social services such as education and health facilities through the development of better roads. Therefore, it is important to incorporate project components that maximize such positive impacts in the project design.

10.7 Evaluation of Ecosystem at the Project Candidate Sites (Current Status and Evaluation of Endangered Species)

Based on the results of the primary screening study, the habitats of endangered species stipulated by the IUCN were investigated as part of the ecosystem survey at 37 project sites selected in the Semi-Longlist. The survey was conducted through interviews with forest offices, park offices and local residents who manage the site (the results are shown in the table below).
As a result of the survey, endangered species were found at 36 candidate sites (about 97% of the total), excluding one of the 37 candidates sites (W-6, Chuzom).
Analysis of endangered species based on their endangered degree (category type) confirmed that there are critically endangered species at nine candidate sites (about 24% of the total).
Endangered species were confirmed at 27 candidate sites (approximately 73% of the total), and Vulnerable species were confirmed at 32 candidate sites (about 86% of the total).
Based on the above survey results, the 36 candidate project sites are judged to be located in an ecologically important area inhabited by precious animals and plants based on international standards.
For this reason, in the Environmental Impact Assessment (EIA) conducted at the time of project implementation, it is necessary to conduct a detailed survey of animal and plant habitats, including the endangered species confirmed in this survey. In addition, it is necessary to implement environmental conservation measures that avoid and minimize the impact of the project on these species.

Table 10-33 Current Status of Endangered Species at Project Candidate Sites

Project code	Project	Category of endangered species			Evaluation
		Critically Endangered	Endangered	Vulnerable	
A-4	Kunzangling	-Chinese Pangolin	-Red Panda -Dhole -Mahseer	-	1
A-5	Tingma	-	-Mahseer	-Leopard -Asiatic Black Bear -Rufous-necked Hornbill -Schizothorax richardsonii	2
A-8	Dorokha	-	-Tiger	-Leopard -Rufous-necked Hornbill	2
W-6	Chuzom	-	-	-	5
W-8	Zangkhepa	-	-	-Sambar -Asiatic Black Bear	3
W-19	Pipingchhu	-	-Tiger -Asian Elephant -Mahseer	-Leopard	2
P-15	Tamigdamchu	-	-	-Leopard -Asiatic Black Bear	3
P-17	Tseykha	-	-Tiger	-Leopard -Asiatic Black Bear	2
P-26	Thasa	-White-bellied Heron	-	-Asian Small-clawed Otter	1
P-28	Kago-1	-White-bellied Heron	-	-	1
P-29	Kago	-	-	-Leopard -Asian Small-clawed Otter	3
P-30	Pinsa	-White-bellied Heron	-	-Asian Small-clawed Otter	1
P-34	Darachhu	-White-bellied Heron	-Tiger	-Cycas Pectinata -Rufous-necked Hornbill	1
P-35	Dagachhu-II	-White-bellied Heron	-Tiger	-Cycas Pectinata -Rufous-necked Hornbill	1
P-38	Tashiding	-White-bellied Heron	-Tiger	-Rufous-necked Hornbill	1
M-5	Bemji	-	-Tiger -Red Panda	-Leopard -Asiatic Black Bear	2

				-Takin	
M-6	Jongthang	-	-	-Leopard -Asiatic Black Bear	3
M-11	Wangdigang	-White-bellied Heron	-Mahseer	-Gee's Golden Langur -Sambar -Rufous-necked Hornbill -Cycas pectinate	1
M-17	Buli	-	-Tiger	-Leopard -Gee's Golden Langur	2
M-18	Nyekhar	-Chinese Pangolin	-Mahseer	-Snow Trout	1
C-7	Chamkharchhu-IV	-	-Red Panda -Himalayan Muskdeer -Tiger	-Black necked crane -Rufous-necked Hornbill -Chestnut breasted partridge	2
C-10	Chamkharchhu-II	-	-Tiger, -Mahseer	-Leopard	2
K-13	Minjey	-	-Tiger	-Leopard -Rufous-necked Hornbill	2
K-15	Phawan	-	-Tiger	-Leopard -Rufous-necked Hornbill	2
G-6	Khamdang	-	-Tiger	-Capped Langur -Leopard	2
G-7	Gongri	-	-	-Cycas pectinate	3
G-9	Gamrichhu-3	-	-Tiger	-Capped Langur	2
G-10	Gamrichhu-2	-	-Tiger	-Capped Langur	2
G-11	Gamrichhu-1	-	-Tiger	-Capped Langur	2
G-13	Sherichhu	-	-Red Panda -Tiger -Mahseer	-Leopard	2
G-14	Uzorong	-	-Mahseer	-Leopard -Black-necked Crane	2
G-16	Jerichhu	-	-	-Leopard	3
G-19	Nagor	-	-Mahseer	-Leopard -Asian Black Bear	2
G-22	Panbang	-	-Asian Elephant -Mahseer	-Gaur -Leopard -Asian Black Bear	2
N-1	NA Kangpara	-	-Mahseer	-Leopard -Asian Black Bear -Sambar	2
N-2	Lamai Gonpa	-	-Mahseer	-Leopard -Asian Black Bear -Sambar	2
N-3	Paydung-Kangpar	-	-Mahseer	-Leopard -Asian Black Bear -Sambar	2

(Source: Forest and Nature Conservation Act of Bhutan, 1995; Amendment 2017)

10.8 Cumulative environmental impact assessment in each basin

Targeting the 18 dams listed as promising development sites in the master plan, the cumulative impacts of multiple dams which will be added currently planned dams (weirs) and/or existing dams (weirs) in the same river basin are predicted in terms of impacts on migratory fish and sediment loads downstream.

10.8.1 Distribution of 18 sites to be constructed by the master plan and existing dams (including those under construction)

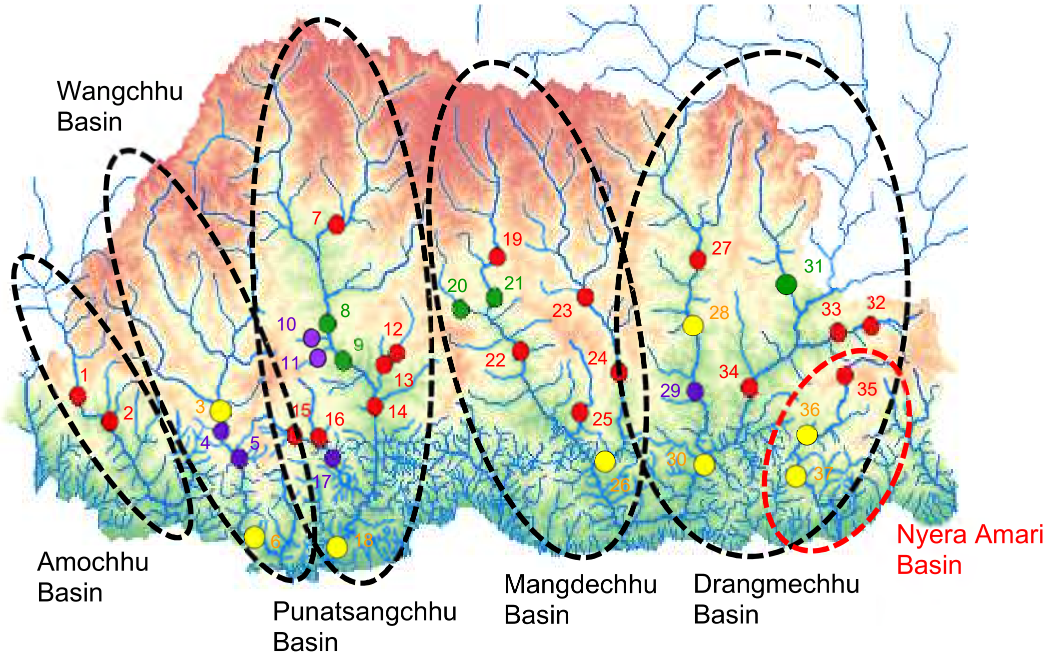
Table 10-34 and Figure 10-20 show the distribution and specifications of the 18 dams (weirs) to be constructed through the master plan and existing (including planned) dams (weirs). The type of dam to be constructed is all concrete gravity dams.
A cumulative impact assessment was conducted for the five basins of Amochhu basin, Punatsangchhu basin, Mangdechhu basin, Drangmechhu basin, and Nyera Amari basin. For the Wangchhu basin, there are no new dam (weir) constructions based on the master plan, so it is not included in the cumulative impact assessment forecast.

Table 10-34 Specifications of 18 sites to be constructed through the master plan and existing (including planned) dams.

Basin	New/ Existing /Planning	Project code	Name of Project	Type of Generation	Height of Dam(m)	Reservoir Area (ha)
Amochhu	New	A-5	Tingma	ROR	35	13.5
		A-8	Dorokha	ROR+Pond	57	52.7
Wangchhu	Planned	-	Bunakha	Pondage	168	
		-	Wangchhu	Pondage	96	
Punatsangchhu	New	P-17	Tseykha	ROR+Pond	20	5.2
		P-29	Kago	ROR	5	0
		P-30	Pinsa	ROR	5	0
		P-26	Thasa	ROR	85	131.8
		P-34	Dagachhu	ROR	5	0
		P-35	Dagachhu-II	ROR	5	0
	Existing	-	Basochhu-I	ROR+Pond	5	0
		-	Basochhu-II	ROR+Pond	5	0
		-	Dagachhu-I	ROR+Pond	26	
	U.C.	-	Punatsangchhu-I	ROR+Pond	71	
		-	Punatsangchhu-II	ROR+Pond	68	
	Planned	-	Sankosh	Reservoir	220	
Mangdechhu	New	M-6	Jongthang	ROR+Pond	25	94.4
		M-11	Wangdigang	ROR+Pond	100	99.6
		M-17	Buli	ROR	5	0
		C-7	Chamkharchhu-IV	Pondage	78	112.3
		C-10	Chamkharchhu-II	ROR+Pond	60	15.8
	U.C.	-	Mangdechhu	ROR+Pond	61	
		-	Nikachhu	ROR+Pond	38	
	Planned	-	Chamkharchhu-I	Pondage	86	
Drangmechhu	New	K-13	Minjey	Pondage	105	205.4
		G-10	Gamrichhu-2	ROR	25	0
		G-11	Gamrichhu-1	ROR	25	0
		G-14	Uzorong	Pondage	170	686.5
	Existing	-	Kurichhu	ROR+Pond	60	
	U.C.	-	Kholongchhu	Pondage	62	
	Planned	-	Dorjilung	Pondage	87	
		-	Kuri-Gongri	Reservoir	249	
Nyera Amari	New	N-1	N.A. Kangpara (G)	ROR	5	0
	Planned		Nyera Amari-I	Pondage	29	
			Nyera Amari-II	Pondage	15	0

U.C. : Under construction

(Source: JICA Survey Team)



Amochhu Basin			Punatsangchhu Basin			Mangdechhu Basin			Drangmechhu Basin		
1	A-5	Tingma	7	P-17	Tseykha	19	M-6	Jongthang	27	K-13	Minjey
2	A-8	Dorokha	8	U. C.	punatsangchhu-I	20	U. C.	Nikachhu	28	Planning	Dorjilung
Wangchhu Basin			9	U. C.	punatsangchhu-II	21	U. C.	Mangdechhu	29	Existing	Kurichhu
3	Planning	Bunakha	10	Existing	Basochhu-I	22	M-11	Wangdigang	30	Planning	Kuri-Gongri
4	Existing	Chhukha	11	Existing	Basochhu-II	23	M-17	Buli	31	U. C.	Kholongchhu
5	Existing	Tala	12	P-29	Kago	24	C-7	Chamkharchhu-IV	32	G-10	Gamrichhu-2
6	Planning	Wangchhu	13	P-30	Pinsa	25	C-10	Chamkharchhu-II	33	G-11	Gamrichhu-1
			14	P-26	Thasa	26	Planning	Chamkharchhu-I	34	G-14	Uzorong
			15	P-34	Darachhu	U. C. : Under Construction			Nyera Amari Basin		
			16	P-35	Dagachhu-II				35	N-1	N.A. Kangpara (G)
			17	Existing	Dagachhu				36	Planning	Nyera Amari-I
			18	Planning	Sankosh				37	Planning	Nyera Amari-II

(Source: JICA Survey Team)

Figure 10-20 Distribution and basins of 18 sites to be constructed through the master plan and existing dams (including those under construction)

10.8.2 Prediction on Impact on Migratory Fish and Sediment Inflow into Downstream

Bhutan has approximately 91 fish species. In terms of the main migratory fish[41], the habitats of Golden Mahseer, Indian Walking Catfish, Barak River Mountain Catfish[42], etc. have been recorded.
Here, Golden Mahseer which is widely distributed throughout each Bhutan basin and designated as an endangered species (EN) in the IUCN Red List (2018), is used as an indicator of the potential impacts caused by dams (weirs).
Golden Mahseer winters in a river near the Indian border in southern Bhutan, and goes upstream to spawn at the beginning of the monsoon season (June to September), before the river water volume increases. Golden Mahseer is estimated to fall downstream again after spawning, but the actual ecological life cycle situation is unexplored.
In addition, it is necessary to investigate the effect of a series of consecutive dams on the behavior and ecology of the migratory fish in the EIA to be conducted at the time of project implementation.
When adverse impacts on the migratory fish are assumed, it is necessary to consider an optimal plan or optimal environmental protection plan, including changing plans to avoid or minimize the adverse impacts.

Furthermore, Cumulative impact on sediment loads at downstream area were predicted when multiple dam (weir) are constructed in the same basin.

(1) Amochhu basin

Dams will be constructed at two locations in this basin, as shown in the table below.
The upper stream of this river is designated as a protected area (Jigme Khesar Strict Nature Rreserve), and ecological surveys and researches on the migratory fish Golden Mahseer are being conducted.

Table 10-35 Specifications of dams to be constructed in Amochhu basin

New/ Existing	Project code	Name of Project	Type of Generation	Height of Dam(m)	Reservoir Area (ha)
New	A-5	Tingma	ROR	35	13.5
	A-8	Dorokha	ROR+Pond	57	52.7

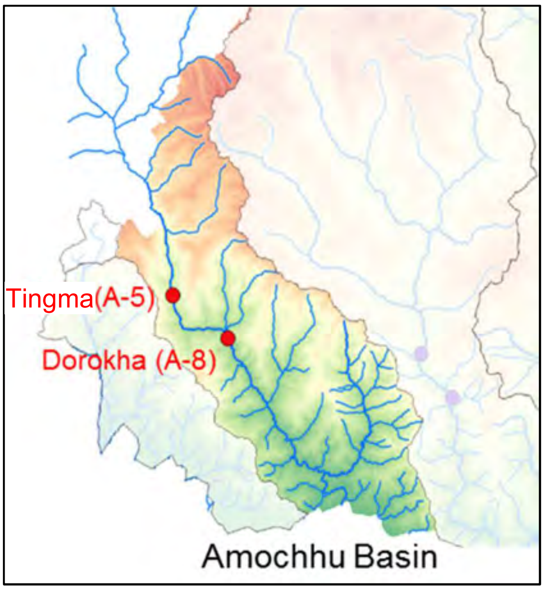
(Source: JICA Survey Team)

■ Impacts on migratory fish

From the ecological aspect of migratory fish, it can be said that the ideal river conditions are present in this basin, as there are no artificial structures to impede the upstream movement of Golden Mahseer. The dam construction is expected to cause adverse impacts on the upstream behavior, but these can be mitigated by installing fish passages in each dam.

■ Impacts on sediment loads at downstream

As there are large and small tributaries that supply a large amount of earth and stone flow into the downstream area of the dam, no impacts are expected on the sediment inflow in the downstream area due to the construction of each dam.



(Source: JICA Survey Team)

[41] The Fifth National Report to the Convention of Biological Diversity Secretariat (National Environment Commission, Royal Government of Bhutan, 2016)
[42] Potential Cumulative Impacts of Hydropower Development in The Kuri-Gongri Basin in Bhutan, 2018,World Bank

(2) Punatsangchhu basin

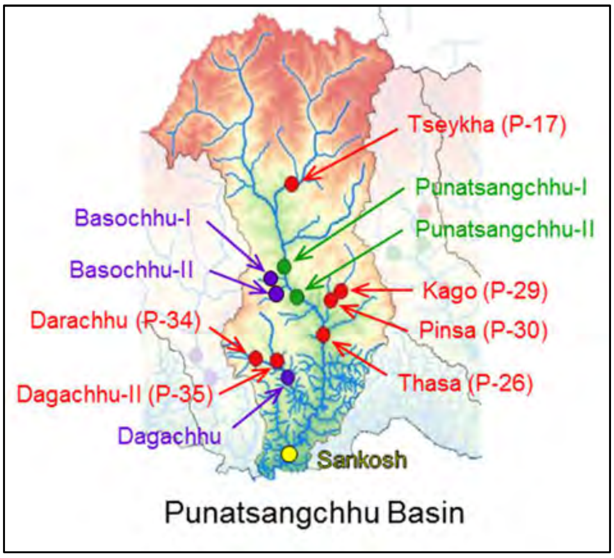
As shown in the table below, there are six existing dams (two of them are currently under construction, and one is at the planning stage). In this master plan, dams (weirs) are to be constructed at six locations.

Table 10-36 Specifications of dams (weirs) in (2) Punatsangchhu basin

New/ Existing/ Planned	Project code	Name of Project	Type of Generation	Height of Dam(m)	Reservoir Area (ha)
New	P-17	Tseykha	ROR+Pond	20	5.2
	P-29	Kago	ROR	5	0
	P-30	Pinsa	ROR	5	0
	P-26	Thasa	ROR	85	131.8
	P-34	Dagachhu	ROR	5	0
	P-35	Dagachhu-II	ROR	5	0
Existing	-	Basochhu-I	ROR+Pond	5	-
	-	Basochhu-II	ROR+Pond	5	-
	-	Punatsangchhu-I*	ROR+Pond	71	-
	-	Punatsangchhu-II*	ROR+Pond	68	-
	-	Dagachhu-I	ROR+Pond	26	-
Planned	-	Sankosh	Reservoir	220	

Note) * : under construction (Source: JICA Survey Team)

■ Impacts on migratory fish



(Source: JICA Survey Team)

- Since there is an existing (under construction) dam with no fish passage installed in the downstream area of the Tseykha (P-17) dam, no migratory fish have been found around this dam. Therefore, serious impact on migratory fish due to construction of the dam is not expected.
- Around Kago (P-29), Pinsa (P-30), Thasa (P-26), Darachhu (P-34), and Dagachhu-II (P-35), the five planned dams (weirs), migratory fish have been identified. After completion of the planned Sankosh dam (height 220m: water storage type) at the lowermost area downstream of the basin, the ecological behavior of migratory fish will be changed, so their extinction in this basin may also be predicted. However, as there are unknowns in the ecological behavior of Golden Mahseer, from this point, it can be reasonably assumed that the migratory fish winter in the main river and tributaries upstream from the Sankosh dam and go up for spawning, starting from here, to the cold water zone in the north. In this report, with the above assumptions, the impacts of dams on migratory fish are evaluated.
- Impacts on migratory fish caused by construction of the Kago (P-29) and Pinsa (P-30) dams (weirs) can be mitigated by the installation of fish passages because the dam height is low, but the Thasa (P-26) dam, which is planned for downstream of these two dams (weirs), may cause serious impacts by preventing the fish from going up from this point, due to its dam height (85m). At the time of project implementation, it is necessary to consider mitigation measures to ensure that the upstream movement of migratory fish is preserved (artificial fish capture and transportation project) or guidance measures to guide fish to a tributary.
- The existing dam (Dagachhu-I) located downstream of the Darachhu (P-34) Dam, and Dagachhu-

II (P-35) Dam has a fish passage. Therefore, as both dams to be newly built will have fish passages installed, the impact on migratory fish due to the new dams can be mitigated.

■ Impacts on sediment loads at downstream

A sediment sluicing gate is to be installed at dams (Thasa, P-26) newly constructed in the main river (Punatsangchhu), and there is a large amount of sediment supply from large and small tributaries in the downstream area. From this, no impacts are expected on sediment inflow downstream.

(3) Mangdechhu basin

There are 3 existing dams (two of them are currently under construction, and one is under planning) as shown in the table below. In this master plan, dams will be constructed at five locations.

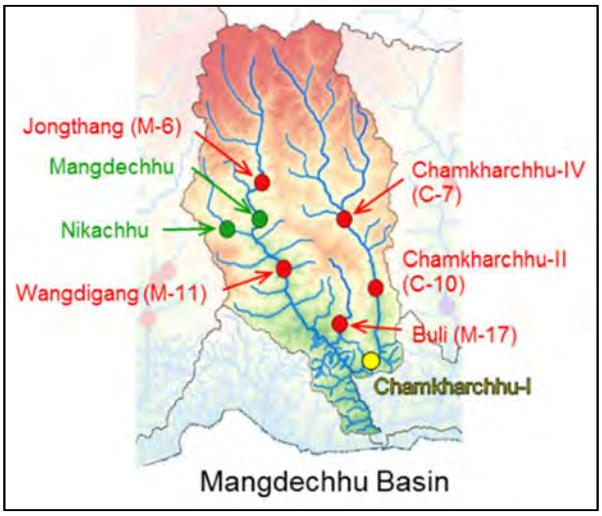
Table 10-37 Specifications of dam (weir) in Mangdechhu basin

New/ Existing/ Planned	Project code	Name of Project	Type of Generation	Height of Dam(m)	Reservoir Area (ha)
New	M-6	Jongthang	ROR+Pond	25	94.4
	M-11	Wangdigang	ROR+Pond	100	99.6
	M-17	Buli	ROR	5	0
	C-7	Chamkharchhu-IV	Pondage	78	112.3
	C-10	Chamkharchhu-II	ROR+Pond	60	15.8
Existing	-	Mangdechhu*	ROR+Pond	61	
	-	Nikachhu*	ROR+Pond	38	
Planned	-	Chamkharchhu-I	Pondage	86	

Note) * : under construction (Source: JICA Survey Team)

■ Impacts on migratory fish

➢ Due to the high dam height (100m) of Wangdigang (M-11), migratory fish are blocked at this site, which may cause a serious impact. At the time of project implementation, it is necessary to consider mitigation measures to ensure that the upstream movement of migratory fish is preserved (artificial fish capture and transportation project) or guidance measures to guide fish to a tributary. Even if the upstream movement support project is implemented, the existing Mangdechhu Dam and Nikachhu Dam upstream are not equipped with fish passages, so the upstream movement distance of migratory fish will be limited.



(Source: JICA Survey Team)

➢ Impacts on migratory fish, which inhabit the upper basin from Mangdechhu Dam, caused by construction of the Jongthang (M-6) dam (weir) can be mitigated by the installation of fish passages because the dam height is low (25m).

➢ Migratory fish species have been identified in the waters around the three dam (wire) sites of Chamkharchhu-II(C-10), Chamkharchhu-IV(C-7) and Buli(M-17). After completion of the planned Chamkharchhu-I (height 86m: pondage type) at the lowermost downstream of the basin, the ecological behavior of migratory fish will be changed, and then extinction of migratory fish in this basin (Buli is not applicable as connecting to other tributary) may be also predicted. However, as there is an unknown part in the ecological behavior of Golden Mahseer, from this point, it reasonably can be assumed that migratory fish winters in the main and tributaries upstream from the Chamkharchhu-I dam and going up for the spawning behavior starting from here to the cold water zone in the north. In this report, with the above assumptions, the impacts of dams on migratory fish are evaluated.

- The Chamkharchhu-II (C-10) dam, which is planned for downstream of Chamkharchhu-IV (C-7), prevents fish from moving upstream at this site because the dam height (60m) is high. There are concerns that the Chamkharchhu-IV(C-10) dam will have a significant impact on migratory fish. At the time of project implementation, it is necessary to consider mitigation measures to ensure that the upstream movement of migratory fish is preserved (artificial fish capture and transportation project) or guidance measures to guide fish to a tributary.
- Impacts on migratory fish caused by construction of the Buli (M-17) dam (weir) can be mitigated by installation of fish passages because the dam height is low.

■ Impacts on sediment loads at downstream

A sediment sluicing gate is to be installed at the three dams of Wangdigang (M-11), Chamkharchhu-II (C-10) and Chamkharchhu-IV (C-7), which are to be newly constructed, and there is a large amount of sediment supply from large and small tributaries in the downstream area. From this, no impacts are expected on sediment inflow downstream.

(4) Drangmechhu basin

There are 4 existing dams (one of them is currently under construction, and three of them are at the planning stage), as shown in the table below. In this master plan, dams will be constructed at four locations.

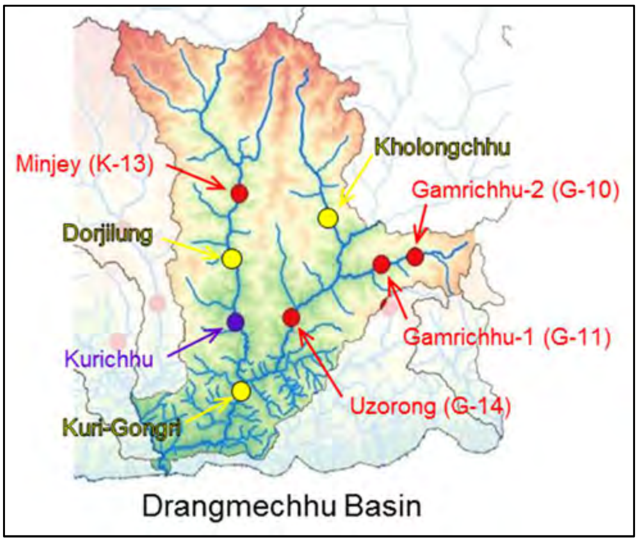
Table 10-38 Specifications of dams (weirs) in Drangmechhu basin

New/ Existing/ Planned	Project code	Name of Project	Type of Generation	Height of Dam(m)	Reservoir Area (ha)
New	K-13	Minjey	Pondage	105	205.4
	G-10	Gamrichhu-2	ROR	25	0
	G-11	Gamrichhu-1	ROR	25	0
	G-14	Uzorong	Pondage	170	686.5
Existing	-	Kurichhu	ROR+Pond	60	
Planned	-	Dorjilung	Pondage	87	
	-	Kuri-Gongri	Reservoir	249	
	-	Kholongchhu	Pondage	62	

(Source: JICA Survey Team)

■ Impacts on migratory fish

- Migratory fish have been identified around Gamrichhu-2 (G-10), Gamrichhu-1 (G-11), and Uzorong (G-14), three of the planned dams (weirs). After completion of the planned Kuri-Gongri dam (height 249m: Reservoir type) at the lowermost downstream area of the basin, the ecological behavior of migratory fish will be changed, so their extinction in this basin may also be predicted. However, as there are unknowns in the ecological behavior of Golden Mahseer, from this point, it can reasonably be assumed that migratory fish winter in the main and tributaries upstream from the Kuri-Gongri dam, and go up for spawning, starting from here, to the cold water zone in the



(Source: JICA Survey Team)

north. In this report, with the above assumptions, the impacts of dams on migratory fish are evaluated.

- There is an existing dam (Kurichhu) where a fish passage is installed in the lower reaches of the Minjey (K-13) dam. However, due to design problems it does not work efficiently, so migratory fish such as Golden Mahseer are blocked at this site (per information from an interview at a forest office). For this reason, there are no concerns about the impact of the Minjey (K-13) dam, which is planned for the upper reaches, on migratory fish.
- Impacts caused by construction of the Gamrichhu-2 (G-10) Dam, and Gamrichhu-1(G-11) Dam on migratory fish that inhabit the upper basin can be avoided, because the heights of the dam (25m) are low and the dams (weirs) are to be accompanied with water passages. However, after completion of the Uzorong (G-14) dam (height 170m: Pondage) at the lowermost downstream area of the basin, the ecological behavior of migratory fish will be changed, so their extinction in this basin may also be predicted. At the time of project implementation, it is necessary to consider mitigation measures to ensure that the upstream movement of migratory fish is preserved (artificial fish capture and transportation project) or guidance measures to guide fish to a tributary.

■ **Impacts on sediment loads at downstream**

A sediment sluicing gate is to be installed at the dam of Uzorong (G-14), which is to be newly constructed, and there is a large amount of earth and stone supplied from large and small tributaries in the downstream area. From this, no impacts are expected on sediment inflow downstream.

(5) Nyera Amari basin

There are 2 existing dams (at the planning stage), as shown in the table below. In this master plan, a dam (weir) will be constructed at one location.

