

ANNEX 7

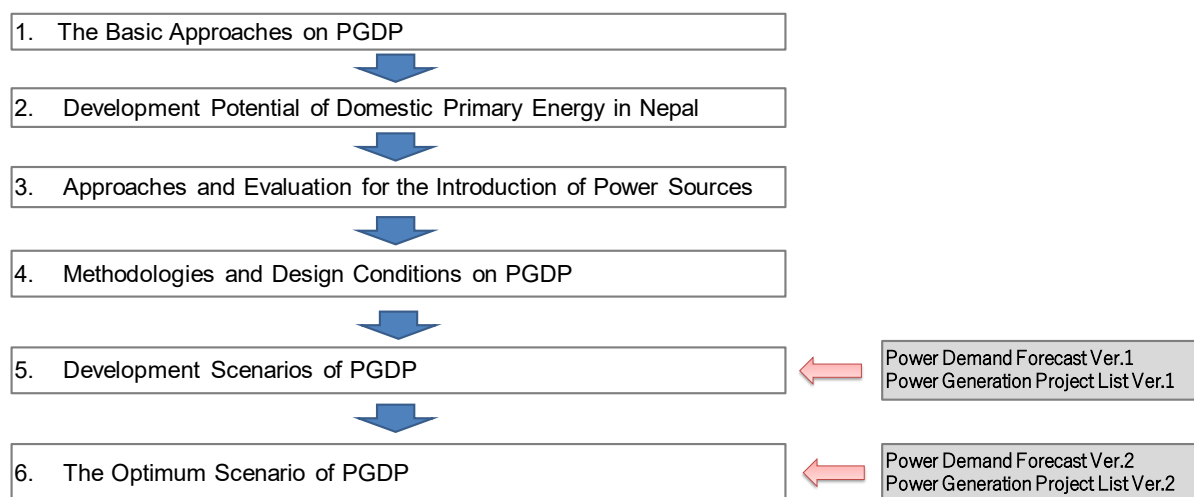
POWER GENERATION DEVELOPMENT PLANNING

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ANNEX 7 POWER GENERATION DEVELOPMENT PLANNING

This Chapter formulates PGDP (Power Generation Development Planning) for the IPSDP (Integrated Power System Development Plan) in accordance with the flow chart shown in Figure 7-1. First, the basic approaches for the power generation development planning is introduced in terms of energy security, finance, environmental and social considerations and the national policy in power sector. Then, the domestic development potential of primary energy sources is identified and the strategy for the introduction of each source into the power generation development planning is assessed. Then, the design conditions are set and future direction of the power generation is evaluated in accordance with the studies on Development Scenario of the generation mix. Finally, the Optimum Scenario will be selected and formulated as the power generation development planning in Nepal.

In power generation development planning, power demand forecasts and project lists are crucial inputs. Typically, the same data would be desirable for analysis in both Development Scenarios and Optimum Scenario. However, it is expected to use the latest data available due to significant progress in the power sector's development from 2021 to 2023, leading to the application of updated data for power demand forecasts and project lists in the Optimum Scenario.



Source: JICA Study Team

Figure 7-1 Flow Chart of Power Generation Development Planning

In the studies of Development Scenario, although results of “Chapter 8 Power Trade”, “Chapter 9 Power System Planning”, “Chapter 10 Environmental and Social Considerations” and “Chapter 11 Economic and Financial Analysis” are described, details shall be referred to each Chapter.

7.1 THE BASIC APPROACHES ON POWER GENERATION DEVELOPMENT PLANNING

Based on the law, policy and development plan related to the electric power sector in Nepal, the basic approaches of 3E (Energy security, Economy and Environment) + Policy on PGDP (Power Generation Development Planning) of IPSDP are described as follows;

7.1.1 Energy Security

As stable electric power supply and energy security is significantly vital issues for Nepal, improvement of energy self-sufficiency will contribute to the stable operation of the Country. The IEA defines energy security as the uninterrupted availability of energy sources at an affordable price. Energy security has many aspects: long-term energy security mainly deals with timely investments to supply energy in line with economic developments and environmental needs. On the other hand, short-term energy security focuses on the ability of the energy system to react promptly to sudden changes in the supply-demand balance.

Despite of the abundant hydropower potential which is much more than the power demand in Nepal, 15% of electric power for the domestic supply is currently imported from India. IPSDP aims to achieve the reliable electric power supply by domestic primary energy and to contribute to realize the stable power supply in the regional power pool through the interactive and flexible power trade with BBIN (Bangladesh, Bhutan, India and Nepal) + 1 countries.

7.1.2 Reduction of Financial Burden and Economic Growth

Development of the power system require huge initial investment and O&M cost in long term. Therefore, the power development plan without the actual situation and practical strategies could increase the future financial burden of people and disturb the improvement of living standard and economic growth. In addition, increase of power import may lead to the outflow of foreign currency.

Electric power supply will be established at a lower financial burden for the people through clean and cheap hydropower and renewable energy. Furthermore, export of clean energy will be really important proposition after the fulfillment of domestic power demand. From the perspective of job creation through the development itself and foreign currency earning through the power trade, hydropower expected to be considered as the future growth industry and be promoted in Nepal

7.1.3 Environmental and Social Considerations

In addition to mitigating global environmental impacts, consideration of the local natural and social environment through power development is vital for sustainable national development. Although hydropower development requires the advantage of domestically produced clean energy, the resettlement and ecological destruction caused by development are significant in Nepal. Therefore, it is essential that measures are taken throughout the life cycle of the project, from the survey design, construction and monitoring, to ensure that the project is acceptable and affordable to the social and ecological environment.

In addition, utilization of hydropower, which is far less CO₂ emission compared with thermal power, is important in climate change and Nepal aims to supply clean energy to BBIN +1 countries.

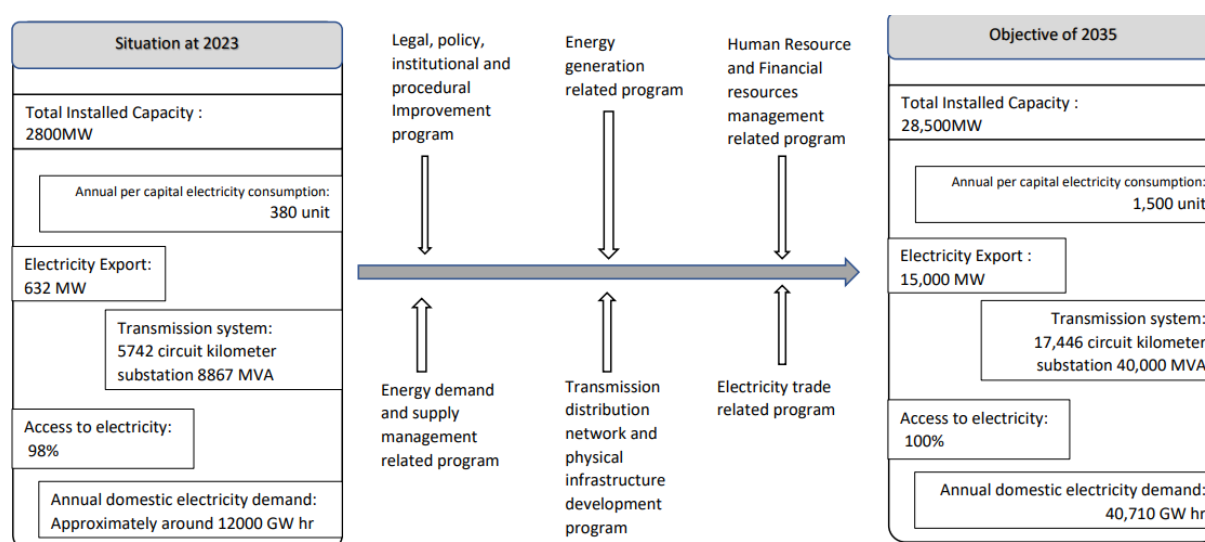
7.1.4 Policy in the Power Sector

GoN considers the hydropower development as the one of fundamental policy and it is important

to secure the consistency between IPSDP and their policy.

Policy objectives in higher level policies in the power sector is “Energy, Water Resources and Irrigation Sector’s Current Status and Roadmap for Future (White Paper)” published by MoEWRI in 2018.

Currently, MoEWRI (Ministry of Energy, Water Resources and Irrigation) is developing the "Energy Development Roadmap and Work Plan 2035" as its energy policy up to 2035 which is under discussion by the cabinet. This roadmap sets the development goals by 2035 to include a power demand consumption of 40,710 GWh (3.4 times increase), total power generation capacity of 28,713 MW (10.2 times increase), transformer capacity of 40,000 MVA (4.5 times increase), and power exports of 15,000 MW (23.7 times increase) as shown in Figure 7.1-1. 85 work plans are proposed in four areas: “1. Improvement of the legal system”, “2. Capacity development for GoN”, “3. Promotion of infrastructure development” and “4. Establishment of business function on power market”. It is necessary for IPSDP to align with such higher-level policies, particularly considering the achievement of the goals set forth in this Energy Development Roadmap and Work Plan.



Source: Energy Development Roadmap and Workplan, MoEWRI

Figure 7.1-1 Energy Development Roadmap and Work Plan 2035

7.2 DEVELOPMENT POTENTIAL OF DOMESTIC PRIMARY ENERGY IN NEPAL

In this section, demand and supply balance of primary energy in Nepal is summarized and future directions of development is considered. Then, potential of development of fossil fuels and renewable energy is assessed. It is noted that hydropower and power trade are respectively discussed in Chapter 6 & 8 and are excluded from this section.

7.2.1 Demand and Supply Balance of Primary Energy in Nepal

(1) Supply of Primary Energy

1) Supply Amount of Primary Energy in Nepal

Transitions in total primary energy supply (TJ) and total population (millions) in Nepal are shown in Figure 7.2-1, total primary energy supply per capita (GJ/capita) in Figure 7.2-2 and the percentage of primary energy supply by source in 2021 in Figure 7.2-3.

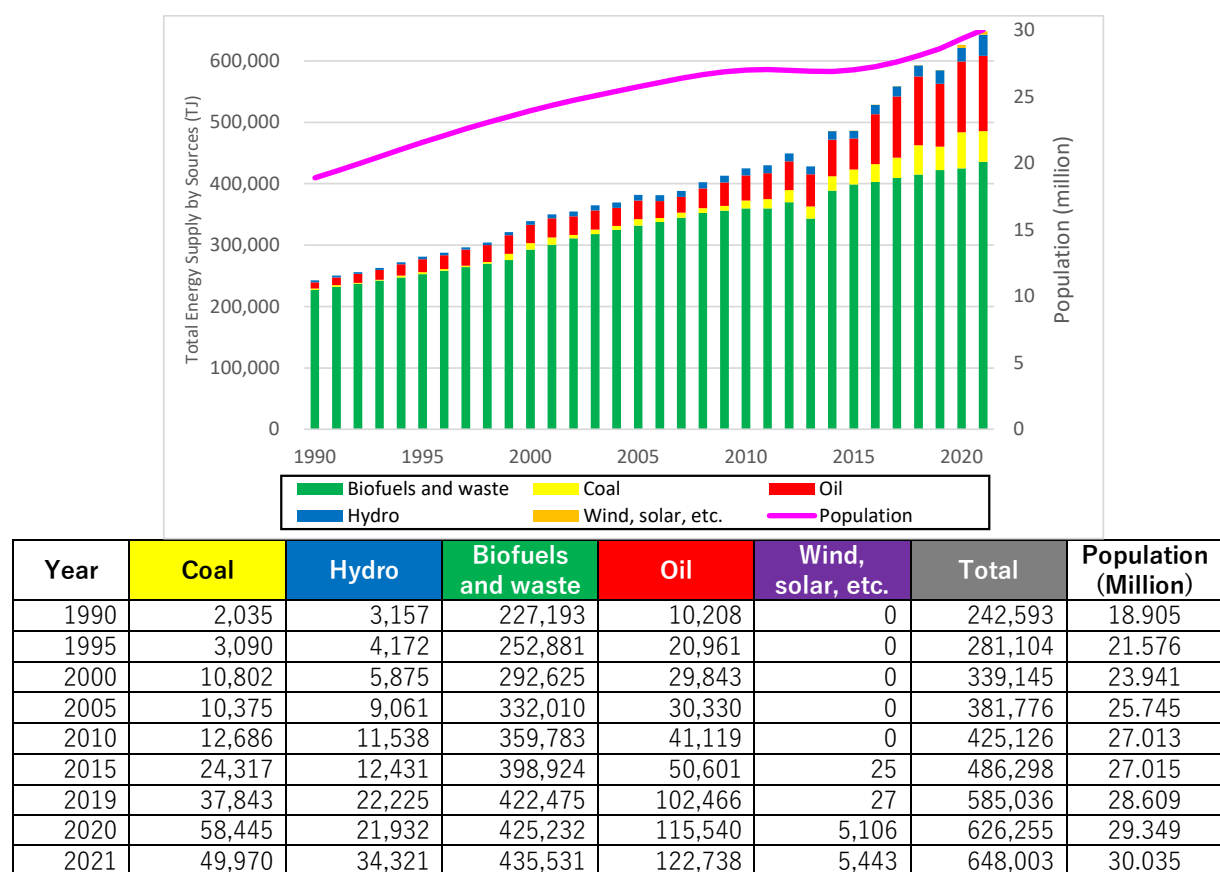
With regard to the population, it has grown remarkably from 18.905 million in 1990 to 30.035 million in 2021, a 1.59 times increase in 30 years.

The same trend is shown for primary energy supply, which has increased significantly from 242,593 TJ in 1990 to 648,003 TJ in 2021, a 2.41 times increase over 30 years. By source of supply, coal increased from 2,035 TJ to 49,970 TJ (24.56 times), hydropower from 3,157 TJ to 34,321 TJ (10.87 times), conventional biomass from 227,193 TJ to 435,531 TJ (1.92 times), oil products from 10,208 TJ to 122,738 TJ (12.02 times) between 1990 and 2021.

Of these, conventional biomass, which accounts for the majority of primary energy supply, has grown close to population growth. On the other hand coal, hydropower and petroleum products, which are more closely correlated with economic activity, have grown more.

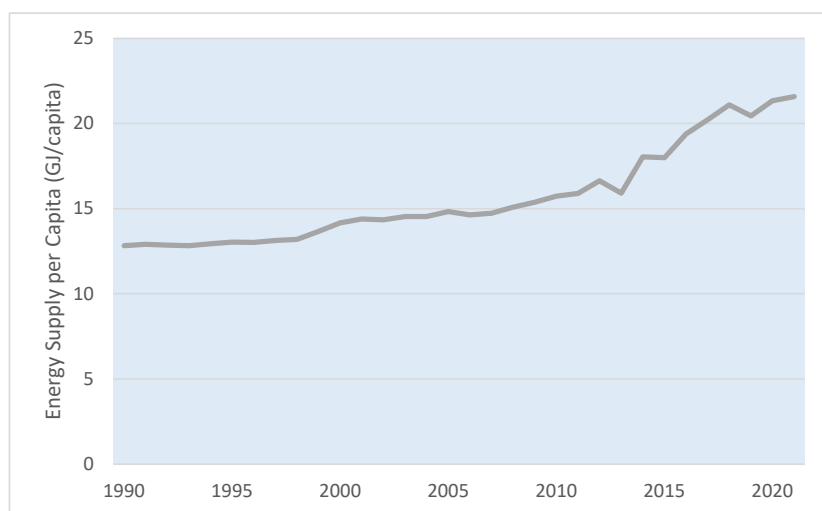
As for total primary energy supply per capita, it was 12.83 GJ/capita in 1990 but it will be 21.57 GJ/capita by 2021 with a growth of 1.68 times which is close to population growth. By decade, the increase remained flat or slow between 1990 and 1998, with growth in 1999 and 2000, but continued to increase at a slow rate of less than 1% per year until 2010. Thereafter, there is a sharp increase from 2011 onwards. Growth in the most recent decade, 2010-2021, is marked by supply increases in coal, oil, hydropower and renewables.

In terms of the share of primary energy supply, biomass accounts for 67% of the total in 2021. These conventional types of biomass are distinct from fuels for power generation, with the majority being firewood, which is used for cooking and heating. In general, it can be assumed that as economic development progresses, these conventional biomass sources will tend to be replaced by electricity or fossil fuels such as coal, oil, and gas. The share of other sources will increase in the future.



Source: JICA Study Team based on World Energy Balances 2023, IEA

Figure 7.2-1 Total Energy Supply and Population

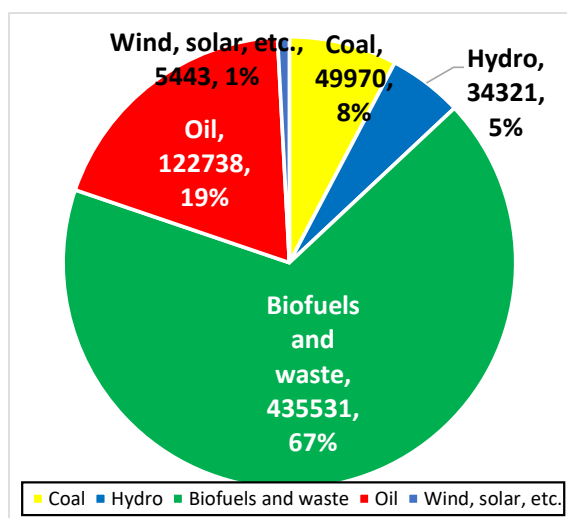


Source: JICA Study Team based on World Energy Balances 2023, IEA

Figure 7.2-2 Total Energy Supply per Capita (GJ/Capita)

2) Total Energy Supply except Conventional Biomass

Total energy supply except conventional biomass is shown in Figure 7.2-4.

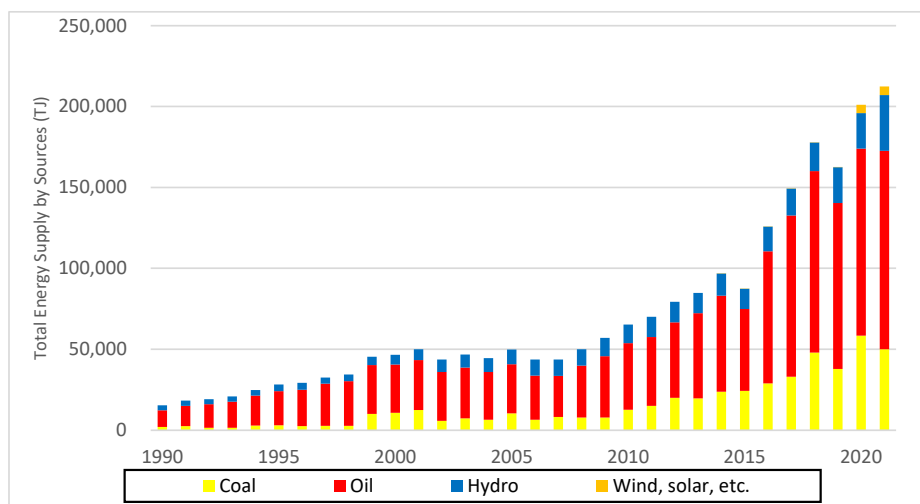


Source: JICA Study Team based on World Energy Balances 2023, IEA

Figure 7.2-3 Composition of Total Energy Supply by Sources in 2021

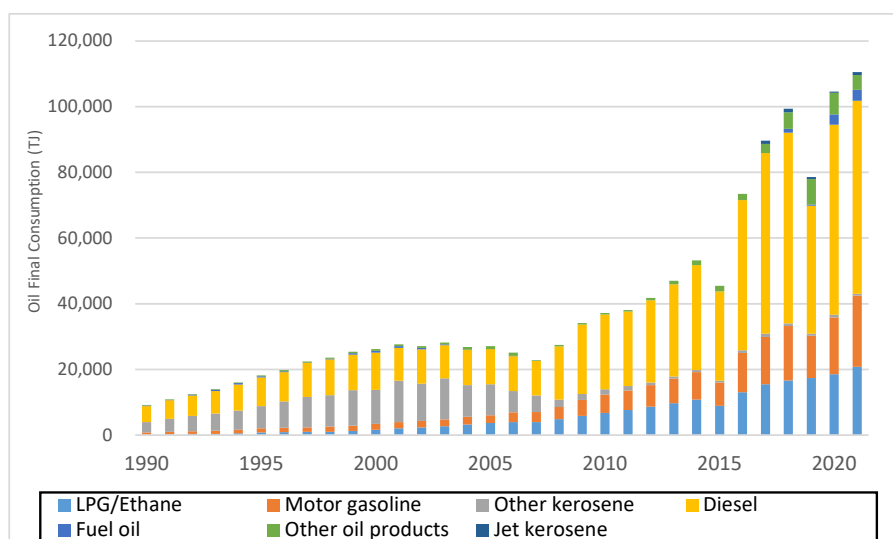
In 2021, primary energy supply excluding conventional biomass was 49,970 TJ (23.0%) from coal, 122,738 TJ (58.0%) from petroleum products, 34,321 TJ (16.0%) from hydropower and 5,403 TJ (3.0%) from renewable energy.

With regard to these primary energy sources, hydropower and renewables are domestically produced, while over 98% of coal and all petroleum products are supplied by imports from India. The sources of petroleum products by fuel are shown in Figure 7.2-5.



Source: JICA Study Team based on World Energy Balances 2023, IEA

Figure 7.2-4 Total Energy Supply except Biomass



Source: JICA Study Team based on World Energy Balances 2023, IEA

Figure 7.2-5 Total Energy Supply of Oil Products by Fuel (TJ)

Until 2007, kerosene which is used for mainly lightning at households accounts for nearly 40% of the total. However, both the supply volume and percentage have fallen significantly since 2008, owed to an increase in the electrification rate. In recent years, the supply of Motor Gasoline, Diesel and LPG (Liquefied Petroleum Gas) has increased significantly. The increase in the supply of these fossil fuels has led to an increase in the trade deficit Nepal and became a challenge of foreign currency outflows.

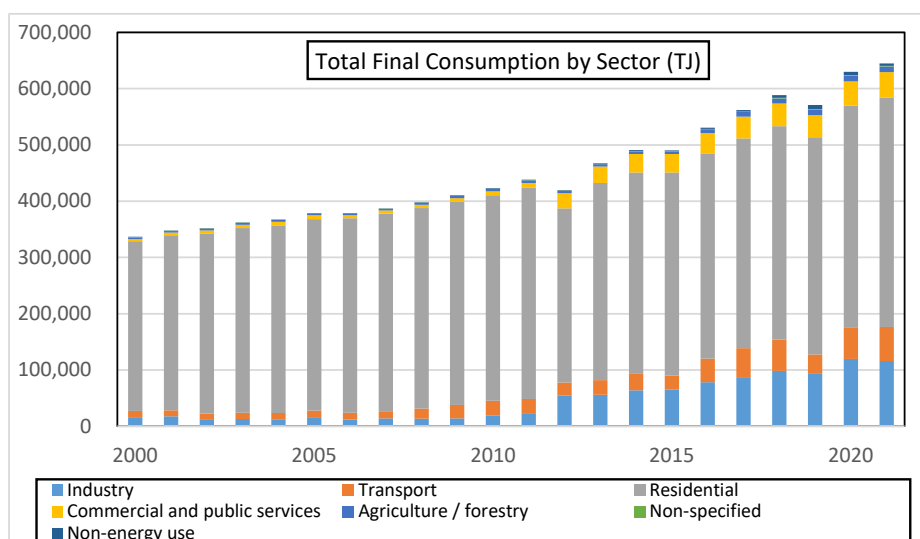
(2) Final Consumption of Primary Energy

Final power consumption of primary energy by sector is shown in Figure 7.2-6 and composition of consumption by sector in 2021 is shown in Figure 7.2-7.

Primary energy consumption has increased significantly from 336,697 TJ in 2000 to 645,011 TJ in 2021, a 1.91 times increase over 20 years. Looking at the growth rate by sector between 2000 and 2021, the industry sector increased from 15,868 TJ to 115,747 TJ (7.29 times), the transport sector increased from 11,302 TJ to 60,605 TJ (5.37 times), the residential sector from 301,465 TJ to 407,472 TJ (1.35 times), the commercial and public services from 4,047 TJ to 45,381 TJ (11.21 times) and the agriculture/ forestry sector has increased from 3,141 TJ to 10,142 TJ (3.23 times).

Similar to the trend in primary energy supply, the industry, transport, commercial/public and agriculture/forestry sectors, which are directly related to economy, show higher growth compared to the residential sector, which increases as same as population growth.

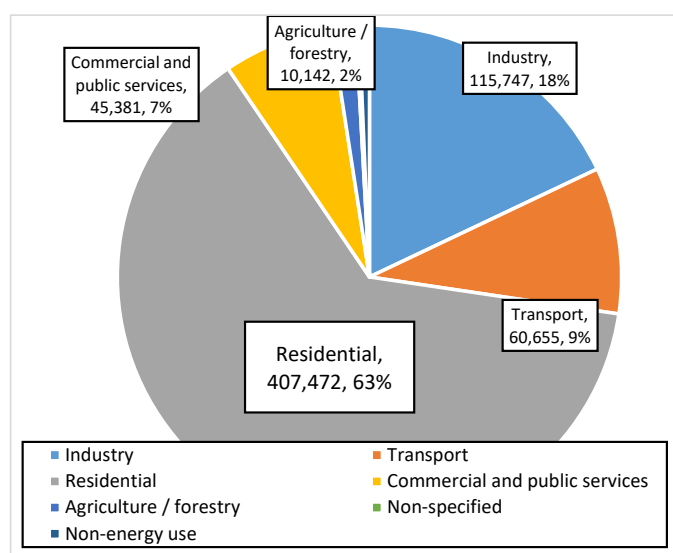
The residential sector accounts for 63% of total primary energy consumption, followed by the industry sector (18%) and the transport sector (9%). In general, the residential sector accounts for a large share of the initial phase in energy consumption, but the share of the industrial sector, which requires energy-intensive manufacturing such as steel and heavy chemical industries, and the transport sector, where traffic increases with economic activity, tends to increase. In the case of neighbouring countries in South Asia, the share of the residential sector in primary energy consumption in 2021 was 26.0% in India, 46.0% in Pakistan, 44.2% in Bangladesh and 28.4% in Sri Lanka. It is assumed that the share of the industry, transport and other sectors will increase in the future as economies grow in Nepal.



Year	Industry	Transport	Residential	Commercial and public services	Agriculture / forestry	Non-specified	Non-energy use	Total
2000	15,868	11,302	301,465	4,047	3,141	406	468	336,697
2005	16,247	11,508	340,353	6,906	3,018	57	858	378,947
2010	18,792	26,657	365,056	7,150	4,933	187	429	423,204
2015	64,831	24,943	361,362	32,592	4,313	374	1,599	490,014
2020	119,835	54,792	395,342	43,085	9,863	1,040	6,060	630,017
2021	115,747	60,655	407,472	45,381	10,142	1,367	4,247	645,011

Source: JICA Study Team based on World Energy Balances 2023, IEA

Figure 7.2-6 Total Energy Consumption by Sector (TJ)



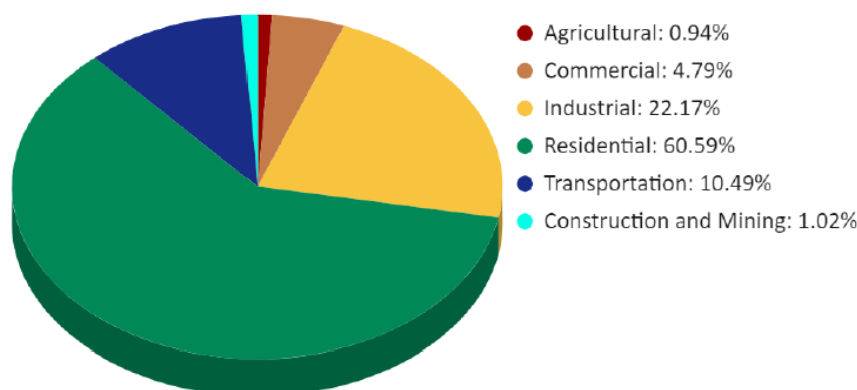
Source: JICA Study Team based on World Energy Balances 2023, IEA

Figure 7.2-7 Composition of Energy Consumption by Sector in 2021

The following section presents that the primary energy consumption situation in the residential, industrial and transport sectors based on “Energy Synopsis Report 2023, WECS (Water and Energy Commission Secretariat)”.

1) National Energy Consumption by Sector

In 2022, the total primary energy consumption in the country was 640 PJ. The household sector accounted for 60.59%, the industrial sector for 22.17%, and the transport sector for 10.49%, with these top three sectors making up 93% of the total consumption. Although over 60% of the population in Nepal is engaged in the agricultural sector, traditional farming activities such as water fetching, plowing, threshing, and harvesting primarily do not use fuel, resulting in the agricultural sector accounting for only 0.94% of the total primary energy consumption. The commercial sector's consumption is also increasing, primarily due to cooking fuel.

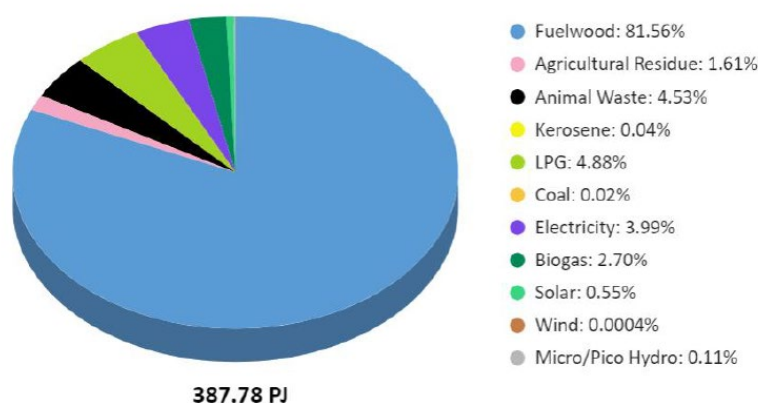


Source: Energy Synopsis Report 2023, WECS

Figure 7.2-8 Composition of Energy Consumption by Sector in 2021

2) Residential Sector

The residential sector is the largest consumer of primary energy, consuming 387.78 PJ (60.59%). Firewood is the primary source of primary energy consumption which accounts for 81.56% decreasing from 87% in 2009. The consumption of imported LPG has doubled over the past decade. The report points out the dependence on LPG in terms of energy security and recommends alternatives such as biogas, solar energy, and electrification through clean energy from hydropower. Traditional firewood cooking remains prevalent in the residential sector and the impact of COVID-19 restrictions was minimal compared to other sectors.

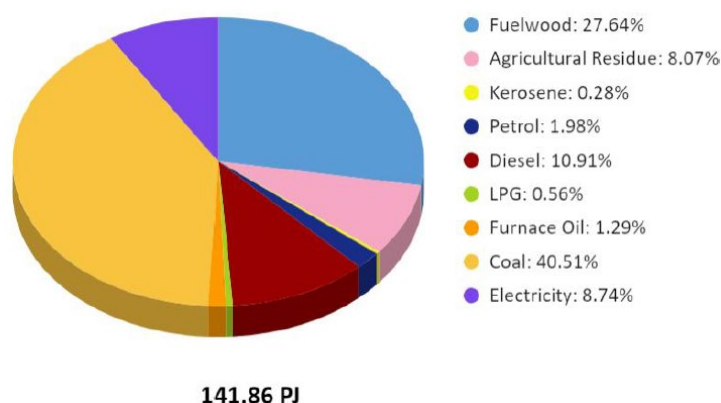


Source: Energy Synopsis Report 2023, WECS

Figure 7.2-9 Primary Energy Consumption in the Residential Sector in 2022

3) Industrial Sector

In the industrial sector, coal (40.51%) and firewood (27.64%) are majority of primary energy sources with agricultural residue biomass also used in boilers. Diesel generators are also convenient power sources, accounting for 10.91%. Diesel and petroleum are also used for thermal purposes in boilers. The industrial sector's primary energy consumption decreased by 5.99% in 2020 due to COVID-19 restrictions. However, there is a 25.36% growth with the relaxation of restrictions from 2020 to 2021.

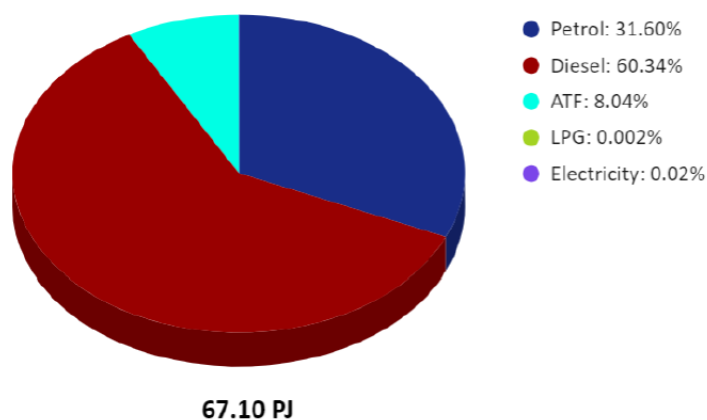


Source: Energy Synopsis Report 2023, WECS

Figure 7.2-10 Primary Energy Consumption in the Industrial Sector in 2022

4) Transport Sector

The primary energy source in transport sector is fossil fuels with electricity usage being only 0.02%. The report predicts that energy consumption by electric vehicles will become more significant with the increase in charging stations and EV charging infrastructure. The primary energy consumption in the transport sector is strongly linked to economic and population factors. Diesel fuel is mainly used in freight and large passenger vehicles which accounts for 60.34% of the total and gasoline is primarily used in small private vehicles which accounts for 31.60%. Due to the impact of COVID-19, the transport system had been halted, resulting in a 45.22% decrease in primary energy consumption compared to the previous year. However, as restrictions were gradually lifted, consumption increased by 38.48% in 2021 and 16.99% in 2022.

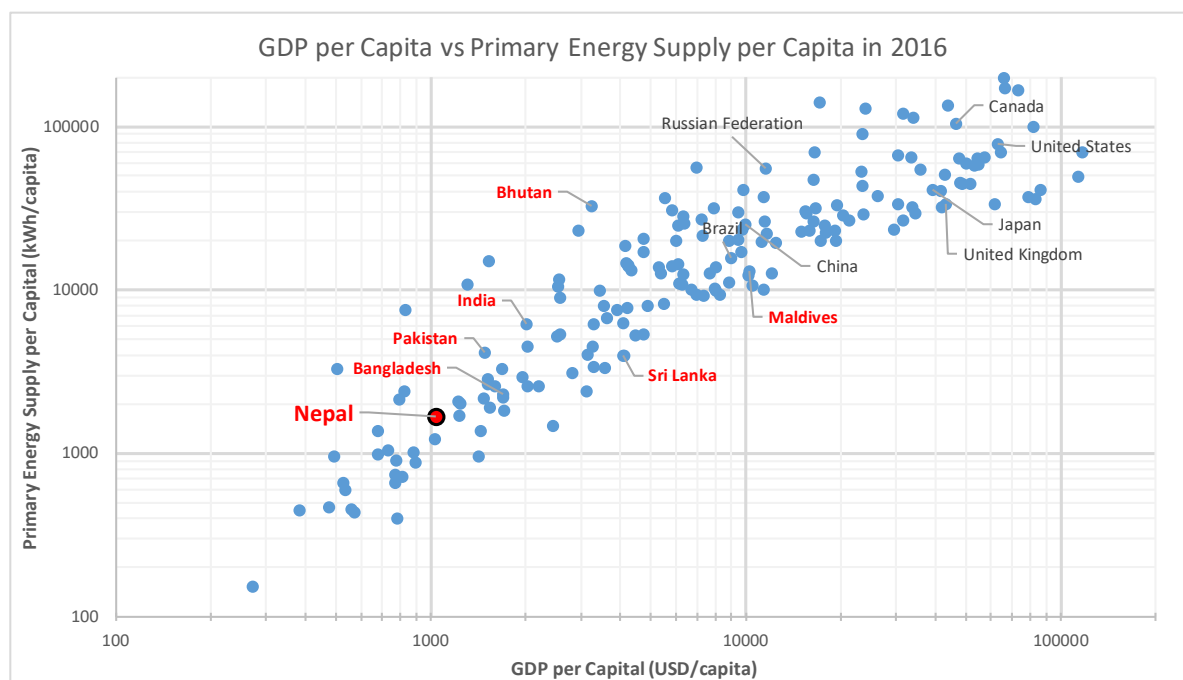


Source: Energy Synopsis Report 2023, WECS

Figure 7.2-11 Primary Energy Consumption in the Transport Sector in 2022

(3) Considerations on Demand and Supply Balance of Primary Energy

The direction of future growth in the primary energy supply and demand balance in Nepal is considered by comparing to the rest of world in 2016. Nepal's GDP (Gross Domestic Product) per capita is 1,038.7USD/capita and energy supply per capita is 1,673.3 kWh/capita, which is different from the world average of 21,846 kWh/capita. Compared to South Asian countries, India is 6,174.7 kWh/capita, Pakistan 4,171.5 kWh/capita, Bangladesh 2,312.0 kWh/capita, Sri Lanka 3,973.0 kWh/capita, Bhutan 32,811 kWh/capita, Maldives 13,019.3 kWh/capita.



Source: JICA Study Team based on Our World in Data

Figure 7.2-12 Energy Supply and GDP per Capita in the World in 2016

The characteristics of energy consumption in the 'ne' countries presented in this section can be summarised as follows.

- Conventional biomass accounts for more than 90% of the primary energy supply.
- The majority of fossil fuels such as petroleum products and coal are dependent on imports.
- The residential sector accounts for more than 70% of primary energy consumption with the industry, transport and other sectors accounting for a lower proportion.
- Energy supply per capita is also low compared to neighbouring countries.

Given this situation, primary energy consumption in Nepal is in the early stages of development and energy demand is expected to increase significantly with future economic growth.

In other countries, primary energy consumption generally grow up in accordance with following steps;

- i. Energy infrastructure is developed and conventional biomass routinely used in the residential sector is replaced by fossil fuels and electricity
- ii. The share of energy consumption is shifted from the residential sector to industry, transport and commercial sectors, as economy grows up with the transition of key industries from agriculture to manufacturing.

iii. Primary energy consumption increases with economic growth.

Energy related infrastructure has also been rapidly developed in recent years in Nepal, including rural electrification, increase of electricity generation and supply of fossil fuels for residential use such as LPG. Furthermore, the development of oil and gas pipelines from India is also under the implementation. It is assumed that Step I will continue to progress rapidly.

On the other hand, the process of economic growth in stage ii varies depending on the circumstances in each country individually and does not necessarily follow the same path. Nepal have some unique characteristics, such as being land-locked country with transport problems for manufacturing, having a thriving tourism industry, and having a high proportion of migrants from abroad. In addition, the country is almost entirely dependent on imports of fossil fuels from other countries, and any increase in primary energy consumption is likely to result in an outflow of foreign currency. Considering the recent trend towards carbon neutrality in climate change, the increased consumption of fossil fuels may also have a negative impact on climate change.

Considering these circumstances, it is assumed that the future direction of primary energy supply and demand in Nepal will be to respond to strong demand growth in the short to medium term by supply increase from natural gas and oil and at the same time to achieve energy self-sufficiency through domestic clean energy, mainly hydro power in the long term.

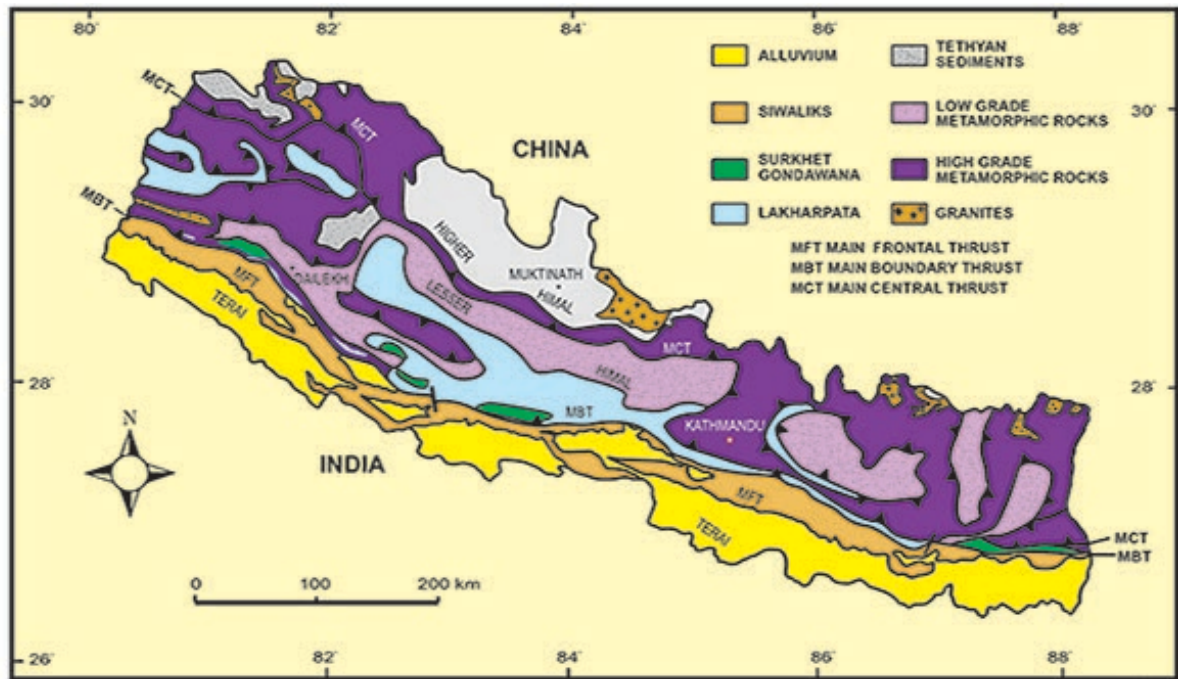
What differs significantly from conventional growth is the growing importance of the energy transition from primary energy sources such as heat supply and power sources, which have until now been dependent on fossil fuels, to electrification with domestic clean energy. In Nepal, the promotion of electrification policies is crucial not only in terms of contributing to climate change by reducing fossil fuels, but also in terms of increasing energy self-sufficiency.

7.2.2 Fossil Fuels

Nepal have abundant reserves of hydropower. On the other hand, although reserves of fossil fuels such as oil, natural gas and coal have been identified, no large-scale commercial plants have been developed. This section summarises the development of fossil fuels in recent years and discusses their potential for use in thermal power plants.

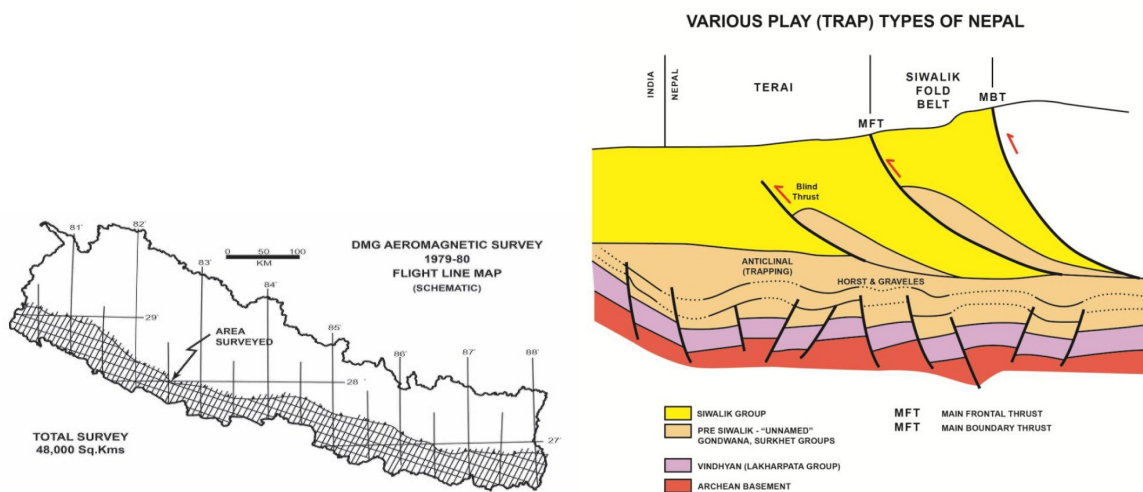
(1) Oil and Natural Gas

A geological map of the whole country of Nepal is shown in Figure 7.2-13 and area of aerial magnetic measurement and the potential of oil reserves at traps are shown in Figure 7.2-14.



Source: Department of Mines and Geology

Figure 7.2-13 Geological Map in Nepal



Source: Department of Mines and Geology

Figure 7.2-14 Area of Aerial Magnetic Measurement and Potential of Oil Reserves in Traps

The DMG (Department of Mines and Geology) has conducted Airborne Magnetic Survey in 1978-79 over the Terai (Indo-Gangetic Plain) and Siwalik (Sub-Himalaya) belt of the country covering an area of about 48,000 Sq. Km with the help of IDA/World Bank. The survey has shown encouraging results. Government of Nepal has established a separate unit "Petroleum Exploration Promotion Project" (PEPP) in 1982 to promote and monitor the exploration works in the country.

Previous studies have indicated the potential for petroleum hydrocarbon reserves in the geological bodies of Siwalik, Surkheta, Gondwana and Lakharpata (Vindhya).

The Siwalik Formation is a geological body comprising the Siwaluk Hills, which extend into the centre of the country and are bordered by HFT (Himalayan Frontal Thrust) with the Terai Plain

Alluvium. The surface geology of Siwalik formation indicates thick and multichannel sandstone of reservoir quality and the lower part of Siwalik formation provides thick and good quality of seals rocks. From the analysis of seismic and Aero-magnetic data the structure and stratigraphy traps are noted in the Siwalik region. However, the possible source rock sample collected from the Siwalik group shows immaturity for oil and gas exploration.

Surkhet group of rock that are exposed in the north of MBT (Main Boundary Thrust) are correlated with the oil and gas formation in Assam and Potwar basins. The outcrop of Surkhet group and subsurface evidence are equivalent to the unnamed formation in the northern India. This group contains potential source and seal rocks. Sample collected from this group are subjected to geochemical analysis and the result shows 2 % to 20 % of TOC (Total Organic Carbon) content in the rock. Thus, Surkhet group is the most targeted group for exploration.

The Gondwana group of rock is divided into two groups: the basal upper Paleozoic series containing both tillites and coal, and the higher upper Paleozoic to lower Mesozoic marine sequence with significant development of shale and limestones. Gondwana beds are prospective for both oil and gas since the facies in Gondwana are favorable and these facies also subcrop over significant areas in the southeastern part of Nepal. Analytical result of the sample collected from this group contain up to 10% TOC.

The Lakharpata equivalent to Vindhyan in India is continuously exposed along the Main Boundary Thrust and occurs in the subsurface unconformably beneath the Siwaliks with thickening in the centre and thinning in the west. The Sangram formation at the base of the Lakharpata group has good source rock with 7% to 9 % TOC obtained from the analysis of collected sample.

Recent activities include the signing of a Memorandum of Understanding with China in February 2019 for the study of oil and gas exploration. The study is divided into three phases of activities over a period of approximately three years, as shown in Table 7.2-1. Various exploration activities are being carried out in the Tansen area of Lumbini province and the Dailek group of Karnali Pradesh province.

Table 7.2-1 Outline of Oil and Gas Survey supported by China

1 st Phase	- Geological and Petroleum Geological mapping in Tansen and Dailekh area, - Geochemical Survey in Dailekh area, - Magnetotelluric Survey in Dailekh area and different part of Nepal - 2D-Seismic Survey in Dailekh area
2 nd Phase	- to identify the drilling site and completion of drilling work.
3 rd Phase	- Overall study of petroleum geological condition and submit the final report to the Department of Mines and Geology

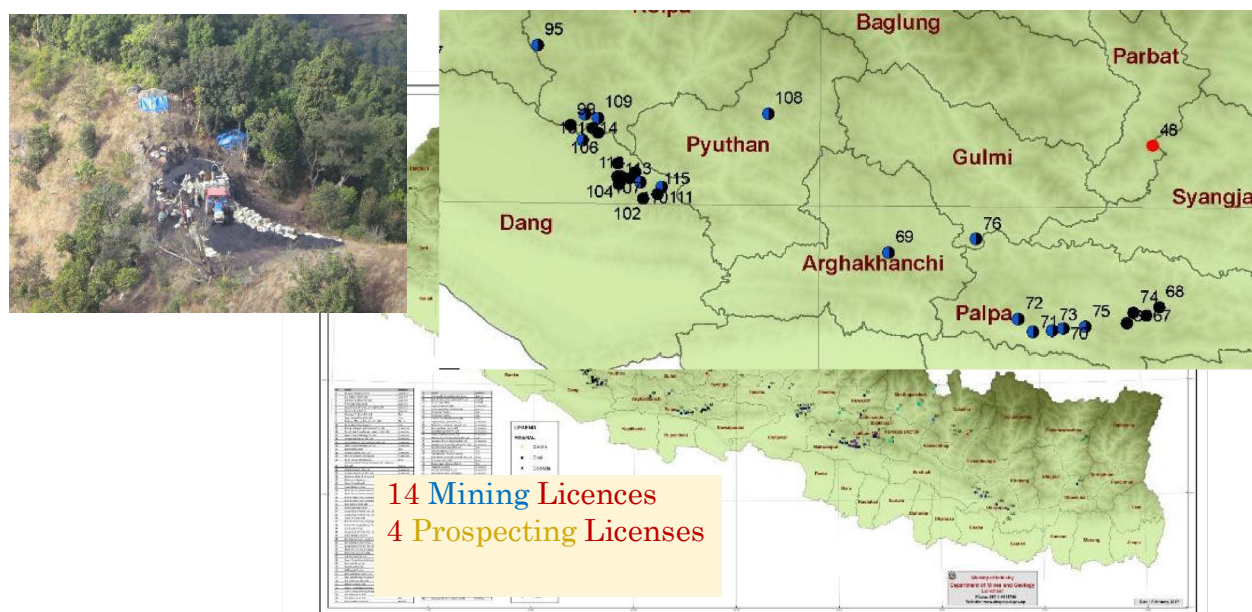
Source: Department of Mines and Geology

(2) Coal

Reserves of coal are mainly confirmed at following four tectonics in Nepal.

- Quaternary Lignite Deposits of Kathmandu Valley
- Siwalik Coal of the Sub – Himalayas
- Cretaceous – Eocene Coal of the Lesser Himalayas
- Gondwana Coal of the Lesser Himalayas

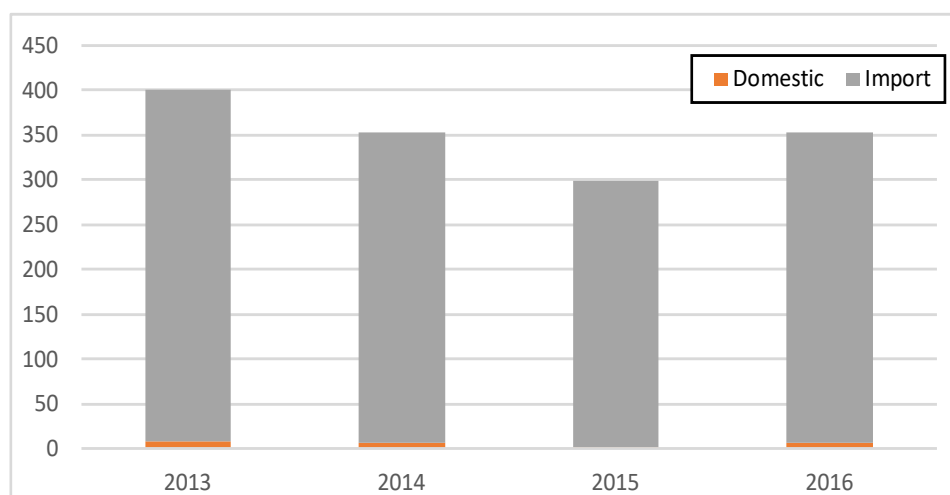
Location of coal mines in Nepal are shown in Figure 7.2-15.



Source: Department of Mines and Geology

Figure 7.2-15 Location of Coal Mines in Nepal

As of 2017, 14 coal mines have been already licensed for operation and four new licences are expected to be granted in Nepal. These mines are intensively located in Dang District, Lumbi Province on the border between the Tarai Plains and the Siwaluk Hills. Others mines are also in operation in Rolpa, Pyuthan and Palpa district. Their Probable Reserve is estimated at 5 million tonnes. In terms of coal properties, sub-bituminous coal with a calorific value of around 5700 - 7000 kcal/kg is dominant at the Tosh mine in Dang. Domestic production and import of coal is shown in Figure 7.2-16.



Source: JICA Study Team based on Department of Mines and Geology

Figure 7.2-16 Domestic Production and Import of Coal in Nepal

The share of domestic production is generally between 1.0% and 2.0%.

(3) Considerations on the Possibility of Thermal Power Plants with Domestic Fossil Fuels

As of February 2022, domestic production of oil and gas remained at the exploration stage. Reserves of them have been not confirmed and commercial operation is not planned at this moment.

Generally, oil or natural gas fields require more than 10 years of lead time from survey to commissioning. Thus, commercial operation is not expected to start until 2030 or later. In addition, interviews indicate that it is difficult to secure required amount of fuel to operate CCGT (Combined Cycle Gas Turbine) connected to the bulk power system.

Regarding the coal reserves, if a single unit of coal thermal power plant with installed capacity 100MW is operated at 85% plant factor, the plant can operate for 20.2 years with the estimated domestic coal reserves of 5 Million Tonnes in Nepal. However, plant life of coal thermal power plants are generally more than 40 years and need to shift to imported coal in the middle of the plant life.

From the above, it is assumed that fossil fuel reserves in Nepal are small compared to the consumption of grid-connected gas or coal thermal power plants with large capacity and it is difficult to develop them for generation. Therefore, if thermal power plants are to be built in Nepal, fuel is required to be procured from other countries.

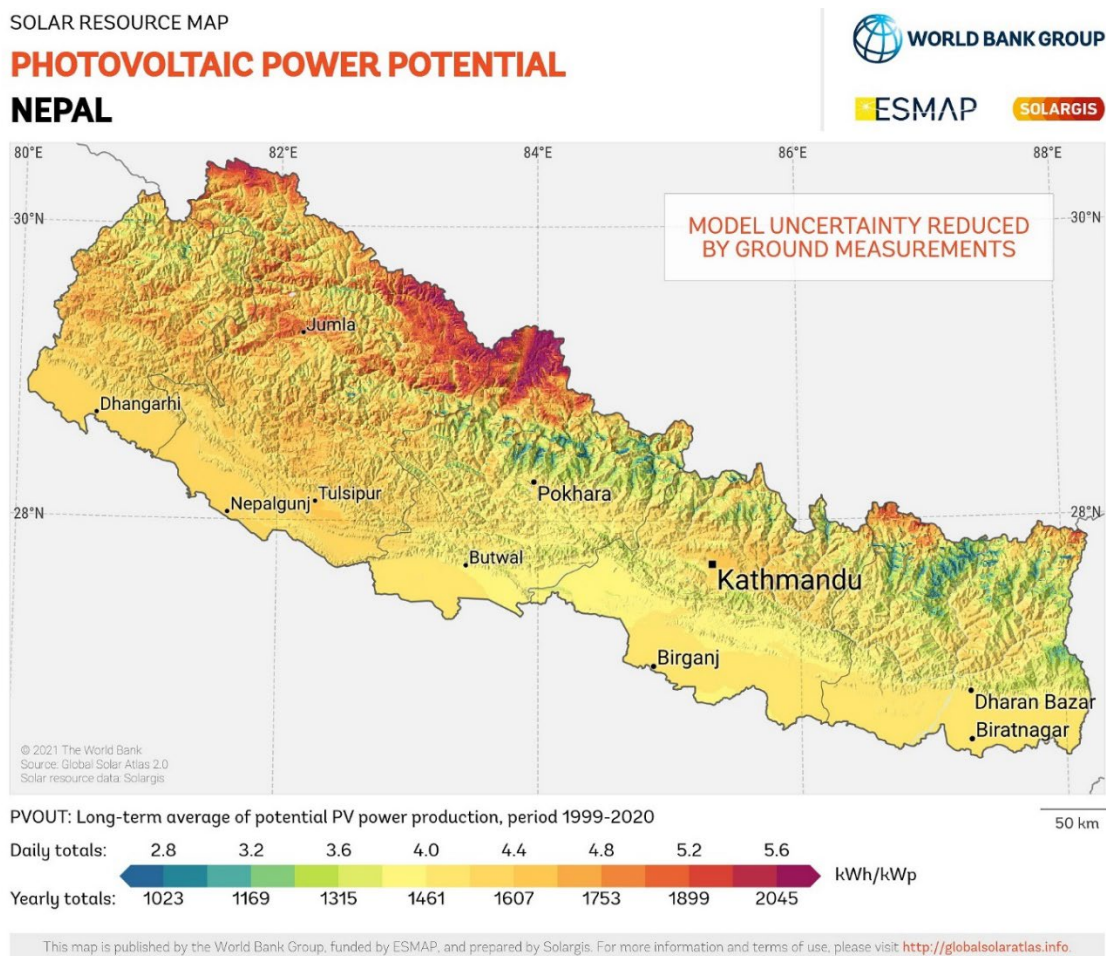
7.2.3 Renewable Energy

(1) Solar

Potential of solar power in Nepal is shown in Figure 7.2-17.

In terms of solar radiation, Mustang district in the north central region has high potential, with 1,899 - 2,045 kWh/m²/year, which is equivalent to 21.6%-23.3% of plant factor. However, it is difficult to secure wide and flat space for solar panel installations in steep mountainous areas. Grid connected large-scale solar plants can be locally developed in the Himalayas, which occupy the northern part of the country, and the Siwaluk Hills, which occupy the central part but suitable sites are supposed to be very limited.

Considering the availability of land, the southern part of the country is covered with flat areas, mainly in the Terai plains. Solar radiation in these areas ranges between 1,388 - 1,534 kWh/m²/year which is equivalent to 15.8% to 17.5% of capacity factor. It is expected to be economically viable. Grid connected solar power plants in Nepal are assumed to be developed in the southern plains such as Nepalgunj, Dhangadhi, Talsipur, Butwal, Birganji and Biratanagar.



Source: Global Solar Atlas 2.0

Figure 7.2-17 Potential of Solar Power in Nepal

As shown in Table 7.2-2, there are a large number of new solar projects with 68 sites and total installed capacity of 1,383.55MW in DoED (Department of Electricity Development) Project List, while existing solar power plants are only 13 sites with 68.4MW. The large solar PV projects exceeding 50MW such as Solar PV Project barju Sunsari (50MW), Solar PV Project Dhalkebar, Mahottari (120MW), Lamadada Lalpur Solar PV Project (100MW) and Bhangaha Solar PV Project, Mahottari (100MW) are intensively located near Janakpur. Concentration of solar sites may cause negative impacts on the power system operation called as “hotspots”. It is assumed that the decentralisation of solar projects will become more important taking into account the power system operation.

Table 7.2-2 DoED Project List (Solar)

Category	Project Name	Capacity (MW)	Promoter	District
Construction	Block No 1 Solar Farms Project	5.1	Nepal Electricity Authority	Charghare (Nuwakot)
Construction	Block No 2 Solar Farms Project	8.3	Nepal Electricity Authority	Charghare (Nuwakot)
Construction	Bel Chautara Solar Farm Project	5	Solar Farm Pvt. Ltd.	Khairnitar (Tanahu)
Construction	Som Radha Krishna Solar Farm Project	4.4	Nepal Solar Farm Pvt. Ltd	Rupakot (Kaski)
Construction	Solar PV Pratappur	5	National Solar Power Company	Pratappur (Nawalparasi)
Construction	Bhrikuti Solar Power Project	9	First Solar Developers Nepal Pvt. Ltd.	Barakulpur (Kapilbastu)

Category	Project Name	Capacity (MW)	Promoter	District
Construction	Grid Connected Solar Project Block 4, Nuwakot	1.37	Nepal Electricity Authority	Bidur N.P. (Nuwakot)
Construction	Grid-Connected Solar Power Project, Dhalkebar, 33 kV S/S	3	Sagarmatha Energy & Construction Pvt. Ltd.	Dhalkebar (Dhanusha)
Construction	Grid Connected Solar PV Project, Ramgram, Nawalparasi	2	Saurya Bidhyut Power Pvt. Ltd	
Construction	Grid-Connected Solar Power Project, Duhabi, 33 kV S/S	8	Global Energy & Construction Pvt. Ltd.	Duhabi (Sunsari)
Construction	Utility Scale Solar PV	6.8	G I Solar Pvt. Ltd,	Banigama (Morang)
Construction	Solar PV Project Banke, block-2	10	Pure Energy Pvt. Ltd	Raniyapur (Banke)
Construction	Solar PV Project, Raniyapur, Block 1	10	Pure Energy Pvt. Ltd	Raniyapur (Banke)
Construction	Grid Connected Solar PV Project, Ganeshpur, Kapilbastu	10	Positive Energy Pvt. Ltd	Ganeshpur (Kapilbastu)
Construction	Solar Power Project, Dhalkebar 11 kV S/S	1	Api Power Company Ltd.	Dhalkebar (Dhanusha)
Construction	Baigundhara Solar PV project	5	East Solar Pvt. Ltd	Gaurandaha (Jhapa)
Construction	Mithila 2 Solar PV Project, Dhanusa	10	Eco Power Development Pvt. Ltd.	Begadawar (Dhanusha)
Construction	Dharamnagar Solar Farm Project	10	Pashupati Renewables Pvt. Ltd.	Birpur (Kapilbastu)
Construction	Grid Tied Solar Farm Project	3.09	Nepal Electricity Authority	Charghare (Nuwakot)
Construction	Grid Tied Solar Farm Project Block n. 5	6.5	Nepal Electricity Authority	Bidur N.P. (Nuwakot)
Construction	Grid Connected Solar Project, Shivasatakshi Jhapa	10	Jhapa Energy Limited	Panchganchi (Jhapa)
Application for Construction License	Grid-Connected Solar Power Project, Lahan , 33 kV S/S	4	Asian Tech Corporation Pvt. Ltd.	Lahan N.P. (Siraha)
Application for Construction License	Solar Power Project, Simara, 11 kV S/S	1	Api Power Company Ltd.	
Application for Construction License	Grid Connected Solar PV Project Part II, Kapilbastu	10	Positive Energy Pvt. Ltd	Ganeshpur (Kapilbastu)
Survey	Bhadrapur Solar PV Project	5	Rairang Hydropower Development Company Ltd	Bhadrapur NP (Jhapa)
Survey	Ridi Solar PV Project	0.99	Ridi Hydropower Development Company Limited	Ruru (Gulmi)
Survey	Grid Connected Solar PV Project, Birendranagar Surkhet	1.2	G.C.Solar Energy Group	BirendraNagar N.P. (Surkhet)
Survey	Grid Connected Solar PV Project, Lamahi	10	Pioneer Energy Pvt. Ltd	Satbariya (Dang)
Survey	Grid Connected Solar PV Project, Lamahi 1	10	Progressive Energy Pvt. Ltd	Satbariya (Dang)
Survey	Grid Connected Harmony Solar Farm, Bardiya	5	Harmony Solar Pvt. Ltd	Neulapur (Bardiya)
Survey	Kalikhola Solar PV Project	3	Goodluck Glocal Power Energy Pvt. Ltd	Bidur N.P. (Nuwakot)
Survey	Mithila Solar Project	5	Solar Star Pvt. Ltd.	Hariharpur (Dhanusha)
Survey	Jira Bhawani Sedawa PV Project	7.7	Tarai Solar Pvt. Ltd.	Sedhawa (Parsa)
Survey	Pratappur Solar PV Project	10	National Solar Power Company	Pratappur (Nawalparasi)
Survey	Belbari Solar PV Project	10	Shreeyanshi Urja Pvt. Ltd.	Belbari (Morang)
Survey	Tek Samundra Solar PV Project, Thakurbaba	5	Tek Samundra Khetibari Pvt. Ltd.	Neulapur (Bardiya)
Survey	Udayapur Solar PV Project	10	Sunlight Energy Pvt. Ltd	Jogidaha, Gaighat (Udayapur)
Survey	250MW Grid connected Solar Project in Kohalpur and Banganga	250	Risen Clean Energy Nepal Pvt. Ltd.	
Survey	Jhimruk On Grid Solar Project	7	Butwal Power Company Limited	Khaira (Pyuthan)
Survey	Sonaha Solar Farm Project	10	Bharati Laxmi Energy Pvt. Ltd	Suryapatawa (Bardiya)
Survey	Lahan Solat PV Project	10	Eco Sun Power Development Pvt. Ltd	Lahan N.P. (Siraha)
Survey	Lalbandhi Solar PV Project	10	Eco Gham Power Company Pvt. Ltd.	Lalbandi (Sarlahi)

Category	Project Name	Capacity (MW)	Promoter	District
Survey	Solududhakuna Solar PV Project	10	Gham Kheti Pvt. Ltd.	Tingla (Solukhumbu)
Survey	Kalikhola-A Solar Electricity Project	7	Goodluck Global Power Energy Pvt. Ltd	Bidur N.P. (Nuwakot)
Survey	Dharamnagar Solar Farm-II	15	Pashupati Renewables Pvt. Ltd.	
Survey	Nepalgunj SVP Power Plant	200	G.T. Energy Pvt.Ltd.	
Survey	Jhapa SPV Power Plant	300	G.T. Energy Pvt.Ltd.	Surunga (Jhapa)
Survey	Solar PV Plant Block 2, Kailali	10	Advik energy Limited	Godawari (Kailali)
Survey	Solar PV Plant, Block-1, Kailali	10	Advik energy Limited	Godawari (Kailali)
Survey	Amarawati Solar Project Part 1	10	Amarawati Solar Energy Pvt. Ltd	Godawari (Kailali)
Survey	Amarawati Solar Project Part 2	10	Amarawati Solar Energy Pvt. Ltd	Godawari (Kailali)
Survey	Gami Solar Energy Project	3	Gami Telecom Solutions and Infrastructure Pvt. Ltd.	Begadawar (Dhanusha)
Survey	Shivraj Solar Power Plant	10	Lumbini Energy and Multiple Pvt. Ltd	Jawabhari (Kapilbastu)
Survey	Subha Solar PV Project	9.9	Subha Group & Power Company Pvt. Ltd	Lisankhu (Sindhupalchok)
Survey	Tumlingtar Solar Electricity Project	9.9	Bista Energy House P. Ltd.	
Survey	Shantinagar Solar Project	10	Shubham Nengyuan Pvt.Ltd.	
Survey	Tanahu Solar Power Plant Phase-II	10	Perfect Moon Energy Company(P) Ltd.	
Survey	Saurya Vidyut Aayojana, Bara	7	Kantipur Energy Investment & Construction Pvt. Ltd.	
Survey	Krishnapur Solar PV Project	10	Green Village Ventures Pvt. Ltd.	Bardibas (Mahottari)
Survey	Surunga Utility Scale Grid- Tied Solar Project	10	Time Solar Energy Pvt. Ltd.	Surunga (Jhapa)
Survey	Godawari - Attariya Solar Electricity Project	40	Hive Nepal Pvt. Ltd.	Godawari (Kailali)
Survey	Pahelmanpur Solar Electricity Project	30	Hive Nepal Pvt. Ltd.	Pahelmanpur (Kailali)
Survey	Bhurigau Solar PV, Project	40	Hive Nepal Pvt. Ltd.	Sivapur (Bardiya)
Survey	Nepalgunj Solar PV Project	25	Hive Nepal Pvt. Ltd.	Nepalgunj N.P. (Banke)
Survey	Kohalpur Solar PV Project	40	Hive Nepal Pvt. Ltd.	Banaktwa, Naubasta (Banke)
Survey	Gulariya Solar PV Project	25	Hive Nepal Pvt. Ltd.	Gulariya (Bardiya)
Survey	Tulsi Solar Electricity Project, Dang	7.5	Vinayak Solar Private Limited	Tulsipur (Dang)
Survey	Gandak Saurya Vidyut Project, Nawalparasi	5.8	Nepal Electricity Authority	Pratappur (Nawalparasi)

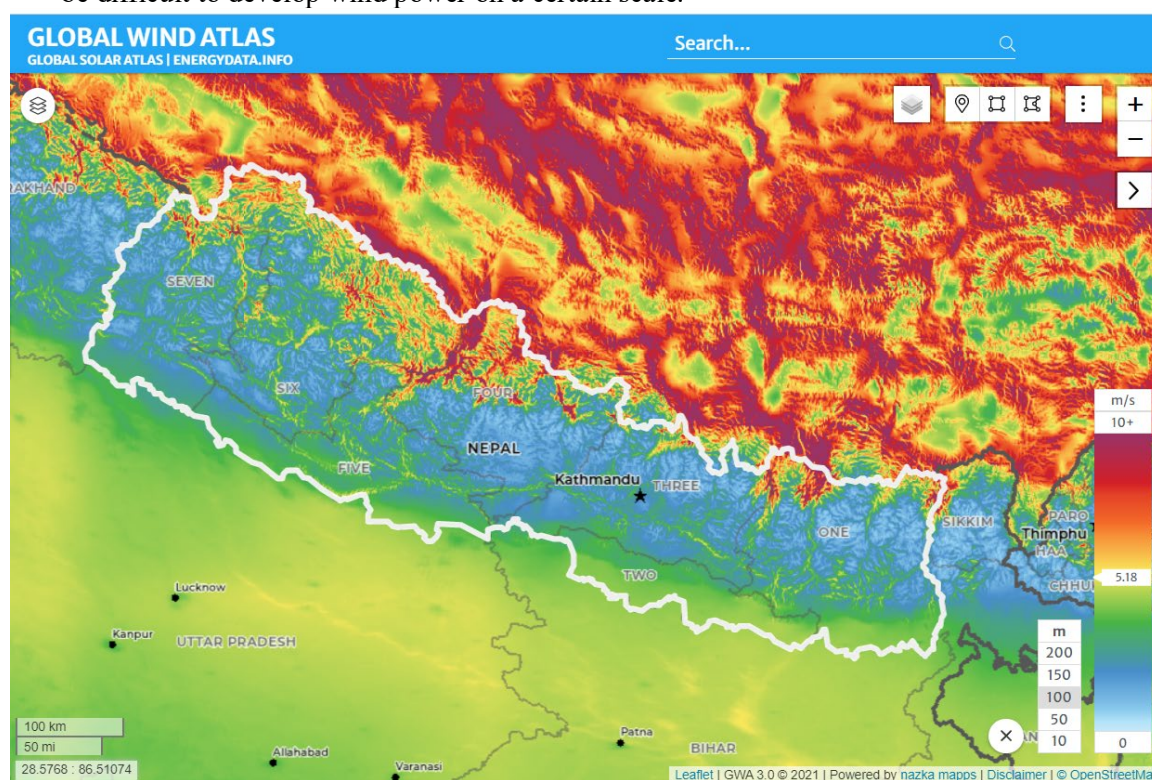
Source: JICA Study Team based on DoED List

As for solar, it is possible to develop SHS (Solar Home System) as a decentralised source of power close to demand areas. SHS has been mainly developed to promote rural electrification under the initiative of AEPC (Alternative Energy Promotion Center). However, the unit cost of SHS equipment has fallen significantly in recent years. As an example of India, Grid connected SHS has been able to be installed for around USD 600/kW in the market. This means that electricity can be generated at the same level as electricity tariff and the introduction of SHS in addition to grid-connected systems is also a considerable option.