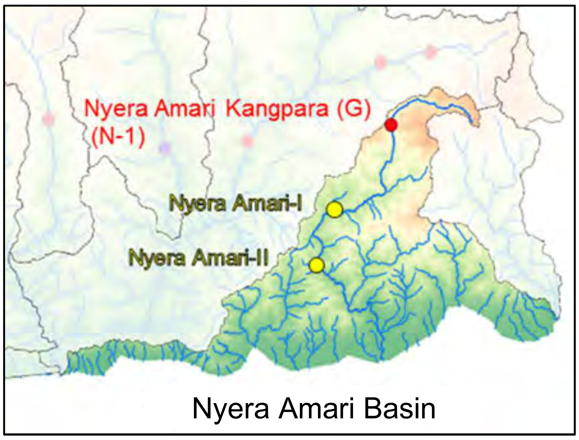
Table 10-39 Specifications of dams (weirs) in Nyera Amari basin

Basin	New/ Existing /Planned	Project code	Name of Project	Type of Generation	Height of Dam(m)	Reservoir Area (ha)
Nyera Amari	New	N-1	N.A. Kangpara (G)	ROR	5	0
	Planned	-	Nyera Amari-I	Pondage	29	
		-	Nyera Amari-II	Pondage	15	0

(Source: JICA Survey Team)

■ **Impacts on migratory fish**

N. A. Kangpara (G) (N-1) has a low dam (weir), with a height of 5m, so it is possible to mitigate the impacts on migratory fish via installation of a fish passage.



(Source: JICA Survey Team)

■ **Impacts on sediment loads at downstream**

Because the height of the dam (5m) is low, there is little risk of the sediment settling down, and there is also a large amount of earth and stone supplied from the large and small tributaries flowing in the downstream area. From this, no impacts are expected on sediment inflow downstream.

10.9 Climate Change

10.9.1 The Paris Agreement (PA)

Bhutan remains committed to addressing climate change. The Nationally Determined Contribution (NDC) to the Paris Agreement (PA) on climate change indicates that Bhutan is committed to remaining carbon neutral by adopting mitigation efforts supporting a low emission development pathway, ensuring that emissions will not exceed the carbon sequestration capacity.

Article 6 of the Paris Agreement establishes a framework for voluntary cooperation amongst the Parties in the implementation of the Agreement towards their NDCs through the use of international carbon market and non-market based approaches. Article 6.2 covers cooperative approaches among the Parties that involve internationally transferred mitigation outcomes (ITMOs) towards meeting their NDCs. Article 6.4 relates to the establishment of a mechanism to contribute to the reduction of emission levels in the host Party, which will benefit from mitigation activities resulting in emission reductions that can also be used by another Party to fulfill its NDC. The framework for non-market approaches to sustainable development is covered under Article 6.8.

While it is premature to understand the impact of the Paris Agreement on hydropower sector, hydropower continues to contribute significantly to climate change mitigation given that hydropower is an important renewable source of energy that contributes significantly to the avoidance of GHG emissions. Storage hydropower could also play an important role in climate change adaptation by maintaining the availability of water resources, ensuring the security of energy supply and furthering the ambitions of non-conventional renewable energy sources by providing a balancing power. Considering Bhutan’s huge potential for generating a significant share of renewable energy, the participation in Article 6 mechanism, as and when it takes shape in the future, will provide a huge opportunity to facilitate global mitigation ambition to meet the objectives of the Paris Agreement.

Article 6

1. Parties recognize that some Parties choose to pursue voluntary cooperation in the implementation of their nationally determined contributions to allow for higher ambition in their mitigation and adaptation actions and to promote sustainable development and environmental integrity.

2. Parties shall, where engaging on a voluntary basis in cooperative approaches that involve the use of internationally transferred mitigation outcomes towards nationally determined contributions, promote sustainable development and ensure environmental integrity and transparency, including in governance, and shall apply robust accounting to ensure, inter alia, the avoidance of double counting, consistent with guidance adopted by the Conference of the Parties serving as the meeting of the Parties to this Agreement.

3. The use of internationally transferred mitigation outcomes to achieve nationally determined contributions under this Agreement shall be voluntary and authorized by participating Parties.

4. A mechanism to contribute to the mitigation of greenhouse gas emissions and support sustainable development is hereby established under the authority and guidance of the Conference of the Parties serving as the meeting of the Parties to this Agreement for use by Parties on a voluntary basis. It shall be supervised by a body designated by the Conference of the Parties serving as the meeting of the Parties to this Agreement, and shall aim:

(a) To promote the mitigation of greenhouse gas emissions while fostering sustainable development;

(b) To incentivize and facilitate participation in the mitigation of greenhouse gas emissions by public and private entities authorized by a Party;

(c) To contribute to the reduction of emission levels in the host Party, which will benefit from mitigation activities resulting in emission reductions that can also be used by another Party to fulfil its nationally determined contribution; and

(d) To deliver an overall mitigation in global emissions.

5. Emission reductions resulting from the mechanism referred to in paragraph 4 of this Article shall not be used to demonstrate achievement of the host Party's nationally determined contribution if used by another Party to demonstrate achievement of its nationally determined contribution.

6. The Conference of the Parties serving as the meeting of the Parties to this Agreement shall ensure that a share of the proceeds from activities under the mechanism referred to in paragraph 4 of this Article is used to cover administrative expenses as well as to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.

7. The Conference of the Parties serving as the meeting of the Parties to this Agreement shall adopt rules, modalities and procedures for the mechanism referred to in paragraph 4 of this Article at its first session.

8. Parties recognize the importance of integrated, holistic and balanced non-market approaches being available to Parties to assist in the implementation of their nationally determined contributions, in the context of sustainable development and poverty eradication, in a coordinated and effective manner, including through, inter alia, mitigation, adaptation, finance, technology transfer and capacity-building, as appropriate. These approaches shall aim to:

(a) Promote mitigation and adaptation ambition;

(b) Enhance public and private sector participation in the implementation of nationally determined contributions; and

(c) Enable opportunities for coordination across instruments and relevant institutional arrangements.

9. A framework for non-market approaches to sustainable development is hereby defined to promote the non-market approaches referred to in paragraph 8 of this Article.

10.9.2 Green House Gas Emission Reduction

The hydropower plant is a power generation system which does not generate CO_2 during the operation of the plant. However, there may be an emission of CH_4 caused by the biochemical process from the small pond constructed to gain head and for operation flexibility but the quantum is usually insignificant. As such, the development of Hydropower plant in Bhutan has contributed significantly in the reduction of emission of Green House Gas (GHG) as well as in the neighborhood through the displacement of development of coal-fired thermal power plants.

According to the CO_2 Baseline Database for the Indian Power Sector, CEA (2016), the CO_2 emissions factor of 2016 is 0.82 t-CO_2/MWh. The factor is expected to gradually decrease with a promotional policy and fast pace development of renewable energy including hydropower plant in India. By developing 36.9GW of Hydropower plants with design energy of 154.1TWh in Bhutan, it will help in reducing the CO_2 emission in India from coal-fired thermal power plants by around 126.4 million tons of CO_2 annually. Therefore, it's expected to generate 126.4 million Certified Emission Reductions (CER), [One ton CO_2 is equal to one CER].

With regard to the CH_4, the assessment entails detailed data collections and information of reservoir storage, which is normally conducted during the project detailing. Therefore, due to the non-availability of reservoir impoundment data, CH_4 assessment was not carried out in this Master Plan. Moreover, the GHGs emissions from the reservoirs can be studied within the Environment Impact Assessment process.

At present, there is no active market for trading CO_2 emissions and it's difficult to estimate the trading prices. As a result, the benefit of CO_2 trading is not determined in this study.

10.9.3 Impacts caused by Climate Change

There are concerns about the occurrence of floods and GLOF due to global warming caused by climate change.

There are natural and anthropogenic causes of climate change. Natural factors include not only the atmosphere itself but also ocean fluctuations, the increase of aerosols (fine particles in the atmosphere) due to volcanic eruption, and changes in solar activity. In particular, the ocean, which accounts for 70% of the surface of the earth, exchanges heat and water vapor with the atmosphere through the sea surface, and fluctuations in the ocean current and sea surface temperature greatly affect the movement of the atmosphere. On the other hand, anthropogenic factors include an increase in greenhouse gases such as CO_2 accompanying human activities, an increase in aerosols, and deforestation. An increase in greenhouse gases such as CO_2 raises the surface temperature, and changes in vegetation such as deforestation affect the circulation of water and the amount of solar radiation reflected on the earth's surface.

In recent years, the concern for global warming due to the increase of atmospheric CO_2 concentration caused by the consumption of a large amount of fossil fuels, such as petroleum and coal, has intensified, and the concern about climate change due to anthropogenic factors has intensified.

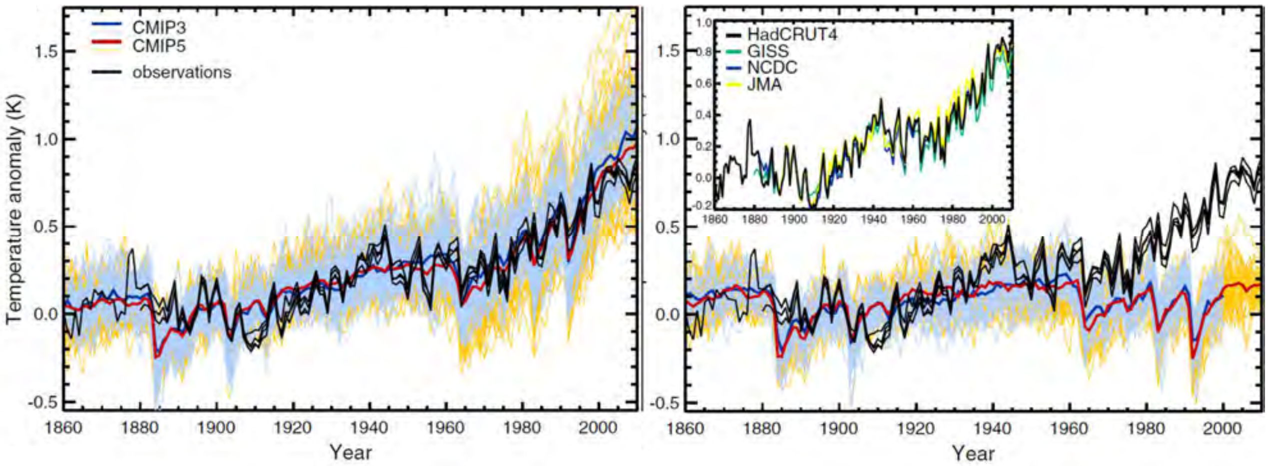
(1) Possibility of climate change caused by anthropogenic factors

The following is a comparison of near-surface air temperature (TAS) changes using multiple climatic models, with all radiative forcing[43] (left figure) and with only natural radiative forcing (right figure).

[43] External factors that reduce the earth's energy by radiation from the earth to the universe (lower the temperature) are called negative radiative forcing and external factors that raise the earth's energy by radiation from the universe to the earth (raise the temperature) are called positive radiative forcing.

This is an excerpt from a paper[44] published by Gareth S. Jones et al., who belong to the Meteorological Office, UK, in the Journal of Geophysical Research in 2013.

(with all radiative forcing) (with only natural radiative forcing)



Black lines: average for four observational data sets (Small figure on the right: comparison of four observational data)
Thin blue lines: Global annual mean TAS for CMIP3, Blue line: Weighted ensemble average for CMIP3
Yellow lines: Global annual mean TAS for CMIP5, Red line: Weighted ensemble average for CMIP5

Figure 10-21 Simulation Results on TAS[45]

The estimation results given all radiative forcing (left figure) are a good match with the observed global mean surface temperature deviation trend. On the other hand, according to the estimation results given by only radiative forcing of natural origin (right figure), the deviation from the actual temperature rise occurs in the late 20th century. In other words, the temperature rises in the latter half of the 20th century can't be explained by natural factors alone, and it is assumed that anthropogenic causes are included.

(2) Prediction of temperature and precipitation at the end of the 21st century

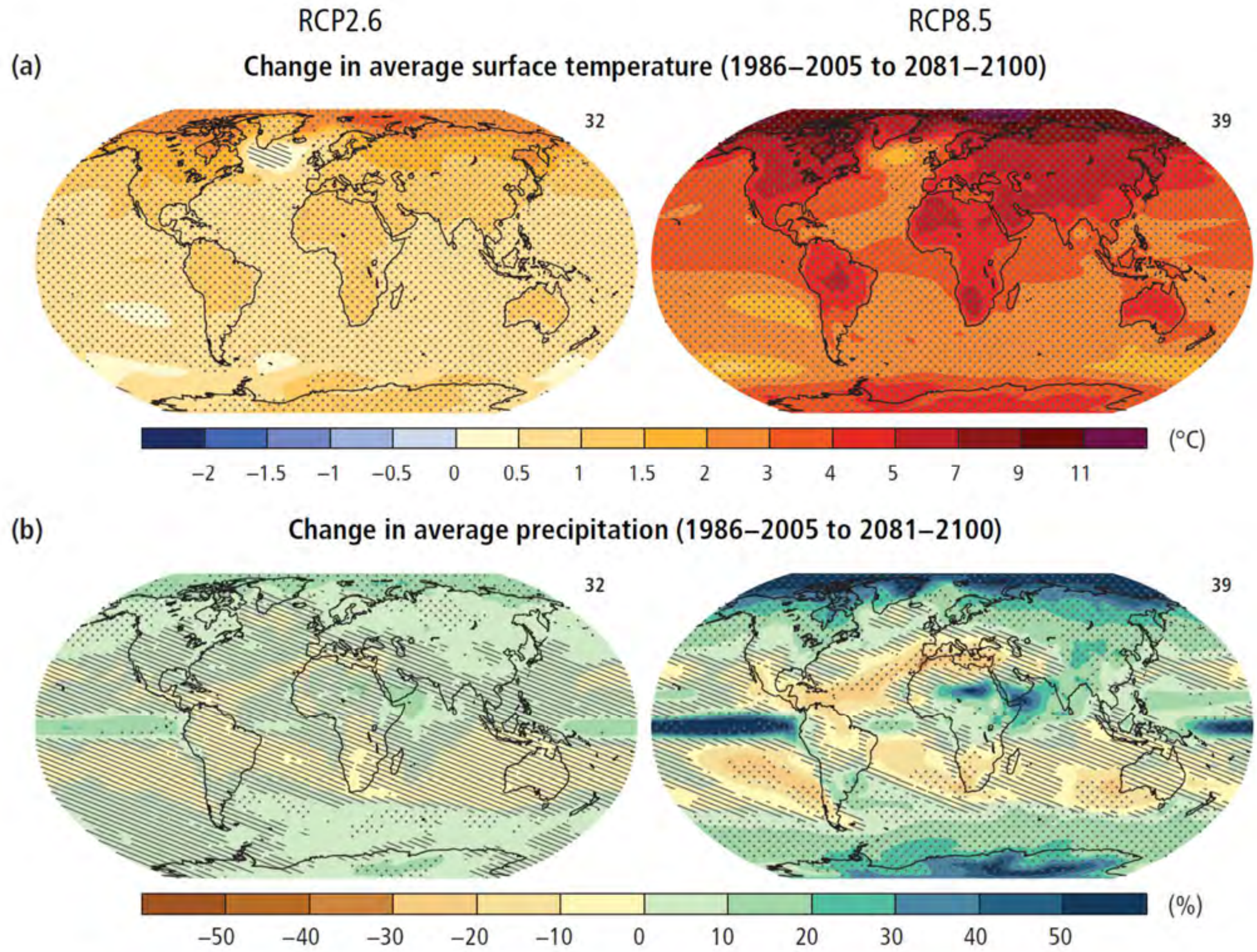
The following is a review of two papers on climate change that predicted temperature and precipitation at the end of the 21st century (2081-2100). The RCP scenario is shown as a scenario used by the Intergovernmental Panel on Climate Change (IPCC) in the fifth assessment report for climate forecasting. The representative concentration pathways (RCP) are shown on the assumption that the concentration of greenhouse gases will be stabilized in the future by differences in policy mitigation measures. Specifically, the following four scenarios are selected.

RCP 2.6 Low-level stabilization scenario: assuming temperature rise is limited to 2°C
RCP 4.5 Middle-level stabilization scenario
RCP 6.0 High-level stabilization scenario
RCP 8.5 High-level reference scenario: assuming no policy mitigation measures

[44] Attribution of observed historical near-surface temperature variations to anthropogenic and natural causes using CMIP5 simulations (JOURNAL OF GEOPHYSICAL RESEARCH: ATMOSPHERES, VOL. 118, 4001–4024, doi:10.1002/jgrd.50239, 2013)
[45] The CMIP3 model was used in the IPCC Fourth Report (2007), and the CMIP5 model was used in the IPCC Fifth Report (2013).

(a) IPCC Fifth Assessment Report[46]

In the Fifth Assessment Report issued by the IPCC in 2014, global surface temperature and precipitation changes at the end of the 21st century (2081 to 2100) are forecasted. The results are as follows.



(Source: Climate Change 2014 - Synthesis Report, IPCC)

Figure 10-22 Change Forecast in Surface Temperature and Precipitation

According to this report, the surface temperature change around Bhutan at the end of the 21st century (2081-2100) is expected to rise by only about 1.5°C for RCP 2.6 compared to the surface temperature from 1850 to 1900. However, in RCP 8.5, it is expected to be a large increase of about 5°C.

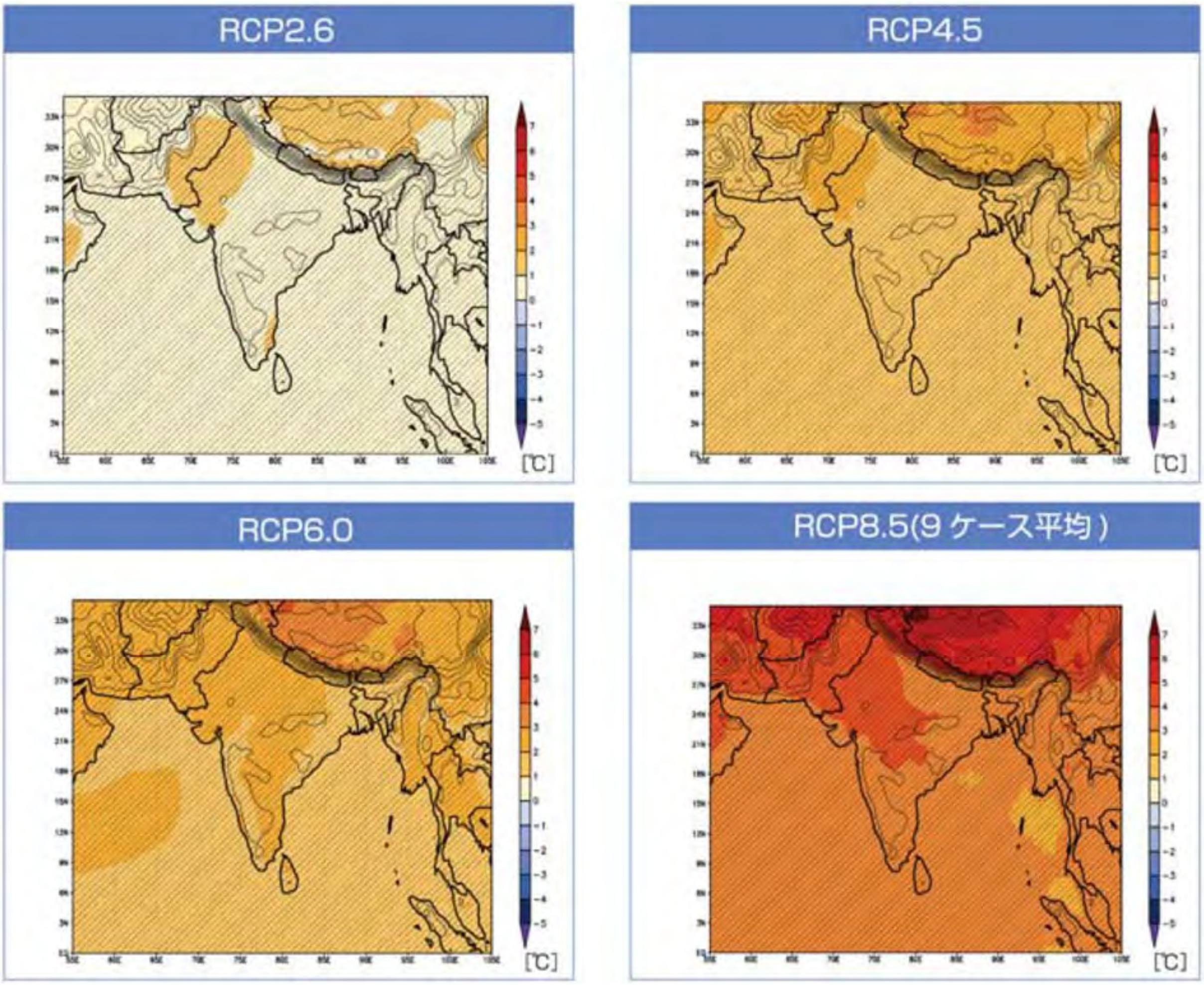
The change in precipitation is not uniform, with some areas decreasing and some increasing. Under the RCP 8.5 scenario, in many midlatitude and subtropical arid areas, average precipitation may decrease, but in many midlatitude wet areas, average precipitation may increase. It also predicts that extreme precipitation events occurring on most mid-latitude lands and tropical wetlands will be even more frequent.

46 https://www.ipcc.ch/site/assets/uploads/2018/02/SYR_AR5_FINAL_full.pdf

(b) Climate Change in South Asia (Ministry of Environment, Japan)[47]

The Ministry of the Environment (MOE) in Japan created a climate change projection dataset (global climate model outputs and regional climate model outputs) with a view to performing impact assessments and drawing up adaptation measures in Japan. The global climate model outputs (hereinafter referred to as "GCM data") are the results of calculations using an atmospheric model covering the entire world with an image resolution of about 60 km. For the future climate of 20 years from 2081 to 2100, 3 cases each for the RCP 2.6, RCP 4.5 and RCP 6.0 emission scenarios, and 9 cases for the RCP 8.5 emission scenario were calculated. The reason for performing calculations on multiple cases for the same scenario is to take into consideration uncertainties associated with future sea surface temperature patterns and the simulation method of climate change projection models. GCM data is prediction calculation data for not only Japan but the entire world, and the data is basically available in any country.

In March 2015, the MOE in Japan published the forecast results from GCM data in the South Asia region in a booklet called "Climate change in South Asia". The forecasted results of future climate changes described in the booklet are shown below.



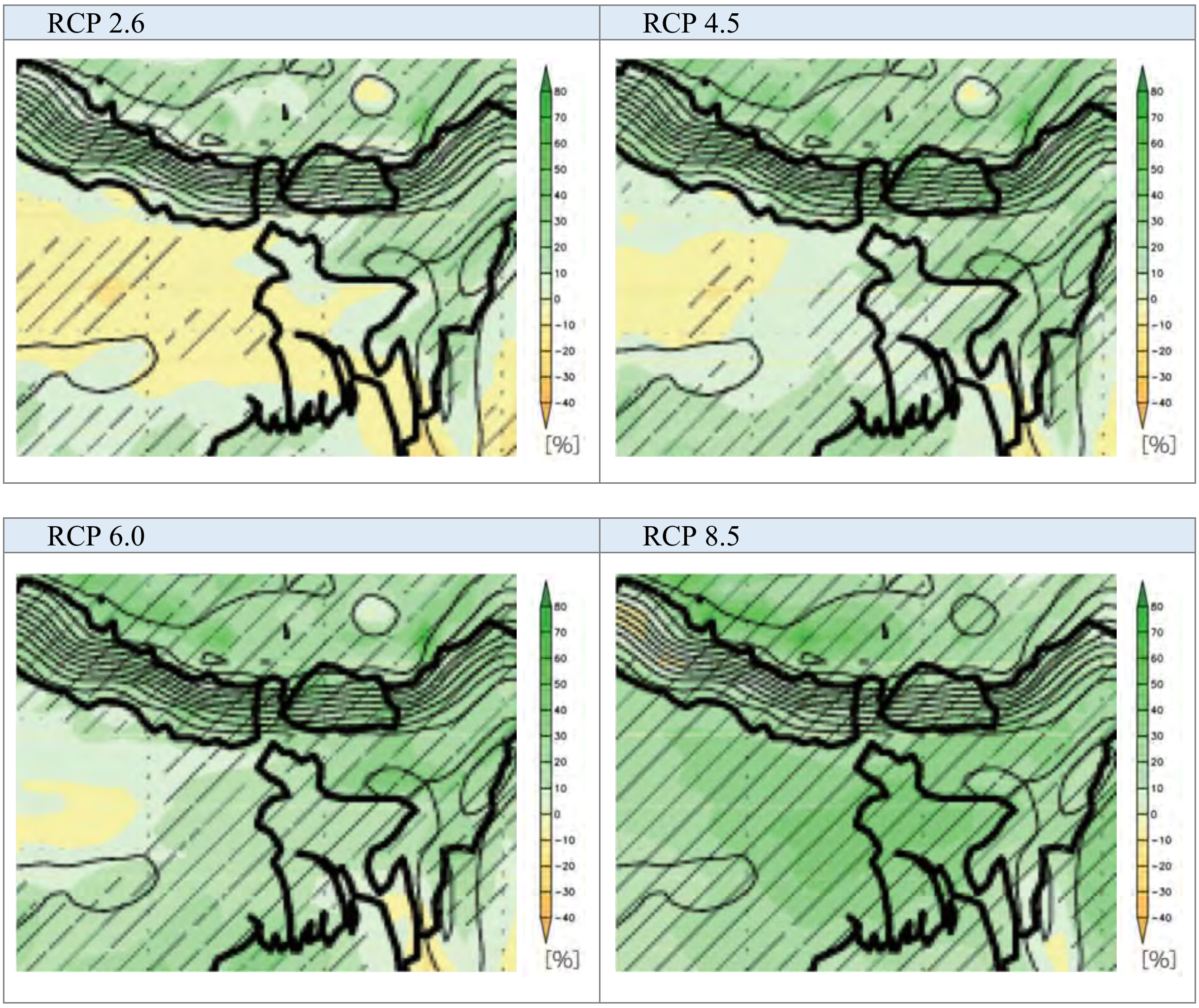
(Source: Climate change in South Asia, MOE in Japan)

Figure 10-23 Changes in Annual Mean Surface Temperatures in South Asia

The temperature tends to rise in every scenario. There is a regional pattern of temperature rise, and the amount of temperature rise around high latitudes and the Himalayas is large.

The forecasted future precipitation changes around the Bhutan area are shown below.

[47] https://www.env.go.jp/earth/ondanka/pamph_gcm/gcm_southasia_en.pdf

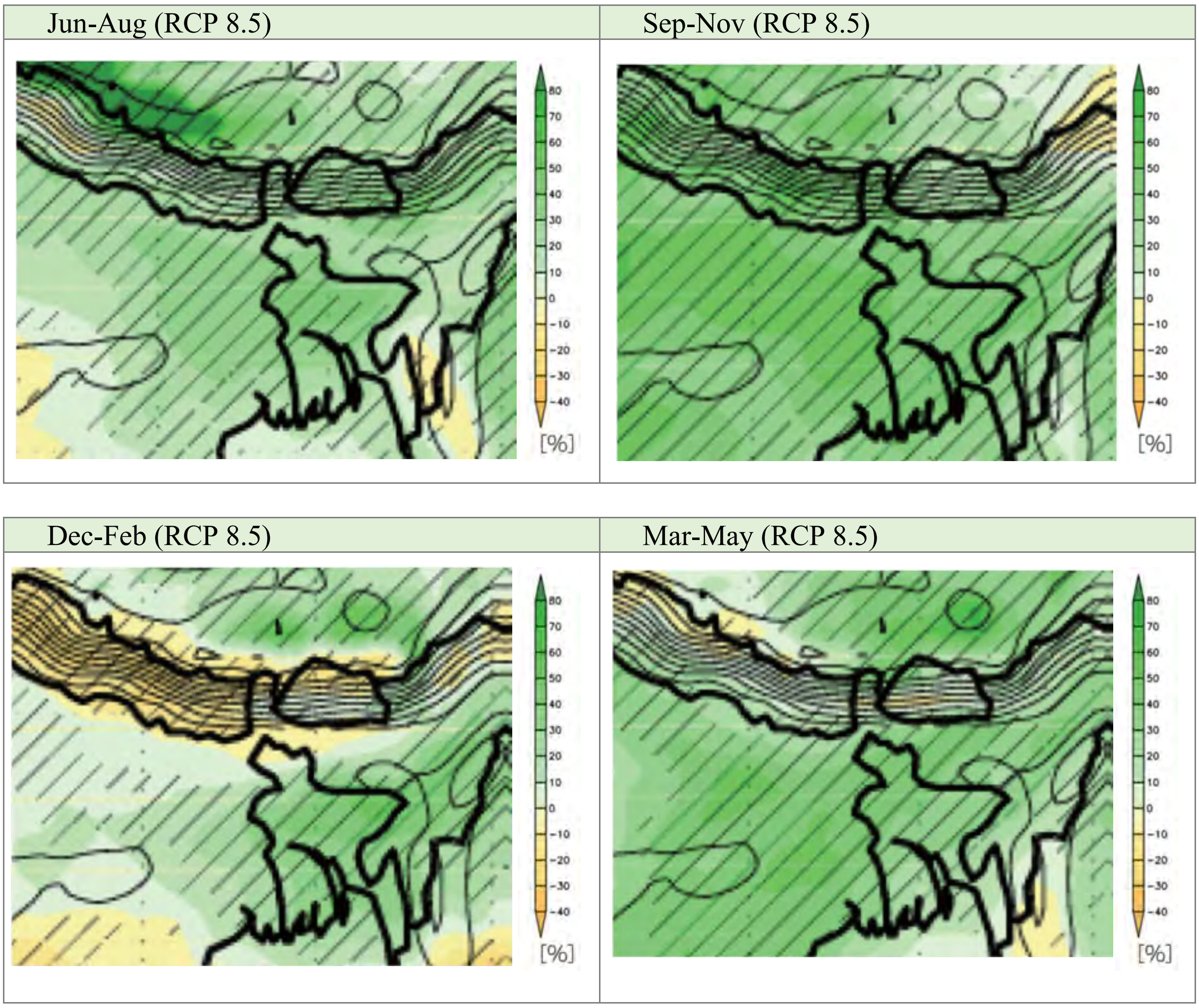


(Source: Climate change in South Asia, MOE in Japan)

Figure 10-24 Changes in Annual Mean Precipitation around Bhutan

The forecasted change in annual precipitation around Bhutan tends to decrease slightly in the south, but it is assumed that there will be no significant changes overall. When comparing each scenario, it can be confirmed that the precipitation tends to increase slightly as the concentration pathways become larger (from RCP 2.6 to RCP 8.5), but the amount is very small, and future annual precipitation is considered to have not changed significantly compared to the current situation.