(2) Wind

Average annual wind velocity in Nepal is shown in Figure 7.2-18. Generally, an average wind speed of 6.0 m/s which is equivalent to plant factor of approximately 25% is required for candidates of wind power sites. In Nepal, these conditions are assumed to be met in Mustang, Myagdi and Manang district in northern area of Gandaki Province and Dolakha, Solukhumbu and Sankhuwasabha district in Province 1. These areas have high altitude and are also difficult to access except Mustang district. There are local potential areas with wind speeds of 6.0 m or higher in other regions, but they are distributed along high mountain ridges and it is assumed that it would

be difficult to develop wind power on a certain scale.



Source: Global Wind Atlas 2.0

Figure 7.2-18 Average Annual Wind Velocity in Nepal

There are three wind power projects with total installed capacity of 5MW in Mustang district and one project with 1MW in Jumla district in the DoED Project List as shown in Table 7.2-3. Although Nepal has a certain level of wind potential, grid connected large scale wind power is not planned at this moment.

Table 7.2-3 DoED Project List (Wind)

Category	Project Name	Capacity (MW)	Promoter	District
Survey	Mustang Wind Project	3.00	Future Wind Power Pvt. Ltd	Jomosom (Mustang)
Survey	1 MW Wind Energy Mini Grid System	1.00	Amarjyoti Bayu Urja Users' Committee via Tatopani RM	Tatopani (Jumla)
Other Projects	Kagbeni Wind Energy Project	1.00	Everest Wind Energy Pvt. Ltd.	Kagbeni (Mustang)
Other Projects	Wind Electric Power Tangbe	1.00	Everest Wind Energy Pvt. Ltd.	
Total		6.00		

Source: JICA Study Team based on DoED List

(3) Biomass

Terai plains are agricultural area in where rice, sugarcane, potato, corn and wheat are cultivated and it is assumed that there is potential for biomass. On the other hand, at present, large-scale development of biomass power has not been considered in the policy of Nepal.

In the DoED Project List, Cogeneration sites are assumed to be biomass oriented, with four sites and 24 MW as shown in Table 7.2-4. Details of biomass power generation will be confirmed and

described in the Interim Report.

Table 7.2-4 DoED Project List (Cogeneration)

Generation type	Category	Project Name	Capacity (MW)	Promoter	District
Biomass	Construction	Cogeneration	3.00	Reliance Sugar and Chemical Industries Pvt. Ltd	
Biomass	Construction	Indushankar Cogeneration and Transmission Project	3.00	Indu Shnakar Chini Udyog Ltd.	Haripur (Sarlahi)
Biomass	Survey	Relaince Sugar Cogeneration	15.00	Relaince Sugar and Chemicals Industries Pvt. Ltd	Manaharwa (Bara)
Total			21.00		

Source: JICA Study Team based on DoED List

(4) Possibility of Renewable Energy in Nepal

As indicated in this Clause, it is assumed that solar has abundant potential in the southern Terai plains and is promising as large-scale grid connected renewable energy development in Nepal. Wind and biomass are also expected to have potential and it is necessary to continue the study.

Solar power, with its large output fluctuations, together with wind power, is defined as VRE (Variable Renewable Energy) that has negative impacts on power system operation. Uncontrolled introduction may disturb the stable power system operation. Compared with wind and hydropower, solar power plants have less restriction on the location of sites and scale conditions and can take various development style such as SHS or reservoir floating. However, IPPs (Independent Power Producers) who are considered as main developers of solar power projects, often select sites from the economic perspective of land use, solar radiation and power system connectivity. Actually, new projects are concentrated in the southern part of the country where good conditions are. This preference tends to concentrate suitable sites in limited location and to create hotspots of solar power projects. These have problems such as impact of output fluctuations on power system operation and transmission line capacity constraints.

Therefore, the development of solar power plants should not only focus on potential, land use and connectivity to the power system, but should also consider decentralised deployment in harmony with power system operation. For these grid connected solar projects, power system operators are expected to have the initiative to plan the development capacity and areas, not rely in on the proposal of IPPs.

On the other hand, if hydropower is classified as a renewable energy source, domestic electricity supply in Nepal is almost entirely provided by renewable energy sources except the import from India. In increasing hydropower power exports in the future, securement of regulating function in power system operation by hydropower will be crucial for high-value electricity with better tariffs. Regulating capacity for the fluctuation of solar power is expected to be particularly important because India, a major export destination, has pledged to massively deploy solar power in the future. It should be noted that it is desirable to determine the amount of solar introduction based on the beneficial effects for Nepal, rather than simply introducing solar as a renewable energy source.

7.3 CONSIDERATIONS AND EVALUATION FOR THE INTRODUCTION OF POWER SOURCES

This Section considers the possibility for the introduction of hydropower, gas-fired power, coal-fired power, renewable energy and power trade and selects the power sources to be introduced by assessing their applicability to PGDP in Nepal from the perspective of the 3E (Energy Security, Economy and Environment) + Policy.

Although thermal power generation is a major power generation source in other countries, the availability of fuel within Nepal is limited. Fuel procurement is depended on imports with high costs, leading the actual development to low feasibility. This section aims to broadly examine options that Nepal could adopt, including comparisons with hydropower, solar, wind, and power trade. It shall be noted that the intention here is not to promote thermal power plants but to consider it as one of the options for comprehensive evaluation.

7.3.1 Hydropower

Candidates of hydropower projects shall be 716 sites with total installed capacity of 38,859.7MW proposed on the DoED Project List described in Chapter 6. Generation scheme of hydropower is classified into four sub-category of ROR (Run of River), PROR (Peaking Run of River), STO (Storage) and PS (Pumped Storage).

There are some hydropower projects not on the DoED Project List such as Sapta Koshi multi-purpose dam project (3000 MW) on the lower reaches of the Koshi main river and the Pancheshwar multi-purpose dam project (6780 MW including reverse regulating reservoir) on the border with India. These projects are expected to be developed through bilateral cooperation with India. They have large installed capacity and reservoirs with vast impounded areas. Generally, large hydropower development takes a long lead time of 20-30 years from planning to operation. Thus, it is uncertain whether the project will be operational by 2040. In addition, as the development is based on bilateral cooperation with India and the electricity generated is expected to be exported to India via a dedicated line, it is possible to consider the project independently of the IPSDP. Given the circumstances, both sites are excluded from consideration in the IPSDP, but it should be noted that this does not preclude future development.

(1) Definition of Power Generation Scheme

Regarding the classification of generation scheme to candidates, original scheme is applied to sites which information is available. If there are no enough information, following definitions in PPA (Power Purchase Agreement) prepared by ERC (Electricity Regulatory Commission) as shown in Table 7.3-1, Table 7.3-2 and Table 7.3-3 are applied

Table 7.3-1 Tariff of ROR in PPA

Period			Tariff
1.- Dry and wet season 6 months each	Wet Season	Jestha 16 to Mangsir 15 [May 29 or 30 – Nov 30 or Dec 1]	4.8 NRp
	Dry Season	Mangsir 16 to Jestha 15 [Dec 1 or 2 – May 28 or 29]	8.4 NRp
2.- Dry season 4 months and Wet season 8 months	Baishak to Mangsir	[April 15 or 16 to December 14 or 15]	4.8 NRp
	Poush to Chaitra	[December 15 or 16 to April 14 or 15]	8.4 NRp

Source: ERC

For ROR, there is a difference in the tariff of PPAs depending on the share of electricity generated in the dry and rainy seasons. The power purchase rate from the ROR project whose generation is a maximum 70% of total annual energy in Wet Season (Jestha 16 to Mangsir 15) have advantage of higher tariff rate during six months in dry season (Mangsir 16 to Jestha 15).

Table 7.3-2 Tariff of PROR in PPA

Period		Peaking Hours	Tariff
Dry Season	Mangsir 16 to Jestha 15 [Dec 1 or 2 – May 28 or 29]	1 hr to less than 2 hrs	8.5 NRp
		2 hrs to less than 3 hrs	8.8 NRp
		3 hrs to less than 4 hrs	9.4 NRp
		4 hrs to 6 hrs	10.55 NRp
		Non-Peaking hours	8.4 NRp
Wet Season	Jestha 16 to Mangsir 15 [May 29 or 30 – Nov 30 or Dec 1]	All Hours	4.8 NRp

Source: ERC

All PROR Project, must be capable of providing daily peaking at rated capacity for minimum 1 hour to 6 hours at a time. The energy of six months (Jestha 15 to Mangsir 16) shall be a maximum of 70% of total annual energy.

Table 7.3-3 Tariff of STO in PPA

Period		Generation Composition	Tariff
Wet Season	Jestha 16 to Mangsir 15 [May 29 or 30 – Nov 30 or Dec 1]	less than 65%	7.1 NRp
Dry Season	Mangsir 16 to Jestha 15 [Dec 1 or 2 – May 28 or 29]	more than 35%	12.4 NRp

Source: ERC

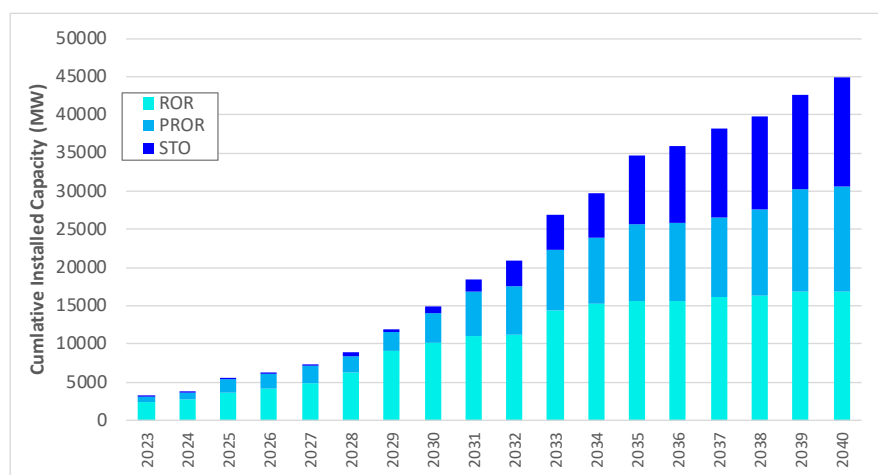
STO is required to fulfil following three conditions;

- Active Storage Volume of Reservoir Project shall not be less than the Volume corresponding to the design discharge of 15 days.
- Dead Storage Volume shall be designed in a way that it does not get filled by the sediments, at least for 50 years.
- The minimum energy of six months shall be 35% during the period of Mangsir 16 to Jestha 15.

Regarding PS, there is no definition in PPA and original information shall be applied. Two projects of Begnas-Rupa Storage HEP (150MW) and Kulekhani Sisneri Pumped Storage HEP (100MW) are proposed in the DoED Project List.

(2) Forecast of Development of each Power Scheme

Installed capacity and commissioning year for ROR, PROR and STO in DoED list is shown in Figure 7.3-1. Commissioning year is assigned to each hydropower site referring existing F/S or MoEWRI Energy Development Roadmap and Work Plan 2035. In case of lack of information, it is assumed based on location, development status of surrounding river system and estimated construction period.



Source: Prepared by JICA Study Team based on DoED List

Figure 7.3-1 Installed Capacity (MW) and Commissioning Year for ROR, PROR and STO in DoED List

This graph indicates that ROR will have been mainly developed until 2030 and PROR will follow it after 2030. STO which are currently undeveloped and are long lead time from survey to commissioning will developed after 2032.

7.3.2 Thermal Power (Gas and Coal)

(1) Location of Thermal Power Plants

As mentioned in Section 7.2.2, it is assumed that domestic reserves of oil, gas and coal in Nepal are insufficient to provide required fuel for large scale thermal power plants. Therefore, if thermal power plants are to be developed in Nepal, fuel will be imported from India. This Section examines the possibility on the development of gas-fired and coal-fired power plants for domestic electric power supply, assuming fuel imports from India. In general, thermal power plants are expected to be located in the following conditions.

- near the port, cargo terminal and gas pipelines at where fuel procurement is easy such as
- near rivers or canals at where cooling water is easily supplied
- less environmental impacts of resettlement or deforestation
- near the bulk power system
- near the demand area

In Nepal, the oil pipeline between Motihari (India) - Birgunj (Nepal) - Amalekhunj (Nepal) have been in operation since 2019. A gas pipeline from Gorakhpur (India) to Rupandehi (Nepal) is also under investigation by the bilateral cooperation. These sites have rivers nearby and it is assumed that they can be developed with relatively low environmental impact compared to coal power, if densely populated areas are avoided. As for the demand sites, the former is located in Kathmandu and the latter in Pokhara, Butwal and other major cities. There are 132kV power system, too. In addition, Birgunji is planned as the entrance to Nepal side in the Kathmandu-Raxaul railway study concluded in October 2021, and is expected to remain a key location for transport and energy infrastructure.

Based on the above, it is assumed here that candidates of thermal power plants in Nepal are to be located in Rupandehi for gas-fired power plants and in Birgunji for coal-fired power plants.

(2) Specification of Thermal Power Plants

GT (Gas Turbine), CCGT and GE (Gas Engine) are typical examples of gas-fired power plants, but GT has lower thermal efficiency than the CCGT and GE and can't be an option for developments above a certain size. GE is easy to install as it uses ready-made cubicles and can generate power in a short lead time if fuel and a site can be secured. It is also used as a short-term rental power source due to its advantages of construction period and easiness of installation. In recent years, their thermal efficiency has also improved around 30%-40%. This study compares CCGTs and GEs.

In terms of the scale of power plants, there are gas-fired power plants of 500 MW class on a single axis for CCGT and coal-fired power plants of 660 MW class with a single unit capacity in the world. On the other hand, as the scale of demand is not that large in Nepal, a 300 MW class CCGT and a supercritical coal-fired power plant are assumed. As for GE with short lead times, it is possible to install the required number of cubicles of 5 MW or less, 1MW unit, which is widely used in many countries around the world, are applied.

(3) Roles of Thermal Power Plants in Power System Operation

In terms of the expected role of power plants in power generation, it is assumed that gas-fired power plants will operate as a regulating power source to respond the seasonal fluctuations of hydropower. They are expected to operate as base or middle load during the dry season, when hydropower output declines and as peak load or reserve operation during the rainy season. As Coal-fired power takes time to start up and adjust its output, it will basically be operated as base load. It may be operated as reserve during the rainy season.

(4) Commissioning Date of Thermal Power Plants

The construction period is generally two years for CCGT, one year for GE and four years for coal-fired power plants. However the transport infrastructure of fuel such as gas pipelines and coal railways has not yet been developed. As it usually takes five to ten years to develop these transport infrastructures, it is assumed that thermal power plants will be commissioned after 2030.

(5) Role in Energy Security

Due to the lack of fossil fuel reserves within Nepal, fuel procurement for thermal power plants depends on imports from India. Therefore, there is similarity of dependence on India for energy security between generation by thermal power plants and fuel procurement.

(6) Environmental Considerations

Regarding environmental and social considerations, while the impact of construction of domestic thermal power plants is relatively smaller compared to large-scale STO HPPs, it is still necessary to carry out an assessment equivalent to Category A of JICA's Environmental and Social Considerations Guidelines. Additionally, increase of CO₂ emissions would gain negative affect on the goal of achieving carbon neutrality by 2045. Furthermore, the investment environment for new thermal power projects is becoming increasingly stringent each year from the perspective of climate change countermeasures. As intensely debated at COP26, new investments in coal-fired power, are expected to face challenges in securing development aid and foreign investment financing.

7.3.3 Renewable Energy

(1) Effect of VRE to the Power System Operation

In recent years, the massive introduction of renewable energy has become a major trend in the energy sector around the world. Among renewable energies, the costs of solar and wind power have fallen drastically over the past 10 years, and are now lower than the cost of thermal power in many countries. Nowadays, solar and wind power are introduced not only in terms of CO₂ reduction but also merit order of power generation operation.

As mentioned in Section 7.2.1, solar power has been introduced in recent years as an economic power source. On the other hand, solar and wind power which do not have a constant output are regarded as variable sources of renewable energy, VRE. It is always necessary to balance the supply and demand of electricity and to plan and operate power plants, transmission, and distribution facilities in the power system to ensure that supply meets demand.

It is necessary to harmonize the introduction of VRE not only with the power plant alone, but also with the power system. Recently the focus has been on “Flexibility of Power System”. According to the IEA, in its broadest sense, flexibility refers to the regulating function to ensure system-wide coordination in order to maintain the balance between supply and demand effectively and efficiently. Such flexibility is not only limited to the conventional generation side, such as controllable generators like gas fired power plants or STO hydropower, but also energy storage, demand response and power trade. Furthermore, attention is also being paid to energy supply sources other than electricity, such as cogeneration and electric vehicles (EVs).

Although targets for the introduction of renewable energies are determined on a policy basis according to individual circumstances of countries, it is commonly necessary to set an introduction amount that can ensure the flexibility. Two broad perspectives can be envisaged when considering the introduction target: 1) the share in generation mix of rated installed capacity and 2) the share in total power generation. For the former, it is often set that renewable energy account for around 10% to 30% of the total installed capacity in the target year. The latter is widely considered that power generation of renewable energy dominate around 5% and 50% in annual power generation of the target year.

Table 7.3-4 Introduction Phase of VRE and Affect to Power System Operation

Phase	Ratio of VRE in Generation	Situation	Countries Correspond
Phase 1	3%	VRE generation doesn't affect to operation of the power system for electricity supply.	Nepal, Indonesia, Mexico, South Africa.
Phase 2	3~15%	It is necessary for system operators to monitor the generation of VRE or to adjust the operation.	Japan, India, Belgium, Australia, Sweden and China.
Phase 3	10~25%	It is necessary to deal with the fluctuation of VRE in power system operation.	Portugal, Spain, Greece, Germany, Italy, UK
Phase 4	25~50%	As VRE generation sometimes account for 100% of power generation, power system operation is restricted by it.	Denmark, Ireland

Source: System Integration of Renewables 2018, IEA

According to the IEA, introduction of VRE is classified into four phases based on its share in the total power generation as shown in Table 7.3-4. Developed countries are generally classified as Phase 2 (3-15% of electricity production) to Phase 3 (10-25% of electricity production). Most developing countries where power supply development is still developing are classified as Phase 1. They generally don't have serious problems due to VRE in the power system operation. However, there are some cases, such as India, Vietnam and Pakistan, where challenges due to the

concentration of VRE deployment have become apparent. As for the Nepal, they are currently in Phase 1 and are expected to shift to Phase 2 as 851 MW of new projects on the DoED Project List are implemented.

(2) Target of Introduction of Renewable Energy in Nepal

In considering the targets for the introduction of renewable energy in Nepal, the following conditions need to be taken into account;

- When considering hydropower as a renewable energy source, almost the entire electricity supply in Nepal is covered by clean energy with low CO₂ emissions, except for the import of electricity from India
- The country has abundant hydropower potential and plans to export electricity abroad in addition to supply to domestic demand.
- As India, a major export destination, plans to introduce large amounts of solar power, there is likely to be added value to regulating function to absorb the fluctuations of solar.

From an energy security perspective, the introduction of solar will contribute to the diversification of power sources in Nepal. Meanwhile, even the energy self sufficiency rate is already high owed to domination of hydropower in Nepal even at present. In terms of Value for Money, it is necessary to examine whether relatively inexpensive solar can contribute to reducing the cost of power generation, or whether it would be more beneficial to conserve the regulating function in view of exports to India.

Based on the recognition above, following two development targets are proposed in this study. Considering the target in White Paper, Option 1 is the 10% share of renewable energy in total domestic demand (GWh) which is equivalent to Phase 2 of IEA definition. Option 2 is 25% which is equivalent to Phase 3. Even Option 1 has an installed capacity of 3,673 MW in 2040, which is higher than the total installed capacity of Nepal in 2020. It is necessary to develop approximately four (4) times of 829.78MW proposed on DoED Project List. For Option 2, the development capacity is even higher and it will be applied to a renewable energy-oriented scenario.

Table 7.3-5 Target of Renewable Energy Introduction

Share of Renewable Energy in Gross Domestic Demand (GWh)	Installed Capacity (MW)		VRE Introduction Phase by IEA
	Development Scenarios	Optimum Scenario	
Option 1: 10%	3,673MW	4,135MW	Phase 2
Option 2: 25%	9,314MW	10,435MW	Phase 3

Source: JICA Study Team

The Development Scenarios will compare these two options and examine the contribution of renewable energy introduction to PGDP.

(3) Introduction of Renewable Energy

The following approaches will be applied to the introduction of renewable energy to PGDP.

- Set a target of renewable energy introduction
- All solar, wind and cogeneration planned on the DoED Project List will be introduced.

- Any shortfall against the target will be distributed as Renewable_Candidate (100 MW) in accordance with the demand of each substation.

It shall be noted that Renewable_Candidate in the calculations is assumed to be solar, which has abundant potential, but the actual plan is not limited to it, but includes wind, biomass and small hydropower.

7.3.4 Power Trade

For power trade, the capacity (MW) of the grid connection line needs to be considered both in terms of electricity imports into Nepal and electricity exports to other countries. Details of Power Trade are shown in Chapter 8. As shown in Section 8.2-1, 1,490MW of existing international interconnection line capacity and 13,700MW of new development up to 2035, for a total of 15,190MW is proposed in the future.

This capacity is higher than the maximum power demand in 2040 in Chapter 5, which are 5,594 MW (Low case), 11,510MW (Middle case) and 21,120MW (High case). On the other hand, if the 716 sites and 38,859.7 MW included in the DoED Project List are to be developed, the capacity of the interconnection line would be insufficient, even after subtracting the domestic demand.

The study of power trade in this chapter calculates the interconnection line capacity (MW) and amount of power trade (GWh) from the perspective of development and demand on PGDP. In general, it is necessary to import electricity to Nepal in rainy season and to export electricity in rainy season. The location and capacity of individual interconnection lines are described in Chapter 8.

7.3.5 Comparison of Power Sources

(1) Comparison of Power Sources

Table 7.3-6 Evaluation Criteria for the Comparison of each Power Sources

Item		Evaluation
(1) Energy Security	Utilization of Domestic Energy	Sources are derived from domestic or imported.
	Impact by International Issues	Uncertain risks such as bilateral disputes.
(2) Economy	Levelised Cost of Electricity	Cents/kWh
	Regulating Function of Generation	Output is controllable or not.
	Vulnerability for Fuel Cost Fluctuation	Risks of inflation
(3) Environmental and Social considerations	Natural and Social Impacts	Negative affects due to the development such as deforestation, destruction of ecosystem or resettlement.
	Impacts on Climate Change	Emission of GHG (g-CO ₂ /kWh)

Source: JICA Study Team

In this section, a comparative evaluation of hydropower (ROR, PROR, STO, PS), thermal power (gas and coal), renewable energy (solar, wind and biomass) and power trade is carried out to select power sources to be applied in PGDP. The evaluation criteria based on the 3E are shown in Table 7.3-6. Although the content of project costs, reservoir capacity and environmental impact differs

greatly depending on the characteristics of individual sites, each power source is assessed qualitatively to ascertain the direction of the power sources required for Nepal. The characteristics of individual sites are discussed in the Optimum Scenario.

1) Calculation of LCOE

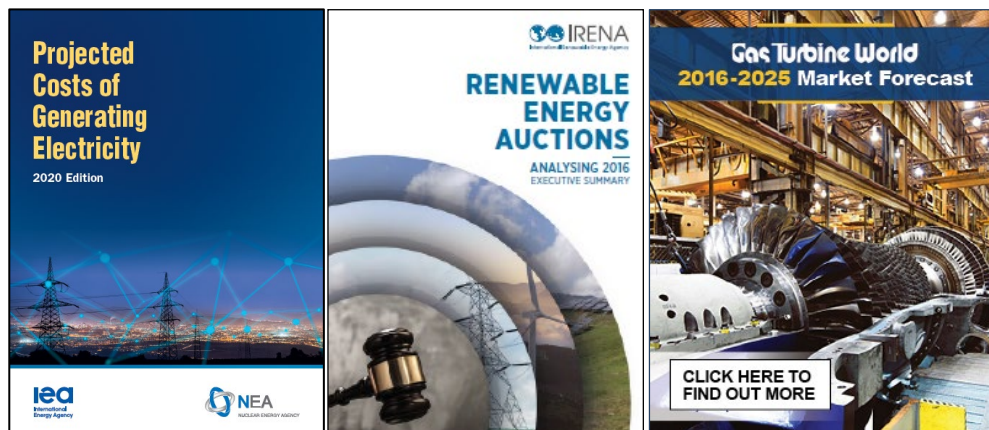


Figure 7.3-2 *References on Cost of Generation Projects*

The Levelised Cost of Electricity (LCOE) is calculated as an economic evaluation indicator. Information was collected on the following three assumptions for each power source in the analysis, including capital investment costs (USD/kW), maintenance costs (USD/kW-year), thermal efficiency (%) and fuel costs. The assumptions for the costs of each power source are summarized in Table 7.3-7. It shall be noted that, at the time of preparing the Progress Report, the data collection had not been completed, but care was taken to ensure that the settings were as close to the actual situation as possible. It will be updated to the latest version at the time of preparation of the Interim report.

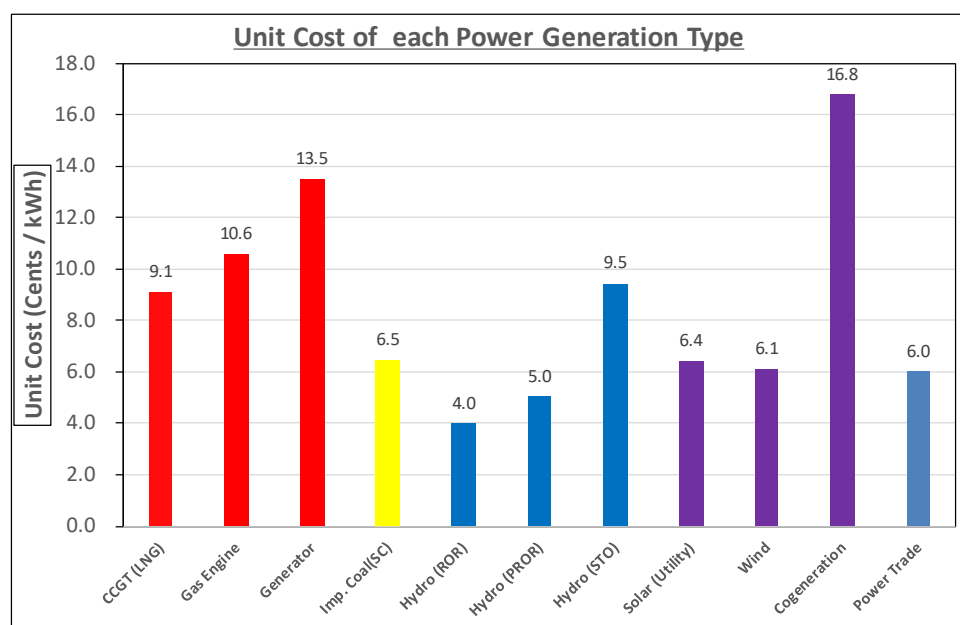
- Actual performance of existing power plants in Nepal
- Project cost under planning in Nepal.
- Global standards and South Asian cost trends published by international organizations such as the IEA
- As of February 2022, fuel prices were rapidly rising due to invasion of Ukraine. Transition for the past two years are not indicative of actual situation, as they have been highly volatile due to the COVID 19. For this reason, LNG 10 USD/MMBTU and coal 83 USD/ton are used as fuel costs for the Asia region in the Projected Costs of Generating Electricity 2020 Edition. Capital investment costs are applied at Indian cost with 10% premium. For hydropower, the actual examples are used as a reference for the setting. For these costs, the price of capital investment is set at a level that includes the cost of environmental measures that meet international environmental standards.

Table 7.3-7 Summary of Analysis Conditions for LCOE Calculation¹

Coal	Steam Coal - SUBCRITICAL	Applied	Nepal	Europe	United States	Japan	China	India	Brazil	Average
	Capital Cost (USD/kW)	-	-	1,700	1,800	2,100	600	1,000	1,300	1,422
	Efficiency (%)	-	-	39%	39%	39%	37%	36%	39%	38%
	Steam Coal - SUPERCRITICAL	Applied	Nepal	Europe	United States	Japan	China	India	Brazil	Average
	Capital Cost (USD/kW)	1,320	-	2,000	2,100	2,400	700	1,200	1,600	1,689
	Efficiency (%)	36%	-	43%	43%	43%	41%	36%	43%	41%
	Steam Coal - ULTRASUPERCRITICAL	Applied	Nepal	Europe	United States	Japan	China	India	Brazil	Average
	Capital Cost (USD/kW)	-	-	2,200	2,300	2,600	800	1,400	2,189	1,910
	Efficiency (%)	-	-	45%	45%	45%	44%	40%	45%	44%
Gas	CCGT	Applied	Nepal	Europe	United States	Japan	China	India	Brazil	Average
	Capital Cost (USD/kW)	770	-	1,000	1,000	1,100	560	700	958	846
	Efficiency (%)	52%	-	59%	59%	59%	57%	52%	58%	57%
	Gas turbine	Applied	Nepal	Europe	United States	Japan	China	India	Brazil	Average
	Capital Cost (USD/kW)	-	-	500	500	500	350	400	400	439
	Efficiency (%)	-	-	40%	40%	40%	38%	38%	38%	38%
Hydropower	Hydropower - Reservoir	Applied	Nepal	Europe	United States	Japan	China	India	Brazil	Average
	Capital Cost (USD/kW)	2,500	2,500	2,650	2,700	2,400	1,600	2,000	2,100	2,200
	Capacity Factor (%)	43%	43%	28%	30%	22%	28%	36%	40%	33%
	Construction Time (year)	5	4	5	5	5	5	5	5	5
Hydropower	Hydropower - Run of River	Applied	Nepal	Europe	United States	Japan	China	India	Brazil	Average
	Capital Cost (USD/kW)	1,650	1,650	2,650	2,700	2,400	1,600	2,000	2,100	2,200
	Capacity Factor (%)	67%	67%	28%	30%	22%	28%	36%	40%	33%
	Construction Time (year)	2	2	2	2	2	2	2	2	2
Solar	Solar photovoltaics - Large scale	Applied	Nepal	Europe	United States	Japan	China	India	Brazil	Average
	Capital Cost (USD/kW)	691	-	708	1,072	2,006	730	629	1,197	1,020
	Capacity Factor (%)	17%	17%	14%	23%	14%	15%	18%	21%	17%
	Construction Time (year)	1	1	1	1	1	1	1	1.0	1
Wind	Wind Onshore	Applied	Nepal	Europe	United States	Japan	China	India	Brazil	Average
	Capital Cost (USD/kW)	965	-	1,458	1,343	2,282	1,174	877	1,314	1,610
	Capacity Factor (%)	25%	-	25%	35%	24%	25%	22%	45%	28%
	Construction Time (year)	1.5	-	1.5	1.5	1.5	1.5	1.5	1.5	2

Source: JICA Study Team based on Projected Costs of Generating Electricity 2020 Edition, IEA

The LCOE calculated under these assumptions is shown in Figure 7.3-3



Source: JICA Study Team

Figure 7.3-3 Results of LCOE for Each Power Sources

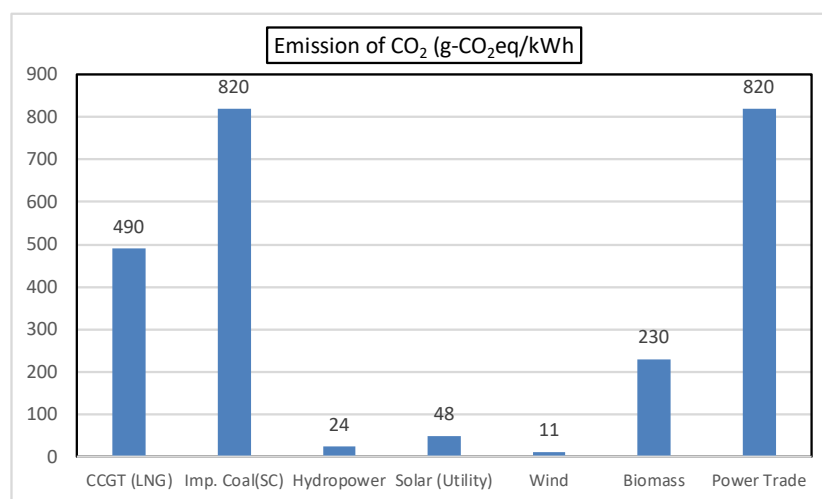
¹ Capital Cost and efficiency in each region in “Projected Costs of Generating Electricity 2020” has been prepared based on past performances including latest experiences

The main thermal power sources are CCGT at 9.1 cents/kWh and coal-fired at 6.5 cents/kWh. Gas Engine and Generator, which are less thermally efficiency, are more expensive at 10.6 cents/kWh and 13.5 cents/kWh respectively. For hydropower, ROR is the cheapest at 5.5 cents/kWh, PROR at 5.6 cents/kWh and STO at 7.7 cents/kWh. It should be noted that STO is low plant factor and the kW value and regulating capacity are not evaluated in the LCOE. Renewable energy sources are 6.4 cents/kWh for solar, 6.1 cents/kWh for wind and 16.8 cents/kWh for biomass.

Electricity from India is cheap at 6.0 cents/kWh, but coal-fired, hydropower and solar/wind power are at a competitive level with it. On the other hand, price of the power trade is highly volatile. It shall be noted that the tariff for power trade hikes in March 2022.

2) CO₂ Emission from Power Sources

As an impact on climate change, the Lifetime-based CO₂ emissions per kWh (g-CO₂ eq/kWh) for each power source are summarized in Figure 7.3-4, based on the Technology-specific Cost and Performance Parameters (2014) published by IPCC (Intergovernmental Panel on Climate Change). For power trade, the country-wide emissions for India in 2018 are applied.



Source: Technology-specific Cost and Performance Parameters (2014), IPCC

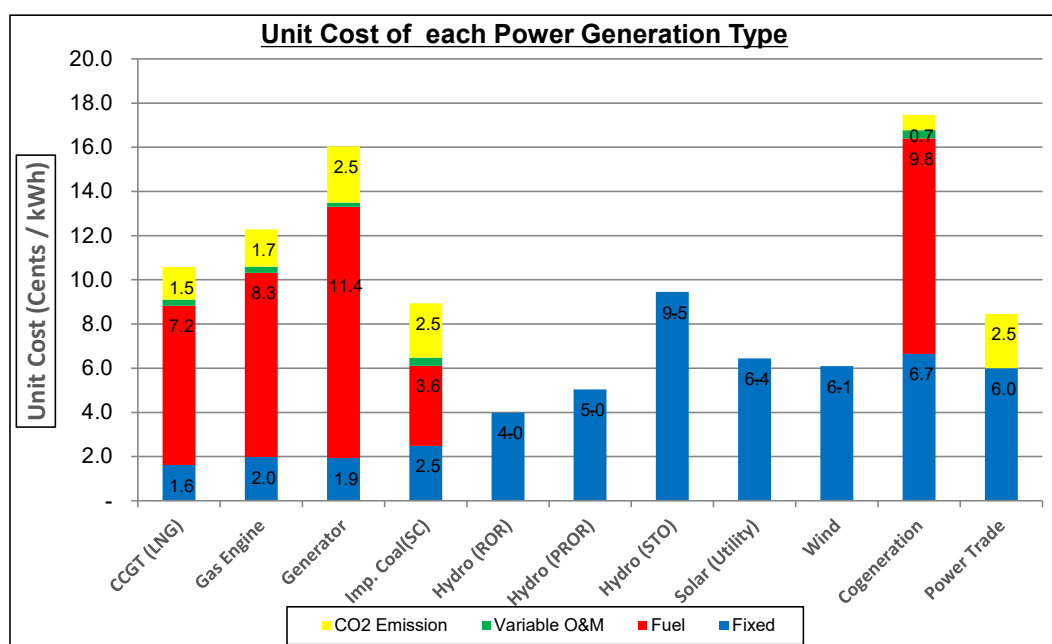
Figure 7.3-4 CO₂ Emission (g-CO₂ eq/kWh) of each Power Sources

The highest emissions are from coal-fired power at 820 g-CO₂ eq/kWh, with the same value for electricity supplied from India. IPCC estimation apply to supercritical for coal for power generation, but India has many older, subcritical, lignite-using power plants. The country as a whole includes gas-fired, hydropower and renewable for hydropower, solar and wind power, CO₂ is generated during the equipment manufacturing and construction stages, but it is lower than thermal power in absolute terms. For biomass, CO₂ is generated in the fuel procurement and combustion process.

Nowadays, there has also been a growing debate on the imposition of a carbon tax as a climate change measure. The price of carbon tax varies from 10 USD/ton to 100 USD/ton and only few countries have institutionalized it as a national law and regulation. However, there is a possibility that carbon taxes will be levied in the future in the world to reduce CO₂ emissions. As a reference, considering 30USD/ton for CO₂ emission which is applied in the Projected Costs of Generating Electricity 2020 Edition, the LCOE with CO₂ expense is shown in Figure 7.3-5.

The increased costs due to the CO₂ are 2.5 cents/kWh for coal-fired power, 1.5 cents/kWh for CCGT and 2.5 cents/kWh for the power trade, which is a very large burden for power sources with high CO₂ emissions. From the perspective of Nepal, the competitiveness of clean energy sources such as hydropower and solar power could be increased. The added value of clean energy needs to be fully considered when future electricity exports are taken into account.

Low decarbonization in response to recent climate change measures is a global trend. Nepal, who has abundant potential in hydropower and renewable energy are expected to contribute to low decarbonization, including in the South Asian region, through the development of these resources.



Source: JICA Study Team

Figure 7.3-5 Results of LCOE with Carbon Tax (30USD/ton) for each Power Sources

(2) Hydropower (ROR, PROR, STO and PS)

Results of evaluation for hydropower plants of ROR, PROR, STO and PS are presented in Table 7.3-8. Although it is difficult to assess hydropower plants collectively due to the individual characteristics of project cost and environmental impacts. In general, following characteristics are considered.

- Hydropower is domestic clean energy and is a useful source of power in the context of energy security and climate change measures.
- Although the initial investment is high, it is cheaper than thermal power generation and there are no concerns about fuel inflation, etc. On the other hand, risks such as drought due to climate change need to be considered.
- Output regulation varies by type, but even STOs are subject to significant seasonal fluctuations.
- While RORs have relatively little environmental impact, PRORs, STOs and PSs are affected by inundation and resettlement due to dam construction.

It shall be noted that the LCOE does not reflect the regulating power or kW value of STO and PS.

Thus, they are more expensive than ROR and PROR while they are very important power sources from the perspective of balancing supply and demand. Making a simple comparison is difficult.

Table 7.3-8 Evaluation of Hydropower (ROR, PROR, STO and PS)

Hydropower (Run of River)

Item		Evaluation
(1) Energy Security	Utilization of Domestic Energy	Hydropower is domestic clean energy.
	Impact by International Issues	None
(2) Economy	Levelised Cost of Electricity	5.55 cents/kWh
	Regulating Function of Generation	Daily stable but seasonably fluctuated
	Vulnerability for Fuel Cost Fluctuation	None
(3) Environmental and Social considerations	Natural and Social Impacts	Relatively small
	Impacts on Climate Change	24 g-CO ₂ /kWh

Hydropower (Peaking Run of River)

Item		Evaluation
(1) Energy Security	Utilization of Domestic Energy	Hydropower is domestic clean energy.
	Impact by International Issues	None
(2) Economy	Levelised Cost of Electricity	5.59 cents/kWh
	Regulating Function of Generation	1-6 hour peaking but seasonably fluctuated.
	Vulnerability for Fuel Cost Fluctuation	None
(3) Environmental and Social considerations	Natural and Social Impacts	Dam and regulating pond cause negative impacts.
	Impacts on Climate Change	24 g-CO ₂ /kWh

Hydropower (Storage)

Item		Evaluation
(1) Energy Security	Utilization of Domestic Energy	Hydropower is domestic clean energy.
	Impact by International Issues	None
(2) Economy	Levelised Cost of Electricity	7.69 cents/kWh
	Regulating Function of Generation	Daily peaking and seasonable regulation.
	Vulnerability for Fuel Cost Fluctuation	None
(3) Environmental and Social considerations	Natural and Social Impacts	Dam and reservoir causes serious impacts
	Impacts on Climate Change	24 g-CO ₂ /kWh

Hydropower (Storage)

Item		Evaluation
(1) Energy Security	Utilization of Domestic Energy	Hydropower is domestic clean energy.
	Impact by International Issues	None
(2) Economy	Levelised Cost of Electricity	32.35 cents/kWh
	Regulating Function of Generation	Variable control in short period as a battery.
	Vulnerability for Fuel Cost Fluctuation	None
(3) Environmental and Social considerations	Natural and Social Impacts	Dam and regulating pond cause negative impacts.
	Impacts on Climate Change	24 g-CO ₂ /kWh

Source: JICA Study Team

(3) Thermal Power (CCGT, GE, Diesel, Coal)

Evaluation for thermal power plants of CCGT, GE, Diesel and Coal are presented in Table 7.3-9. Considerations on thermal power plants are presented below.

- All of the power sources rely on imports of fuel from India, which have a risk of bilateral issues in terms of energy security. If a dispute with India are to occur, there is a risk of fuel supply disruptions.
- Generation costs are expensive except coal-fired power.
- CCGT, GE and Diesel have stable and variable output on a daily and seasonal basis and can be operated as a base, middle or peak load. Coal-fired power is not suitable for daily fluctuations and should be operated on a base load.
- In terms of the environment, impacts by the project is limited compared to hydropower, and environmental pollution and other impacts can be reduced if environmental measures are taken.

Table 7.3-9 Evaluation of Thermal Power Plants (CCGT, GE, Diesel and Coal)

Combined Cycle Gas Turbine (Imported LNG)

Item		Evaluation
(1) Energy Security	Utilization of Domestic Energy	LNG will be imported from India
	Impact by International Issues	Bilateral disputes may cause interruption of fuel supply.
(2) Economy	Levelised Cost of Electricity	9.11 cents/kWh
	Regulating Function of Generation	Output is controllable.
	Vulnerability for Fuel Cost Fluctuation	LNG price is fluctuating by the market. Inflation risk should be considered.
(3) Environmental and Social considerations	Natural and Social Impacts	Countermeasures to emissions are required.
	Impacts on Climate Change	490 g-CO ₂ /kWh

Gas Engines (Imported LNG)

Item		Evaluation
(1) Energy Security	Utilization of Domestic Energy	LNG will be imported from India
	Impact by International Issues	Bilateral disputes may cause interruption of fuel supply.
(2) Economy	Levelised Cost of Electricity	10.59 cents/kWh
	Regulating Function of Generation	Output is controllable.
	Vulnerability for Fuel Cost Fluctuation	LNG price is fluctuating by the market. Inflation risk should be considered.
(3) Environmental and Social considerations	Natural and Social Impacts	Countermeasures to emissions are required.
	Impacts on Climate Change	566 g-CO ₂ /kWh

Source: JICA Study Team

Hybrid Generator (Heavy Oil)

Item		Evaluation
(1) Energy Security	Utilization of Domestic Energy	Heavy oil will be imported from foreign countries
	Impact by International Issues	Bilateral disputes may cause interruption of fuel supply.
(2) Economy	Levelised Cost of Electricity	13.49 cents/kWh
	Regulating Function of Generation	Output is controllable.
	Vulnerability for Fuel Cost Fluctuation	Heavy oil price is fluctuating by the market. Inflation risk should be considered.
(3) Environmental and Social considerations	Natural and Social Impacts	Countermeasures to emissions are required.
	Impacts on Climate Change	848 g-CO ₂ /kWh

Super Critical Coal Power Plants (Imported Coal)

Item		Evaluation
(1) Energy Security	Utilization of Domestic Energy	Coal will be imported from foreign countries
	Impact by International Issues	Bilateral disputes may cause interruption of fuel supply.
(2) Economy	Levelised Cost of Electricity	6.48 cents/kWh
	Regulating Function of Generation	Stable but difficult to change output in short time.
	Vulnerability for Fuel Cost Fluctuation	Coal price is fluctuating by the market but affects of inflation against generation cost is relatively smaller.
(3) Environmental and Social considerations	Natural and Social Impacts	Countermeasures to emissions and yard are required.
	Impacts on Climate Change	820 g-CO ₂ /kWh

Source: JICA Study Team

(4) Renewable Energy (Solar, Wind and Biomass)

Evaluation for renewable energy of solar, wind and biomass is presented in Table 7.3-10. Considerations on renewable energy sources is presented below.

- All sources are domestically produced clean energy.
- Generation costs for solar and wind power are also sufficiently competitive due to recent cost reductions. Biomass is relatively expensive, although a uniform assessment is difficult because it depends on the fuel procurement method.
- VRE such as solar and wind power is difficult to adjust output, and fluctuations need to be adjusted by other power sources. Biomass is subject to fluctuations depending on the harvesting season of the crops used as fuel, but is operated as a base load with a constant output during operation.
- In terms of the environment, the impact of the project is limited compared to hydropower, although there are some impacts such as land expropriation.

Table 7.3-10 Evaluation of Renewable Energy (Solar, Wind and Cogeneration)

Renewable Energy (Solar)

	Item	Evaluation
(1) Energy Security	Utilization of Domestic Energy	Solar is domestic clean energy.
	Impact by International Issues	None
(2) Economy	Levelised Cost of Electricity	5.64 cents/kWh
	Regulating Function of Generation	Output is based on sunshine and is required to be regulated by other sources.
	Vulnerability for Fuel Cost Fluctuation	None
(3) Environmental and Social considerations	Natural and Social Impacts	Relatively small.
	Impacts on Climate Change	48 g-CO ₂ /kWh

Renewable Energy (Wind)

	Item	Evaluation
(1) Energy Security	Utilization of Domestic Energy	Wind is domestic clean energy.
	Impact by International Issues	None
(2) Economy	Levelised Cost of Electricity	6.1 cents/kWh
	Regulating Function of Generation	Output is based on wind and is required to be regulated by other sources.
	Vulnerability for Fuel Cost Fluctuation	None
(3) Environmental and Social considerations	Natural and Social Impacts	Relatively small.
	Impacts on Climate Change	11g-CO ₂ /kWh

Renewable Energy (Biomass)

	Item	Evaluation
(1) Energy Security	Utilization of Domestic Energy	Domestic biomass energy is utilized.
	Impact by International Issues	None
(2) Economy	Levelised Cost of Electricity	16.77 cents/kWh
	Regulating Function of Generation	Generally stable.
	Vulnerability for Fuel Cost Fluctuation	None
(3) Environmental and Social considerations	Natural and Social Impacts	Countermeasures to emissions are required.
	Impacts on Climate Change	230 g-CO ₂ /kWh

Source: JICA Study Team

(5) Power Trade

Evaluation of power trade is presented in Table 7.3-11. Considerations on power trade are shown below.

- Energy self-sufficiency is reduced because of imports from foreign countries.
- Imports from India and Bangladesh will be interconnected through India, and the risk of bilateral relations with India needs to be taken into account, even if the electricity is to be flexibly imported from Bangladesh.
- The average tariff of import in 2021 is inexpensive and cheaper than estimation of domestic thermal power generation. However it has been remarkably rising since the beginning of 2022 due to the affect from hiking of imported fuel price and imbalance between demand and supply.
- It is assumed that the amount of electricity supplied in the power trade can be handled flexibly if India has a surplus in the supply-demand balance, but the form of the contract will need to be reviewed.
- In terms of the environment, the impact is relatively minor, limited to the interconnection lines and substations within the country. On the other hand, regarding climate change, India's

main power source is coal-fired power and high CO₂ emissions per kWh need to be taken into account.

- 6.0cents/kWh as the past records until 2021 is applied to this analysis.

Table 7.3-11 Evaluation of Power Trade

Power Trade		
	Item	Evaluation
(1) Energy Security	Utilization of Domestic Energy	Import from India, Bangladesh and China.
	Impact by International Issues	Bilateral risks with partner countries should be considered.
(2) Economy	Levelised Cost of Electricity	6.00 - 30.0 cents/kWh
	Regulating Function of Generation	Controllable within the range of the contract of power trade.
	Vulnerability for Fuel Cost Fluctuation	depending on supply sources
(3) Environmental and Social considerations	Natural and Social Impacts	Only interconnection.
	Impacts on Climate Change	820 g-CO ₂ /kWh (Average emission of India in 2018)

Source: JICA Study Team

(6) Evaluation of each Power Source

1) Utilization of Domestic Energy

A summary of the evaluation of power sources is presented in Table 7.3-12. Hydropower is the most important power source in Nepal in terms of policy and is expected to be developed as far as possible where it is economically viable and acceptable in environmental and social considerations. Renewable energy is also expected to be utilized as inexpensive domestic energy sources as long as they are affordable in the power system operation. However, it should be noted that it may be more economical to secure the regulating capacity of hydropower as a value added power source against solar fluctuation in India from the aspect of power trade.

In PGDP, priority is also given to the introduction of hydropower and renewable energies as a means of utilizing domestic energy.

2) Comparison between Thermal Power and Power Trade

When deploying hydropower and renewable energy sources, thermal power or power trade are expected to be in charge of controllable power sources in power generation to adjust for the lower electricity production during dry season and for daily output shortfalls and fluctuations.

From an energy security perspective, thermal power and power trade depend on imports of fossil fuels or electricity from India, respectively. For power trade, interconnection with Bangladesh and China is an option, but the former is ultimately influenced by India as the interconnection line passes through the country. As for the latter, exports from China have not been discussed so far, and the possibility of power trade in the required quantities is unknown.

In terms of supply reliability, the introduction of gas-fired power would enable the country to secure regulating capacity in base, middle and peak operations. Coal-fired power can be used as a base power source, especially during the dry season. As long as fuel procurement is possible, the introduction of thermal power will contribute to improving supply reliability in power system operations. Although it depends on the procurement of fuel from India, power

trade can be responsible for the regulating function of power generation in Nepal which is very small scale power system compared with India.

Gas-fired power is more expensive than other power sources and is more fragile to inflation. The cost of coal-fired power generation is equivalent to power trade, but the cost will increase if the plant factor falls. Power trade is less flexible, as it depends on contracts with the India side for supply capacity and regulating power. There are also concerns about price increases during fuel inflation. On the other hand, current prices are at very low levels.

As mentioned in Section 7.3.2, new thermal power plants are expected to start operation after 2030 at the earliest. Additionally, it is necessary to consider the difficulties in environmental impact assessment and financing for them. Power trade has no such concerns as it utilizes the existing international interconnection lines. From the aspect of CO₂ emission, there is no difference of increase between thermal sources and power trade because the main source of power trade is coal-based thermal power.

Based on the above understanding, if a comparison is made between domestic thermal power plants and power trade, it is assumed that from the perspective of energy security, there will still be a heavy reliance on India for both options. Power trade is relatively cheaper while inflation risks are supposed. However even fossil fuel imports essentially pose the same concerns. It will be more practical to continue to strengthen power trade with India in order to stabilise electricity supply in Nepal.

On the other hand, the tariff for import from India is volatized with unit cost of 38 NRp / kWh (31.4 cents/kWh) due to the rapid increase of fossil fuels in the world. Increase of cost for the power trade will be heavy financial burden for Nepal. Although power trade is necessary for the stable power supply, reduction of the dependence on the power supply should be considered.

3) Input of Power Sources in IPSDP

The results of the comparison in this section summarize PGDP as follows:

- The plan will be based on hydropower and renewable energy as domestically produced clean energy sources, and on power trade including the export of surpluses and imports of shortfalls.
- Hydropower, a domestically produced clean energy source, will continue to be the main power source, and development will be promoted to the maximum extent within the acceptable and affordable amount in the aspect of economy and environmental and social considerations.
- Similarly, renewable energy, domestically produced clean energies is recommended to introduce more than 10% of power demand in consumptions (GWh). Considering the diversity of power sources, it will be developed with a focus on solar power, which has large-scale potential. The amount of installed capacity will be considered based on the flexibility of power system and the added value of the regulating power in power trade.
- Power trade will be based on exports when a surplus of electricity is generated, and imports when there is a shortage of domestic supply capacity during the dry season.

Table 7.3-12 Summary of Comparison of Each Power Source

Sources	Type	(1) Energy Security		(2) Economy			(3) Environmental and Social considerations	
		Utilization of Domestic Energy	Impact by International Issues	Levelised Cost of Electricity	Regulating Function of Generation	Vulnerability for Fuel Cost Fluctuation	Natural and Social Impacts	Impacts on Climate Change
Hydropower	Run of River	Hydropower is domestic clean energy.	None	5.55 cents/kWh	Daily stable but seasonably fluctuated	None	Relatively small	24 g-CO2/kWh
	Peaking Run of River	Hydropower is domestic clean energy.	None	5.59 cents/kWh	1-6 hour peaking but seasonably fluctuated.	None	Dam and regulating pond cause negative impacts.	24 g-CO2/kWh
	Storage	Hydropower is domestic clean energy.	None	7.69 cents/kWh	Daily peaking and seasonable regulation.	None	Dam and reservoir causes serious impacts	24 g-CO2/kWh
	Pumped Storage	Hydropower is domestic clean energy.	None	32.35 cents/kWh	Variable control in short period as a battery.	None	Dam and regulating pond cause negative impacts.	24 g-CO2/kWh
Thermal Power	Gas Power Plants (Imported)	LNG will be imported from India	Bilateral disputes may cause interruption of fuel supply.	9.11 cents/kWh	Output is controllable.	LNG price is fluctuating by the market. Inflation risk should be considered.	Countermeasures to emissions are required.	490 g-CO2/kWh
	Gas Engines (Imported LNG)	LNG will be imported from India	Bilateral disputes may cause interruption of fuel supply.	10.59 cents/kWh	Output is controllable.	LNG price is fluctuating by the market. Inflation risk should be considered.	Countermeasures to emissions are required.	566 g-CO2/kWh
	Hybrid Generator (Heavy Oil)	Heavy oil will be imported from foreign countries	Bilateral disputes may cause interruption of fuel supply.	13.49 cents/kWh	Output is controllable.	Heavy oil price is fluctuating by the market. Inflation risk should be considered.	Countermeasures to emissions are required.	848 g-CO2/kWh
	Super Critical Coal Power Plant	Coal will be imported from foreign countries	Bilateral disputes may cause interruption of fuel supply.	6.48 cents/kWh	Stable but difficult to change output in short time.	Coal price is fluctuating by the market but affects of inflation against generation cost is relatively smaller.	Countermeasures to emissions and yard are required.	820 g-CO2/kWh
Renewable Energy	Solar	Solar is domestic clean energy.	None	5.64 cents/kWh	Output is based on sunshine and is required to be regulated by other sources.	None	Relatively small.	48 g-CO2/kWh
	Wind	Wind is domestic clean energy.	None	6.1 cents/kWh	Output is based on wind and is required to be regulated by other sources.	None	Relatively small.	11g-CO2/kWh
	Biomass	Domestic biomass energy is utilized.	None	16.77 cents/kWh	Generally stable.	None	Countermeasures to emissions are required.	230 g-CO2/kWh
Power Trade		Import from India, Bangladesh and China.	Bilateral risks with partner countries should be considered.	6 cents/kWh	Controllable within the range of the contract of power trade.	depending on supply sources	Only interconnection.	820 g-CO2/kWh (Average emission of India in 2018)

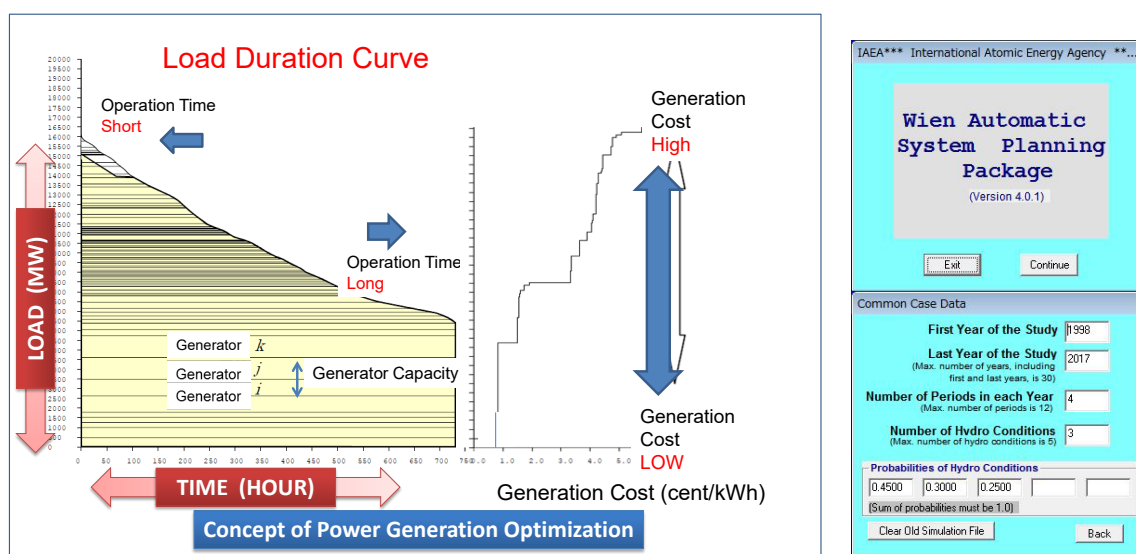
Source: JICA Study Team

7.4 METHODOLOGIES AND DESIGN CONDITIONS ON PGDP

7.4.1 Methodologies of Analysis

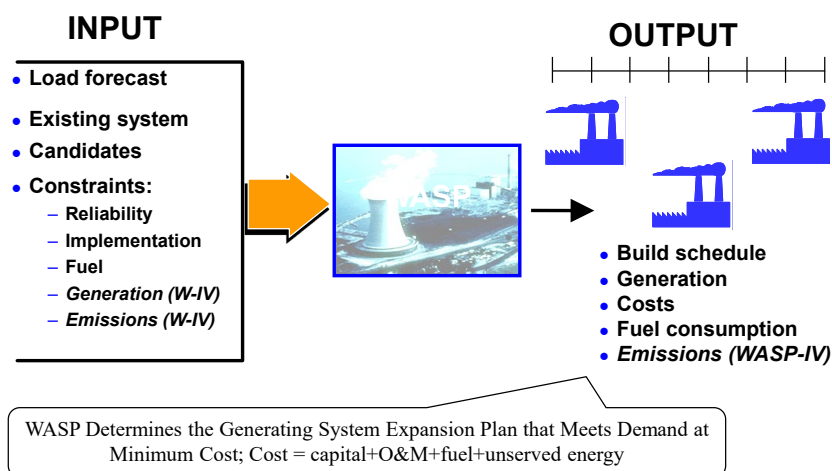
(1) Analysis Tool

In IPSPD, WASP (Wien Automatic System Planning) is applied to the analysis tool of PGDP. WASP is developed for optimization tool of power generation development by IAEA (International Atomic Energy Agency) and is widely utilized in formulation of development plan in many countries. Basic concept of WASP is minimization of objective function (Generation Cost) by Dynamic Programming, namely optimization of power generation planning by least cost. Based on the load duration curve, the power generation facilities of lower construction and operation costs are simulated to be operated sequentially. Outline of WASP and image of optimization of PGDP by least cost operation are shown in Figure 7.4-1 and Figure 7.4-2.



Source: JICA Study Team

Figure 7.4-1 Outline of WASP



Source: WASP Manual

Figure 7.4-2 Optimization of PGDP by Least Cost Operation

Subject function of WASP is total cost composed of construction cost, fuel cost and O&M as shown below

$$B_j = \sum_{t=1}^T [\overline{I_{j,t}} - \overline{S_{j,t}} + \overline{F_{j,t}} + \overline{L_{j,t}} + \overline{M_{j,t}} + \overline{O_{j,t}}]$$

- Objective function (B)
- Capital investment costs (I)
- Salvage value of investment costs (S)
- Fuel costs (F)
- Fuel inventory costs (L)
- Non-fuel operation and maintenance costs (M)
- Cost of the energy not served (O)
- Time in years (1, 2, ... , T)
- Number of expansion plan (j)

(2) Operational Conditions of each Power Source

The operating conditions for each power source in the WASP are set out below. It should be noted that the majority of new power sources currently planned in MoEWRI are expected to be developed by IPPs, and it is assumed that the operating conditions will differ at individual sites. For example, the peak hours of PROR during the dry season will be set under contractual conditions based on consultations with the power system operator, NEA (Nepal Electricity Authority). The optimum PGDP under the IPSDP does not impose operational constraints to achieve minimum costs, but determines and calculates the operating hours and timing of each power source through WASP and sets the minimum costs according to the supply and demand balance. Plan. It should be noted that the full purchase of generated electricity from IPPs is basically guaranteed for hydropower and renewable energy sources.

- ROR will operate at a constant output for 24 hours a day, depending on the monthly flow rate.
- PROR determines its operating hours and output based on the capacity of the regulating pond and the amount of electricity that can be generated in each month.
- STO determines its operating hours and output based on the capacity of the reservoir, the amount of electricity that can be generated in each month and the annual operation.
- PS pumps water when there is surplus power during the night time and generates power in peak time. In principle, surplus power of ROR is assumed for the pumping.
- Solar and wind power will be operated according to the generation pattern predetermined.
- Biomass will be operated at a constant output.
- Regarding power trade, hydropower and renewable energy will be exported if their output exceeds demand, and imported if it supply capacity is insufficient to demand.

7.4.2 Preparation of Input Data

Major input data of WASP is shown below;

Hydro Plants

- Type
- Code Name
- Description of Hydro Plant Type

- O&M Cost
- Hydro Plants
- Type
- Year of Operation Installed Capacity (MW)
- Storage Capacity (GWh)
- Inflow Energy (GWh)
- Min Generation (GWh)
- Ave Capacity (MW)

Thermal Power Plants

- Installed Capacity (MW)
- Min. Operating Level (MW)
- Max Generating Capacity (MW)
- Fuel Type (Coal, Lignite, Oil, Natural Gas, Gas Turbine)
- Heat Rate (Kcal/kWh)
- Fuel Cost (cents/million Kcals)
- Fixed O&M [Operation & Maintenance] Cost (\$/(kW · month)
- Schedule Maintenance Days per years (days)
- Forced Outage Rate (%)
- Capital Cost (\$/kW)

The source of input data primarily references the DoED project list but information is updated as needed depending on the stage of technical reviews. It should be noted that the Development Scenarios comparison shown in Section 7.5 refers to data as of May 2021 (version 1) and the Optimum Scenario shown in Section 7.6 refers to data as of March 2023 (version 2).

7.4.3 Design Conditions of PGDP

The analysis conditions and operating criteria for PGDP are shown in Table 7.4-1. The analysis period is 2022-2040 and the base case is applied to the power demand forecast.

For the operating criteria, reserve margin of supply capacity is set at 5% in February, 2040 which is lowest output in hydropower plants considering the drought case and LOLP (Loss of Load Probability) is set at 1 day per year from 2027 onwards.

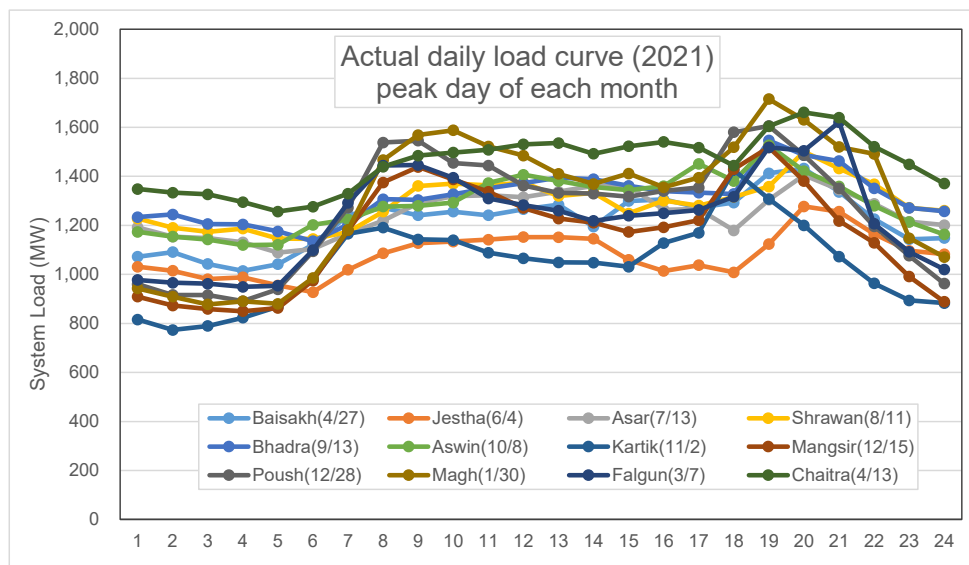
Table 7.4-1 Design Conditions of PGDP

Item	Description
Analysis Period	2022 - 2040
Demand	Base Case Development Scenarios :Power demand 56,112GWh and Peak 10,352MW (ver.1) Optimum Scenario :Power demand 62,390GWh and Peak 11,510MW (ver.2)
Tool	Wien Automatic System Planning Package IV (WASP IV) to find optimal expansion plan
Operation Criteria	Reserve Margin : 5% in February, 2040 LOLP (Loss of Load Probability) : 1 day per year from beginning of 2027

Source: JICA Study Team

7.4.4 Daily Load Duration Curve

The daily load duration curves up to 2040 used for PGDP are considered in this section. It is assumed that the shape of load curves will not significantly change and the actual records in 2021 (version 2) is used as the most recent data. The daily load duration curves of the day with peak demand in each month as shown in Figure 7.4-3.



Source: JICA Study Team

Figure 7.4-3 Daily Load Duration Curve in 2021

As mentioned in Chapter 5, the peak demand for 2021 is 1,715 MW and it is forecasted to grow up to 11,510 MW (version 2) by 2040. The ratio $2040 / 2021$ is equal to $11,510 \text{ MW} / 1,715 \text{ MW} = 6.71$ times and this ratio is applied to daily load duration curves in 2040 daily load curve. The daily load curves for other years are determined in a similar manner.

7.5 DEVELOPMENT SCENARIOS OF PGDP

In this Section, Development Scenarios for the power generation mix are developed and the direction of the power sector is considered based on several perspectives, including the legal systems, policies, natural conditions, current status of primary energy and future plans for power sources in Nepal that have been organized.

Based on the results and analysis on the power sector in Nepal, the following approaches are assumed to be important for the study of the future power generation mix.

- PGDP in Nepal will basically be dominated by hydropower and the power generation mix will depend on its possibility to be developed. In other words, the success or failure of hydropower development will determine the direction of the power sector.
- If the hydropower developments on the DoED Project List are fully developed, how much surplus power will be generated compared to electricity demand, whether export is feasible in terms of generation costs, flexibility and timing, and whether financing the development costs is feasible.
- What action will be required if the planned hydropower development is not realized? In case of the shortfall, what is the scale of required amount of power trade imported from neighboring countries, mainly India and how much is necessary for the expense of it?
- Will renewable energy such as solar power contribute to the power generation mix? What is the impact on imports and exports in terms of power trade and supply capacity on peak time?

Several Development Scenarios will be composed with obvious concepts in order to explore the direction of the power sector in which Nepal aims based on 3E + Policy.

7.5.1 Setting of Development Scenarios

(1) Direction in accordance with the Development Capacity of Hydropower

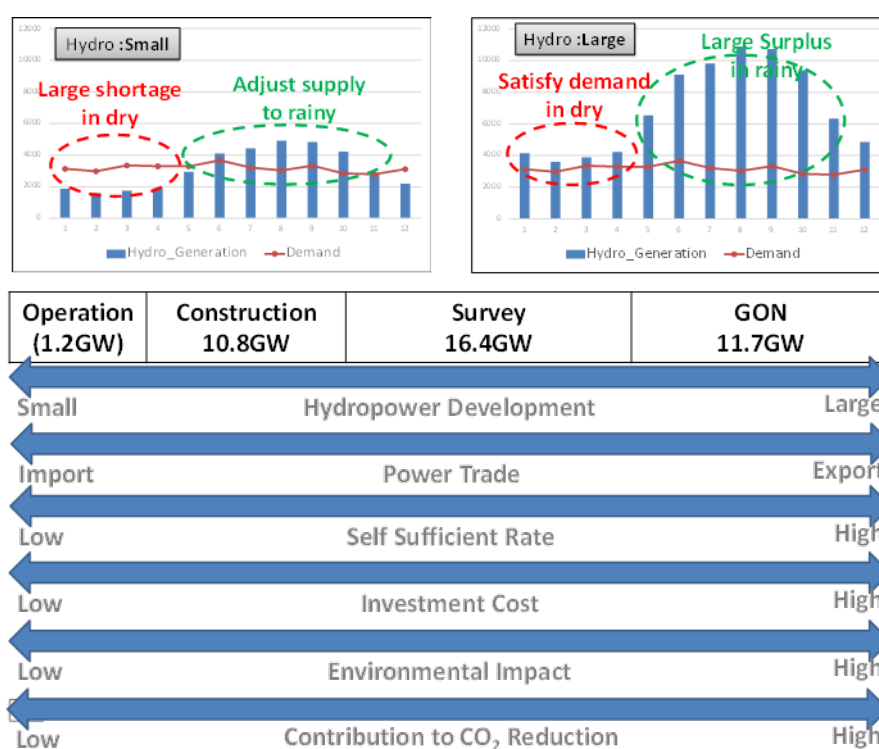
As indicated in Chapter 6, amount of hydropower generation in Nepal varies widely between rainy and dry seasons. It is only about 30% of electricity generated in dry season compared to rainy season. Although the effect of the regulating capacity of reservoir operation of STO to reduce these fluctuations is confirmed in this Study, it should be noted that there is still a large gap in the amount of power generation between dry and rainy season.

In terms of power generation development planning, the shortfalls caused by monthly fluctuations of hydropower output are usually adjusted by thermal power such as gas and coal power. On the other hand, the alternative for regulation of power generation is assumed to be responded by power trade with India as mentioned in Section 7.3.5. In addition, surplus power is assumed to be exported to neighbouring countries or be utilized for storage / electrification. The utilization of surplus power such as power storage or electrification will be considered in Optimum Scenario, while power export is assumed in Development Scenarios.

Based on the results of the Study in Chapter 6 and Section 7.3, it is assumed that the supply and demand of power is balanced by hydropower and power trade in Nepal. Therefore the capacity of hydropower development determine the direction of the power generation development planning. The following section discusses the direction based on development capacity of hydropower.

- (i) Development capacity of hydropower is small
Hydropower is developed in order to meet peak demand in rainy season and shortages are supplemented by power import in dry season.
- (ii) Development capacity of hydropower is large
Hydropower is developed to meet peak demand in dry season and excess electricity generated is exported.

In other words, it is important to consider two overall approaches for the future direction: (1) Restrict hydropower development and accept power import in dry season or (2) Promote hydropower development and power export. It is necessary to recognize the trade-off of hydropower development in amount of power trade, capital investment cost and environmental and social impacts in order to respond growing power demand in Nepal. These concepts are summarised in Figure 7.5-1.



Source: JICA Study Team

Figure 7.5-1 Direction by the Development Capacity of Hydropower

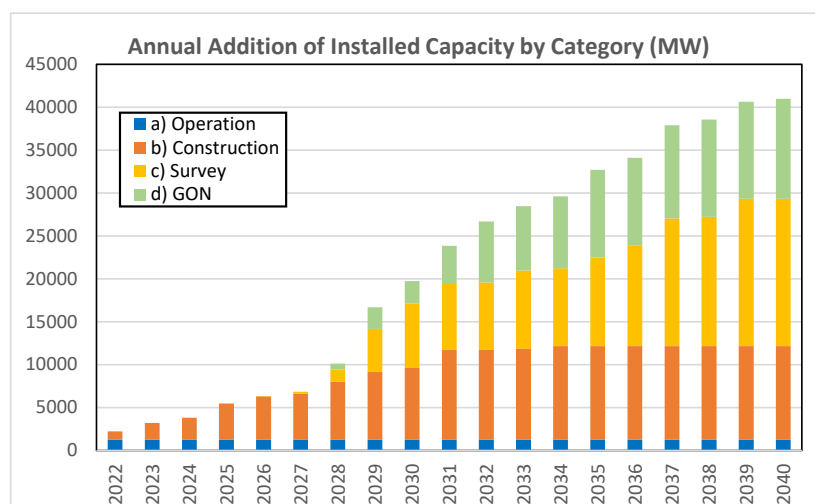
In terms of 3E + Policy, if the development capacity of hydropower is large, energy security is improved owed to the increase of self-sufficiency rated of electric power and export to neighbouring countries. Increase of export also contribute to the economy in Nepal by earning foreign currency and climate change through the reduction of CO₂ emission. At the same time, it is also essential to consider the feasibility of financing, the selection of economically viable projects and negative environmental impacts.

If the development capacity of hydropower does not meet demand, it is necessary to prepare options to supplement shortages by the introduction of renewable energy or power trade. There are also benefits in terms of environmental impacts and lower capital investment costs in the development with small scale. These impacts need to be assessed from various perspectives in comparison of Development Scenarios.

(2) Direction from Time Scale

Development capacity of hydropower by the progress shown in Section 6.5.1 is shown in Figure 7.5-2.

- a) Operation: Existing power plants that are currently operational.
- b) Construction: Sites that are either under construction or have applied for a construction license (Construction License or Application for Construction License).
- c) Survey: Sites that are either under survey or have applied for a survey license (Survey License or Application for Survey License).
- d) GoN (Government of Nepal): Sites where the government holds the rights.



Source: JICA Study Team

Figure 7.5-2 Development Capacity of Hydropower by the Progress

When looking at the power generation development over the short, medium and long term timeframes, the direction of generation scheme and power systems in (i) (ii) are summarized as follows.

Short-term power development is mainly carried out by the committed ongoing projects in b) Construction which are progressed regardless of the direction of scenarios. As these projects build up, power export in rainy season will increase but import is still required in dry season. Power export is expected to exceed import in 2025 as an annual balance of power trade. Although it is assumed that the projects of b) Construction will be steadily developed, there is no difference in the short-term outlook between (i) and (ii). In the power system planning, the 400 kV backbone system and international interconnection lines are planned correspondingly.

Looking to the medium and long-term outlook beyond 2025, the development of projects in c) Survey and d) GoN is important. Some of these projects can be commissioned as early as 2026 or later. The developable capacity will increase from 2028. As capacity of b) Construction is only 10.8 GW, the development of c) Survey and d) GoN is required to achieve the policy target with the development of 28,000MW until 2035.

If these hydropower developments do not progress in case of (i), power import will increase as demand increases. It is also necessary to confirm the both amount of import and export in power trade to design the capacity of interconnection lines.

In the case of (ii) which development is progressing, the trend of short-term export growth is expected to continue and import will no longer be required in dry season in the early 2030s. By

this time, it is necessary to prepare generation plans aiming to exports in projects of c) Survey and d) GoN considering the power generation development planning that are consistent with the supply and demand plans of export destinations such as India and Bangladesh. In addition, in the power system planning, it is necessary to verify whether power export is feasible with the currently planned international interconnection lines.

(3) Setting of Development Scenarios

Four Development Scenarios in PGDP will be set up: Scenario 1: Power Import, Scenario 2: Renewable and Scenario 3: Hydro Middle and Scenario 4: Hydro Maximum. The setting conditions and concepts of these scenarios are as follows.

Table 7.5-1 Setting Conditions of each Scenario

Item	Scenario 1 Power Import	Scenario 2 Renewable	Scenario 3 Hydro Middle	Scenario 4 Hydro Maximum
Hydropower	a) Operation b) Construction	a) Operation b) Construction	a) Operation b) Construction c) Survey	a) Operation b) Construction c) Survey d) GoN
Renewable Ration against Power Demand (GWh)	10%	25%	10%	10%
Power Trade	Dry :Import Rainy :Export	Dry :Import Rainy :Export	Dry :Import Rainy :Import	Dry :Import Rainy :Import

Source: JICA Study Team

(Scenario 1 :Power Import)

- ✓ **Only committed hydropower projects** with Construction License are developed.
- ✓ Shortage of electricity is supplemented **by import** in dry season. Surplus is partially exported in rainy season.

(Scenario 2 :Renewable)

- ✓ **Only committed hydropower projects** with Construction License are developed.
- ✓ Shortage of electricity is supplemented **by import and solar** in dry season. Surplus is partially exported in rainy season.

(Scenario 3 :Hydro Middle)

- ✓ **Committed and promising hydropower projects** with Construction License and Survey License are developed.
- ✓ Surplus electricity is exported. In drought year, it may be necessary to import electricity in dry season.

(Scenario 4 :Hydro Maximum)

- ✓ **All hydropower projects** which are proposed in DOED List are developed.
- ✓ Surplus electricity is exported.

Scenarios 1 and 2 correspond to (i) small hydropower development, setting scenarios when the demand in dry season is supplied by hydropower and power import from India. Scenario 2 increases the introduction of renewable energy compared to Scenario 1 in order to verify whether renewable energy contributes to improvement of the balance between power supply and demand. Scenarios 3 and 4 correspond to (ii) large hydropower development, setting scenarios with power supply throughout the year by hydropower. The scenarios compare the power supply and demand balance, export volumes and investment costs between the developments of hydropower in intermediate or maximum levels.

These scenario settings examine the scale of hydropower development and generation mix in Nepal, selecting the Optimum Scenario for future development.

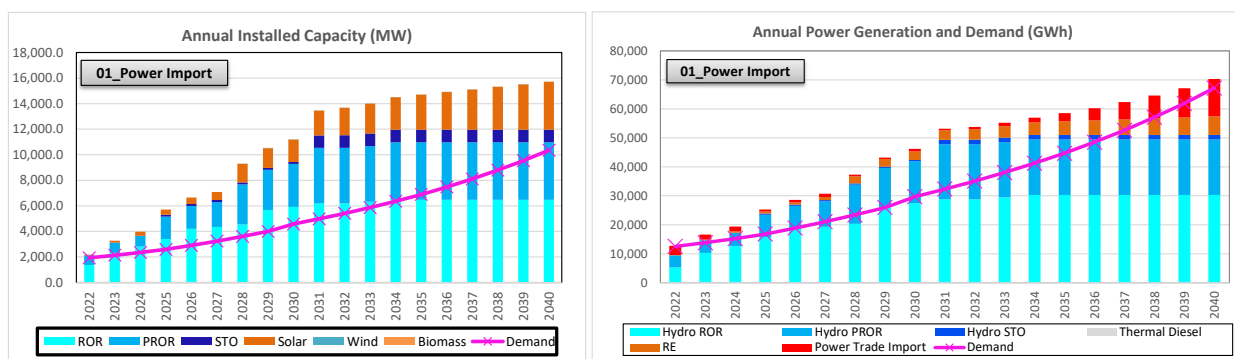
7.5.2 Results of the Analysis for Development Scenarios

This Section describes the results of analysis of Development Scenarios of Sscenario 1: Power Import, Scenario 2: Renewable and Scenario 3: Hydro Middle and Scenario 4: Hydro Maximum.

(1) Scenario 1: Power Import

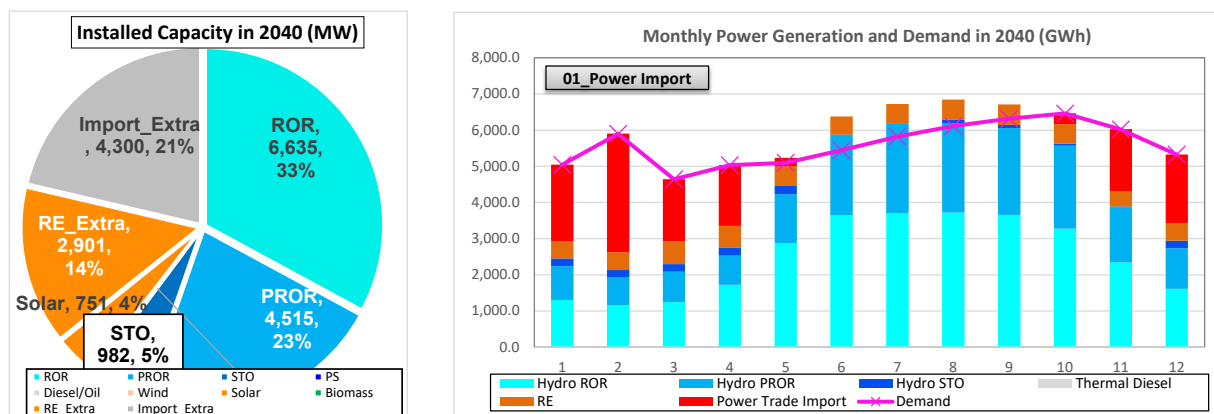
Figure 7.5-3 shows the installed capacity and annual power generation and Figure 7.5-4 shows the installed capacity monthly power generation in 2040. The total installed capacity in 2040 is 20,158MW, comprising ROR 6,635MW (33%), PROR 4,515MW (23%), STO 983MW (5%), solar 751.4MW (4%), additional renewable energy 2,901MW (14%), diesel 53MW, wind 6MW, biomass 15MW and power trade 4,300MW (21%).

Annual power generation in 2040 is 57,389GWh, imported electricity is 12,931GWh and exported electricity is 3,115GWh. The maximum monthly power generation is 6,846.1 GWh in August and the minimum is 2,622.7 GWh in February. The monthly difference in power generation is 38.3% in the smallest month compared to the largest month which is slightly above a third. In terms of power trade, the amount of power generation exceeds demand during rainy season and can be exported. However, imports are required during dry season. As a result, 19.2% of the annual power demand is needed to be imported in normal years and 22.0% in drought years.



Source: JICA Study Team

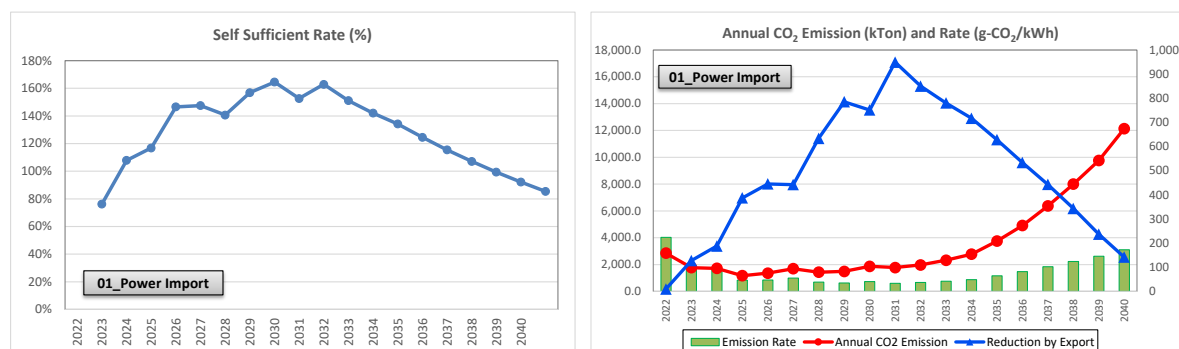
Figure 7.5-3 Scenario 1 Power Import: Installed Capacity and Annual Power Generation



Source: JICA Study Team

Figure 7.5-4 Scenario 1 Power Import: Installed Capacity and Annual Power Generation in 2040

Figure 7.5-5 shows self-sufficiency rate of power generation² and CO₂ emissions in Scenario 1. The self-sufficiency rate of power generation increases as hydropower development progresses, reaching 164.5% in 2029. It decreases as new hydropower operations decline, reaching 85.4% in 2040, below 100%.

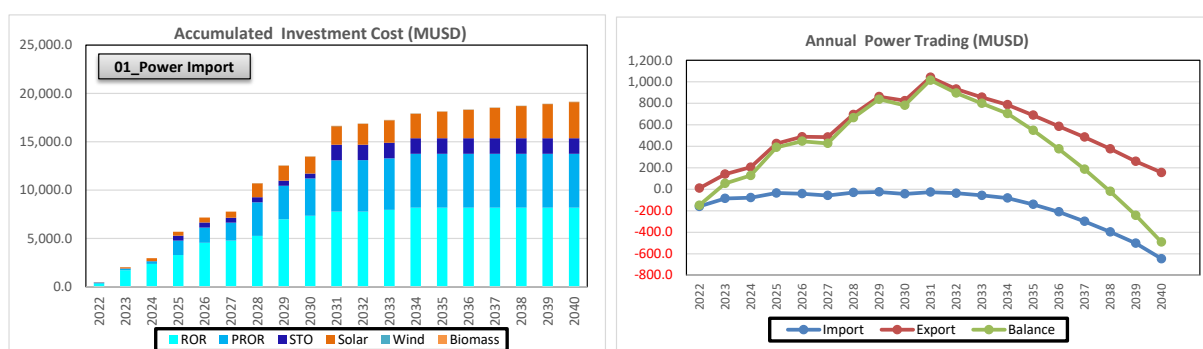


Source: JICA Study Team

Figure 7.5-5 Scenario 1 Power Import: Self-Sufficient Rate of Power Generation and CO₂ Emissions

In terms of CO₂ emissions, in the short to medium term until 2030, emissions amount and emission rate per kWh will fall as hydropower (24 g-CO₂/kWh) increases and electricity imports from India (820 g-CO₂/kWh) decrease. CO₂ emissions reductions from power exports will also increase. However, from 2031 onwards, power imports will increase as new hydropower commissioning decrease. As a result, average annual emissions rate will rise to 172.5 g-CO₂/kWh in 2040. However, it should be noted that this figure is very low compared to India and other countries.

Figure 7.5-6 shows the cumulative investment costs and balance of power trade. The total investment required by 2040 is 19,138MUSD, averaging 1,007MUSD per year. Regarding power trade, exports exceed imports from 2023 onwards, reaching 1,015 MUSD/year in 2031. However, imports increase thereafter due to the lack of new hydropower projects and it will be resulted in a deficit of -490.8 MUSD/year in 2040.



Source: JICA Study Team

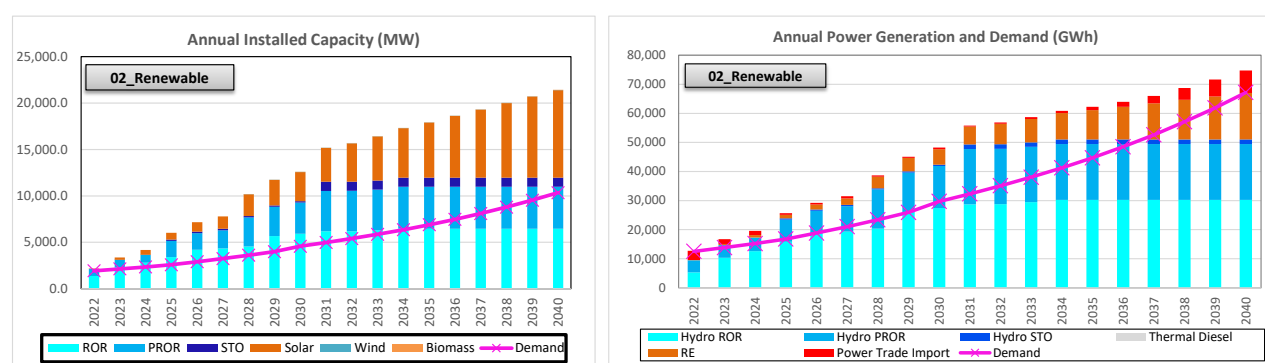
Figure 7.5-6 Scenario 1 Power Import: The Cumulative Investment Cost and Annual Balance of Power Trade

² The self-sufficiency rate of power generation indicates the amount of electricity supply from domestic energy originated from domestic resources and power trade accounts for the total of exports and imports.

(2) Scenario 2: Renewable

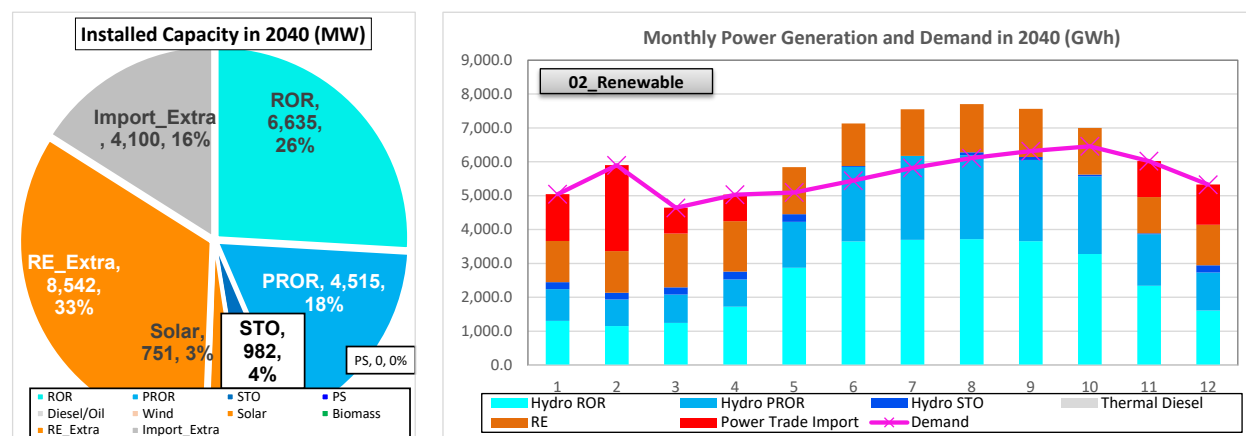
Figure 7.5-7 shows the installed capacity and annual power generation and Figure 7.5-8 shows the installed capacity monthly power generation in 2040. The total installed capacity in 2040 is 25,559MW, comprising ROR 6,635MW (26%), PROR 4,515MW (18%), STO 983MW (4%), solar 751.4MW (4%), additional renewable energy 8,542MW (33%), diesel 53MW, wind 6MW, biomass 15MW and power trade 4,100MW (16%).

Annual power generation in 2040 is 67,028GWh, imported electricity is 7,726GWh and exported electricity is 7,549GWh. The maximum monthly power generation is 7,699.7GWh in August and the minimum is 3,361.9GWh in February. The monthly difference in power generation is 43.7% in the smallest month compared to the largest month. In terms of power trade, the amount of power generation exceeds demand during rainy season and can be exported. However, imports are required during dry season. As a result, 11.2% of the annual power demand is needed to be imported in normal years and 13.3% in drought years.



Source: JICA Study Team

Figure 7.5-7 Scenario 2 Renewable: Installed Capacity and Annual Power Generation



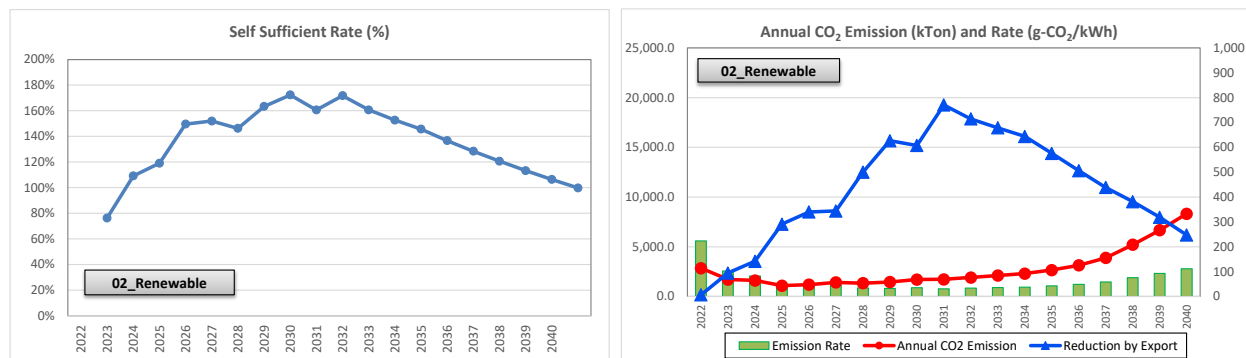
Source: JICA Study Team

Figure 7.5-8 Scenario 2 Renewable: Installed Capacity and Annual Power Generation in 2040

Figure 7.5-9 shows self-sufficiency rate of power generation and CO₂ emissions in Scenario 2. The self-sufficiency rate of power generation increases as hydropower development progresses, reaching 172.4% in 2029. It decreases as new hydropower operations decline, reaching 99.7% in 2040.

In terms of CO₂ emissions, in the short to medium term until 2030, emissions amount and emission

rate per kWh will fall as hydropower (24 g-CO₂/kWh) increases and electricity imports from India (820 g-CO₂/kWh) decrease. CO₂ emissions reductions from power exports will also increase. However, from 2031 onwards, power imports will increase as new hydropower commissioning decrease. As a result, average annual emissions rate will rise to 111.4 g-CO₂/kWh in 2040. However, it should be noted that this figure is very low compared to India and other countries.

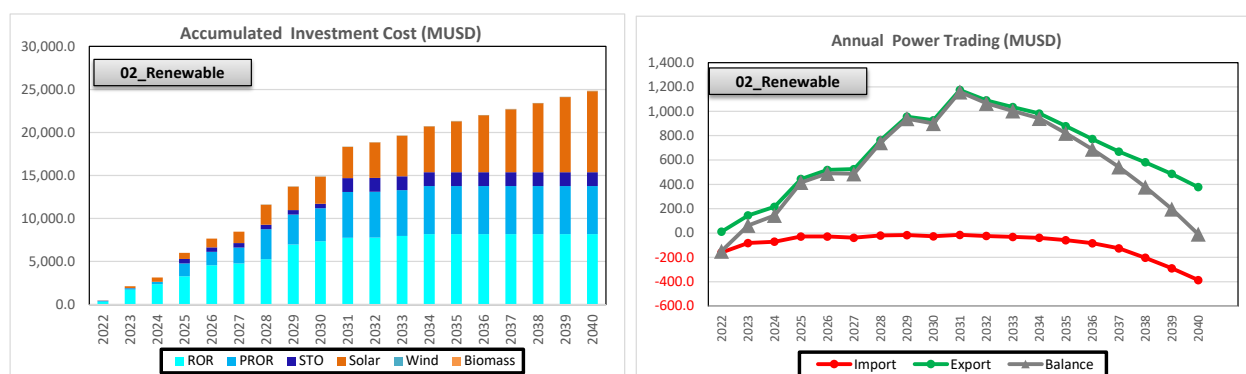


Source: JICA Study Team

Figure 7.5-9 Scenario 2 Renewable: Self-Sufficient Rate of Power Generation and CO₂ Emissions

Figure 7.5-10 shows the cumulative investment costs and balance of power trade. The total investment required by 2040 is 24,838MUSD, averaging 1,307MUSD per year. Regarding power trade, exports exceed imports from 2023 onwards, reaching 1,159MUSD/year in 2031. However, imports increase thereafter due to the lack of new hydropower projects and it will be resulted in a deficit of -9 MUSD/year in 2040.

Renewable energy contributes to a reduction of power imports in dry season when output of hydropower decrease. However, it remarkably exceeds power demand in rainy season. Therefore, exports of generated power should be considered in the introduction of renewable energies, especially during the rainy season.



Source: JICA Study Team

Figure 7.5-10 Scenario 2 Renewable: The Cumulative Investment Cost and Annual Balance of Power Trade

(3) Scenario 3: Hydro Middle

Figure 7.5-11 shows the installed capacity and annual power generation and Figure 7.5-12 shows the installed capacity monthly power generation in 2040. The total installed capacity in 2040 is 32,048MW, comprising ROR 12,193MW (38%), PROR 10,738MW (34%), STO 5,397MW (17%), solar 751.4MW (2%), additional renewable energy 2,901MW (9%), diesel 53MW, wind 6MW and

biomass 15MW.

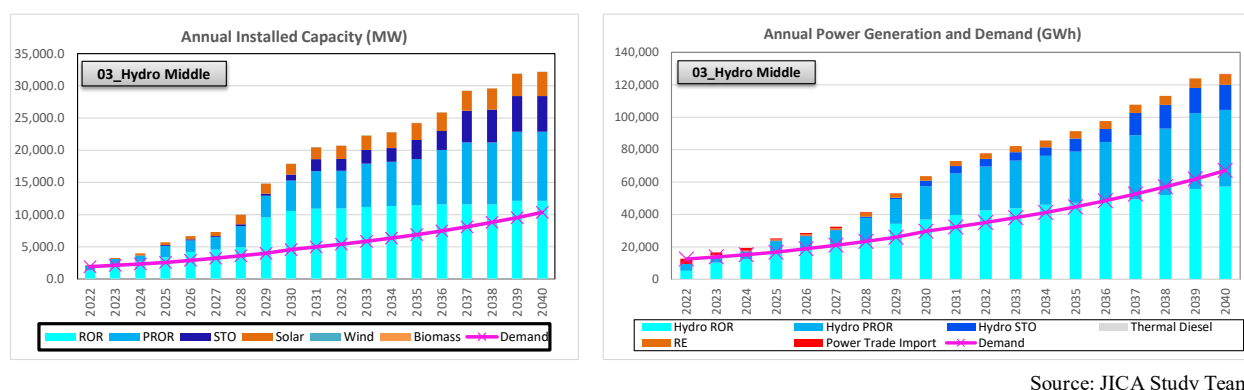


Figure 7.5-11 Scenario 3 Hydro Middle: Installed Capacity and Annual Power Generation

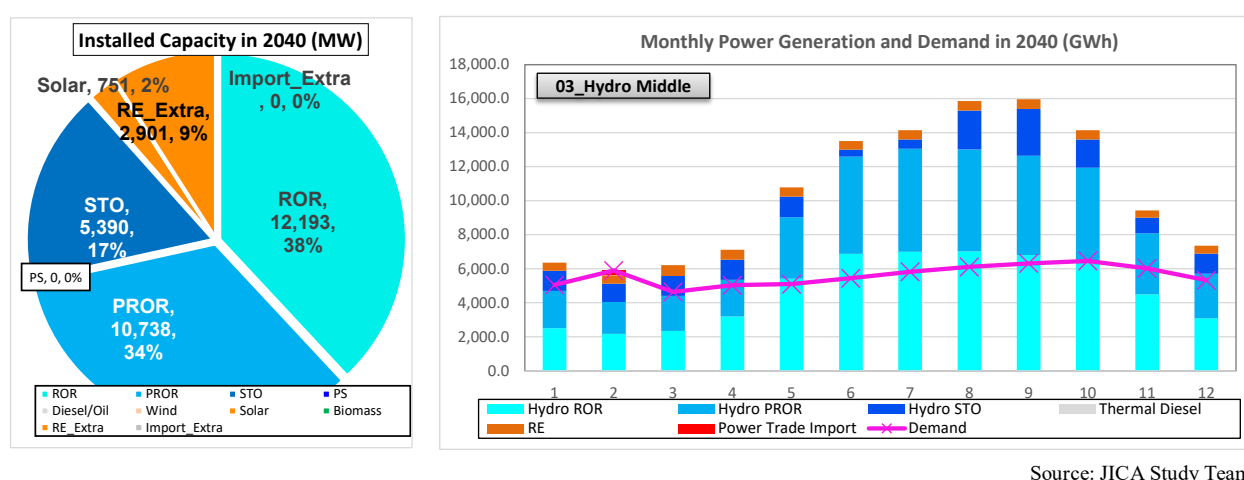
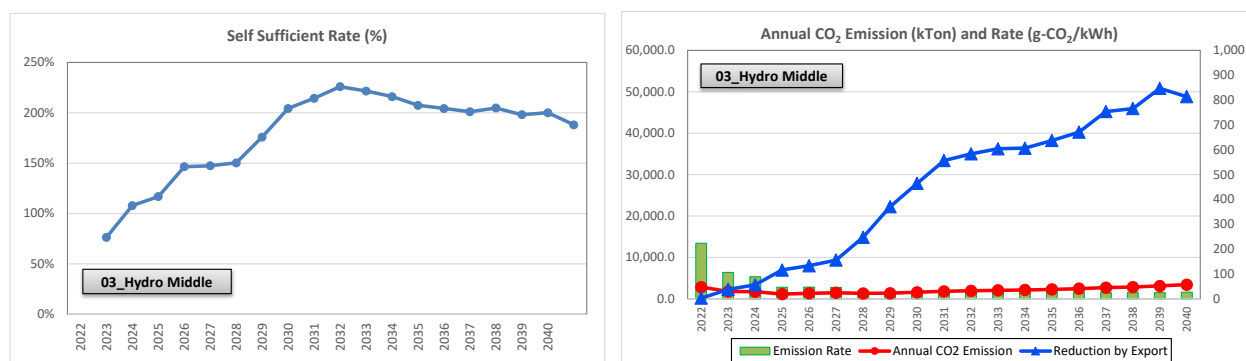


Figure 7.5-12 Scenario 3 Hydro Middle: Installed Capacity and Annual Power Generation in 2040

Annual power generation in 2040 is 126,467GWh, imported electricity is 2,88GWh and exported electricity is 59,548GWh. The maximum monthly power generation is 15,959.0GWh in August and the minimum is 5,614.2GWh in February. The monthly difference in power generation is 35.2% in the smallest month compared to the largest month, which is slightly above a third. In terms of power trade, the amount of power generation exceeds demand during most periods and it is possible to export through a year. However, imports are required only during February. As a result, 0.4% of the annual power demand is needed to be imported in normal years and 1.0% in drought years.

Figure 7.5-13 shows self-sufficiency rate of power generation and CO₂ emissions in Scenario 3. The self-sufficiency rate of power generation increases as hydropower development progresses, reaching 226.0% in 2031 when the development of c) Survey peaks. It decreases as new hydropower operations decline gradually, reaching 188.2% in 2040 which is still much more than domestic demand.

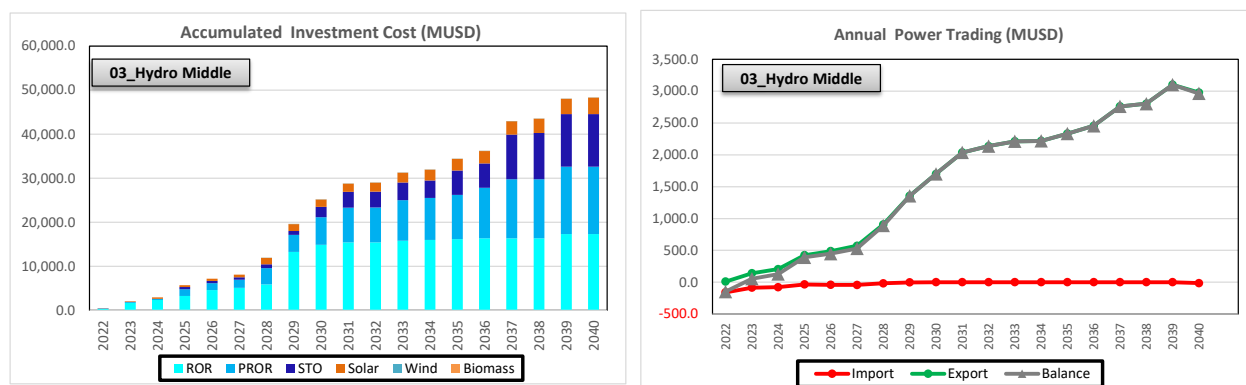
In terms of CO₂ emissions, in the short to medium term, emissions amount and emission rate per kWh will fall as hydropower (24 g-CO₂/kWh) increases and electricity imports from India (820 g-CO₂/kWh) decrease. After 2028, emission rates is ranged in the almost same value as hydropower. Reduction of CO₂ emissions by power export also increase, contributing to a reduction of 48,829 000 tonnes in 2040.



Source: JICA Study Team

Figure 7.5-13 Scenario 3 Hydro Middle: Self-Sufficient Rate of Power Generation and CO₂ Emissions

Figure 7.5-14 shows the cumulative investment costs and balance of power trade. The total investment required by 2040 is 48,345MUSD, averaging 2,544MUSD per year. Regarding power trade, exports exceed imports from 2023 onwards, reaching 2,036MUSD/year in 2031 and 2,963MUSD/year in 2040.



Source: JICA Study Team

Figure 7.5-14 Scenario 3 Hydro Middle: The Cumulative Investment Cost and Annual Balance of Power Trade

(4) Scenario 4: Hydro Maximum

Figure 7.5-15 shows the installed capacity and annual power generation and Figure 7.5-16 shows the installed capacity monthly power generation in 2040. The total installed capacity in 2040 is 43,887MW, comprising ROR 14,869MW (34%), PROR 12,831MW (29%), STO 12,370MW (28%), solar 841MW (2%), additional renewable energy 2,901MW (7%), diesel 53MW, wind 6MW, and biomass 15MW.

Annual power generation in 2040 is 154,640GWh, imported electricity is 0GWh and exported electricity is 87,435GWh. The maximum monthly power generation is 20,440.9GWh in September and the minimum is 7,118.3GWh in February. The monthly difference in power generation is 34.8% in the smallest month compared to the largest month, which is slightly above a third. Generated electricity exceeds power demand thorough the year and it is possible to export electricity even in the drought year.

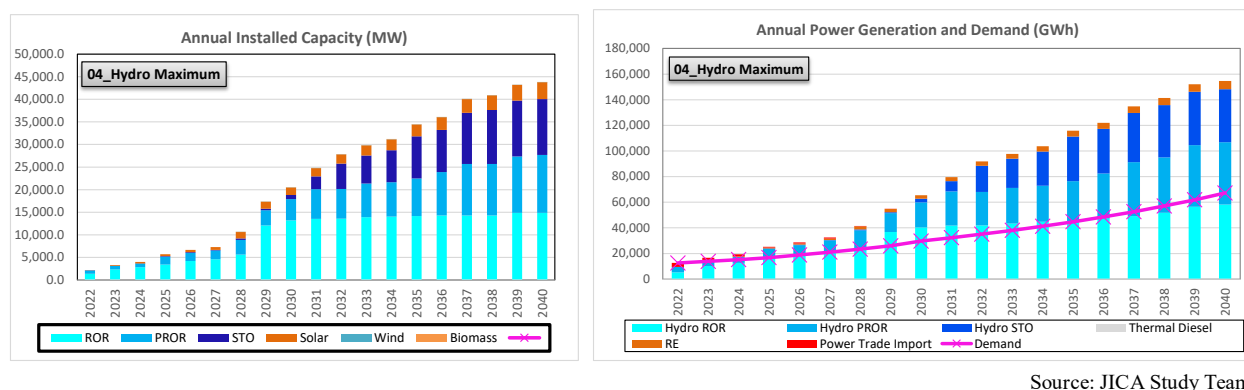


Figure 7.5-15 Scenario 4 Hydro Maximum: Installed Capacity and Annual Power Generation

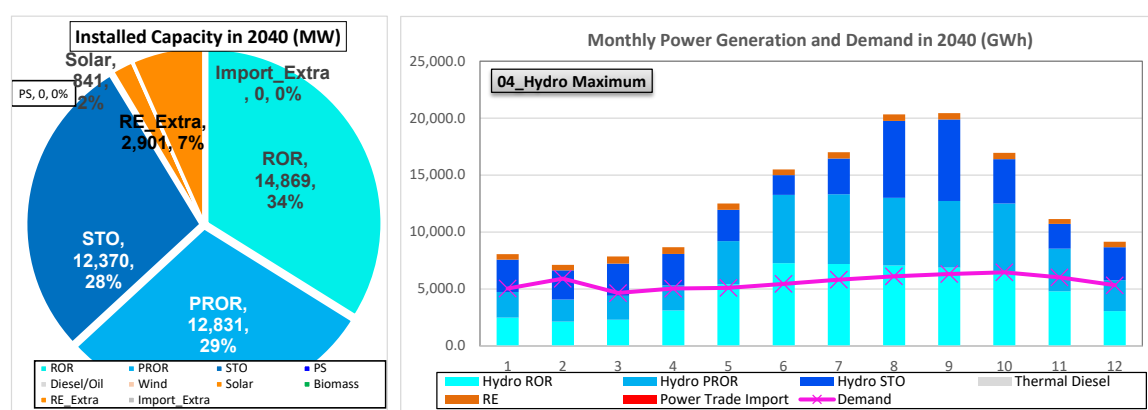
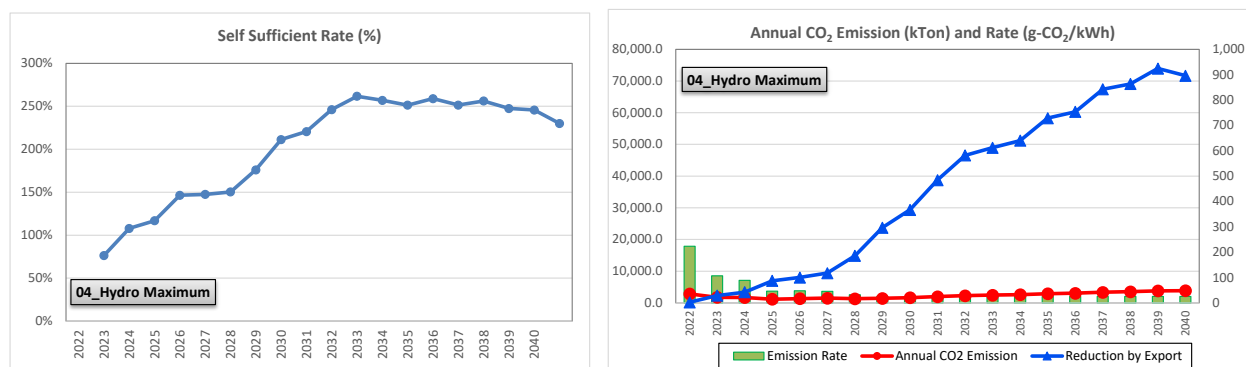


Figure 7.5-16 Scenario 4 Hydro Maximum: Installed Capacity and Annual Power Generation in 2040

Figure 7.5-17 shows self-sufficiency rate of power generation and CO₂ emissions in Scenario 4. The self-sufficiency rate of power generation increases as hydropower development progresses, reaching 261.7% in 2031 when the development of c) Survey and d) GoN peaks. It decreases as new hydropower operations decline, reaching 230.1% in 2040 which is still much more than domestic demand.

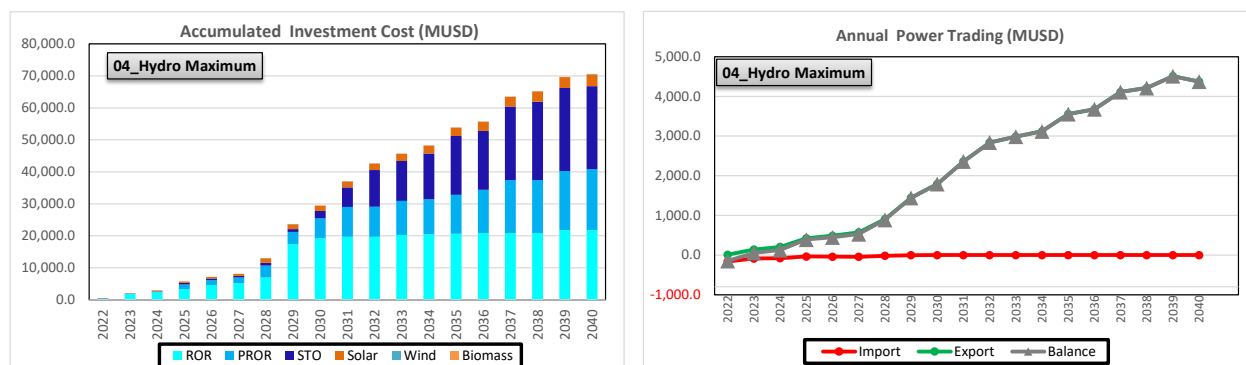
In terms of CO₂ emissions, in the short to medium term, emissions amount and emission rate per kWh will fall as hydropower (24 g-CO₂/kWh) increases and electricity imports from India (820 g-CO₂/kWh) decrease. After 2028, emission rates is ranged in the almost same value as hydropower. Reduction of CO₂ emissions by power export also increase, contributing to a reduction of 71,696 000 tonnes in 2040.



Source: JICA Study Team

Figure 7.5-17 Scenario 4 Hydro Maximum: Self-Sufficient Rate of Power Generation and CO₂ Emissions

Figure 7.5-18 shows the cumulative investment costs and balance of power trade. The total investment required by 2040 is 70,531MUSD, averaging 3,712MUSD per year. Regarding power trade, exports exceed imports from 2023 onwards, reaching 2,362MUSD/year in 2031 and 4,372MUSD/year in 2040.



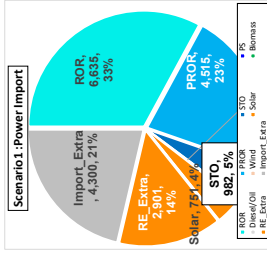
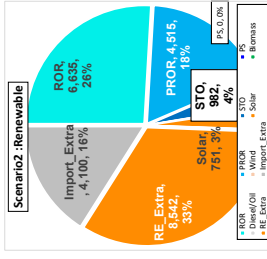
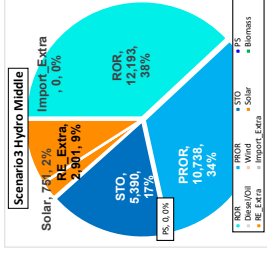
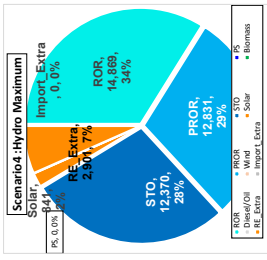
Source: JICA Study Team

Figure 7.5-18 Scenario 4 Hydro Maximum: The Cumulative Investment Cost and Annual Balance of Power Trade

7.5.3 Comparison of Development Scenarios

Results of the comparison of Development Scenarios are shown below. Firstly, results of comparison according to 3E+ Policy is shown in Table 7.5-2 and detailed analysis results are shown respectively.

Table 7.5-2 Summary of the Evaluation of Development Scenarios

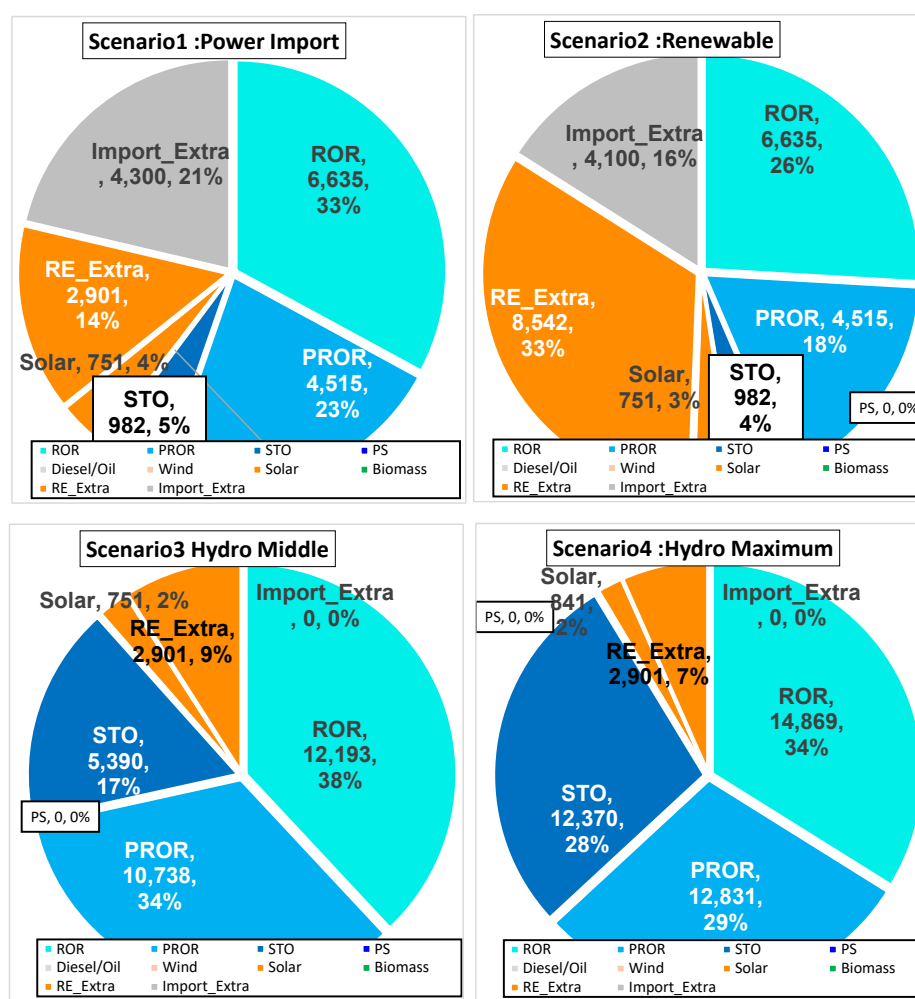
Evaluation Items		Scenario 1 Power Import	Scenario 2 Renewable	Scenario 3 Hydro Middle	Scenario 4 Hydro Maximum
(1) Energy Security	Generation Mix				
	Self Sufficiency Rate of Power Generation (%)	20,158MW	25,599MW	32,048MW	43,887MW
	International Issues	85.4%	99.7%	188.2%	230.1%
	Grid Stability	None	Impacts by VRE	None	None
	Cumulated Investment Cost	19,138 MUSD (1,015MUSD/year)	24,838 MUSD (1,307MUSD/year)	48,345 MUSD (2,544MUSD/year)	70,531 MUSD (3,712MUSD/year)
(2) Economy	Cumulated Balance of Power Trade	7,360MUSD	10,820MUSD	30,366MUSD	41,270MUSD
(3) Environmental and Social considerations	Vulnerability for Fuel Cost	Fuel Inflation in India		None	None
	Natural and Social Impacts	Relatively small		Intermediate	Large
	Cumulated CO ₂ Emissions (million ton)	69.1 million ton	52.4 million ton	39.5 million ton	44.5 million ton
	CO ₂ Emissions Rate (g-CO ₂ /kWh)	172.5 g-CO ₂ /kWh	111.4 g-CO ₂ /kWh	27.0 g-CO ₂ /kWh	25.0 g-CO ₂ /kWh
	Cumulated Reduction of CO ₂ Emissions by Power Export (million ton)	169.1 million ton	205.7 million ton	505.7 million ton	684.3 million ton
Policy	Target of 15000MW in 2030	Not achieved	Achieved	Achieved	Achieved
	Introduction of ARE				

Source: JICA Study Team

(1) Installed Capacity

A comparison of the installed capacity of each Scenario in 2040 is shown in Figure 7.5-19 and Table 7.5-3. Installed capacity of Development Scenarios are Scenario 1: 20,104MW, Scenario 2: 25,546MW, Scenario 3: 31,994MW and Scenario 4:43,833MW. With regard to the ratios to the capacity of Scenario 1 as 100%, these of Scenario 2, Scenario 3 and Scenario 4 127%, 159% and 200% respectively.

Regarding the generation mix, hydropower projects to be developed in Scenarios 1 and 2 is mostly ROR and PROR. STO accounts for a low proportion in them. The power supply in dry season has to be regulated by power import. In Scenario 2, renewable energy accounts for as much as 36% of power generation, particularly during dry season, when solar PV occupies most of the daytime power output. Sufficient regulating power is required for the introduction of solar power of VRE which has large output fluctuations. However supply capacity in the domestic sources is insufficient and needs to be regulated from India connected to the power system of Nepal during this time.



Source: JICA Study Team

Figure 7.5-19 Comparison of Installed Capacity in 2040 (MW)

Table 7.5-3 Summary of Installed Capacity of each Scenarios (MW)

Scenario 1 Power Import							Scenario 2 Renewable						
Year	Hydro			RE	Power Trade	Total	Year	Hydro			RE	Power Trade	Total
	ROR	PROR	STO					ROR	PROR	STO			
2025	3,410.5	1,740.0	154.0	412.2	0	5,717	2025	3,410.5	1,740.0	154.0	712.2	0	6,017
2030	6,092.7	3,358.1	154.0	1,672.5	1,200	12,477	2030	6,092.7	3,358.1	154.0	3,072.5	1,100	13,777
2035	6,634.6	4,515.1	982.0	2,672.5	2,700	17,504	2035	6,634.6	4,515.1	982.0	5,872.5	2,500	20,504
2040	6,634.6	4,515.1	982.0	3,672.5	4,300	20,104	2040	6,634.6	4,515.1	982.0	9,314.0	4,100	25,546

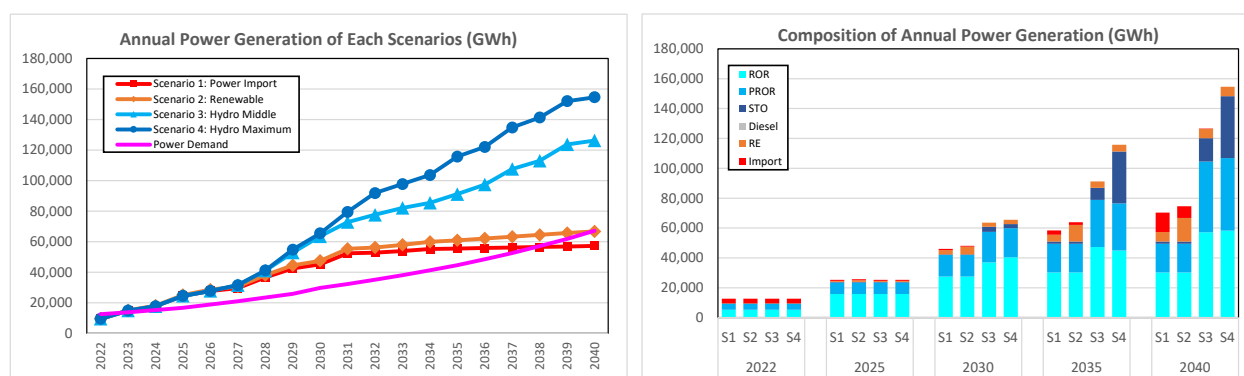
Scenario 3 Hydro Middle							Scenario 4 Hydro Maximum						
Year	Hydro			RE	Power Trade	Total	Year	Hydro			RE	Power Trade	Total
	ROR	PROR	STO					ROR	PROR	STO			
2025	3,410.5	1,740.0	154.0	412.2	0	5,717	2025	3,410.5	1,740.0	154.0	412.2	0	5,717
2030	10,612.0	4,726.1	790.7	1,572.5	0	17,701	2030	13,176.4	4,726.1	925.7	1,662.5	0	20,491
2035	11,482.8	7,191.5	2,813.3	2,572.5	0	24,060	2035	14,159.2	8,312.5	9,322.9	2,662.5	0	34,457
2040	12,192.8	10,737.9	5,390.3	3,672.5	0	31,994	2040	14,869.2	12,831.0	12,370.0	3,762.5	0	43,833

Source: JICA Study Team

(2) Annual Power Generation

Figure 7.5-20 shows a comparison of annual power generation and composition by source and Figure 7.5-21 shows the self-sufficient rate of power generation. The gap between Scenario 1&2 and Scenario 3&4 is widening after 2027 when the commissioning of hydropower projects on c) Survey and d) GoN begin. The annual power generation of Scenario 1 is 57,389GWh, Scenario 2 is 67,028GWh, Scenario 3 is 126,466GWh and Scenario 4 is 154,640GWh in 2040. With regard to the ratio to Scenario 1 as 100%, Scenario 2, Scenario 3 and Scenario 4 would generate 117%, 220% and 269% of the electricity, respectively.

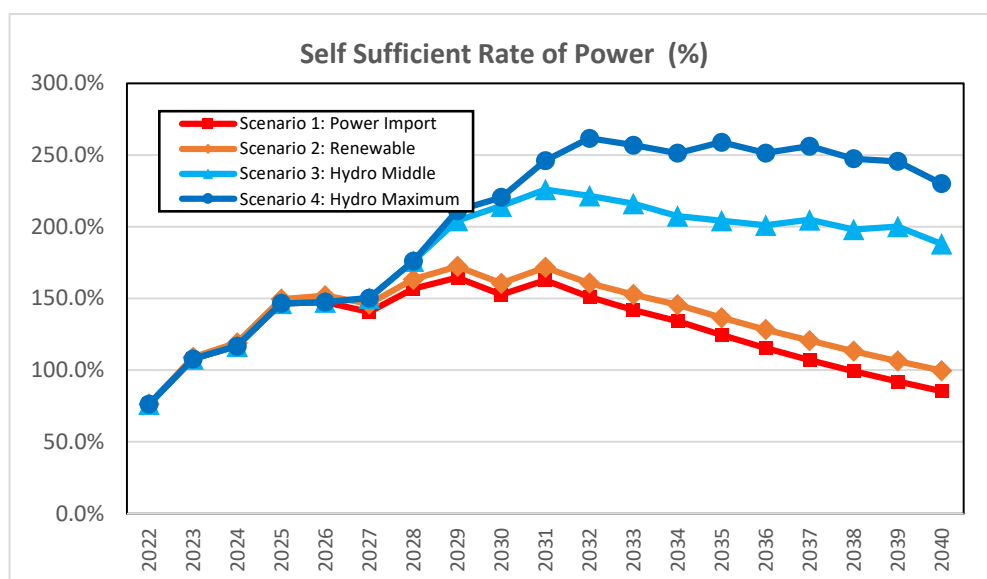
With regard to the composition of power generation by scheme, the share of PROR increases in each scenario after 2025 and the share of STO increases after 2035 particularly in Scenario 4. In Scenarios 1 and 2, power imports are required mainly during dry season after 2035. It should be noted that imports will also be required even in Scenario 3 in February, the driest month, although the share of it is very small.



Source: JICA Study Team

Figure 7.5-20 Comparison of Annual Power Generation (GWh)

As with the self-sufficient rate of power generation, the difference between Scenarios 1&2 and Scenarios 3&4 widens after 2027 as same as the annual power generation. As hydropower development under each Scenario generally peaks in the early 2030s, the self-sufficient rate has been a gradual decline since then. In 2040, Scenario 2 will have a self-sufficient rate of approximately 100%, while Scenario 1 will have 85.4% which means that Nepal alone will not be able to respond to domestic power demand.



Source: JICA Study Team

Figure 7.5-21 Comparison of Self-Sufficient Rate of Power Generation

The results of the composition of annual power generation by scheme and the self-sufficient rate of power generation indicate difficulties in balancing between the demand and supply in Nepal which generation mix is heavily depended on hydropower. It is necessary to recognize that electricity is imported during dry season in Scenarios 1 and 2 which significantly exceed the peak power demand in terms of installed capacity. Furthermore, Scenario 3 may require a small amount of electricity imports during dry season in February.

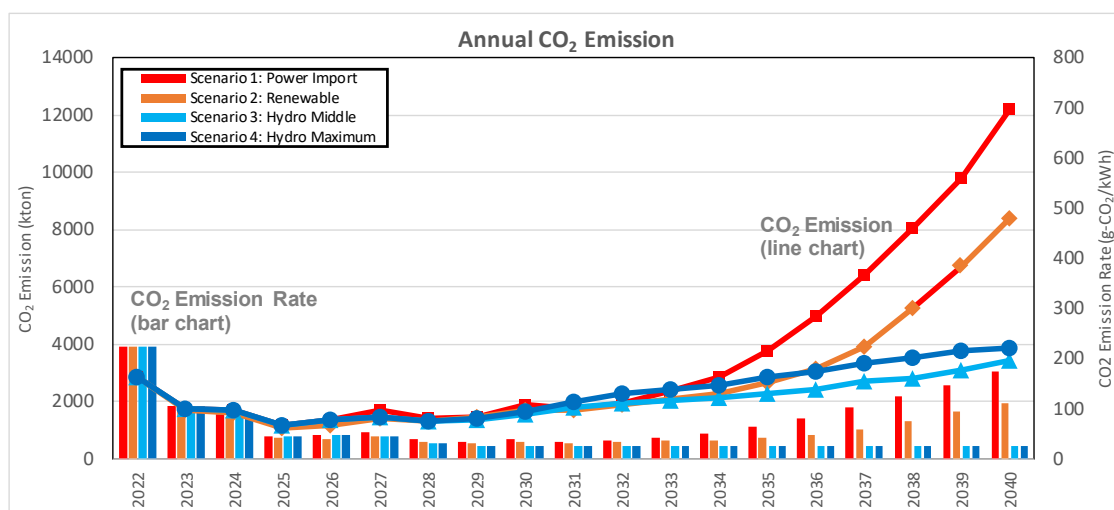
These results indicate following remarkable findings in the medium to long term;

- It will be necessary to develop almost double the domestic demand in terms of annual power generation in order to secure self-sufficiency in dry season including drought years
- Huge amount of power export is required in rainy season in all Scenarios

(3) CO₂ Emission

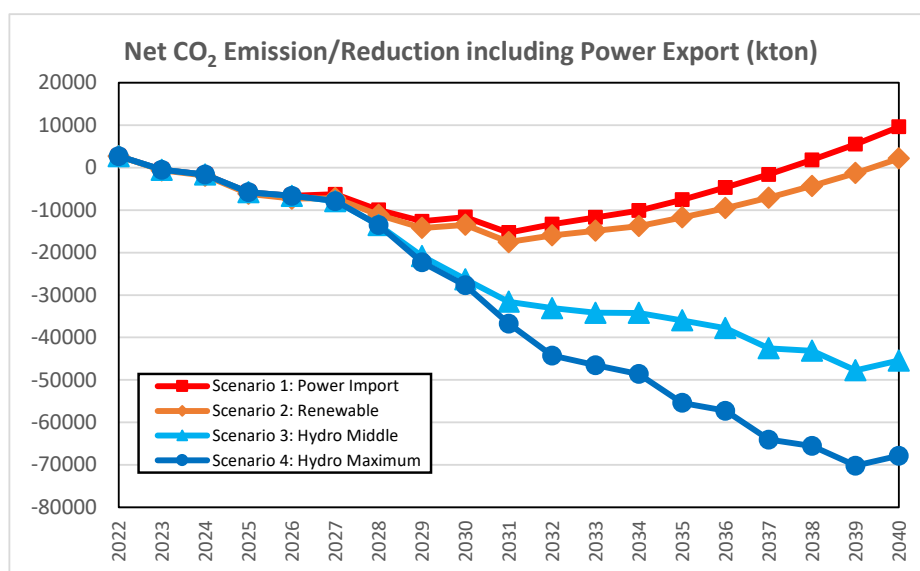
The annual CO₂ emissions (k ton) and emissions rate (g-CO₂/kWh) are shown in Figure 7.5-22 and reductions of CO₂ emission by power export to neighbouring countries (k ton) are shown in Figure 7.5-23. As power generation is mainly composed of hydropower and renewable energy in Nepal, CO₂ emissions are still lower than in other countries even in 2022. Emissions rate will be gradual declines as the introduction of hydropower increases in all Scenarios.

CO₂ emissions will increase in Scenarios 1 and 2, as hydropower development decreases and electricity imports increase. Emissions will remain at extremely low levels in Scenarios 3 and 4. However, it should be noted that emissions are low compared to neighbouring countries even in Scenarios 1 and 2.



Source: JICA Study Team

Figure 7.5-22 Comparison of CO₂ Emissions and Rate



Source: JICA Study Team

Figure 7.5-23 Comparison of CO₂ Emissions including Power Export

In Scenarios 3 and 4, reductions of CO₂ emissions by electricity exports will increase after 2027 when hydropower development is accelerated and it really contributes to reduction of CO₂ emission in India and Bangla which are mainly depended on thermal power in power supply. At present, incentives from these CO₂ reductions have not been institutionalised. However, if a carbon tax or other incentive system is developed in the future, benefits such as carbon credits may be available in addition to the power purchase which contribute to the increase of income for Nepal. In case of the carbon tax with 30USD/ton, the reduction in Scenario 4 in 2040 is 70,531kton equivalent to 2,115.9MUSD in price.

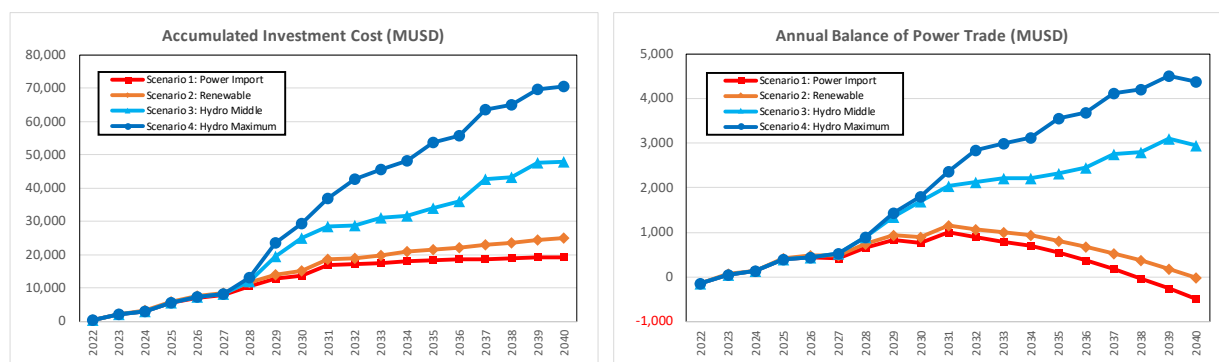
(4) Cost for Power Generation Development

The cumulative investment cost and balance of power trade (MUSD) for the power generation development planning are shown in Figure 7.5-24. The cumulative cost and annual average amounts until 2040 are 19,138MUSD (1,015MUSD/year) for Scenario 1, 24,838MUSD

(1,307MUSD/year) for Scenario 2, Scenario 3 is 48,345MUSD (2,544MUSD/year) and Scenario 4 is 70,531MUSD (3,712MUSD/year). In terms of ratios to Scenario 1 as 100%, Scenario 2, Scenario 3 and Scenario 4 would cost 130%, 253% and 369% respectively.

As same as power generation and CO₂ emissions, the gap is wider after 2027 when new hydropower projects are start to commission in c) Survey and d) GoN.

Although the balance of power trade also shows similar trend, power import increases in Scenario 1 and 2. Finally, expenditures by imports will exceed income by export in 2038 for Scenario 1 and in 2040 for Scenario 2 again. Annual balance of the power trade in 2040 is -492MUSD in Scenario 1, -9MUSD in Scenario 2, 2,963MUSD in Scenario3 and 4,372MUSD in Scenario 4.



Source: JICA Study Team

Figure 7.5-24 Comparison of the Cumulative Investment Cost and Balance of Power Trade

Compared to Scenarios 1 and 2, the capital investment cost in Scenarios 3 and 4 is extremely large. It is necessary to consider the viability of project finance in Nepal. On the other hand, if power exports are realised, income from power trade will also be significant.

7.5.4 Selection of Optimum Scenario

The future direction of the power generation development planning in Nepal is discussed by comparing each scenario based on 3E (Energy Security, Economy and Environment) + Policy presented in Section 7.5.3. The results of the comparative study of each Scenario based on 3E + Policy are as follows.

In terms of energy security, the self-sufficient rate of power generation is below 100% in Scenarios 1 and 2 in 2040. It is necessary to rely on power imports from India. For Scenarios 3 and 4, the self-sufficiency is almost secured. In the event of international problems with neighbouring countries such as India, domestic power supply may be disrupted in Scenarios 1 and 2. It may not be possible to export electricity in Scenarios 3 and 4, making it difficult to recover the investment cost in each power plant. All Scenarios carry the risk of international problems with neighbouring countries but meanings are different. For scenarios 3 and 4, domestic power supply is possibly maintained and energy self-sufficiency can be improved through an effort to promote electrification. In Scenario 2, the grid stability during periods of low demand which happen in dry season is supposed to be fragile due to the massive introduction of renewable energy.

The development capacity of hydropower has a trade-off relation with financial burden and economic growth through electricity exports. If large-scale development is pursued as shown in Scenarios 3 and 4, power exports will increase. If not realised, exports will decrease as shown in Scenarios 1 and 2. However, in both scenarios, the accumulated balance of power trade until 2040 is in surplus and the promotion of power exports is important regardless of which Scenario is

chosen. In terms of vulnerability to fuel inflation, Scenarios 1 and 2 which require electricity imports, have these risks. In the event of global fuel inflation such as 2022, the risk of financial burden caused by the rapid inflation of power purchase cost from India needs to be considered.

With regard to environmental and social considerations, the impact on the natural and social environment will increase if hydropower development goes ahead. In particular, large STO projects which are mainly included in d) GoN require large reservoirs and have a significant environmental impact.

In terms of climate change actions, further hydropower development would make a significant contribution to reduction of regional CO₂ emissions by power trade with neighbouring countries in where thermal power plants play main roles in power generation. In addition, incentives from these reductions can be expected in the future.

In terms of consistency with Nepal's electricity policy, the development of 15,000 MW in 2030 is not achievable in Scenarios 1 and 2 with the development of only b) Construction. However, Scenarios 3 and 4 can accomplish it with the development of c) Survey and d) GoN. In addition, it is possible to achieve the introduction target of 10% in domestic power demand by alternative energy sources including renewable energy.

Summary of evaluation each Scenario in accordance with 3E + Policy are as follows;

◆ Scenario 1: Power Import

Power Import is assumed to be a feasible Scenario with low capital investment and environmental impact. However, it has low energy self-sufficiency in 2040, supply risks of power import interruptions and cost escalation risks such as fuel inflation. It is also difficult to achieve the goals set out in the policy of power sector.

◆ Scenario 2 Renewable:

As same as Scenario 1, the capital investment cost and environmental impact is relatively lower and the import dependency is also low owed to the generation of renewable energy. On the other hand, it is necessary to include the regulation capacity from neighboring countries against the intermittency of VRE mainly derived from solar in order to secure the grid stability.

◆ Scenario 3: Hydro Middle

Hydro Middle requires power imports only during February but it is possible to supply power to domestic demand and neighboring countries even in drought years. Although the capital investment required is high, it is assumed to be feasible in case of power trade promoted. The environmental impact is also significant and measures to reduce the impact based on the results of the SEA are important.

◆ Scenario 4: Hydro Maximum

Hydro Maximum can secure to supply power to domestic demand and neighboring countries even in the drought year. Compared to Scenario 3, the capital investment and environmental impact would also be very high and feasibility needs to be fully considered.

Based on the results of the comparative study of Development Scenarios described above taking into account the evaluation of 3E and consistency with the Policy, Scenario 3: Hydro Middle is selected as the base case for Optimum Scenario which development scale can be optimized.

7.6 FORMULATION OF OPTIMUM SCENARIO

This section updates Scenario 3: Hydropower Middle which is selected as the Optimum Scenario and formulates the power generation development plan in IPSDP. The scenario analysis reflects the following updates of two input conditions:

- Power Demand Forecast ver.2
- Project List ver.2 (Hydropower database as of March 2023 in Section 6.2 and Hydropower Screening in Section 6.5)
- CO₂ Emission Factor for Power Trade (820g-CO₂/kWh←716 g CO₂/kWh)

7.6.1 Input Projects for the Optimum Scenario

The projects to be introduced in the Optimum Scenario are set as follows:

(1) Hydropower Projects

The hydropower projects to be introduced in the Optimum Scenario are 643 sites with a rating of 45 points or more and a total capacity of 32,189.2 MW based on the hydropower screening results examined in Section 6.5 as shown in Table 7.6-1.

Table 7.6-1 Hydropower Projects to be introduced in the Optimum Scenario

Category	Status	DOED Status	ROR		PROR		STO		Subtotal	
			Site	Installed Capacity (MW)	Site	Installed Capacity (MW)	Site	Installed Capacity (MW)	Site	Installed Capacity (MW)
a) Existing	PS	(1)Existing Power Plants	135	1,394.9	4	720.0	1	14.0	140	2,128.9
b) Committed	CL	(2)Construction License	233	5,314.5	21	2,887.8	2	153.0	256	8,355.3
	ACL	(3)Application for Construction License	71	1,848.6	18	3,654.8	6	1,584.6	95	7,088.0
c) Screened	SL	(4)Survey License	78	2,065.6	20	2,881.6	6	2,887.0	104	7,834.2
	ASL	(5)Application for Survey License	34	671.8	0	0.0	1	271.4	35	943.2
	GON	(6)GON Reserved Projects	2	534.0	2	785.8	9	4,519.9	13	5,839.7
Total		-	553	11,829.4	65	10,930.0	25	9,429.9	643	32,189.2

Source: JICA Study Team

As described in Section 6.5, this screening is a consistent evaluation using GIS (Geographic Information System) on the same criteria and is superior for assessing many sites in similar manners. However, the accuracy is rough, and it should be noted that decisions of individual projects must be carried out based on F/S (Feasibility Study) and ESIA (Environmental and Social Impact Assessment) stages.

From this perspective, this examination is based on a list of individual sites for analysis and shows the scale of power generation capacity for the target year. However, it should be noted that the results don't intend to indicate the project-wise feasibility and to recommend the implementation of individual sites. Promising hydropower projects are discussed on Section 7.7.

(2) Renewable Energy

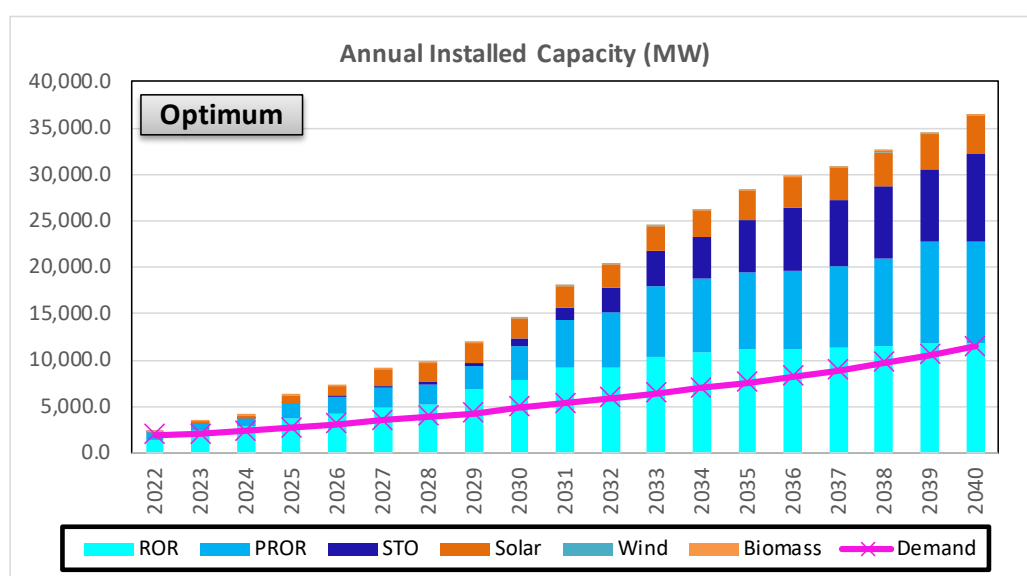
Regarding the introduction of renewable energy in the Optimum Scenario, it was pointed out in evaluation of "Scenario 2: Renewable" with 25% introduction of renewable energy against domestic demand (GWh) that power supply in Nepal is occupied with a significant portion of clean energy by hydropower and the impact on power system stability is more concerning than CO₂ reduction.

Therefore, 10% against domestic power demand after 2030 is applied as an introduction target for renewable energy which corresponds to phase 2 of IEA's VRE introduction. In this case, the renewable energy capacity in 2040 will be 4,135 MW.