The following shows the changes in precipitation for each season for the RCP 8.5 scenario.



(Source: Climate change in South Asia, MOE in Japan)

Figure 10-25 Changes in Precipitation by Season

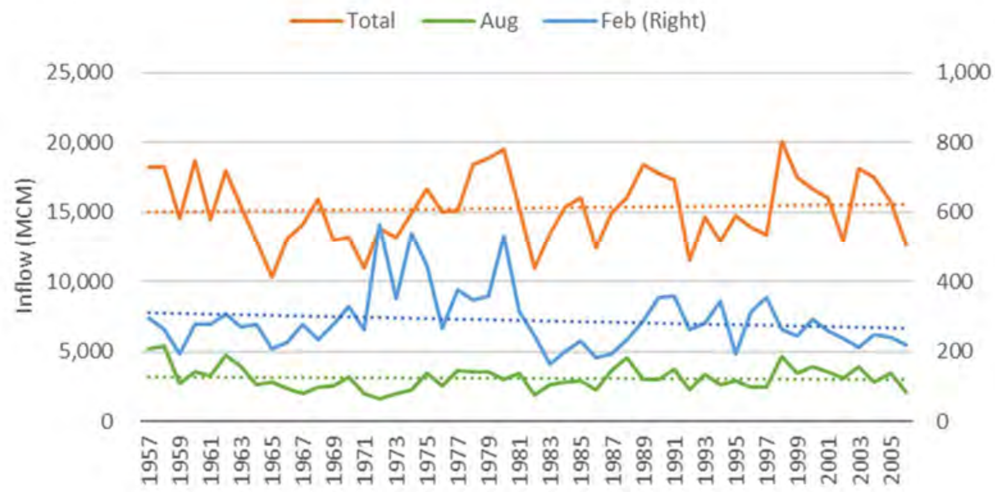
The difference between seasons is large, and it tends to increase from June to November (rainy season) and decrease from December to February (dry season). Note that this figure shows the average value of the 9 cases studied, and the meshed areas indicate areas where the signs of future changes coincide in all cases (areas with high confidence). The forecast from December to May is considered to be uncertain as it is not meshed.

The degree of impact of climate change varies depending on the scenario, but it is assumed that the probability of occurrence of GLOF will increase because the amount of temperature rises around the Himalayas due to global warming is large. It is assumed that the change in annual precipitation will not be particularly large, and the annual power generation by hydropower plants will not change too much. However, unless countries keep pace with the global warming prevention measures on a global scale, it is assumed that the size and probability of occurrence of floods will increase in the future.

(3) Transitional changes in river flow

In Bhutan, there is concern that climate change may have a major impact on the amount of power generated by hydropower plants, which is one of the income sources for Bhutan.

The following shows the river inflow at the Sankosh dam site via calculation using the basin area ratio based on 50 years of river flow data from 1957 to 2006, measured at a river gauging station near Sankosh.



(Source: DPR of Sankosh Power Plant)

Figure 10-26 Transitional Results for River Inflow at the Sankosh Dam Site

The total annual inflow has shown a slightly increasing trend in 50 years, but a slightly decreasing trend in the dry season of February. However, there is a large variation in the river flow every year, and it is difficult to say that these tendencies are remarkable from the data for the past 50 years.

10.9.4 Impact on Climate Change

It is considered that there are almost no adverse effects on climate change with hydropower development. Although not directly affecting climate change, the expected effects from hydropower development are as follows.

(1) CO_2 emissions

Unlike power generation using fossil fuels, hydropower generation is a power generation method that does not generate any CO2. Therefore, it is possible to reduce the CO2 emissions emitted from thermal power plants in export partner countries by developing a hydropower plant that utilizes abundant water resources in Bhutan and selling electricity to neighboring countries such as India. On a global scale, this contributes to the prevention of global warming.

(2) Flood control

Due to climate change, there is concern about the occurrence of huge typhoons and GLOF. It has been pointed out that there will be a huge impact when a huge natural disaster occurs, sediment flows into the dam lake for the hydropower plant, and power generation has to be stopped for a long time due to the inability to take in water. However, if the dam does not exist, this would cause very serious damage to the lives of many residents living downstream.

Since dams for power generation essentially do not have a capacity for flood control, they cannot avoid flooding. However, they have the function of temporarily stopping debris flow from the upstream, and this can be expected to mitigate the damage due to debris flow that occurs with floods and GLOF. However, if the flood flow rate can't be processed, the dam body may be destroyed, causing serious damage downstream. Therefore, it is necessary to design flood flows considering the impact of future climate change.

Chapter 11. GIS Database

Information such as catchment areas, longitudinal profiles of rivers, important facilities and protected areas, obtained from geospatial information, are important input for the evaluation and examination of potential sites, river flow rates, and the scale of power generation. Therefore, it is important to organize and utilize geospatial information in hydropower planning.

Technology transfer for database creation and management and GIS processing methods was carried out. It aims to allow DHPS to collect, edit, update and analyze geospatial information using GIS in order to organize information for the hydropower plan.

11.1 GIS Database Establishment

Geospatial information related to this project was collected from relevant organizations, such as NLCS (National Land Commission Secretariat), DHS (Department of Human Settlement), NCHM, etc., and a GIS database was established.
Regarding the base-map as a background, an existing 1/50,000 topographic map provided by NLCS and a new topographic map from "Project on Establishment of National Geo-Spatial Data Infrastructure for Bhutan" (Southern part of Bhutan, 1/25,000), and satellite imagery from "Project for Formulation of Comprehensive Development Plan for Bhutan 2030" (Whole country, 1/25,000 level) were utilized.

11.1.1 GIS Data

In the establishment of the GIS database, in order to integrate the geospatial information collected, such as topographic maps and satellite images, in overlaying it on the base-map, "DRUKREF 03", which is the national coordinate system in Bhutan, was defined as the standard coordinate reference system (hereinafter referred to as the CRS) for this project.

- CRS in the GIS database
  Coordinate system: DRUKREF03/Bhutan National Grid
  Ellipsoid: GRS 1980
  (Equator radius a = 6, 378, 137.000 m, oblateness 1 / f = 298.257333101)
  Unit: meters

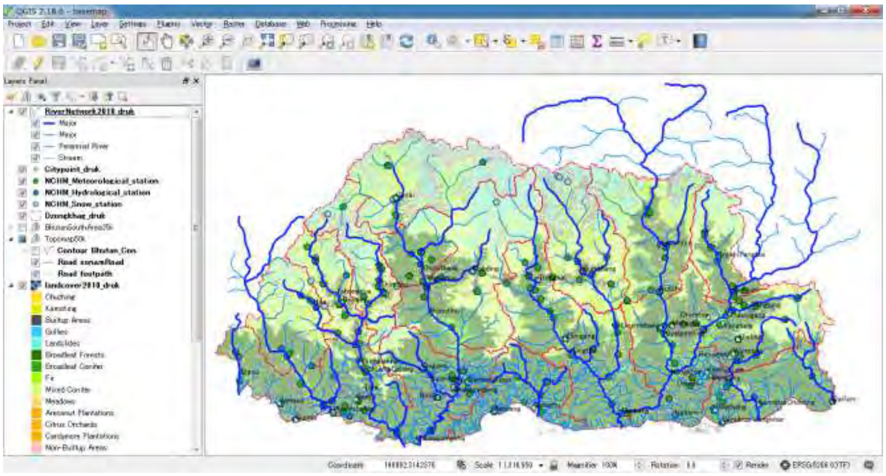
The geospatial information collected was converted into "Shape file format", which can be handled by GIS, with the "DRUKREF 03" CRS. An existing PC owned by DHPS was used as a data-server to manage, organize and backup the geospatial information. Each piece of data is stored in a prescribed folder, classified as administrative circle, transportation, vegetation, water department, topography, etc., depending on its content, and it can be used in ordinary activities by DHPS. Considering data sharing in the future, technology transfer of information security was also introduced.

Table 11-1 Contents of the GIS Database

Folder Name	Data Content
_00_project	QGIS project file
_01_Boundaries	Administrative boundaries
_02_Transportation	Roads and Transportation
_03_Buildings	Buildings/Facilities
_04_Utilities	Power/Water supply/Communications
_05_Industries	Factories/Mines
_06_Vegetation_and_Specific_Area	Specific Area/Land use /Vegetation/National Parks/Reserves
_07_Hydrography	Rivers/Lakes/Swamps/Ponds
_08_Terrain	Terrain/DEM

Folder Name	Data Content
_10_Annotation	Place names/Facility Names
_11_Info	Source information
_20_maps	Thematic map data
_30_BaseTopomap	Existing 1/50,000 topographic map New 1/25,000 Southern Bhutan topographic map
_31_SatelliteImagery	Satellite Imagery
_90_Document	Manuals or Related documents

(Source: JICA Survey Team)



(Source: JICA Survey Team)

Figure 11-1 GIS Database Establishment using QGIS

Using an integrated GIS database based on the existing geospatial information and functions that GIS has, such as "overlay layers", "measurements" and "analysis", enables us to perform spatial analysis combining various types of information. Based on the geospatial information, it is possible to comprehensively evaluate various factors to be considered in the hydropower plan, such as geology, environmental and social considerations, and protected areas.

The GIS database established for utilization in the formulation of MP 2040, and the effects obtained from GIS analysis, are as follows.

Table 11-2 Utilization of GIS Database

<table>
<tr><th>GIS database</th><th>Analysis</th><th>Effects</th></tr>
<tr><td>Topographic maps
Satellite imagery</td><td>◆ Geographic situation
(Mountainous areas, Flat land, Sloping terrain etc.)</td><td rowspan="6">➢ Select optimum location of dam and power station
➢ Consideration of waterway route
➢ Calculation of power generation scale
➢ Select optimum site for power pylons under transmission line and substation facilities
➢ Construction plan
➢ Power network diagram</td></tr>
<tr><td>River information
DEM
(Numerical Elevation Model)</td><td>◆ River basin and catchment areas and extent
◆ River slope, River width
◆ Topographic situation in upstream area</td></tr>
<tr><td>Buildings
Facilities</td><td>◆ Cultural or historical sites, Heritage
◆ Resident areas, Religious facilities, Important facilities
◆ Relocation</td></tr>
<tr><td>Roads</td><td>◆ Accessibility</td></tr>
<tr><td>Land use
(Public/Private)</td><td>◆ Land acquisition
◆ Relocation</td></tr>
<tr><td>Land use
(Designated area)</td><td>◆ Protected areas, Natural parks, Natural environment conservation areas</td></tr>
</table>

(Source: JICA Survey Team)

11.1.2 GIS Thematic Map Creation

Based on the GIS database, thematic map data, which is an element in the evaluation and examination of the potential sites, was created includes Background base-map, River basin area, River profile, Water surface area etc.

(1) Background base-map creation

For the formulation of MP 2040, such as in the evaluation and examination of potential sites, hydropower planning etc., firstly, a background base-map is needed to ascertain the topographic situation across the whole country. It is important for hydropower generation to use background base-map that can identify terrain information and height information. Therefore, contour line data that covers whole of Bhutan was created as a background base-map.

In order to create contour line data for a background base-map, reliable DEM data that covers the whole of Bhutan and the surrounding area with little difference in topographical changes compared with the current situation was required. The existing 1/50,000 topographic map was first published in 1960s, and does not reflect the current situation, as there are now differences in the terrain and topographical changes in roads/rivers/mountains/hills. A recently developed 1/25,000 topographic map, covering only the southern area, was also partially available for the study. DHPS also possess a DEM (ALOS DSM, resolution 10 meters) shared by the Department of Geology and Mines. The DEM was originally acquired for the mapping of glaciers and glacial lakes via a JICA-assisted project. Therefore, the accuracy of the DEM was checked by evaluating its elevation values with respect to the values in the 1/25,000 scale topographic map. The standard deviation of the elevation difference was 14.8 m for approximately 13,000 positions. Since the accuracy of the DEM is relatively high and there is not much variation in the elevation values, it was judged that the DEM (ALOS DSM) was reliable for the study, and based on this, contour line data at intervals of 10 m/20 m/100 m were generated.

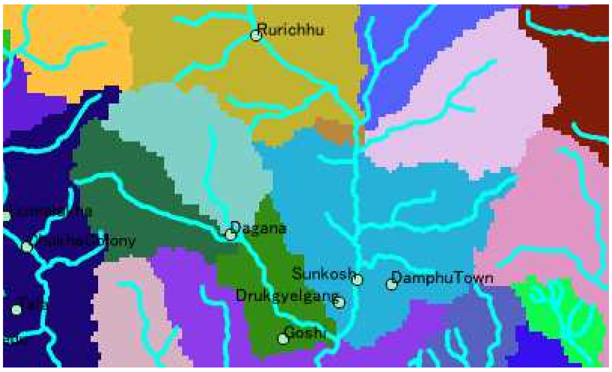
The latest river line data was updated by overlaying satellite imagery and the new 1/25,000 topographic map, based on existing river line data created by DHPS.

(Source: JICA Survey Team)

Figure 11-2 Background Base-Map (Contour lines, Rivers, Roads)

(2) River basin and Catchment areas

River basins and catchments at the intakes identified were created using GIS analysis tools. Based on the DEM altitude information, the slope and cumulative flow of the terrain on the DEM were analyzed and the watersheds were generated. The catchment area of the respective rivers could then be calculated from the converted watersheds' area polygons.



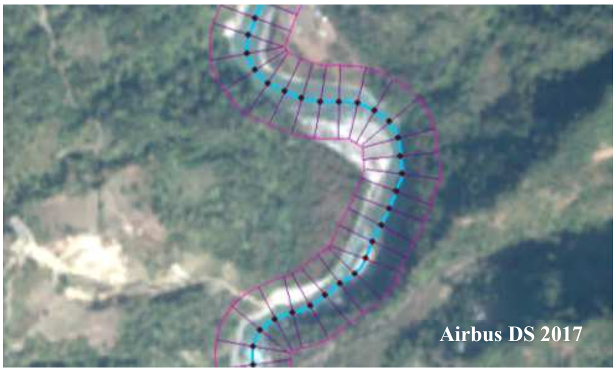
(Source: JICA Survey Team)

Figure 11-3 River Basin Area Map

(3) River profile data creation

In order to evaluate and examine the potential sites via the differences in elevation (longitudinal gradient) of the target river, the river profile element information was generated using DEM altitude information and river center lines. River center points at 50m intervals were generated. Then the altitude information was acquired from the DEM at the same position as each center point via GIS spatial analysis. In the final, the list of spatial information of the center points (horizontal coordinates and altitude) was created as elements of the river profile for each river.

In order to correct and adjust positioning errors between the river center line and the estimated position of the river on the DEM, a process of taking the minimum elevation value on the cross section line at each center point was carried out.



(Source: JICA Survey Team)

Figure 11-4 River Profile and Cross Section Line

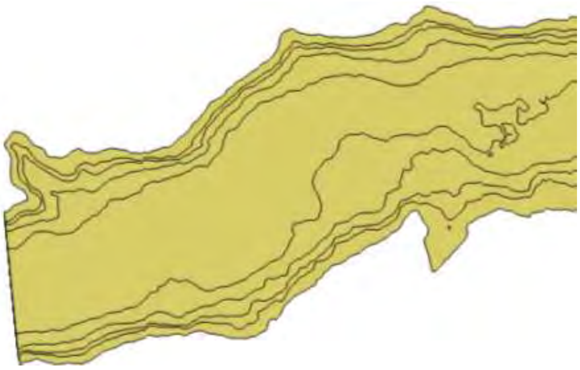
Id	ORIG_FID	name	category	elevation	POINT_X	POINT_Y
63487	673	Tangochhu	Major	2373	215038.08834399999	3046165.6201399997
63488	673	Tangochhu	Major	2366	215078.08834399999	3046195.6201399997
63489	673	Tangochhu	Major	2363	215118.08834399999	3046225.6201399997
63490	673	Tangochhu	Major	2362	215149.40570599999	3046264.1032099998
63491	673	Tangochhu	Major	2365	215170.22260499999	3046308.3618800002
63492	673	Tangochhu	Major	2365	215180.02841100001	3046357.3909200001
63493	673	Tangochhu	Major	2369	215206.17605700000	3046399.1133500002

(Source: JICA Survey Team)

Figure 11-5 River Profile Information

(4) Water surface area for the estimation of reservoir capacity

In order to estimate the reservoir capacity of the 15 potential sites for reservoir/adjustment pond type out of the long list, the water surface area was calculated using contour lines from the DEM. Water surface polygons were created of each contour line, and the area for each water surface polygon was calculated.



(Source: JICA Survey Team)

Figure 11-6 Water surface area in each contour line interval

11.2 GIS Technology Transfer

Through establishment of GIS database, technology transfer for GIS data management and the QGIS data maintenance and basic processing methods was carried out via Off-JT/OJT. This included QGIS operation (measurement or analysis), CRS settings, background base-map and various GIS thematic maps for the evaluation and examination of potential sites or hydropower planning.

With regard to the content of each technology transfer area, it was aimed for the continuous utilization of GIS by GIS engineers and further technology transfer to other engineers via the operation manual.

11.2.1 Introduction of QGIS

ArcGIS license has been allocated to DHPS from the Bhutan government, and it is being used for collecting and confirming geospatial information, or creating GIS thematic map data, etc. However, in order for other DHPS officers to use GIS data, additional licenses are required for each of them, so utilization of the GIS has been limited.
In order to expand the utilization of GIS data, not only among GIS engineers but also other officers, the JICA Survey Team recommended introducing “QGIS” (open source) and carried out technology transfer to DHPS.

The reason for recommending QGIS is that it is free of charge and open source GIS software and it has functions equivalent to ArcGIS (commercial software). When comparing QGIS and ArcGIS, there are no big differences in the functions (editing, attribute information, printing, and even other advanced functions). QGIS has functions that are required for the current GIS processing work at DHPS, as standard. For GIS processing work such as "Contour line creation from DEM" and "River basin area creation", which are related to the basic information for the hydropower plan, the function “Raster-data (Image data) spatial analysis” is required in the GIS software. This function is included in QGIS as standard, but in ArcGIS, an additional license is required. In consideration of these points, it was judged that QGIS is the optimal tool for dissemination of GIS in DHPS and utilization of the GIS database.

Table 11-3 Comparison between QGIS and ArcGIS

License/Function	QGIS	ArcGIS (Standard)	Remarks
License type	Free of charge/Open source	Paid	
Vector data Spatial analysis	Available	Available	
Raster data Spatial analysis	Available (Using GRASS/Saga)	Licensed (Spatial Analyst)	Create Contour line/River basin area from DEM
Transform Coordinate system	Available	Available	
Import Web-based online maps	Available	Available	
Multiple users editing simultaneously	Available (multi-access) (Using Spatialite format)	Available	
Web GIS server	N/A	Available	Web GIS construction and distribution
Advanced Network Analysis	Available partially	Licensed (Network Analyst)	Traffic network analysis (detection of nearest facility, shortest route analysis, etc.)

(Source: JICA Survey Team)

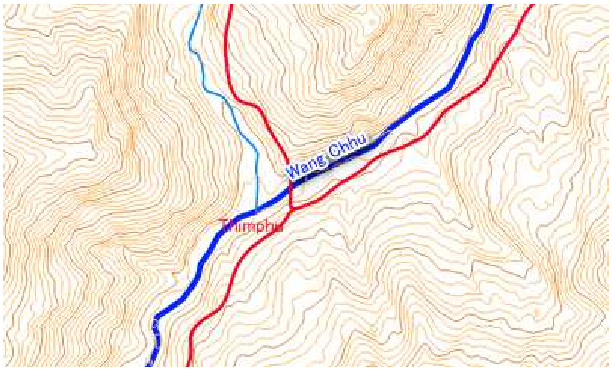
OJT for QGIS setup and practical for basic operation was carried out in the technology transfer, taking into consideration that the transfer of GIS technology from GIS engineers to other officers will also be carried out in the future.

i) Setup
ii) Basic settings (CRS, Style, Label)
iii) Basic operation (Import, Selection, Editing, Move, Attribute table, Creation)
iv) Print settings

11.2.2 CRS Setting

Normally, most of the geospatial information used in GIS is created based on the national coordinate system defined by the country or institution. Even if the current data has been set with a different coordinate system, if the original data had been set with the correct coordinate system when it was created, the data can be overlaid and integrated with other geospatial information to form one map by using GIS. However, some of the old geospatial information was created during a period when GIS and digital information were not widely used, and there are some data defined with an incorrect coordinate system because of an unknown original definition or mistakes when they were updated. In this case, even if GIS is used, it is impossible to integrate the various geospatial information into one map because each piece of information cannot be overlaid at the correct location.
Some of the geospatial information collected this time featured inconsistencies with the position of the base-map, such as topographic maps or satellite imagery, because the coordinate system was incorrect.

In the technology transfer, OJT was carried out in the following areas.
i) Confirmation of position inconsistencies
ii) Identification of original coordinate system at the time of data creation
iii) Redefining the correct coordinate system
iv) Coordinate transformation for the GIS database
v) Confirmation of position consistency



(Source: JICA Survey Team)

Figure 11-7 CRS Differences

(Blue: River data - correct location with satellite imagery and DEM; Red: incorrect CRS)

11.2.3 GIS Thematic Map Creation

An outline explanation during Off-JT, and practical operation using QGIS during OJT were carried out concerning the method of background base-map and GIS thematic map creation.

i) Transformation of DEM from ellipsoidal height to orthometric height
ii) Creating contour lines from DEM
iii) Updating river data using satellite imagery
iv) Creating river basin area by raster analysis
v) Creating river profile data

11.2.4 Evaluation of Technology Transfer

In order to confirm the effectiveness of/degree of achievement in Off-JT and OJT with regard to technology transfer, the GIS processing skills of engineers were evaluated to assess whether or not they are at a level that enables actual implementation/operation.

Table 11-4 Content of Technology transfer and Evaluation

Work	Content	Evaluation	Criteria
Data management	Appropriate data storage	5	5: Trainer level 4: Self-operation level 3: Understands and practices independently 2: Assistance required 1: Re-guidance required
QGIS basic operation	Introduction	5	
	Settings (CRS, Style, Label)	5	
	Operation (Import, Select, Edit, Move, Attribute table, Creating)	5	
	Advanced operation (Attribute table processing, Geospatial analysis, Utilization of additional functionality)	4	
	Print settings	3	
CRS (Coordinate reference system)	Confirmation of positioning consistency	4	
	Identification of original CRS and Re-definition	4	
	Transformation of GIS database CRS	5	
GIS thematic map creation	Transformation of DEM from ellipsoidal height to orthometric height	3	
	Creating contour lines from DEM	5	
	Updating river data using satellite imagery	5	
	Creating river basin area by raster analysis	5	
	Creating river profile data	3	

(Source: JICA Survey Team)

11.2.5 Information Security Training

As part of the operation and management of geospatial information that has been collected for the GIS database building, information security training was introduced 2 GIS engineers. In consideration of the fact that a GIS engineer who has been trained would become a trainer for other engineers in the future, explanation of the training includes elements of "Training of Trainers".

Not only Satellite/Aerial imagery, Topographic/Cadastral maps, and Thematic maps, but also all kinds of other information, such as Name, Category, Numeric value, Personal information, can serve as Geospatial information by combining positional information.
However, Geospatial information can be categorized as "Personally identifiable information" in terms of privacy, because the location of individuals can be identified by using positional information.
Therefore, Geospatial information and GIS must be secured at the same level of security as the "Information Assets" of the organization, according to the same information security policy.

In the past, data backup for 2 GIS client PCs at DHPS was regularly performed through a network connection by a GIS server. However, since an OS update of the GIS server was not performed in parallel with the GIS client PCs and there is no network connection between the server and client, data backup by the GIS server is not currently being performed.
Data backup for geospatial information is currently performed by another GIS PC that is equipped in the GIS room.

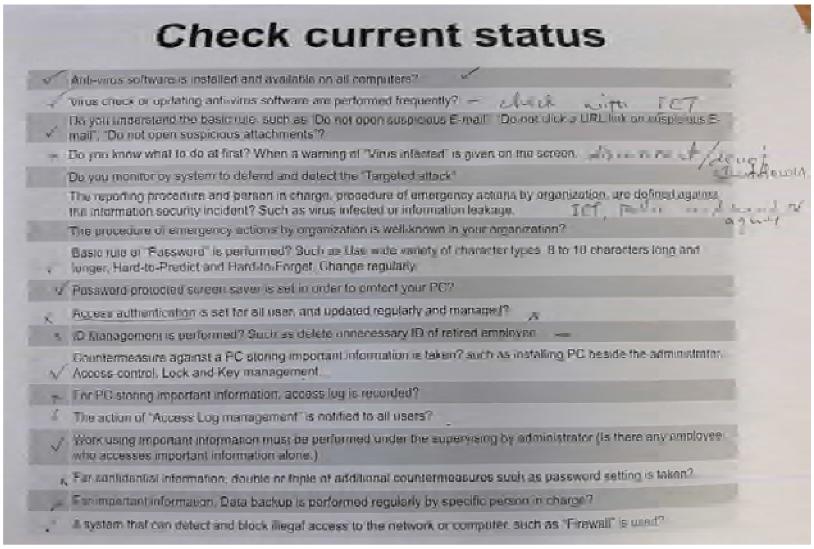
In order to easily start information management that is suitable for the current situation and takes into account information security, detailed explanations that can be difficult to approach, such as detailed information-asset management or risk-analysis, were excluded in this training.
Using a sample of important GIS information that is generally used, explanations on the understanding of current management status and an examination of future management methods were carried out. Then, a demonstration of "information-asset management sheet" creation was carried out, in order to assess the current status of information-assets and the associated risks.

Table 11-5 Content of Information security training

No.	Items	Method
1	Necessity of Information Security Actions	Lecture
2	What are Information Security Actions?	Lecture
3	Impact on organization caused by Information security incidents	Lecture
4	Information Assets	Lecture
5	Information Asset Management	Lecture
6	Information Security Actions for Geospatial Information and GIS	Lecture
7	Priority of Information Security Actions	Lecture
8	Actions by Organization	Lecture
9	Actions at office/Actions in Computer use/Personal Actions	Lecture
10	Check of current status	Lecture/Demonstration
11	Information assets management sheet	Lecture/Demonstration

(Source: JICA Survey Team)

The current management status regarding whether information security actions are being performed or not for PCs or geospatial information has been confirmed via the demonstration "Check of current status". The objective of the "check of current status" is not to evaluate whether the action is being performed. Understanding the current status enables us to know the targets for the information security actions and conduct an examination of future management methods.



(Source: JICA Survey Team/DHPS)

Figure 11-8 Check of current information management status

In the demonstration "Information assets management sheet", we extracted a sample of important information from the geospatial information that is generally used, then integrated and evaluated the content, such as storage conditions, administrators, threats likely to cause damage and so on.

Both the demonstrations “Check of current status” and “Information assets management sheet” have clarified the targets for information security actions, and enabled people to understand their necessity. This training led to measures being taken concerning information security actions, such as locking the GIS room, re-confirming password configurations, and data backup using external HDD.