7.6.2 Analysis Results of the Optimum Scenario

(1) Installed Capacity (MW)

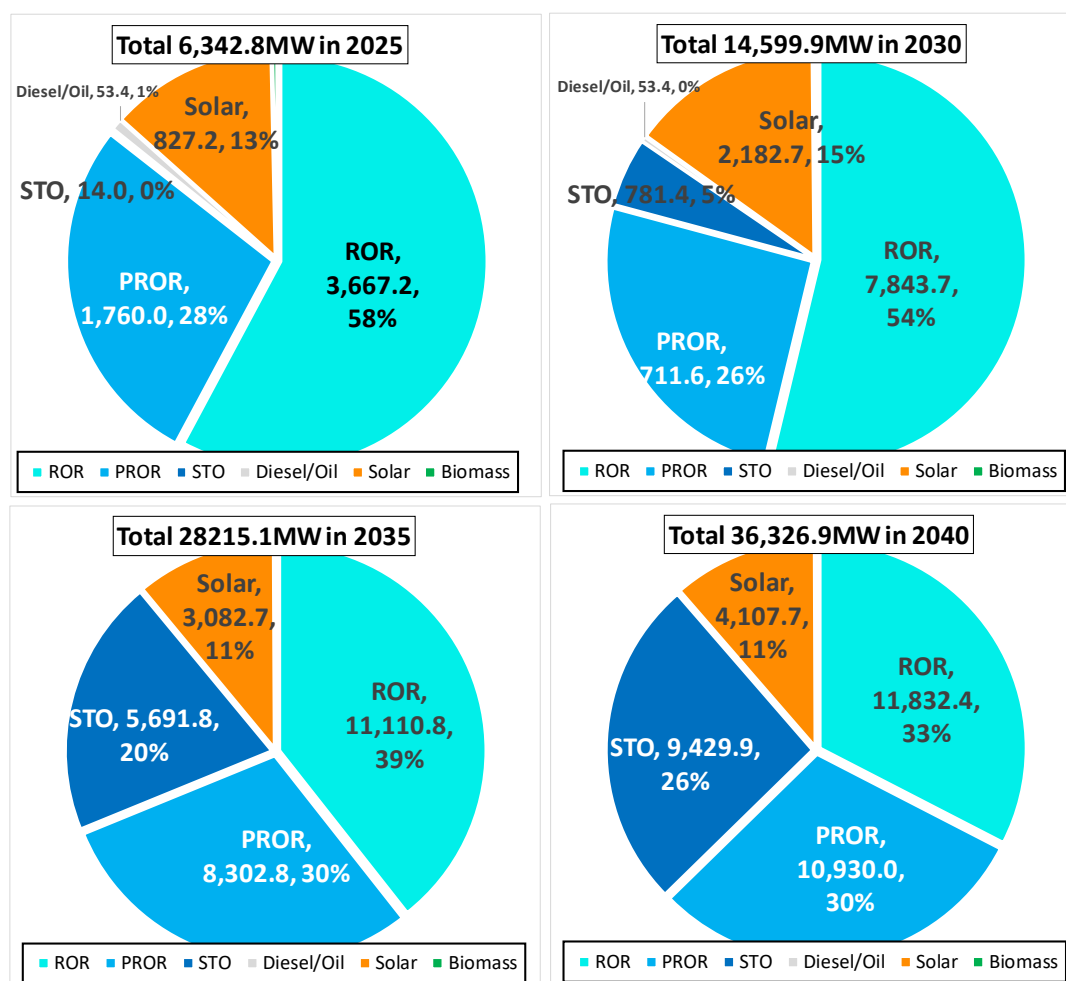
The transition of installed capacity and demand in the Optimum Scenario and the generation mix in 2025, 2030, 2035, and 2040 are shown in Figure 7.6-1 and Figure 7.6-2 respectively.



Year	Hydro			RE			Total
	ROR	PROR	STO	Solar	Wind	Biomass	
2022	1,486.1	747.6	14.0	45.0	0.0	3.0	2,296
2023	2,430.8	787.6	14.0	145.0	0.0	3.0	3,380
2024	2,917.8	840.0	14.0	322.2	0.0	6.0	4,100
2025	3,667.2	1,760.0	14.0	827.2	0.0	21.0	6,289
2026	4,274.9	1,851.2	154.0	927.2	0.0	21.0	7,228
2027	4,884.7	2,145.1	154.0	1,782.2	0.0	21.0	8,987
2028	5,247.1	2,195.1	310.0	1,982.7	6.0	21.0	9,762
2029	6,865.1	2,560.1	310.0	2,082.7	6.0	21.0	11,845
2030	7,843.7	3,711.6	781.4	2,182.7	6.0	21.0	14,546
2031	9,188.2	5,091.4	1,426.3	2,282.7	6.0	21.0	18,016
2032	9,245.1	5,841.4	2,671.3	2,482.7	6.0	21.0	20,267
2033	10,427.9	7,552.4	3,730.3	2,682.7	6.0	21.0	24,420
2034	10,822.8	8,040.4	4,365.3	2,882.7	6.0	21.0	26,138
2035	11,110.8	8,302.8	5,691.8	3,082.7	6.0	21.0	28,215
2036	11,110.8	8,454.0	6,891.8	3,282.7	6.0	21.0	29,766
2037	11,354.8	8,784.3	7,109.8	3,492.7	6.0	21.0	30,769
2038	11,511.6	9,466.3	7,759.9	3,697.7	6.0	21.0	32,463
2039	11,815.6	10,930.0	7,759.9	3,907.7	6.0	21.0	34,440
2040	11,832.4	10,930.0	9,429.9	4,107.7	6.0	21.0	36,327

Source: JICA Study Team

Figure 7.6-1 Installed Capacity (MW) of the Optimum Scenario



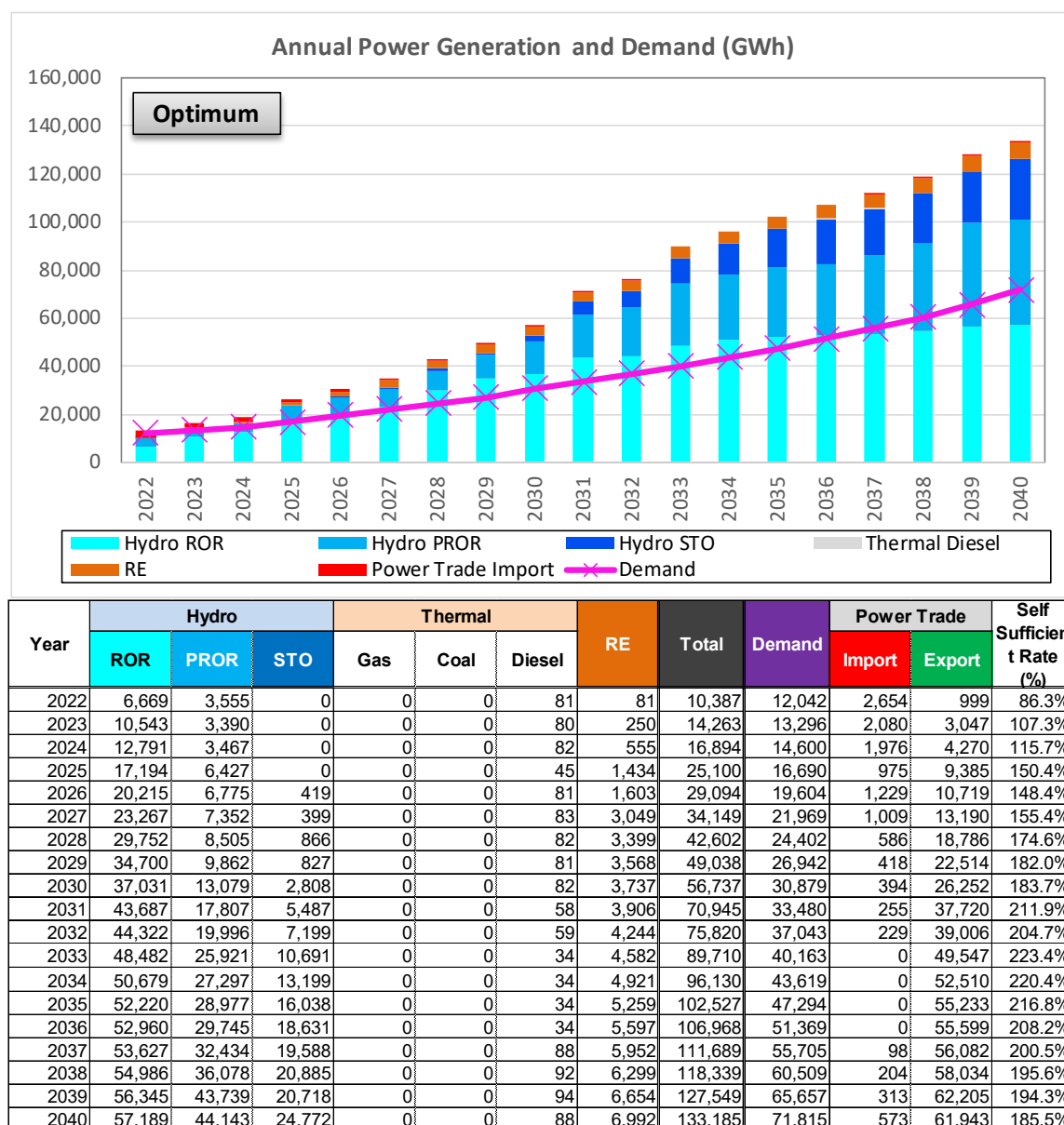
Source: JICA Study Team

Figure 7.6-2 Installed Capacity in 2025, 2030, 2035 and 2040

The total capacity in 2040 will be 36,327 MW, with the breakdown being ROR 11,832.4 MW (33%), PROR 10,930.0 MW (30%), STO 9,429.7 MW (26%), solar power 4,107.7 MW (11%), wind power 6 MW and biomass 21 MW.

(2) Power Generation (GWh)

The transition of power generation and demand (GWh) until 2040 is shown in Figure 7.6-3 and the monthly power generation (GWh) for 2025, 2030, 2035, and 2040 is shown in Figure 7.6-4.

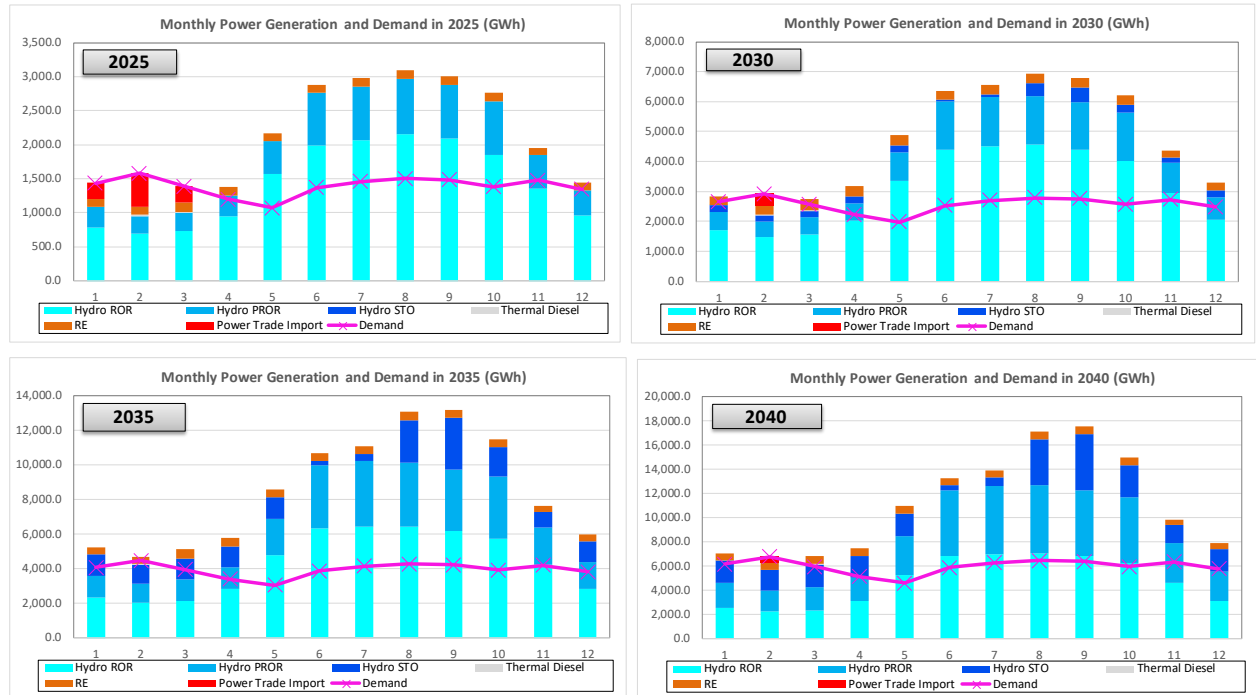


Source: JICA Study Team

Figure 7.6-3 Power Generation of the Optimum Scenario (GWh)

In the Optimum Scenario, power exports will exceed imports in 2025, achieving net zero in power trade. Power generation projects currently under Survey License will begin to commence in 2027 and power generation development will accelerate from 2028. Operations of GoN sites will begin in 2031 and annual self-sufficiency in power supply will be achieved in 2033. Finally, the government's targets in roadmap for installed capacity and power generation will be achieved in 2035.

The annual power generation in 2040 will be 133,185 GWh with power imports at 573 GWh and exports at 61,943 GWh. The monthly power generation will peak in September at 17,538.0 GWh and be lowest in February at 6,236.2 GWh. Seasonal difference of monthly power generation is about one-third, at 35.5% from the maximum to minimum months. The annual power generation will exceed demand even in drought years, allowing power exports.



Source: JICA Study Team

Figure 7.6-4 Monthly Power Generation and Demand (GWh) in 2025, 2030, 2035 and 2040

The operation in February when power generation drops the most is optimized to import a small amount of electricity particularly during peak times from 2037 onwards. For example, it plans to import 573.4 GWh (about 8.4%) against a power demand of 6,786 GWh in February, 2040. It becomes more economical to use export sources to meet the marginal demand increase in February than to introduce new power plants after 2035.

This analysis provides a least cost operation for PGDP optimizing CAPEX and OPEX under securement of domestic power supply. Although selling price for power exports and purchasing price for power imports are assumed at a constant price throughout the year, these would fluctuate daily and hourly if power markets like IEX (Indian Energy Exchange Limited) are considered. Additionally, it is assumed that the selling prices during the rainy and dry season are also different. Demand is more in rainy season and prices would be higher in India and Bangladesh.

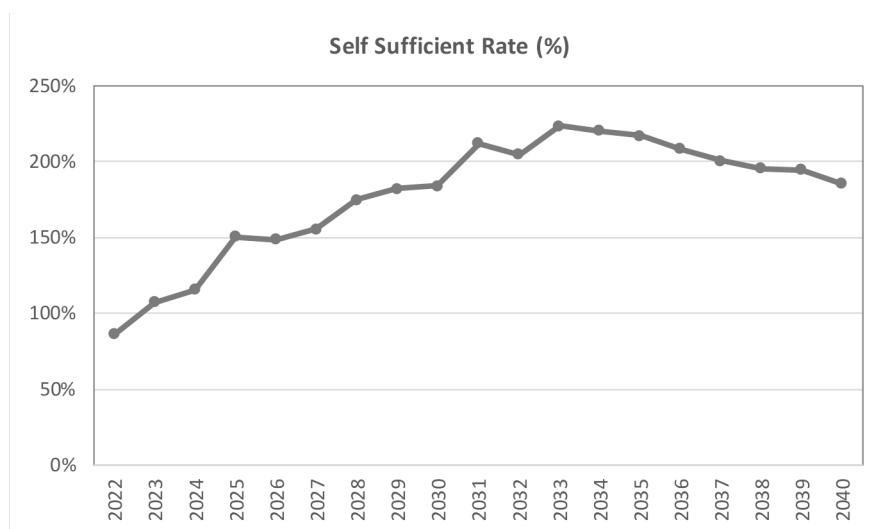
It is a recent trend to materialize market-wise trade in Nepal and responding to these new demands is necessary. Flexible operation of power supply and demand and trade with neighboring countries could increase annual benefits. Future considerations should include such power supply and demand operation analysis.

(3) Self Sufficient Rate and CO₂ Emissions

Figure 7.6-5 and Figure 7.6-6 show the self-sufficiency rate of power and CO₂ emissions. The energy self-sufficiency rate increases as hydropower development progresses. It will exceed domestic power demand significantly after 2029, reaching 223.4% in 2032 when the development of c) Survey and d) GoN peaks. It gradually decreases as new hydropower operations start to decline, reaching 185.5% by 2040.

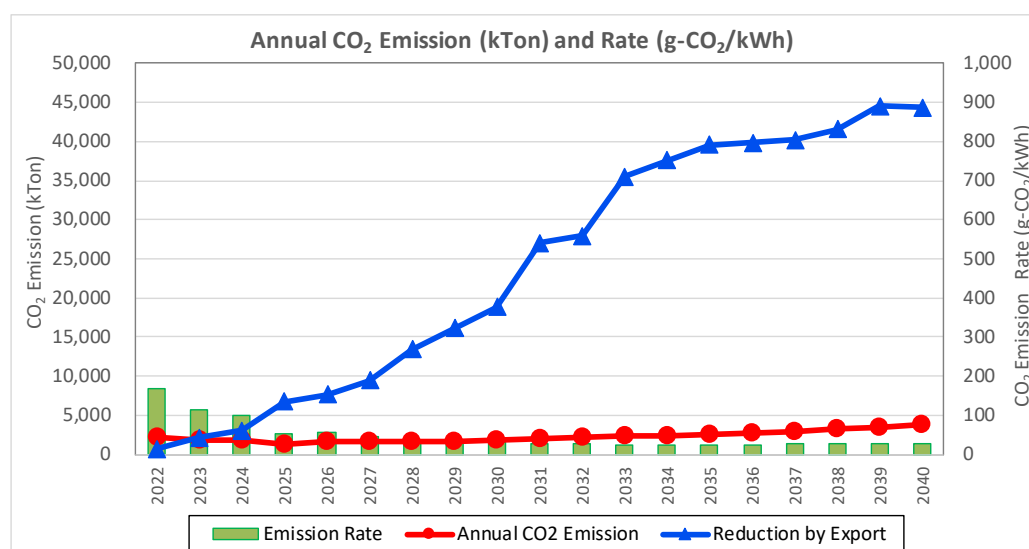
Regarding CO₂ emissions, as hydropower (24 g-CO₂/kWh) increases and electricity imports from India (716 g-CO₂/kWh) decrease, the annual average CO₂ emissions per kWh and total emissions decrease. Rate per kWh moves towards hydropower equivalent emissions after 2029. Also, the

amount of CO₂ reduction due to electricity exports increases, contributing to a reduction of 44,531 thousand tons by 2040.



Source: JICA Study Team

Figure 7.6-5 Self-Sufficiency Rate of Power Generation in the Optimum Scenario (%)

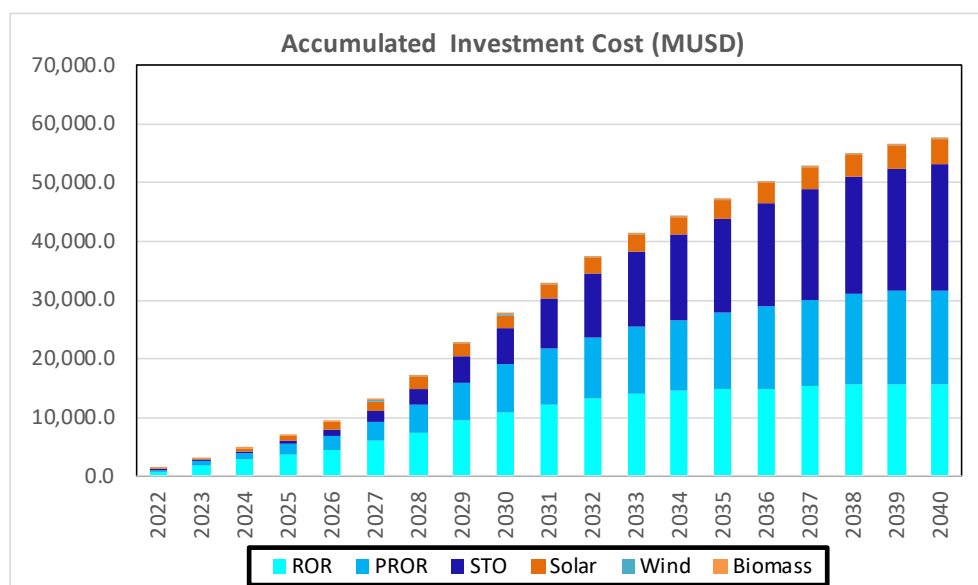


Source: JICA Study Team

Figure 7.6-6 CO₂ Emissions (kTon) and Rate per kWh (g-CO₂/kWh) in the Optimum Scenario

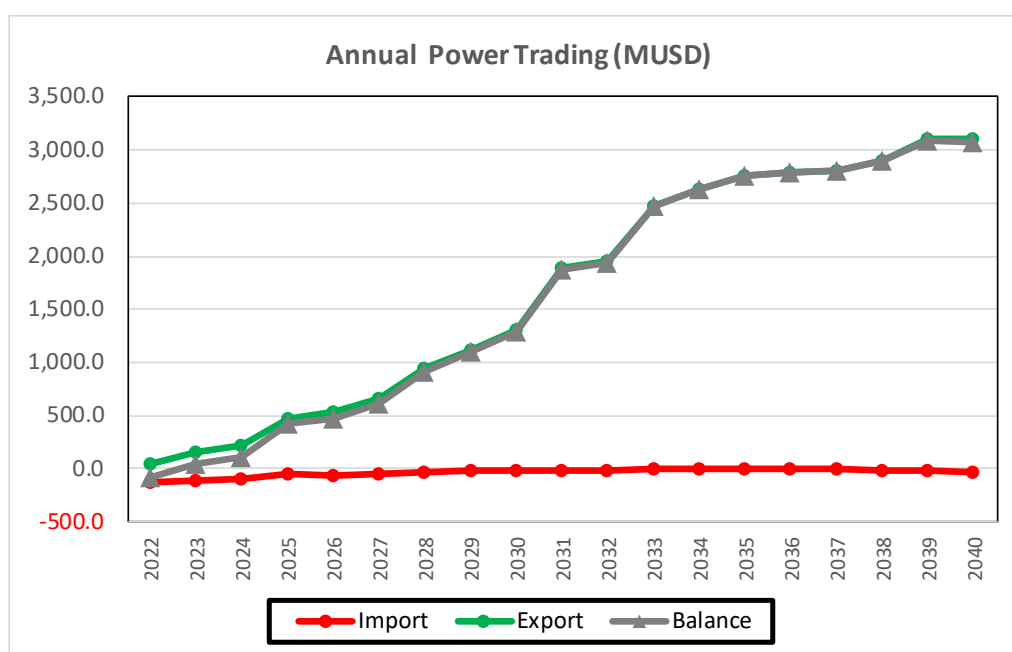
(4) Investment Costs (MUSD)

Figure 7.6-7 and Figure 7.6-8 show the cumulative investment costs and the balance of power trade. The total investment required by 2040 is 57,384 MUSD with an annual average of 3,020 MUSD. Regarding the balance of power trade, exports exceed imports after 2023, reaching 1,873 MUSD/year by 2031 and 3,069 MUSD/year by 2040.



Source: JICA Study Team

Figure 7.6-7 Cumulative Investment of the Optimum Scenario (MUSD)



Source: JICA Study Team

Figure 7.6-8 Annual Balance of Power Trade for the Optimum Scenario (MUSD)

7.6.3 Consideration of Balancing for Power Supply and Demand Operation

This Section discusses the balancing power for power supply and demand operations until 2040 showing the roles of ROR, PROR, STO, and power trade and highlighting the need for securing balancing power.

(1) Definition of Balancing Power

While balancing power is examined globally by various institutions, this study applies the definition from the Organization for Cross-Regional Coordination of Transmission Operators (OCCTO) in Japan:

"Balancing power is defined as the capacity of power generation facilities (including pumped storage power plants), energy storage, demand response systems or other power supply and demand control systems necessary for frequency control, supply-demand balance adjustment and other grid stabilization operations within a supply area."

The functions required as balancing power are shown in Table 7.6-2. This consideration focuses on two key aspects: (1) supply-demand balance adjustment and (2) frequency control, which are critical in medium- to long-term plans.

Table 7.6-2 Functions Required as Balancing Power for Supply-Demand Operations

Item	Function
(1) Supply-Demand Balance Control	When imbalances occur in the system, general electric utilities must adjust them. Supply-demand balance adjustment refers to the process of matching supply and demand by compensating for or taking in the energy imbalances caused by system users. To make this adjustment, system operators typically utilize the reserve power from partially loaded thermal generators, operating reserves from hydropower, and standby reserves from idle thermal generators that can be started within a few hours.
(2) Frequency Control	Frequency control refers to the adjustment that maintains the system's frequency without replenishing the power supply. Even if all generation and retail operators achieve 30-minute simultaneous supply-demand matching, it is necessary to adjust the frequency fluctuations (ripples) within those 30-minute intervals. Short-cycle frequency adjustments, which range from a few seconds to a few minutes, are carried out using instant reserves such as Governor Free (GF). Long-cycle frequency adjustments, from a few minutes to about 20 minutes, are handled by the reserve capacity of partially loaded thermal generators or hydropower (LFC: Load Frequency Control).
(3) Power Flow Adjustment	When accidents or troubles occur in transmission or distribution equipment, and the power flow balance within an area becomes unstable, wide-scale power outages can occur. In such cases, general transmission and distribution operators issue commands to the necessary power sources, considering the distribution of operational power sources in response to supply-demand conditions (power flow adjustment). It is essential to specify the necessary amount of power for such special power flow commands.
(4) Voltage Adjustment	Voltage adjustments accompanying power generation are a system interconnection requirement for power sources. Additionally, voltage control mechanisms installed at substations are typically accounted for as transmission and distribution costs. Even with these considerations, if voltage rises or falls occur due to the operational status of power sources or the distribution of demand, adjustments (such as synchronous condenser operations by hydropower generators or generator operations for voltage maintenance) should be performed by general transmission and distribution operators.
(5) Grid Security Pump-Up	When accidents occur during low-load periods, the system may lack sufficient upward reserve capacity to restore the frequency immediately. In such cases, pumped storage generators can perform pump-up operations, stopping instantly during an accident to restore the frequency.
6) Black Start	In the event of a wide-scale blackout, black start operations refer to starting generation without any external power supply. For example, some pumped storage or hydropower plants possess self-generation equipment and fuel, enabling them to secure internal power and start the generators independently.

Source: JICA Study Team

(2) Consideration of Balancing Power by Sources in Nepal

Table 7.6-3 presents the balancing power by source in Nepal including ROR, PROR, STO, PS and power trade (import and export). Solar power lacks balancing power and is excluded from consideration.

ROR operating continuously for 24 hours can only adjust its output to decrease it during overflow. Since this involves controlling output that could otherwise be used for power generation, it represents an opportunity loss in demand-supply operations requiring compensation for IPPs. PROR can operate output upward and downward adjustments³ during the dry season. It operates at maximum output continuously during the rainy season, similar to ROR, with only downward adjustments with spilled discharge. STO allows for various adjustments throughout the year except during sediment flushing or 24-hour operations when its reservoir is full.

Furthermore, if governor-free operation is installed to generators of ROR, PROR, and STO, instantaneous reserve power can be ensured. PS has both demand-supply adjustment and frequency regulation functions, but its introduction should be considered with economic factors in mind.

Table 7.6-3 Balancing Power by Sources in Nepal

Item		ROR	PROR	STO	PS	Power Trade
Demand and Supply	Ramp up	none	Dry : Good Rainy : none	Good but depending on reservoir operation	Good	Good
	Ramp down	poor (Compensation required)	Dry : Good Rainy : poor (Compensation required)		Good	Good
	Necessity	-	-	-	Decided by profitability	Import : Shortage Export : Surplus
Frequency Control	Spinning reserve	Possible to ensure reserve with Governor-free operation			Good	Good
	Operation reserve	none	Dry : Good Rainy : poor (Compensation required)	Good but depending on reservoir operation	Good	Good
	Contingency reserve	none				Good (Indian System)

Source: JICA Study Team

(3) Consideration of Balancing Power in the Optimum Scenario

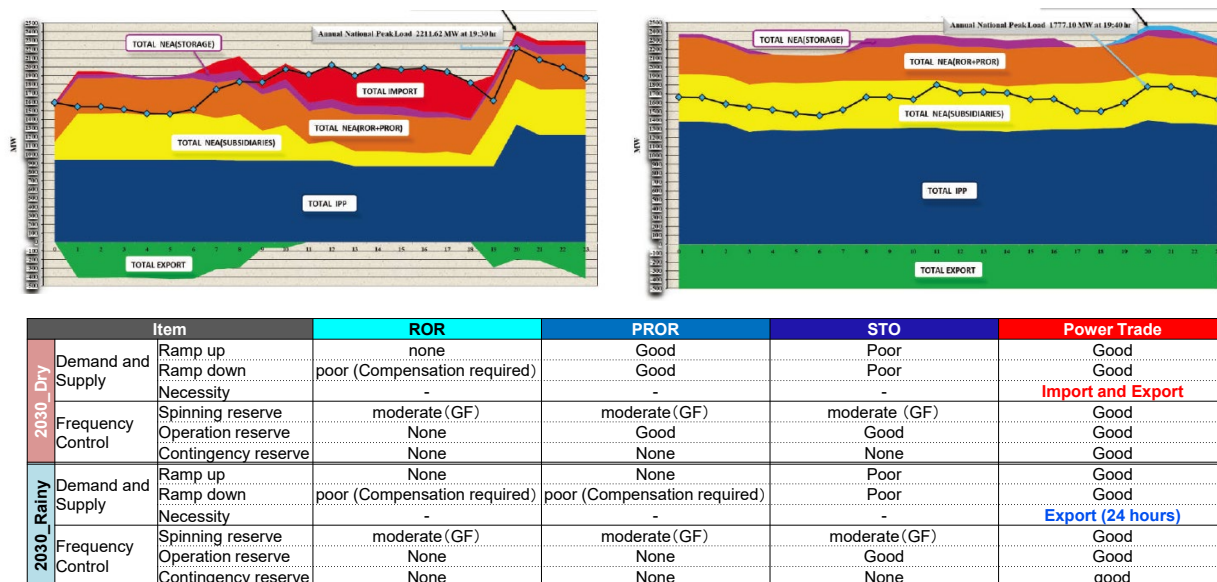
Based on the PGDP results of the Optimum Scenario, balancing power is considered. The daily power supply and demand and balancing power by sources for the dry season (February) and rainy season (August) in 2023/24, 2030, 2035, and 2040 are shown from Figure 7.6-9 to Figure 7.6-12.

Regarding the dry season power supply and demand for 2023/2024, power trade has indicated the trend where imports (red) are made during the day when IEX electricity prices are low and exports (green) occur at night when prices are higher. IPP (navy blue) serves as the base power source and also responds to the lighting peak from 8 PM to 11 PM (4 hours). NEA-owned generation (orange) generally functions as a constant base load, while NEA_Storage (purple) is used for overall supply-demand adjustments. However, there is a shortage of both supply capacity and balancing power over the 24-hour period, leading to a reliance on imports for supply-demand gap adjustment. At the same time, operations are optimized to maximize daily benefits.

During the rainy season, supply capacity exceeds demand throughout the 24-hour period, and a

³ Upward adjustment is the balancing capacity by increasing electricity supply or reducing the demand when power system fall into shortage of electricity supply. Downward adjustment is the one by reducing electricity supply or increasing the demand when power system is in surplus of electricity supply: <https://www.eprx.or.jp/>

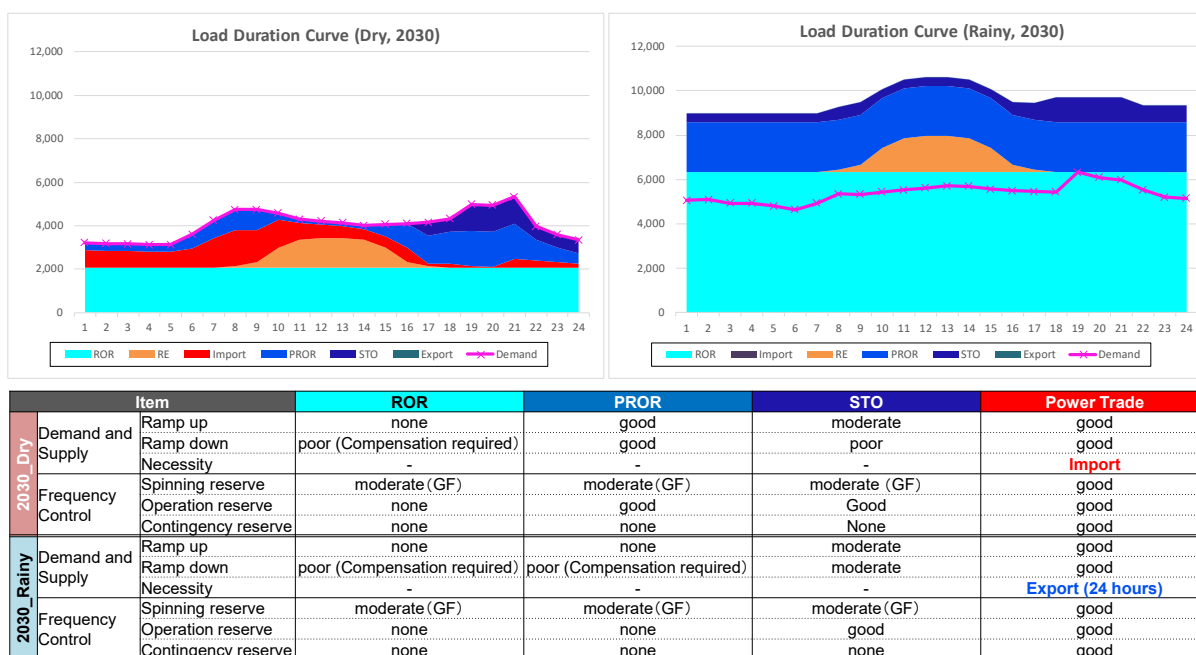
certain amount of electricity is exported. Detailed supply-demand operations are managed by each power source, with final adjustments handled by NEA_Storage. A small amount of imports (light blue) is required from 6 PM to midnight. Overall, there is a surplus of supply capacity, but exports are capped at a fixed output of 500 MW. While there is sufficient room for ramping down (reducing output due to spillover), ramping up is still required to be relied on imports.



Source: JICA Study Team

Figure 7.6-9 Daily Power Supply and Demand (Left: Dry Season, Right: Rainy Season) and Balancing Power by Power Source for 2023/24

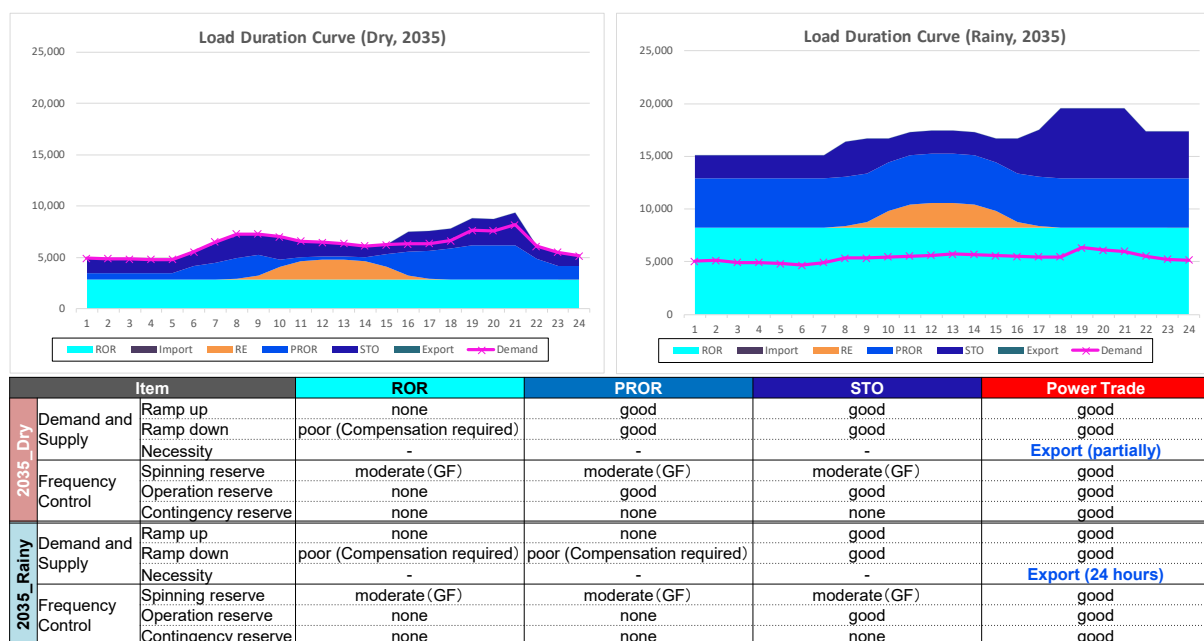
Regarding 2030 power supply and demand, electricity exports will significantly surpass imports on an annual basis. However, given the relatively small installed capacity of STO, exports will still be necessary during the dry season to balance supply. ROR will continue to serve as a base load with PROR and STO functioning as balancing power sources. It shall be noted that import is still required to adjust imbalance. Solar power will not be subject to balancing adjustments. STO generation will be limited and assumed to address the 8-hour peak in the evening and PROR handles adjustments during other hours. Imports will be focused on times when IEX prices are low. During the rainy season, supply capacity will exceed demand throughout the 24-hour period and electricity will be exported. While STO will primarily handle detailed supply-demand adjustments, any shortage in capacity for imbalance adjustments will be supplemented through imports. Maximizing benefits by aligning electricity exports with higher prices in evening peak will also be important.



Source: JICA Study Team

Figure 7.6-10 Daily Power Supply and Demand (Left: Dry Season, Right: Rainy Season) and Balancing Power by Power Source for 2030

In 2035, Nepal is expected to achieve self-sufficiency in power supply throughout the year, with sufficient domestic balancing power. Surplus electricity will be used to maximize benefits, such as addressing the duck curve associated with intensive solar power decrease. ROR will continue as the base load, while PROR and STO will be used as balancing sources. STO is responsible for final adjustment of imbalance. Solar power will not be subject to balancing adjustments. Surplus electricity will be sold during the expensive evening-to-night peak on IEX. During the rainy season, supply will exceed demand throughout the 24-hour period and electricity will be exported. Supply-demand adjustments will be primarily managed by STO. There will be sufficient capacity for imbalance adjustments. Surplus electricity will be sold during the evening-to-night peak when IEX prices are higher.



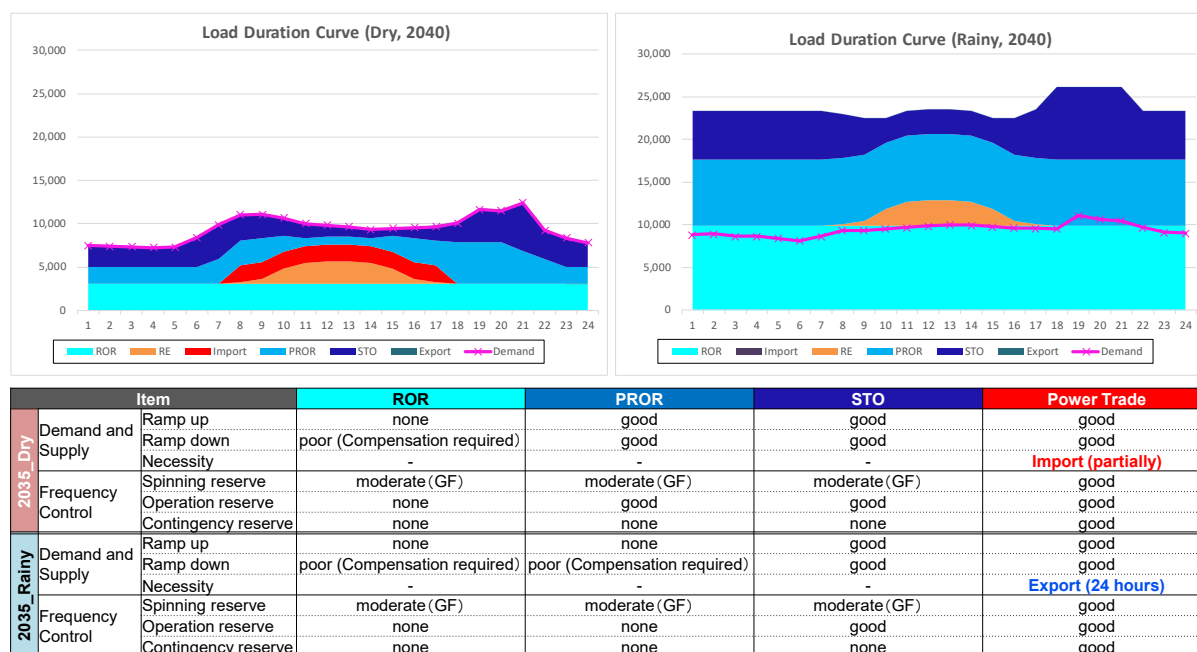
Source: JICA Study Team

Figure 7.6-11 Daily Power Supply and Demand (Left: Dry Season, Right: Rainy Season) and Balancing Power by Power Source for 2035

Regarding the 2040 power supply and demand, Nepal is expected to have sufficient balancing power domestically, though approximately 1,000 MW × 8 hours of imports will be necessary during the daytime in February of the dry season. By this time, power markets and transactions will have become more active and flexible operations are expected in terms of power supply and demand.

For the dry season, ROR will serve as the base load, while PROR and STO will function as balancing sources. Solar power will not be subject to balancing adjustments. Imbalances will be handled by STO and PROR but any shortfall in supply will be supplemented through imports during the daytime when prices are low. It is worth noting that imports will only be necessary in February of the dry season, making up a small percentage of the overall annual supply. After 2036, it may be more economical to rely on imports rather than developing new power sources solely to cover the dry season peak demand. Although it would be possible to adjust the operations of STO to meet this need, the optimization in terms of minimizing generation costs would be to rely on imports.

During the rainy season, supply will exceed demand throughout the 24-hour period and electricity will be exported. Supply-demand adjustments will primarily be handled by STO and there will be sufficient capacity for imbalance adjustments. Surplus electricity will be sold during the evening-to-night peak when IEX prices are higher.



Source: JICA Study Team

Figure 7.6-12 Daily Power Supply and Demand (Left: Dry Season, Right: Rainy Season) and Balancing Power by Power Source for 2040

(4) Consideration of Balancing Power

Based on the PGDP results, two operational modes are expected for power supply and demand. Until around 2033, balancing power by import will be required for both ramping up and down adjustments during the dry season. After 2033, Nepal is expected to secure balancing power domestically year-round with the introduction of STO.

Additionally, Nepal will be able to provide balancing power not only domestically but also to neighboring countries, emphasizing the importance of utilizing hydropower potential. The provision of balancing power, including through pumped storage hydropower and demand response, should also be considered.

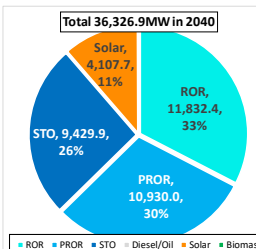
If power trade is regarded as a balancing power source, it is preferable to procure electricity during the daytime when IEX prices are relatively low (e.g., 4.30 INR/kWh or 7.00 NPR/kWh in 2023). Even at an average price throughout the year (5.53 INR/kWh or 8.84 NPR/kWh in 2023), this could still be cheaper than the generation cost of STO at 11.2 NPR/kWh. Therefore, it will be crucial to establish a more flexible scheme for power trade with India, including the functionalization of NPTCL (Nepal Power Trading Company Limited).

On the other hand, any imbalances arising from supply-demand control will be subject to DSM (Deviation Settlement Mechanism), requiring an additional surcharge. Furthermore, from an energy security perspective, it is undesirable for Nepal to rely too heavily on India for balancing power. Hence, it is expected that Nepal will need to secure its own balancing power for both the dry and rainy seasons.

7.6.4 Evaluation of the Optimum Scenario

The evaluation of the analysis results of the Optimum Scenario is shown in Table 7.6-4 based on the 3E + Policy framework.

Table 7.6-4 Evaluation of the Optimum Scenario according to 3E + Policy

Evaluation Items		Optimum Scenario
Generation Mix in 2040		 Total 36,326.9MW in 2040 ROR, 11,832.4, 33% PROR, 10,930.0, 30% STO, 9,429.9, 26% Solar, 4,107.7, 11% Legend: ROR, PROR, STO, Diesel/Oil, Solar, Biomass
		36,327MW
(1) Energy Security	Self Sufficiency Rate of Power Generation (%)	185.5%
	International Issues	Interruption of power exports
	Grid Stability	None
(2) Economy	Cumulated Investment Cost	57,384 MUSD (3,020MUSD/year)
	Cumulated Balance of Power Trade	31,202MUSD
	Vulnerability for Fuel Cost	None
(3) Environmental and Social considerations	Natural and Social Impacts	Intermediate
	Cumulated CO ₂ Emissions (million ton)	44.6 million ton
	CO ₂ Emissions Rate (g-CO ₂ /kWh)	29.0 g-CO ₂ /kWh
	Cumulated Reduction of CO ₂ Emissions by Power Export (million ton)	522.4 million ton
Policy	28000MW in 2035	Achieved
	Introduction of RE	Achieved

Source: JICA Study Team

From the perspective of energy security, the self-sufficiency rate will be 185.5% in 2040. It is possible to complete self-sufficiency in electricity supply including the dry season. However, it is necessary to consider events of unfavorable issues with neighboring countries. Although domestic power supply is possible, it is difficult to sell electricity to them. This interruption could make investment recovery for new power plants difficult. Therefore, it is crucial to establish a mutual relationship with neighboring countries by promoting projects and investment participation from them and ensuring the continuation of power trade even in such kind of affairs. Additionally, energy transition could be risk hedge to mitigate effect of unsealing surplus energy. Further promotion of electrification policies and enhancement of energy self-sufficiency should be considered.

The trade-off between reducing financial burden and economic growth through power exports exists with the capacity of hydropower development. The Optimum Scenario requires significant development of power sector than the current scale. Regarding the power sector's financial balance, if power export is realized, the cumulative balance of power trade will be significantly in surplus. Regarding vulnerability to fuel inflation, domestic power self-sufficiency minimizes the impact even if global fuel inflation occurs as in the first half of 2022. Therefore, the power sector needs to scrutinize whether this scale of development is feasible, verified through economic and financial analysis shown in Chapter 11.

Concerning environmental and social considerations, the Optimum Scenario includes many STO site developments, potentially increasing impacts on the natural and social environment. Mitigation measures presented in Chapter 10 need to be implemented to achieve acceptable development for socio-ecological environment.

From the perspective of climate change measures, hydropower development will contribute to reduction of regional CO₂ emission through electricity exports to neighboring countries which are mainly depended on thermal power plants. Additionally, incentives resulting from these reductions can be anticipated in the future.

Regarding the alignment with Nepal's power policy, the development target of 28,000 MW by 2035 shown in the Energy Development Roadmap and Work Plan will be achieved and the introduction of renewable and alternative energy meeting 10% of domestic demand is also secured.

7.7 HYDROPOWER PRIORITY PROJECTS AND STRATEGIC INITIATIVES BY THE MOEWRI

7.7.1 Hydropower Priority Projects

(1) Selection of Hydropower Priority Projects

This section selects priority projects from among the hydropower development sites introduced in the Optimum Scenario to accelerate future hydropower development. The selection criteria for priority projects are shown in Table 7.7-1.

Table 7.7-1 Evaluation Criteria for the Selection of Hydropower Priority Project

Item	Points
Installed capacity over 100MW	Over 100MW : +2 point 30 MW~100MW : +1 point
Generation type	STO : +2 point PROR : +1 point
Governmental developers	GoN Entities : +1 point
Contribution to cascade operation	STO : +2 point PROR : +1 point
Score of screening	Over 65 score : +3 point 55 – 65 score : +2 point 45 – 55 score : +1 point
Consistency with MoEWRI Energy Development Roadmap and Work Plan	Listed : +1 point
Assistance of Development Partners	Supported : +1 point
Power Trade Projects	Export Project : +1 point
Negative impacts on environment due to the large scale reservoirs	Serious Impacts : -2 point

Source: JICA Study Team

The list of hydropower priority projects is shown in Table 7.7-2. Out of the 643 sites to be elaborated in Optimum Scenario excluding 140 existing power plants, 503 sites were scored using the above selection criteria. Analysis results were confirmed between Nepalese side and JICA Study Team. As a result, the top 26 sites with scores of 5 or higher were selected as priority hydropower projects. It should be noted that projects in this list are selected within the scope of this study and the possibility of each site must be ultimately determined through Feasibility Studies (F/S) and Environmental Impact Assessments (ESIA). In particular, ESIA requires comprehensive studies for individual site conditions and this report does not guarantee the implementation of each site.

Furthermore, the list includes sites where development rights are held by government entities such as NEA and VUCL (Vidhyut Utpadan Co., Ltd.), as well as those held by private companies, considering all as important projects regardless of the developer's attributes.

Table 7.7-2 Hydropower Priority Projects

Status in DoED List	Commissioning	Name	River System	Generation Scheme	Installed Capacity (MW)	Annual Power Generation (GWh)
Construction	2026	Tanahu HEP	Trishuli	STO	140	503
	2025	Arun 3	Arun	PROR	900	3,466
	2030	Tila-1 Hydropower Project	Karnali	PROR	299	
	2030	Tila-2 Hydropower Project	Karnali	PROR	297	
	2030	Upper Marsyangdi 1	Trishuli	PROR	102	587
Application for Construction License	2029	Budhi Gandaki Ka	Trishuli	PROR	226	641
	2038	Adhikhola Storage HEP	Kaligandaki	STO	180	693
	2038	Betan Karnali HEP	Karnali	PROR	442	2,319
	2032	Phukot Karnali HEP	Karnali	PROR	480	2,448
	2034	Chainpur Seti HEP	Karnali	PROR	210	1,158
	2039	Kimathanka Arun HEP	Arun	PROR	450	2,558
	2035	Begnas- Rupa Storage HEP	Trishuli	STO	150	206
	2032	Nalsyau Gad Storage HEP	Karnali	STO	417	1,232
Survey	2030	Tamor Storage	Tamor	STO	200	1,079
	2030	Jagdulla HEP	Karnali	PROR	106	615
	2031	Lower Seti (Tanahu) HEP	Trishuli	STO	126	521
	2037	Bajhang Upper Seti HEP	Karnali	PROR	216	1,245
	2034	Dudhkoshi Storage HEP	Sunkoshi	STO	635	3,362
	2028	Madi Storage HEP	Others	STO	156	456
	2033	Upper Arun HEP	Arun	PROR	1,061	4,478
	2035	Kulekhani Sisneri Pumped Storage HEP	Others	STO	100	317
	2031	Budhigandaki Prok-1 HEP	Trishuli	PROR	103	
Application for Survey License	2030	Bheri 4 HEP	Bheri	STO	271	1,593
GoN Projects	2038	Bharbung HEP	Bheri	STO	470	1,339
	2033	SR-06 Storage	Karnali	STO	309	1,684
	2035	Sunkoshi 3	Sunkoshi	STO	680	2,300
	2033	West Seti Storage HPP	Karnali	STO	750	2,876

Source: JICA Study Team

(2) Considerations on Hydropower Priority Projects

1) Trends in Project Selection

The selection results highlight a preference for large sites in relatively undeveloped river systems such as the Karnali, Bheri, West Seti, and Arun. While there have been more existing hydropower plants with medium to small scale in Gandaki and Trishuli river systems, future development is expected to shift towards these less developed river systems. Despite their abundant hydropower potential, these systems have lagged in development due to reasons such as their relatively small domestic demand scale, distance from the main grid, and difficult access. However, pathway to electricity exports to India and Bangladesh is now open, it is important to proceed the development in these river systems.

2) Consideration by Progress Status

Progress status and required assistance is discussed based on the project progress status listed in the DoED list. It's important to note that the progress of individual projects may not always reflect the categories in the list and actual assistance measures need to be considered for each site, highlighting a general policy direction. Among the sites listed as Construction, Tanahu and Arun 3 are already under construction. These sites are critical as they are the first HPP (Hydro Power Plant) in the country to have large reservoirs and are significant scale for power exports to India. It is necessary for them to support smooth implementation in construction works. Other sites are held by IPPs but have not yet started construction. Various options including the expiry of development rights for these sites must be considered along with complex factors like finance shortages, access roads, and transmission line to promote development.

There are several HPPs by government entities under Application for Construction License without financing. Phukot Karnali (Karnali), Chainpur Seti (West Seti) and Nalsyau Gad Storage (a tributary of Bheri) are promising sites in the underdeveloped Karnali system and are important for accelerating development in this system.

Survey sites vary widely in progress. Projects like Upper Arun supported by WB (World Bank) and multiple development partners, Dudhkoshi Storage supported by ADB (Asian Development Bank), Tamor Storage and Lower Seti to be developed by NEA are notable. Dudhkoshi Storage is a key site for the development of large reservoirs with ODA (Official Development Assistance) finance model.

For Application for Survey License and GoN Projects, progress varies by sites. NHPC (National Hydroelectric Power Corporation), Indian governmental hydropower developer, show interest to develop West Seti and SR-6. Participation by Indian and Bangladeshi companies is expected to accelerate hydropower development in Nepal. For instance, NHPC have developed a lot of hydropower projects in India involving financial support from development partners such as JICA and ADB and it is also expected for them to utilize their lending capacity to develop hydropower projects in Nepal. Sunkoshi-3 is planned as tri-nation interconnection through Nepal, India and Bangladesh and NEA is implementing consultant bidding for Detailed Project Report. This project could serve as a pilot for power export projects.

Begnas-Rupa and Kulekhani Sisneri are planned to be developed as pumped storage and under NEA reviews. There are several challenges in economics, operation, and environmental impact but pumped storage are promising regulating function for power system operation and expected to be studied more. Exploring additional pumped storage options is also important.

7.7.2 MoEWRI's Strategic Projects and Large Reservoir Hydropower

Table 7.7-3 presents MoEWRI's strategic projects and large reservoir hydropower as listed in the Energy Development Roadmap and Work Plan until 2035. The plan mentions Dudhkoshi Storage, Budhigandaki Storage, Nalsyaugad Storage, Naumure Multipurpose, Jadulla PProR, and Upper Arun as national strategic projects. Additionally, large reservoir hydropower projects planned in the lower reaches of major rivers, such as Saptakoshi, Pancheshwor, and Karnali Chisapani Multipurpose, are also referenced.

These sites have broad social and ecological environmental impacts due to large reservoirs. It is crucial to evaluate the validity of project implementation by F/S and ESIA respectively.

Table 7.7-3 MoEWRI's Strategic Hydropower Projects and Large Reservoir Projects

SN	Program	Deadline	Main Responsible body	Assisted by	Remarks
49	To declare as national priority projects and accelerate construction of Dudhkoshi storage project, BudhiGandaki Storage project, Nalgad storage project, Naumure Multipurpose project, Jagadulla PRoR and Upper Arun	continuous	Organizations related to project development.	MoEWRI, Ministry of finance.	To start the construction within 2 years.
68	To complete the study of SaptaKoshi Multipurpose HPP and develop in joint venture with India Nepal cooperation	continuous	Nepal government, MoEWRI	DoED	These programs are to be continued and implemented even after 2035
69	To complete the detail design study of Pancheshwor multipurpose project and develop in joint venture with India Nepal cooperation	continuous	Nepal government, MoEWRI	Pancheshwor Development Authority	
70	To update the study of Karnali Chisapani Multipurpose HPP and accelerate the construction by fixing the development modality	continuous	Nepal government, MoEWRI	NEA	

Source: Energy Development Roadmap and Workplan, MoEWRI

ANNEX 8

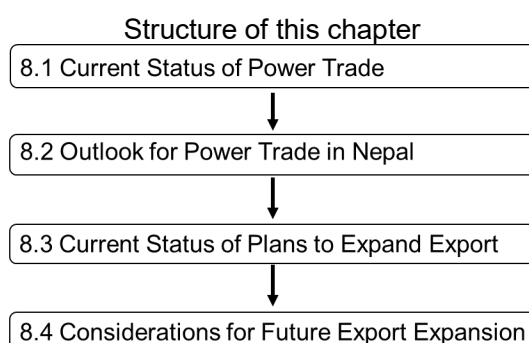
CURRENT STATUS OF POWER TRADE BETWEEN NEPAL AND NEIGHBORING COUNTRIES

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ANNEX 8 POWER TRADE BETWEEN NEPAL AND NEIGHBORING COUNTRIES

Due to hydropower development in Nepal, surplus power is currently exported during the rainy season, but as noted in Chapter 7, surplus power is expected to be twice as large as demand by 2040. Therefore, if the current mechanism with the NEA (Nepal Electricity Authority) as a single buyer is maintained, the NEA will be at risk of having a large amount of surplus power.

In this chapter, the current status of power trade with neighboring countries and the future power supply and demand outlook of neighboring countries are reviewed, and a power trade scheme is proposed that will reduce the risk of NEA and help promote hydropower development in Nepal through IPP (Independent Power Producers).



8.1 CURRENT STATUS OF POWER TRADE

8.1.1 Interconnection Line and Power Plants for Export

(1) Current status and development plan of interconnection lines

Nepal has been exchanging electricity with India, and there are international interconnection lines between Nepal and India such as 400kV Dhalkebar – Muzaffarpur transmission line, 132kV and 33kV transmission lines. 400kV Dhalkebar – Muzaffarpur transmission line started to be operated as a 220kV transmission line from 2018 and was raised to 400kV as the voltage level in 2020. Table 8.1-1 lists the existing and planned interconnection lines, and Figure 8.1-1 shows the 400 kV and 132 kV international interconnection lines. The 400 kV Dhalkebar - Muzaffarpur transmission line is used in both G to G trade and IEX (Indian Energy Exchange Limited) trading schemes. (The respective schemes of trading are described in 8.1.3) The trading scheme for the New Butwal- Gorakhpur interconnection line and subsequent 400 kV interconnection lines will be considered in the future¹.

The 400 kV Dhalkebar-Muzaffarpur interconnection line, which is currently the main transmission line of power trading with India, is technically capable of transmitting up to 1,250 MW. NEA has a 25-year contract for the exclusive use of this 400 kV transmission line, and NEA pays the full amount of the capacity charge regardless of the actual amount of power transmitted. As for the 132 kV interconnection line, it was constructed with the support of the Government of India, including the transmission line in Nepal.

¹ Based on the results of the NEA hearings.

**Table 8.1-1 Existing and Planned Interconnection Lines between Nepal and India
(400kV, 132kV, 33kV)**

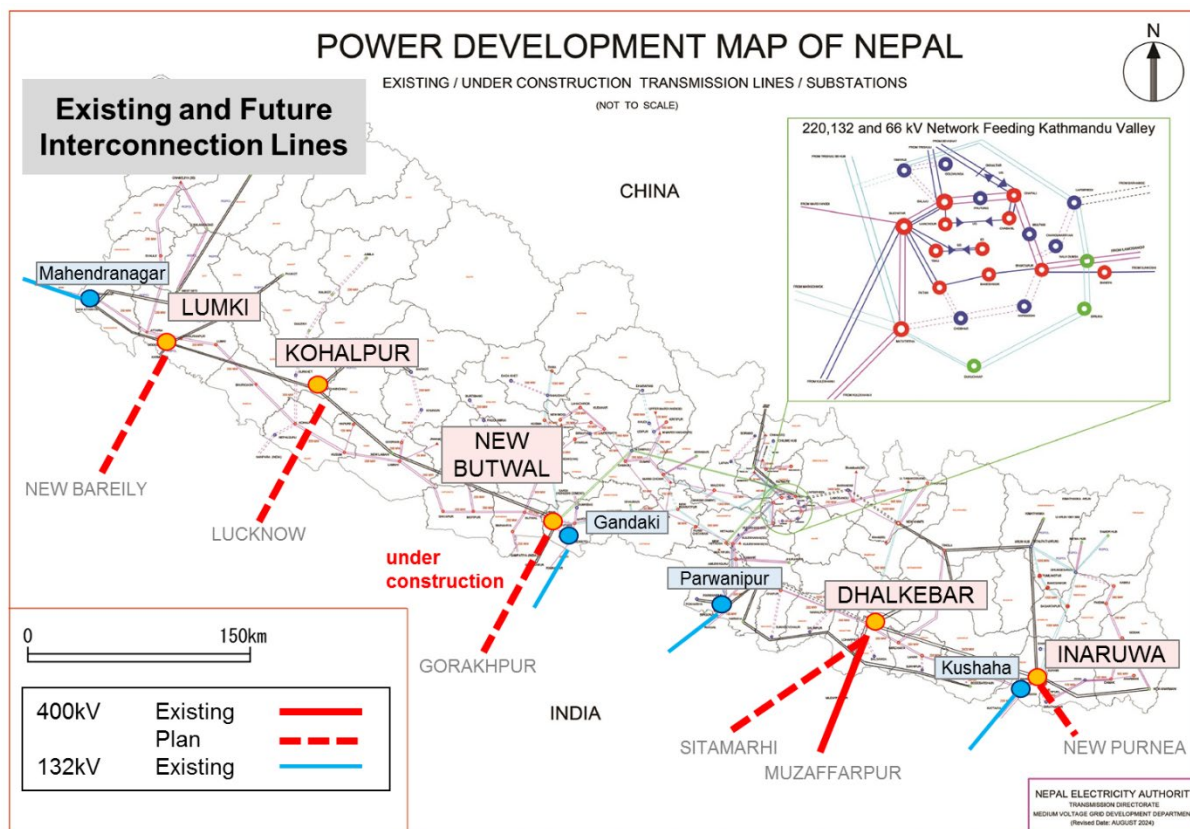
Voltage (kV)	Cross Border Points / Lines	Trade type	Operation year	Length(km) (Nepal side)	Length(km) (India side)	Import volume (GWh)*4	Export volume (GWh)*4	Capacity (MW)
AC 33*2	Siraha - Jaynagar	PEC mechanism	Under operation	-		42.6	0.0	-
	Birgunj - Raxaul							
	Sursant (Jaleswor) -Sitamadi							
	Biratnagar - Kataiya							
	Nepalgunj-Nanpara							
AC 132	Kushaha - Kataiya	PEC mechanism and IEX	Under operation	13	13*3	116.6	1.5	200
	Parwanipur - Raxaul			16	3*3	128.1	19.5	100
	Gandaki - Ramnagar			-		120.4	11.3	100
	Mahendranagar - Tanakpur	G to G trade and IEX		12	4	329.1	0.0	100
AC 400	Dhalkebar - Muzaffarpur	G to G trade and IEX	2020	78	62	806.4	0.1	1250
	New Butwal - Gorakhpur	-	Under construction	15	120	-	-	2500
	Lumki - Bareilly	-	2030	42	161	-	-	3000
	Inaruwa - Purnea	-	2030	49	59	-	-	1800
	Dhalkebar-Sitamarhi	-	2035	-		-	-	-
	Kohalpur-Lucknow	-	2040	-		-	-	-
	Kohalpur-Lucknow	-	2040	-		-	-	-

*1 Unavailable data is shown in "-". *2 Currently not used *3 Measured from a map *4 FY2021/2022 results *5 FY2020/2021 results

Source: Annual report 2021/2022, Nepal Electricity Authority / Prepared by JICA Study Team

There are plans to construct five (5) 400kV international interconnection lines between Nepal and India for 2040. Especially, Nepal and Indian agreed on 400kV New Butwal - Gorakhpur international interconnection line, which is planned to start operation in 2025, starting to be constructed by establishing a new company in a ministerial-level meeting held in the beginning of 2022. As with the "400 kV Dhalkebar - Muzaffarpur Interconnection Line," NEA will pay the full cost of 400kV New Butwal - Gorakhpur interconnection line as Capacity Charge, regardless of the actual amount of power transmitted. The cost sharing for the subsequent 400 kV interconnection lines has not yet been determined.

New interconnection lines for 2030 include the Lumki (Dodohara)-Bareilly interconnection line, which will transmit hydroelectric power from the western Karnali system; the Inaruwa-Purnea interconnection line, which will transmit power from the Arun and Tamor systems; and the Dhalkebar- Sitamarhi interconnection line, which transmits hydroelectric power from the Arun and Tamor systems.



Source : A year Book-Fiscal Year 2022/2023, Transmission/Project Management Directorate, NEA

Figure 8.1-1 Map of Interconnection Lines between Nepal and India

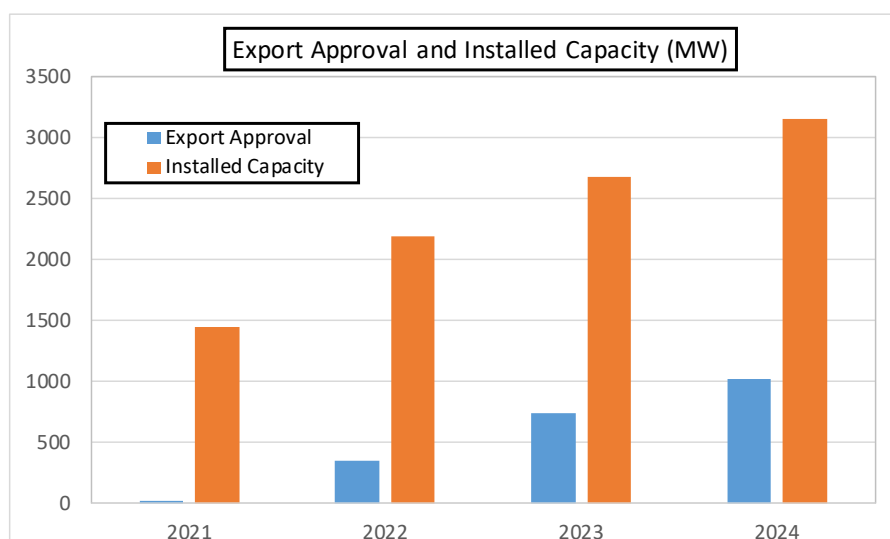
(2) Hydropower plants for export

As mentioned later in Section 8.1.2, power exports to India require export licenses on a plant-by-plant basis, starting in 2021 with the Devighat (14.6 MW) and Chilime (21.4 MW) hydroelectric power plants, totalling 36 MW. The list of hydropower plants for export as at October 2024 and the permitted export capacity for each year are shown in Table 8.1-2 and Figure 8.1-2 respectively.

Table 8.1-2 List of approved hydropower plants for export as at October 2024

Starting Year of Export	Time Period for Export	Project Name	Capacity (MW)	Duration	Remarks
2021	All Time	Devighat Hydropower Project	14.6	Annual Update to IEX	
2022		Kaligandaki 'A' Hydropower Project	140.0		
2022		Likhu IV Hydropower Project	51.0		
2022		Marsyangdi Hydropower Project	67.0		
2022		Middle Marsyangdi Hydropower Project	68.0		
2023		Kabeli B-1 Hydro Power Project	24.3		
2023		Lower Modi Hydro Power Project	19.4		
2023		Solu Hydropower Project	22.8		
2023		Upper Balephi A	34.9		
2023		Upper Chameliya	37.3		
2023		Upper Dordi A	24.3		
2023		Upper Kalangagad Hydro Power Project	32.7		
2024		Dordi 1	11.6		
2024		Down Piluwa	10.0		
2024		Dudhkunda	11.6		
2024		Gandak	14.6		
2024		Mathilo Solu	19.2		
2024		Maya Khola	14.5		
2024		Modi	14.4		
2024		Tallo Khare	10.7		
2024		Uppalo Khimti	11.6		
2024		Upper Khimti II	6.8		
2023	June to October	Dordi Khola	26.2	5 years (2023 - 2027)	Converted from IEX to Haryana Discom
2023		Solu Khola (Dudhkoshi) Hydro Power Project	83.4		Converted from IEX to Haryana Discom
2023		Mistri Khola	40.7		to Haryana Dicom
2023		Super Madi	42.7		to Haryana Dicom
2023		Upper Chaku'A'	7.0		to Haryana Dicom
2024		Likhu 1	75.0		to Haryana Dicom
2024		Likhu 2	50.9		to Haryana Dicom
2024	June to November	Chilime Hydropower Project	21.4	5 years (2024 - 2028)	Started with IEX in 2021 and converted to Bangladesh trade in 2024
2024		Trishuli Hydropower Project	23.3		Started with IEX in 2023 and converted to Bangladesh trade in 2024
Total			1,031.9		

Source: Prepared by JICA Study Team by CEA documents



Source: Prepared by JICA Study Team by NEA documents

Figure 8.1-2 Approved export capacity to India and installed capacity in Nepal in 2021-2024

The hydropower plant capacity licensed for export to India has expanded significantly since 2021, growing by more than 300 MW/year, 362 MW in 2022, 758 MW in 2023 and 1,032 MW in 2024 respectively.

There are significant day-to-day changes, such as the change of export destination for Chilime Hydro and Trishuli Hydro from IEX to Bangladesh following the start of electricity exports to Bangladesh. It should be noted that this table is current as of October 2024.

The power export agreement and the trade type is summarized in Table 8.1-3 and the interconnection lines and hydropower plants related to power exports is listed in Table 8.1-4. As of October 2024, the capacity of power plants approved to export electricity to India is approximately 1,000 MW. In January 2024, Nepal and India agreed to trade up to 10,000 MW by 2035 for future power exports, and the current trading volume between India and Nepal is equivalent to about 10% of the total trading volume agreed upon.