ID	Name	Administrator	Confidential	Secret	Unremovable	Impact	Personal	Valuable	Storage medium	Retention period	Place of use	User	Threats	Countermeasure	Frequency	Format	Risk
1	[redacted]	Dechen Wangmo/Wangmo	Yes	No	No	3	No	3	PC	1 yr	Office	DHPS	PC failure, Leakage, Loss of data	Back up (HDD), Lock, password protection, Access control	Once in a year	Shapefile	Low
2	[redacted]	Dechen Wangmo	Yes	No	No	3	No	3	PC	2 yrs	Office	DHPS	PC failure, Leakage, Loss of data	Back up (HDD), Lock, password protection, Access control	Once in a year	Shapefile	Low
3	[redacted]	Dechen Wangmo	Yes	No	No	4	No	4	PC	1 Yrs	Office	DHPS	PC failure, Leakage, Loss of data	Back up (HDD), Lock, password protection, Access control	Once in a year	Shapefile	Medium
4	[redacted]	Dechen Wangmo	No	No	No	3	No	3	PC	1 Yrs	Office	DHPS	PC failure, Leakage, Loss of data	Back up (HDD), Lock, password protection, Access control	Once in a year	Shapefile	Low
5	[redacted]	Dechen Wangmo	No	No	No	2	No	3	PC	5 Yrs	Office	DHPS/DG PC	PC failure, Leakage, Loss of data	Back up (HDD), Lock, password protection, Access control	Once in a year	Excel Sheet	Low
6	[redacted]	Dechen Wangmo	No	No	No	2	No	3	PC	5 Yrs	Office	DHPS/DG PC	PC failure, Leakage, Loss of data	Back up (HDD), Lock, password protection, Access control	Once in a year	Excel Sheet	Low
7	[redacted]	Dechen Wangmo	No	No	No	3	No	3	PC	5 yrs	Office	DHPS/DG PC	PC failure, Leakage, Loss of data	Back up (HDD), Lock, password protection, Access control	Once in a year	Excel Sheet	Medium
8	[redacted]	Dechen Wangmo/Wangmo	Yes	Yes	No	5	Yes	5	PC	10 yrs	Office/GIS room	DHPS	PC failure, Leakage, Loss of data	Back up (HDD), Lock, password protection, Access control	Two times a year	Shapefile	High
9	[redacted]	Dechen Wangmo/Wangmo	No	No	No	2	No	2	PC	3 yrs	Office/GIS room	DHPS	PC failure, Leakage, Loss of data	Back up (HDD), Lock, password protection, Access control	Once a year	Shapefile	Low
10	[redacted]	Dechen Wangmo/Wangmo	Yes	Yes	No	5	Yes	5	PC	2 yrs	Office/GIS room	DHPS	PC failure, Leakage, Loss of data	Back up (HDD), Lock, password protection, Access control	Two times a year	Shapefile	High
11	[redacted]	Wangmo	Yes	No	No	2	No	3	PC	1 Yrs	Office/GIS room	DHPS	PC failure, Leakage, Loss of data	Back up (HDD), Lock, password protection, Access control	Once in a year	Shapefile	Low
12	[redacted]	Wangmo	Yes	No	No	4	No	4	PC	5 Yrs	Office/GIS room	DHPS	PC failure, Leakage, Loss of data	Back up (HDD), Lock, password protection, Access control	Once in a year	Raster	Medium
13	[redacted]	Wangmo	Yes	No	Yes	3	No	5	PC	10 yrs	Office/GIS room	DHPS	PC failure, Leakage, Loss of data	Back up (HDD), Lock, password protection, Access control	Once in a year	Raster	Low
14	[redacted]	Dechen Wangmo/Wangmo	No	No	Yes	5	No	5	Shelf	3 Yrs	Office/GIS room	DHPS	Loss of Business Information, Theft, Fire/wear & tear	Lock, Digitize the hard copy	Always	Document	High

(Source: JICA Survey Team/DHPS)

Figure 11-9 Results of GIS Information assets management sheet creation (created by DHPS GIS engineer in the training)

Chapter 12. Financial and Economic Analysis

12.1 Financial Conditions of Hydropower Organizations[48]

12.1.1 DGPC

The total amount of electricity generated by DGPC in 2017 was 7,248GWh, down by 4.2% as compared to 2016. Its total gross income (electricity revenue plus other income including interest earned) amounted to Nu. 12,277 million, and profit before tax (with operational expenditures deducted from the gross income) was Nu. 7,224 million, which decreased by 9.2% from that of the previous year. After tax payments (mostly corporate tax) and some adjustments, the net profit was Nu. 5,176 million, a 7.2% decrease as compared to Nu. 5,580 million in 2016. The reasons for the decline in profits are due to a drop in sales and the payment of higher wheeling charges as a result of an increase in wheeling charges from Nu. 0.114/kWh to 0.195/kWh, which became effective from January 2017.

The capital adequacy ratio (own capital/total assets) was 84% in 2017, higher than the international standard for very healthy companies, i.e., 70% (in Japan the capital adequacy ratio of even blue-chip or good-standing companies is about 40-60%). In the balance sheet, DGPC had Nu. 1,277 million of "cash or equivalents", an increase of Nu. 178 million from the previous year. Main cash outflows for the investment and financing activities were: (i) dividend payment of Nu. 4,253 million (Nu. 3,819 million in 2016); (ii) repayments and interest payments for loans of Nu. 1,908 million (Nu. 2,725 million in 2016).

Ratio analyses help to understand the financial conditions of the company concerned, particularly pertaining to: general strengths (productivity), profitability, safeness, efficiency and growth potential. If DGPC'S financial performances in 2017 are looked at from the ratio analyses angles, the following information emerges:

(1) Net profit sales ratio

"Net profit sales ratio (net profit/sales)" was 42.2% (43.3% in 2016), far exceeding the general index of profitable performances of 5%.

(2) Return on equity

"Return on equity (RoE: net profit/net worth (or own capital)" showed 11.0% (12.6% in 2016), indicating generally fine productivity or general strength (for instance, RoEs of power companies in Japan are in the range of about 8%).

(3) Current/Quick Ratio

In the context of safeness, "current ratio (current assets/current liabilities)" was 139% in 2017 (132% in 2016). The current ratio did not meet the general high criterion of "more than 150%-200%". Given the nature of the power generation business, where there is hardly any inventory or work in progress, a more appropriate financial performance index is the quick ratio (current assets minus inventory/current liabilities). The quick ratios were 126% in 2017 and 120% in 2016, surpassing the general rule of thumb of 100%.

Thus, DGPC's financial positions show good performance, particularly in terms of profitability.

[48] The sources for this section are the 2017 Annual Report (particularly, financial statements of each organization and RGoB documents, including the 2017 Revenue Report, 2017/18 Budget, and others. It should be noted that while financial statements cover a calendar year (from January to December), government documents are based on the fiscal year (from July to June of next year).

12.1.2 BPC

BPC is a subsidiary company of DHI, as is the case with DGPC, with its main businesses being power distribution to domestic customers and power transmission for export to and import from India. BPC has almost achieved (nearly 100%) its target of national electrification, with 185,130 customers domestically. In 2017 it added 7,979 new customers, including 16 high voltage customers and 59 medium voltage customers. Domestic energy sales were 2,185.1GWh, an increase of 8.1% compared to that in 2016. The peak load was recorded at 362.1 MW in November of that year. Transmission and distribution losses were very small at 2%, while the tariff collection rate was 98.5%, a very high rate in international standards. BPC plans further strengthening in transmission and distribution capabilities through vigorous investments in the Dagapela 220kV substation, and double-circuit transmission lines for the route of Kanglung-Phuentshotang-Montanga-Nganglam.

BPC's main income sources are domestic electricity sales, construction contracts and transmission wheeling charges up to the Indian border. Its gross sales in 2017 amounted to Nu. 11,507 million, a decrease of 2.9% (Nu. 11,853 million in 2016). Electricity sale revenues themselves increased by 38.1% to Nu. 6,627 million in 2017 from Nu. 4,799 million in 2016. The wheeling charge revenues also grew by 57.2% from Nu. 659 million in the previous year to Nu. 1,036 million[49]. However, BPC's other income source, construction contracts, dropped almost to half (Nu. 3,446 million), contributing to an overall reduction in revenue.

On the expenditure side, because of the purchasing prices increase from DGPC[50] and the abolishment of previous free supply in kind by Royalty Energy[51] from DGPC, the total expenditure for power purchases rose almost 2.5 times to Nu. 3,699 million in 2017 from Nu 1,408 million in 2016. On the other hand, as the major construction work for transmission lines has been completed and the outlay for construction equipment and materials decreased accordingly, the total expenditures ended at Nu. 1,892 million, or a 15.9% increase. Thus, total expenditures in 2017 were almost the same level as the previous year at Nu. 9,615 million (Nu. 9,601 million in 2016). However, reflecting the decrease in electricity sales, the gross and net profits decreased to Nu. 1,893 million (Nu. 2,251 million in 2016) and Nu. 1,328 million (Nu. 1,578 million in 2016), respectively, both decreasing nearly 16% as compared to 2016.

If BPC'S financial performances in 2017 are looked from the ratio analyses angles, the following information emerges:

(1) Net Profit Sales Ratio

BPC's net profit sales ratio in 2017 was 11.5% (13.3% in 2016), higher than the international criterion of 5%.

(2) Return on Equity

While profitability was thus high, another index, return on equity (RoE: net profits/own equity), which indicates the general strength, has remained around the 10% international criterion in the past few years, and was 9.7% in 2017 and 11.4% in 2016 (higher than the simple average of power companies in Japan, which is 8-9%).

(3) Current and Quick Ratios

The current ratio was below the general criterion (more than "150-200%"), showing 102.2%, declining from the previous year's 138.0%. As stated in the paragraph above for DGPC, a more appropriate measure of liquidity and safety is the quick ratio, which was 96% in 2017 (131% in 2016), slightly

[49] The growth in sales is largely due to an increase in the wheeling charges, from the fixed Nu. 0.114/kWh to Nu. 0.195/kWh.

[50] The tariff revision in 2017 increased the power purchase price from Nu.1.39/kWh to Nu.1.59/kWh.

[51] After the change in RE payment mechanism in 2017, the free supply of Royalty Energy from DGPC to BPC was abolished and MoF receives RE in cash transfers from DGPC. From RE, MoF provides a block grant to BPC as a subsidy corresponding to the lower tariff applied to small electricity consumers.

below the benchmark of 100%. Therefore, the financial safety of BPC is not at any alarming level, but there is a decline in operation financing capacity between 2016 and 2017.

12.1.3 DHI Group

DHI group is a group of public and public-private corporations managed by a holding company, DHI Ltd., which is 100% owned by RGoB. The group includes 23 Bhutanese representative corporations/companies as its subsidiaries and affiliates: eleven (11) corporations having 100% shares such as DGPC and BPC, as well as Bhutan Telecom, Druk Air and others; nine (9) affiliated companies having more than 51% shares (like the Bank of Bhutan); and three (3) linked companies with less than 51% shares, as shown in the following Table 12-1.

Table 12-1 DHI Group Companies

No	Group Companies	Business Type	Equity Share (2017 end)
1	Druk Holding and Investments Ltd.	Holding Company	100.00
2	Bank of Bhutan Ltd	Finance	80.00
3	Dungsum Polymers Ltd	Manufacturing	51.00
4	Bhutan Board Products Ltd	Manufacturing	57.60
5	Bhutan Board Exports Ltd	Manufacturing	57.60
6	State Trading Corporation of Bhutan Ltd	Trading	56.60
7	Construction Development Corporation Limited	Real Estate	100.00
8	Thimphu TechPark Ltd (previously named Thimphu TechPark Private Ltd)	Real Estate	100.00
9	State Mining Corporation Ltd	Non-trading	100.00
10	Bhutan Telecom Ltd	Communications and Transport	100.00
11	Drukair Corporation Ltd	Communications and Transport	100.00
12	Druk Green Power Corporation Ltd	Energy and Resources	100.00
13	Bhutan Power Corporation Ltd	Energy and Resources	100.00
14	Natural Resources Development Corporation Ltd	Energy and Resources	100.00
15	Dagachu Hydropower Corporation Ltd	Energy and Resources	59.00
16	Tangsibji Hydro Energy Ltd	Energy and Resources	100.00
17	Wood Craft Centre Limited	Manufacturing	100.00
18	Penden Cement Authority Ltd	Manufacturing	40.00
19	Koufuku International Limited	Manufacturing	80.00
20	Bhutan Ferro Alloys Ltd	Manufacturing	28.42
21	Royal Securities Exchange of Bhutan Ltd	Manufacturing	16.35
22	Kholongchhu Hydro Energy Limited	Energy and Resources (JV)	50.00
23	Bhutan Hydro Services Limited	Energy and Resources (JV)	51.00

(Source: Annual Report of DHI 2017)

As a public corporation owned 100% by RGoB, DHI has to pay dividends as well as taxes to the MoF from the group's profits. The DHI dividend to RGoB is paid not based on a fixed percentage but is determined on the basis of the "Residual Dividend Policy", wherein dividend is to be paid taking its financial positions and future plans/investment into consideration.

The following description of DHI's financial performances is based on its consolidated financial statements, representing all group companies as a whole.
DHI's total assets increased from Nu. 51,092 million at the time of its establishment in 2008 to Nu. 172,950 million (fixed assets of Nu. 141,660 million and current assets of Nu. 31,290 million) in 2017, at an annual growth rate of 14%. The total revenues reached Nu. 38,896 million. Expenditures amounted to Nu. 26,996 million. Against the total assets (Nu. 172,950 million), total capital (or net worth) comprises Nu. 88,713 million in capital and Nu. 84,237 million in liabilities. The net profit sales ratio

was 15.5% and the capital adequacy ratio was 51.3%, both showing good financial status in terms of profitability and stability. The current ratio was 203% (240% in 2016), easily meeting the general standard of "150-200%"). However, RoE, which indicates the general strength of the company, was 7.4%, (7.0% in 2016), below the criterion of "10%".

The following Table 12-2 shows the financial positions of DGPC and BPC within the DHI group.

Table 12-2 Financial Relationship of DGPC and BPC within DHI Group

(Unit: Nu. Million)

	DHI	DGPC		BPC	
Assets	172,950	54,943	32%	28,964	17%
Liabilities	84,237	8,776	10%	15,269	18%
Fixed Assets	141,661	48,330	34%	23,111	16%
Own Capital	88,713	46,167	52%	13,695	15%
Reserves within Own Capital	38,034	14,621	38%	5,820	15%
Sales	38,896	12,277	32%	11,507	30%
Before Tax Profit	11,900	7,224	61%	1,893	16%
Tax	5,889	2,137	36%	564	10%
After Tax Profit	6,011	5,176	86%	1,328	22%
Dividend	4,254	4,253	100%	1,449	34%

Note: % indicates share within DHI Group

(Source: annual reports of DHI, DGPC, and BPC for the year 2017)

Given the fact that DGPC and BPC together have 49% of the total assets within the group, the contributions by the two companies in terms of sales and after-tax profits, 62% and 108% for the group respectively, are quite outstanding, implying that the profits from these on-going energy businesses are offsetting the losses elsewhere. However, it must be noted that DHI has a mandate to play a catalytic role in the development of the private sector in Bhutan as well as sound management of assets of public interest.

It is also noted that the dividends paid out by DGPC and DHI are almost equal in 2017, indicating that dividends from other companies are retained within DHI Ltd. The percentages of dividends to own equity and share capital appear to be kept at around 5% and 10% respectively, which comply with standard practice. When the equity structure is examined, the retained earnings as the reserve are as large as the total annual sales of the group, i.e. both at the level of Nu. 38 billion. These reserves define the financing capacity of the DHI group as a whole.

12.2 Implementation Models for Hydropower Projects

12.2.1 Categories of Hydropower Stations

BSHDP has categorized hydropower projects in terms of scale (or MW) as follows:

- Mini/Micro Project: less than 1MW;
- Small Project: 1MW-25MW;
- Medium Project: 25MW-150MW;
- Large Project: 150MW-1,000MW; and
- Mega Project: more than 1,000MW.

12.2.2 Implementation and Financing Modalities

Out of the above categories, for bigger than the medium-scale projects the governments of foreign countries and/or companies are encouraged to participate in the development, through the following methods or models: financing modalities; partner/cooperation countries or agencies; implementation agencies inclusive of responsibilities for debt repayment; and others[52]. Table 12-3 below shows the implementation/financial modalities contemplated in BSHDP and international practices.

[52] According to DGPC, revision work for the Policy is currently ongoing.

Table 12-3 Implementation Financing Modalities for Hydropower Projects

Sector		Implementation Modality	Debt Servicing Agency	Equity Composition	Financing Modality	Debt Guarantee	Remarks	Actual Implementation in Bhutan
Government	G-G (IG)	Special Purpose Authority (SPA)	RGoB/DGPC	100% RGoB/DGPC	Grant + Loan	RGoB	Based on the intergovernmental (IG) agreement between RGoB and partner government (eg. GoI), a special purpose authority (SPA) to be established and assume the responsibility for project implementation and operation.	Chhukha, Kurichhu, Tala, Mangdechhu, (Punatsangchhu I&II)
	JV	Special Purpose Company (SPC)	SPC	50% RGoB/DGPC	Grant + Loan	RGoB	Concession period for generation and transmission for 30 years after the commencement of operations with possibility of extension. 50% equity from SJVNL. The project needs to be inspected by RGoB to ensure proper implementation and operation.	Kholongchhu
	G-G (General Case)	DGPC	SPC	100% DGPC	Reserve + Loan	RGoB	Concession for 30 years granted after commencement for operation for SPC. The SPC is 100% owned by RGoB/DGPC.	Nikachhu
		SPA	RGoB/DGPC	100% RGoB/DGPC	Grant + Loan	RGoB	PMU or PIU to be established by the government for implementation.	Basochhu
Public Private Participation	Build-Own-Operate-Transfer (BOOT)	Build-Own-Operate-Transfer (BOOT)	SPC	Majority DGPC	Equity + Loan	Proportion to Equity Participation	Concession period for generation and transmission for 30 years after the commencement of operations with possibility of extension. The project needs to be inspected by RGoB to ensure proper implementation and operation.	Dagachhu

(Sources: BSHDP and others)

The hydropower projects funded by GoI, generally referred to as “Bilateral Assistance”, took the form of “Government-Government (G-G)”, where, based on the agreements of the two governments, a special purpose company (or authority) is to be established by the public corporations of the respective countries to implement and operate the project concerned. The public corporations were nominated by each Government and selected without bidding. This method is called a “Joint Venture (J/V)” by both Governments.

For general international practices under the G-G basis, (or bilateral assistance), a Project Management Unit (PMU) and/or a Project Implementation Unit are established within the power companies.[53]

BSHDP also defines and classifies other methods of project implementation, including “Build-Own-Operate-Transfer (BOOT)”, “Public-Private Partnership (PPP)”, and Strategic Partnership (SP)”. Under BOOT, RGoB will select and allot project investors who will get a 30 year commission to operate the project after completion until transfer to RGoB, with a possibility of extension. Under the 2009 Agreement between both Governments, this BOOT model is encouraged for future projects. This BOOT model is also slightly different from general practices as the developers are to be nominated by the Governments without a bidding process. In this context, this method appears to be similar to the SP model, where the strategic partners to implement the project are selected by both Governments without a bidding process. BOOT model was adopted for the first time in the Dagachhu Project. In addition to the equity injected by DGPC, with a 59% stake of the total equity, the Tata Power Company of India and the National Pension and Provident Fund of Bhutan held shares of 26% and 1%, respectively. On the liabilities side, ADB provided grants and concessional loans, and the Raiffeisen Zentralbank Osterreich AG (RZB) of Austria also provided loans. The second PPP is being implemented for the Nikachhu Project with the assistance of ADB.

Under the general G-G model, as mentioned above, PMU and/or PIU, established by the power companies concerned, manage and implement the project. However, under the GoI-funded projects, a “J/V” or special purpose company undertakes project implementation. The difference between PMU/PIU and “J/V” rests on whether they are involved in operations after the project’s completion. “J/V” is responsible for construction as well as operations. The reason for adopting “J/V” under GoI-financed projects seems to be that as GoI has funded most of the project’s costs and imports most of the electricity generated by the projects, it seems to think it necessary to hold an influential voice regarding operations.

12.2.3 Hydropower Projects (Implemented, Under Construction, and Planned)

Table 12-4 lists all hydropower projects completed, under construction and planned with foreign assistance.

[53] While the PMU generally manages the implementation of the project, including the related work for the selection of consultants/contractors, monitoring of the work’s progress, managing of project accounts, preparation of disbursements, and regular reporting to the government and financiers, PIU is technically responsible for project implementation.

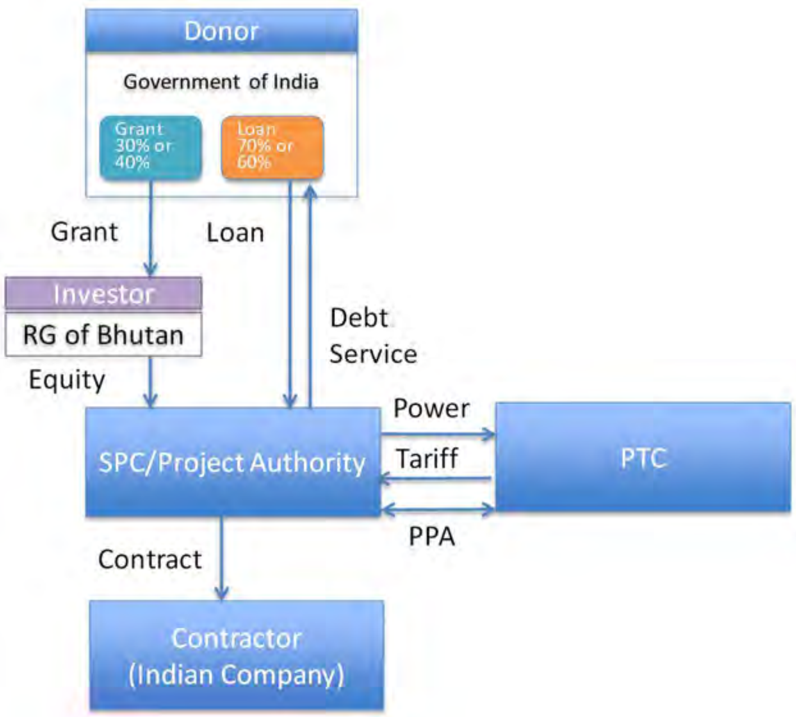
Table 12-4 List of Hydropower Stations and Implementation Models

No.	Name of Project	Capacity (MW)	Completion Year	Implementation Agency (Current Owner)	Implementation Method	Financing Modality	Construction Cost (Nu.Mil.)	Financing	Remarks
	On Operation								
1	Chhukha	336	1986-1988	Chhukha HP Authority (DGPC)	Special Purpose Authority (SPA)	G-G	2,465	GoI (Grant: 60%), Loan: 40%)	Loan: Interest: 5.0%, 15 years Repayment
2	Kurichhu	60	2001-2002	Kurichhu Project Authority (DGPC)	SPA	G-G	2,240	GoI (Grant: 60%), Loan: 40%)	Loan: Interest: 10.75%, 12 years Repayment
3	Basochhu	64	2001-2004	Basochhu HP Corp. (DGPC)	Special Purpose Company (SPC)	G-G	1,446	Government of Austria (Grant:37%, Loan:49%), RGoB: 14%	Loan: Interest: 0%, 20 years Repayment
4	Tala	1,020	2006-2007	Tala HP Authority (DGPC)	SPA	G-G	41,259	GoI (Grant: 60%), Loan: 40%)	Loan: Interest: 9.0%, 12 years Repayment
5	Dagachhu	126	2015	Dagachhu Hydro Power Corporation (DHPC)	SPC	BOOT	12,520	Equity: (1) DGPC: $49M (59% Equity), (2) Tata Power: $21.5M (26% Equity) (3) NPPF: $12.4M (15% Equity) Loan: (1) ADB: Hard loan $51M, concessional loan: $29.4M, Additional concessional loan: $35.1M, (2) Austrian Export Credit Agency: $54.1M.	(1) Part of DGPC Equity contribution was financed by ADB Grant and Concessional Loan. (2) ADB Concessional Loan: Interest 3.15%, 40 years repayment (including grace period of 8 years), Hard loan: interest based on LIBOR 25 years repayment (5 years grace), Additional Loan interest 1-1.5%, 30 years repayment (8 years grace). (3) Based on PPA, power is transmitted and sold in India by Tata Power Trading.
	Under Construction		**Commencement/ Completion**						
6	Mangdechhu	720	(Nov. 2018)	Mangdechhu HP Authority	SPA (MHPA)	G-G	52,709	GoI (Grant: 30%), Loan:70%)	Loan: Interest 10.0%, 17 years Repayment
7	Nikachhu	118	2015 (2020)	Tangsibji Hydro Energy Ltd. (DGPC's Subsidiary)	SPC	BOOT	11,891	Total Cost: $198 million Debt/Equity Ratio: 65%/35% Equity: $69 million/ DGPC 100% (ADB: $50.5 million, Grant/Loan 50:50) Loan: $129 million/ ADB: $70 million, ICB: $59 million	
8	Punatsangchhu I	1,200	(2022/23)	Punatsangchhu HP Authority	SPA (PHPA)	G-G	93,756	GoI (Grant: 40%), Loan: 60%)	Loan: Interest 10.0%, 15 years Repayment
9	Punatsangchhu II	1,020	(2020/21)	Punatsangchhu HP Authority	SPA (PHPA)	G-G	72,906	GoI (Grant: 30%), Loan:70%)	Loan: Interest 10.0%, 15 years Repayment
10	Kholongchhu	600	2015 (2023/24)	Kholongchhu HE Limited (J/V)	SPC (KHEL)	(J/V)	38,690	DGPC: 50%, SJVN, India: 50%. GoI provided DGPC with grant for the part of equity	Listed in 2009 Agreement
11	Sankosh	2,585	2019/20 (2027/28)	TBD	TBD	G-G	97,628	TBD	

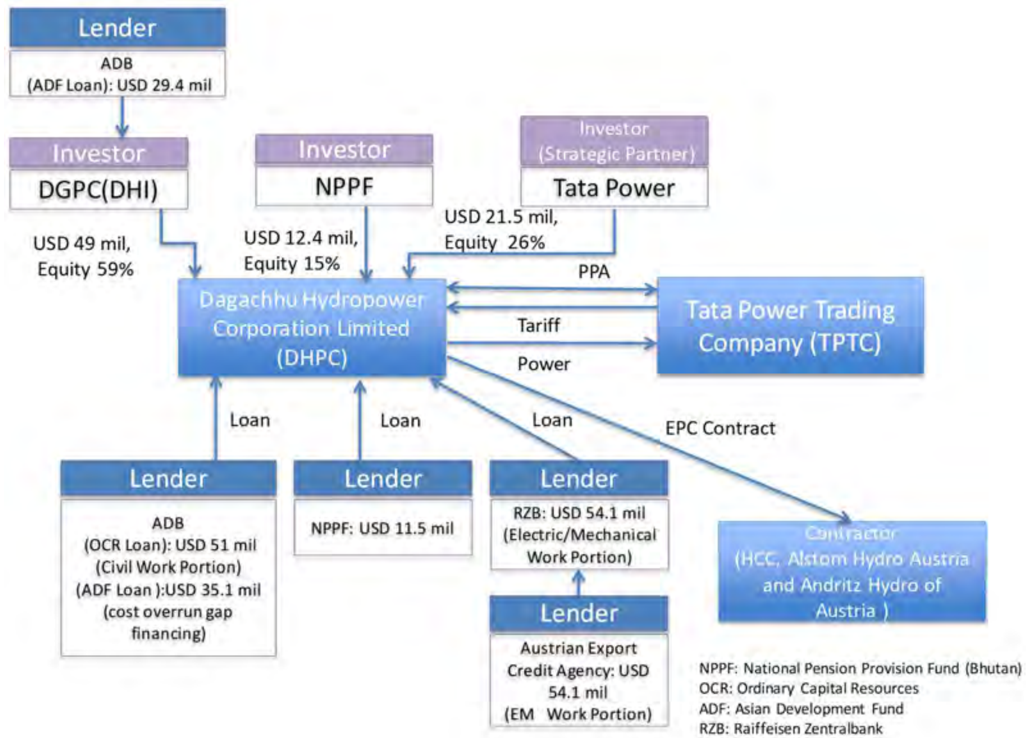
No.	Name of Project	Capacity (MW)	Completion Year	Implementation Agency (Current Owner)	Implementation Method	Financing Modality	Construction Cost (Nu.Mil.)	Financing	Remarks
Planned									
12	Druk Bindu I&II	18/8	TBD	DGPC	TBD		TBD	TBD	DPR completed in 2017
13	Nyere Amari I&II Integrated	404	TBD	DGPC	TBD		TBD	TBD (ADB under discussion)	DPR completed in 2017
14	Dorjilung	1,125	TBD	TBD	TBD		TBD	TBD	DPR completed in 2017
15	Kuri-Gongri	2,640	TBD	TBD	G-G		TBD	Expected GoI assistant	
16	Wangchhu	570	TBD	SPC (J/V)	SPC (J/V)	(J/V)	TBD (40,028)	Expected GoI assistant	Listed in 2009 Agreement
17	Chamkharchhu- I	770	TBD	SPC (J/V)	SPC (J/V)	(J/V)	TBD (47,760)	Expected GoI assistant	Listed in 2009 Agreement
18	Bunakha	180	TBD	SPC (J/V)	SPC (J/V)	(J/V)	TBD (24,926)	Expected GoI assistant	Listed in 2009 Agreement

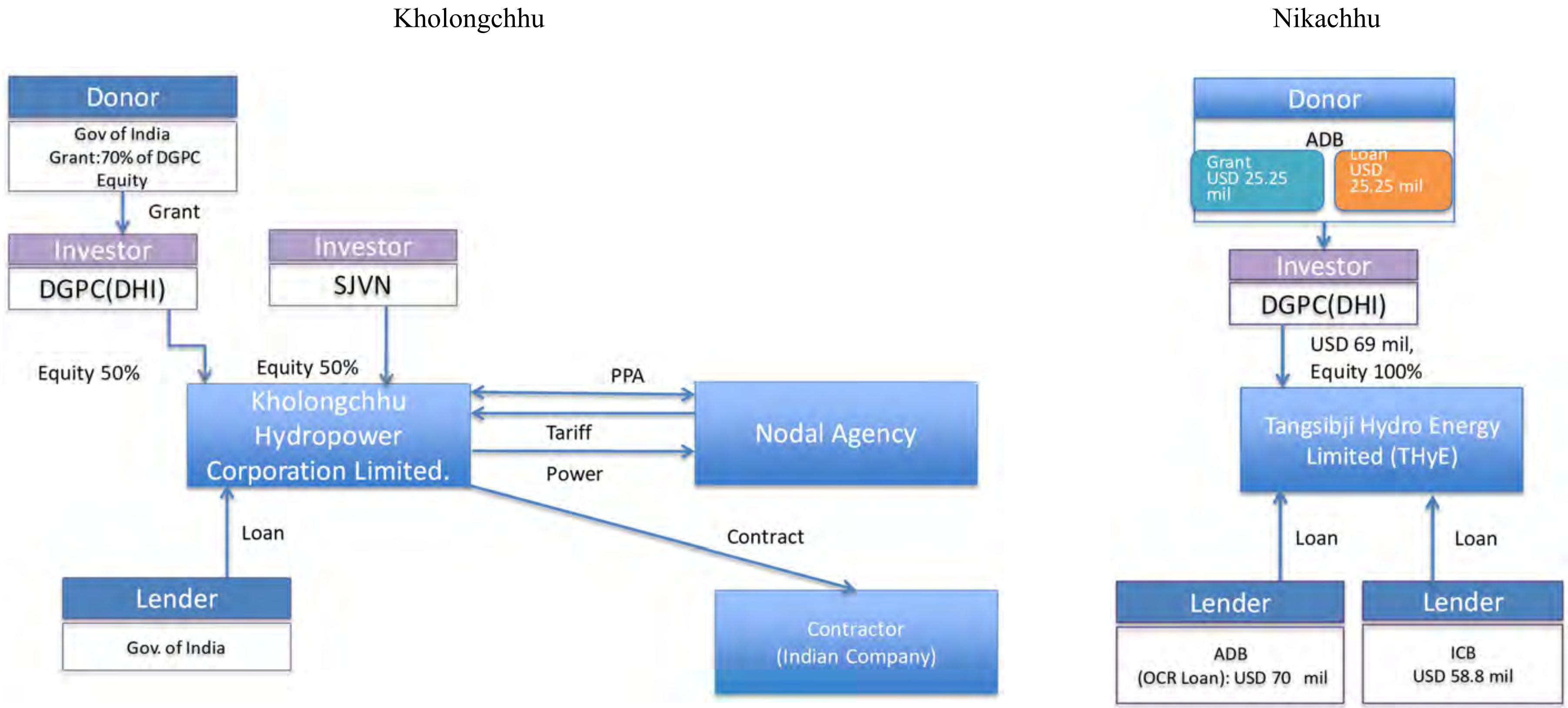
(Sources: DHPS)

G-G Public-public Partnership



Dagachhu





(Source: JICA Survey Team)

Figure 12-1 Examples of Implementation Financing Modalities

12.3 Financial Analysis of a Potential Hydropower Development Site

12.3.1 Cash Flow Projection and Comparison via Project Implementation Modality

In this section, the financial analysis of a hydropower generation project is presented taking the Pinsa site as a model case. Various implementation modalities are compared in the analysis, such as the existing G-G scheme in cooperation with GOI, ODA scheme using donor loans, PPP scheme with private sector investment, etc.