Table 8.1-3 Power export agreements and trade type

Country	Date	Agreement		Trade Type
		Content	Capacity	
India	1992	Nepal - India Power Exchange Committee (PEC) was constituted for consultation of power trade. This mechanism has been used mainly for imports since the past. Prices and trading volumes are determined annually by the committee.	-	PEC Mechanism
	2014 October	The contract is for power trading between Nepal and India for a period of 25 years. After 25 years, the contract will be automatically renewed every 10 years if there are no objections from either party.	-	G to G Trade
	2021 October	Power exports through IEX has started in October 2021. The list of power plants for this trade will be renewed annually.	36.0MW (2021) 362.0MW (2022) 557.7MW (2023) 661.3MW (2024)	IEX
	2023 September	Export to the Indian state of Haryana during Nepal's rainy season from June 1 to October 31 for five years starting in 2023.	109.6MW (2023) 325.9MW (2024)	G to G Trade Haryana Discom
Bangladesh	2024 October	For five years starting in 2024, 40 MW will be exported to Bangladesh via India. This will take place between 15 June and 15 November, the rainy season in Nepal.	40.0MW	G to G Trade Bangladesh

Source: Prepared by JICA Study Team by NEA and CEA documents

Table 8.1-4 The trades related to export and interconnection lines and hydropower plants for export (MW)

Country/Trade			2021	2022	2023	2024
India	IEX	TL	400kV Dhalkebar - Muzaffarpur	400kV Dhalkebar - Muzaffarpur	400kV Dhalkebar - Muzaffarpur	400kV Dhalkebar - Muzaffarpur 132kV Kushaha - Kataiya 132kV Parwanipur - Raxaul 132kV Gandaki Ramnagar 132kV Mahendranagar - Tanakpur
			Chilime 21.4 Devighat 14.6	Chilime 21.4 Devighat 14.6 Kaligandaki 'A' 140.0 Likhu IV 51.0 Marsyangdi 67.0 Middle Marsyangdi 68.0	Chilime 21.4 Devighat 14.6 Kaligandaki 'A' 140.0 Likhu IV 51.0 Marsyangdi 67.0 Middle Marsyangdi 68.0 Kabeli B-1 24.2 Lower Modi 19.4 Solu 22.8 Upper Balephi A 34.9 Upper Chameliya 37.3 Upper Dordi A 24.2 Upper Kalangagad 32.7 Dordi 1 11.6 Down Puluwa 9.9 Dudhkunda 11.6 Gandak 14.6 Mathilo Solu 19.2 Maya Khola 14.4 Modi 14.4 Tallo Khare 10.6 Uppalo Khimti 11.6 Upper Khimti II 6.8	Devighat 14.6 Kaligandaki 'A' 140.0 Likhu IV 51.0 Marsyangdi 67.0 Middle Marsyangdi 68.0 Kabeli B-1 24.2 Lower Modi 19.4 Solu 22.8 Upper Balephi A 34.9 Upper Chameliya 37.3 Upper Dordi A 24.2 Upper Kalangagad 32.7 Dordi 1 11.6 Down Puluwa 9.9 Dudhkunda 11.6 Gandak 14.6 Mathilo Solu 19.2 Maya Khola 14.4 Modi 14.4 Tallo Khare 10.6 Uppalo Khimti 11.6 Upper Khimti II 6.8
		HPP (MW)				
			Subtotal 36.0	362.0	557.7	661.3
	G to G Trade Haryana Discom	TL			400kV Dhalkebar - Muzaffarpur	400kV Dhalkebar - Muzaffarpur
		HPP (MW)			Dordi Khola 26.1 Solu Khola (Dudhkoshi) 83.4	Dordi Khola 26.1 Solu Khola (Dudhkoshi) 83.4 Mistri Khola 40.7 Super Madi 42.6 Upper Chaku'A' 6.9 Likhu 1 75.0 Likhu 2 50.8
			Subtotal		109.6	325.9
Bangladesh	Bangladesh/ G to G Trade	TL				400kV Dhalkebar - Muzaffarpur
		HPP (MW)				Chilime 21.4 Trishuli 23.2
		Subtotal				40.0
Total	Total	TL	400kV Dhalkebar - Muzaffarpur	400kV Dhalkebar - Muzaffarpur	400kV Dhalkebar - Muzaffarpur	400kV Dhalkebar - Muzaffarpur 132kV Kushaha - Kataiya 132kV Parwanipur - Raxaul 132kV Gandaki Ramnagar 132kV Mahendranagar - Tanakpur
		HPP (MW)	36.0	362.0	667.3	1,027.2

Source: Prepared by JICA Study Team by NEA and CEA documents

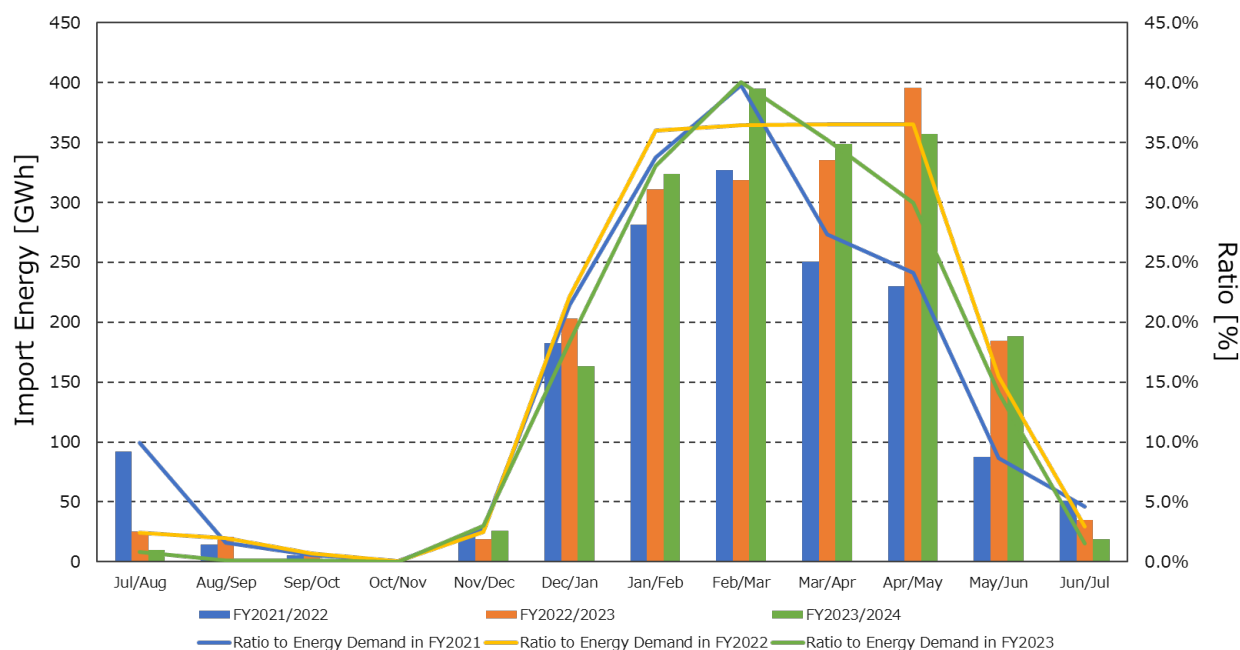
8.1.2 International Power Trade Results

India and China are bordering Nepal. India is currently trading with Nepal. Bangladesh, which has a three-country linkage via India, has started power trade with Nepal. As for China, discussions for power trade is also in the process. This section describes the results of power trade with India and Bangladesh and the status of power trade with China.

(1) Power Trade results with India

Figure 8.1-3 shows the monthly importing energy and the percentage of it against monthly domestic peak demand of the year in FY2021/2022, FY2022/2023 and FY2023/2024. Nepal lacks

electricity during the dry season and imports electricity from India to cover domestic supply.

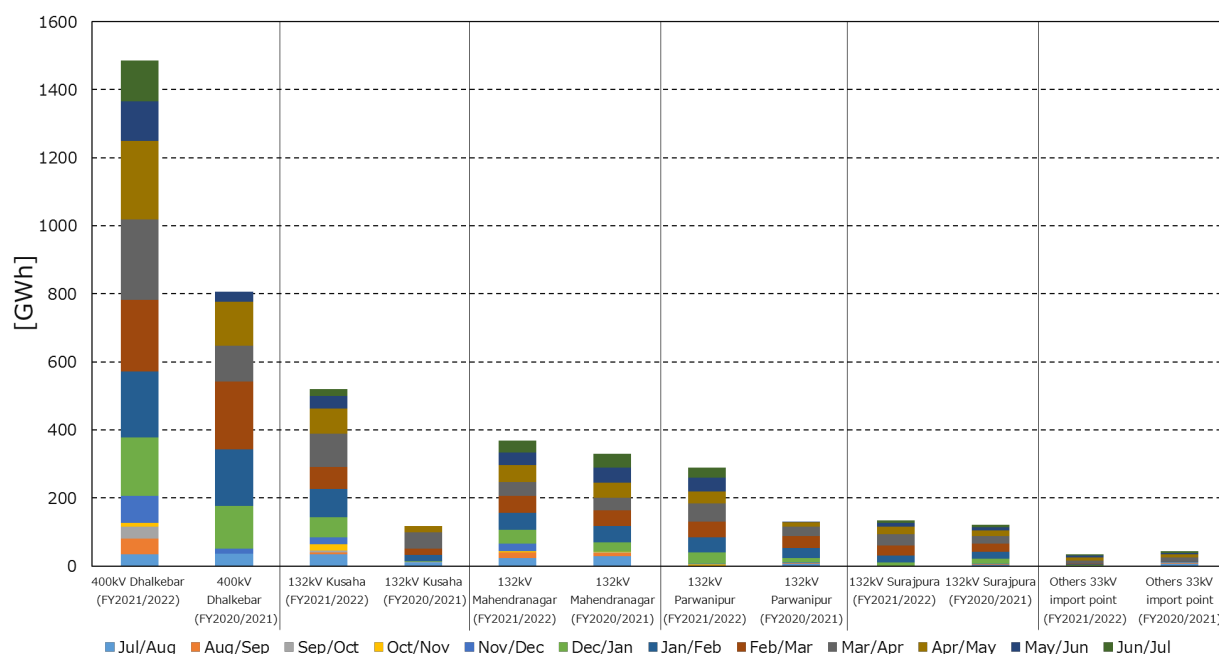


Source: Prepared by JICA Study Team by NEA Annual Report 2021/2022, 2022/2023, 2023/2024

Figure 8.1-3 Monthly² amount of imported electricity in the past three years and the percentage of imported electricity to consumed electricity for each month

The amount of importing power of each international interconnection line from India is shown in Figure 8.1-4. Since electricity imports per individual transmission line were published until FY2021/2022, data for FY2020/2021 and FY2021/2022 are shown. This figure indicate that power imports from India were conducted mainly through 400 kV transmission lines, but also some through 132 kV and other transmission lines. The 132kV Mahendranagar transmission line in western Nepal is used for power imports because the western part of the country is far from domestic power sources.

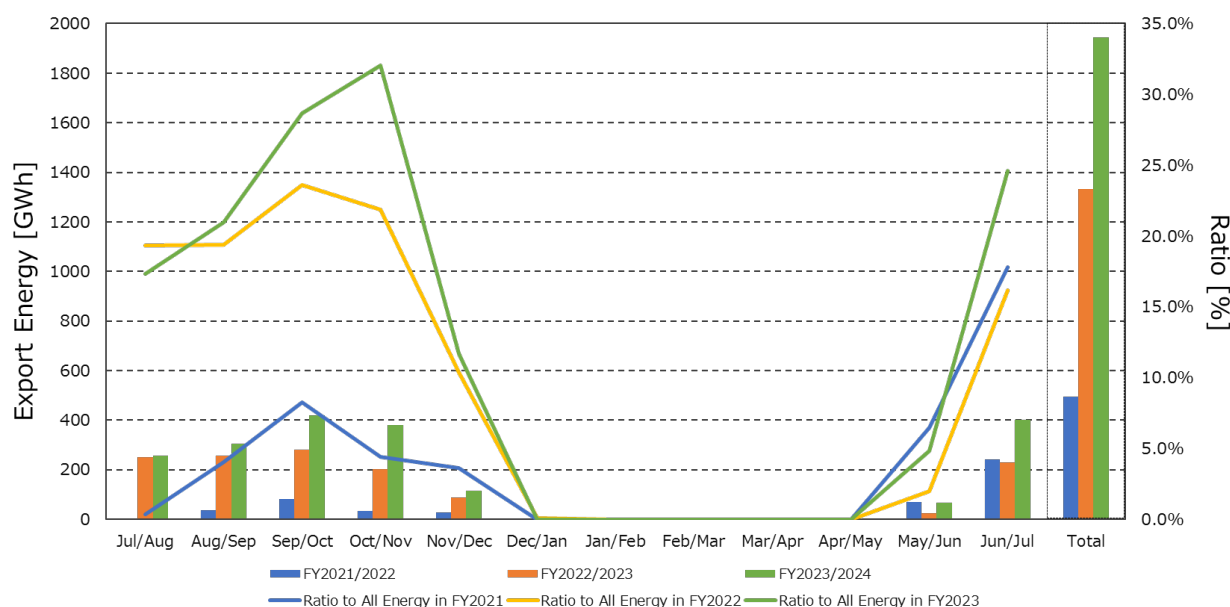
² For Figures 8.1-2~8.1-5, months are listed in Bikram history. For example, for Jul/Aug, it refers to 7/17 - 8/16.



Source : Prepared by JICA Study Team by NEA Annual Report 2021/2022

Figure 8.1-4 Imported Energy from different lines in FY2020/21 and FY2021/22

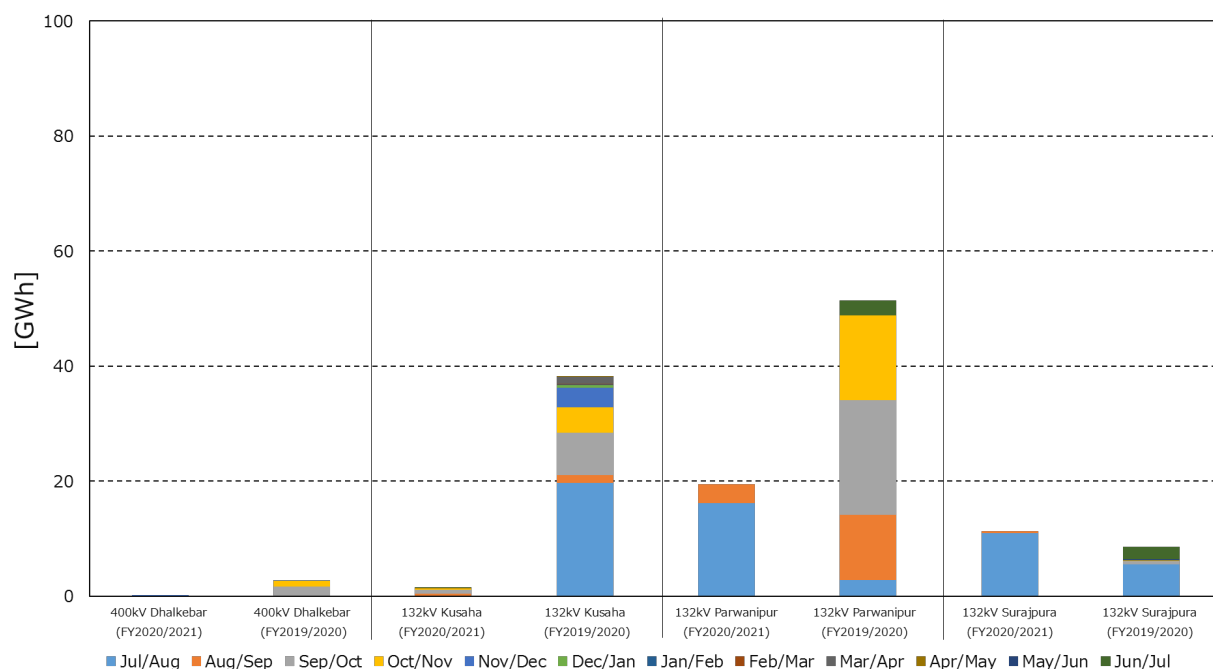
On the other hand, Figure 8.1-5 shows the monthly amount of exporting power to India and the percentage of the amount of the exporting power for the total amount of power produced of the year in FY2021/2022, FY2022/2023 and FY2023/2024. The three-year trend shows that power exports are implemented during the rainy season, while little power export during the dry season. In addition to the increase in generating capacity from new hydropower development, the expansion of export quotas is expected to lead to an increase in export volume.



Source : Prepared by JICA Study Team by NEA Annual Report 2021/2022, 2022/2023, 2023/2024

Figure 8.1-5 Monthly amount of exported electricity in the past three years and the percentage of exported electricity for the total generation amount of the year

The amount of exporting power of each international interconnection line is shown in Figure 8.1-6. Since electricity exports per individual transmission line were published until FY2020/2021, data for FY2019/2020 and FY2020/2021 are shown. Power exported mostly through 132kV transmission lines.



Source: Prepared by JICA Study Team by NEA Annual Report 2019/2020, 2020/2021

Figure 8.1-6 Exported from different lines in FY2019/20 and FY 2020/21

In addition, as a condition for exporting electricity to India, an export license is required on a power plant basis. As a nation, it is necessary to conclude a “Bilateral agreement on power sector cooperation” with India. For example, since China has not signed the above agreement with India, India will not purchase power from power plants involving China within Nepal. While there is no problem in supplying Nepal's domestic demand, there are many challenges when looking at exports. In day-to-day power trades, India constantly monitors the output (MW, MVAR) of power plants in Nepal and the amount of electricity (MWh) and the flow through the interconnection line between Nepal and India by SCADA (Supervisory Control And Data Acquisition) at India's central load dispatch center. By comparing with the amount of flow through the interconnection line and the total amount of electricity generated by the power plants permitted to export to India, it indirectly confirms that electricity from non-permitted power plants is not being exported to India.

(2) Power Trade result with Bangladesh

Bangladesh has a large fossil fuel based power source. Bangladesh is also seeking low-carbon power sources (hydropower) as it seeks to decarbonize. The desire of hydropower-rich Nepal and Bangladesh for low-carbon power sources coincides, and Nepal, India, and Bangladesh have approved the export of 40 MW of electricity from Nepal to Bangladesh over a five-year period via an Indian transmission line. For this trade, electricity will be exported from Nepal to Bangladesh over a five-month from June 15 to November 15. The reason for the 40 MW transaction volume is that 40 MW was allocated as the transmission capacity of the 400 kV HVDC (High Voltage Direct Current) transmission line connecting India and Bangladesh, which can be transmitted without any upgrades.

For this trade, it is necessary to obtain permission from India on a power plant basis, as the trade

will involve Indian transmission lines. The 40 MW project is not a development of a new power plant for Bangladesh, but rather a development of the Trishuli (24 MW) and Chilime (22 MW) power plants that have been approved for trading to Bangladesh. These had previously been approved for trading on the IEX and were converted for export to Bangladesh. The signing ceremony for the trade was held on October 3, 2024, in the presence of senior officials from Nepal, Bangladesh, and India. The actual trade has started on 15 November 2024 after approval by CEA (Central Electricity Authority) in India and the results of the trade were recorded for one day only for 2024. For 2025, power trade is scheduled to start on 15 June.

The unit price for trade between Bangladesh and Nepal will be 6.4 cents/kWh, and metering for power trade will be done at Muzaffarpur in India, and Bangladesh will pay India for the use of transmission lines and the cost³ equivalent to transmission losses occurring within India.

Nepal decided to conduct a feasibility study for a transmission line between Anarmani, east of Nepal, West Bengal in India. Under current framework, Nepal and Bangladesh have to use transmission lines constructed and managed by India that does not prefer to trade power only among the two countries, so it may not be able to realize depending on India's movement. There are still issues for trading power to Bangladesh, and it may take a long time to realize.

(3) Power Trade status with China

Although China is next to Nepal, there are no international interconnection lines between Nepal and China currently. An interconnection line to Tibet Autonomous Region has been planned recently, which will be able to export power to China if it can realize. There are two planned interconnection lines, and the feasible study of the international interconnection line among Ratmate - Rasuwagadhi - Kerung has been already completed, which has a high possibility to be late to start operating though the project has a plan to complete in FY2024/2025.

Table 8.1-5 Proposed Interconnection Lines between Nepal and China

Ends of Line		Voltage (kV)	Circuit Type	Flow (MW)	Year
Nepal	China				
Ratmate	Kerung	AC 400	Double	1500	2040
U Arum	Latse	AC 400	Double	700	2040

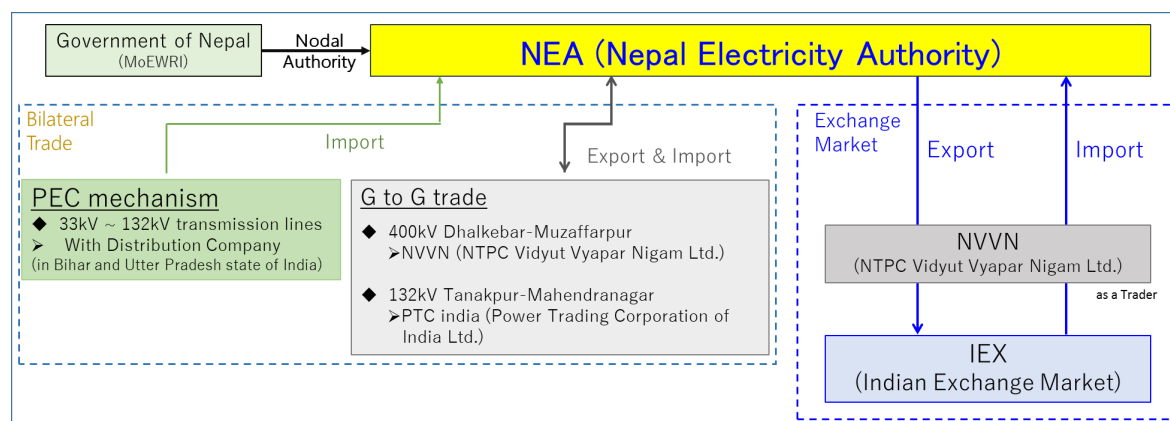
Source: Prepared by JICA Study Team

8.1.3 Power Trade Scheme

As mentioned above, most of Nepal's power trades have been with India, with only one day of transactions with Bangladesh, on November, 2024. Therefore, this section describes in detail the scheme of Nepal's current power trade with India.

In Nepal, NEA is designated by GoN (Government of Nepal) as "Nodal Authority" and conducts the power trade. The Power Trade between Nepal and India can be divided into two categories in broad strokes, and one is Bilateral method and the other is a trade through IEX (Detail about IEX is provided later). Bilateral trade has PEC (Power Exchange Committee) mechanism which is a power trade with distribution companies in India and G to G trade executed under "Guidelines for Import Export Cross Border of Electricity 2018 India" formulated in 2018. Its image is shown in Figure 8.1-7.

³ According to the results of the hearing to the NEA, Bangladesh will pay 1.3 INR/kWh to India for the use of transmission lines in India, plus an amount equivalent to transmission losses incurred in India.



Source: Prepared by JICA Study Team

Figure 8.1-7 Relationship of Power Trade between Nepal and India

All power plants exporting to India, regardless of the type of trade, are required to obtain permission from India. The permission will be conducted by CEA in accordance with Guidelines for Import Export Cross Border of Electricity 2018 and Procedure for Approval and Facilitating Import/Export (Cross Border) of Electricity.

For the power plants to be traded on the IEX, NEA submits an application every year, which is approved by CEA. For bilateral trade, once permission is obtained, no annual application is required for the duration of the contract. With regard to the seasons, power plants permitted to export power through IEX are allowed to export throughout the year, while those to Haryana and Bangladesh are set to export only during the rainy season. The conditions required for exporting power to India are listed in Table 8.1-6 and the period of export approval by the Government of India for each type of transaction is listed in Table 8.1-7

Table 8.1-6 Requirements for exporting electricity to India.

Item	Requirement
Power plant	Foreign power plants exporting electricity to India must be located in countries that have signed “Bilateral agreement on power sector cooperation” with India.
	If a country bordering India, directly or indirectly, is involved in the development of a power plant, that country need to sign “Bilateral agreement on power sector cooperation” with India.
Application	The maximum power capacity of the trade and the duration of the trade are applied for and approved by the India. In IEX, the maximum trading period is one year for a single application.
Demand	Exports of electricity to India are permitted when domestic demand exceeds domestic supply capacity in India.

Source: Prepared by JICA Study Team by CEA documents

Table 8.1-7 Trade type and duration of export approval by India.

Trade type	Approval period
IEX	Up to 1 year
Bilateral trade	Bilateral contract period

Source: Prepared by JICA Study Team by CEA documents

For the trade that started in November 2024 with Bangladesh, it is a G to G trade, but the scheme for further trades with Bangladesh for the future has not been decided. NEA has an outlook that the first step will be to expand G to G trade, based on the history of expanding trade with India.

Also, there are no decisions yet regarding trading with China. So far the trade would start as a G to G trade scheme same as in India and Bangladesh.

For each trade, the main information is summarized below.

(1) Bilateral Trade

1) PEC mechanism

- This is one of the mechanisms for power trading between Nepal and India.
- The meeting for this mechanism is held once a year. The amount of power trade and its tariff is mainly discussed. This mechanism is applied to power trading in areas remote from the 400kV interconnection point with India.

2) G to G trade

- G to G Trade is based on the agreement between the governments of Nepal and India on the volume and price of the trade, and the exchange of electricity within the agreed volume and the agreement is applied to two (2) international interconnection lines, 400kV Dhalkebar – Muzaffarpur and 132kV Tanakpur – Mahendranagar. In the past, it was used for imports from India to compensate for Nepal's electricity shortage, but now it is used for export to India.
- The 400 kV Dhalkebar - Muzaffarpur transmission line is traded through NVVN⁴ (NTPC Vidyut Vyapar Nigam Ltd).
- The 132kV Tanakpur – Mahendranagar transmission line is traded through PTC⁵ (PTC India Limited) and the current trading capacity is 75 MW. These trading capacities are fixed on a monthly basis and updated annually.
- Both NVVN and PTC are recognized trading companies by the Indian government. The difference between NVVN and PTC is that NVVN has both rights of a trader and a Nodal Agency but PTC has only the right of a trader. Only Nodal Agency can get involved in a process of settlement of power trade, so PTC cannot do that. For example, in case that a default on the contract etc. happens on power trade, the penalty etc. are dealt with through NVVN.
- G to G trade has not used on a daily basis, as market trade and the PEC mechanism currently have higher priority. G to G trade is intended to be used in emergencies when power is short.

(2) IEX

There are three electricity markets in India: IEX, HPX India (Hindustan Power Exchange), and PXIL (Power Exchange India Limited). Among them, IEX is currently used by NEA for trading.

1) Overview of IEX

- IEX is licensed and regulated by CERC (Central Electricity Regulatory Commission), the regulate authority of the Indian power sector, and has been in operation since June 27, 2008.

⁴ NVVN was established in 2002 to expand power trading in India. NVVN has also been designated as the central agency for cross-border power trading within India as well as with Bangladesh, Bhutan, and Nepal.

⁵ PTC was established in 1999 with the objective of power trading to achieve economic efficiency and security of supply and to expand power trading in India. It also plays a role in the development of electricity markets within India and in South Asia.

IEX is composed of participants over 7,500 from all over India, distribution utilities over 60 and conventional generators over 600 and renewable energy generators over 1,800. In addition to it, commercial and industry consumers over 4,400 such as metals, food processing, textile, cement, ceramic, chemicals, automobiles, information technology industries, institutional, housing, real estate, commercial entities and so on have joined.

- Trading on the IEX includes the "Day-Ahead Market," the "Term Ahead Market," and the "Real Time Market. There is also a market that focuses on renewable energy such as solar and wind power (Green Market). The largest volume of trade is in the Day-Ahead Market. Table 8.1-8 summarizes the trading period and target power sources in each market.

Table 8.1-8 Trading period and target power sources each market

Market	Period	Power source
Day Ahead	Tomorrow	All power sources
Real Time	On that day	
Term Ahead	Up to 90 days	
Green Day Ahead	Tomorrow	Renewable energy ⁶
Green Term Ahead	Up to 90 days	

Source: Prepared by JICA Study Team

2) NEA's Participation in IEX

- NEA joined IEX in October 2021 as the first market participant from outside India, trading in the Day-Ahead Market. In the future, Bhutan and Bangladesh are expected to join the market with the aim of establishing a comprehensive electricity trading market in South Asia.
- Power generated from the Kaligandaki-A hydropower plant and Marsyangdi hydropower plant is exported to India. The permitted trading volume is frequently updated according to the development of power sources and the supply and demand situation in India, and at present, exports to India are set at 661 MW and imports from India at 0 MW, as shown in Table 8.1-2, and electricity through IEX Imports are not possible (as of 2024).
- Power imports from India are conducted through Bilateral trade. On the other hand, since Nepal and India are connected to the grid through AC transmission line, when there is a shortage of supply relative to demand in Nepal, imports are unintentionally made, which is subject to DSM (Deviation Settlement Mechanism). (Details of the DSM are described below.)
- Future increases in the maximum trading volume are being coordinated with the Indian government. On the other hand, it is difficult to make a stable outlook for the short-term trading volume.
- Power trading in IEX is conducted by the NEA's LDC (Load Dispatch Centre), which is in charge of coordinating supply and demand for the entire country of Nepal, through NVVN. However, the Power Trade Department of NEA manages the contracts related to power trading, and checks IEX information on its website and receives regular reports on trading performance from the LDC.

⁶ Renewable energy in this context refers to solar, wind, biomass, and hydroelectric power generation.

3) Day-Ahead Market and Green Day-Ahead Market trading results

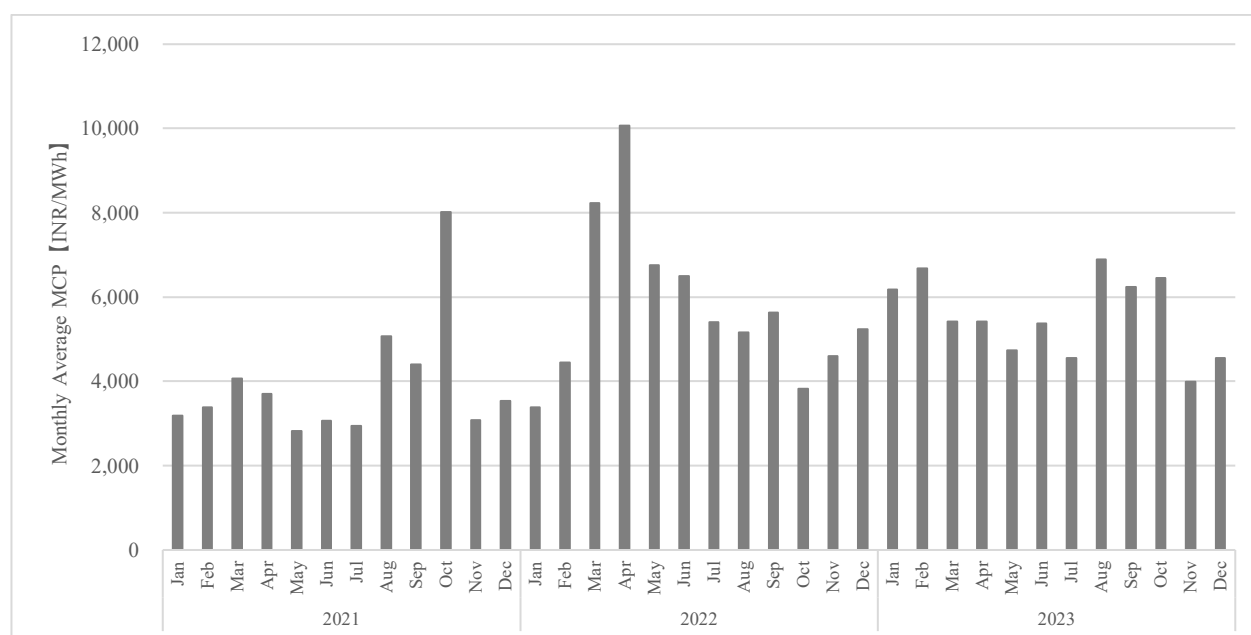
As shown in Table 8.1-8, IEX has five main markets. This section describes the trading performance of the Day-Ahead Market and the Green Day-Ahead Market, the two markets with the highest trading volume.

(a) Day-Ahead Market

The mechanism is basically the same as in JEPX (Japan Electric Power Exchange), where buyers and sellers bid blindly without disclosing the other party's bidding trends, and the MCP (Market Clearing Price) and MCV (Market Clearing Volume) are determined at the intersection of the supply-demand curve. The biddings are conducted for 96 blocks (every 15 minute) the day before it, and each MCP is determined in 24 hours later.

Figure 8.1-8 shows the monthly average of MCP results for the years 2021~2023. In 2022, the prices are higher than in 2021 and 2023 due to the high fuel prices triggered by the war in Ukraine.

The monthly MCP for the years 2021 and 2023, excluding 2022, show that the prices tend to be high in the IEX from August to October. This period is Nepal's rainy season, when electricity production in Nepal increases. Exporting surplus electricity from Nepal to IEX during this period will enable Nepal to trade at a higher price, which is advantageous for Nepal's electricity exports.



Source: Prepared by JICA Study Team from IEX HP

Figure 8.1-8 Monthly Average of IEX Price (MCP) of past 3 years (INR/MWh)

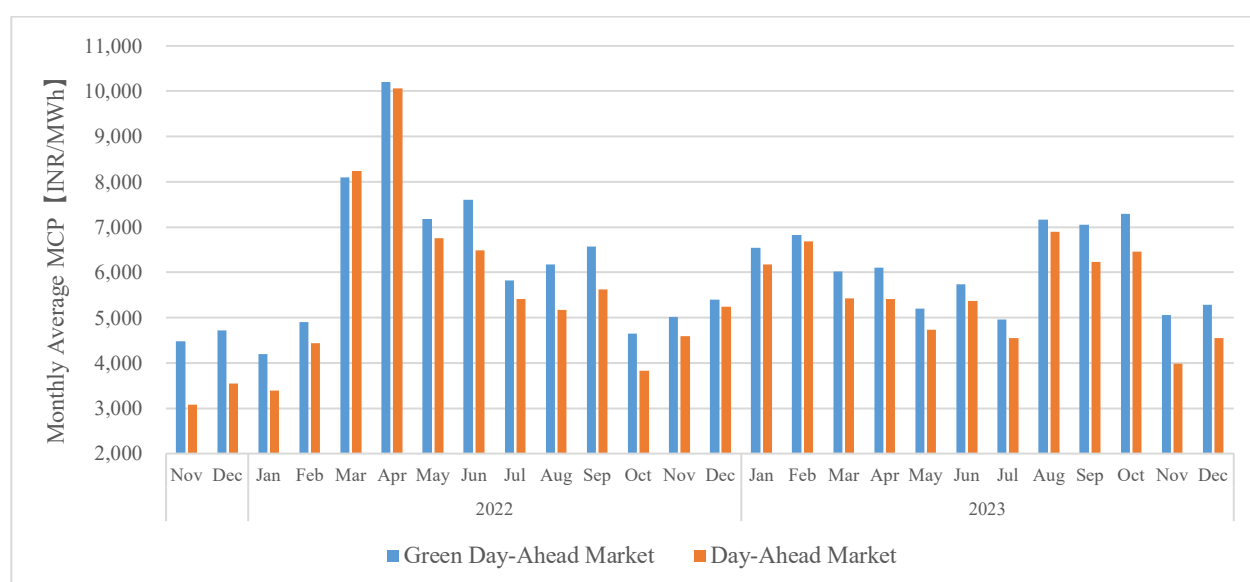
(b) Green Day-Ahead Market

The main market for renewable energy trading on IEX is the Green Day-Ahead Market. This market has been in operation since October 2021, and as described in Chapter 8.2.1, amid the global trend of achieving decarbonization, India is also formulating plans to reduce greenhouse gases. As a measure to promote the introduction of renewable energy, it requires power distribution companies to procure a certain percentage of renewable

energy. Therefore, it is expected that the trading volume in this market will increase in the future.

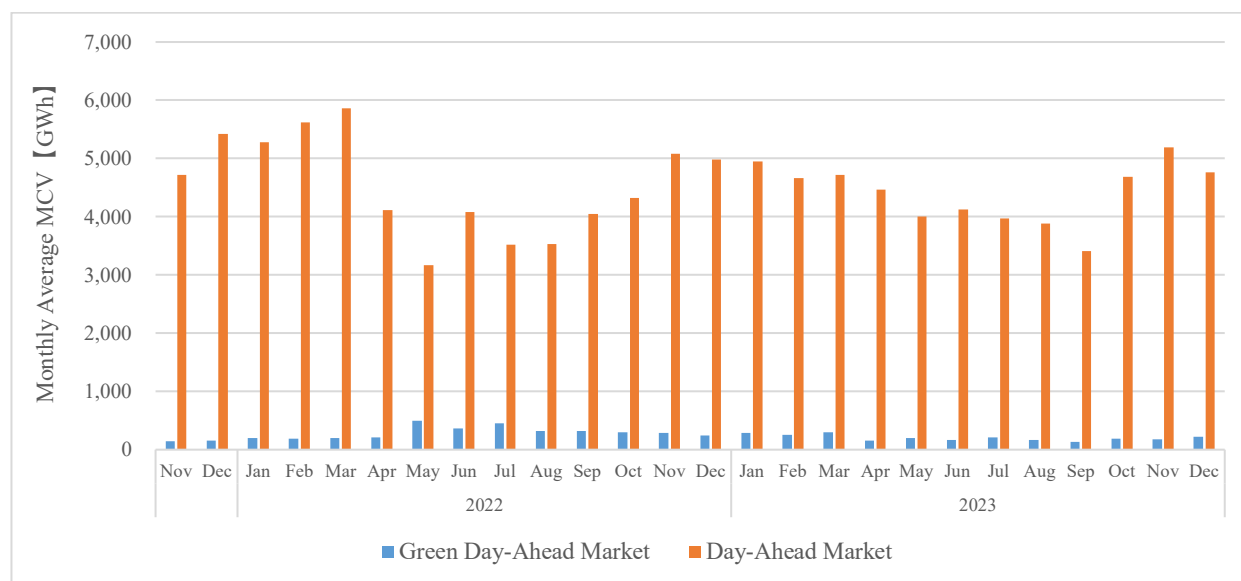
The results of comparing MCP and MCV with the trading performance on the Day-Ahead Market from November 2021 to December 2023 are shown in Figure 8.1-9 and Figure 8.1-10.

The amount of electricity traded on the Green Day-Ahead Market during the period from November 2021 to December 2023 was approximately 5.4% of the amount traded on the regular Day-Ahead Market. Regarding prices, Green Day-Ahead Market is trading at about 10% higher prices. The electricity traded in the Green Day-Ahead Market is derived from renewable energy sources and is more valuable to consumers due to its superior environmental performance. Therefore, it is assumed that it is traded at a higher price than the Day-Ahead Market contract price. On the other hand, the contract volume is smaller than that of the Day-Ahead Market. This is assumed to be because the Green Day-Ahead Market is a new market and many operators do not see the advantage of buying electricity at a higher price than the Day-Ahead Market.



Source: Prepared by JICA Study Team from IEX HP

Figure 8.1-9 Monthly Average of IEX Price (MCP) comparison (INR/MWh)



Source: Prepared by JICA Study Team from IEX HP

Figure 8.1-10 Monthly Average of IEX Volume (MCV) comparison (MWh)

As for the Green Day-Ahead Market, MCP tend to be higher than those of the regular Day-Ahead Market, and MCV is expected to increase due to procurement for the purpose of reducing greenhouse gas emissions in India in the future. Since March 2023, electricity generated by hydropower plant has also been traded on this market. According to interviews with IEX officials, all hydropower plants in India can now participate in the Green Day-Ahead Market, and even run-of-river hydropower plants, which are common in Nepal, can participate. However, under the current regulation, power plants outside India cannot participate in the Green Dar-Ahead Market, so from now on it will be necessary to obtain permission for participation in this market from outside India through government negotiations.

(3) Deviation Settlement Mechanism (DSM)

DSM is a system that is applied in the electricity market when the contracted quantity does not match the actual volume traded.

The DSM is applied either nationwide system managed by CERC, or states level system managed by each SERC (State Electricity Regulatory Commission). Generators that trade power with interstates and supply power across states are subject to DSM system by CERC, and generators that supply power in a state and distribution companies are subject to DSM systems by SERC. Therefore, Nepal is applied to DSM by CERC regarding exporting power to India. For each state's DSM system, the basic policy on how to set prices and penalties is in accordance with CERC.

A unit price of DSM is determined based on the frequency average in the power grid at each time block (every 15 minute). In the event that the actual trading results deviate from the previously agreed-upon amount of electricity generated or demanded by each generator or purchaser, the difference is calculated and settled by multiplying the DSM unit price by the amount of difference. Under the nation-wide DSM system of CERC, the settlement amount is calculated by Regional Power Committee in each area based on data which provided Regional Load Dispatch Center in 5 areas every week with, and the amount is claimed and paid to each company.

Previously, DSM rate unit prices were set to vary with each time block average system frequency. However, this was based solely on actual frequency and did not take into account market price

volatility. Therefore, if the normal market price was expected to be higher than the DSM rate, distribution companies could arbitrarily choose the less expensive DSM rate instead of the spot market. Therefore, a price mechanism has now been adopted that incorporates a market price component in the price vector that determines the DSM unit price.

Figure 8.1-11 shows the image of the unit price of DSM calculated. “P” in the table means the daily average unit price of ACP of Day-Ahead Market. The system of the formula to calculate the unit price of DSM is as follows: As the system frequency decreases from 50.05Hz to 50.00Hz. The unit price increases linearly from 0 to P, and the unit price increases linearly from P to 800paise/kWh (8INR/kWh) as the system frequency decrease from 50.00Hz to 49.85Hz. The price is constant by 800paise/kWh as the upper limit if the system frequency is under 49.85Hz.

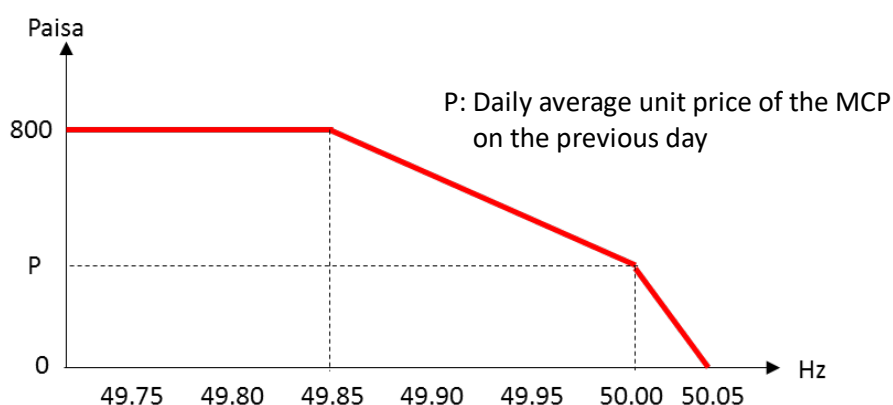


Figure 8.1-11 Deviation Price in Deviation Settlement Mechanism

If companies causes the excessive deviation, they have to pay a penalty. In each time block, if generation companies or distribution companies cause the deficit imbalance of more than 12% or 150MW, they have to pay the following penalty in the concerned time block.

Table 8.1-9 Unit price surcharge in DSM

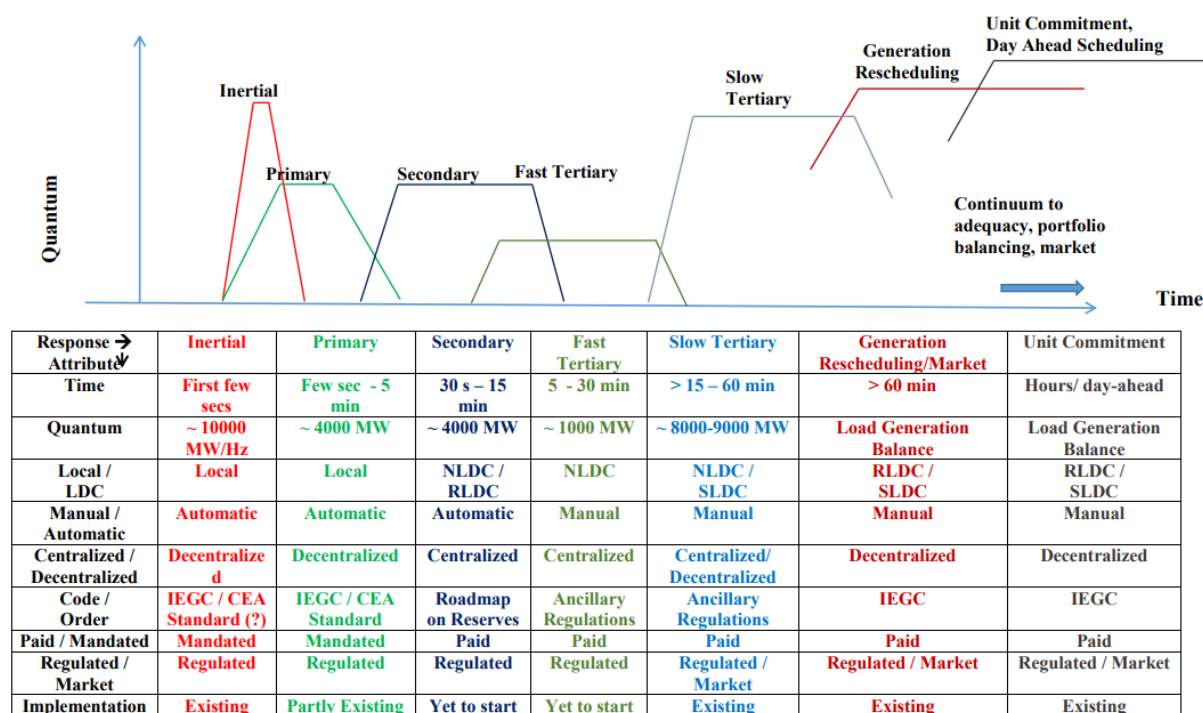
Shortage imbalance generated	Penalty
12~15% or 150~200MW	20% increase
15~20% or 200~250MW	40% increase
20% or Exceeds 250MW	100% increase

In addition, the total amount of imbalance generated per day was also penalized. Concretely, in case that the difference between the total planned amount of a day and the total actual amount of a day is over 1% for generation companies and over 3% for purchaser, they are imposed on the penalty that the amount of payment of DSM increases by 20%. Also, it includes additional regulations not only for the amount of the deviation but also the deviation vector. In case that the deviation with the same direction (surplus / shortage) continues for more than 7 time blocks, the companies have to pay the price of DSM which increases by 20% per a day.

(4) Efforts to establish an Ancillary Market

India is preparing for an ancillary market. Figure 8.1-12 shows a schematic diagram of the design of the Ancillary Market in India. For example, Secondary service requires generation within 30 seconds to 5 minutes of command, and the plan is to secure about 4,000 MW. The Fast Tertiary service requires power generation within 5 to 30 minutes of command, and is planned to secure

approximately 1,000 MW. In the future, hydropower plants in Nepal are also expected to participate in the Ancillary Market.



Source: Report of Expert Group to review and suggest measures for bringing power system operation closer to National Reference Frequency, CERC, Nov 2017)

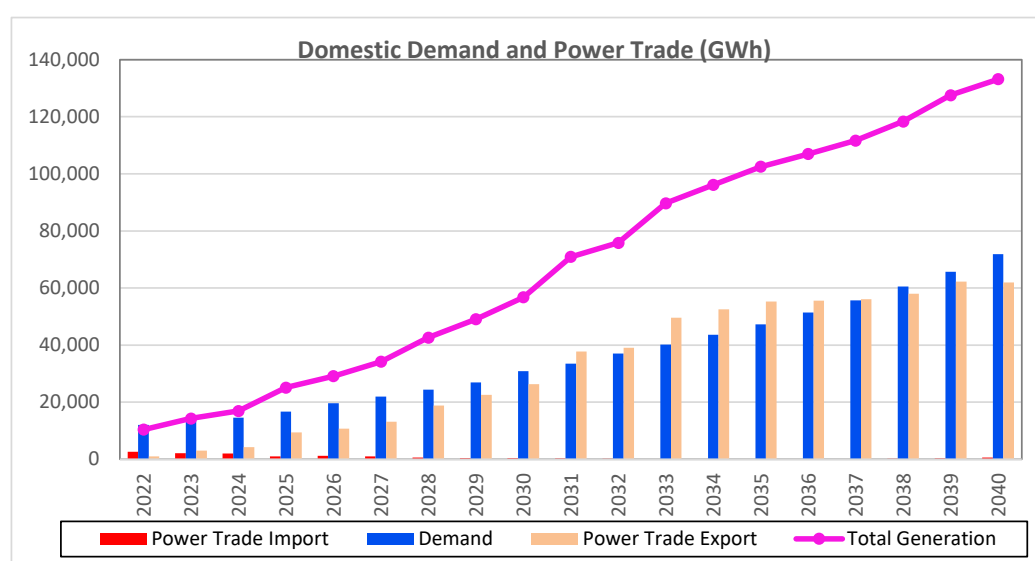
Figure 8.1-12 Overview of the Ancillary Market in India

8.2 OUTLOOK FOR POWER TRADE IN NEPAL

8.2.1 Assumption of the Amount of Electricity that can be Exported

As described in Chapter 7, future development will be based on the Optimum Scenario, which is based on Scenario 3: Hydro Middle. Figure 8.2-1 shows the annual power generation and demand forecast under the optimal scenario. The peach line represents total power generation, the blue bars represent estimated demand, the orange bars represent possible exports volume, and the red bars represent import requirements volume.

Scenarios 3 results in a large surplus of electricity toward 2040, which is assumed to provide more opportunities to export electricity to neighboring countries. Table 8.2-1 shows the peak demand for each country and Nepal's generation capacity through 2040. India's peak demand is assumed to be about 50 times Nepal's peak demand and Bangladesh's peak demand is assumed to be more than 4 times Nepal's peak demand as of 2040.



Source: Prepared by JICA Study Team

Figure 8.2-1 Forecasted Annual Power Generation and Demand (Scenario 3)

Table 8.2-1 Peak demand in each country and Nepal's generation capacity by 2040

	Installed capacity in Nepal	Peak demand in Nepal	Peak demand In India	Peak demand In Bangladesh
2025	6,343 MW	2,675 MW	260,118 MW	22,883 MW
2030	14,600 MW	4,949 MW	350,670 MW	31,910 MW
2035	28,215 MW	7,581 MW	465,531 MW	41,050 MW
2040	36,327 MW	11,510 MW	574,689 MW	50,253 MW

In neighboring countries, India and Bangladesh, the power demand will increase in the future, and they make policies that they will not only develop own power sources but also export power from their neighboring countries. In addition to it, Nepal is expected to be able to contribute to decarbonizing and the power supply by exporting power to neighboring countries because Nepal has a potential of hydropower generations and generators without emitting CO₂ have been focused on by a trend of decarbonizing.

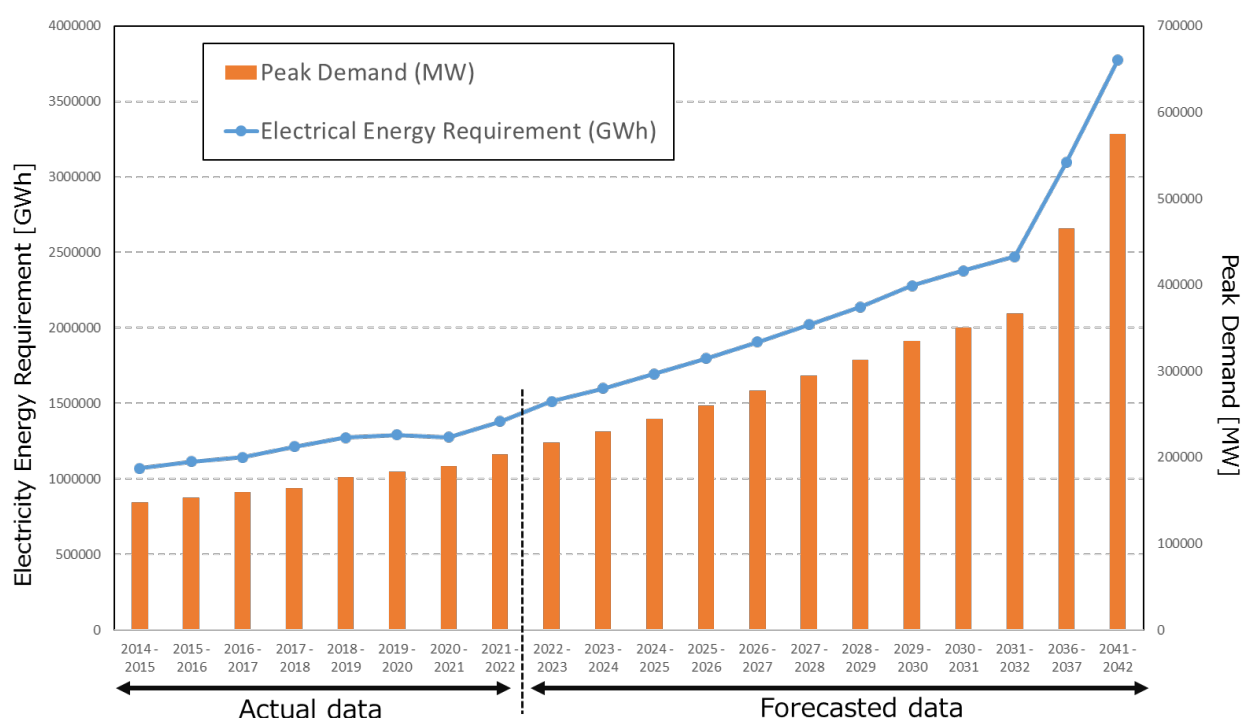
In the future, Nepal will have a high expectation because the amount of generation exceed to domestic demand and they can export to neighboring countries in not only the rainy season but also the dry season. In January 2024, a long-term electricity export agreement was signed between India and Nepal. As part of this agreement, both parties have agreed that the amount of electricity exported from Nepal to India will be 10,000MW over the next 10 years, and the amount of electricity exported to India is expected to increase. The long constant supply and profit will be expected by power trade with IEX more and if bilateral agreements including PPA (Power Purchase Agreement) contracts can be conducted. With considering that India has mainly coal-typed thermal power generations, Nepal will be able to contribute to power supply for India and to decarbonizing by exporting power generated by the renewable energy, hydro-powers, of Nepal.

8.2.2 Electricity Supply and Demand Outlook in India

(1) Electricity Demand Forecast

The result of the generated amount including T&D losses in India is approx. 1,210TWh in FY2018, approx. 1,300TWh in FY2019 and approx. 1,280TWh in FY2020, which basically shows that the amount has increased (It decreased a little in FY2020 due to the impact of COVID-19). Also, peak demand in India has increased; approx. 177GW in FY2018, approx. 180GW in FY2019 and approx. 190GW in FY2020.

CEA made a report, 20th Electric Power Survey in November 2022, and the report has the power demand forecast for every year to 2041/2042. Figure 8.2-2 shows the actual and forecasted data of Energy Requirement including T&D losses and of Peak Demand. It is forecasted that the peak demand reaches 574GW and the electricity energy requirement does 3,776TWh at 2041/2042.



Source: Prepared by JICA Study Team from 20th Electric Power Survey

Figure 8.2-2 Actual and forecasted data of Energy Requirement including T&D losses and of Peak Demand

(2) Future Energy Policy

Based on the Electricity Act formulated in 2003, CEA makes the National Energy Plan. They also made ten-year National Electricity Plan Volume I (Generation).

At the 21st COP (the Conference of the Parties) to UNFCCC (United Nations Framework Convention on Climate Change), emission of greenhouse gas will decrease by 33 to 35% to GDP ratio compared with 2005 by 2030, and Power Sector is also subject to the policy. Based on the policy, the National Electricity Plan says that aging thermal power plants that cannot follow the environment regulation are going to be abolished by 46.29GW from 2022 to 2027. Table 8.2-2 shows the power development plans in India through 2032. India will not abolish coal-thermal power plants completely and will install new ones by about 35GW by 2032. Although India consider reducing CO₂ emission, they think that coal is a significant energy source by 2040 at least.

Table 8.2-2 Power development plan by power source in India

	2022~2027	2027~2032
Thermal	approx. 26GW	approx. 25GW
Nuclear	approx. 6GW	approx. 7GW
Hydro	approx. 11GW	approx. 10GW
Solar	approx. 132GW	approx. 179GW
Wind	approx. 33GW	approx. 49GW
Biomass	approx. 2GW	approx. 3GW
Pumped storage	approx. 3GW	approx. 19GW
total	approx. 212GW	approx. 292GW

Source: Prepared by JICA Study Team from REPORT ON TWENTIETH ELECTRIC POWER SURVEY OF INDIA (VOLUME-I)

On the other hand, India has traded power with Bhutan since before and started to do with Nepal recently. The plan says that the amount of importing power from Bhutan and Nepal are expected to increase by 2027 but not to increase the amount from 2028 to 2030, which may be based on hydropower plants planned and constructed currently. Therefore, this plan may be changed in the future because of the change of the trading allowance between Nepal and India.

The Indian government has introduced a policy for certain consumers, including distribution companies, to procure a certain percentage of electricity from renewable energy sources, and the percentage is shown in Table 8.2-3. In addition, hydropower plants only covered electricity from within India, but from April 2024, it has been decided that hydropower plant from outside India will also be covered by this system.

Table 8.2-3 Renewable energy procurement ratio required for distribution companies in India

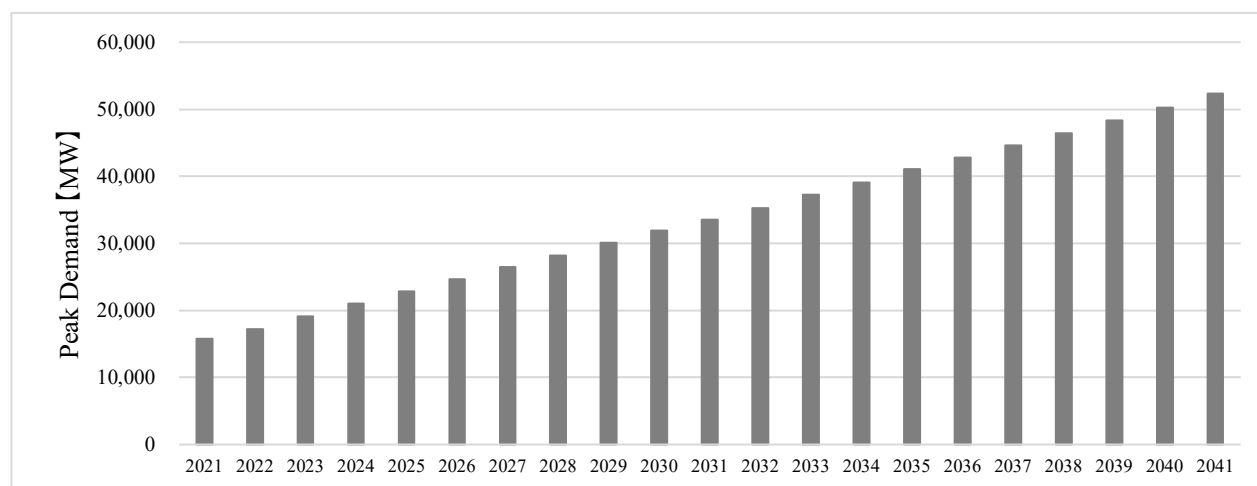
Year	Wind Renewable Energy	Hydro Renewable Energy	Distributed Renewable Energy	Other Renewable Energy	Total Renewable Energy
2024-25	0.67%	0.38%	1.50%	27.35%	29.91%
2025-26	1.45%	1.22%	2.10%	28.24%	33.01%
2026-27	1.97%	1.34%	2.70%	29.94%	35.95%
2027-28	2.45%	1.42%	3.30%	31.64%	38.81%
2028-29	2.95%	1.42%	3.90%	33.10%	41.36%
2029-30	3.48%	1.33%	4.50%	34.02%	43.33%

Source: Prepared by JICA Study Team from Ministry of Power HP

8.2.3 Electricity Supply and Demand Outlook in Bangladesh

(1) Electricity Demand Forecast

The Integrated Energy and Power Master Plan (IEPMP) 2023 was developed by the Government of Bangladesh. In the plan, peak demand projections to 2041 are shown in Figure 8.2-3. Peak demand is expected to increase by 2.5 times by 2041. It is forecasted that the peak demand reaches 52GW at 2041.



Source: JICA Study Team from Integrated Energy and Power Master Plan 2023

Figure 8.2-3 Peak Demand Forecast in Bangladesh

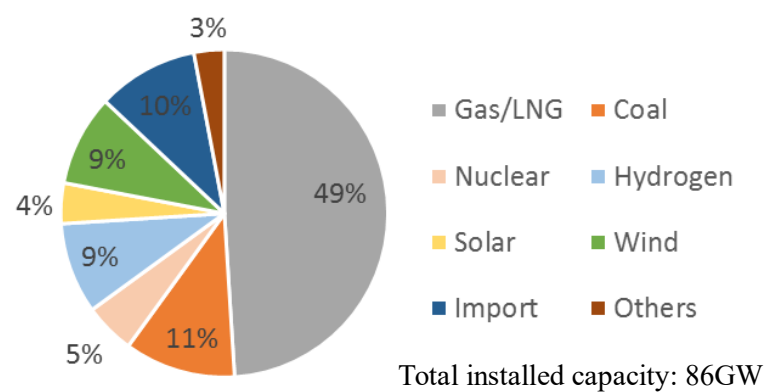
(2) Future Energy Policy

Government of Bangladesh published “8th five-year plan” in December, 2020. It says that Power Sector has been the most significant, which was also stated in “7th five-year plan”. Also, it says that the strategy for Power Sector is mentioned, whose goals are mainly that “Optimal Energy Mix and Reduction of T&D losses” and “Implementation of power system with minimum costs by utilizing renewable energies and so on. The following policy is one of the nine major policies listed for the power sector:

Enhance the exploitation of gas, coal, renewable resources, increased energy imports particularly hydropower from neighbouring Bhutan and Nepal in order to optimize the energy mix and reduce the dependence on imported furnace oil and HSD. In this regard hydropower, given its abundance in the neighbouring countries and expected cheaper cost of production, will be given prime importance among other renewable resources. The other renewable resources include wind power, solar energy, biomass and waste to power, where the core strategic goal will be to make the energy available at optimum rate to all consumers;

The detailed strategy aims to shift from high cost power sources such as HSD (High Speed Diesel) and generators using Furnace Oil to renewable energies and to structure Energy Mix with low costs such as Coal-Fired thermal power plants and so on. Also, it mentions that power trade of hydropower plants of neighboring countries is the most significant factor and it designs a plan to increase the amount of power trade among Bhutan, India and Nepal.

Figure 8.2-4 shows the power source composition of Bangladesh in 2041. As of 2041, Bangladesh still has a high percentage of fossil fuel-derived power sources, so importing hydroelectric power from Nepal is an option for Bangladesh, which wants to increase its share of renewable energy.



Source: JICA Study Team from Integrated Energy and Power Master Plan 2023

Figure 8.2-4 Peak Demand Forecast in Bangladesh

8.3 CURRENT STATUS OF PLANS TO EXPAND EXPORTS

Efforts to expand electricity exports can be broadly classified into two types of trades: one involving exports from the NEA power grid to the power grids of neighboring countries such as India and Bangladesh, and the other involving exports from individual power generation projects in Nepal to neighboring countries. The former is the Bilateral Trade (PEC mechanism, G to G Trade) and expansion of IEX, while the latter assumes export-oriented hydropower projects such as Arun 3. This section summarizes the current status of projects related to electricity exports under consideration as of November 2024, divided into both formats.

8.3.1 Status of Electricity Exports from Nepal's Grid

Nepal is in discussions with neighboring countries of India and Bangladesh to expand export volume. The current status of discussions with neighboring countries is shown in Table 8.3-1.

Table 8.3-1 Status of negotiations with Neighboring countries

Country	Period	Status of negotiations
India	January, 2024	Both parties have agreed to export up to 10,000 MW of electricity from Nepal to India over the next 10 years.
	April, 2024	The Indian government has established an obligation for Indian electricity consumers to purchase hydropower, and as part of this obligation, it has established a provision that allows for purchases from hydropower outside of the country to be accounted for.
	May, 2024	Nepal is in discussions with the Indian states of Haryana and Bihar to conclude medium-term power purchase agreements. Of these, discussions are underway with the state of Haryana for a bilateral trade with local government to export 400 MW of power between June and November for a period of five years.
	August, 2024	India has approved the export of an additional 251 MW from 12 new hydropower projects in Nepal for trading on IEX. Nepal can export 941 MW of electricity from 28 hydropower projects in total.
Bangladesh	October, 2024	A government-to-government trade between Nepal and Bangladesh to export 40 MW of electricity to Bangladesh over a 5 year period has been approved between Nepal, India, and Bangladesh. For this tripartite G to G trade, electricity will be exported from Nepal to Bangladesh over a five-month period from June to November, which is Nepal's rainy season. The CEA permit was granted on November 15, 2024, and exports from Nepal to Bangladesh were implemented, only for one day as for 2024. The unit price for trade between Bangladesh and Nepal will be 6.4 cents/kWh, and metering will be done in Muzaffarpur in India. In addition, Bangladesh will pay to India a transmission charge and cost equivalent to transmission losses occurring within India.

Source: Prepared by JICA Study Team based on interviews with NEA Power Trade Division

Regarding power exports from NEA's grid, power exports to India have been increasing every year, and a MOU (Memorandum of Understanding) has been signed that sets a maximum of 10,000 MW for exports to India over the next 10 years. In addition, an agreement to export 40 MW of electricity to Bangladesh has also been signed, and this trade is expected to expand in the future.

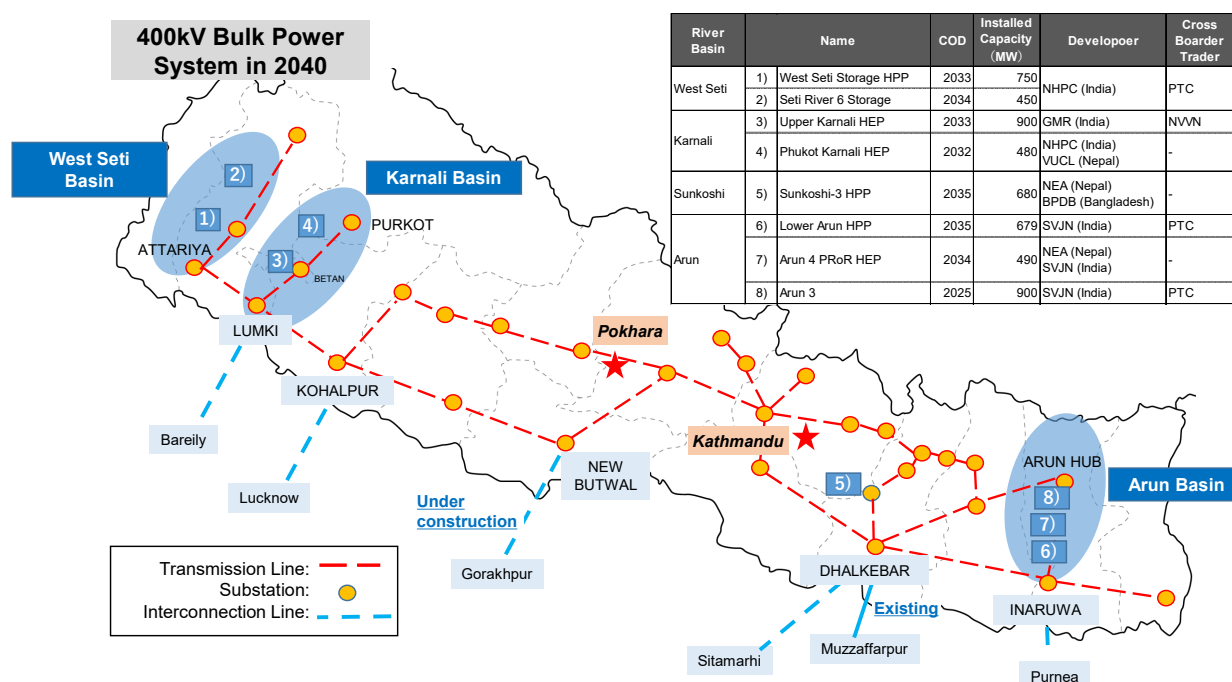
In the Energy Development Roadmap and Work Plan 2035 being developed by MoEWRI, power exports for 2035 are planned to be 10,000 MW for India and 5,000 MW for Bangladesh. The Power Development Plan has been formulated with this in mind, and as shown in Table 8.2-1, Nepal's power generation capacity in 2035 is 28,215 MW and domestic demand is 7,581 MW, ensuring

sufficient supply capacity.

While power exports are expected to expand over the medium to long term, the current IEX trade, which is the main power export scheme, requires approval for each power plant every year for exporting power to India. Therefore, NEA is unable to make stable sales forecasts for the medium to long term, and is forced to bear the risk of purchasing power from IPPs.

8.3.2 Status of Exports from Individual Hydropower Plants

Hydroelectric power plant for export is located in the West Seti, Karnali, Sunkoshi, and Arun water systems. The West Seti and Arun water systems are led by NHPC (National Hydroelectric Power Corporation) and SJVN (Satluj Jal Vidyut Nigam), respectively, which are Indian public corporations. These have a different trade scheme described in 8.1.1 (2): they are expected to sell power directly to NVVN, PTC or the distribution companies in India, rather than through the NEA. This section summarizes the status of hydropower development for export in these water systems and discusses future issues, including the domestic grid and interconnection lines. Figure 8.3-1 provides an overview and location map of the eight export-oriented hydropower sites currently planned and under construction in Nepal, and summarizes the implementation status of each water system.



Source: Prepared by JICA Study Team

Figure 8.3-1 Location map of hydroelectric power plants and transmission lines for export

(1) West Seti water system

In the West Seti system, two hydroelectric projects are planned for export: 1) West Seti HPP (750 MW) and 2) Seti River 6 Storage (450 MW). Although this system has long been recognized as a promising hydropower potential and technical studies have been conducted, no concrete development plan had been raised due to its remote location away from the main grid. However, in August 2022, NHPC obtained a Survey License from IBN (Investment Board of Nepal) and is currently conducting an F/S (Feasibility Study) update and EIA (Environmental Impact Assessment).

These points are expected to be supplied to India through the Lumki - Bareilly interconnection line via the West Seti - Attariya transmission line, which will be developed along the West Seti River, part of the domestic 400kV system. It is announced that PTC India, a trading company, will be in charge of supplying power to India.

West Seti and Seti River 6 are large STOs (Storage), so environmental impacts are also a concern, but from the perspective of power export, the development of the West Seti-Attariya-Lumki 400 kV domestic transmission line and the Lumki - Bareilly international interconnection line will be a challenge. Since it is expected that the two sites will be operational in the early 2030s, the developers and financing for both the 400 kV domestic grid and the interconnection line have not yet been decided.

(2) Karnali water system

In the Karnali water system, two sites, 3) Upper Karnali HEP (900 MW) and 4) Phurkot Karnali HEP (480 MW), are planned as hydropower plant for export.

Upper Karnali has development rights held by GMR, an Indian infrastructure company, which signed a Project Development Agreement with IBN in 2014. The site is envisioned to supply electricity to Nepal, India, and Bangladesh, and the PPA was signed with BPDB (Bangladesh Power Development Board) and NVVN of India in 2023. However, the term of the PDA (Project Development Agreement) has been repeatedly extended due to the lack of funding prospects, and in May 2023, the Supreme Court indicated that it would not allow further extensions, and in August 2024, IBN notified the expiration of the PDA in January 2025.

VUCL (Vidhyut Utpadan Co., Ltd.) of Nepal holds the development rights for Phurkot Karnali, and a DPR (Detailed Project Report) has been completed. In the interview with VUCL, VUCL stated that it expects to implement the project with NHPC, but that it will also consider Nepal-led development if the two parties are unable to reach an agreement. VUCL is considering signing a Memorandum of Understanding (MOU) with India's NHPC for the development of the site in 2023, with NHPC holding 51% and VUCL 49%, with India taking the lead in implementation. In the hearing from VUCL, VUCL stated that it expects to implement the project with NHPC, but that it will consider Nepal's initiative in the event that the two parties cannot reach an agreement.

These export points on the Karnali water system are expected to supply power to India via the Phurkot - Betan - Lumki transmission line on the 400 kV domestic grid and through the Lumki - Bareilly interconnection line. The Upper Karnali is expected to be supplied to India via the Phurkot - Betan - Lumki transmission line. Upper Karnali is also expected to supply power to Bangladesh, but the India-Bangladesh flow has not been studied at this time. Export to Bangladesh will be subject to Nepalese and Indian tariffs. NVVN is expected to be in charge of settlement.