(1) General assumptions

Table 12-5 shows the general assumptions applied in the financial analysis.

Table 12-5 General Assumptions of Financial Analysis

Item	Assumption					
1. General						
- Potential development site for analysis	Pinsa					
- Project commencement year	2026 (commencement of construction)					
- Duration of operation	30 years					
- Construction period	6 years (base case)					
- Currency	Million Nu. (expressed in nominal price including price escalation)					
- Price escalation (annual rate)	Foreign Currency 2.0% Local Currency 4.3％					
- Cost of equity (used to estimate levelized generation cost)	15.0% per annum					
2. Power generation and sales revenue						
- Electricity export tariff	4.2 Nu./kWh (for export to Indian in G-G scheme and ODA scheme) 4.6 Nu./kWh (for export to another country denominated in foreign currency assumed from import price in Bangladesh estimated in Bangladesh PSMP)					
- Power generation capacity	153MW					
- Annual generated energy	672GWh					
- Generation and transmission loss	1.2％					
3. Initial investment cost (construction cost) and reinvestment cost (overhaul cost)						
- LC/FC ratio of construction cost	1.5					
- Disbursement schedule for construction	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Power plant	10%	20%	20%	20%	20%	10%
Transmission line	—	—	20%	70%	10%	—
- Overhaul during operation period	25% of construction cost for electro-mechanical work after 15 years of operation					
- Overhaul at the end of operation	50% of construction cost for electro-mechanical work					
4. Operation and maintenance (O&M) cost and other expenses						
- Annual O&M cost	1% of construction cost					
- Depreciation	30 year straight line depreciation					
- Corporate income tax	30% of profit before tax					

(Source: JICA Survey Team)

(2) Construction cost

Table 12-6 shows the disbursement schedule for the initial investment based on the Pinsa site construction cost estimated in the evaluation of potential development sites. The construction cost including price escalation amounts to 13,715 million Nu. in the case that the construction commences in 2026.

Table 12-6 Initial Investment Cost (Disbursement Schedule for Construction Cost)

Item		2018 Price (Base Cost)	Nominal Cost with Price Escalation						
			Total	2026	2027	2028	2029	2030	2031
Direct Cost		**7,105**	**10,176**	**721**	**1,492**	**1,992**	**3,219**	**1,894**	**856**
	I. Preparation Work	235	336	31	64	66	68	71	37
	II. Environmental Mitigation Cost	16	23	2	4	4	5	5	2
	III. Civil Works	1,578	2,254	207	428	442	458	474	245
	IV. Hydromechanical Works	778	1,111	102	211	218	226	234	121
	V. Electrical Works	2,902	4,145	380	786	814	842	872	451
	VI. Transmission Line	1,596	2,308	0	0	447	1,621	240	0
Non-construction Cost		**2,479**	**3,540**	**324**	**671**	**695**	**719**	**744**	**385**
	VII. Administration and Engineering Cost	826	1,180	108	224	232	240	248	128
	VIII. Contingency	1,653	2,360	216	448	463	480	496	257
Total		**9,584**	**13,715**	**1,046**	**2,164**	**2,687**	**3,939**	**2,639**	**1,242**

(Source: JICA Survey Team)

(3) Implementation modalities for hydropower development project

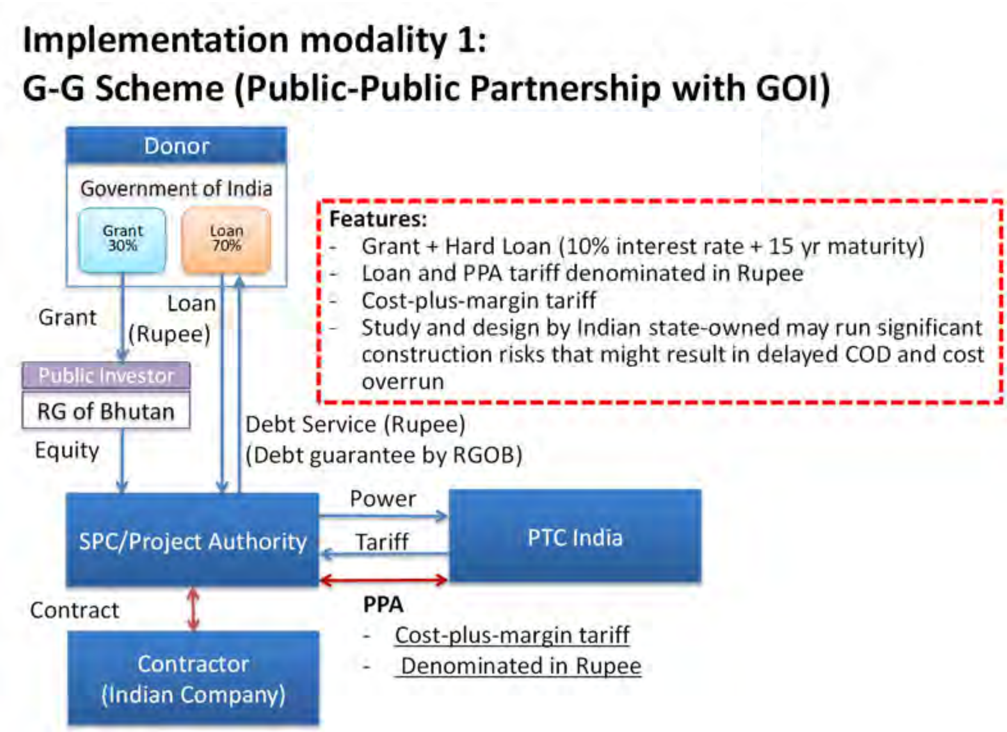
The implementation modalities to be compared in the analysis are illustrated in Figure 12-2 through Figure 12-7. Table 12-7 summarizes the financing and RGoB's revenue conditions in each implementation scheme.

Table 12-7 Assumptions on Implementation Schemes

Item	Assumption
1. G-G Scheme	
- Debt ratio	70%
- RGoB's own funding requirement	None (30% of initial investment cost is covered through grant assistance)
- Loan conditions (Denominated in LC)	Interest rate: 10.0% per annum Grace period: 6 years (construction period), Repayment period: 15 years
- Revenue of RGoB	RGoB's energy share: 100%
2. ODA Scheme	
- Debt ratio	85% (concessional ODA loan by donor organization)
- RGoB's own funding requirement	15% of initial investment cost
- Loan conditions (ODA loan denominated in FC)	Interest rate: 0.9% per annum Grace period: 10 years, Repayment period: 20 years
- Revenue of RGoB	RGoB's energy share: 100%
3. PPP Scheme	
- Debt ratio	70% (Private Sector Investment Finance loan by donor: 35%, Commercial bank loan:35%)
- RGoB's own funding requirement	15% of initial investment cost as equity investment by RGoB
- Loan conditions	- Private Sector Investment Finance loan (foreign currency) Interest rate: 3.5%, Grace period: 4 years, Repayment: 16 years - Commercial bank loan (local currency) Interest rate: 10.0%, Grace period: 4 years, Repayment: 10 years
- Revenue of RGoB	RGoB's energy share: 50% Energy Royalty revenue (first 12 years: 12%, next 18 years: 18%)
4. IPP Scheme – 1	
・ Equity ratio	30% (fully covered by equity investment by private investor)
・ Debt ratio	70% (Private Sector Investment Finance loan by donor: 35%, Commercial bank loan:35%)
- RGoB's own funding requirement	None
- Loan conditions	- Private Sector Investment Finance loan (foreign currency) Interest rate: 3.5%, Grace period: 4 years, Repayment: 16 years - Commercial bank loan (local currency) Interest rate: 10.0%, Grace period: 4 years, Repayment: 10 years
- Revenue of RGoB	Energy Royalty revenue (first 12 years: 12%, next 18 years: 18%)
5. IPP Scheme – 2	
- Equity ratio	30% (same as in IPP Scheme – 1)

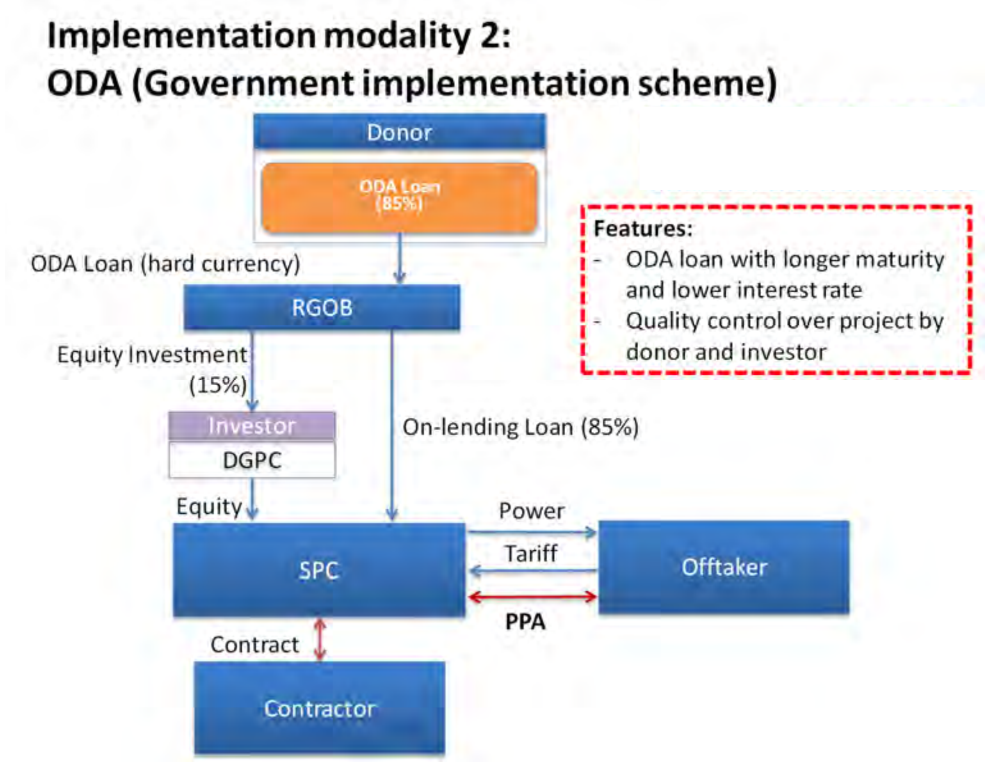
-	Debt ratio	70% (same as in IPP Scheme – 1)
-	RGoB's own funding requirement	None
-	Loan conditions	Same as in IPP Scheme – 1
-	Revenue of RGoB	Energy Royalty revenue (12% over 30 years of operation period) 21.8% of annual energy sold as Free Energy
6.	**IPP Scheme – 3**	
-	Equity ratio	30% (same as in IPP Scheme – 1)
-	Debt ratio	70% (same as in IPP Scheme – 1)
-	RGoB's own funding requirement	None
-	Loan conditions	Same as in IPP Scheme – 1
-	Revenue of RGoB	Energy Royalty revenue (12% over 30 years of operation period) Capacity Royalty revenue (first 15 years: 248 Nu./kW, next 15 years: 1116 Nu./kW Free Equity dividend (27% of annual free cash flow of SPC)

(Source: JICA Survey Team)



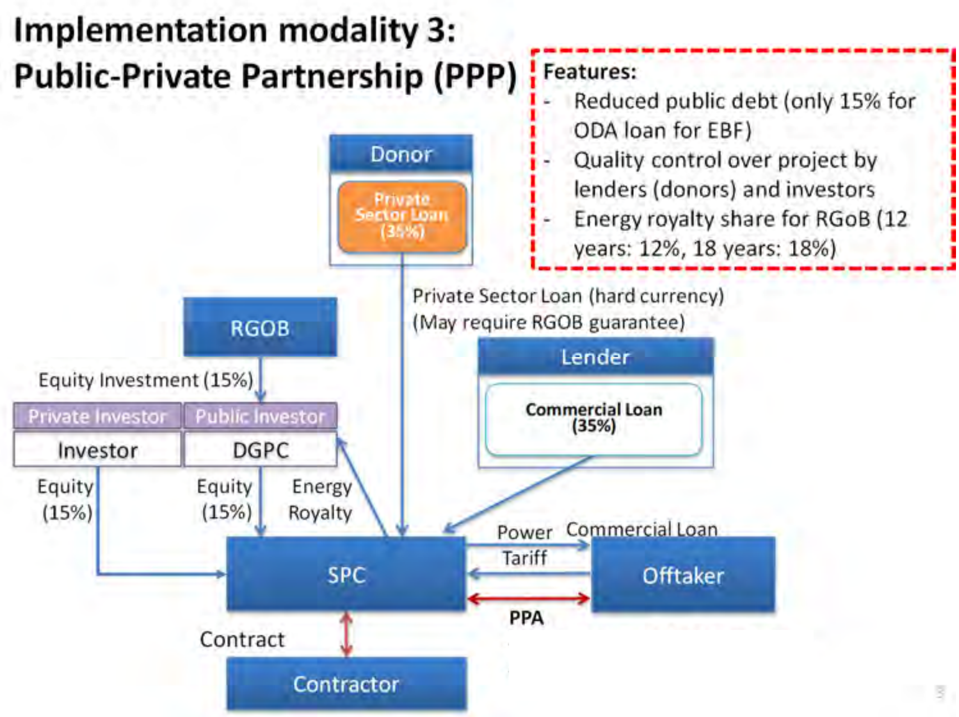
(Source: JICA Survey Team)

Figure 12-2 G-G Scheme



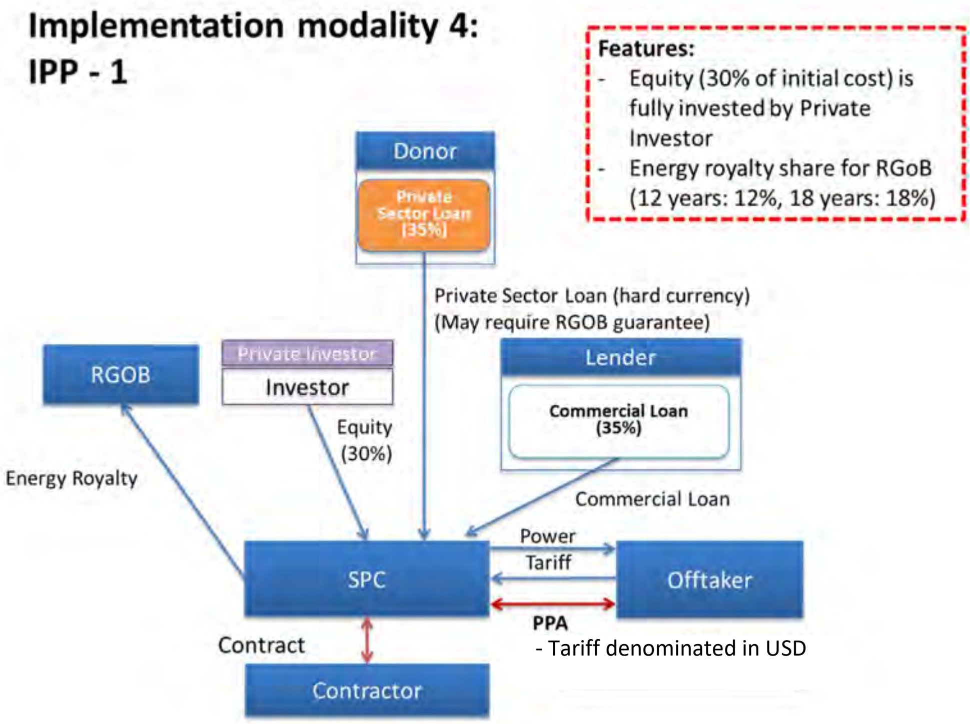
(Source: JICA Survey Team)

Figure 12-3 ODA Scheme



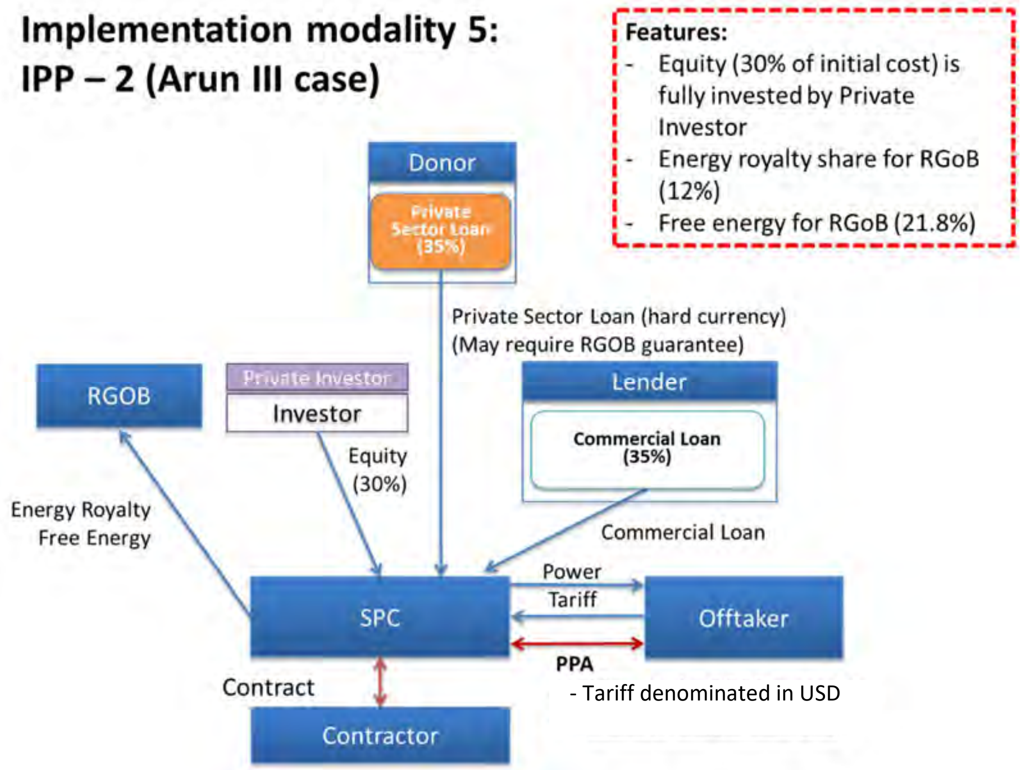
(Source: JICA Survey Team)

Figure 12-4 PPP Scheme



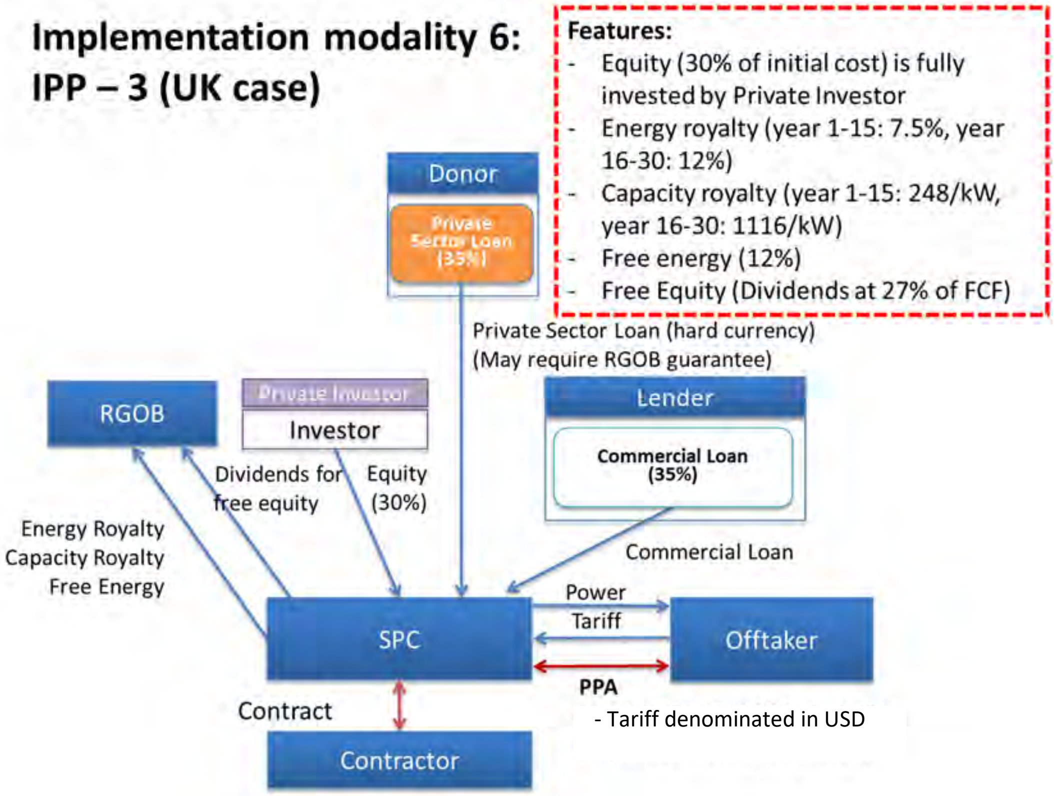
(Source: JICA Survey Team)

Figure 12-5 IPP Scheme - 1



(Source: JICA Survey Team)

Figure 12-6 IPP Scheme - 2



(Source: JICA Survey Team)

Figure 12-7 IPP Scheme - 3

(4) Financial analysis results and comparison of implementation modalities

A cash flow projection is developed for each implementation modality based on the aforementioned assumptions to estimate all cash in-flows and out-flows of RGoB in each case (see Appendix 7). Net present value (NPV) of the cash flows has been calculated with a 10% discount rate for comparison as shown in Table 12-8. Also, RGoB's NPV has been estimated in the case of a three-year construction delay as well as with the assumption of a 6% exchange risk premium for foreign currency loans.

Table 12-8 Results of Financial Analysis (Comparison of RGoB Total Net Cash Flow)

NPV (2026-2061) @ 10% DR (BTN million)	Funding Requirement for RGoB During Construction	Total Cash Flow of RGoB (Net Present Value)						
		Base Case	3 Year Construction Delay			PSIF and ODA loan for RGoB (+ 6.0% exchange risk premium)		
		NPV	NPV	Difference		NPV	Difference	
1-1: G-G (RGoB 100%)	None	9,922	6,102	-3,819	-38%	-	-	-
1-2: G-G (JV Case: RGoB 50%)	None	4,961	3,051	-1,910	-38%	-	-	-
2: ODA	2,065	11,756	7,667	-4,089	-35%	9,101	-2,655	-23%
3: PPP	2,065	7,558	5,097	-2,460	-33%	6,375	-1,183	-16%
4-1: IPP (Energy Royalty 12 ~ 18%)	None	3,568	2,738	-831	-23%	-	-	-
4-2: IPP (Arun III case)	None	8,609	6,662	-1,947	-23%	-	-	-
4-3: IPP (UK case)	None	7,974	5,852	-2,121	-27%	-	-	-

(Source: JICA Survey Team)

(a) G-G scheme

The net present value of RGoB's cash flows has been estimated at 9,922 million Nu. in the G-G scheme, which applies the existing project implementation modality with GOI assistance. In the case

of a J/V scheme implemented with an Indian state-owned company, the NPV of RGoB will be reduced to 4,961 million Nu. because the RGoB's energy share will be 50%.
Since 30% of the initial investment cost is provided as grant assistance by GOI, RGoB is not required to provide any of its own funding for initial investment, which makes the G-G scheme the most beneficial implementation modality.
However, the G-G scheme requires countermeasures for construction risks and quality control issues, due to the procurement being limited to Indian companies, which have been observed in the ongoing projects. It is also necessary to examine whether the favorable financing conditions, such as grant assistance, that benefit the on-going projects will be available for future projects.

(b) ODA scheme
In the ODA scheme, the NPV of RGoB's cash flows has been estimated as 11,756 million Nu., the largest among other schemes reflecting the concessional conditions of an ODA loan, especially its repayment period, which can be as long as 30 years including the grace period. However, this decreases to 9,101 million Nu. when assuming an exchange risk premium of 6.0% per annum for the foreign loan.
The scheme also requires RGoB to secure its own funding of 15% for the initial investment (2,065 million Nu.) and the ODA loan amounting to 11 billion Nu. from donor organizations.

(c) PPP scheme
In the PPP scheme, NPV for RGoB is estimated as 7,558 million Nu. with energy royalty revenue; however, RGoB is required to secure its own funding for 15% of the initial investment cost. Since the electricity sales in the PPP scheme is assumed as export to countries other than India such as Bangladesh and denominated in US dollar, it will offset the exchange risk derived from the foreign loans for the project.

(d) IPP scheme
The IPP scheme features benefits for RGoB in that there is virtually no obligation for RGoB to provide its own funds for initial investment or to make debt repayments during operation because it does not require equity investment by RGoB and all financing requirements must be secured by the private investors. For IPP Scheme – 2, where RGoB benefits from 21.8% free energy in addition to the royalty revenue, the NPV of RGoB amounts to 8,609 million Nu.

Table 12-9 summarizes a comparison of the financial analysis results and the features of the implementation modalities.

Table 12-9 Comparison of Implementation Modalities

Item	G-G	ODA	PPP	IPP
Net present value of RGoB's cash flows	9,922 million Nu.	11,756 million Nu.	7,558 million Nu.	8,609 million Nu. (IPP Scheme – 2)
RGoB's own funding requirements for initial investment	None	15% of initial investment (2,605 million Nu.)	15% of initial investment (2,065 million Nu.)	None
RGoB's obligation to secure debt financing and repayments	GOI loan	ODA loan	None (Financing secured by private investor)	None
Procurement and construction supervision	Procurement and construction supervision limited to Indian companies	International competitive bidding under regulation by donor	Procurement and quality control by private companies	Procurement and quality control by private companies

(Source: JICA Survey Team)

(5) Comparison of levelized costs of energy sold

Table 12-10 shows the estimated levelized costs of energy sold in the G-G scheme, ODA scheme and PPP scheme. As a result, the levelized tariff of the ODA scheme (2.59 Nu./kWh) has been estimated as the lowest because of the long repayment period for its financing.

Table 12-10 Levelized Costs of Energy Sold

Outgoing Cost	1: G-G	2: ODA	3: PPP
O&M Cost (BTN mn)	7,556	7,556	7,556
Income Tax (BTN mn)	35,220	37,425	40,793
Debt Service (BTN mn)	20,651	13,418	15,505
Reinvestment and overhaul (BTN mn)	15,639	15,639	15,639
Total (BTN mn)	**79,066**	**74,037**	**79,493**
Levelized cost (BTN/kWh, @15% Cost of Equity)	**3.79**	**2.59**	**3.72**

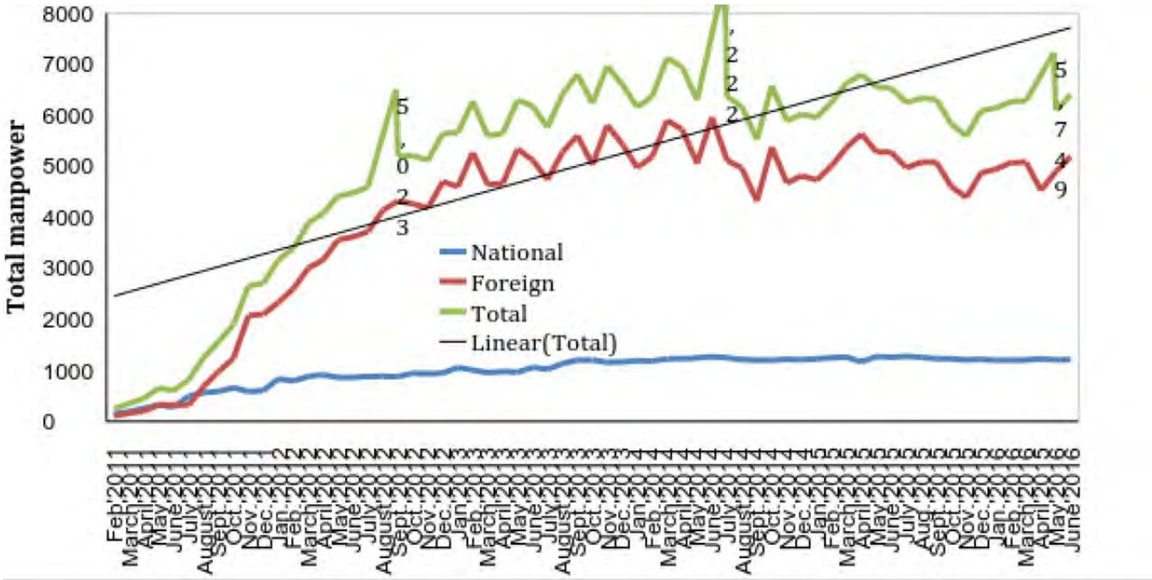
(Source: JICA Survey Team)

12.3.2 Impact Assessment on Regional Economy

During construction of a large-scale hydropower plant, over 5,000 construction workers move around the plant site and live for over 5 years. In general, the area around the hydroelectric power plant construction site is far from urban areas, there are no large settlements, and many residents there earn a small amount of money from primary industry, mainly agriculture. Therefore, when construction of a hydroelectric power plant is started, a big lifestyle change will occur for the residents of the surrounding area. Specifically, beneficial effects are expected from the construction of new houses, the creation of employment opportunities, and the purchase of ingredients and supplies. For these effects, the impact on the regional economy is evaluated with reference to the "Study on Spillover Impacts of Hydropower Projects (A Case Study on Kholongchhu Hydro Energy Project)" (RMA, DGPC: 2016).

(1) Number of construction workers

The number of construction workers for Punatsangchhu-II (PHPA II) given in "Study on Spillover Impacts of Hydropower Projects" is shown below.



(Source: Study on Spillover Impacts of Hydropower Projects (RMA, DGPC: 2016))

Figure 12-8 Number of Construction Workers for PHPA II

For about half a year from the start of the construction there were a few hundred workers, but this gradually increased to around 3,000 after one year and around 5,000 after one and half. There have been around 6,000 workers since then. Looking at the ratio of national workers and foreign workers, foreign workers account for over 80%.

The required number of construction workers depends on the size and type of power plant to be developed. In a 500 MW or more hydropower plant, where relatively large dams are to be built, around 5,000 to 6,000 workers are engaged in construction work during the peak period of construction.

(2) Benefits to the regional economy

The benefits to the regional economy on Uzorong site (840 MW) are evaluated. This site has the same scale as Punatsangchhu I (1,200 MW) and Punatsangchhu II (1,020 MW) which are referred to by "Study on Spillover Impacts of Hydropower Projects" and Kholongchhu (600 MW), covered by the report. The conditions for the evaluation are as follows.

- Number of construction workers: 5,000 to 6,000 on average
- Ratio of national workers: 10% to 20%

- Construction period: 6 years

(a) Construction of new houses

Because workers must commute every day to the construction site, it is necessary to live relatively close. It is therefore necessary to construct many new houses (colonies) in order to secure residences for all workers. In addition, with the new construction of these houses, infrastructure development such as water supply and sewage, power supply, roads etc. will be required. The conditions for the calculation are as follows.

- Foreign workers: secure all residences
- National workers: secure 50% residences
- Construction costs for one house (including infrastructure development costs, furniture, etc.)
    - Accommodation for families (permanent facility): Nu. 4.0 million
    - Simple dormitory (1 room): Nu. 0.1 million
- Simple dormitory: 90% of the total (senior staff use accommodation for families)

450-570 houses for families and 4,050-5,130 rooms for single workers (assuming one room per person) will be required. It is expected that 30% of new constructions for these houses and infrastructure development will be given to builders, furniture vendors and infrastructure development companies in the surrounding area. The beneficial effect on the regional economy is Nu. 662 to 838 million.

(b) Creation of employment opportunities

The number of national workers in PHPA II is around 10 to 20% of the total number of workers. Basically, the construction site needs personnel with special skills that are necessary for the construction of power plants, such as assembly workers, concrete workers, rebar workers and welders. However, in Bhutan, which has little experience in construction, there is a shortage of such personnel.

As a result, personnel who can be hired from residents living in the surrounding area are drivers, security guards, cafeteria workers, cleaning staff, simple assistants, etc., for jobs that require less skill. For this reason, it is assumed that the salary level will not be particularly high.

- Number of workers who live in surrounding area: 5% of the total (250 to 300)
- Monthly salary: Average Nu. 12,000/month

The beneficial effect on the regional economy is Nu. 36 to 43 million/year.

(c) Purchase of edible items

Almost all workers will eat and drink in the cafeteria prepared by the contractor during the construction period. Among the ingredients to be prepared in the cafeteria, fresh food products (vegetables, meat, eggs, etc.) are basically purchased from nearby areas. On the other hand, it is assumed that Indian contractors will import materials from India for stored materials such as cereals, oils and beans, so the beneficial effects for the region are considered to be small.
Some workers will not be satisfied with eating only in the cafeteria and buy ingredients and make food for themselves. It is considered that some workers will purchase ingredients from the surrounding area for individual consumption. The conditions for the calculation are as follows.

- Cost of ingredients required for meals at cafeteria (per capita): Nu. 2,200/month
- Percentage of fresh food in ingredients costs: 30%
- Proportion of stored materials purchased from surrounding areas: 10% to 20%
- Cost of ingredients as individual consumption (per capita): Average Nu. 500/month

The beneficial effect on the regional economy is Nu. 79 to 106 million/year.

(d) Purchase of daily necessities, beverages, etc.

Every worker must buy the essential daily necessities (soap, detergent, toilet paper, toothpaste, etc.) to live their life from a local store. Many items necessary for daily life (for example, stationery, clothes, shoes, etc.) will also be purchased from a local store. In addition to these, confectionery such as sweets and beverages such as alcohol will also be purchased from local shops. The conditions for the calculation are as follows.

- Consumption of daily necessities etc. (per capita): Average Nu. 1,000/month
- Consumption of confectioneries and beverages (per capita): Average Nu. 2,000/month

The beneficial effect on the regional economy is Nu. 180 to 216 million/year.

(e) Other effects

The following events can be considered as other effects. However, if the contractor prepares collectively, the beneficial effects on the surrounding area are considered to be small. Therefore, these effects are not anticipated in this calculation.

- Consumption of ingredients and daily necessities by workers' families
- Increase in simple work such as road maintenance work and cleaning duties
- Increase in transportation operations due to the activation of distribution
- Accommodation, eating and drinking by people who visit the construction site from outside in meetings or inspections
- Increase in use of taxis when workers return home
- Increase in automobile fuel consumption due to activated distribution and commuting

(3) Positive impact on the regional economy

The beneficial effects which are calculated in the previous paragraph are as follows. Among these, since the development of new houses will be carried out prior to construction, this will be evenly distributed over the six years of the construction period as a yearly beneficial effect. In addition, it is necessary to subtract raw materials and purchasing costs that are not related to the local economy, from the aspect of increasing the income of local residents.

Table 12-11 Beneficial Effects on the Regional Economy

	Item	Beneficial Effect (million Nu./year)	Raw material ratio unrelated to regional economy	Income increase effect (million Nu./year)
1	Construction of new houses	110 - 140	30%	77 - 98
2	Creation of employment opportunities	36 - 43	0%	36 - 43
3	Purchase of ingredients	79 - 106	0%	79 - 106
4	Purchase of daily necessities etc.	180 - 216	70%	54 - 65
	Total	405 - 505		246 - 311

(Source: JICA Survey Team)

The area surrounding the Uzorong site is shown below.

(Source: JICA Survey Team)

Figure 12-9 Gewogs surrounding Uzorong Site

As shown in the figure above, there are 3 Dzongkhags (Trashigang, Mongar and Pemagatshel) and 16 Gewogs within a 20 km radius from the Uzorong site. The survey results for the living conditions of those 16 Gewogs is shown below.

Table 12-12 Living Conditions of surrounding 16 Gewogs

Dzongkhag	Gewog	Resident population	Per capita income (Nu.)	Total income (million Nu.)
Mongar	Balam	912	35,181	32
	Chagskhar	2,375	41,324	98
	Dramedtse	1,798	26,888	48
	Drepoong	895	39,106	35
	Kengkhar	1,833	34,820	64
	Mongar	3,450	49,702	171
	Na-Rang	1,188	32,192	38
	Ngatshang	1,628	49,945	81
	Thang-Rong	1,605	31,885	51
Pemagatshel	Nanong	2,102	23,185	49
	Shumar	3,085	43,752	135
	Zobel	1,511	33,657	51
Trashigang	Kanglung	3,600	61,881	223
	Khaling	2,261	38,008	86
	Lumang	3,463	36,404	126

Dzongkhag	Gewog	Resident population	Per capita income (Nu.)	Total income (million Nu.)
	Uzorong	2,733	29,712	81
Total		34,439	39,785	1,370

(Source: Bhutan Living Standards Survey 2012 (BLSS2012))

Approximately 34,000 people live in these 16 Gewogs, which are within a 20km radius from the Uzorong site. The annual income of the whole region is Nu. 1,370 million, and the average annual income per capita is around Nu. 40,000. The income increase effect on the local people due to the development of the Uzorong site is Nu. 246 to 311 million per year, and an income increase of about 20% can be expected compared to the current situation.

Also, if 70% of total regional income increases in the three Gewogs closest to the Uzorong site, which are Uzorong, Thang-Rong and Chagskhar, an 80% to 90% income increase can be expected compared to the current situation in these three Gewogs.

12.4 Impact on National Debt

12.4.1 Debt Stock

As of the end of June 2017, the total debt stock of the country amounted to Nu. 170.3 billion and accounted for 106.6% of its GDP (see Table 12-3 below). Although this debt/GDP ratio has been steadily declining, this is still the second highest of Asian countries together with Singapore, following Japan (the largest debtor with 236.4%). The debts related to hydropower construction were worth Nu. 124 billion in 2017, comprising about 77% of the total external debts (or 73% of the country's total debts including domestic ones).

Table 12-13 Debt Stock (as of the end of June 2017)

(Unit: Nu. Billion)

Borrower/Purpose	Hydropower	Non-Hydropower	Total
External Debt			**160**
Government	0	29	29 (18% of External Debt)
DGPC/SPC*	124	0	124 (76% of External Debt) (in Rupee: 74%) (in Convertible Currencies: 26%)
RMA**	0	7	7 (4% of External Debt)
Domestic（T-Bills）		10	**10**
Total	**124**	**46**	**170 (100%)**

(Sources：National Budget 2017/18, MoF)

*SPC: Special Purpose Companies
**Royal Monetary Authority

Debt servicing has been on the increase. On the other hand, it is expected that new hydropower projects such as Mangdechhu and Nikachhu are to be completed within the coming few years, and that construction work for large-scale projects like Punatsangchhu I & II has entered its latter half and imports for the main equipment and materials have been decreasing. In addition, the contributions to GDP from other sectors have been increasing. In the contexts above, the debt stock ratio is anticipated to decline gradually for the short and medium term. The "Budget Report 2018" by MOF forecast that the debt/GDP ratio will decline from the current level exceeding 100% to 99.9 % in 2017/18, 96.3% in 2018/19, and further to 91.8% in 2019/20. In addition, debt repayment will follow immediately after the commencement of operations of the under-construction projects from new power export revenues, contributing to a reduction of debts outstanding. The international financing institutions such as IMF/WB and ADB, even though aware of the high debt stock of the country, are also aware that over 70% of the debt is connected to hydropower, with its accrual power to service debt by itself, and thus are not alarmed by the debt level itself.

In 2016/17, the total debt servicing amounted to Nu. 4,897 million or 8.7% of the total RGoB revenues, of which 57% was for the repayments of the principals of loans and the remaining 43% was expensed for interest payments. The debt servicing ratio (DSR), which is calculated as "debt servicing value/total exports value) was projected at 14.8% in the 2018 Budget Report for the budget period of 2017/18, and allocated the equivalent expenditure. The country's DSR is far below the "general" or "textbook" cautious percentage, which is 20% (recently, various ways of risk hedging have been developed, and DSR has an upward tendency exceeding 20% all over the world). Further, DSR is anticipated to decline for the same reason as the debt/GDP ratio. In view of the above, the country's debt position could be judged as sound and prudent.

12.4.2 Public Debt Policy

In addition to a relatively higher debt stock, it has become evident that it is becoming difficult for Bhutan to receive concessional loans and grants as the country has been categorized as a middle-income country by the international organizations. To cope with these changing conditions, MoF published a comprehensive "Public Debt Policy 2016". The Policy emphasized at the outset the need to maintain minimum foreign currency reserves that are adequate for one year's import values, pursuant to the Public Finance Act 2007. Then, it stipulates as follows (in relation to the hydro sector debts):

- the annual external debt servicing shall not exceed 25% of total exports;
- non-hydro debt shall not exceed 35% during the Five Year period;
- debt financing shall be done only when grant financing has been found difficult;
- only concessional loans shall be made;
- borrowing shall be on a needs and absorptive capacity basis but not motivated by availability;
- commercial borrowing shall be only for investments in financially viable sectors;
- ensure appropriate currency composition, interest rate, and maturity structure of the debt stock;
- while borrowing for public corporations is in principle possible with the approval of the Minister, MoF, when direct borrowing is difficult, it might be possible for RGoB to borrow and on-lend it with a service charge of 0.75%;
- debt service coverage ratio (which is obtained by "cash flow for the year/total debt servicing values) shall be more than 1.2;
- maintain less than a 40% level of the hydro sector debt servicing values against the sector's annual export values; and
- debt-to-equity ratio for hydropower projects shall meet 70:30.

The current debt status of the country is examined in accordance with the conditions laid out above by the Debt Policy. The foreign currency reserves amounted to USD 1,033 million, equivalent to 11.5 months' exports ("2018 Monetary Statement" by MoF), and have not met the provision of the Debt Policy. RGoB needs to accumulate further foreign currency reserves. The "2018 Monetary Statement" noted that RGoB would increase the foreign currency reserves for the medium term to USD 1,651 million, equivalent to 18.5 months' import values. Debt servicing in 2016/17 was Nu. 4,897 million, equaling 13% of GDP, which was far below the 25% ceiling under the Debt Policy. Non-hydro sector debts accounted for 23%, much less than the 35% ceiling of the Debt Policy.

12.4.3 Simulation of the Impact on National Finances and National Debt

The development of hydropower plants is the largest business for Bhutan. Therefore, the impact on the national finances and debt is also very large. As mentioned above, as of the end of June 2017, Bhutan's total debt amounted to Nu. 170.3 billion, which was 106.6% of the total GDP in the same year. 77% of the total debt - that is, Nu. 124 billion - is foreign debt for the construction of hydroelectric power plants. Based on these points, simulations are carried out on the state of the national debt, which will increase with hydropower development, and the impact on the national finances.

(1) Power development plan

The COD (Commercial operation date), the construction costs, and the amount of power generation for the following sites (13 sites), which are out of the scope of this MP, are shown below. The years of operation are allocated to be relatively even within the five years described in NTGMP 2018.

Table 12-14 Status of the 13 Sites which are out of Scope of this MP

Name	Capacity (MW)	Energy (GWh)	COD	Cost (million Nu.)	Conditions of Loan
Punatsangchhu-1	1,200	5,585	2023	93,756	Loan: 60%, Grant: 40%
Punatsangchhu-2	1,020	4,667	2022	72,906	Loan: 70%, Grant: 30%
Mangdechhu	720	2,924	2019	48,184	
Sankosh	2,595	6,215	2029	114,720	Not yet decided
Kuri-Gongri	2,640	10,056	2035	200,000	
Amochhu	540	1,835	2045	37,917	
Kholongchhu	600	2,569	2023	38,689	JV (50%:50%) Loan: 70%, Grant: 30%
Wangchhu	570	2,280	2031	40,608	
Bunakha	180	719	2032	29,528	
Chamkharchhu I	770	3,373	2033	47,760	
Nikachhu	118	492	2021	11,960	ADB Equity: 35% (Loan: 50%, Grant: 50%)
Nyera Amari	404	1,700	2030	22,080	
Dorjilung	1,125	4,558	2026	84,050	Not yet decided

(Source: Created by JICA Survey Team based on the data provided by DHPS)

The funding conditions for the Sankosh, Kuri-Gongri, Amochhu, and Dorjilung site have not been determined, but in the simulation, the funding conditions are set to Loan: 70%, Grant: 30%, the same as for Mangdechhu.

The COD, construction costs, and generated energy for the Short-listed site extracted in this MP are shown below. The COD rationale is basically to develop one site each year in descending order of B/C.

Table 12-15 Status of the Short-listed Sites

Project code	Name	Capacity (MW)	Energy (GWh)	COD	Cost (million Nu.)
A-8	Dorokha	550	2,407	2034	50,444
C-10	Chamkharchhu-II	414	1,814	2033	38,628
P-30	Pinsa	153	672	2031	10,543
A-5	Tima	783	3,428	2036	42,798
M-6	Jongthang	227	995	2040	25,791
G-14	Uzorong	840	3,678	2038	84,074
P-17	Tseykha	215	943	2042	23,803
P-26	Thasa	706	3,094	2047	82,467
P-29	Kago	58	255	2048	6,104
P-34	Darachhu	89	389	2049	10,077
P-35	Dagachhu-II	71	311	2049	8,526
M-11	Wangdigang	502	2,200	2044	52,772

Project code	Name	Capacity (MW)	Energy (GWh)	COD	Cost (million Nu.)
M-17	Buli	69	302	2048	7,080
C-7	Chamkharchhu-IV	451	1,974	2041	42,332
K-13	Minjey	673	2,948	2043	87,385
G-10	Gamrichhu-2	108	471	2046	12,330
G-11	Gamrichhu-1	150	656	2046	15,381
N-1	N.A. Kangpara (G)	71	312	2050	7,948

(Source: JICA Survey Team)

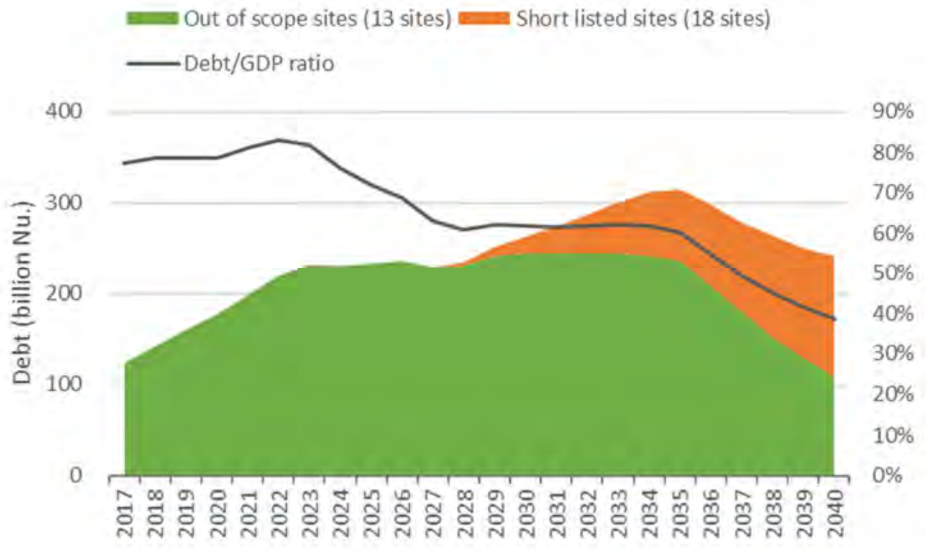
Although the funding conditions for these sites have not been determined, a PPP scheme with 50% shares of RGOB is applied in the simulation. As for the distribution of power generation, Bhutan takes 15% as royalty energy, and the remaining 85% is split in half.

(2) National debt situation related to hydropower development

The national debt situation related to hydropower development is simulated under the following conditions.

- Borrowing funds: Repay equally over 12 years after COD
- IDC: 10%
- Construction period: 5 to 8 years (depending on the development scale)
- Escalation rate: Not considered

The simulation results are shown below.



(Source: JICA Survey Team)

Figure 12-10 National Debt Situation Forecast

The national debt related to hydropower development is a debt that can be repaid by selling electricity after the power plant starts operation, and it is not a big problem even if the amount is increased. The national debt related to hydropower development is expected to increase gradually, and to exceed Nu. 200 billion in 2022. If the development covers only the 13 sites that are out of the scope of this MP, it will not exceed Nu. 300 billion. However, there is a possibility that the debt will increase further if the operation start times are delayed after the construction starts, or if the construction costs become higher than originally expected.

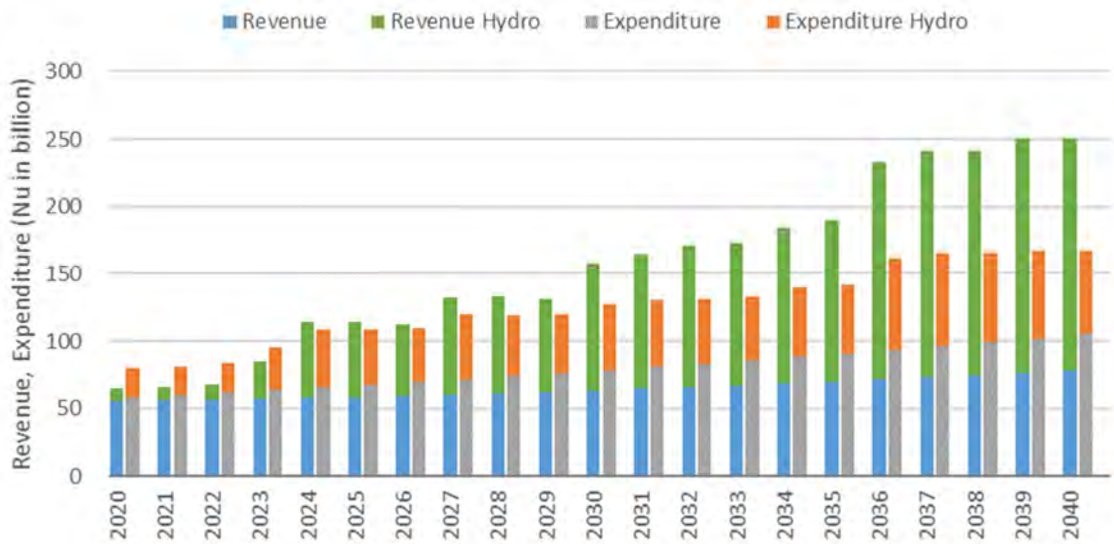
GDP is assumed to increase by a fixed amount (Nu. 20 billion) every year, and the ratio of national debt to GDP will remain high, at around 80%, until 2023. After that, it will decline gradually, and even if the Short-listed 18 sites are developed, it will decrease to about 40% in 2040.

(3) State balance situation

The balance of the state is simulated under the following conditions.

- In 2018, revenue and expenditure are balanced at Nu. 55,000 million
- Both revenue and expenditure excluding new hydropower plants will increase by 3% annually. However, the grant part of revenue (about 30% in 2018) will decrease by 5% each year
- All generated power excluding supply for domestic demand is sold at Nu. 4.2/kWh
- Annual O&M expenses of hydropower plants: 1% of the construction cost
- Borrowing funds: Repay equally over 12 years after COD
- Interest rate: 10%

The simulation results are shown below.

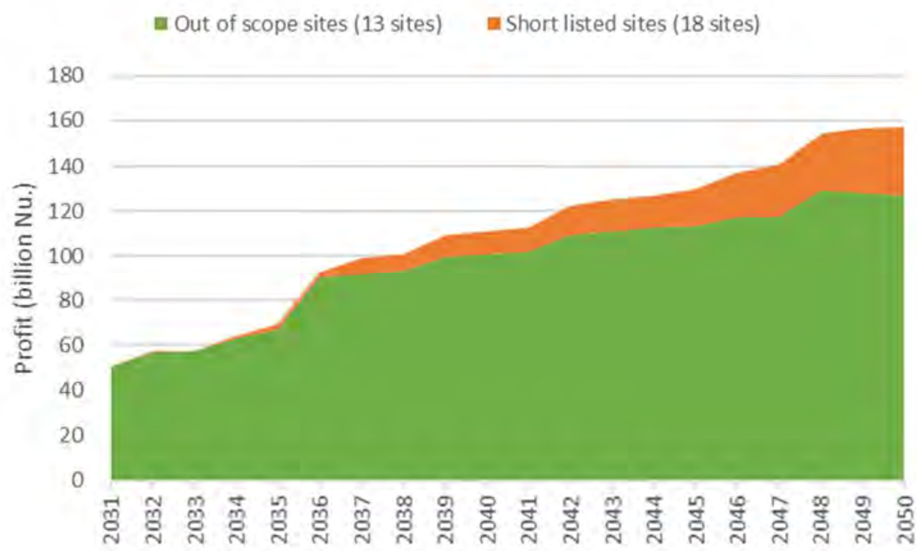


(Source: JICA Survey Team)

Figure 12-11 State Balance Situation Forecast

The balance situation of revenue and expenditure will continue until 2026, but after 2027 the power generation revenue from hydroelectric power plants will increase, and the revenue will gradually rise above the expenditure. With the increase in national revenue, it will be possible to secure a budget for implementing the various policies (for example, road development, welfare policies, etc.) necessary for the country to advance.

Among the balance of payments mentioned above, only the balance (revenue - expenditure) from hydropower development is shown below.
Until 2040, most of the revenues are from the 13 out of scope sites. However, from 2041, the revenue from the Short-listed sites extracted in this MP will also gradually increase and account for about 15% of the whole in 2050.



(Source: JICA Survey Team)

Figure 12-12 State Balance Situation Forecast from Hydropower Development

Chapter 13. Capacity Building

The purpose of this study is to support the formulation of the Power System Master Plan 2040 (PSMP 2040) in Bhutan and to strengthen the medium- and long-term PSMP formulation capacity of the Department of Hydropower and Power Systems (DHPS) staff. Therefore, in order to build DHPS staff's capacity to formulate the next master plan independently, a capacity building program was conducted for this staff.

13.1 Identifying Needs for Master Plan Formulation in Bhutan

The content of work necessary for power system master plan formulation in Bhutan is as follows.