In terms of power exports, the development of the Phurkot - Betan - Lumki transmission line and the Lumki - Bareilly interconnection line for the 400 kV domestic system is a concern. Phurkot - Betan - Lumki transmission line is to be constructed by RPGCL (Rastriya Prasaran Grid Co. Ltd.), but interviews with VUCL indicate that it is at the study stage at this time. In addition, VUCL has no experience in hydropower development and recognizes the need to strengthen its technical, environmental, commercial, and legal capabilities in establishing a joint venture (JV) with NHPC, a large hydropower operator in India. In the future, it will be necessary to proceed with JVA (Joint Venture Agreement), grid interconnection with India, and PPA negotiations with Indian trading companies and customers.

(3) Sunkoshi water system

In the Sunkoshi water system, 5) Sunkoshi 3 HPP (680 MW) is planned as a hydropower site for export. This site is being developed under the leadership of NEA, and is expected to export electricity to Bangladesh and India. According to interviews with NEA, a D/D (Detailed Design) consultant is currently being recruited and discussions with the Indian side began last year. The Indian operator has been in discussions since last year, and will be considering the project implementation structure, including financing. The participants also shared the understanding that the site is not economically feasible, and that a loan from a development assistance organization will be required.

The Sunkoshi 3 sites are easily accessible from the road and can be easily connected to the domestic grid. The 400 kV domestic Sunkoshi - Dhalkebar 400 kV transmission line is expected to be constructed and exported to India and Bangladesh via the existing Dhalkebar - Muzzaffapur or Sitamathi, and these developments should also be pursued.

In terms of power export, it is necessary to confirm the transmission line capacity for the development of a 400 kV domestic grid and for export from the existing Dhalkebar interconnection line. NEA has abundant experience in domestic hydropower development, and also has experience in inter-grid power exchange with NVVN and PTC in India. However, this is the first case of developing an individual plant-to-grid power plant for export, and NEA will need to take the initiative in studying the feasibility of PPA, grid interconnection, and transmission charges.

(4) Arun water system

In the Arun water system, 6) Lower Arun HPP (679 MW), 7) Arun 4 PRoR (490 MW), and 8) Arun 3 (900 MW) are planned as hydropower sites for export. For these power plants, SVJN, a power company in the Indian state of Himachal Pradesh, has been granted development rights by IBN for Lower Arun and Arun 3, and joint development with SVJN is being considered for Arun 4, although NEA has the development rights. Arun 3 is the only export hydropower site that is in the construction phase and is scheduled to be operational in 2025. Lower Arun has also signed a PDA for 2023 and regarding trading company Arun 3 and Lower Arun are expected to be handled by PTC.

Regarding transmission lines, SVJN is developing the Arun 3 - Dhalkebar transmission line for the 400 kV domestic system and the Dhalkebar - Sitamarhi interconnection line for the export of Arun 3. Once Arun 3 – Dhalkebar transmission line is developed, it will be possible to export electricity from this system. On the other hand, the Lower Arun will be exported from Inaruwa due to its location, and the Upper Arun (1060 MW) and Kimarathanka Arun (456 MW) are planned to be developed upstream of the Arun water system, and the Arun Hub - Inaruwa 400 kV domestic transmission line will be developed. Therefore, future power exports from the Arun water system, including the Lower Arun, are being considered for transmission via the Arun Hub - Inaruwa transmission line.

Arun 3, the first export project in Nepal, is expected to be operational within the next few years, although it has been delayed from the initial plan. SVJN, an Indian public company, is leading the development of the project from the power plant to the transmission line, and Nepal's involvement in the financial, commercial, and legal aspects of the project is limited. Although 21.9% of Free Power has been obtained as a benefit to Nepal, Nepal has not accumulated experience and achievements as an implementing agency in terms of promoting electricity exports. For this reason, the Nepalese side is expected to be involved in Arun 4 and other projects in the future.

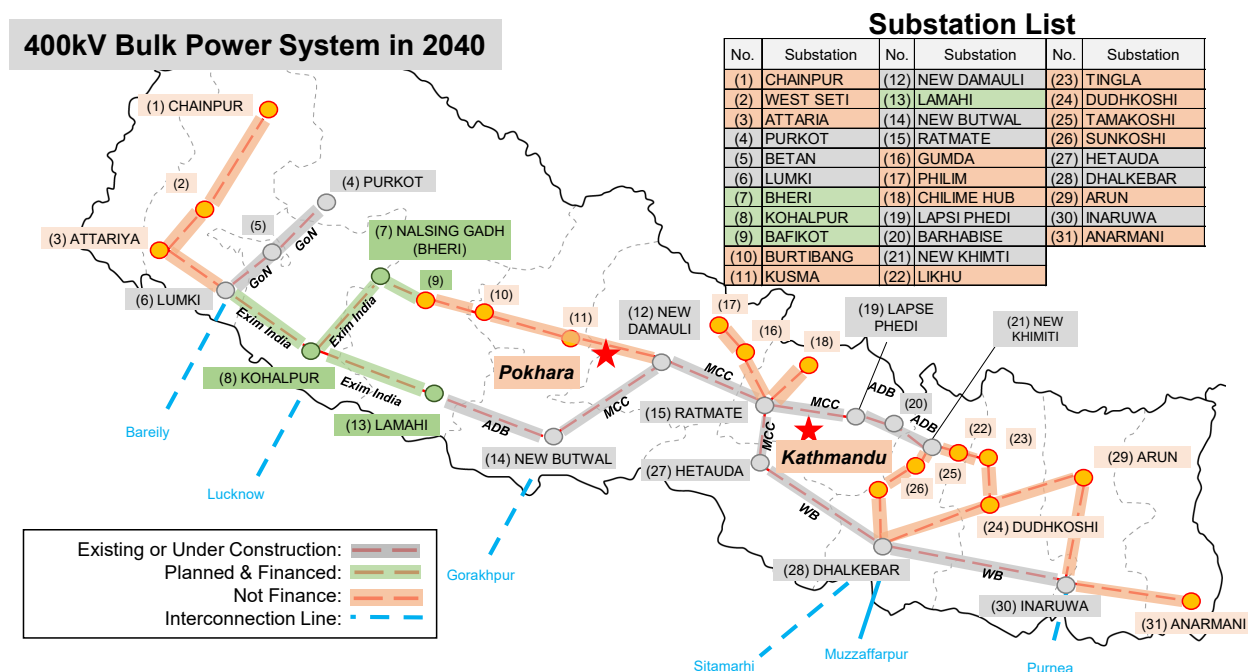
8.4 CONSIDERATION FOR FUTURE EXPORT EXPANSION

8.4.1 Challenges for Future Export Expansion

Issues related to the development of transmission lines, including domestic power systems and international interconnection lines, as well as issues related to various contracts and applications are summarized below.

(1) Challenges in Grid Development

Based on the status of individual hydropower plants described in the previous section, it was clarified that the transmission line for grid development will require both a 400 kV domestic grid in Nepal and interconnection lines connecting Nepal and India. Based on this understanding, Figure 8.4-1, Table 8.4-1, and Table 8.4-2 summarize the development status of the 400 kV domestic grid.



Source: Prepared by JICA Study Team

Figure 8.4-1 Current status of development plans for 400kV grid and interconnection lines

Table 8.4-1 Current status of development plans for 400kV substation

No.	Substation	State	Developer	Finance
(1)	CHAINPUR	Plan	-	-
(2)	WEST SETI	Plan	RPGCL	-
(3)	ATTARIA	Plan	-	-
(4)	PURKOT	Under Construction	RPGCL	GoN
(5)	BETAN	Under Construction	RPGCL	GoN
(6)	LUMKI	Under Construction	RPGCL	GoN
(7)	BHERI	Plan	-	Exim India
(8)	KOHALPUR	Plan	NEA	Exim India
(9)	BAFIKOT	Plan	NEA	Exim India
(10)	BURTIBANG	Plan	NEA	-
(11)	KUSMA	Plan	NEA	-
(12)	NEW DAMAULI	Under Construction	NEA	MCC
(13)	LAMAHI	Plan	NEA	Exim India
(14)	NEW BUTWAL	Under Construction	NEA	ADB
(15)	RATMATE	Under Construction	NEA	MCC
(16)	GUMDA	Plan	NEA	-
(17)	PHILIM	Plan	NEA	-
(18)	CHILIME HUB	Plan	-	-
(19)	LAPSI PHEDI	Under Construction	NEA	MCC
(20)	BARHABISE	Under Construction	NEA	ADB
(21)	NEW KHIMTI	Under Construction	NEA	ADB
(22)	LIKHU	Plan	NEA	-
(23)	TINGLA	Plan	NEA	-
(24)	DUDHKOSHI	Plan	NEA	-
(25)	TAMAKOSHI	Plan	NEA	-
(26)	SUNKOSHI	Plan	NEA	-
(27)	HETAUDA	Under Construction	NEA	MCC
(28)	DHALKEBAR	Existing	NEA	WB
(29)	ARUN	Plan	NEA	-
(30)	INARUWA	Under Construction	NEA	WB
(31)	ANARMANI	Plan	NEA	-

Source: Prepared by JICA Study Team

With the support of MCC (Millennium Challenge Corporation), WB (World Bank), ADB (Asian Development Bank), etc., the 400 kV domestic grid is under construction or planned for most of the major cities in the country, including Kathmandu and Pokhara. As for the interconnection lines, the existing Dhalkebar-Muzzaffapur interconnection line and the New Butwal-Gorakhpur interconnection line under construction are capable of handling power imports to major cities in the country and hydropower exports in the Gandaki water system and western Koshi water system, both of which are already under construction.

Table 8.4-2 Current status of development plans for 400kV transmission line

Substation From	Substation To	State	Developer	Finance
(1) CHAINPUR	(2) WEST SETI	Plan	-	-
(2) WEST SETI	(3) ATTARIA	Plan	RPGCL	-
(3) ATTARIA	(6) LUMKI	Plan	NEA	-
(4) PURKOT	(5) BETAN	Under Construction	RPGCL	GoN
(5) BETAN	(6) LUMKI	Under Construction	RPGCL	GoN
(6) LUMKI	(8) KOHALPUR	Plan	NEA	Exim India
(7) BHERI	(8) KOHALPUR	Plan	-	Exim India
(7) BHERI	(9) BAFIKOT	Plan	-	Exim India
(8) KOHALPUR	(13) LAMAHI	Plan	NEA	Exim India
(9) BAFIKOT	(10) BURTIBANG	Plan	NEA	-
(10) BURTIBANG	(11) KUSMA	Plan	NEA	-
(11) KUSMA	(12) NEW DAMAULI	Plan	NEA	-
(12) NEW DAMAULI	(14) NEW BUTWAL	Plan	NEA	MCC
(12) NEW DAMAULI	(15) RATMATE	Plan	NEA	MCC
(13) LAMAHI	(14) NEW BUTWAL	Under Construction	NEA	ADB
(15) RATMATE	(16) GUMDA	Plan	NEA	-
(15) RATMATE	(18) CHILIME HUB	Plan	-	-
(16) GUMDA	(17) PHILIM	Plan	NEA	-
(15) RATMATE	(19) LAPSI PHEDI	Plan	NEA	MCC
(15) RATMATE	(27) HETAUDA	Plan	NEA	MCC
(19) LAPSI PHEDI	(20) BARHABISE	Under Construction	NEA	ADB
(20) BARHABISE	(21) NEW KHIMTI	Under Construction	NEA	ADB
(21) NEW KHIMTI	(22) LIKHU	Plan	NEA	-
(21) NEW KHIMTI	(25) TAMAKOSHI	Plan	NEA	-
(22) LIKHU	(23) TINGLA	Plan	NEA	-
(23) TINGLA	(24) DUDHKOSHI	Plan	NEA	-
(24) DUDHKOSHI	(28) DHALKEBAR	Plan	NEA	-
(24) DUDHKOSHI	(29) ARUN	Plan	NEA	-
(25) TAMAKOSHI	(26) SUNKOSHI	Plan	NEA	-
(26) SUNKOSHI	(28) DHALKEBAR	Plan	NEA	-
(27) HETAUDA	(28) DHALKEBAR	Under Construction	NEA	WB
(28) DHALKEBAR	(30) INARUWA	Existing	NEA	WB
(29) ARUN	(30) INARUWA	Plan	NEA	-
(30) INARUWA	(31) ANARMANI	Plan	NEA	-

Source: Prepared by JICA Study Team

On the other hand, in consideration of future export expansion, it will be necessary to develop 400 kV domestic grids and interconnection lines for water systems that will be developed in the future, such as the West Seti, Karnali, Bheri, Dudhokoshi, Arun, and Tamor water systems. Based on this recognition, the issues of grid development for power export are summarized.

1) Strengthening the NEA and RPGCL implementation framework

Regarding the development of the domestic grid, the construction of transmission lines from power plants to interconnection lines should be systematically developed under the leadership of NEA and RPGCL, the grid operators, for the following reasons.

- Rivers where hydroelectric power plants are located are in steep mountainous areas, and transmission line voltage and capacities must be set for each water system because the routes where transmission lines can be constructed are limited.
- When power producers such as IPPs construct transmission lines, the transmission line capacity is set based on the installed output of individual power plants, which is a disincentive for new hydroelectric power plants.

- For the Tarai Plain, there are no topographical difficulties in constructing transmission lines, but many issues from the perspective of land expropriation have arisen, and the construction of individual transmission lines by IPPs must be avoided.

NEA and RPGCL are also aware of these issues, and have expressed their intention to take the lead in developing the domestic system after Arun 3. On the other hand, since the only experience of implementing 400 kV transmission and substation facilities in Nepal is the existing Dhalkebar international interconnection line and the Inaruwa - Dhalkebar - Hetauda transmission line under construction, it is assumed that strengthening the capacity of NEA and RPGCL is also important. In addition, RPGCL is expected to merge with NEA's transmission division in the future, following the separation of NEA's transmission and distribution operations, and it will be important to strengthen the capacity of each organization with a view to integration in the short to medium term.

2) Steady implementation of grid development

In order to realize the expansion of electricity exports through hydropower development after 2030, it is necessary to also realize the operation of the domestic grid and interconnection lines. On the other hand, interviews with various stakeholders also raised concerns about the progress of transmission line development.

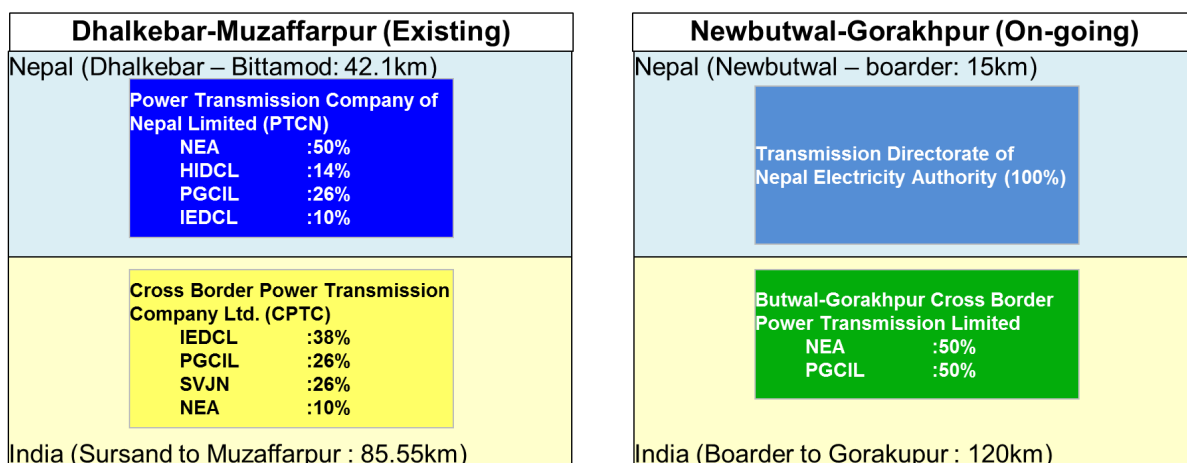
The lead time for the development of the transmission and substation facilities is expected to be about 6 years in total: 2 years for investigation, 1 year for bidding, and 3 years for construction. If the power plant is to be partially put into operation in 2030, it will not be ready in time if the survey is not started at this point. Even if the target year is 2033, when the power plant will be in peak operation, the survey should be started in 2027.

As for the sections that currently have no development prospects, the domestic system is mainly a north-south transmission line along the rivers connecting the West Seti, Sunkoshi, and Arun water systems, and the Bheri - New Damauli transmission line. For the international interconnection lines, future development will be required for the Dodohara (Lumki) - Bareilly, Kohalpur - Lucknow, Inaruwa - Purnea, and Dhalkebar - Sitamarhi interconnection lines.

For electricity exports to India and Bangladesh, delays in the operation of power plants or transmission lines are assumed to be compensable, and it is important that grid development is also carried out on schedule.

3) Interconnection line development structure

While NEA and RPGCL are expected to be the implementing entities for the 400 kV domestic grid, the international interconnection line will be a joint project with India, so coordination between the two countries, including the project implementation structure, will be important. The development of the interconnector is assumed to be done by dividing the operating companies (Dhalkebar-Muzaffarpur) and by transmission companies (New Butwal-Gorakhpur). Figure 8.4-2 shows this project structure.



(Left: Dividing operating companies, Right: Transmission companies)

Figure 8.4-2 Project development structure for interconnection line

The existing Dhalkebar - Muzaffarpur transmission line was constructed and operated through the establishment of a SPC (Special Purpose Company) in Nepal and India.

For New Butwal-Gorakhpur, which is under construction, the Nepal side is being built by NEA, while the Indian side is being built by an SPC half owned by the PGCIL (Power Grid Corporation of India) and NEA. As with the “400 kV Dhalkebar - Muzaffarpur Transmission Line,” NEA will pay the full development cost of the transmission line as a capacity charge, regardless of the actual amount of power transmission.

In interviews with NEA regarding future development, the Indian side has commented that they would like the structure same as existing Dhalkebar - Muzaffarpur project to be split into separate operating companies. If the division of the project company is assumed, PTCN, which will be the operator of the Nepalese side, will be responsible for completing the development of the Nepalese side. If the development lead time is 6 years, the project will not be operational until 2030 even if it is started now, so it is necessary to coordinate with the Indian side and implement the project promptly.

4) Grid development outside of Nepal

Regarding grid development outside of Nepal, an India-Bangladesh interconnection is envisioned. Currently, although an interconnection line between India and Bangladesh exists, there is no available transmission capacity, making it difficult to expand exports to Bangladesh. In order to expand the export of electricity to Bangladesh in the future, it will be necessary to increase the transmission capacity of this interconnection line.

It should be noted that the Nepal-Bangladesh interconnection line must pass through Indian territory and requires Indian permits and approvals.

(2) Challenges in exporting electricity from Nepal's Grid

As described in the previous section on the current status of electricity exports from Nepal's power system, exports are expanding as of November 2024. India is taking the lead in the electricity interconnections among BBIN (Bangladesh, Bhutan, India and Nepal) countries and is operating under the framework of the Guidelines for Import / Export (Cross Border) of Electricity-2018, MOP. This section describes the following four issues in exporting electricity from Nepal's power system, based on interviews with Nepalese officials and the findings of the JICA research team.

1) Restrictions on power plants for export

A condition for exporting electricity to India is that an export permit must be obtained on a power plant-by-power plant basis. To obtain this export permit, a country must conclude a “Bilateral agreement on power sector cooperation” with India, and power from power plants related to countries that have not concluded such an agreement cannot be exported to India. In addition, electricity to be exported to Bangladesh also passes through India, so only power plants that have been approved by India can export electricity.

Since export approvals for each power plant must be applied for annually, there is a risk that NEA will not be able to establish a medium-term outlook for power exports.

2) NEA's risk of purchasing all electricity

Currently, in all trading formats (G to G, PEC mechanism, and IEX), NEA purchases all electricity generated in Nepal as a single buyer and then exports it to India. Considering the future expansion of electricity trading volume, there is concern about the increased risk (full sale and selling price) of NEA purchasing all electricity generated in Nepal. In particular, while NEA is forced to purchase all electricity from IPPs under the take-or-pay clause, there are concerns that NEA's debt will increase if it is unable to export electricity. In order to promote power development in Nepal by IPPs and others in the future, it is necessary to establish an option that does not rely on the PPA with NEA and reduce NEA's risk.

3) Open access to Nepalese grid

The Nepalese grid is not open access, and IPPs cannot freely use the grid in Nepal. As a result, IPPs will not be able to trade directly with trading companies in Nepal or with consumers in neighboring countries even if NEA's obligation to purchase the entire amount of electricity is removed. Therefore, it is necessary to establish an open access mechanism for Nepal's domestic grid.

4) Securing domestic supply

If exports from NEA's power system increase in the future, there is concern that Nepal's domestic supply capacity may become insufficient to secure the export volume stipulated in the contract. In particular, there is a possibility that electricity exports will be prioritized because the unit price of electricity sold to India is currently higher than the wholesale unit price in Nepal. It is necessary to establish a mechanism to secure domestic supply capacity in consideration of these situations.

(3) Challenges in exporting electricity from individual hydropower plant

1) Results of Nepal-led power generation projects for export

Table 8.4-3 summarizes the current status of export projects for each type of power producer in the future expansion of electricity exports.

Table 8.4-3 Current status of export projects by type of power producer

Item	1) Foreign producers	2) JV between Nepal and overseas producers	3) Nepal producers
Development site	(1) West Seti, (2) SR6, (3) GMR, (6) Lower Arun, (8) Arun 3	(4) Phurkot Karnali, (5) Sunkoshi 3, (7) Lower Arun	N/A
Power Purchaser	Large overseas consumers, trading companies	NEA, large overseas consumers, trading companies	NEA, large overseas consumers, trading companies
Nepal Grid	Individual project will be developed as needed, but in principle, existing facilities are used.		
Interconnection line	Existing facilities utilization		

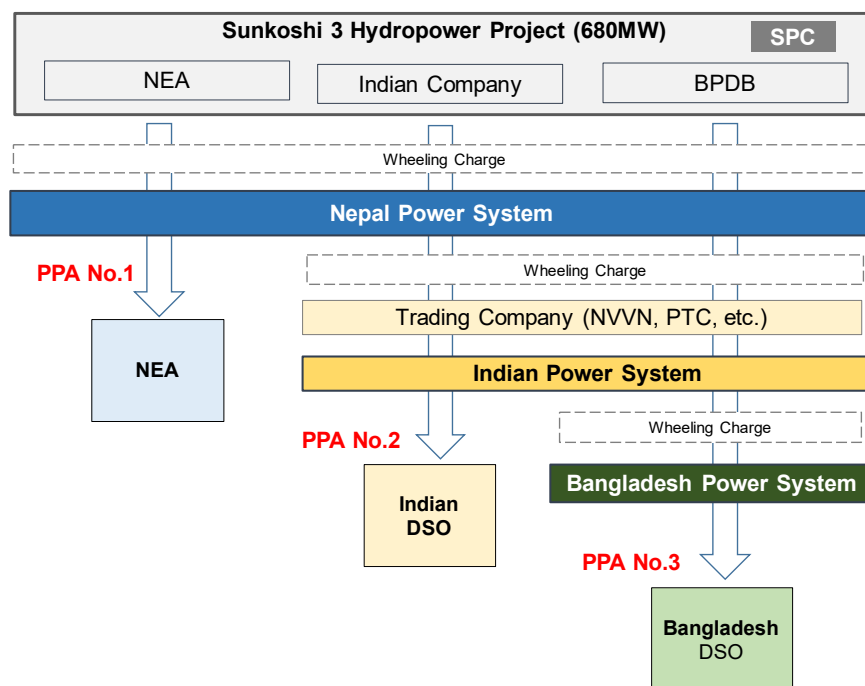
Source: Prepared by JICA Study Team

As for the cases of power producers, 1) Only foreign operators accounted for 5 out of 8 cases, and there are no cases of independent development of individual power export projects only Nepal, including NEA. As mentioned in Arun 3, even if an only foreign operators develop a project, it can gain benefits such as free power, regional development, and employment expansion, but its contribution to Nepal's assets and development experience will be small. Therefore, in the future, the 2) model, in which the Nepalese side is also involved, will be increased, and it will be necessary for Nepal company to acquire knowledge and experience in technical studies, finance, commercial affairs, and legal affairs. In the future, it is also expected that Nepal companies will be able to implement projects for export independently in 3).

2) Improve commercial and legal capabilities

In addition to the development of hardware, procedures such as the establishment of SPCs by operators in Nepal, neighboring countries, and third countries, PPAs with neighboring countries, setting of transmission tariff, and application for grid connection are necessary to promote export expansion. The only project that has made concrete progress in 2024 is Arun 3, but since this site is being developed by SJVN, an Indian company, there are no particular obstacles to the application of these procedures. On the other hand, in the case of a project led by a Nepalese company, the executing entity must take the lead in these procedures, consultations and negotiations with partners and related organizations in each country.

Figure 8.4-3 shows an image of the various procedures for the Sunkoshi 3 HPP, which is expected to export electricity to Bangladesh via India.



Source: Prepared by JICA Study Team

Figure 8.4-3 Image of commercial procedures in Sunkoshi-3 HPP

The following application procedures should be considered for implementation of this project by Nepal operators;

- Application of legal systems necessary for project implementation
- Application for grid interconnection among the three countries
- Study of the transmission charges for grid interconnection in each country
- Establishment of SPC by developers in each country and conclusion of shareholder agreement
- Conclusion of PPAs with off-takers in each country

Sunkoshi 3 HPP will be an example of a project that also includes Bangladesh. Bilateral projects between Nepal and India, such as Phurkot Karnali and Arun 4, are basically the same items that need to be considered. Coordination among the parties concerned in each country is essential for these studies, and it is necessary to establish a system that enables collaboration for the success of the project.

8.4.2 Measures to Promote Export Expansion

(1) Challenges in exporting electricity from individual hydropower plant

As noted in the previous section, development of the 400 kV system was primarily focused on importing power to major domestic cities and exporting hydropower already installed/under construction. It is assumed that future development will be more oriented toward hydropower exports from various water systems. Table 8.4-4 summarizes the interconnection lines that are expected to be developed in the future and the domestic grids corresponding to each water system.

Table 8.4-4 Future 400kV interconnection line and target water system

400kV Interconnection line	400kV Nepal grid	Target water system	Operators
Lumki – Bareily	Chaipur Seti – West Seti – Attariya	West Seti	RPGCL (Only West Seti – Attariya)
	Phurkot – Betan – Lumki	Karnali	RPGCL
Kohalpur – Lucknow	Bheri – Kohalpur	Bheri	NEA
Dhalkebar – Sitamarhi	New-Khimti – Tamakoshi – Sunkoshi – Dalkebar	Sunkoshi, Tamakoshi, Dudhokoshi	NEA
Inaruwa – Purnea	Arun – Inaruwa	Arun, Tamor	NEA, RPGCL

Source: Prepared by JICA Study Team

A summary of the water systems corresponding to each interconnection line and domestic system is shown below.

- The Lumki - Bareily interconnection line will be a linkage line that assumes hydropower exports from the West Seti water system (Chaipur Seti - West Seti - Attariya transmission line) and the Karnali water system (Phurkot - Betan - Lumki transmission line). The Karnali water system has many well-studied sites such as Phurkot Karnali and Upper Karnali, which are expected to be developed in the future.
- The Kohalpur-Lucknow interconnection line is mainly intended for hydropower export from the Bheri water system (Bheri-Kohalpur transmission line). This system has many points such as Nalgad and Jagdulla where government-led development is underway and construction will begin.
- The Dhalkebar - Sitamarhi interconnection line is designed for hydropower exports from the Sunkoshi and Dudhokoshi water systems. Since there are many water systems to be covered, this transmission line should be developed in case the capacity of the existing Dhalkebar - Muzzaffapur interconnection line is exceeded.
- The Inaruwa - Purnea interconnection line is designed to export hydropower from the Arun water system (Arun Hub - Inaruwa) and the Tamor water system, and there are many important sites such as the Upper Arun and Tamor Storage. It is necessary to develop the interconnection line in preparation for the development of these areas.

These domestic and interconnection lines will be developed in a north-south direction, connecting each water system to India rather than building a conventional east-west grid connecting domestic demand center. It is also important to promote the development of power sources and systems from the perspective of integrated development of water systems, regarding the future development of power transmission lines as a single package.

In addition, future grid development will require coordinated development of power sources and transmission line operators. Therefore, it is necessary to cooperate with the NEA's Generation Control Department, which formulates Nepal's transmission line development plan, DoED (Department of Electricity Development), which formulates the development plan for power sources, and hydropower developers. The smooth promotion of the project, including progress management of projects under implementation, is necessary.

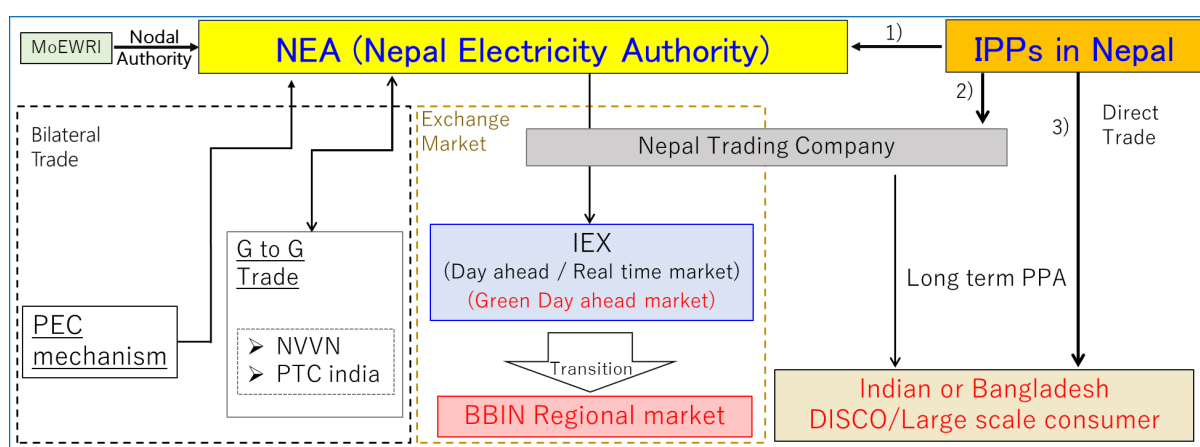
(2) Proposed scheme for diversification in electricity exchange (export)

The most important aspect of the solution to the challenge of increasing export volumes is the

systematic development of power plants for export. The development of power plants for export requires the participation of IPPs, which in turn requires the introduction of a variety of trading options. Below is a proposed scheme for expanding trading options and solutions to problems that may arise from the expansion of trading options.

1) Diversification of trading options

As mentioned above, NEA acts as a single buyer, purchasing all electricity generated in Nepal and then exporting the electricity to India. Considering that the amount of electricity traded will expand in the future, there are concerns that the risks (business partners, trading price) of NEA purchasing all electricity domestically will become too large. And in order to promote power development through IPPs, etc., options that do not rely on PPAs with NEA are necessary. As an option that does not rely on PPA with NEA, we think it will be necessary to introduce a system where IPPs in Nepal can directly conduct bilateral agreements with IEX and customers. Possible future trading schemes are shown in Figure 8.4-4.



Source: Prepared by JICA Study Team

Figure 8.4-4 Trading scheme in the future

IEX also has a Green Market that traded electricity derived from renewable energy sources, which is traded 10% higher than the regular market. As mentioned above, India plans to continue to increase its procurement of electricity derived from renewable energy sources, and future market expansion can be expected. In addition to IEX, it will be necessary to conclude long-term contracts (PPAs) with power distribution companies and large customers in India and Bangladesh in order to secure long-term stable power export.

Regarding trade with Bangladesh, there are plans to build a direct interconnection line between Nepal and Bangladesh. And considering that IEX is expected to be operated as a wide-area power exchange in South Asia, the idea of Bangladesh joining IEX will contribute to an increase in the volume of electricity trading between Nepal and Bangladesh, albeit indirectly.

When looking at electricity trading from the perspective of a power generators, the supplier and the price at which electricity is sold are important factors to consider when examining business feasibility. Currently, PPAs sell electricity price to NEA domestic customers at an average of about 4.4 cents/kWh in 2023/24, and to exporters at 6.6 cents/kWh, the latter being the higher price. Power generators need to consider both domestic trading and electricity exporting as wholesale customers. We propose the following three specific schemes of electricity wholesale customers. 1) is conventional trading, and 2) and 3) are new forms of trading that assume electricity export.

- 1) NEA
- 2) Power Trading Companies
- 3) Direct to DSO/customer in India/Bangladesh

1) is a conventional scheme of trading that is completed through domestic transactions with NEA. Since NEA distributes the purchased power to the domestic retail market and the surplus to India, the generators are not directly involved in power trade.

Although the purchase price will be lower for the generator, it is assumed that this will continue to be the mainstream scheme for small and medium-sized power generation projects in Nepal, as it does not require any administrative procedures such as grid connection applications or PPAs with customers in other countries.

2) is a scheme through power trading companies. In the future, Nepal's Electricity Act will be amended to allow power trading business, and it is expected that the function of power distribution, which NEA is responsible for, will be partially transferred to Nepal Trading Companies. NEA has established NPTCL (Nepal Power Trading Company Ltd.), the first trading company in Nepal, in 2021, and NPTCL is expected to operate this trading business for the time being. The power generation companies will be able to choose whether to use the PPA with the power trading companies as the price at which they sell electricity, or whether the price will be linked to the market.

3) is a scheme in which power generation companies deal directly with power distribution companies and major customers in India and Bangladesh, and it offers economies of scale in structuring project financing with the participation of investors from various countries.

There is no restriction that only one scheme of trading should be selected for each project, but flexible combinations are expected to be possible. For example, during the dry season, electricity could be sold to Nepal through NEA in the scheme of 1), and during the rainy season, electricity could be sold to India and Bangladesh in the scheme of 2) and 3). If this scheme of trade is possible, the power generation plans required, especially for medium to large scale projects, are expected to change.

Table 8.4-5 Comparison by trading scheme from IPP's viewpoint

Scheme	1) NEA	2) Trading Company	3) Direct Trade
Purchaser	NEA	Trading Company	Large consumers in overseas
Selling Price	PPA with NEA	PPA with Trading Company Market Price	PPA with Consumers
Pros	- Purchase volume and price are secured. - There are transmission costs only within Nepal.	[PPA] - Purchase volume and price are secured. [Market] - Electricity can be sold when surplus power is generated.	- Purchase volume and price are secured. - IPP can choose the customer with the best contract conditions by themselves.
Cons	Limited amount of NEA purchases.	The purpose and function of the Trading Company has not yet been determined.	- IPPs need to secure their own customers - Transmission costs are incurred outside of the Nepal in addition to that of within Nepal

Source: Prepared by JICA Study Team

2) Guarantee of domestic electricity supply

In order to ensure the supply of electricity to the domestic demand, it will be necessary to require a certain amount of domestic supply throughout the year when granting a license to each power producer.

At the time of construction of the power plant, the amount of supply required for domestic use will be taken into consideration based on the projected future domestic demand in Nepal. By requiring a certain amount of domestic supply throughout the year, including the dry season, it will be possible to ensure a stable supply of electricity even if domestic demand increases in Nepal in the future. Electricity in excess of a certain amount of domestic supply can be traded directly with trading companies and distribution companies/larger customers in India/Bangladesh.

For this mechanism to work, close coordination between DoED, which grants licenses to power generators, and NEA, which is in charge of supply and demand planning in Nepal, is necessary to determine which licenses to grant, but currently there is not enough communication between NEA and DoED. In addition to this, it is necessary for NEA to appropriately formulate medium- and long-term supply and demand plans. Currently, NEA's capacity to formulate supply and demand plans isn't enough, so it is necessary to improve NEA's supply and demand planning capacity.

The role of the Trading Company will mainly be to purchase surplus power from NEA and IPPs and sell it to IEX and other markets, but if domestic supply cannot be secured, a mechanism to procure power via the Trading Company can be secured to ensure stable domestic supply capacity.

(3) Promoting Nepal-led development of hydropower projects for export

Diversification of electricity exports not via NEA will be important for Nepal to promote hydropower development in the future. As shown in Table 8.4-3, most of the export-oriented hydropower plants currently underway are led by Indian companies. In order to utilize the country's hydropower resources in the future, it will be important for Nepal to take the lead in developing hydropower plants for export. On the other hand, as mentioned, in addition to technical studies, commercial and legal expertise will also be important in advancing these developments, including interconnection lines across multiple countries, SPC establishment under various parties, and consensus building related to PPAs and grid interconnection. Interviews with Nepalese stakeholders also yielded comments on the importance of capacity building and accumulation of knowledge in these areas in order to consult with the Indian government or developers on an equal footing.

Based on the above recognition, it is assumed that pilot projects including many of the issues listed will be effective in resolving this situation, and that once PPAs, tariffs, grid interconnection, etc. are developed, they can be applied to other projects, and that one good practice can serve as a benchmark for subsequent projects. This pilot project will need to proceed while solving various issues, which is likely to be an unacceptable risk for the private sector. Therefore, it is preferable that a public agency such as NEA or VUCL selects the project as the implementing agency and carries out the project in cooperation with the relevant agencies and development partners.

The following three sites are candidates for the pilot project, which should involve Nepal operators.

- Phurkot Karnali HPP (NHPC, VUCL)
- Sunkoshi 3 HPP (NEA, BPDB)

- Arun 4 HPP (SJVN, NEA)

In particular, the Sunkoshi 3 HPP is an NEA-led project for exporting through three parties collaboration between Nepal, India, and Bangladesh, and is expected to be a promising candidate as a pilot project for export promotion, although its technical and environmental aspects need to be evaluated separately.

ANNEX 9

POWER SYSTEM DEVELOPMENT PLANNING

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ANNEX 9 POWER SYSTEM DEVELOPMENT PLANNING

9.1 Outline for Power System Development Plan

In the power system development plan, after studying and reviewing the existing power system plans, the transmission and substation facilities are planned, considering the balance of supply reliability and development costs based on the power demand forecast and the power generation development plan. A framework of the power system development plan is as follows.

Table 9.1-1 Framework for the Study of the Power System Development Plan

Target area	Whole area of Nepal
Target year	Study of 2025, 2030, 2035, and 2040 cross sections with 2040 as the final year
Target Facilities	400kV Transmission lines and Substations
Planning criteria	NEA grid code
Software for power system analysis	PSS/E

Source: JICA Study Team

The steps in reviewing the power system development plan shall be as follows. It is necessary to carry out studies by trial and errors and to improve the accuracy phase by phase. In IPSDP, overall strategies on the power system is firstly shown based on the Development Scenarios described in Chapter 7 and specific configurations of the power system is planned in the Optimal Scenario. Work flow of this specific procedures are described on Chapter 9.1.3.

Table 9.1-2 Study Steps for Power System Development Plan

	Steps of implementation	Details
Step 1	Research and review of existing power system plans	➤ Validation based on the results of power demand forecasts
Step 2	Creation of a proposed system extension	➤ Consistency with regional power demand ➤ Consistency with plans to develop power sources, mainly hydro power ➤ Inclusion of import and export power with neighboring countries
Step 3	Validation by power system analysis	➤ Technical validity using analysis software PSS/E
Step 4	Planning and drawing power system diagram	➤ Create 2025, 2030, 2035, and 2040 cross sections
Step 5	Calculation of transmission development costs	➤ Development costs through 2040

Source: JICA Study Team

9.1.1 Criteria for Power System Expansion

The following items are to be studied whether or not the existing transmission system needs to be augmented based on the NEA Grid Code.

- 1) Power flow analysis
- 2) Short Circuit Current
- 3) Transient stability analysis
- 4) Steady-state stability analysis

The applicable criteria for the N-1 standard for existing facilities are as follows.

General transmission line	In case of transmission capacities exceeding 50MW in a radial system.
Transmission lines from new power plants	Direct comparison of investment cost and transmission losses, unless otherwise economically justifiable, double circuits or multiple circuits should be applied only for plants where the size is beyond the maximum sustainable system fault.
Transformer	Either installation of excess capacity in the order of the largest transformer unit in the same region or transformer spares shall be shared in the same region.

The power quality standards for power system development are as follows.

Voltage (normal operation)	±5% of nominal voltage
Voltage (during emergency)	±10% of nominal voltage
Frequency (during emergency)	±5% of nominal frequency

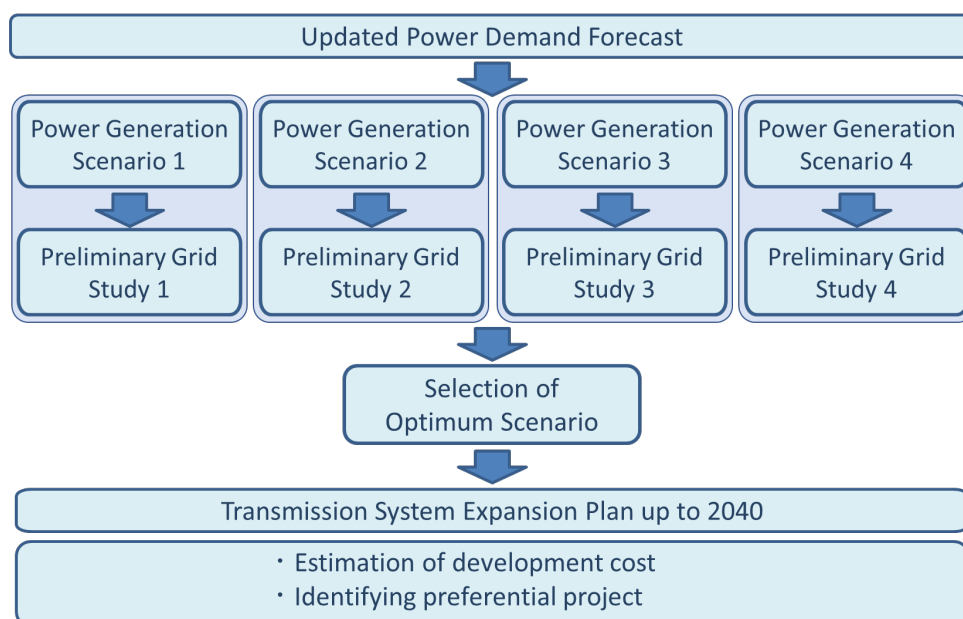
The transmission capacity limits for facilities are as follows.

	Transmission line	Transformer
Normal Conditions	100% of transmission capacity of line @ 85°C	100% of rated transformer capacity
Single Outage Conditions	120% of transmission capacity of line @ 85°C	120% of rated transformer capacity
Severe Outage Conditions	120% of transmission capacity of line @ 85°C	120% of rated transformer capacity

9.1.2 Methodology for Power System Development Plan

The power system expansion plan begins with a schematic study of the grid for each power generation development scenario based on demand forecasts. Then, establish a policy for the transmission system required by the power generation development plan, including a scenario in which domestic hydro power is actively developed, a scenario in which the development of renewable energy sources other than hydro power is also promoted, and a scenario in which imports are actively pursued, and outline the characteristics and development costs of the system.

Based on the plan selected as the optimal power generation development scenario, a detailed study is conducted and a grid development plan is presented every five years until 2040. After that, power system development cost is calculated. A schematic diagram of these is shown below.



Source: JICA Study Team

Figure 9.1-1 The Formulation Flow of the IPSDP

As described in Chapter 7, Power Generation Development Plan, and Chapter 8, Power Trade, the consideration of cross-border interconnection lines is an important point.

In the short term, this is to meet domestic power demand. Nepal, which has a large amount of hydro power generation with run-of-river type, is particularly vulnerable to power shortages during the dry season and relies on imports from India. The country also suffers from power shortages during the rainy season, and cross-border interconnection lines are important to ensure a stable supply of electricity throughout the year. According to the NEA Annual Report 2018, after the completion of the 220kV international interconnection line (Dhalkebar - Muzaffarpur, this transmission line is currently undergoing voltage uprating to 400kV operation), import power from India have increased significantly, allowing the country to escape the planned power outages that had been the normal situation.

In the medium to long term, the development of hydro power sources, such as Upper Tamakoshi (456 MW), is expected to generate a surplus of electricity to meet the country's power demand. According to the current development plan, it is assumed that as power supply development proceeds, there will first be a surplus of supply capacity during the rainy season, and if further planning proceeds, supply will exceed demand throughout the year. Exporting surplus power is expected to contribute to the promotion of national economic development and power source development.

Based on the power generation plan and the existing cross-border interconnection line plan that takes these points into account, the scale and timing of the construction of the required international interconnection lines will be considered and reflected in the power system development plan.

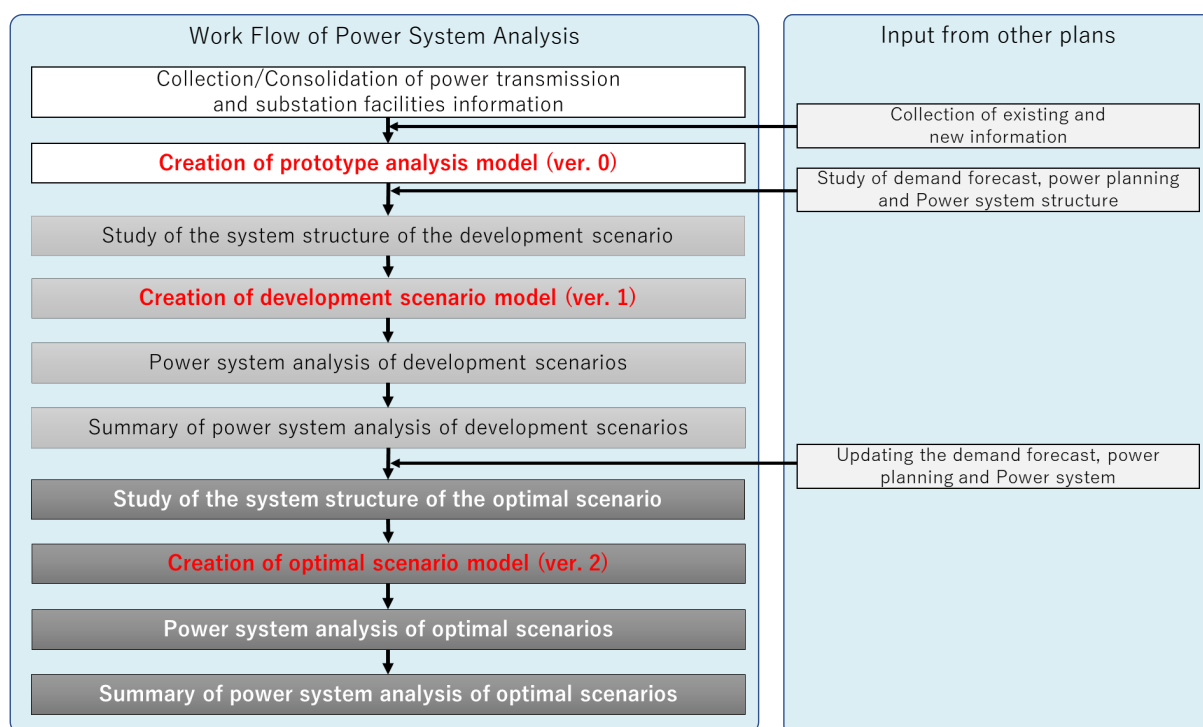
9.1.3 The Study Method of Power System Analysis

The purpose of power system analysis is to verify the master plan of the bulk power system in Nepal using computer simulation. The analysis method is to verify the adequacy of the master plan by creating the system model of 400kV bulk power system based on the demand forecast up to 2040, the power generation development plan, and the power system plan, and by performing

various simulations using PSS/E¹ software. The verification results are power flow calculation, voltage calculation, short circuit current calculation, and system stability calculation, and verify that they are within the standards of transmission lines and substations and that the system is stable.

Figure 9.1-2 shows the work flow of power system analysis. We mainly assume three steps. First, the prototype power system model (ver.0) is created using existing system data, and analysis is performed on the trial basis. Next, create the power system model (ver.1) of the development scenario that reflects the concrete demand assumptions, multiple power generation development plan scenarios, and the examination results of the bulk power system configuration, and carry out system analysis for multiple scenarios. Finally, the power system model (ver.2) of the optimal scenario selected from the development scenarios is created, and system analysis is performed while considering the annual cross section.

The power system model (ver.2) incorporates the latest information from the system development plan, as well as updates on power demand forecast and power generation development plan. This model will serve as the IPSPD's power system planning.



Source: JICA Study Team

Figure 9.1-2 Work Flow of Power System Analysis

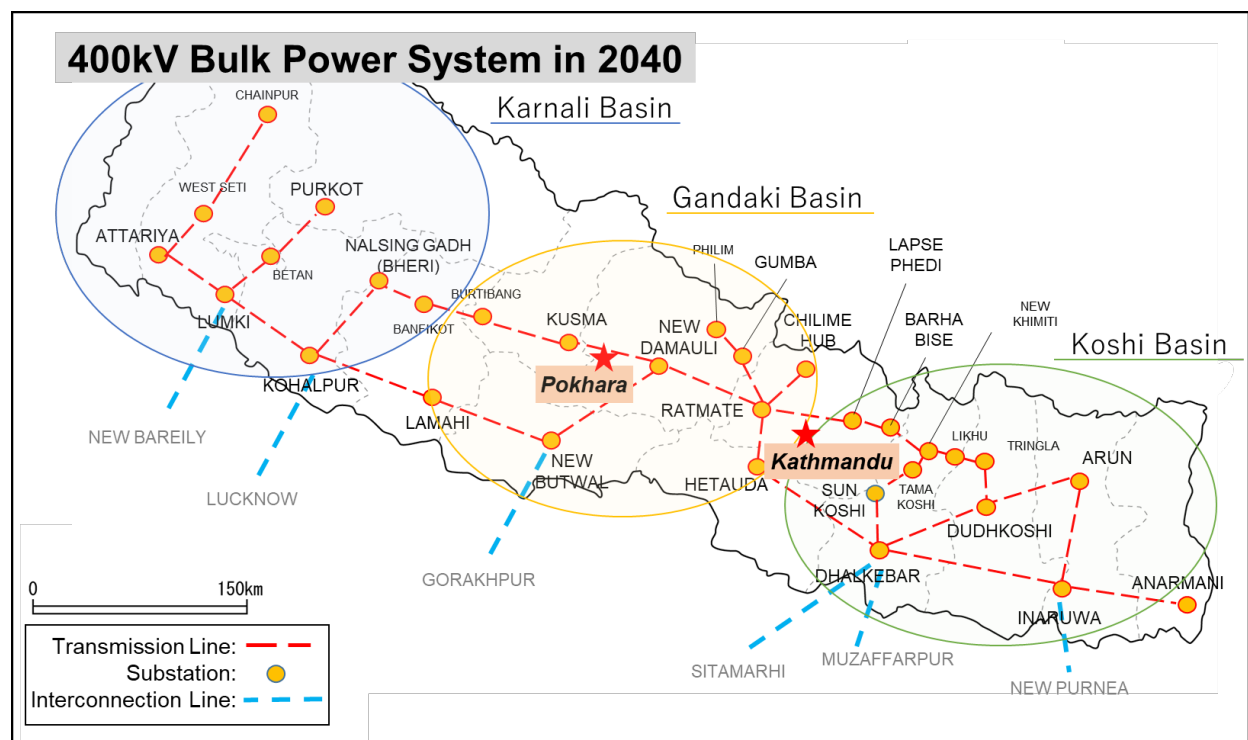
¹ PSS/E is a commercially available software internationally used for simulating power transmission networks of power systems.

9.2 Study of Power System Planning / Power System Analysis in Each Power Generation Development Scenario

9.2.1 Precondition of Power System Planning / Power System Analysis in Each Power Generation Development Scenario

(1) 400kV Bulk Power System

The 400kV bulk power system in Nepal proposed in this master plan in 2040 was proposed through discussions with NEA and RPGCL based on the existing system and past development plans, as shown in Figure 9.2-1. The future 400kV bulk power system in Nepal will be studied using this system. Here, the red dashed lines indicate the 400kV transmission lines, and the orange dots indicate the locations of the 400kV substations. The circle also encloses the Karnali, Gandaki and Koshi rivers, which are the major river systems of the country.



Source: JICA Study Team based on NEA Annual Report 2020/2021

Figure 9.2-1 400kV Bulk Power System and Major River Systems (as of 2040 year)

As mentioned in Chapter 3, the existing power system mainly consists of 132kV and 66kV. In addition to this, there are 400kV interconnection line with India (Dhalkebar – Muzaffarpur), which were constructed under NEA implementation and have been in operation since last year, and 220kV transmission line and substation facilities around hydro power plants. The main existing transmission line is a 132kV transmission line that runs east-west through southern Nepal. This transmission line connects Anarmani in the east through Kathmandu and Pokhara, which are demand areas, to Attariya in the west.

The major power demand areas are Kathmandu, Pokhara, and Dhalkebar, and about 75% of the demand is concentrated in these three locations. In addition, many of the hydro power plants are located in the northern part of Nepal, and these power plants mainly transmit power to the south via transmission lines along rivers between the north and the south.

As the basic concept of this system, along the existing 132 kV transmission line that runs east to west, the south route of the 400kV transmission line that will be the backbone of the first route, and to make this system more robust, The North route of the 400kV transmission line of the second route is planned.

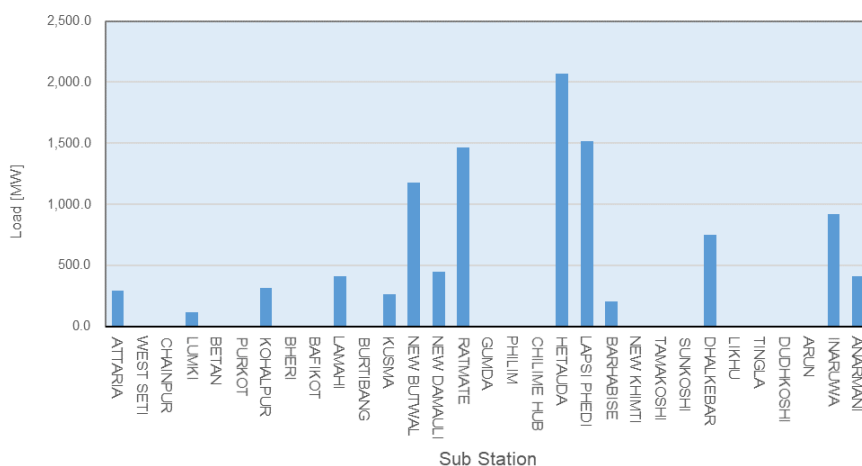
In addition to these east-west routes, north-south transmission lines are planned to connect the power plants along the main rivers of Nepal's three major rivers, the Karnali, Gandaki and Koshi Rivers. The transmission lines along these river systems will be interconnected with two east-west transmission lines to deliver electricity from each power station to the country or abroad. Nepal's domestic power system in 2040 will consist of these two east-west transmission lines and the transmission lines that will be constructed along major north-south rivers.

This domestic grid is also important to study power trade with India and other BBIN countries and the configuration of these grids. Based on the future power trade with India planned by NEA, will be six 400kV interconnection lines, scenarios 1 to 4 will be verified based on power trade through these six lines at NEA's request.

(2) Load allocation method for 400kV power system (Common in each scenario)

Regarding the allocation of load for the 400kV substations within the aforementioned 400kV system, it was calculated based on the peak power demand projected for the year 2040 in the demand estimation from Chapter 5, as well as the latest actual substation load data. Then, the load for the year 2040 was predicted by multiplying the growth rate to the actual substation load data from 2017, and these values were aggregated as the planned load for the nearest 400kV substations.

The results are shown in Figure 9.2-2. The load was applied during the rainy season (August) when demand at the maximum.



Source: JICA Study Team

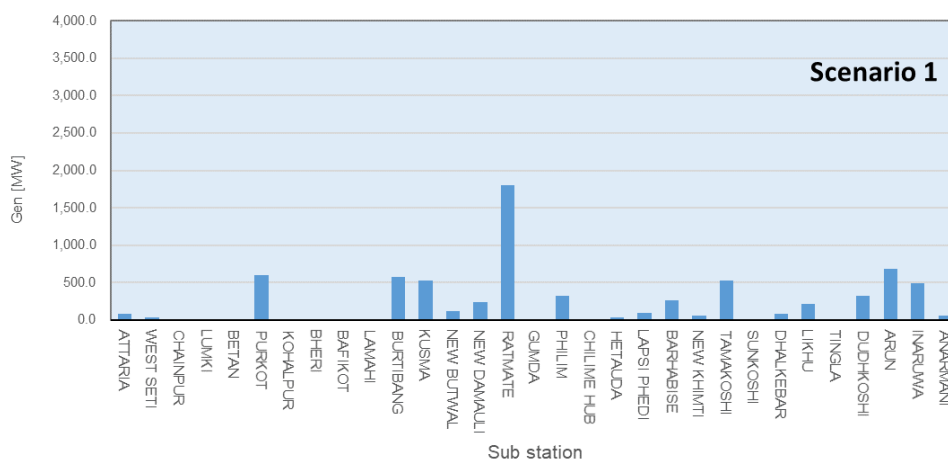
Figure 9.2-2 Load Allocation of 400kV System (based on actual data)

(3) Power generation allocation methods for 400kV systems (by 4 scenarios)

In the 400kV system mentioned above, the power allocation of the 400kV substation was calculated from the power output based on the power development amount in 2040 in the power development plan in Chapter 7.

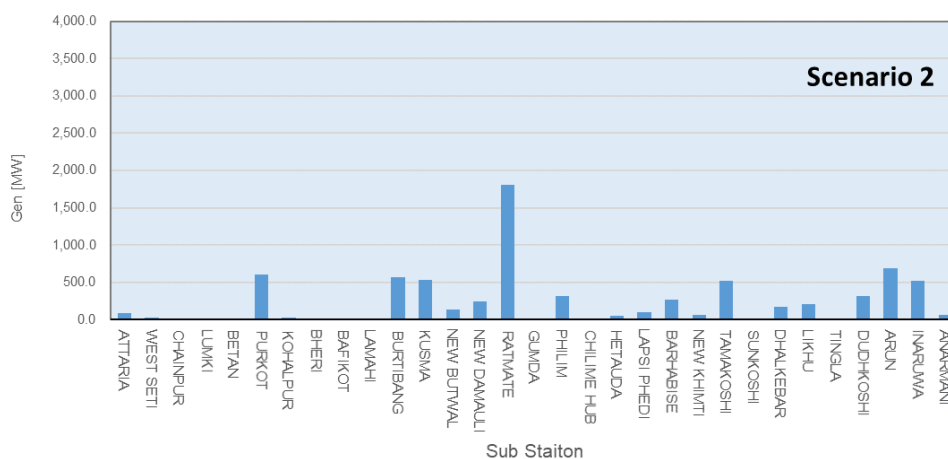
The power generation capacity of the 400kV substation in 2040 was calculated by aggregating the

power output of each power station to the nearest 400kV substation. The results of scenarios 1 to 4 are shown in Figure 9.2-3, Figure 9.2-4, Figure 9.2-5, and Figure 9.2-6.



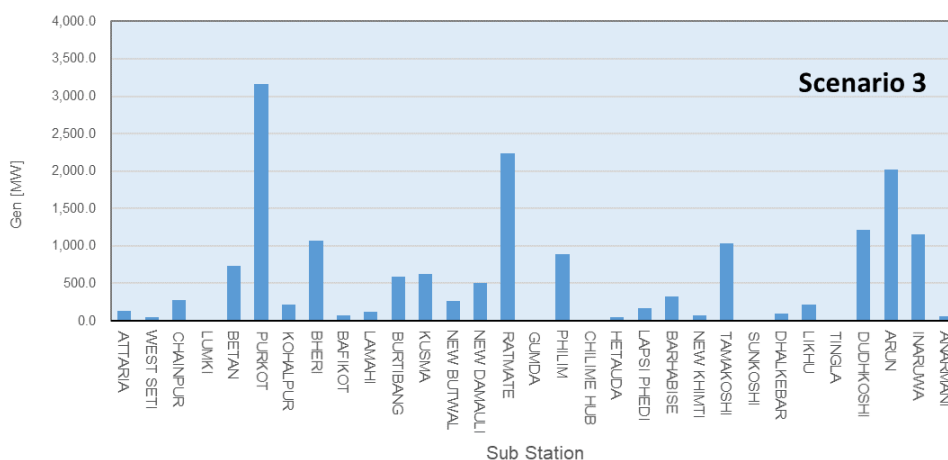
Source: JICA Study Team

Figure 9.2-3 Scenario 1: Power Generation Allocation of 400kV System



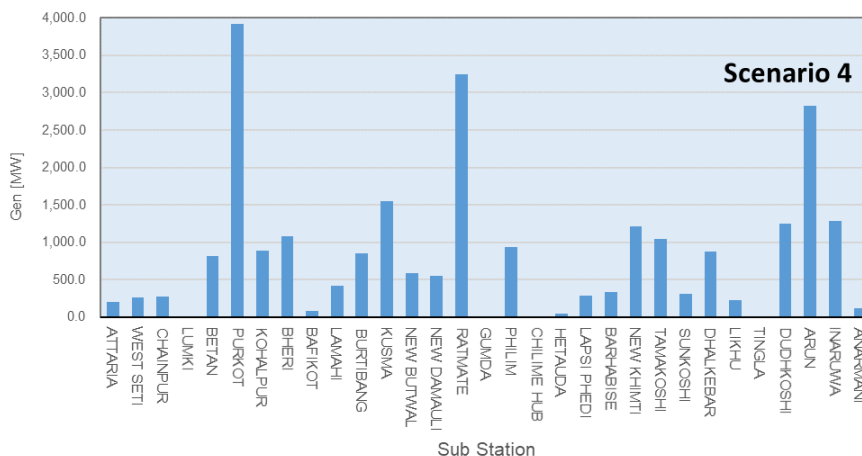
Source: JICA Study Team

Figure 9.2-4 Scenario 2: Power Generation Allocation of 400kV System



Source: JICA Study Team

Figure 9.2-5 Scenario 3: Power Generation Allocation of 400kV System



Source: JICA Study Team

Figure 9.2-6 Scenario 4: Power Generation Allocation of 400kV System

System operation will balance supply and demand by using the difference between power generation output and load as the power trade amount. The power generation and demand balance for each scenario is shown in Table 9.2-1. In Scenarios 1 and 2, power imports from India will be necessary, while in Scenarios 3 and 4, power exports to India will be possible.

Table 9.2-1 The Power Generation and Demand Balance for Each Scenario

	Total generator output (MW)	Load (MW)	Power trade (MW)
Scenario 1	7,211.6	10,352	-3,140.4 (Import)
Scenario 2	7,380.2		-2,971.8 (Import)
Scenario 3	17,367.4		+7,015.4 (Export)
Scenario 4	25,515.4		+15,163.4 (Export)

Source: JICA Study Team

(4) Study criteria

The assumptions for the power system analysis conducted in this study are as follows:

- Analysis Target
2040 rainy season peak load (August: maximum generation output and power demand)
- Interconnection Lines
Verification of the power balance between total generation and total demand, with any surplus or deficit equally distributed among the six interconnection lines.
- Domestic supply-demand balance is shown in Table 9.2-1.

In this study as well, these analyses will be conducted based on the NEA Grid Code to the validity of the power system. The criteria for study are as follows:

- Power flow calculation
The power flow of each 400kV transmission line must be within the heat capacity of 2,618 MW².

² 1.732 x 400 (kV) x 0.829 (A) (current capacity per line of ACSR410sq) x 4 (conductor) x 0.95 (power factor) x 1.2 (long-term overload factor in Nepal) = 2,618 MW

- Voltage calculation
The bus voltage of each 400kV substation must be within $400\text{kV} \pm 5\%$.
- Short-circuit current calculation
The breakdown current of each substation must be within 50kA.
- System stability simulation
After a single line fault (assuming a three-phase short circuit fault near the transmission end substation) at the highest power flow section of the 400kV transmission line, the fault will be cleared after five cycles. Then, the phase difference with the base generator will be verified to conform stable operation of the generator.

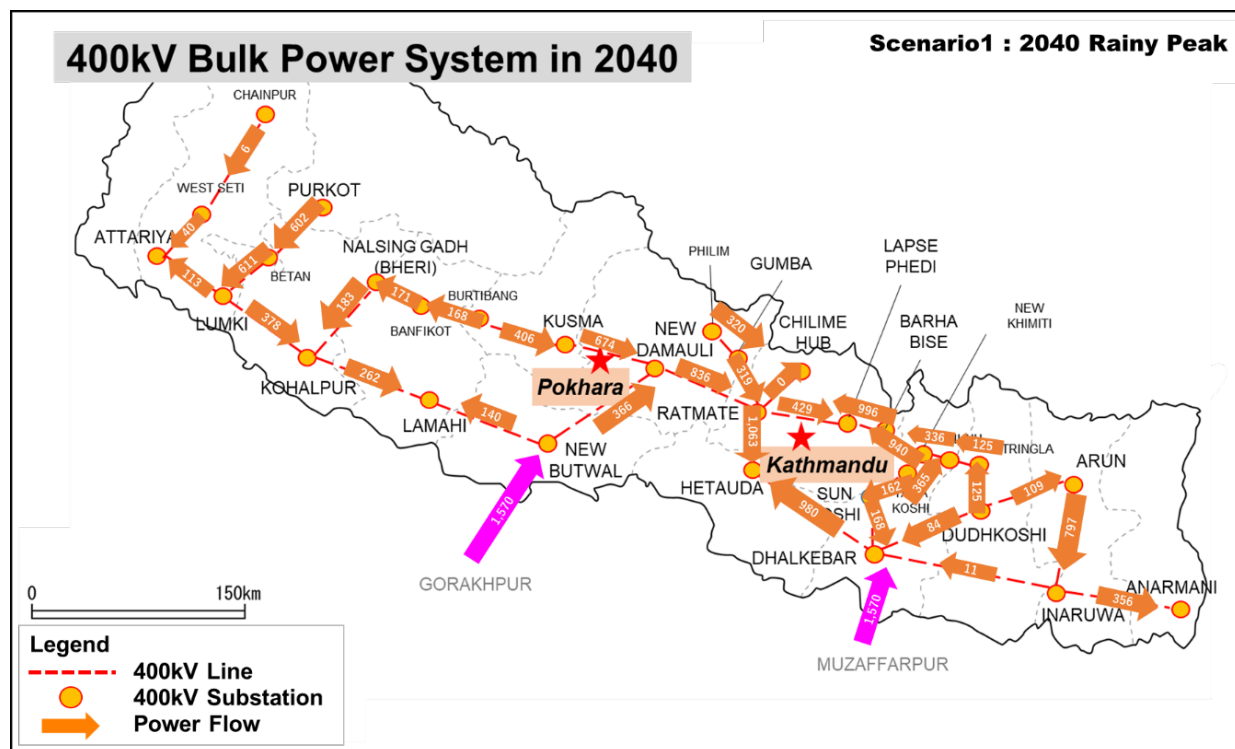
9.2.2 Power System Analysis Results and Evaluation in Each Power Generation Development Scenario

(1) Power Flow Calculation

Based on the preconditions described in the previous section, we carried out the power system analysis based on the power plant location, the power output, and load assumptions for scenarios 1 to 4 of the power generation development plan, targeting the 400kV bulk power system, and the resulting power flow diagram. Are shown in Figure 9.2-7, Figure 9.2-8 , Figure 9.2-9, and Figure 9.2-10. The arrows in the figure represent power flows in transmission lines. The power supply-demand balance was different in each scenario, with different plans for power imports and exports and different numbers of interconnection lines.

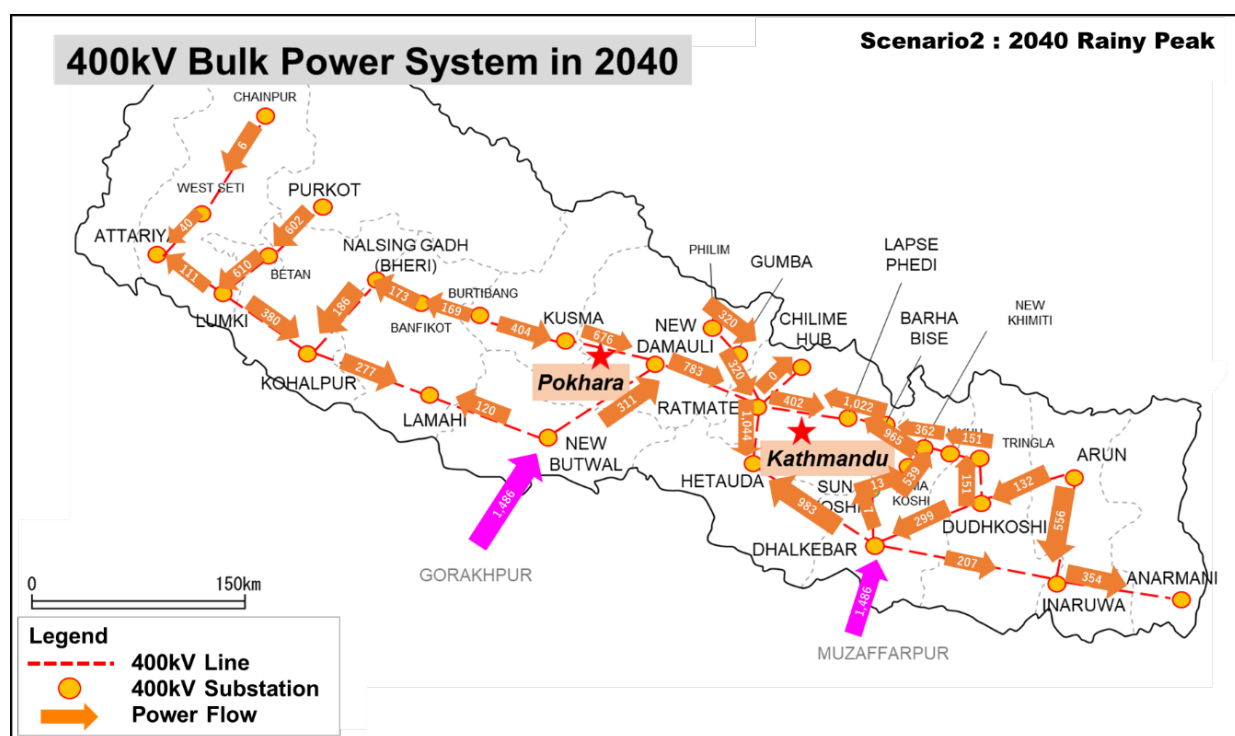
In each scenario, the power flow of each transmission line was found to be within the allowable range of transmission capacity. In Scenario 1, power is imported via interconnection lines because domestic power generation is insufficient. In addition, there is a large power flow on the transmission line between Ratmate and Hetauda towards Hetauda in the south of Kathmandu where demand is high. Furthermore, it was confirmed that the power flows from the power plants along the three rivers located in the eastern, central and western regions, are tended to flow toward Kathmandu in the center. The same trend is observed for Scenario 2.

From the results of Scenario 3, there is a surplus of domestic power generation, so electricity is exported. On the west side, there is a large power flow from Purkot near the Karnali River, where there are many large-scale hydro power plants, to Lumki. A similar trend can be seen on the east side, where there is a large power flow from Dudhkoshi near the Koshi River, which has many large-scale hydro powers, to Dhalkebar. Furthermore, since the power plants along three rivers located in the eastern, central, and western regions generate more power than Scenario 1, the tendency that there are more power flows from the east and the west toward Kathmandu in the center, can be confirmed. The same trend is observed for Scenario 4.