Table 13-1 Contents of Work necessary for Master Plan Formulation

Work	Item	Contents
Potential site identification	Civil design	Setting conditions for making plot plans of main civil structures (dam, waterway, powerhouse, etc.)
	Hydrology	Confirmation of certainty of measured hydrological data Understanding the flow regime of each river basin
	Q-GIS	Thematic map creation Acquisition of river profile crossing points Calculation of river basin area at intake point
Comparison of projects (Site reconnaissance)	Cost estimation	Power plant facilities (civil, electro-mechanical) Transmission and transformation facilities O&M expenses
	Benefit evaluation	Calculation of available annual energy generation Setting of power sales tariffs Value of firm power Value of ancillary service provision
	Geological survey	Method of ascertaining both morphological and geological features Specific content for geotechnical investigation planning and overall interpretation viewpoint (importance of corroboration with designers)
	Environmental survey	Points to check when conducting natural and social environment surveys Judgment basis for MCA items regarding natural and social environment
	SEA	Differences between the basic ideas of SEA and EIA Comparison and examination of alternatives Basic ideas on Cumulative Impacts and Impacts on Climate Change Points to be noted in EIA implementation for candidate projects
Creation of PDP	Financial analysis	Project financial analysis based on discounted cash flow projection (calculation of IRR, NPV, etc.) Basic analysis of corporate financial statements (income statement, balance sheet and cash flow statement)
Creation of grid expansion plan	System analysis	Power flow analysis, Voltage analysis, Fault current analysis, Stability check etc.

(Source: JICA Survey Team)

Capacity building is implemented by means of both OJT (On the Job Training) and Off-JT, with the aim of getting DHPS staff to acquire skills in the work content described above and formulate their own master plans.

13.2 Hydropower Development Planning

13.2.1 First Off-JT

(1) Outline of Training

(a) Date: 10:30-14:00 on March 8th, 2018

(b) Venue: Financial Institutions Training Institute (FITI), 4F Training Room

(c) Participants: Total of 27 members from 5 departments and agencies
BPC: 2 members, BEA: 4 members, DHPS: 17 members, DGPC: 3 members, DRE: 1 member

(2) Content of Training

The Civil Team from the JICA Survey Team made a presentation on the following themes, and Question and Answer sessions followed this.

(a) Hydropower Planning (Conventional Type)
Outline of Chapter 5. Planning via Reconnaissance Study Method and Chapter 6. Preliminary Estimation of Construction Costs in "Guideline and Manual for Hydropower Development" (JICA, 2011) were explained.

(b) Supplemental Materials
Supplemental materials on the following primary themes were prepared and explained.
In addition, the JICA Survey Team gave a task on hydropower potential identification to DHPS and will evaluate its study results in the third site survey.

- Map Reading
- Flow Prediction
- Dam Stability Analysis
- Homework on hydropower potential identification (a river system was selected and this should be done)

(c) Meteorology in Topographical and Geological Investigation for Hydropower Planning
The basic method and procedure for topographical and geological interpretation at the potential investigation stage and the Pre-FS investigation stage in Bhutan were explained and their interpreted results were evaluated. At the same time, outlines were given on examples of concrete investigation plans and the results of individual completed projects in Japan and other countries.


Presentation on Guideline


Presentation on Supplemental Material


Presentation on Topographical & Geological Investigation

Training

Training

(3) Outcomes

Some specific questions were asked by a civil engineer regarding topographical and geotechnical investigation plans and interpretation work, and a lively discussion ensued. Realistically, some investigation items are impossible in Bhutan (seismic prospecting, etc., which cannot normally be carried out due to the difficulty in obtaining explosives licenses), so there is an issue of how to cover such lacking parts.

(4) Future development

Among some problematic topographical and/or geological features in the wide area, some of them are not considered to be a problem depending on the target structure and scale. It is necessary to give practical guidance considering that appropriate evaluation taking into account the economics of the project and the impact on the surrounding environment is essential, based on the basics of topographical and geotechnical problems at a higher level with applied geological aspects, such as civil engineering geology or geotechnical engineering.

13.2.2 Second Off-JT (Hydrology and Meteorology)

(1) Outline of Training

(a) Date: 14:30-17:00 on March 12th, 2018

(b) Venue: DHPS conference room, 2nd Floor of the MOEA Building

(c) Participants: Total 19 members from 5 departments and agencies
BEA: 4 members, DHPS: 8 members, DGPC: 2 members, DRE: 3 members, NCHM: 2 members

(d) Handouts
Off-JT for Hydrology
Off-JT for Hydrology: SWAT
Off-JT for Water Balance Analysis using MODSIM

(2) Training Items

- Outline of hydrological study
- Outline and demonstration of Run-Off analysis using Soil and Water Assessment Tool
- Outline of water balance analysis using MODSIM

(3) Content of Training

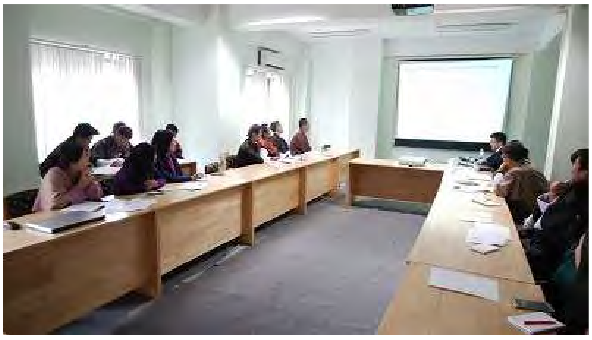
(a) Outline of hydrological study

An outline of the hydrological and meteorological analysis was explained with a handout (Off-JT for Hydrology) distributed. The handout was prepared based on the context presented in the "Guideline and Manual for Hydropower Development" prepared by JICA in 2011, which includes the following study items:

- Study Items and Purposes
- Hydrological Investigation Method
- Runoff Analysis for Hydropower Planning
- Study on Evaporation
- Study on Reservoir Sedimentation
- Flood Analysis for Dam Design

(b) Outline and demonstration of Run-Off analysis using Soil and Water Assessment Tool
SWAT (Soil and Water Assessment Tool) is free software that can calculate long term runoff, and the model has been widely applied in developing countries. SWAT is a hydrological tool but it is not stand-alone type software. It works on Graphical Information Software, such as Arc GIS or QGIS, as an external function. For explanation purposes, SWAT which works on QGIS (called QSWAT) was used and examples of its runoff analysis were demonstrated during the training. The installer for QGIS and SWAT were also distributed to participants.

(c) Outline of water balance analysis using MODSIM
An outline of the optimum water allocation model for river networks, using "MODSIM", was explained during the training. MODSIM is a stand-alone application developed by Colorado State University in the US, and it is freely available from the university's website. MODSIM has been widely applied in projects under the US bureau of reclamation (USBR) as well as in developing countries.



13.2.3 Third Off-JT

(1) Outline of Training

(a) Date: 10:00-12:00 on May 22, 2018

(b) Venue: Conference Room at MoEA

(c) Participants: Total of 24 persons from 4 departments/agencies
BPC (Bhutan Power Corporation Limited): 4 persons
BEA (Bhutan Electricity Authority): 5 persons
DHPS (Development Hydropower and Power System): 11 persons
DGPC (Druk Green Power Corporation): 4 persons

(2) Contents of Training

The JICA Survey Team's Civil Team gave a presentation on the following themes. Question and Answer sessions followed.

(a) Conventional Hydrology – Estimation of Flow Duration Curve

The JICA Survey Team explained the methodology for checking the reliability of gauging data (double mass curve method) and the method for supplementing deficient data. The Team explained the annual flow duration curves of the 7 main river systems, prepared based on river flow rates over 11 years which had been observed at the Primary and Secondary gauging stations, and for which the data's reliability had been confirmed.

(b) General Operation of QGIS and Base Map Creation

The JICA Survey Team explained the general operation method for QGIS, the method for creating a topographic map from elevation data in a 10m mesh, and the method for allocating a river system basin and calculating each catchment area.

(c) Potential Site Identification (Wangchhu)

The JICA Survey Team explained a longitudinal profile of the river in the Wangchhu by using the above topographical map data, and identified the potential hydropower site, the design discharges calculated based on the annual flow duration curves and the annual precipitation contour map, and the total installed capacity of potential sites in the Wangchhu.

	
Training session	Training session

(3) Training Outcome and Issues

Trainees were able to acquire knowledge at a high level, judging from the results of question-and-answers, etc. during Off-JT. Furthermore, it is judged that each C/P was able to achieve a practical outcome, since the JICA expert in each field has transferred technology separately to his C/P, including Off-JT data, analysis results and so on. However, because there are various technical fields (topography, geology, hydrometeorology, and civil engineering), the number of trained engineers is limited to about 2 people for each field. Therefore, it is necessary to improve organizational quality control capabilities so that they can scale up the MP for themselves in the future.

13.2.4 On the Job Training

(1) Outline of Training

(a) Date: Primary Site Reconnaissance (14 Nov. 2018 - 11 Dec. 2018)
Secondary Site Reconnaissance (16 Jan. 2019 - 30 Jan. 2019)

(b) Place: 37 Semi-longlisted Sites

(c) Trainees: Primary Site Reconnaissance: 8 members from DHPS (Civil: 6, Geology: 2)
Secondary Site Reconnaissance: 3 members from DHPS (Civil: 1, Geology: 2)

(d) Handouts

- Every QGIS plot plan
- Intake dam/weir, waterway and powerhouse locations plotted on Google Earth for each site
- Intake dam/weir, waterway and powerhouse locations plotted on the geological map by Long
- Unstable slopes, linearments, major faults, and so on illustrated on Google Earth image

(2) Training items

■ Civil Engineering

- Check items regarding civil engineering
- Selection techniques for Dam/Weir axis and type
- Selection techniques for Waterway route
- Selection techniques for Penstock route
- Selection techniques for Powerhouse location and type (ground surface/underground)
- Research techniques using Drones

■ Geological Analysis

- Check items regarding geology
- Geological structure analysis
- Analysis of slope collapse and unstable slopes caused by Mass rock creeping and/or hydrothermal alteration
- Evaluation techniques for bed rock classification
- Evaluation techniques for weathering and loosening
- Examination techniques for distribution of permeable rock mass

Explanation of Geology

Explanation of Research Techniques using Drones

(3) Outcomes, and issues

By contrasting the pre-considerations and the actual on-going and planned site conditions, concrete training was performed to judge whether progress was as expected or not. Through the Q&A training, the trainees might be able to learn how to evaluate site-specific conditions quantitatively from a qualitative analysis of natural phenomena.

With regard to how to proceed to the planning site, in order to gain an understanding of how to use the above-mentioned information learned at the preceding planning site while reviewing its content, technical research must be conducted observing various sites in Bhutan and foreign countries. As it is necessary to improve the technology, it is necessary to include time and budget considerations for young engineers.

13.2.5 GIS Basic Training

In order for DHPS to utilize Geographic information by itself in its activities, such as hydropower planning, GIS basic skill training (lectures and practical training) was carried out, with the aim of furthering the utilization of GIS. It was intended for beginners who did not usually specialize in GIS. GIS engineers also participated in this training as support trainers, which enabled them to practice and be evaluated with regard to the role of a GIS trainer through this training.

(1) **Contents of the training**

There were a total of 10 participants, from DHPS, DGPC, BPC, and JICA's Bhutan office. Because there were novices in GIS the basics of GIS were explained, such as an introduction to and theory of GIS, and its capabilities.

(2) **Evaluation of the training**

With regard to evaluating participants' understanding of, or proficiency in, the training, the trainees were evaluated by their achievement of each process target. As there were no participants who had fallen behind in skills or had poorly achieved in in the training, an average evaluation was made for them.

In terms of evaluating the GIS engineers, one good aspect was that they participated as support trainers for this training, which gave them the opportunity to be trainers and practically provide the participants with detailed instructions and advice. In addition, the GIS engineers gave detailed explanations to the beginner participants by asking questions which were prepared by imagining what participants would ask about. This was another good aspect of the evaluation.

Table 13-2 Content of Training and Evaluation

Work	Content	Evaluation	Criteria
GIS Basic theory	What is GIS? Data Types for GIS Layers Databases Analysis Coordinate reference system	3	3: Understands and can practice oneself 2: Assistance required 1: Re-guidance required
QGIS Basic operation	Introduction	3	
	Import, Selection, Creation	3	
	Style and Label setting, Editing	3	
	Attribute tables, Calculation	2	
GIS Thematic map creation	Contour line creation	3	
	River watershed area creation	2	
	River profile point creation	2	

(Source: JICA Survey Team)

13.2.6 Reservoir Management and Operation Optimization

(1) Outline of the Training

(a) Date and Time:

1st Day: 13:30 – 16:00, 14th June, 2019
2nd Day: 10:00 – 16:00, 18th June, 2019
3rd Day: 10:00 – 15:30, 19th June, 2019
4th Day: 10:00 – 12:00, 20th June, 2019

(b) Venue: Conference Room at DHPS

(c) Participants: Total of 11 persons from MoEA

DHPS: 8 persons, DRE: 3 persons
Survey Team: Seki, Ito, Tamakawa, Uematsu(Lecturer), Ueda(Lecturer), Makita

(d) Handouts

Off JT: Reservoir Management Optimization Introduction
Off JT: Reservoir Management in Japan
Off JT: Reservoir Operation via Mass Curve
Off JT: Optimization Theory
Off JT: DP Software (CSUDP) and Example of DP Sankosh, and relevant materials.

(2) Agenda for Training

- Introduction to reservoir management in Japan
- Reservoir operation simulation using mass curve method.
- Learning optimization theory.
- Learning dynamic programming.
- Learning how to use the dynamic programming software (CSUDP)

(3) Contents of Training

(a) Introduction to reservoir management in Japan (1st Day: Lecturer, Ueda)

Based on materials distributed (Off JT: Reservoir Management in Japan), the following outline of reservoir management in Japan (water control and water use) and examples are covered.

- Outline of Reservoir Management
- Flood Management
- Low Water Management
- Sediment Management

(b) Reservoir operation simulation using mass curve method (1st Day: Lecturer, Uematsu)

- In the Hydropower Development Guide Manual, reservoir operation using the mass curve method was introduced in a reservoir operation simulation for reservoir type hydropower. In the training, participants learned how to create a mass curve, and did an exercise in making a mass curve using the Sankosh hydropower plant as an example.

(c) Learning Optimization Theory (2nd Day: Lecturer, Uematsu)

- As a basis for optimization, participants learned about linear programming and how to solve linear programming problems using the Simplex Method.
- Participants learned how to perform calculations using the Simplex Method through exercises using simple example problems.
- Participants learned the basics of nonlinear programming, and how nonlinear programming is used in the power sector, such as in the economical dispatch of electricity in hydro-thermal power systems. They also learned calculation methods through example problems.
- Participants were given an outline of dynamic programming, which is often used in optimal operation studies for reservoirs.

- An outline of the latest optimization methods, such as genetic algorithms and artificial neural networks, was given.

(d) Learning dynamic programming (3rd Day: Lecturer, Uematsu)

- Participants learned about the dynamic programming calculation methods used for optimum operation of reservoirs, and solved problems in dynamic programming via manual calculations through simple examples.
- Participants did exercises on reservoir operation optimization calculations via manual calculations using the Sankosh hydropower plant as an example.

(e) Learning how to use the dynamic programming software (CSUDP) (3rd & 4th Day: Lecturer, Uematsu)

- The lecturer explained how to use dynamic programming software (CSUDP: free software).
- Taking Sankosh hydropower plant as an example, participants did an exercise on optimization of reservoir operation using dynamic programming methods in CSUDP.
- Finally, participants collected information through the Internet, learned how the optimization methods were applied in an actual project, and summarized the contents of the method, purpose and results. Each person then gave a presentation.

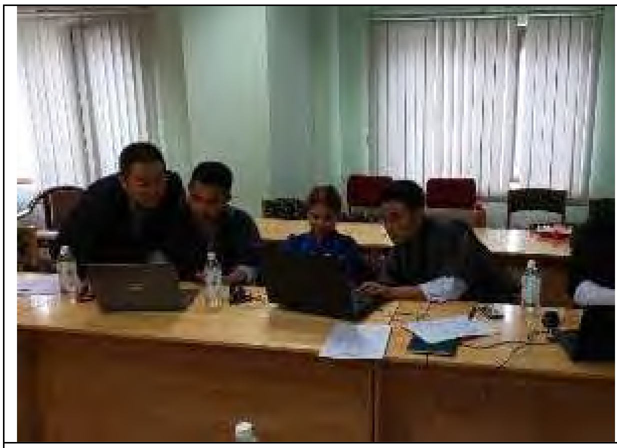
(4) Training Outcome and Issues

【Outcomes】

- Participants understood an overview of reservoir management in Japan.
- Participants understood an overview of the theory of linear programming and non-linear programming, which is the basis of reservoir operation optimization, and understood the content of calculations through simple examples.
- Participants learned about dynamic programming as applied to the optimization of reservoir operation and understood the calculation method through a simple example.
- Participants learned how to operate the optimization calculation software (CSUDP: free software) and understood the content through examples.

【Issues】

When applying optimization to a real problem, considering complex constraints makes the model larger and often requires much time for analysis. Moreover, the method of optimization differs depending on the consultant. In general, optimization theory is complicated: the calculation content tends to be black-boxed and verification becomes difficult. Therefore, in applying the method to a real problem, it is recommended to consult with academic experts or consultants for advice and supervision of the optimization study.

	
Training Scenery	Training Scenery

13.3 System Analysis

13.3.1 First Off-JT

(1) Training outline

(a) Date: 14:30-17:00 on March 6th, 2018

(b) Venue: the JICA Survey Team's office (in DHPS office)

(c) Participants: Total of 9 members from 2 departments and agencies
DHPS - TPSD (Transmission and Power System Division): 1 member
- PCD (Planning and Coordination Division): 4 members
- HDD (Hydropower Development Division): 2 members
BPC - BPSO (Bhutan Power System Operator): 2 members

(d) Handout
PSS/E Training in Bhutan
Example of an existing circuit breaker list (related staff only)

(2) Content

- Outline of analysis on system planning
- Power flow analysis
- Fault current analysis

(3) PSS/E Training

(a) Outline of analysis on system planning
The JICA Survey Team outlined the system plan based on the handout (PSS/E Training in Bhutan). The Team proposed and explained the power system planning criteria to be applied in this project, based on the power system planning standards in India. There was no particular opinion about corrections from participants.

(b) Power flow analysis
Using the PSS/E power flow data in 2020 provided by DHPS, the JICA Survey Team explained in detail the particularly important data among the input data for PSS/E. The JICA Survey Team showed the basic method for implementing power flow calculations in PSS/E individually, using one PC for each pair.

(c) Fault current analysis
As per the power flow analysis, The JICA Survey Team explained the method for fault current calculations using the PSS/E data in 2020. For the fault current calculation conditions, the JICA study team used those applied in India. In addition to these calculation conditions, the JICA study team asked if there were any calculation conditions applied in Bhutan, but did not obtain any such conditions. The JICA Survey Team showed in a tutorial the basic method for fault current calculation in PSS/E, using one PC for 2 people. In addition, the team explained an efficient evaluation method for calculation results using Excel.

(4) Other

There is nothing like circuit breaker records that exists. The JICA Survey Team strongly suggested the preparation of circuit breaker records, which would help to evaluate the fault current calculation results, and asked DHPS to send this once prepared.

13.3.2 Second Off-JT (PSS/E Training)

(1) Objective

Bhutan's future Transmission Development Plan (TDP) is formulated based on its National Transmission Grid Master Plan (NTGMP). Indian consultants created the TDP, and the analytical data (PSS/E data) was also provided from India.

The system planners in Bhutan checked the analytical results but few engineers can do this and no system for technology transfer in system analysis has been established.

As for the analysis itself, if the system planners do not sufficiently understand its purpose, they only waste their time and cannot obtain the desired results. In the worst case, they may mislead their management.

To improve the current situation in Bhutan, the JICA Transmission Development Planning (TDP) survey team implemented PSS/E training based on the following concepts:

+ Increase the number of analytical experts
+ Promote basic knowledge
+ Improve analytical skills

(2) PSS/E Training schedule and program

The training schedule and program are shown in Table 13-3.

Considering the skill levels of participants and requests from DHPC, the JICA TDP survey team prepared several training menus.

Table 13-3 Training Schedule and Program

Date	Training course	Training menu
8/ 9, 2018	Beginner	Basic theory (pu method, Power flow analysis)
8/14	Beginner & Advanced	Basic theory (Fault current analysis)
8/16	Advanced	Parameter making (Tr, TL impedance)

In each menu, PSS/E training is included.

(a) Basic Theory (pu method)

In Bhutan, PSS/E is used as analytical tool and the basic theory is based on the pu method (unit method). Generally, PSS/E data is created via the pu method.

In this course, focusing on the pu method, the basic theory, and how to transfer the data and its use are covered.

(b) Basic Theory (Power flow analysis and fault current analysis)

Mainly for the beginners, power flow analysis and fault current analysis are covered so that participants can learn the basic analytical process and skills using PSS/E. In addition, to promote understanding of the theory the simulation results were confirmed by manual calculations.

Moreover, using problem solving, participants learned the basic countermeasures for voltage violations and fault currents through PSS/E simulation.

(c) Creation of network parameters

For the system analysis, the key components are the system parameters because their accuracy determines the simulation results, so it is necessary to prepare data fitting the actual equipment.

As the current PSS/E data were provided from India, it is very difficult for DHPS experts to judge which parameters should be used when the data from new transmission facilities are installed.

As the JICA TDP survey team received requests on how to create the system parameters from DHPS, the team carried out training on how to create system parameters as an advanced course.

In the training, the JICA survey team explained the PSS/E functions used to create the system parameters, and the free software (ATP) which created them, by modeling towers in detail.

(3) Feedback on Training

7 DHPS staff members participated in this training program. The JICA TDP survey team prepared training menus to match their skill levels and carried them out. The participants said that the training was mostly good and they were satisfied with the program.

In addition, as questions on their practical work became clear through discussion in the training, second-order effects were obtained.

The skilled engineers requested practical On-the-Job training.

(4) Next Steps

Based on the requests of the participants and DHPS's intention to promote the analytical skills used in practical system planning, the JICA TDP survey team will prepare a more practical training program for the engineers with advanced skills.

13.3.3 Third Off-JT Training

(1) Objectives

Since the previous training in August 2018, an engineer who was the most skilled in PSS/E and was in charge of system planning has gone on an overseas study program. The JICA Survey Team therefore prepared for the training in accordance with the technical level of the engineers who took over his job. Moreover, in consideration of the situation whereby some engineers had taken part in the series of training courses since March 2018 for the first time, and because most of them are not in charge of system planning, the JICA Survey Team explained the basic theories related to the system analysis again and conducted training sessions using PSS/E carefully so that all the trainees could keep up. While very simple example models were used in the previous PSS/E training session, the PSS/E files actually used for the draft final report were employed for the training session this time.

(2) PSS/E Training schedule and program

The training schedule and program are shown in Table 13-4. Based on the experience of the system analysts in the JICA Survey Team, usage of the software should be repeated often to acquire specific skills in PSS/E. Since the participants in the training session must have been interested in the results of the Master Plan study, the JICA Survey Team explained the system analysis procedures for the Master Plan and had the trainees perform such analyses which required the same procedures in PSS/E each time.

Table 13-4 Training Schedule and Program

Date	Training areas
6/ 14, 2019	Basic system planning and basic theory for system analysis Explanation of the system part of the draft final report (1/3) OJT under the N-0 condition for 2020 (power flow and voltage analyses, fault current analysis and stability check) Power flow analysis procedure under the N-1 condition
6/18	Explanation of the system part of the draft final report (2/3) OJT under the N-1 condition for 2020 and 3020 (power flow and voltage analyses, and stability check)
6/19	Explanation of the system part of the draft final report (3/3) OJT for 2050 (power flow and voltage analyses under the N-1 condition, fault analysis and stability check)
6/20	Explanation of optional PSS/E functions useful for the system analysis Evaluation of transmission lines to connect new power plants

(a) Basic system planning

The JICA Survey Team explained a sequential study flow from a demand forecast to a generation expansion plan, and a system plan using them as inputs.

(b) Basic theory of the system analysis

1) pu method

An understanding of the pu method is virtually a qualification needed to deal with PSS/E. Since many participants had not used PSS/E, the JICA Survey Team explained the method again to provide minimal basic knowledge.

2) Power flow, fault current, stability

The JICA Survey Team explained that power flow, fault current and stability mutually affect each other with some fundamental theoretical equations.

3) Understanding of the N-1 criteria

The Draft Final Report shows that the N-1 criteria are not met in Bhutan’s 132kV southeast system for 2025. In the report, if a faulted transmission line is tripped, another transmission line will be overloaded. After the tripping of the overloaded line, another transmission line will be overloaded and blackouts will eventually occur in the system. The JICA Survey Team explained this phenomenon, so-called cascading blackout, in the session.

4) Understanding of voltage collapse

The Draft Final Report shows that there is a risk of voltage collapse in 2020 under the N-1 condition due to a shortage of reactive power. The JICA Survey Team explained to participants that generator terminal voltage settings to increase output power from those generators could be a measure to combat the risk.

(c) PSS/E training

The participants practiced system analysis in the form of OJT using PSS/E data for 2020, 2030 and 2050. The participants experienced problem extractions, approaches to them and the formulation of concrete countermeasures for the problems using the PSS/E files used in the actual master plan development, so that DHPS members will be able to make practical use of the analysis data prepared by the JICA Survey Team.

1) Acquisition of basic PSS/E function knowledge

The participants practiced using PSS/E functions useful for system analysis and how to use them with the said PSS/E files.

2) Power flow and voltage analyses

The participants practiced concrete methods for power flow and voltage analyses under the N-0 and N-1 conditions, together with a method of analysis results evaluation and countermeasures. They also practiced automatic calculation procedures with regard to the N-1 contingency analysis. In the practice, the participants especially checked that a power flow calculation did not converge with an outage of some transmission line due to a reactive power shortage.

3) Fault current analysis

The participants practiced concrete fault current analysis procedures, evaluation methods and countermeasures for problems.

4) Stability check

The participants practiced concrete stability check procedures and an evaluation method.

(d) Evaluation of transmission lines to connect new power plants

The JICA Survey Team conducted a desk training course on transmission lines to connect each new power plant with the grid in terms of route, voltage, cost, conductor type, and so on.

(3) Training outcome

While some engineers among the participants this time had taken part in the previous PSS/E training courses, others participated in this course for the first time. The JICA Survey Team conducted the training carefully in consideration of the variation in their levels. After explaining the basic items to some extent, the JICA Survey Team conducted the training course in the manner of OJT, considering the incorporation of the PSS/E analyses into the normal workflow so that the participants could use the new skills just learnt in this course. There were also many questions asked regarding problems in the work that the participants had at present. There was a secondary effect in that a question from a participant triggered a discussion about an approach to problem solving and an analysis process for that, and the training became more participatory. In addition, explanations based on actual cases, such as the power failure in Italy in 2003 as an example of a cascading occurrence, and the voltage collapse accident in Tokyo Electric Power Company in 1987 as an example of the need for reactive power, seemed to stimulate the participants' interest and increase their satisfaction.

13.4 Capacity Building on Financial Analysis

(1) Objective

Provide officials from DHPS and related organizations with basic training in project financial analysis based on discounted cash flow and corporate financial statements, thereby enabling them to undertake appropriate project bankability analyses for future development planning of potential sites identified in the PSMP.

(2) Time and Date

Day 1: 10:00 - 15:30 June 5, 2019
Day 2: 10:00 - 16:00 June 6, 2019
Day 3: 15:30 - 17:00 June 19, 2019
Day 4: 12:00 - 15:30 June 20, 2019

(3) **Venue: Energy Conference Hall, Ministry of Economic Affairs**

(4) **Participants**

Day 1: 26 officials from DHPS, DRE, BPC, etc.
Day 2: 28 officials from DHPS, BPC, BEA, etc.
Day 3: 8 officials from DHPS and DRE
Day 4: 8 officials from DHPS and DRE

(5) **Lecturer: Yusaku Makita, Economic and Financial Analysis, JICA Survey Team**

(6) **Outline**

The training sessions held on the first two days provided basic knowledge in financial analysis through classroom lectures and hands-on practice in financial calculations using Microsoft Excel spreadsheets on each participant's computer.
Later, in the third and fourth sessions, participants reviewed a case study on cash flow projections and financial analysis prepared by DHPS officials for the Uzorong HPP site.

(a) Day 1: Project financial analysis through discounted cash flow method
- Basic understanding of financial analysis: differences between financial analysis and economic analysis, differences in financial analysis subjects (project and business entities), major indicators in financial analysis, understanding of discount rate and present value
- Calculation and analysis of discount factor, net present value (NPV), financial internal rate of return (FIRR), and weighted average cost of capital (WACC)
- Projection of loan disbursement and repayment schedule

(b) Day 2: Financial analysis of business entities, and financial analysis of public-private partnership (PPP) projects and private sector investments
- Basic understanding of corporate financial statements, major financial indicators, etc.
- Structure and features of a private sector investment project and its major financial indicators
- Projection of income statement for private sector investment project
- Calculation and analysis of Equity IRR, debt service coverage ratio (DSCR), and levelized generation cost

(c) Day 3 and Day 4: Case Study - Financial Analysis of Uzorong HPP
- Review of financial analysis spreadsheet prepared by DHPS official s for the Uzorong site, a potential site identified in PSMP

- Calculation and analysis of levelized electricity tariff based on the regulations of India's Central Electricity Regulatory Commission (CERC)
- Calculation of Project IRR and NPV; discussion on interpretation of results
- Update of the financial analysis based on the data and information in latest PSMP
- Sensitivity analysis

(7) **Results and achievements**

Almost all training participants were engineers who had not had any previous experience in financial analysis; however, they were actively engaged in the training. Since they were first-time learners, Day 1 and Day 2 focused on the basic knowledge needed for financial analysis, i.e. various calculations through discounted cash flow method and how to understand corporate financial statements. The hands-on practice and discussions during the sessions enabled deeper understanding among the participants. As officials from other organizations such as BPC participated in the training, the participants proactively exchanged their views and knowledge on practical subjects such as electricity tariff setting.