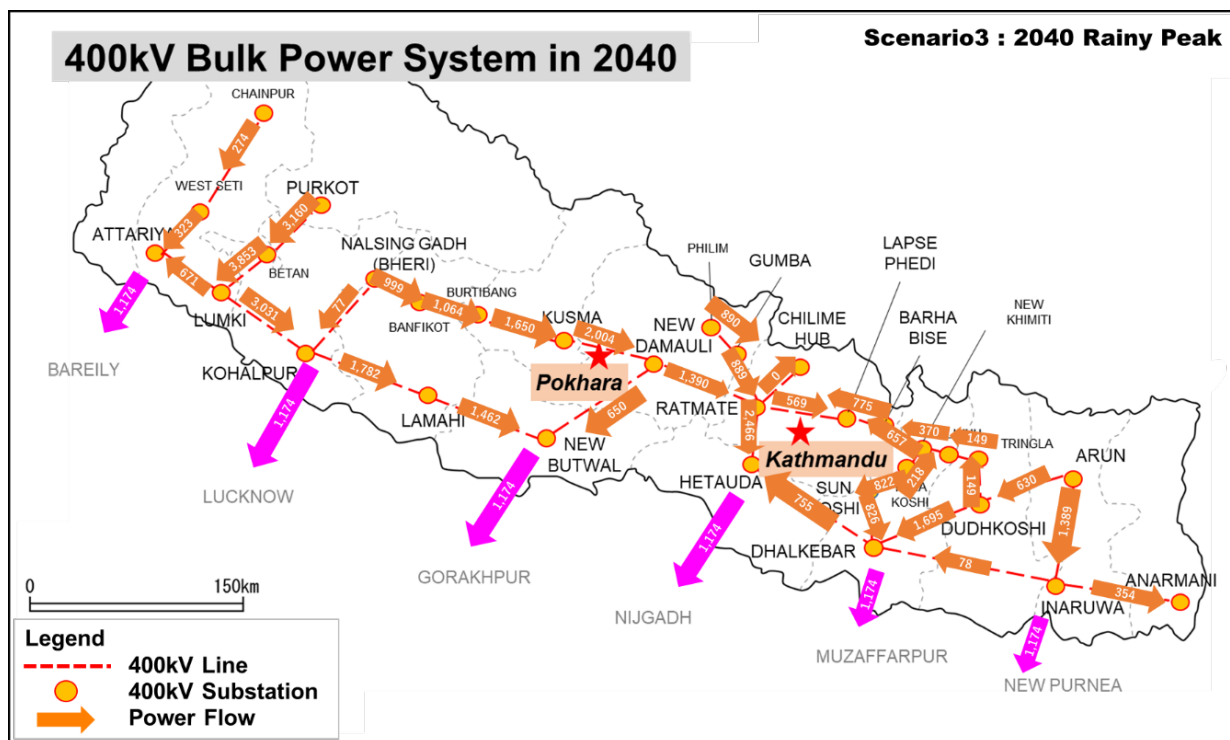
Source: JICA Study Team

Figure 9.2-7 Scenario 1: Power Flow



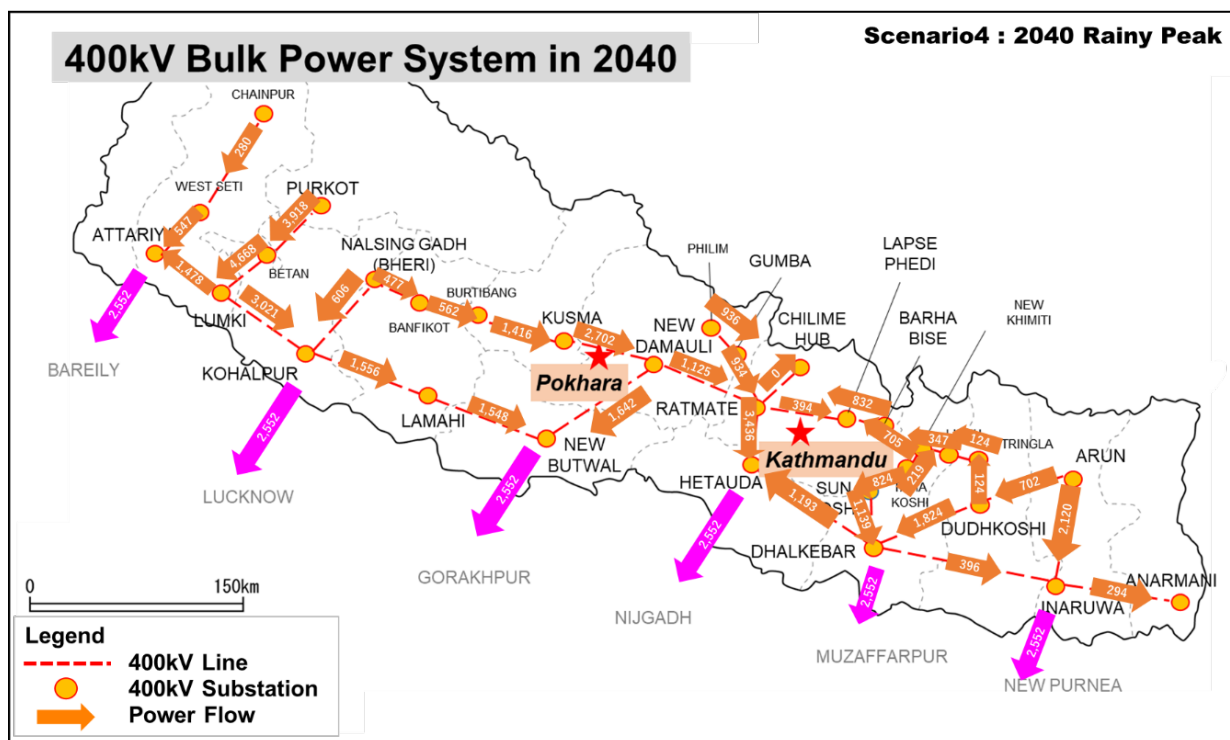
Source: JICA Study Team

Figure 9.2-8 Scenario 2: Power Flow



Source: JICA Study Team

Figure 9.2-9 Scenario 3: Power Flow

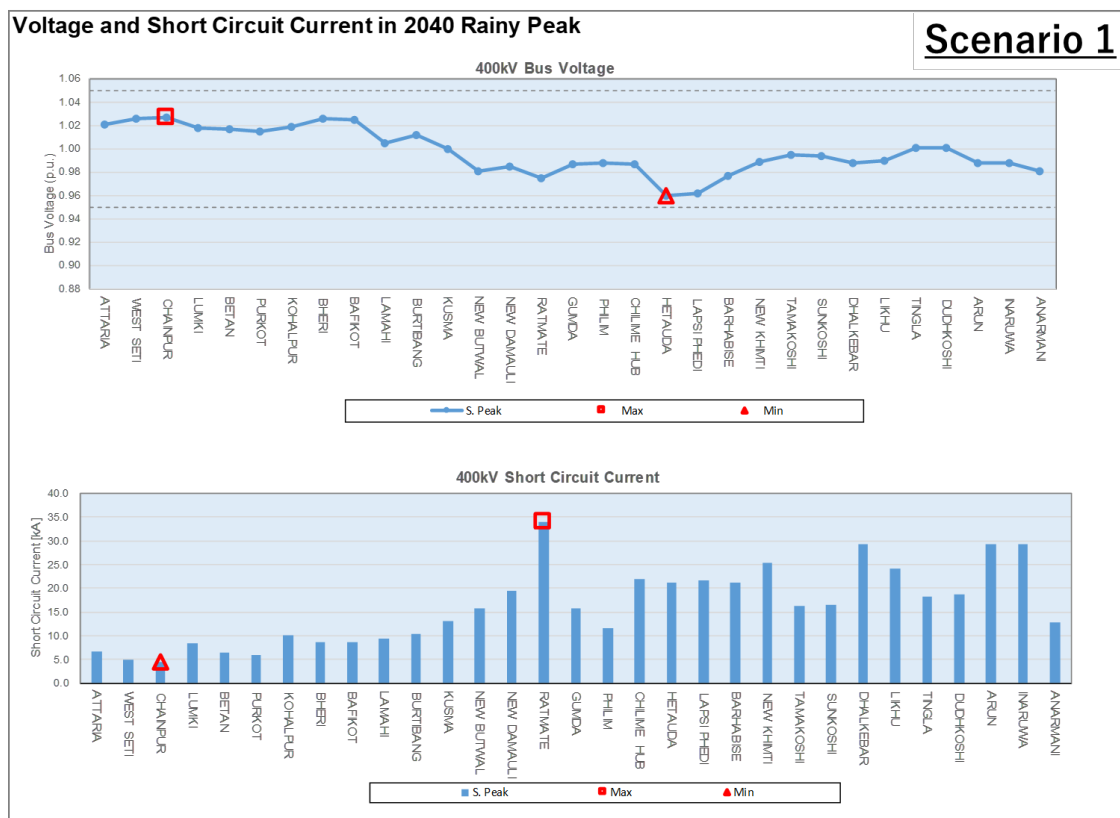


Source: JICA Study Team

Figure 9.2-10 Scenario 4: Power Flow

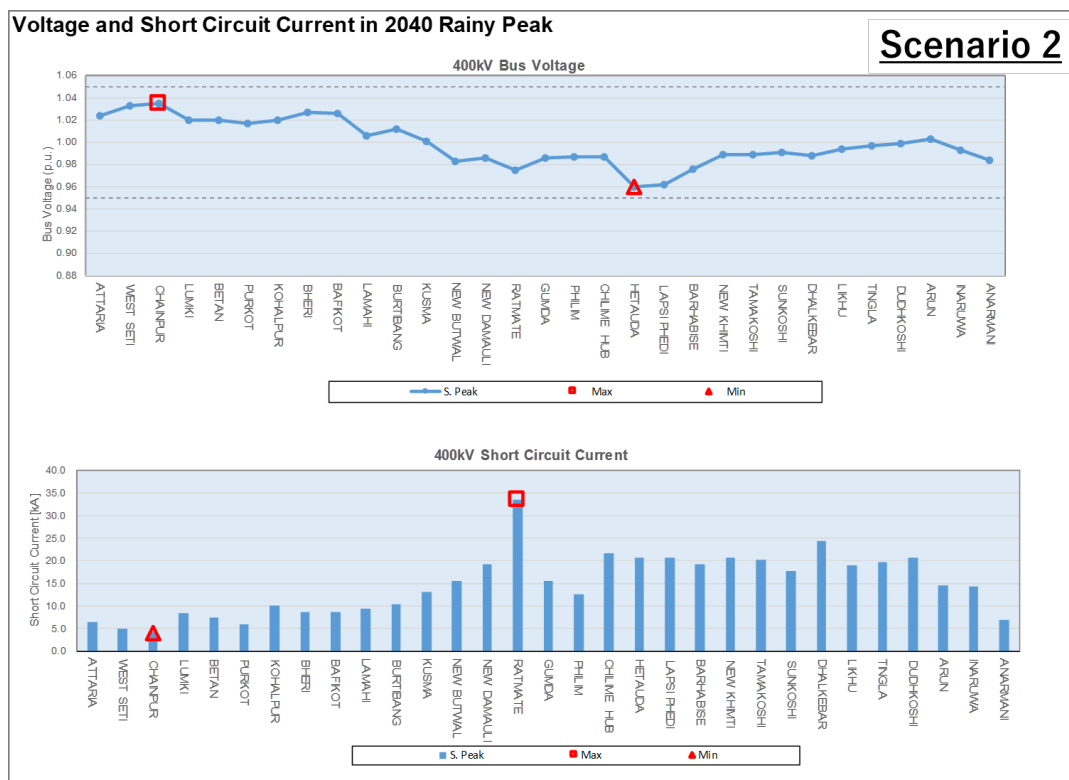
(2) Voltage and short circuit current calculation

Figure 9.2-11, Figure 9.2-12, Figure 9.2-13, and Figure 9.2-14 show the voltage and short circuit current results. The horizontal axis is the substation name, and the vertical axis is the voltage value and the short circuit current value at the time of the accident at each substation. Regarding voltage, in each scenario, it was confirmed that the voltage at substations such as Hetauda, which are close to major demand areas, tends to be low, and was within $\pm 5\%$ of the voltage reference value. Regarding the short circuit current, in each scenario, the short circuit current of Ratmate near the main demand area tends to be large, and it was confirmed that it was within 50kA, which is the capacity of a general 400kV circuit breaker.



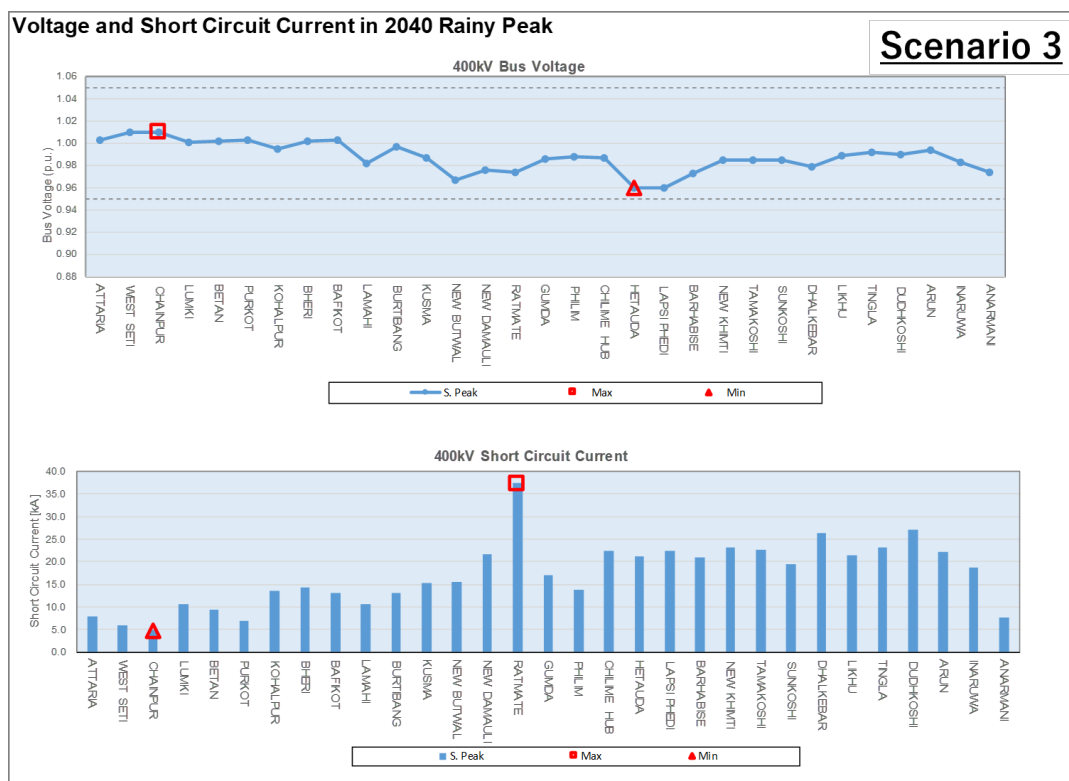
Source: JICA Study Team

Figure 9.2-11 Scenario 1: Voltage & Short-circuit Current



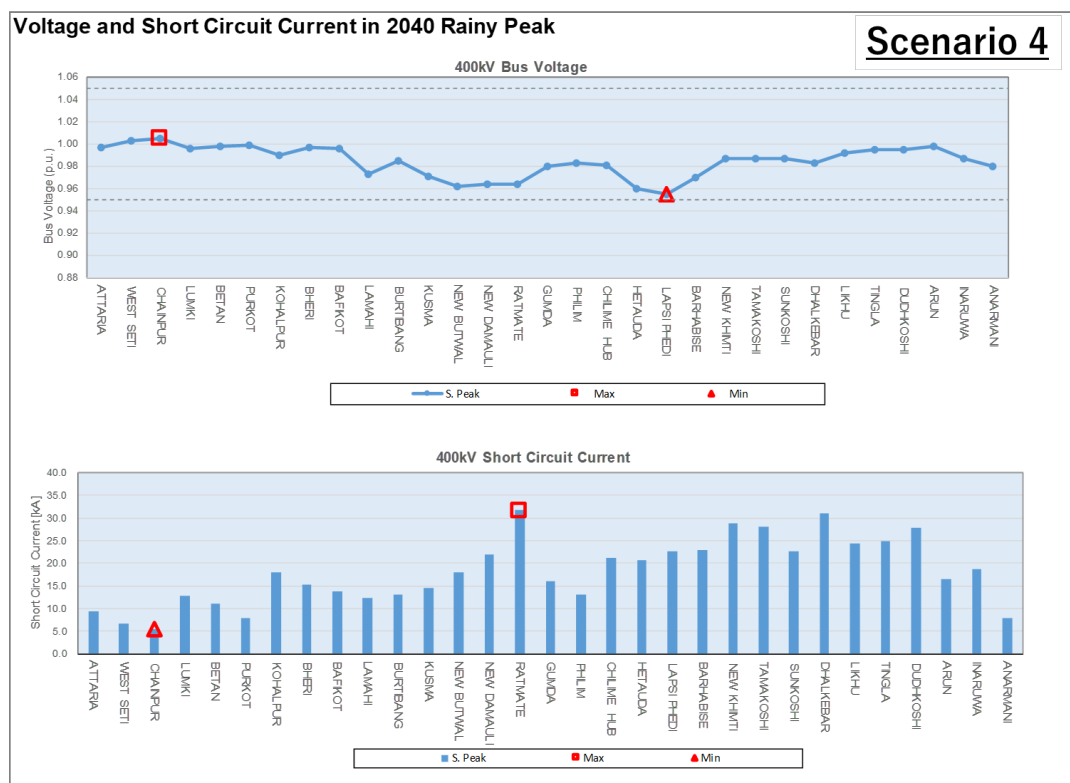
Source: JICA Study Team

Figure 9.2-12 Scenario 2: Voltage & Short-circuit Current



Source: JICA Study Team

Figure 9.2-13 Scenario 3: Voltage & Short-circuit Current



Source: JICA Study Team

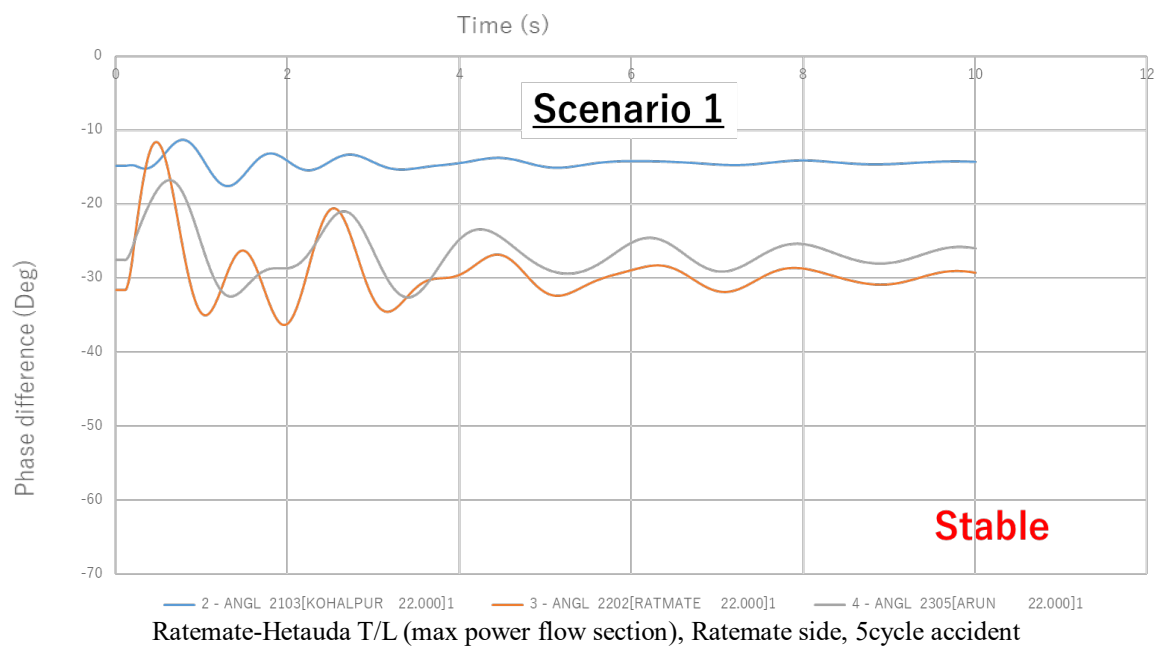
Figure 9.2-14 Scenario 4: Voltage & Short-circuit Current

(3) System stability simulation

The system stability simulation results are shown in Figure 9.2-15, Figure 9.2-16, Figure 9.2-17, and Figure 9.2-18. These graphs show the phase difference between the base generator and the transmission line when a fault occurs.

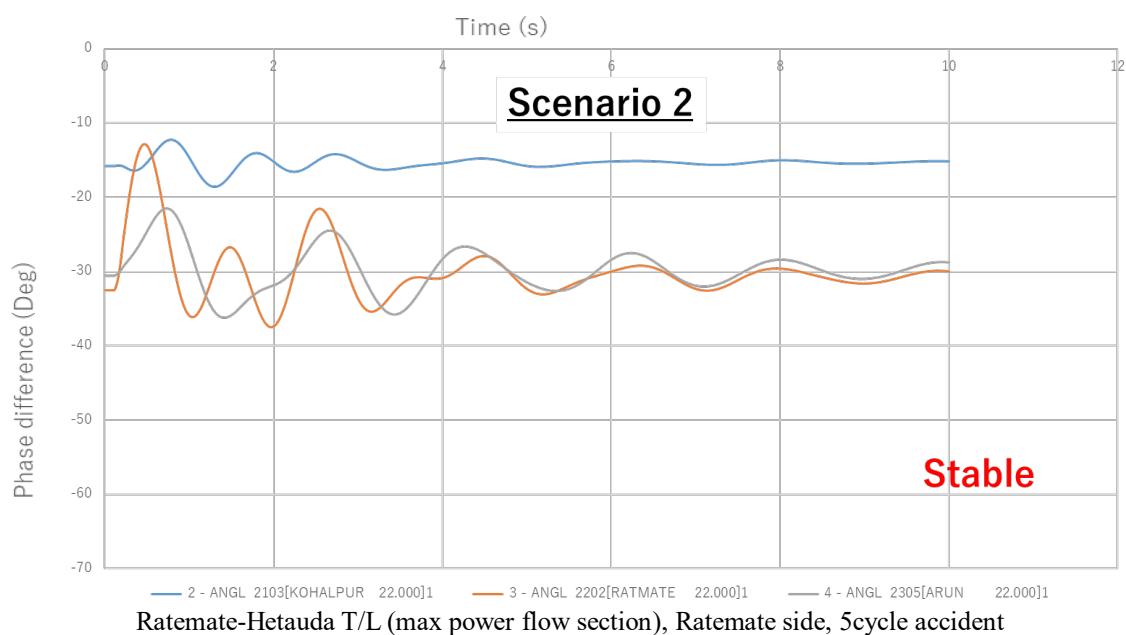
For scenarios 3 and 4, when power export by interconnection lines, the system stability was unstable. The reason is that, with power export through interconnection lines to India, the flow of domestic transmission lines, such as from Purkot on the western side to Lumki, increases power flow, impacting system stability during faults.

Regarding scenarios 3 and 4, system stability was achieved when some power sources were directly exported to India. A detailed explanation of direct export will be given later. The system analysis results shown in Figure 9.2-17 and Figure 9.2-18 shows the case with some power sources directly exported to India (partially direct export).



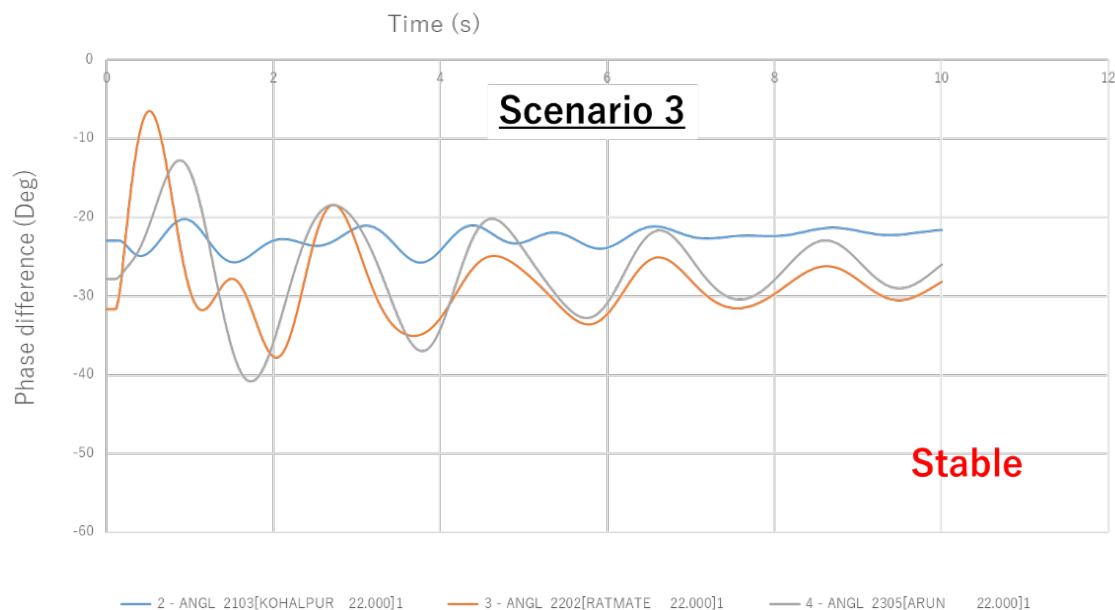
Source: JICA Study Team

Figure 9.2-15 Scenario 1: System Stability Simulation



Source: JICA Study Team

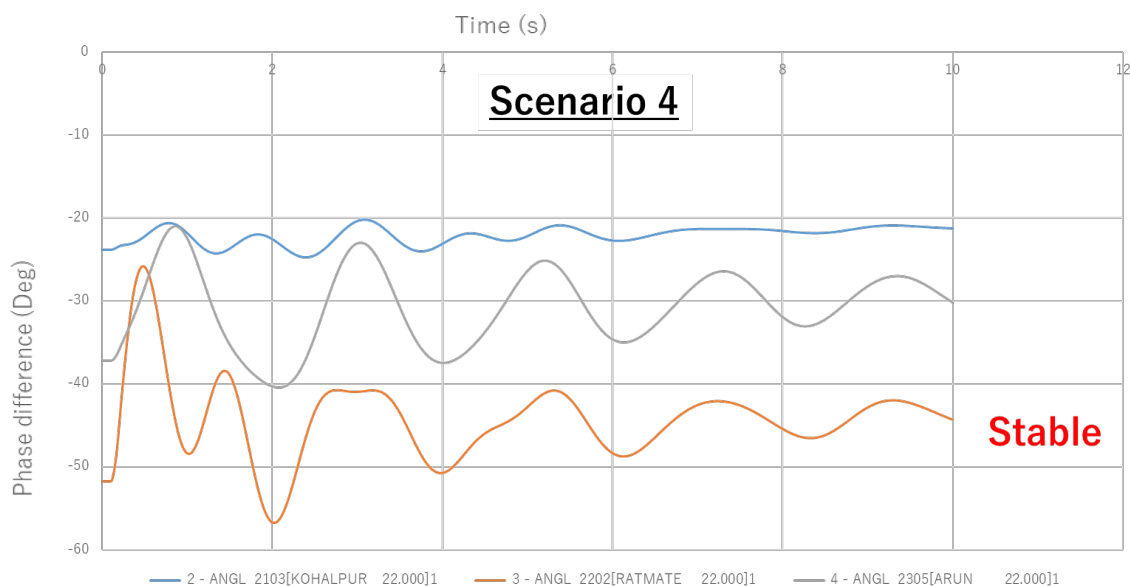
Figure 9.2-16 Scenario 2: System Stability Simulation



Ratmate-Hetauda T/L (max power flow section), Ratmate side, 5cycle accident
(Direct Export: 2.53GW (Purkot))

Source: JICA Study Team

Figure 9.2-17 Scenario 3: System Stability Simulation



Ratmate-Hetauda T/L (max power flow section), Ratmate side, 5cycle accident
(Direct Export: 9.23GW (Purkot, Ratmate, Arun, Kusma))

Source: JICA Study Team

Figure 9.2-18 Scenario 4: System Stability Simulation

(4) Summary

1. System analysis results of 400kV bulk power systems corresponding to four scenario power development plans were carried out, and it was confirmed that the system of each scenario satisfied the technical criteria and was appropriate.
2. In scenarios 3 and 4, direct exports to India will be necessary to maintain system stability. The export method is detailed in Chapter 9.2.3.
3. In Chapter 9.3, other plans were updated, and the validity of the system in the optimal scenario was confirmed based on the latest power system plan.

9.2.3 Study of Electricity Export Methods (Comparison of direct power source line exports and interconnection line exports)

Currently, the power system planned by NEA is to export to India with six lines, but as discussed in Scenarios 3 and 4 above, if there were a large power flow flows in the future, the system stability could not converge. For reference, the results of the stability analysis for Scenario 3 are shown in Figure 9.2-19.

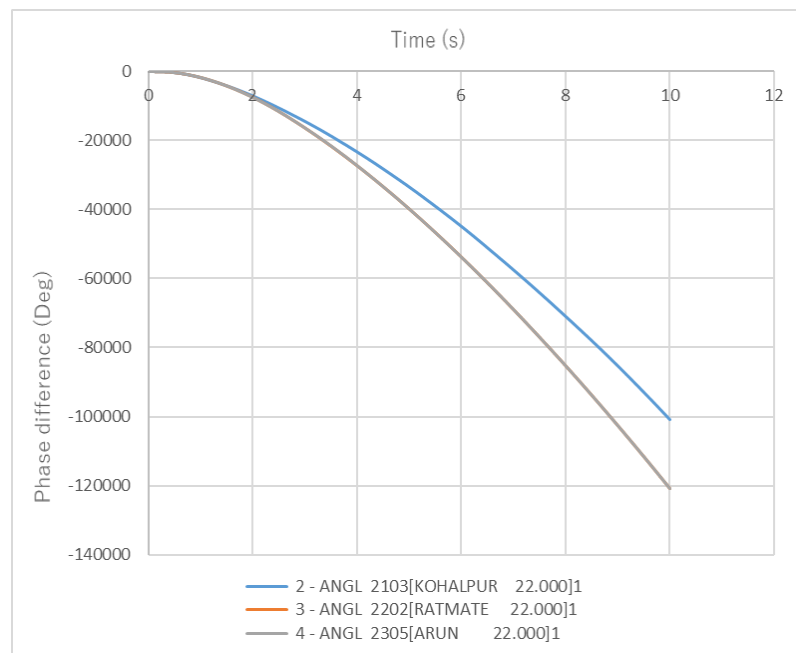
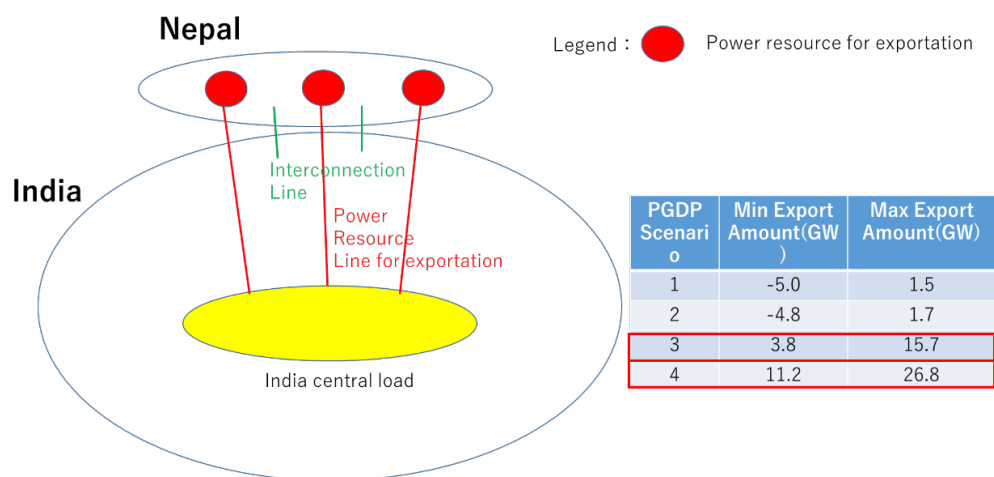


Figure 9.2-19 Scenario 3: System Stability Simulation (not converge)

(1) Study of grid interconnection methods

Therefore, in this study, we are considering two plans for exporting to India. (Figure 9.2-20, Figure 9.2-21).

In Plan B shown in Figure 9.2-21, for scenarios 3 or 4 with significant hydro power development, the concept involves direct export of power from large hydro power plants belonging to Nepal's three major river systems to India through power transmission lines. This concept is a method of directly transmitting electricity from the power source to the demand location.



Source: JICA Study Team

Figure 9.2-20 System Configuration for Large-capacity Power Export (image)

Plan	Export to India By Interconnection line Plan A	Export to India By resource line directly Plan B
System Configuration		
Reliability	Power flow of domestic line are impacted by export power amount, the damage of the power source drop out is large.	Power flow of domestic lines are independent of export power amount, the power system is stable
Cost	Surplus domestic line expansion shall be necessary	Domestic line expansion are not impacted by export power amount, the cost can be reduced

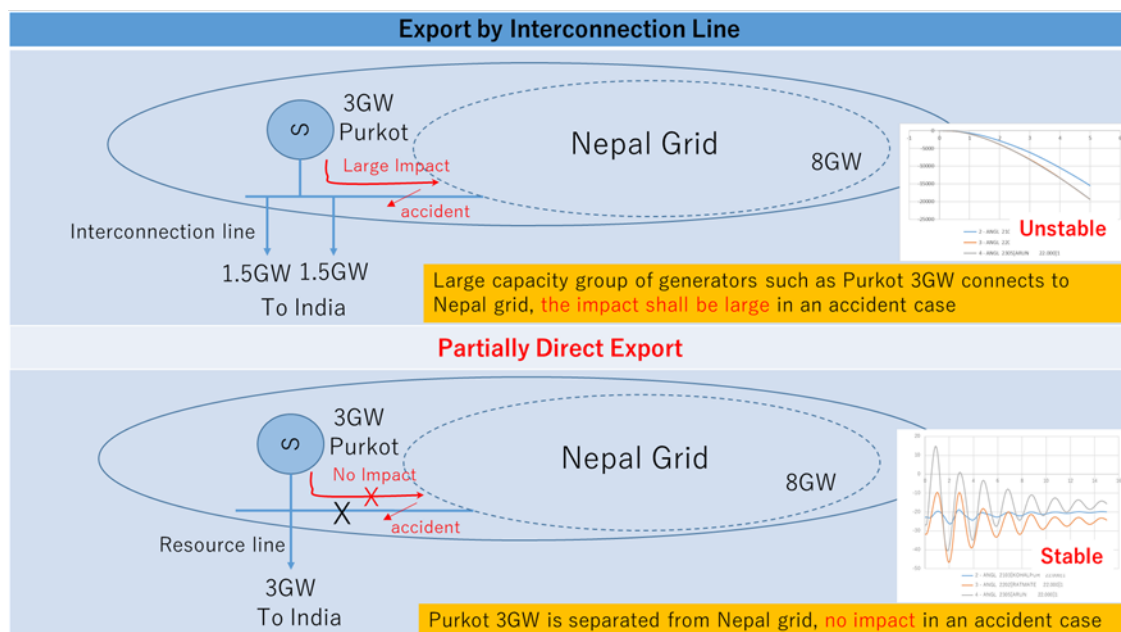
Source: JICA Study Team

Figure 9.2-21 Comparison between the Export Plan (A) using Interconnection Lines and the Direct Export Plan (B) using Power Source Lines

In the example of Japan, it is an image like Kansai area, which has the Kurobe river system and demand areas. As for the power plant on the Kurobe River in Toyama Prefecture, which is outside the commercial area of Kansai Electric Power Co., the electricity generated is sent to Kansai area via a 275kV transmission line. Direct transmission of such a large power source to the demand area does not affect the power grid around the power source, so it can be said that the reliability of the power grid can be improved. Plan A on the left is a plan to export via a domestic power system by using interconnection lines.

In Plan B, the power flow in the domestic system does not depend on the amount of power exported, and the domestic system is stable, so there is no need to increase the number of domestic lines. On the other hand, in Plan A, since the exported power is exported through the domestic system, it is

necessary to reinforce the domestic system in order to transmit the power generated by the hydro power development, as well as the impact of power failure due to an accident. As a result, there is concern that the equipment cost will also increase.



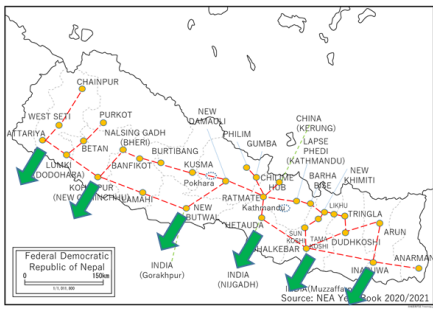
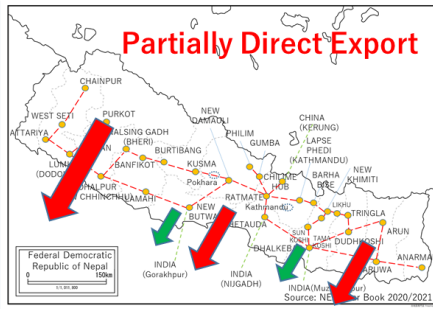
Source: JICA Study Team

Figure 9.2-22 System Stability Image of Interconnection Line Export Plan and Partially Direct Export Plan

For example, in the upper part of Figure 9.2-22, when the 3 GW of power generated from Purkot in the west is connected to the domestic system, the domestic system will be greatly affected in the event of an accident.

This is due to a power failure of a large power source (Purkot is assumed in this case) by an accident in the grid, resulting in a significant drop in the grid frequency. As a result, other generators connected to the grid cannot stably operate in synchronous operation, and there is a high possibility of generators tripping. On the other hand, as shown in the lower part of the figure, direct connection of the Purkot power plant to the Indian side is expected to result in a more stable system without affecting the Nepal domestic system.

In this system analysis, we proposed Plan A', which adopts partially direct export while utilizing the interconnection lines. (Figure 9.2-23)

Plan	Export to India By Interconnection line Plan A	Export to India By resource line directly + Interconnection Line Plan A'
System Configuration		
Dynamic Stability Simulation	For Scenario 3 and Scenario 4, Unstable	For Scenario 3 and Scenario 4, Stable by partially direct export
Voltage	For Scenario 3 and Scenario 4, some voltage is not within $\pm 5\%$	For Scenario 3 and Scenario 4, each voltage is within $\pm 5\%$ by partially direct export

Source: JICA Study Team

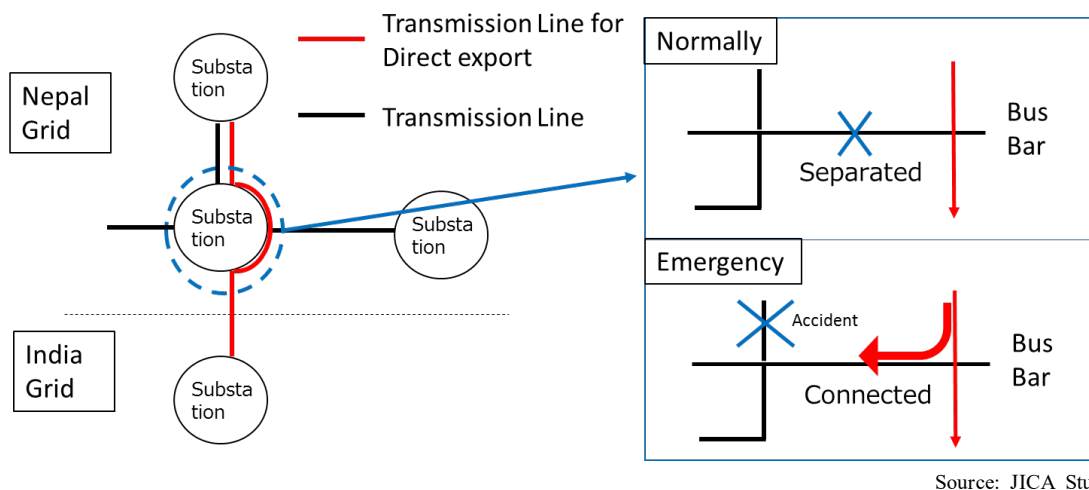
Figure 9.2-23 Comparison between Interconnection Line Export Method (A) and Partially Direct Export Method (A')

So, some of the power plants are exported directly to India, and some are exported via the domestic system to export the surplus. By comparison, it was confirmed that the stability of the system tends to be maintained.

Transmission lines for direct export must also meet Nepal's grid code. Nepal's current grid code prohibits power plants in Nepal from directly connecting to other countries without connecting to the Nepal grid.

Therefore, it is necessary to connect transmission lines for direct export to substations in Nepal. Figure 9.2-24 shows how to ensure grid stability while satisfying the grid code.

Regarding transmission lines for direct export, the busbars inside the substation are kept separate from Nepal's domestic grid during normal times to ensure system stability. However, if there is an emergency situation such as an accident, and it is necessary to transmit electricity to Nepal's domestic grid, by turning on the substation's bus separation switch, power can be directly transmitted from the export transmission line to Nepal's domestic grid.



Source: JICA Study Team

Figure 9.2-24 Direct Export Transmission Line Connection Method

(2) Flow for Introducing Direct Export Transmission Lines

Figure 9.2-25 shows the flow for introducing direct export transmission lines if system stability cannot be maintained in the event of a system fault across six planned interconnection line sections. Stability analysis is conducted on the planned power system, and if stability cannot be maintained, some of the interconnection lines are replaced with direct export transmission lines to reduce power flows within Nepal, thereby minimizing the impact during system faults.

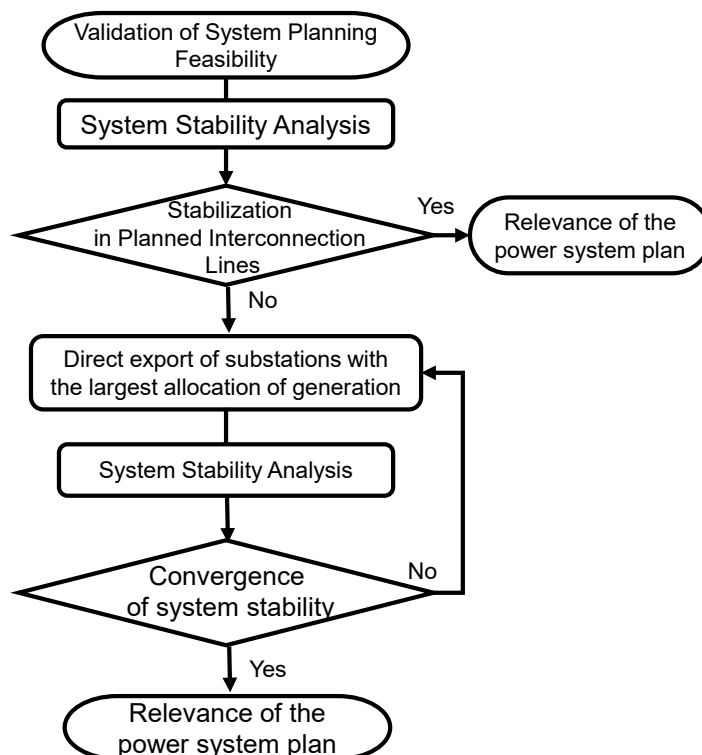


Figure 9.2-25 Flowchart for Introducing Direct Export Transmission Lines

(3) Development plans for interconnection lines

As a summary of the export method, the situation is organized below with the time axis until 2040.

The power plants on the Karnali river system are located in remote areas and are scheduled to be completed after 2030. Therefore, we assume that these Plan A' direct exports will be necessary after 2030. As for power exports, in the short term, the existing Dhalkebar 400kV interconnection line and New Butwal, which is currently under construction, will be useful. In the medium term, as the development of hydro power increases, it will be necessary to respond with the interconnection line that the NEA is considering, and in the long term after 2030, it will be necessary to take measures such as Plan A'.

As shown in the power flow diagram above, power imports and exports differ by scenario. For the system stability simulation, there was a tendency for system stability to diverge as power exports increased (Scenarios 3 and 4). Therefore, the interconnection line method was changed for scenarios 3 and 4 as follows.

Table 9.2-2 The Interconnection line for each scenario

Item	Power trade	Method	Interconnection point
Scenario 1	Import	Interconnection line to be constructed early	2 transmission line
Scenario 2	Import	Interconnection line to be constructed early	2 transmission line
Scenario 3	Export	Partial direct interconnect line to India	6 transmission line
Scenario 4	Export	Partial direct interconnect line to India	6 transmission line

Source: JICA Study Team

Discussions were held with WG members, including the NEA, regarding these power export concepts, and they generally understood the necessity of the export method.

9.3 Study of Optimal Scenario

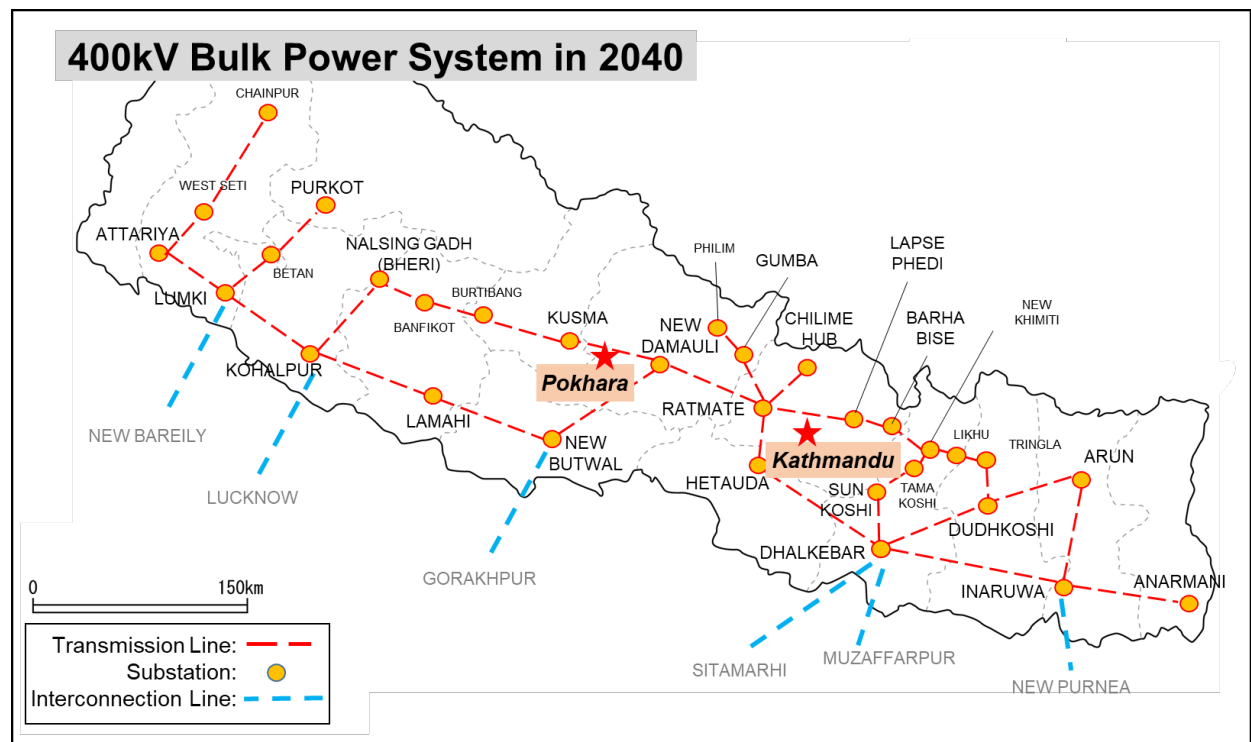
As stated in Chapter 9.2, the validity of the system plan was confirmed for all scenarios. Based on the results of system planning, power development planning, economic and financial analysis, and environmental and social considerations, Scenario 3 was determined to be the optimal scenario (hereinafter referred to as the “optimal scenario”).

For the optimal scenario, a system analysis will be conducted to confirm the validity of the power system plan for optimization for the target year of 2040. During the 8th site survey (December 2023), the priority project list for power development plan and the power demand forecast were finalized. Therefore, the verification will be based on the new demand forecast and power generation list. The verification items for the power system analysis are the same as those in Chapter 9.2.

9.3.1 Precondition of Power System Analysis in Optimal Scenario

(1) 400 kV bulk power system

A detailed examination will be conducted on the optimal scenario (Scenario 3) selected in Chapter 7 to verify the validity of the power system plan. The premise conditions for the detailed examination are described below.

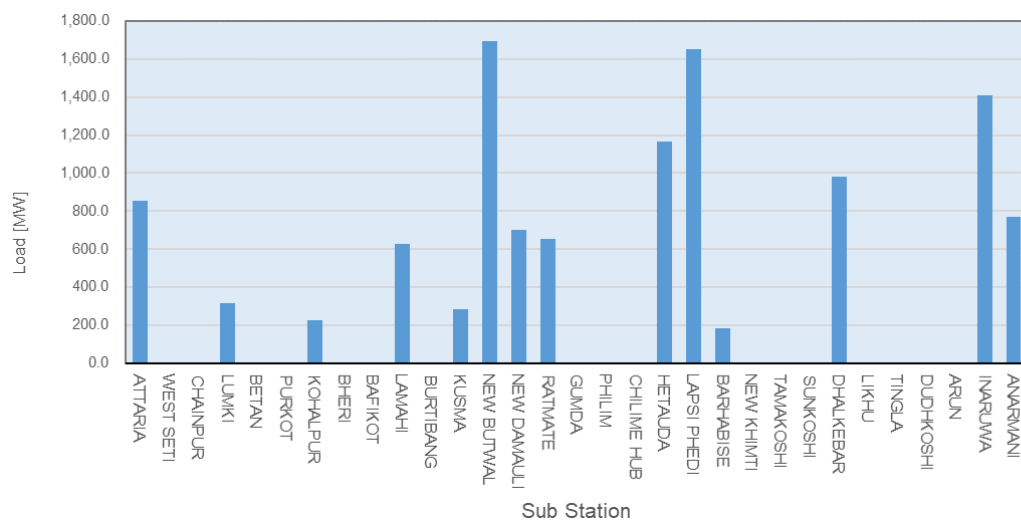


Source: JICA Study Team based on NEA Annual Report 2020/2021

Figure 9.3-1 400kV Bulk Power System (as of 2040 year)

(2) Load allocation

As mentioned in 9.2.1(2), the calculation method utilized the actual load data from existing substations (based on data from 2022). As a result, the peak demand for the 400kV substation in the optimal scenario for the year 2040 was determined to be 11,510MW. The result is shown in Figure 9.3-2.

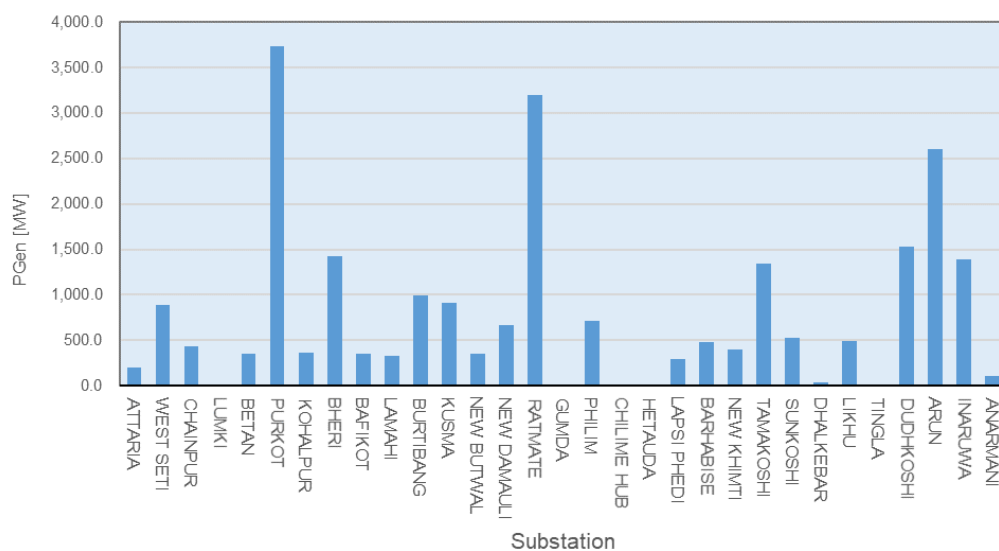


Source: JICA Study Team

Figure 9.3-2 Load Allocation of 400kV System in Optimal Scenario (Rainy Peak)

(3) Power generation allocation

As stated in chapter 9.2.1(3), the power generation for optimal scenario is shown below. The power generation was applied during the rainy season in August.

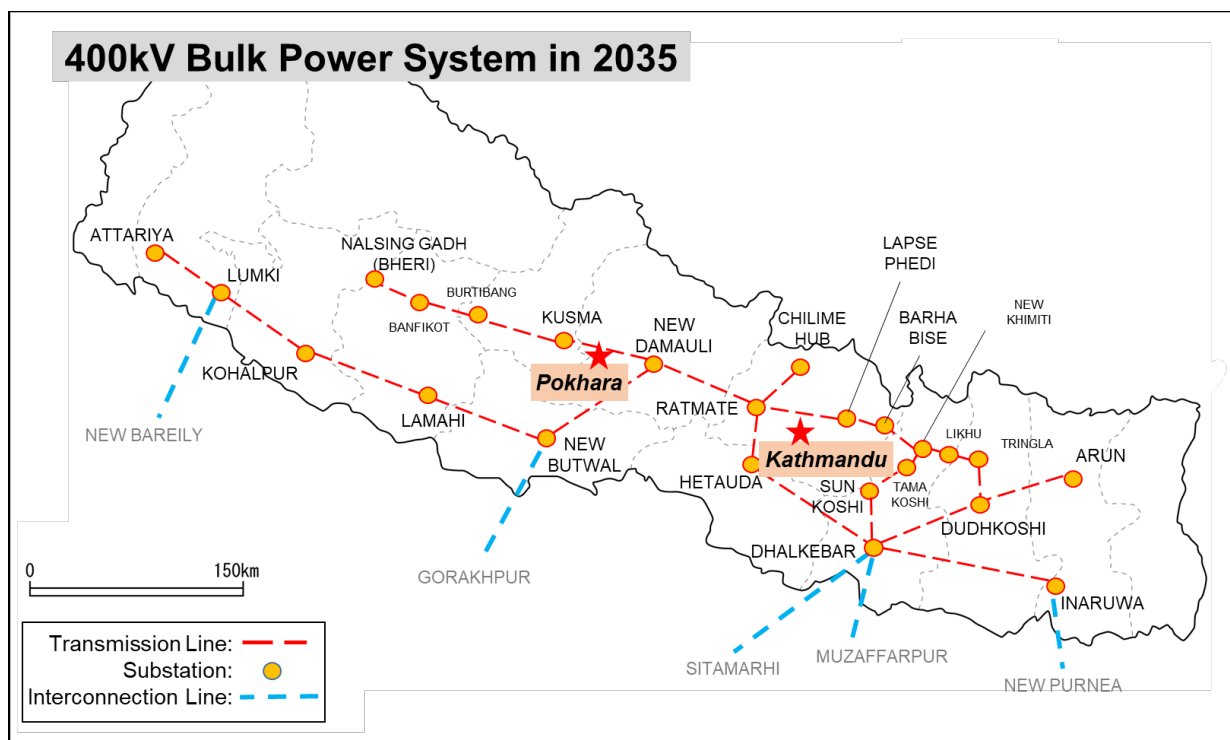


Source: JICA Study Team

Figure 9.3-3 Power Generation Allocation of 400kV System in Optimal Scenario (Rainy Peak)

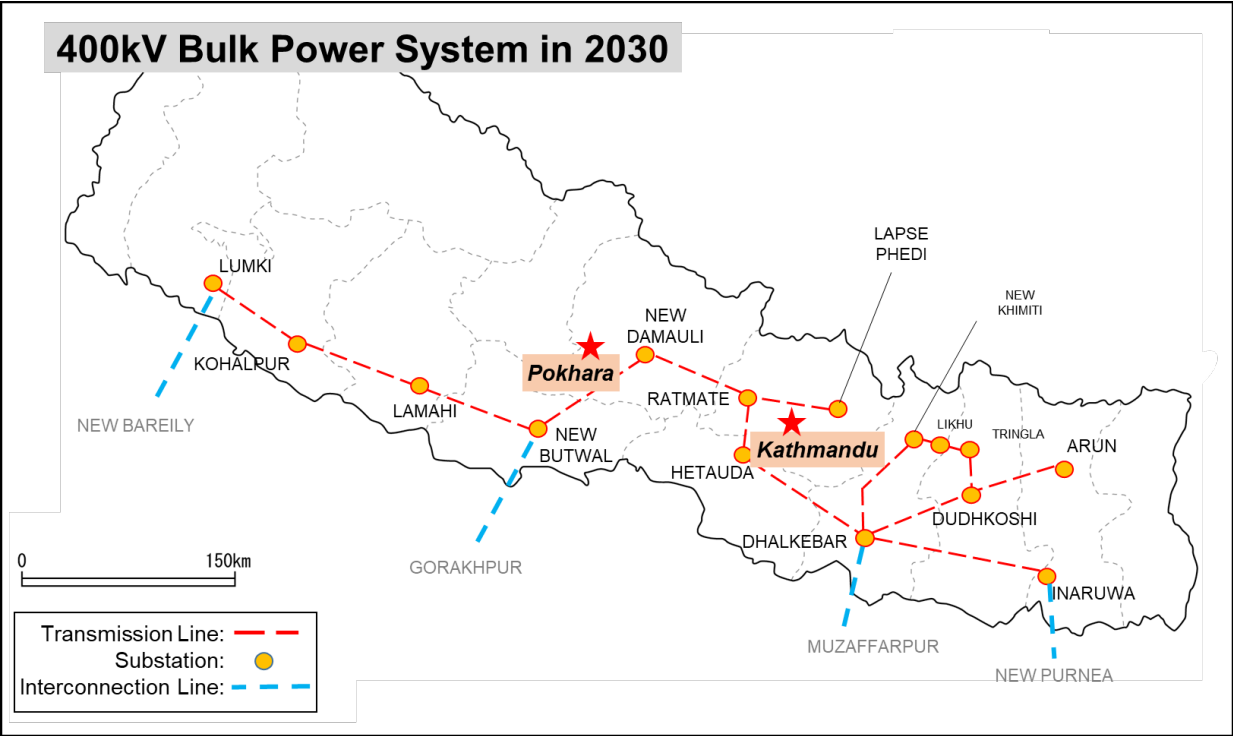
(4) Study of the intermediate year

The system analysis for the intermediate years (2035, 2030, 2025) of the 400kV bulk power system was conducted based on the optimal scenario. Discussion with NEA was performed to assess the status of the 400kV bulk power system in the intermediate years. The results are shown in Figure 9.3-4, Figure 9.3-5 and Figure 9.3-6. The peak demands for each year were set at 7,581MW (2035), 4,949MW (2030), and 2,675MW (2025).



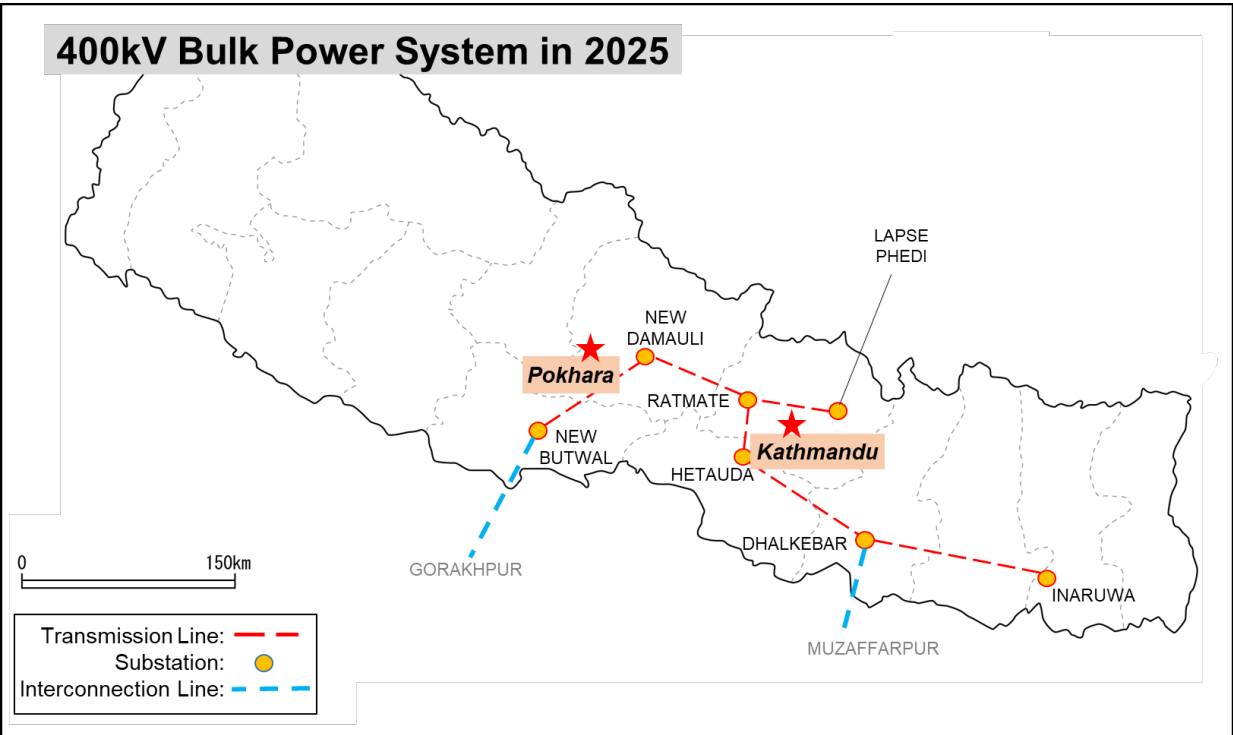
Source: JICA Study Team

Figure 9.3-4 400kV Bulk Power System in 2035



Source: JICA Study Team

Figure 9.3-5 400kV Bulk Power System in 2030



Source: JICA Study Team

Figure 9.3-6 400kV Bulk Power System in 2025

9.3.2 Power System Analysis Results in Optimal Scenario

(1) Study case for the year 2040

Based on the premise conditions mentioned in the previous section, system analysis was conducted for the following cases of the optimal scenario. The power flow, voltage, short circuit current, and system stability were examined, and the results are presented in after sections.

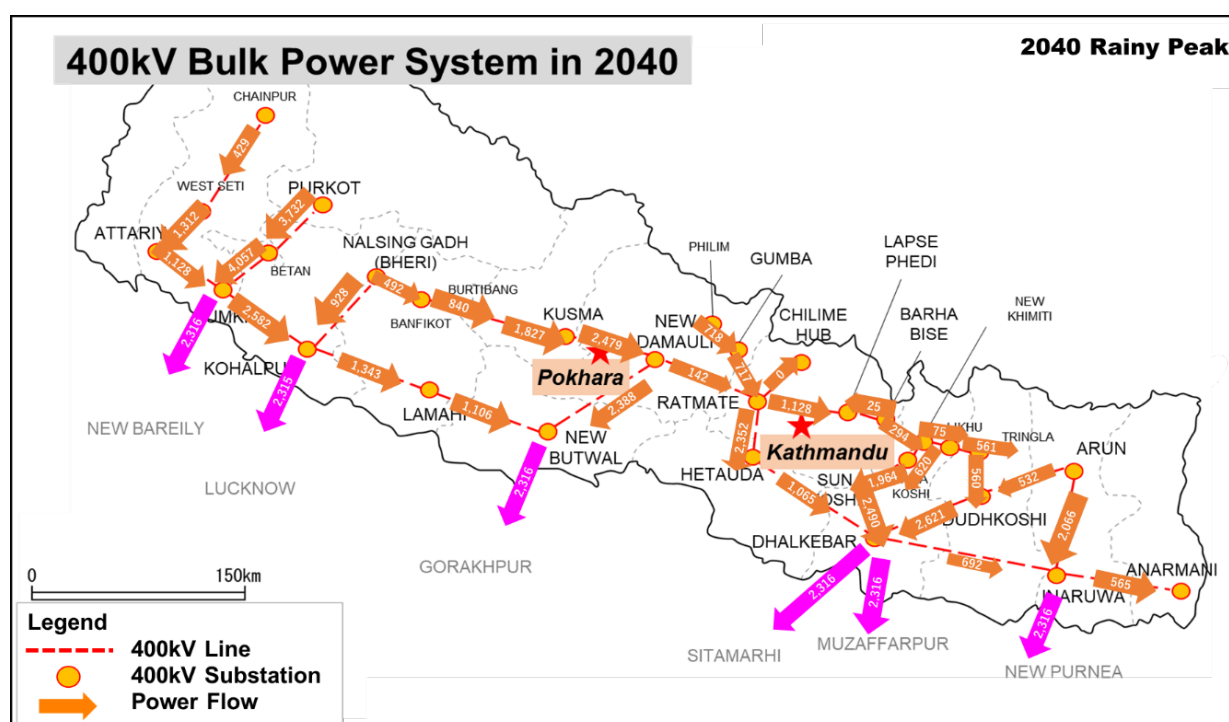
Table 9.3-1 The Study Cases in Optimal Scenario

Targets year of 2040			
No	Case	Conditions of consideration	Direct export
1	2040 Rainy Peak	Maximum power generation during the rainy season Cross section of maximum power demand	3 points
2	2040 Rainy Off Peak	Maximum power generation during the rainy season Cross section of minimum power demand	1 point

Source: JICA Study Team

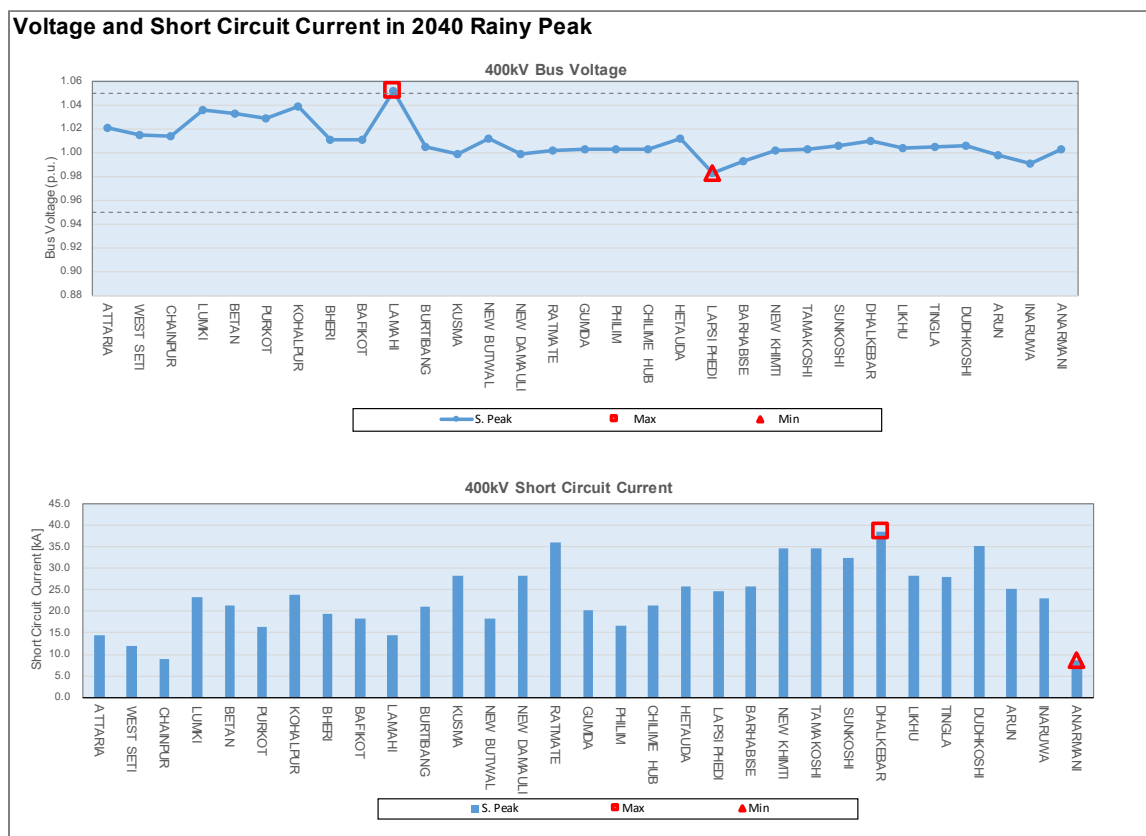
1) 2040 Rainy Peak

The results of the power flow, voltage, short circuit current, and system stability analysis are shown in Figure 9.3-7 to Figure 9.3-9. The interconnection lines are configured to export approximately 2,300 MW of power per location, with direct exports from the Purkot, Betan, Ratmate, and Arun substations. The voltage and short circuit current remained within specified limits, and direct exports contributed to maintaining system stability.