The case study on Day 3 and Day 4 used the financial analysis for Uzorong HPP prepared by DHPS officials. The participants reviewed the levelized tariff and Project IRR calculation based on the knowledge learned in the previous session. They also learned about and discussed the practical process of financial analysis and evaluation.

These capacity building activities helped the DHPS officials gain a deeper understanding of the financial aspects of hydropower development using valid assumptions and analytical skills, instead of just following the guidelines in their future financial analysis and evaluation work by themselves or through outsourcing. It is expected that, based on the knowledge gained in the training, they will be able to determine appropriate consultant TOR and control the output quality in future DPR studies for potential hydropower development sites.

13.5 Environmental and Social Considerations

The JICA Survey Team assisted DHPS in organizing SEA Task Force/WG activities with staff members in charge of environmental and social considerations at DHPS and other relevant government agencies, in order to explain and exchange views and opinions on the SEA concept, scoping method in this survey, MCA evaluation criteria, etc. with a view to developing their capacity. In other words, understanding and knowledge on SEA have been enhanced through SEA Task Force/WG activities and its process. The specific implementation details are as follows:

13.5.1 First Off-JT

(1) Outline

(a) Time and Date: 14:30 - 17:00 March 6, 2018

(b) Venue: Energy Conference Hall, Ministry of Economic Affairs

(c) Participants: DHPS, SEA Task Force/WG members (10 persons)
DHPS: 4, BPC: 2, DGPC: 1, NLCS: 1, DOFPS: 1, DOC: 1

(2) Outline of training

The JICA Survey Team explained the following topics and then conducted a question and answer session.

(a) Idea and concept of SEA

- Purpose and role of SEA. Role of SEA in master plan.
- Framework of SEA system based on JICA guidelines and Bhutanese domestic law.
- Differences between SEA and EIA (stage of assessment, scope of impacts, range of alternatives, characteristics of assessment).

(b) Implementation method for SEA

The following main items were explained.

- Characteristics and advantages of MCA as a survey, forecasting and evaluation method for SEA (concept of quantitative analysis and weighting).
- Thinking behind and method of creation for TOR on SEA, using MCA.
- Concept of SEA scoping using MCA and selection method for scoping items (I).

(c) Handouts

- Draft TOR for SEA
- Draft Scoping for SEA

13.5.2 Second Off-JT

(1) Outline

(a) Time and Date: 09:30 - 13:00 May 16, 2018

(b) Venue: Energy Conference Hall, Ministry of Economic Affairs

(c) Participants: DHPS, SEA Task Force/WG members (8 persons)
DHPS: 3, BPC: 1, DGPC: 1, NLCS: 1, DOFPS: 1, DOC: 1

(2) Outline of training

The JICA survey team explained the following topics and then conducted a question and answer session.

(a) Topics

- SEA scoping method (selection method for survey items; survey method in the field; analysis, prediction and evaluation method for survey results)
- Concept of SEA scoping using MCA and selection method for scoping items (II).
- Analysis method for effects of hydropower development on local communities from the viewpoint of SEA.
- How to proceed with SEA in areas where natural and social environments are weak and where, in principle, it is preferable to avoid hydropower development.

(b) Handouts

- Draft Scoping (survey items, method of survey at sites)
- Survey manual used at sites (checklist used at sites, draft evaluation criteria for each survey item)

13.5.3 Third Off-JT

(1) Outline

(a) Time and Date: 10:00 - 13:00 November 7, 2018

(b) Venue: Energy Conference Hall, Ministry of Economic Affairs

(c) Participants: DHPS, SEA Task Force/WG members (15 persons)
DHPS: 8, BPC: 2, DGPC: 1, NLCS: 1, GHNC: 1, DOFPS: 1, DOC: 1

(2) Outline of training

The JICA Survey Team explained the following topics and then conducted a question and answer session.

(a) Topics

- Project candidate site selection method taking into account environmental and social considerations (selection method for candidate sites with protected areas and where large-scale resettlement is assumed).
- Analysis method for effects of hydropower development on local communities from the viewpoint of SEA.
How to proceed with SEA in areas where natural and social environments are weak and where, in principle, it is preferable to avoid hydropower development (selection method for alternative sites, examination method for environmental protection measures (mitigation measures)).

(b) Handouts

- Draft Scoping (survey items, method of survey at sites, survey period)
- Survey manual used at sites (checklist used at sites, draft evaluation criteria for each survey item)

13.5.4 Fourth Off-JT

(1) Outline

(a) Time and Date: 14:30 - 17:00 January 15, 2019

(b) Venue: Energy Conference Hall, Ministry of Economic Affairs

(c) Participants: DHPS, SEA Task Force/WG members (12 persons)
DHPS: 7, BPC: 1, DGPC: 1, NLCS: 1, DOFPS: 1, DOC: 1

(2) Outline of training

The JICA Survey Team explained the following topics and then conducted a question and answer session.

(a) Scrutiny of and scoring methods for the following MCA items reflecting the field survey results.

- Endangered Species
- Cultural assets of national importance
- Affected farmland
- Ecotourism, handicraft production activities, etc.

(b) Handouts

- Draft Revised Scoping (Survey items, additions and amendments regarding prediction and evaluation methods)

13.5.5 Fifth Off-JT

(1) Outline

(a) Time and Date: 10:00 - 12:00 June 10, 2019

(b) Venue: Conference Hall, Ministry of Economic Affairs

(c) Participants: DHPS, SEA Task Force/WG members (7 persons)
DHPS: 4, DGPC: 1, NLCS: 1, DOC: 1

(2) Outline of training

The JICA Survey Team explained the following topics and then conducted a question and answer session.

(a) Topics

- Analysis method for development effects (positive impacts) of hydropower development on local communities
- Alternative examination methods in SEA (planning level alternatives, project level alternatives)
- Method for making alternative plans (scenarios) with differences in economic, environmental and regional development weightings.
- Research, prediction and evaluation methods for cumulative impacts.
- Prediction and evaluation method for environmental impacts on global scale at SEA level.
- Environmental and social considerations for transmission line planning in connecting each project.
- Environmental and social considerations to be taken into account at the F/S, IEE and EIA stages based on SEA results.

(b) Handouts

- Environmental and social considerations considered in the master plan.
- SEA Report (Draft)

13.5.6 Job Training on field survey concerning SEA implementation

(1) Outline

(a) Time and Date:

The First OJT (November 14 to December 11, 2018)
The Second OJT (January 18 to 30, 2019)
The Third OJT (March 5 to 14, 2019)

(b) Place:
The First OJT: 37 Semi-longlisted Sites
The Second OJT: Secondary Ranking Sites (6 sites)
The Third OJT: Secondary Ranking Sites (3 sites)

(c) Trainees
The First OJT: 2 persons from DHPS (Natural: 1, Social: 1)
The Second OJT: 1 person from DHPS (Natural: 0, Social: 1)
The Third OJT: 1 persons from DHPS (Natural: 0, Social: 1)

(d) Handouts
- Every QGIS plot plan
- Intake dam/weir, waterway and powerhouse locations plotted on Google Earth for each site
- Field survey manual (field survey checklist, draft evaluation criteria for each survey item)

(2) Training items

■ Natural Environment
- Items for natural environment to be checked at sites
- Selection method for ecosystem impact assessment items (concept of indicator species)
- Selection method for forest vegetation evaluation items
- Estimation method for environmental maintenance flow rate
- Environmental protection mitigation measures (greening method, ground stabilization method)

■ Social Environment
- Items for social environment and social development to be checked at sites
- How to ascertain the scope of the project's impact and the impact on the residents
- How to identify and interview stakeholders at each site
- Evaluation method for cultural property at regional level
- How to select social consideration items and how to weight them

13.5.7 Training Results and Future Issues

(1) Training results

For members of the SEA Task Force/Working Group (consists of DHPS and environmental and social considerations staff from relevant government agencies), which were set up to plan and follow the implementation of the SEA with regard to the master plan, training on technical methods to improve understanding of the SEA, and specific implementation of the SEA, was held in five separate meetings. There were three to a maximum of eight participants for the training from DHPS.
The participants who participated in all the training sessions were an executive and one or two different staff members for training.
DHPS does not have an independent environmental section in charge of environmental and social considerations, so staff from other technical departments, including the GIS section, participated within the scope of their original duties.
For DHPS staff who participated in the training, it was assumed that they only partially understood the concept of SEA and the technical methods for implementing it, and that it was difficult for them to systematically understand the system as a whole.

(2) Future issues

It is necessary to carry out training on the technical methods necessary to promote understanding of SEA, assuming that DHPS will have a person in charge of environmental and social considerations.

13.6 Evaluation of Capacity Building

Throughout the MP Survey, capacity building has been implemented for DHPS staff via OJT and Off-JT. Based on the results of this, the JICA Survey Team evaluated the items of work necessary for master plan formulation according to the criteria shown below.

Table 13-5 Evaluation Criteria for Capacity Building

Score	Evaluation criteria
5	DHPS can formulate a MP without problems.
4	Although there is some concern about the details, DHPS can formulate a MP without problems.
3	Some support is needed, but DHPS can formulate a MP.
2	Considerable support is needed for DHPS to formulate a MP.
1	It is impossible for DHPS to create a MP alone. Re-training and further support are necessary.

(Source: JICA Survey Team)

The following are the evaluation results from the perspective of whether DHPS staff can independently formulate the next master plan.

Table 13-6 Evaluation of DHPS's Capacity for Master Plan Formulation

Item	Score	Evaluation
Civil design	4	It seems that DHPS trainees could calculate maximum plant discharge, make river longitudinal profile figures and find and evaluate potential hydropower sites by using Q-GIS software without any problems.
	3	With regard to the method for selecting dam locations, waterway routes (types), and powerhouse locations (types) learned through OJT in the field surveys, it is desirable for trainees to accumulate further experience and improve their technical level in the future.
Hydrology	4	Some DHPS staff have already conducted MP-level assessments of hydrological data, and it will be possible for DHPS staff to conduct hydrological evaluations by themselves in future MP development.
Q-GIS GIS engineers	5	Staff are at a level where they can implement this by themselves, from data creation to advanced analysis processing. In addition, they can give technical instructions to other staff as GIS trainers.
Q-GIS Information security	2	Information security activity an important issue not only in the organization but also in the country of Bhutan. Therefore, it is recommended to take continuous measures while paying great attention to risks from familiar issue.
Q-GIS Introduce use of GIS through DHPS	3	The implementation of GIS and practice in basic operations through this training has provided an environment where the scope of GIS use could be expanded by staff themselves. Since the support environment from the GIS engineer has been also constructed, various types of information creation using GIS, and its operation, can be expected to take place from now on.
Cost estimation (Civil facilities)	3	Because it is not required detailed data at the master plan, DHPS staff will be able to estimate costs using the integration kit prepared in this survey. However, the basic data and calculation method for this tool use the current version, and appropriate version upgrades require external support.
Cost estimation (Transmission and transformation facilities)	4	Because it is not required detailed data at the master plan, DHPS staff will be able to estimate costs using the cost estimation tool prepared in this survey. However, the basic data (unit prices) in this tool is the current version, and an appropriate version upgrade is necessary.
Calculation of available annual energy generation	4	The available annual energy generation (including Firm power) is calculated based on the hydrological data of each gauging station, the catchment area at the intake point, and the effective head. Calculations are possible by acquiring hydrological data analysis and QGIS technology.

Item	Score	Evaluation
Benefit evaluation	4	The benefits used in this MP are the sale of electricity, the value of Firm capacity, and the value of ancillary service provision, and these concepts are well understood. In the future, other benefits such as CO_2 emission reduction effects may be considered, but methods for calculating these as benefits are already in use.
Geological survey	2	The trainees know Bhutan's unique geological characteristics well. However, it is desirable to develop their ability to view the whole project in a top-down manner and evaluate it with regard to comprehensive interpretation of the current landform, of which geologic bodies have been reorganized by the effects of geomorphic agents and weathering.
	3	By reviewing the evaluations on the investigation and design for each prior development project, the trainees were able to recognize that there are some cases where geological investigation results were not taken into consideration for civil design. It is desirable for them to get into the habit of putting the necessary suggestions in writing, evaluating the planning and the results with the intentions of the design side from the aforementioned point of view.
Environmental survey (Natural Environment)	2	Due to the lack of basic knowledge on various natural environment components (plants, terrestrial and aquatic animals, etc.), DHPS cannot be expected to implement natural environment surveys or adequate evaluations of survey results.
Environmental survey (Social Environment)	2	Young officers in DHPS who accompanied Japanese consultants to conduct field surveys seem to have learned how to identify stakeholders and how to collect social information at the project site. It can be evaluated that the DHPS personnel obtained a better understanding on social survey items and the judgment basis for MCA on social considerations through discussions with members of the relevant ministries and other governmental organizations at SEA taskforce/WG meetings. On the other hand, DHPS officers who participated in the field social survey were not members of the SEA taskforce/WG; therefore, the counterpart personnel were not consistent. Due to this, it can be said that the learnings on the DHPS side were still limited in this PSMP2040 project.
SEA	2	There are no technical staff specializing in the environment at DHPS, so participants were hydropower civil engineers and other members who are in charge of the environment in a secondary capacity. The training on technical environmental issues was conducted for them although these issues were out of their expertise. DHPS personnel became able to understand better the concept of SEA and its importance; however, their capacity to implement SEA is insufficient since it requires a high level of knowledge and survey experience regarding the environment.
Financial analysis (management of outsourced study)	3	Since DHPS officials mostly consist of engineers, it is assumed that DHPS will hire outside experts on financial analysis and financing plans for MP formulation. The capacity building in this project provided training on the basic concepts and methods of financial analysis, thereby enabling DHPS officials to gain fundamental knowledge for appropriate management and quality control of financial analysis studies utilizing outside experts in the future. The capacity building also covered review sessions of a financial analysis case study prepared by DHPS officials (reconnaissance study of Uzorong site). These review sessions provided more practical advice and key points in the project financial analysis which DHPS officials may apply promptly to improve their current work.

Item	Score	Evaluation
Financial analysis (in-house implementation of financial analysis)	2	The capacity building provided basic knowledge on financial analysis for DHPS officials. However, appropriate master plan development and potential HPP site development planning from a financial aspect requires expertise and deeper insight on financing plans, PPP regulations, tariff estimation, project risk analysis based on a draft PPA, Project Development Agreements, etc. besides basic knowledge on financial analysis for project cash flow projection. DHPS does not have such in-house experts among its personnel. Therefore, it is imperative for DHPS, just like for similar organizations in any other country, to hire outside financial experts to develop a master plan and site development plan for this particular subject.
Power development planning	4	DHPS is accustomed to using MCA and is fully capable of formulating a power development plan based on the MCA evaluation results.
Power transmission planning	3	Although it is possible for DHPS to select the transmission voltage and connection point of a transmission line, there is concern about their evaluating the validity based on the results of the system analysis.
System analysis	2	Participants in the training session understood the basic study flow for system planning and learned basic usage of the system analysis software (PSS/E). DHPS needs support for the development of concrete countermeasures for overloading, abnormal voltage and excessive fault current. This will be necessary for them to formulate the Master Plan unaided, and for further high-level system analyses (such as automatic calculations under N-1 conditions and calculation of transmission line constants with new types of conductors).

(Source: JICA Survey Team)

Chapter 14. Recommendations and Way Forward

This MP is very different from the previous MP, and while plans for 10 years or more have already been decided and promoted, the next sites of these sites in progress are evaluated and proposed as short listed sites. The Study Team proposes an action plan and a roadmap to be tackled for the issues that are expected to be encountered in advancing this MP in the future.

14.1 Action Plan

14.1.1 Feasibility Studies for Promising Sites

In this survey, three sites, Dorokha (550MW), Pinsa (153MW) and Chamkharchhu-II (414MW), are proposed as development candidate sites from 2031 to 2035. Feasibility Studies (FS) at these three sites will be carried out aiming for early development.

Specifically, topographical and geological surveys (including topographical survey around civil structures on the ground surface and borehole drillings, etc.), and environmental impact surveys are carried out. Basic design, construction planning and cost estimation are implemented, and their feasibility is evaluated. Obtaining permission for an Environmental Impact Assessment Report (EIA) is one of the aims in FS implementation. Before finalizing the plan, several alternatives with different locations for the dam and powerhouse, scale of development, method of construction, etc. are compared and consultations with stakeholders are conducted at the same time.

14.1.2 Diversification of Off-taker and Fund Source

So far, many of Bhutan's hydropower development projects have been funded by the government of India (GOI). Under this scheme, all funds needed for construction are provided by the GOI, and all surplus power is purchased by GOI. Debt repayment is to be deducted from the electricity sales to GOI after a power plant starts operation, and from the perspective of the RGoB it is recognized as a very low risk development scheme. However, with this scheme, at sites currently under construction, risks such as construction quality concerns and rising costs due to delays in construction have become apparent. In addition, it is unclear whether favorable conditions, as currently enjoyed, can be secured in the future.

Considering such a situation, it is important to diversify off-takers not only in India but also in neighboring countries such as Bangladesh and Nepal, with a view to selling electricity outside India. Selling cheap electricity generated in Bhutan to other countries in the South Asian region can contribute to the economic prosperity of the whole South Asian region. In addition, infrastructure development and power supply will improve regional connectivity and promote the prosperity of the whole region, as well as bring stability and prosperity to individual countries.

In the future, it is likely that electricity will be transacted in a large BBIN (Bangladesh, Bhutan, India, Nepal) market, and development with financial sources other than those from GOI will be necessary. However, the resources (funds and human resources) in Bhutan are limited, and there are concerns about delays in hydropower development if the condition that RGoB involves all hydropower development projects by using RGoB's resources. Under the IPP development scheme, RGoB can earn the same level of income as a PPP scheme, depending on conditions such as royalty energy. Therefore, in order to promote hydropower development and secure more national financial resources, it is necessary to consider introducing a scheme that can be developed by IPP as an option.

In addition, if neighboring countries such as Bangladesh and Nepal are included as off-takers, it will be necessary to prepare conditions based on the export of electricity to those countries. Specifically, it is necessary to proceed with the implementation of the following items, but these items also require similar discussions between other countries. For this reason, it is more effective to conduct discussions using a multilateral framework such as BBIN rather than one-to-one discussions with the target countries.

(1) Correct understanding of Indian grid operation rules

In order to export electricity from Bhutan to neighboring countries, it is essential to obtain the understanding of India, because the electricity must pass through the Indian grid. The CERC in India revised the Cross Border Trade of Electricity Regulations in March 2019 with regard to power interchanges with other countries. The Regulations provide sufficient rules on exporting electricity to a third country via India. However, when connecting to an Indian grid, the same grid operation rules as an Indian power company must be applied. Therefore, it is important to understand the Indian grid operation rules correctly, and to resolve any issues in consultation with India.

(2) Consultation with Off-takers (Bangladesh, Nepal etc.)

When exporting electricity to third countries other than India, it is necessary to consult with off-takers such as Bangladesh and Nepal. Specifically, the following items need to be discussed.

- Sales tariff and transaction currency
- Confirmation of off-taker's payment ability and government guarantee
- Composition of development entity, and funding method (including power transmission facilities)
- Confirmation of new construction needs for interconnected power transmission lines and substation facilities, and cost allocation
- Payment method for wheeling charges to India

(3) Strengthening of interconnected transmission lines

When exporting electricity to a third country other than India, it will be necessary to reinforce the transmission lines not only between Bhutan and India but also between India and the export partner. There are also cases where transmission lines in India need to be reinforced. Interconnection transmission facilities have already been completed between India and Bangladesh and India and Nepal. However, if the export volume of electricity is to be increased in the future, there is a high possibility that the transmission capacity will be insufficient, and a new interconnection transmission facility will have to be constructed. Based on these points, it is important to proceed with discussions on strengthening the interconnected transmission lines (refer to 14.1.3 (3)).

14.1.3 Steady promotion of Grid Expansion Plan based on Future Concepts

(1) Promotion of grid expansion plan based on future concepts

The transmission plans for the Short-listed sites extracted in this MP also propose connection to nearby power plants. However, the site area for Punatsangchhu II and the Mangdechhu substation, which has been completed, is narrow, and there is little room for expansion. In the future, when implementing plans for transmission facilities (switching stations) of new power plants (specifically, Dorjilung and Chamkharchhu I), it is necessary to secure expansion space in consideration of new connections for nearby power plants based on the future concepts for system planning.

(2) Study on transmission and substation facilities' standard designs

In Bhutan, it is very important to minimize transmission line routes and shorten transmission line lengths as much as possible from environmental and economic aspects. At present, it is necessary to construct multiple transmission lines in the same areas in order to connect power plants and substations one to one. Adoption of T-branch transmission lines makes it possible to combine a plurality of transmission line routes into one route, which is very effective from environmental and economic aspects. For this reason, it is necessary to study whether or not to adopt a T-branch transmission line, and if possible, to consider a grid expansion plan that adopts a T-branch transmission line.

(3) Enhancement of transmission facilities to sell electricity to neighboring countries

For the construction of interconnection lines with India, Bhutan (BPC) will basically carry out the work in Bhutan, and India (PGCIL) will do so in India. With the development of power plants in Bhutan, construction of many interconnected transmission lines will be needed, but in the future, it will be necessary to take into account not only India but also transmission to Bangladesh and Nepal. For this reason, it is also necessary to closely monitor the progress of the transmission lines between India and Bangladesh, and between India and Nepal, and implement measures to promote plans as necessary.

The development of the Dorjilung site (1,125 MW) has been basically agreed among the three countries, including India, to supply power to Bangladesh. In order to develop this site, construction of long-distance, large-capacity transmission lines from Bhutan to the northern part of Bangladesh via India and related substation facilities is required. It is therefore necessary to immediately start trilateral consultations for the construction of this transmission and transformation facility.

(4) Measures to improve the reliability of Thimphu city power supply

There is no large power plant around the capital Thimphu city, and power is supplied to Thimphu city from the 220kV transmission line connecting the Chhukha power plant (336MW) and the Basochhu power plant (64MW). This transmission line is a dual-end power supply, but it is a single-line transmission line and the transmission capacity is insufficient. Therefore, for the supply to Thimphu city, which is a very important load, the facility configuration is very weak from a supply reliability aspect. The JICA Survey Team recommends the 66kV system be divided and operated in a radial system because an overload would occur in the 66kV system in an accident at this 220kV transmission line in 2025. In 2030, in addition to the 66kV system, the 220kV system is also recommended to be modified to divided operation because the 220kV transmission line is always overloaded in the case of loop operation. However, it is difficult to say that this is desirable from a supply reliability point of view because a power outage occurs once in Thimphu city in a transmission line accident. For this reason, operation measures are insufficient to cope with the issue, and facility expansion measures such as double circuit lines will be required in the future.

If it is possible to construct a new double circuit transmission line, it is not necessary to start the study immediately. However, if it is difficult to secure a right of way (ROW) for the new transmission line, a double circuit line will be constructed by utilizing the current ROW. In this case, it is necessary to temporarily remove the current transmission line. In order to carry this out without disturbing the power supply to the city, there are two plans: building a temporary tower and laying a temporary transmission line, and stopping at every section where the tower is rebuilt. Fortunately, the transmission line is a double-ended power supply, so it is possible to implement a system configuration that will not cause supply outages even if one section is stopped until 2030. For this reason, the method of stopping, removing and rebuilding section by section is a realistic option until 2030. In this construction method, since the construction period until completion is very long, it is necessary to start the study on implementation measures early.

(5) Facility design for Yangbari PS

Many transmission lines will be connected to the Yangbari PS in the current plan. Considering an accident at Yangbari PS, it is not a desirable design from the aspect of supply reliability. In addition, due to the concentration of the power sources, the short circuit current in a 400kV bus accident at the Yangbari PS will be large, and it is possible for it to exceed the maximum rated breaking current (63kA) of a general breaker. If the fault current is up to 63kA, it can be coped with by adopting a breaker with a rating of 63kA, but generally, a breaker with a rating above 63kA would be special and entail a very high cost. Therefore, when the fault current exceeds 63kA, it is basically reduced by changing the system configuration, such as via bus split operation. It is very important to construct a facility configuration that enables bus split operation. As the Yangbari PS will be needed by 2030, the facility design should be implemented as soon as possible, based on the long-term power development plan. In Bhutan, there is no experience of planning and designing such large and complex substation facilities, so assistance from external experts will be vital at the planning and designing stages.

14.1.4 HR Capacity Building

The results of an evaluation on whether DHPS staff can independently formulate the next master plan are shown in Chapter 13. The formation of a master plan requires a very wide range of knowledge and experience. Of course, it is not necessary for everyone to be able to do all of the work, but at least one person needs to be at a level where they can carry out the necessary work almost without problems. Based on the evaluation shown in Chapter 13, the level of technology acquisition in the fields of geological surveys, environmental and social considerations, economic and financial analysis, and system analysis is still low, and it will be necessary to provide support when formulating the next master plan.

Geological surveys and system analysis are very closely related to the routine work of DHPS, and young human resources with a background in geotechnical engineering and electrical engineering have been deployed inside DHPS. Both areas require not only knowledge but also experience in work implementation, and it is desirable to accumulate experience by carrying out this work in specific projects. It is most effective to gain experience under the guidance of seniors with abundant experience and skills, but since DHPS does not have such seniors, know-how and skills that can be gained become reduced even if the same experience is obtained. For this reason, as an immediate measure, it is desirable that an external expert with abundant experience and skills be deployed inside DHPS, and that a scheme for acquiring experience and skills under the expert's guidance be established.

With regard to environmental and social considerations and economic and financial analysis, there are no human resources with a background in environmental studies or economics in DHPS. For this reason, engineers who have studied civil engineering or electrical engineering are conducting these tasks in addition to their own specialized work. This does not lead to the acquisition of deep knowledge, so the support of external experts such as consultants is necessary in the implementation of the master plan level work.
For environmental and social considerations in particular, it is necessary to accurately determine whether, from the aspect of such considerations, the project can be implemented during the initial stages of the plan, such as the Strategic Environmental Assessment (SEA) conducted at an early stage of the construction plan and/or the Initial Environmental Examination (IEE) conducted during Pre-FS. It is also necessary to reflect global environmental conservation measures required by modern society and environmental and social considerations required by international donors in hydropower plant projects. Therefore, it is desirable to create a division specializing in the environment within DHPS and to arrange environmental experts with extensive knowledge, technology and experience regarding the natural and social environments.

The next master plan is scheduled to be formulated in 10 years' time, so it is premature to judge DHPS at its current technical level. However, in order for its staff to formulate the next master plan on their own, significant improvements in skills will be necessary in the future.

14.2 Road Map

The following is a roadmap showing implementation dates and entities in charge of the action plans described in the previous section.

Table 14-1 Road Map

No.	Item	Entity	2020 (1 3 5 7 9 11)	2021 (1 3 5 7 9 11)	2022 (1 3 5 7 9 11)	2023 (1 3 5 7 9 11)	Remarks
	[Feasibility Study for promising site]						
1	Feasibility Study	DHPS, DGPC Consultant					Candidate is Pinsa site. (including environmental impact assessment)
2	Detailed Design	DHPS, DGPC Consultant					5 to 6 years are required as construction period after detailed design is completed
	[Diversification of off-taker and fund source]						
1	Correct understanding of Indian grid operation rules	DHPS					
2	Consultation with Off-takers (Bangladesh, Nepal)	DHPS					
3	Discussion on strengthening of interconnected transmission lines	DHPS					Includes discussion on transmission planning for Dorjilung site
	[Steady promotion of Grid Expansion Plan]						
1	Promotion of grid expansion plan based on future concepts	DHPS, DGPC					Dorjilung, Chamkharchhu I etc.
2	Study on transmission and substation facilities' standard design	DHPS, BPC Consultant					Study on T-branch etc.
3	Enhancement of transmission facilities to sell electricity to neighboring countries	DHPS					
4	Measures to improve the reliability of Thimphu city power supply	DHPS, BPC Consultant					Study on double circuit 220kV transmission line
5	Facility design for Yangbari PS	DHPS, DGPC consultant					
	[Capacity Building]						
1	Deployment of external experts with abundant experience and skills inside DHPS	DHPS					Geological surveys, and system analysis
2	Creation of a division specializing in the environment within DHPS	DHPS					Deployment of environmental experts

(Source: JICA Survey Team)