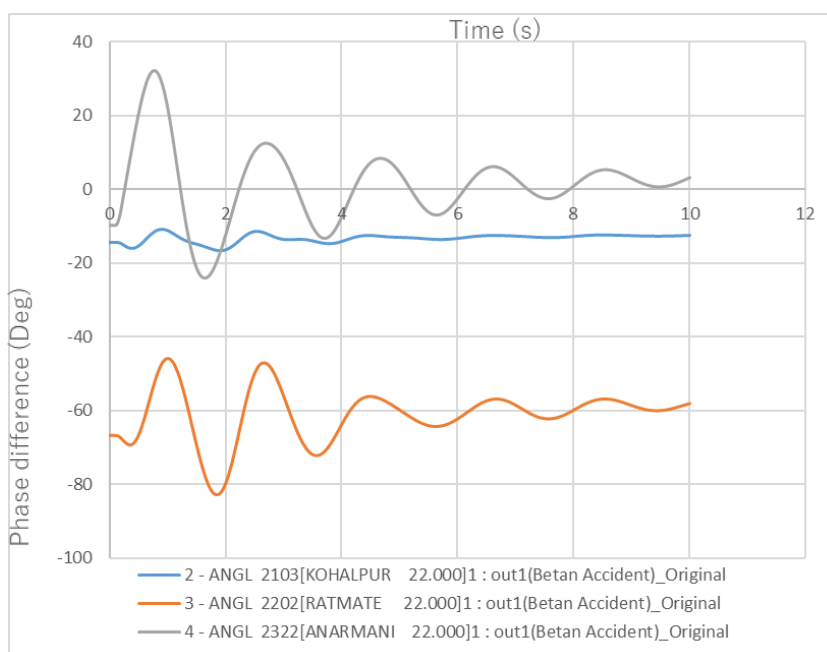
Source: JICA Study Team

Figure 9.3-7 2040 Rainy Peak (power flow)



Source: JICA Study Team

Figure 9.3-8 2040 Rainy Peak (voltage, short circuit current)



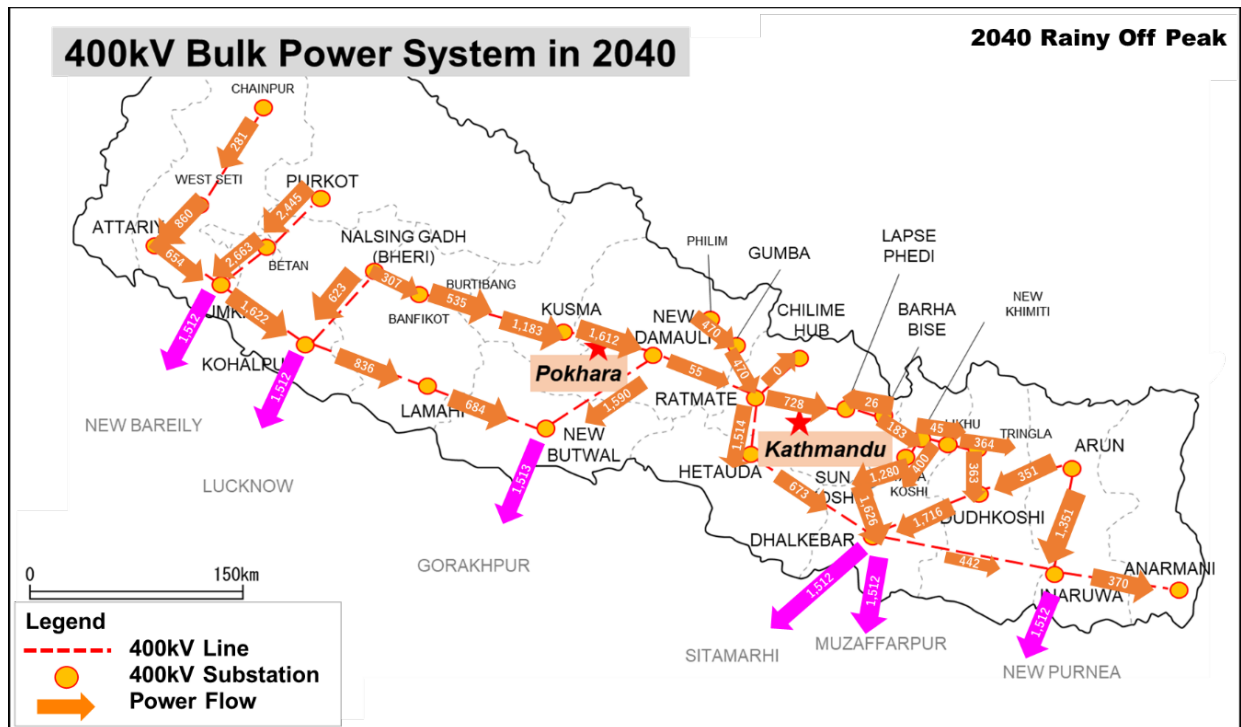
New Damauli – New Butwal T/L (max power flow section), New Damauli side, 5cycle accident
(Direct Export: 7.28GW (Purkot, Betan, Ratmate))

Source: JICA Study Team

Figure 9.3-9 2040 Rainy Peak (system stability)

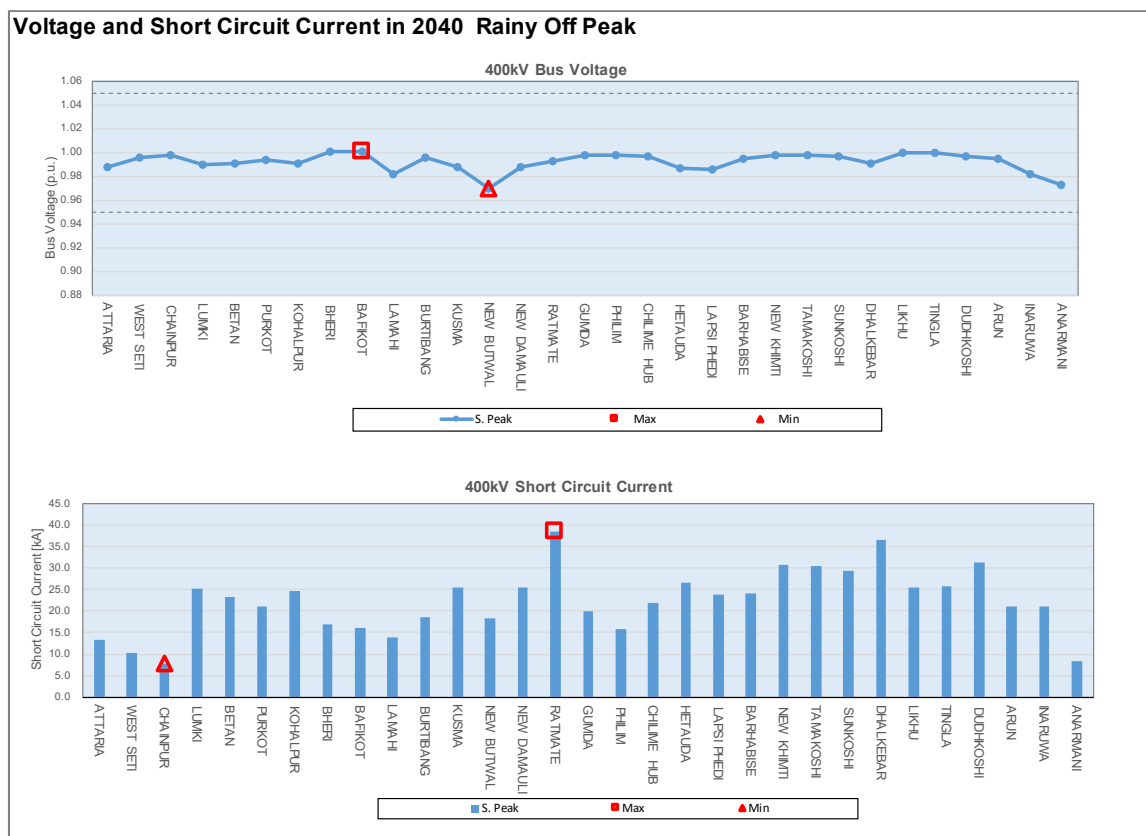
2) 2040 Rainy Off Peak

The results of the power flow, voltage, short circuit current, and system stability analysis are shown in Figure 9.3-10 to Figure 9.3-12. The interconnection lines are configured to export approximately 1,500 MW of power per location, with direct exports from the Purkot, Betan, Ratmate, and Arun substations. The voltage and short circuit current remained within specified limits, and direct exports contributed to maintaining system stability.



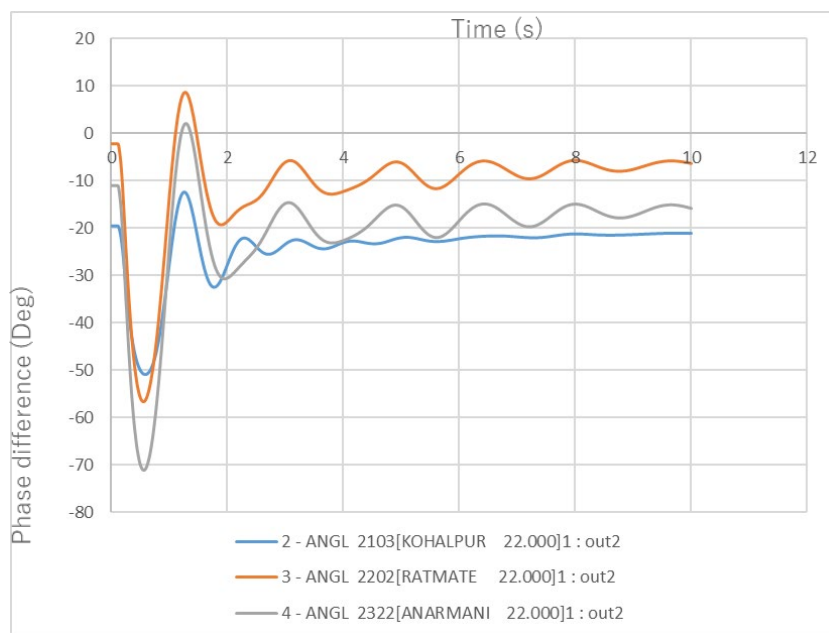
Source: JICA Study Team

Figure 9.3-10 2040 Rainy Off Peak (power flow)



Source : JICA Study Team

Figure 9.3-11 Rainy Off Peak (voltage, short circuit current)



New Damauli – New Butwal T/L (max power flow section), New Damauli side, 5cycle accident
(Direct Export: 2.44GW (Purkot))

Source : JICA Study Team

Figure 9.3-12 Rainy Off Peak (system stability)

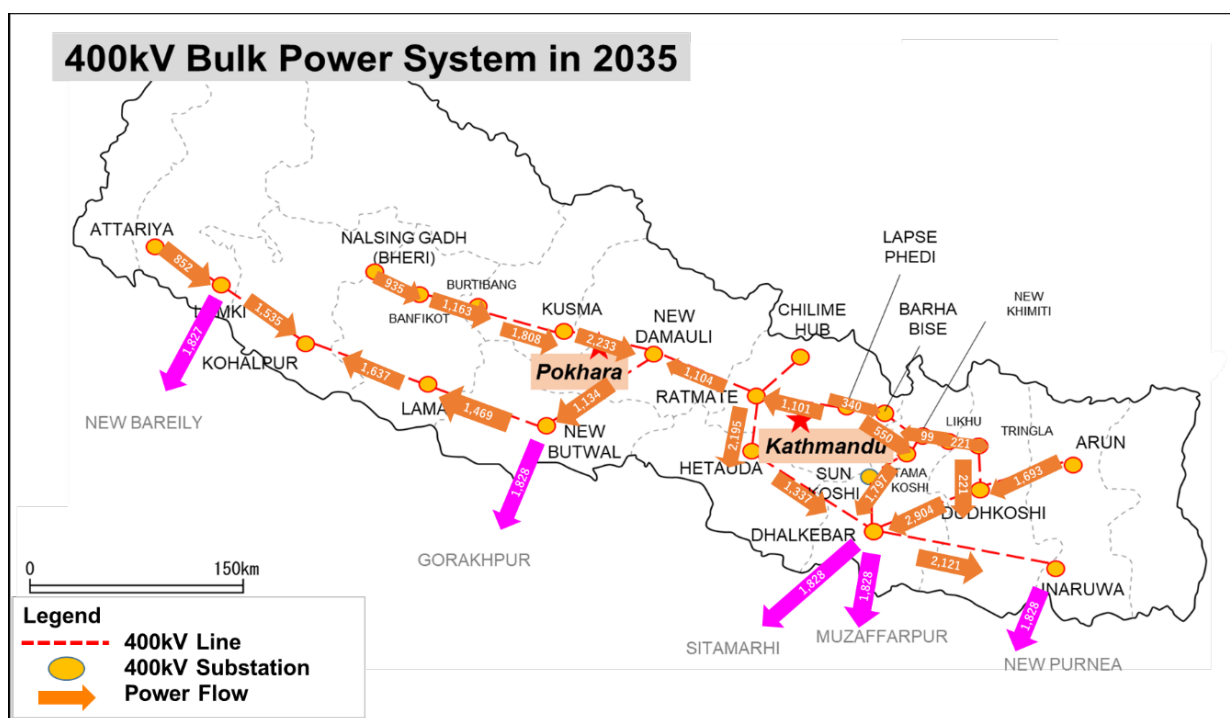
(2) Study case for the interim year

The validity of the intermediate cross-section of the system was confirmed for development toward 2040. The study cases were based on periods with high generation during the rainy season and peak demand every five years. The study cases are as follows:

Targets year of 2035, 2030, 2025		
No	Case	Conditions of consideration
3	2035 Rainy Peak	Maximum power generation during the rainy season as of 2035 Cross section of maximum power demand
4	2030 Rainy Peak	Maximum power generation during the rainy season as of 2030 Cross section of maximum power demand
5	2025 Rainy Peak	Maximum power generation during the rainy season as of 2025 Cross section of maximum power demand

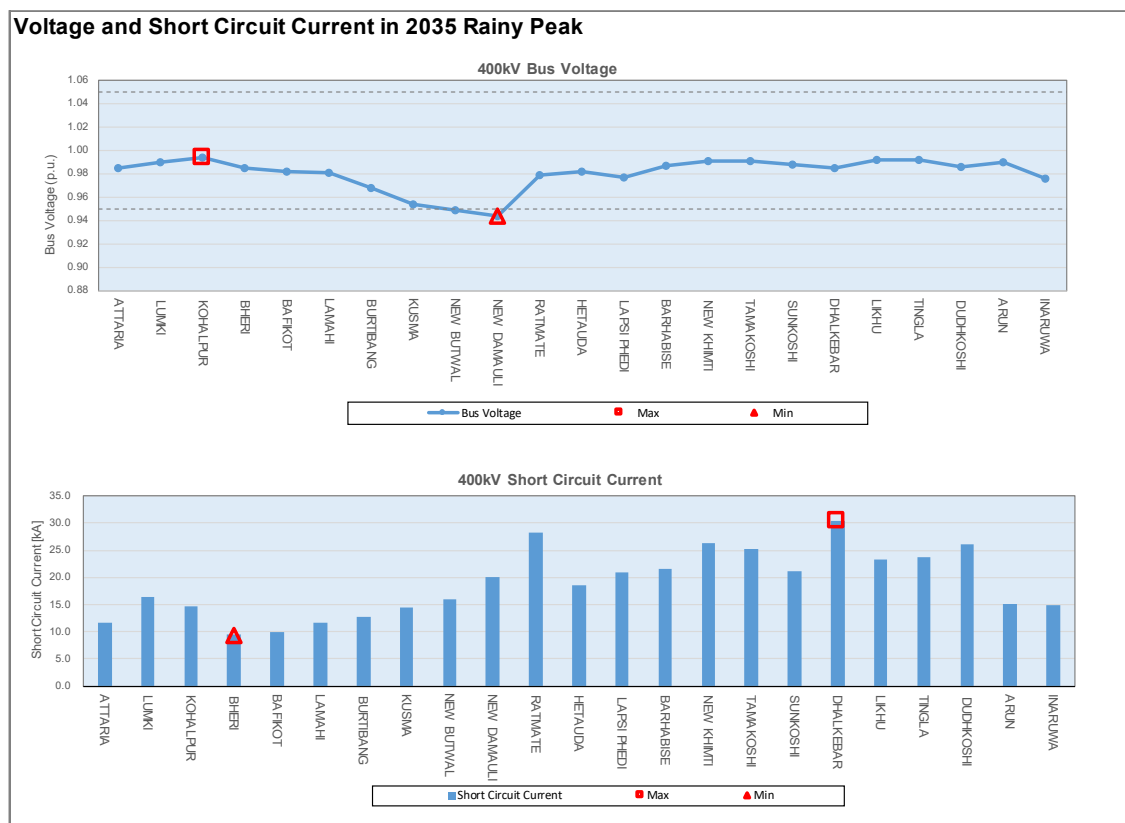
1) 2035 Rainy Peak

The results of the power flow, voltage, short circuit current, and system stability analysis are shown in Figure 9.3-13 to Figure 9.3-15. The interconnection lines are configured to export approximately 1,800 MW of power per location, with direct exports from the Arun and Lumki substations. The voltage and short circuit current remained within specified limits, and direct exports contributed to maintaining system stability.



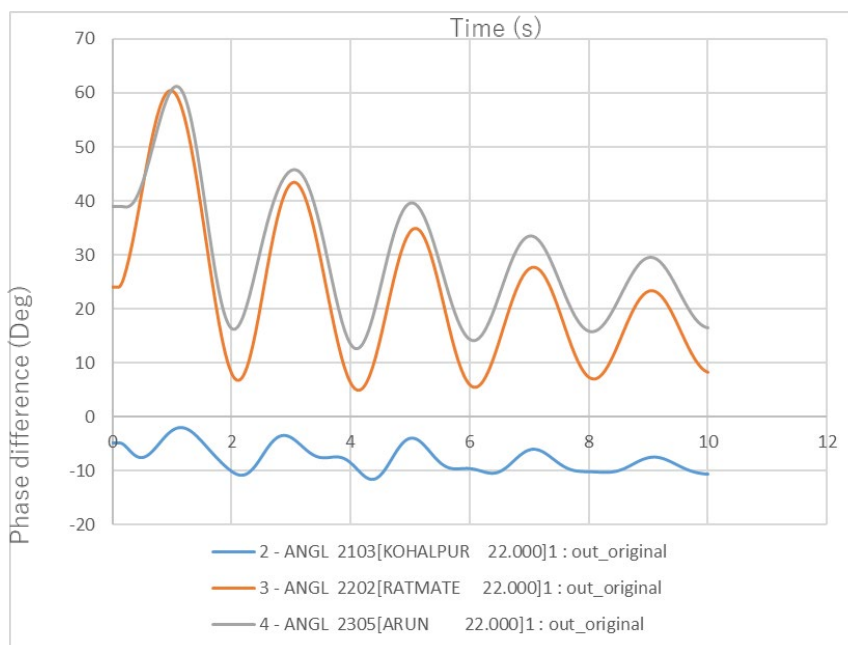
Source: JICA Study Team

Figure 9.3-13 2035 Rainy Peak (power flow)



Source: JICA Study Team

Figure 9.3-14 2035 Rainy Peak (voltage, short circuit current)



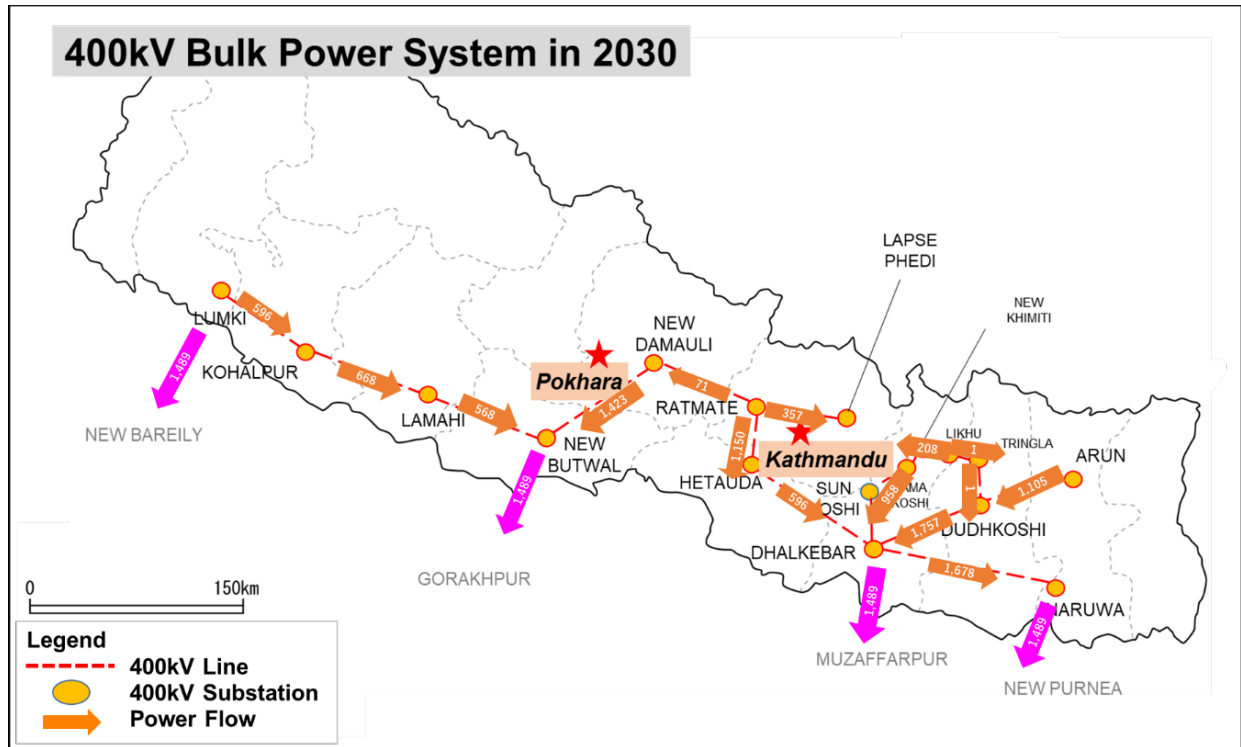
New Damauli - New Butwal T/L (max power flow section), New Damauli side, 5cycle accident
(Direct Export: 2.70GW(Lumki))

Source : JICA Study Team

Figure 9.3-15 2035 Rainy Peak (system stability)

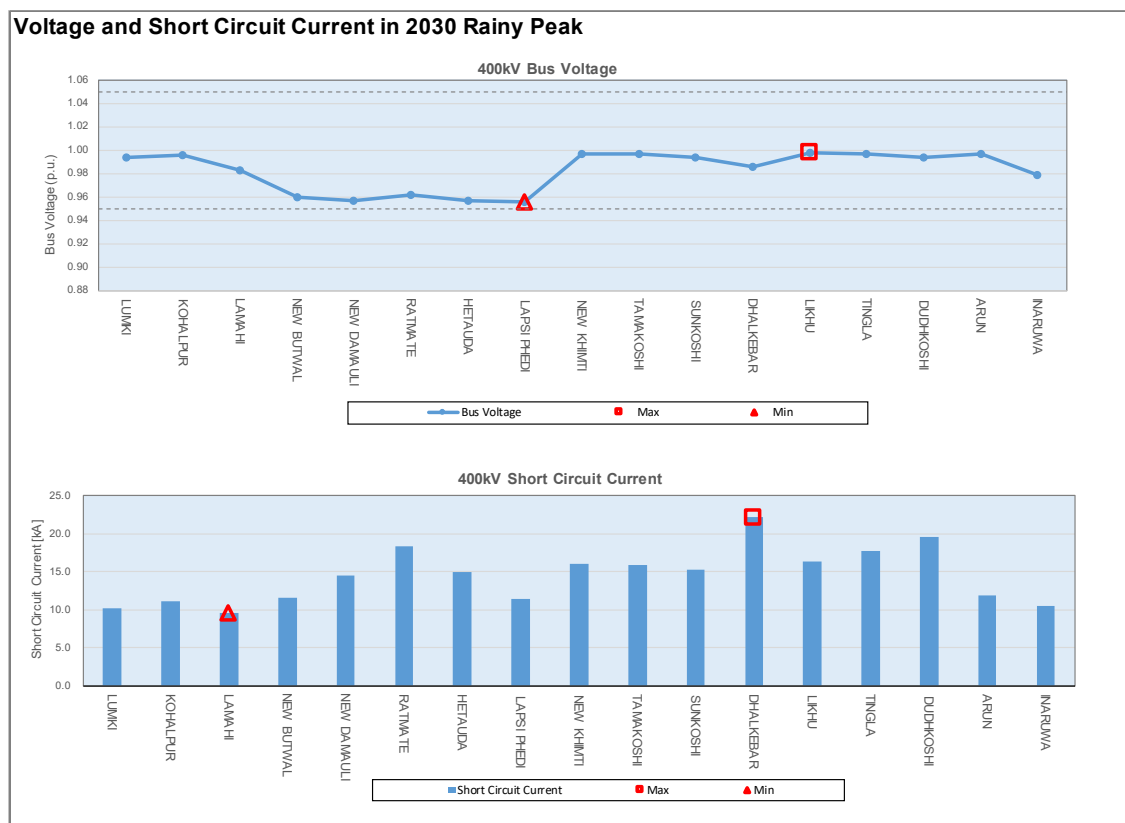
2) 2030 Rainy Peak

The results of the power flow, voltage, short circuit current, and system stability analysis are shown in Figure 9.3-16 to Figure 9.3-18. The interconnection lines are configured to export approximately 1,500 MW of power per location, with direct exports from the Arun, Lumki and Ratmate substations. The voltage and short circuit current remained within specified limits, and direct exports contributed to maintaining system stability.



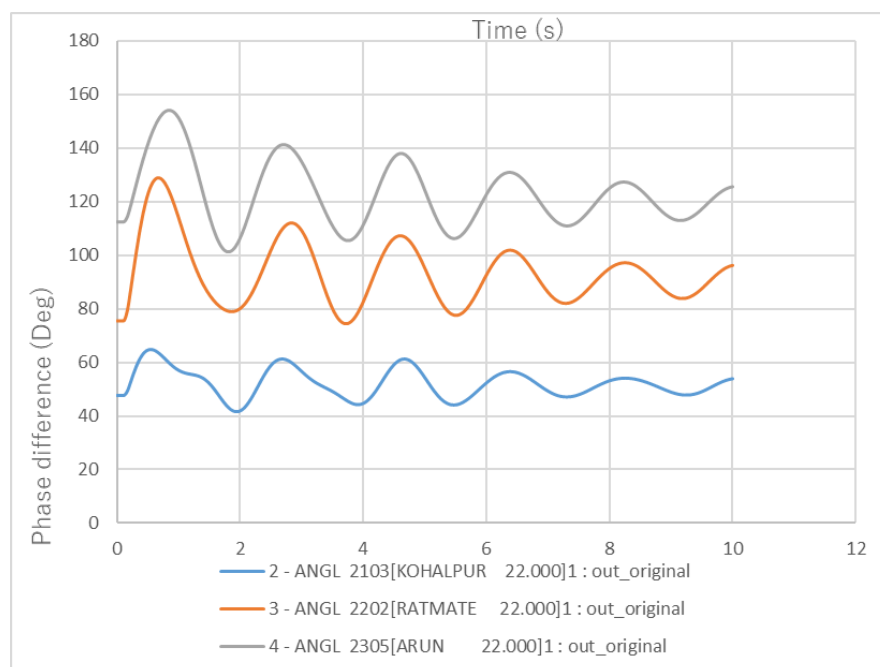
Source: JICA Study Team

Figure 9.3-16 2030 Rainy Peak (power flow)



Source: JICA Study Team

Figure 9.3-17 2030 Rainy Peak (voltage, short circuit current)



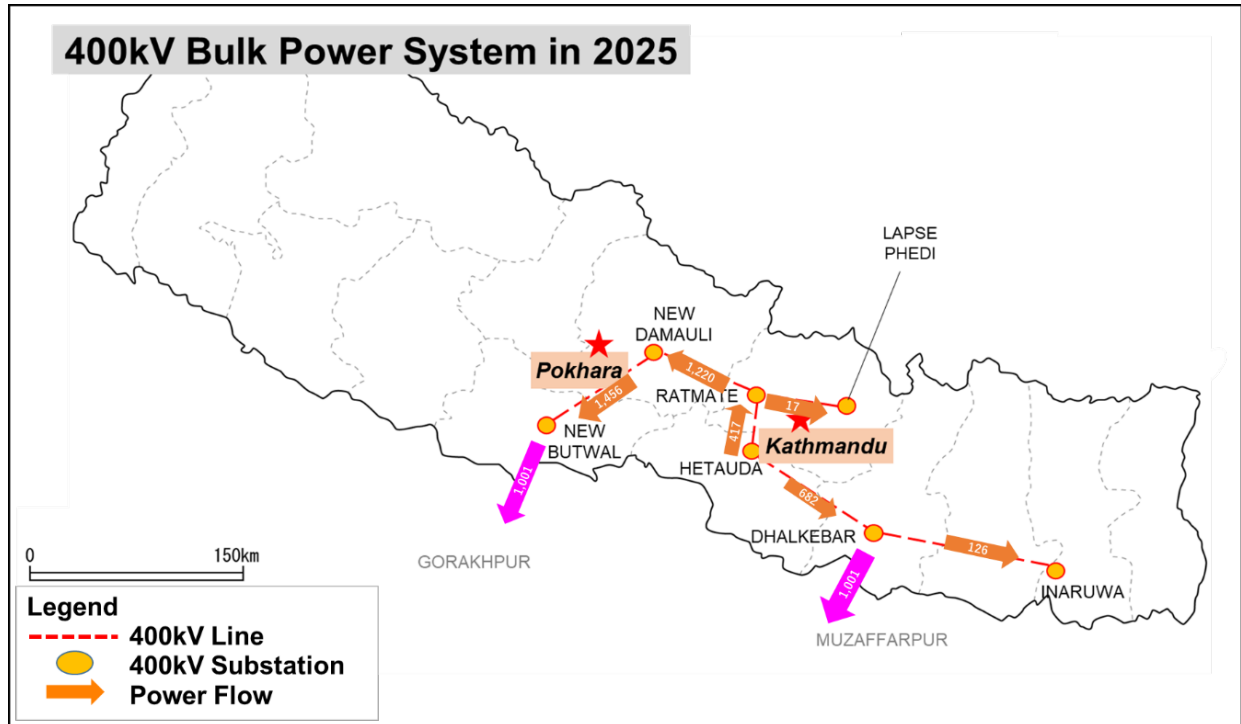
New Damauli - Ratmate T/L (max power flow section), New Damauli side, 5cycle accident
(Direct Export: 4.28GW(Lumki, New Damauli))

Source: JICA Study Team

Figure 9.3-18 2030 Rainy Peak (system stability)

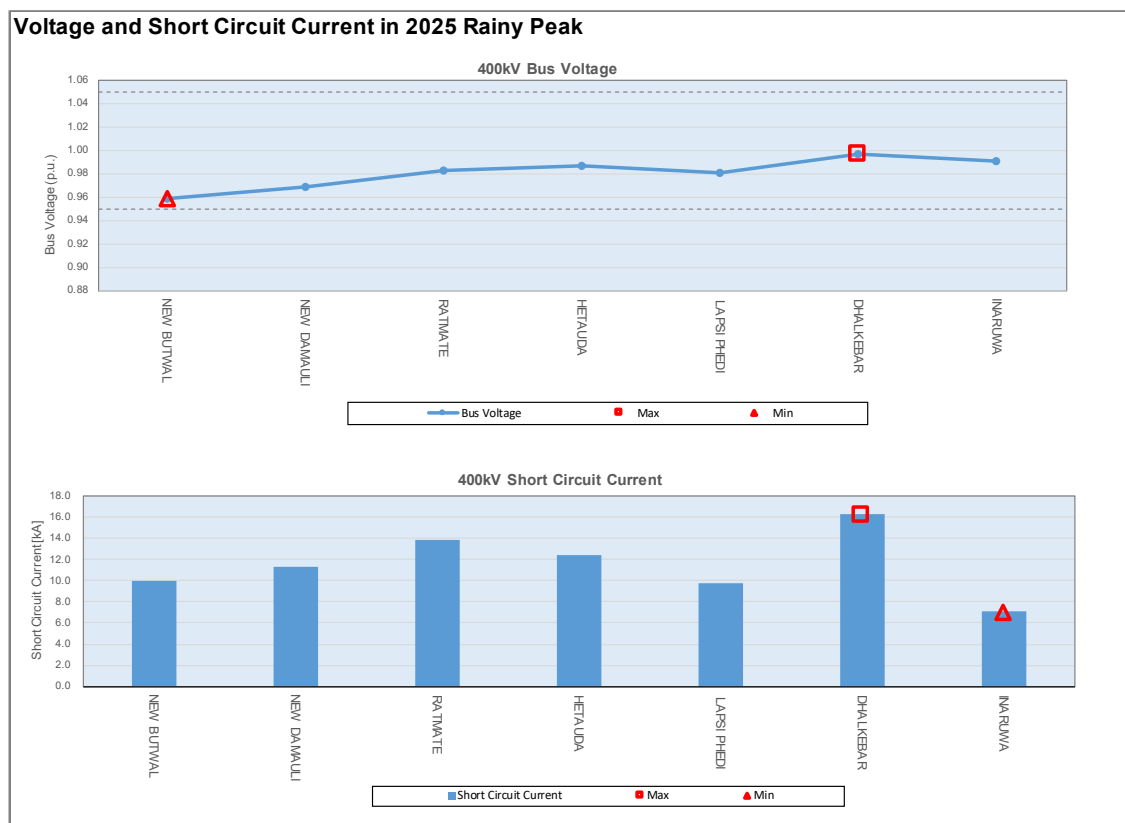
3) 2025 Rainy Peak

The results of the power flow, voltage, short circuit current, and system stability analysis are shown in Figure 9.3-19 to Figure 9.3-21. The interconnection lines are configured to export approximately 1,000 MW of power per location. The voltage and short circuit current remained within specified limits, and direct exports contributed to maintaining system stability.



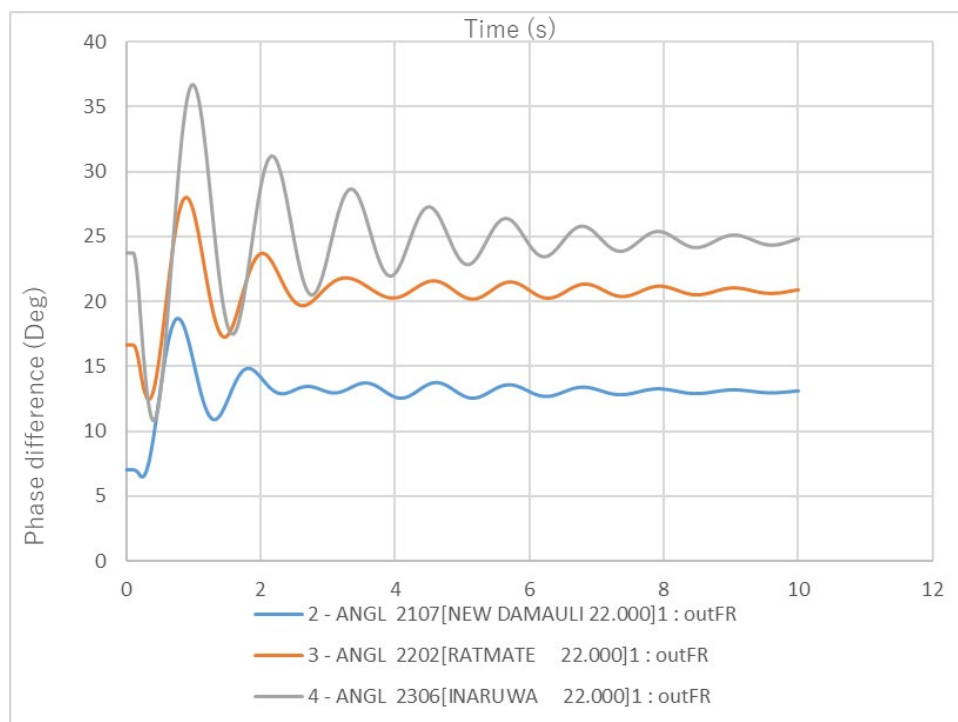
Source: JICA Study Team

Figure 9.3-19 2025 Rainy Peak (power flow)



Source: JICA Study Team

Figure 9.3-20 2025 Rainy Peak (voltage, short circuit current)



New Damauli – New Butwal T/L (max power flow section), New Damauli side, 5cycle accident

Source: JICA Study Team

Figure 9.3-21 2025 Rainy Peak (system stability)

9.3.3 Construction Cost of 400kV Bulk Power System (Domestic System)

Table 9.3-2 shows the estimated construction cost of the 400kV bulk power system (domestic system). The total cost of transmission facilities and substations is 4,440 million USD, and if sub-systems of 220 kV or less (including the construction costs of distribution system) are included, the total construction cost of transmission and substation facilities is expected to be about 9.5 billion USD.

Table 9.3-2 Construction Cost of 400kV Bulk Power System (domestic system)

Year	Substation		Transmission		Distribution Line ³	Total
	400kV	Others ⁴	400kV	Others		
2022	115.8	45.6	69.3	31.6	142.3	404
2023	115.8	45.6	69.3	31.6	142.3	404
2024	115.8	45.6	69.3	31.6	142.3	404
2025	115.8	45.6	69.3	31.6	142.3	404
2026	154.3	60.8	92.3	42.1	203.4	553
2027	154.3	60.8	92.3	42.1	203.4	553
2028	154.3	60.8	92.3	42.1	203.4	553
2029	154.3	60.8	92.3	42.1	203.4	553
2030	154.3	60.8	92.3	42.1	203.4	553
2031	154.3	60.8	92.3	42.1	129.8	479
2032	154.3	60.8	92.3	42.1	129.8	479
2033	154.3	60.8	92.3	42.1	129.8	479
2034	154.3	60.8	92.3	42.1	129.8	479
2035	154.3	60.8	92.3	42.1	129.8	479
2036	154.3	60.8	92.3	42.1	193.8	543
2037	154.3	60.8	92.3	42.1	193.8	543
2038	154.3	60.8	92.3	42.1	193.8	543
2039	154.3	60.8	92.3	42.1	193.8	543
2040	154.3	60.8	92.3	42.1	193.8	543

Source: JICA Study Team

³ Distribution system of 33 kV or less

⁴ 220 kV and 132 kV transmission systems

9.4 220kV, 132kV Subsystem Analysis in the Recent Years

9.4.1 Background and Conditions of the Study

(1) Background of the study

In the 6th site survey, a study of the recent 132, 220kV power system was requested by NEA. We conducted a power flow calculation for 132, 220 kV transmission throughout Nepal.

(2) Conditions of the study

The preconditions used for 220kV, 132kV power system study are as follows. The power generation list was reviewed during the 8th site survey (December 2023), so the following data has also been updated.

Table 9.4-1 Precondition of Study for 220kV, 132kV Subsystem

Item	Value	Source
Peak Demand in the nearest year	2,675 (MW) Approximately 1.5 times of actual peak demand	Results of Power Demand Forecast WG team (Approved by JCC as year of 2025 year)
Load at substation	—	Calculated based on 2021 actual NCC data
132kV, 220kV power system	—	Based on NEA Annual Report (2021/2022)
Number of power plants	103 (places)	Power development plan study results of 10MW or more from the PGDP WG team (reflecting WG study results)
Total output of power plants	4,969 (MW)	Power development plan study results from PGDP WG team (reflecting WG study results)

Source: JICA Study Team

Power flow calculations for the 220kV, 132kV power system were conducted with the above conditions.

9.4.2 Power Flow Analysis Results and Countermeasures

(1) The results of the power flow analysis

We conducted power flow calculations for the 220kV, 132kV power system and the results is shown in the Figure 9.4-1.

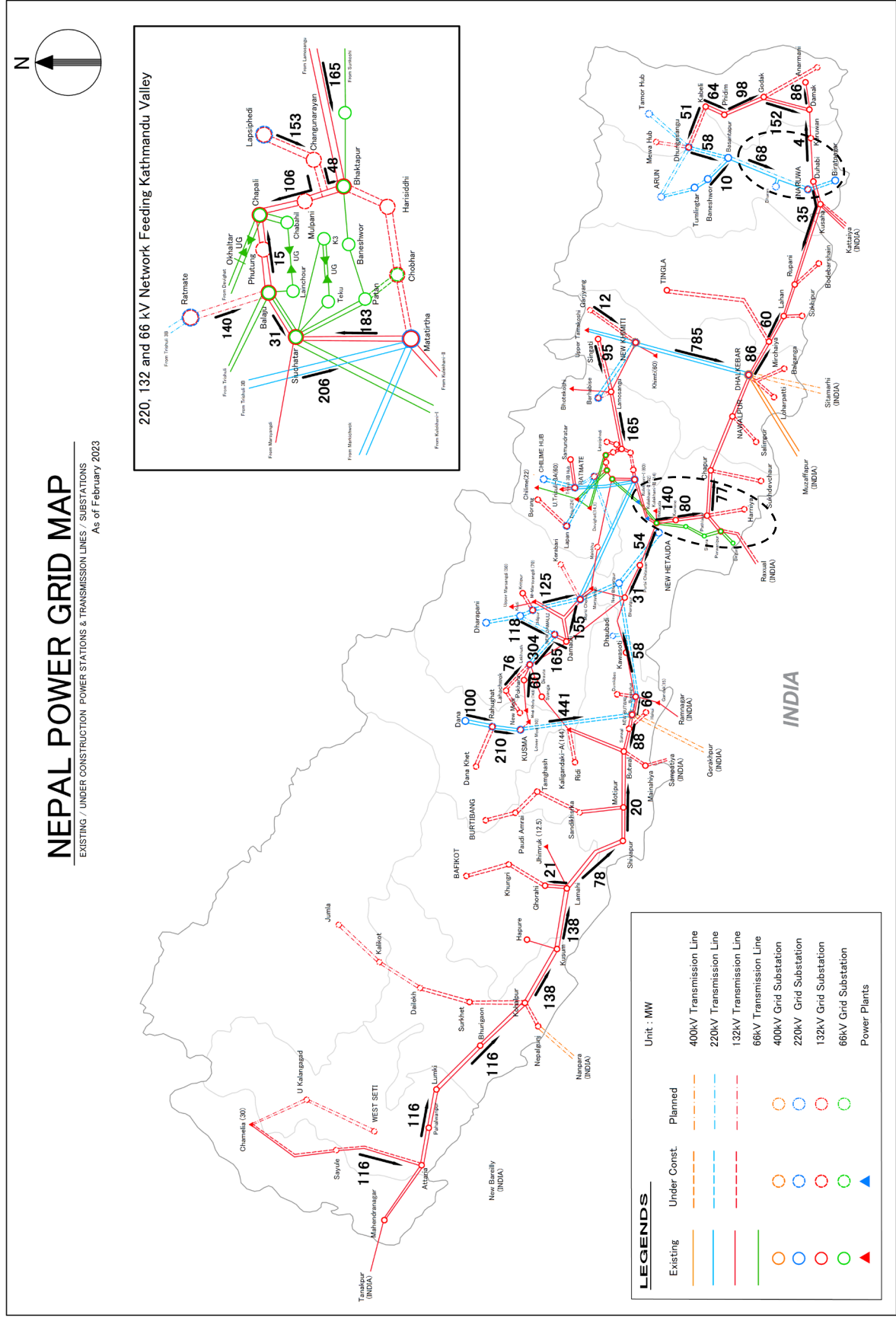


Figure 9.4-1 The Results of the Power Flow Analysis in 220kV, 132kV Power System

(2) The evaluation of 220kV, 132kV subsystem planning in recent years

This Figure 9.4-1 shows the results of measures to these areas where the overflowing transmission capacity of the transmission lines. Without these measures, the following locations were overflowing transmission capacity of the transmission lines. The overflow areas and the measures are shown below.

1) Measures for Kathmandu area

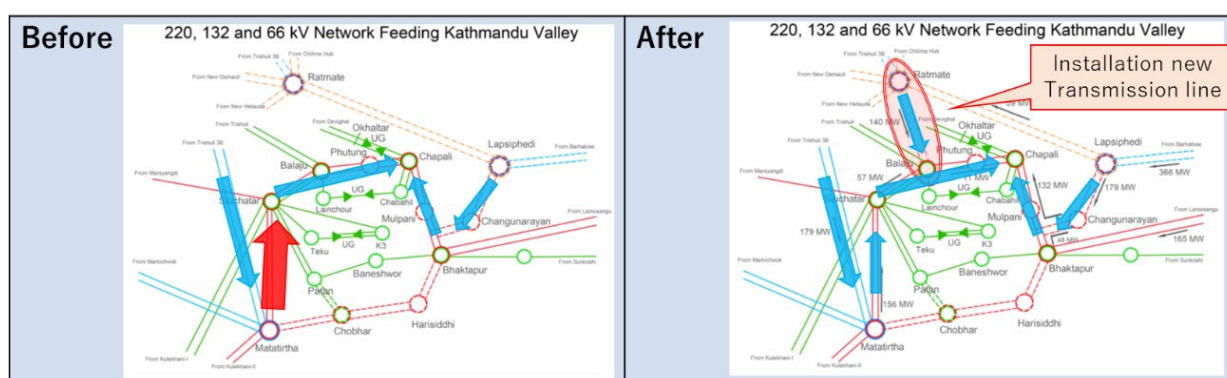
In Kathmandu city area, as shown in Figure 9.4-2, big power flows are observed from east and west to meet the city's power demand. So, it is proposed to construct a new 220kV transmission line from the Trishuli 3B Hub Substation to the Ratmate Substation. This measure is being considered to redirect the power flow from power plants connected to the Chilime Substation to Ratmate Substation via Trishuli 3B Hub Substation.



Source: JICA Study Team

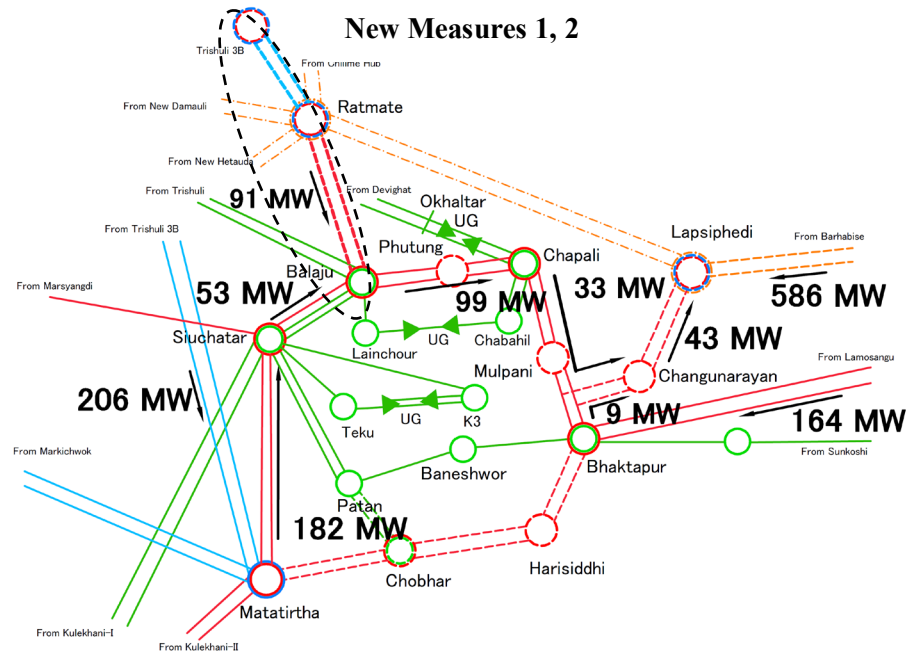
Figure 9.4-2 Measures for Kathmandu area 1

Even after measures for Kathmandu area 1, some transmission lines still overflowing transmission capacity as shown in Figure 9.4-3. Therefore, a new 132kV transmission line has been installed from the Ratmate Substation to the Balaju Substation as a measure to this issue in this area. This measure aims to connect the load of Kathmandu city to the Ratmate Substation.



Source: JICA Study Team

Figure 9.4-3 Measures for Kathmandu area 2

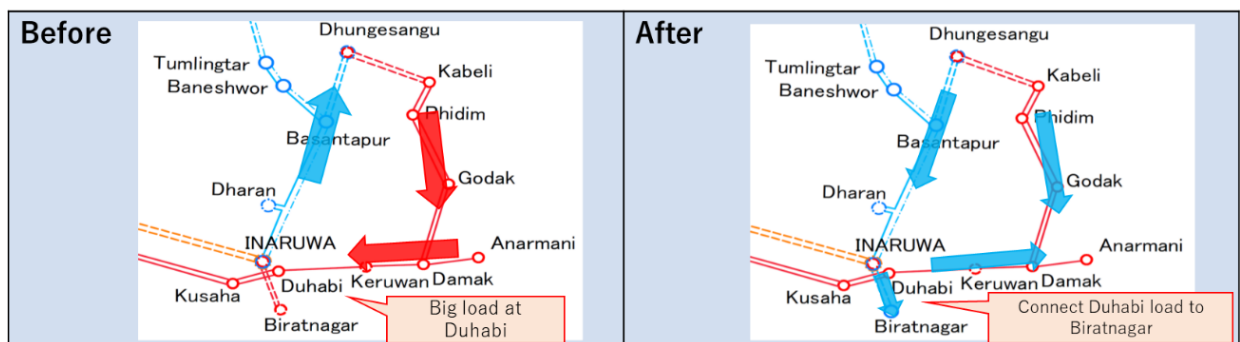


Source: JICA Study Team

Figure 9.4-4 Status of measures for Kathmandu area

2) Switching Duhabi substation load to Biratnagar substation (Inaruwa Area)

This measure is switching the large load connected to the Duhabi Substation to Biratnagar Substation as shown in Figure 9.4-5. The large load at the Duhabi Substation will be covered by power flow from the Inaruwa Substation, with the objective of reducing the power flow in that area.



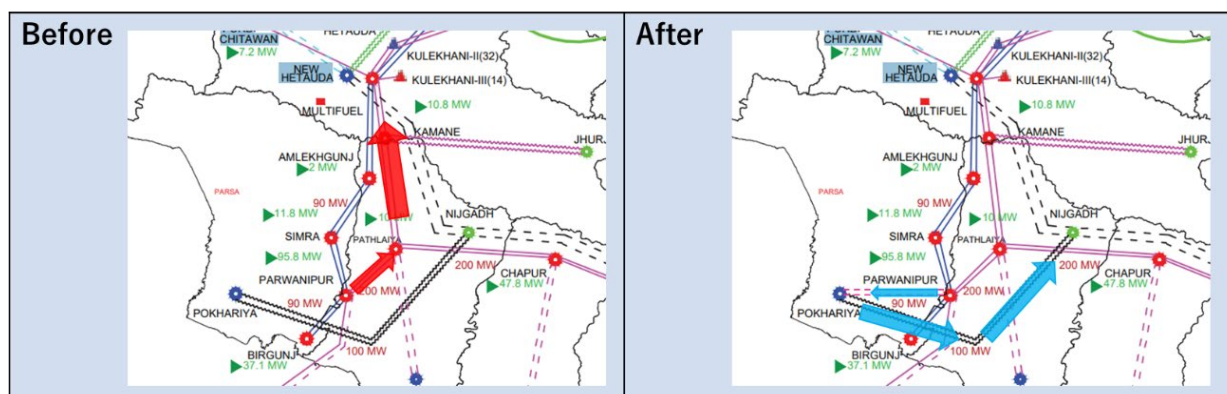
Source: JICA Study Team

Figure 9.4-5 Switching Duhabi Substation load to Biratnagar Substation

3) Measures for the around Parwanipur substation (Hetauda Area)

The industrial estate near the Parwanipur Substation has caused transmission lines from the Hetauda Substation to experience transmission capacity overflow. Therefore, as a measure to this overflow, a new 132kV transmission line is being constructed from the Pokhariya Substation to the Parwanipur Substation.

This transmission line was not documented in system diagrams, such as the yearbook. However, during the meeting with NEA, it was revealed that NEA is also planning on implementing this transmission line.



Source: JICA Study Team

Figure 9.4-6 Measures for the Parwanipur Substation area

9.4.3 Summary of Power Flow Analysis Results and Evaluation of 220kV, 132kV Subsystem Planning in Recent Years

Based on the power flow calculation results, over flow areas were identified, and recommendable measures for reducing the over flow of transmission line are implemented as below.

- I. Switching the station load
- II. Transmission line enhancement

Additionally, based on the findings of this study, the following two points are considered as future challenges:

I. Increase in demand within Kathmandu city

To address the future increase in power demand within Kathmandu city, measures such as enhancing the transmission line and distribution facilities are expected to be necessary. However, due to land constraints within Kathmandu city, it is anticipated that enhance the existing overhead transmission lines in the city would be difficult.

Therefore, it is recommended to consider measures such as reinforcing the overhead transmission lines in the suburbs and implementing new underground transmission lines within the city.

II. Transmission from the new power plants

In the future development of hydro power plants, it is necessary to enhance the transmission to the 400kV substations from the hydro power plants.

As an example, by 2030, there are plans to operate a total output of approximately 1.7 GW in substations around Purkot area.

Considering the future increase in demand centered on Kathmandu, it is to be expected that planning a network configuration based on these measures will be necessary.

Based on the power flow calculation results, the validity of the 220kV and 132kV subsystem planning for Nepal in recent years has been confirmed.

9.5 Summary of Power System Development Plan

As stated in 9.3.2, based on the results of computational simulations and power system analysis, it has been confirmed that our proposed Nepal's backbone system can operate stably in the event of accidents in all cases. Additionally, as mentioned in 9.2.3, while direct power export to India may be necessary in the future, the proposed 400kV bulk power system within Nepal for the year 2040, presented in this power system master plan, has been confirmed to be reasonable and valid. The validity of the system plan for the intermediate section and the nearby lower subsystems was confirmed, and a consistent system development plan until 2040 was formulated.

Based on the study results of the 400kV bulk power system across Nepal and the Kathmandu grid, the following projects are considered important for future grid planning:

- 400 kV bulk power system across Nepal
It is essential to establish a 400kV bulk power system within Nepal to deliver power from the generation areas in the western and eastern regions to the demand area in the Kathmandu. In addition, it is important to build a 400kV bulk power system comprising interconnection lines for export to India.
- 230kV and 132kV Transmission Lines Supplying the Kathmandu Grid from the 400kV bulk power system
The Kathmandu grid is surrounded by a loop system, and a power system plan has been developed to accommodate the increasing demand within the loop system. However, it is necessary to construct 230kV and 132kV transmission lines system to introduce power from the 400kV bulk power system outside the loop to the loop system.

Regarding development costs, it is estimated that a total of approximately 9.5 billion USD will be required for the transmission and distribution systems. Details on funding methods, economic and financial analysis, and environmental and social considerations related to the construction of transmission line will be described in a separate section. IPSDP will create power generation and power system plans based on power demand forecasts and ensure a consistent system development plan in the power sector by integrating economic and financial aspects, governance, and environmental considerations.

To realize this system development, it is important to coordinate system operations domestically and with neighboring countries for interconnected system operations. The following technical challenges are identified.

- System configuration during incidents in the 400kV power system
It is recommended to configure the lower subsystems in a radial system to minimize the spread of incidents when an accident occurs in the 400kV system. A radial system also facilitates easier power flow management. Additionally, as mentioned in chapter 9.2.3, the transmission lines for direct export should be configured so that, in the event of a power shortage within Nepal, the electricity can be consumed domestically rather than being exported.
- Power flow control for interconnection
As plans to increase system interconnections with neighboring countries progress, power flow control between countries will become crucial. Typically, in the BBIN area, India, with its large system capacity, maintains frequency using a constant frequency control method. Meanwhile, Nepal, Bangladesh, and Bhutan ideally should use bias interconnection power control to match interconnection line power flows to specified values.⁵

⁵ Data collection survey for regional grid integration in BBIN (Bangladesh, Bhutan, India and Nepal)

➤ **Securing the balancing capacity**

Currently, Nepal relies on India for its regulation capability. To secure regulation capability domestically, the development of storage hydro power is necessary. Additionally, when securing regulation capability from India, which has a large system capacity, it is important to implement online output control and optimize operations to reduce dependence on India.

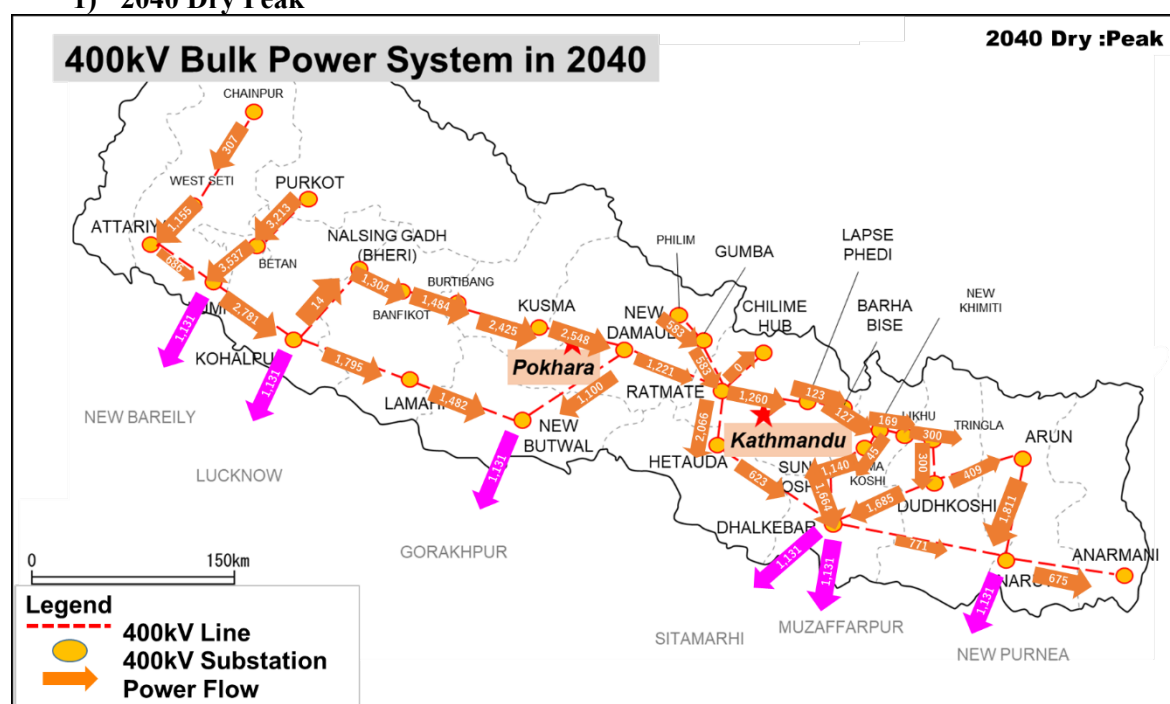
Reference Materials

To confirm the validity of the system plan for the 2040 cross-section, the following study cases were also validated. The analysis results under stringent conditions in the power system confirmed their validity in Chapter 9.3.2, and while these are supplementary cases, their validity was verified.

A study was conducted on increasing the number of interconnection lines to eleven from No. 10, added at the request of NEA during the 8th site survey. Originally, with six interconnection lines, system stability could not be maintained, and there was a plan to export power to India through some direct interconnection lines. The study examined whether increasing the number of interconnection lines to eleven would eliminate the need for direct interconnection lines. However, even with eleven interconnection lines, system stability could not be maintained, thus validating the necessity of direct interconnection lines.

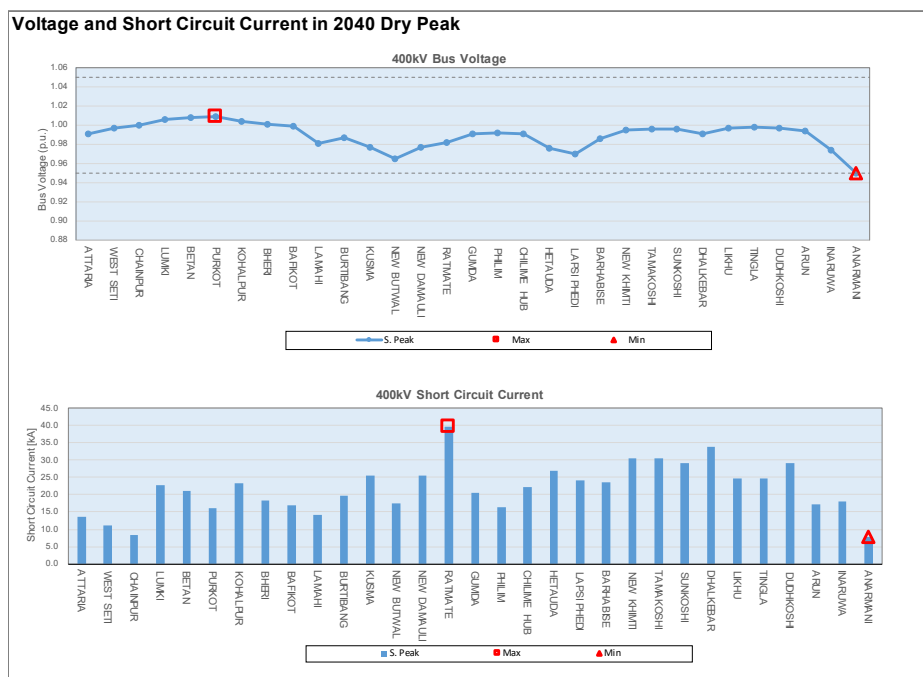
Supplementary consideration		
No	Case	Conditions of consideration
6	2040 Dry Peak	Minimum power generation during the dry season as of 2040 Cross section of maximum power demand
7	2040 Dry Off Peak	Minimum power generation during the dry season as of 2040 Cross section of minimum power demand
8	2040 June Peak	Maximum power exports as of 2040 Cross section of maximum power demand
9	2040 June Off Peak	Maximum power exports as of 2040 Cross section of minimum power demand
10	2040 Rainy Peak 11 interconnection lines	Maximum power generation during the rainy season Cross section of maximum power demand 11 interconnection lines with India

1) 2040 Dry Peak



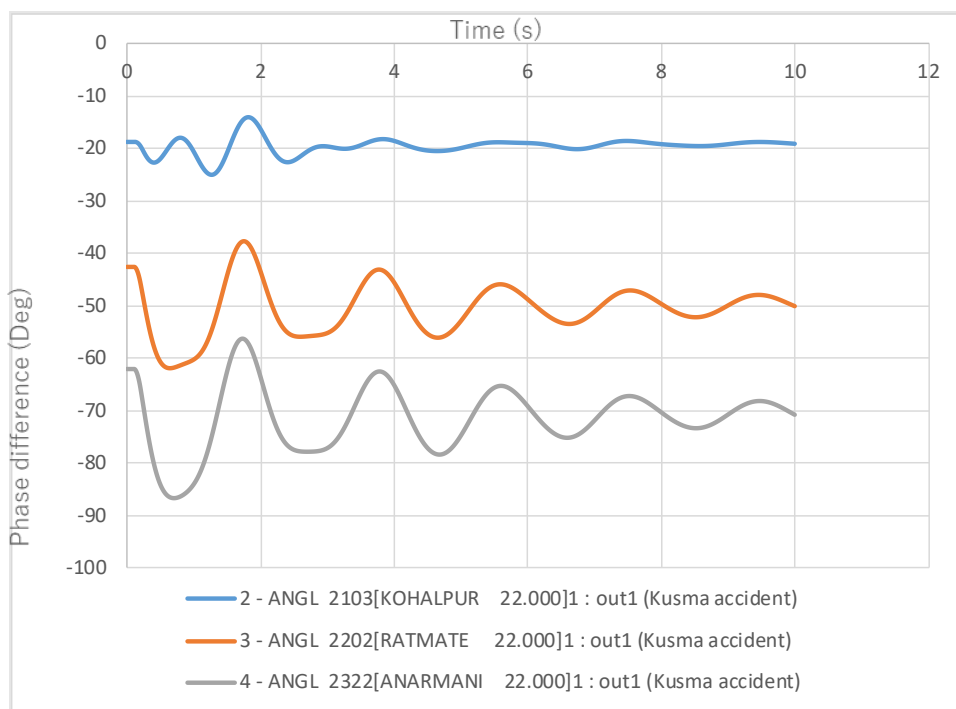
Source: JICA Study Team

2040 Dry Peak (power flow)



Source: JICA Study Team

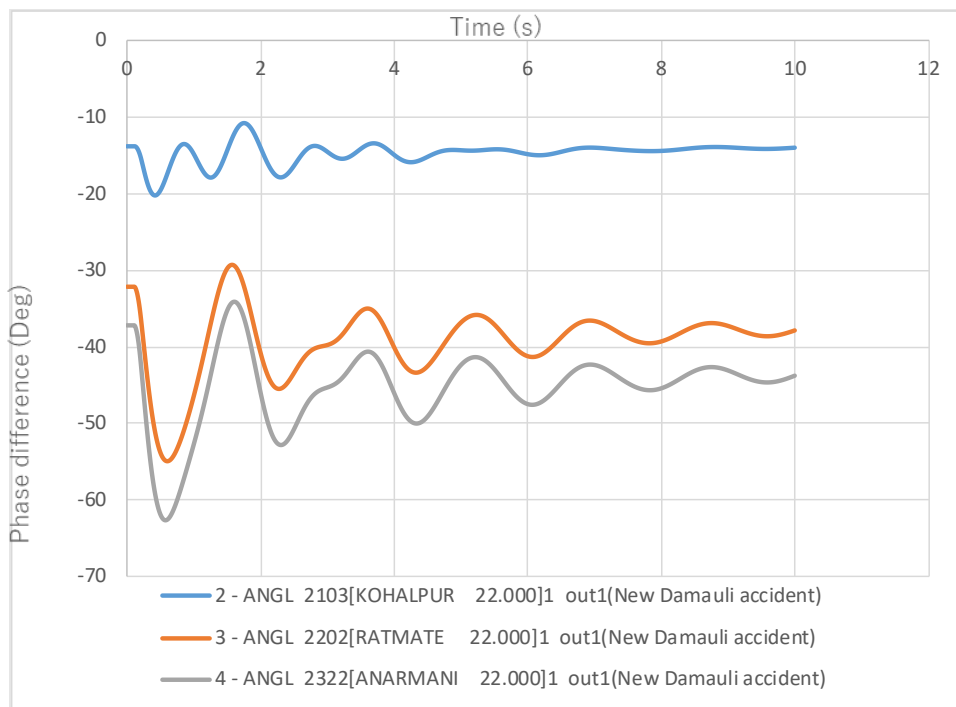
2040 Dry Peak (voltage, short circuit current)



Kusma - New Damauli T/L (max power flow section), Kusma side, 5cycle accident
(Direct Export : 5.63GW (Purkot, Betan, Ratmate, Arun))

Source: JICA Study Team

2040 Dry Peak (system stability)

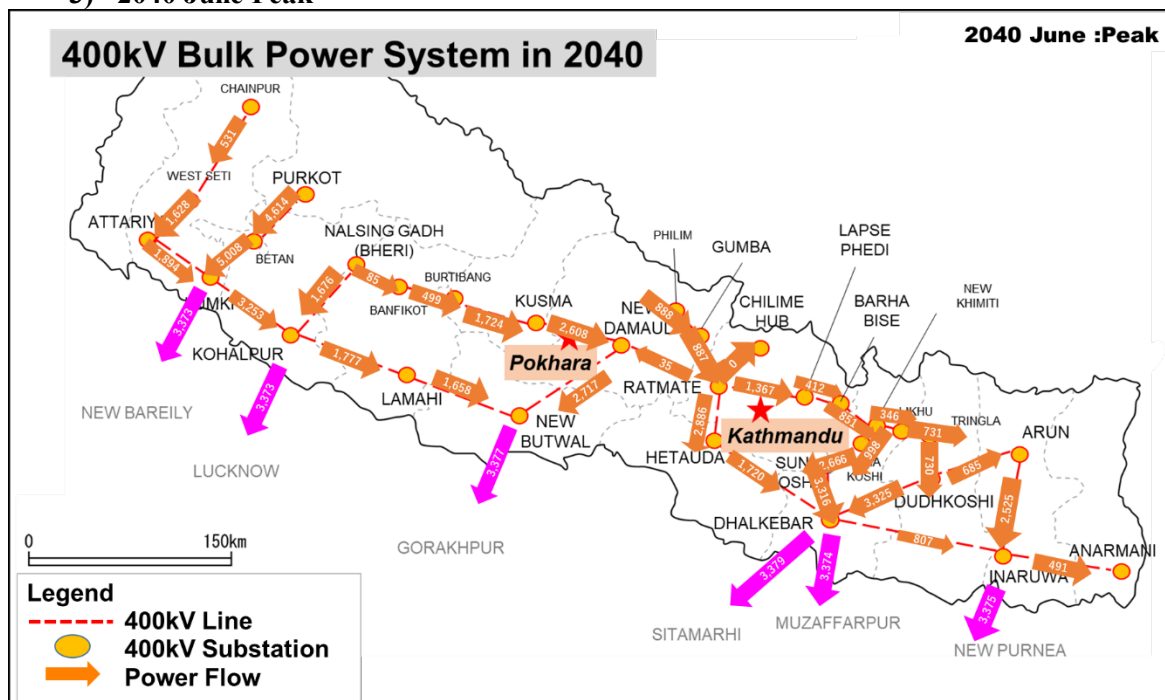


Kusma - New Damauli T/L (max power flow section), Kusma side, 5cycle accident
(Direct Export : 2.23GW (Purkot, Ratmate))

Source: JICA Study Team

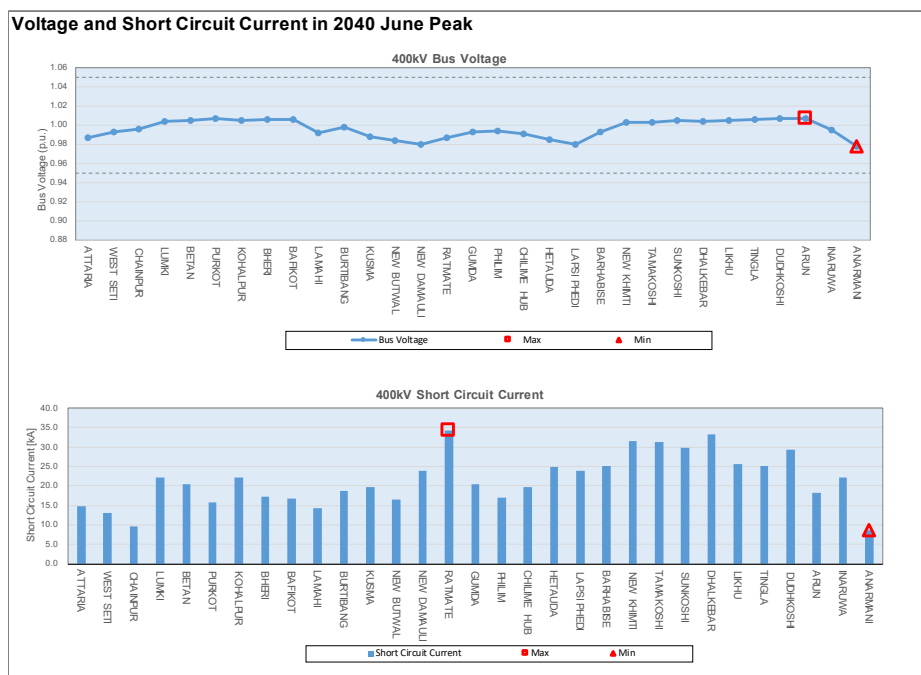
2040 Dry Off Peak (system stability)

3) 2040 June Peak



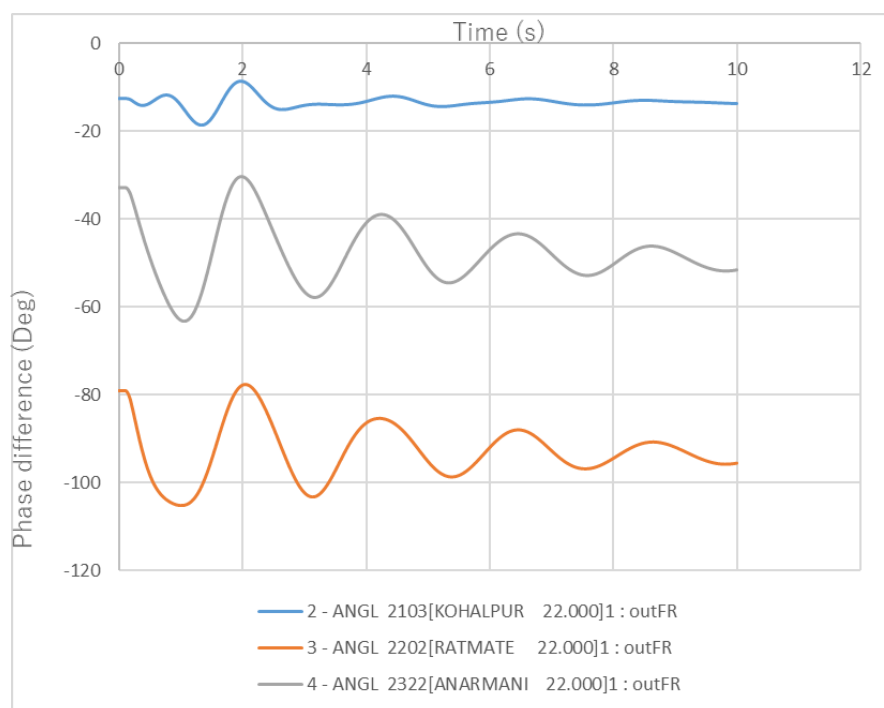
Source: JICA Study Team

2040 June Peak (power flow)



Source: JICA Study Team

2040 June Peak (voltage, short circuit current)

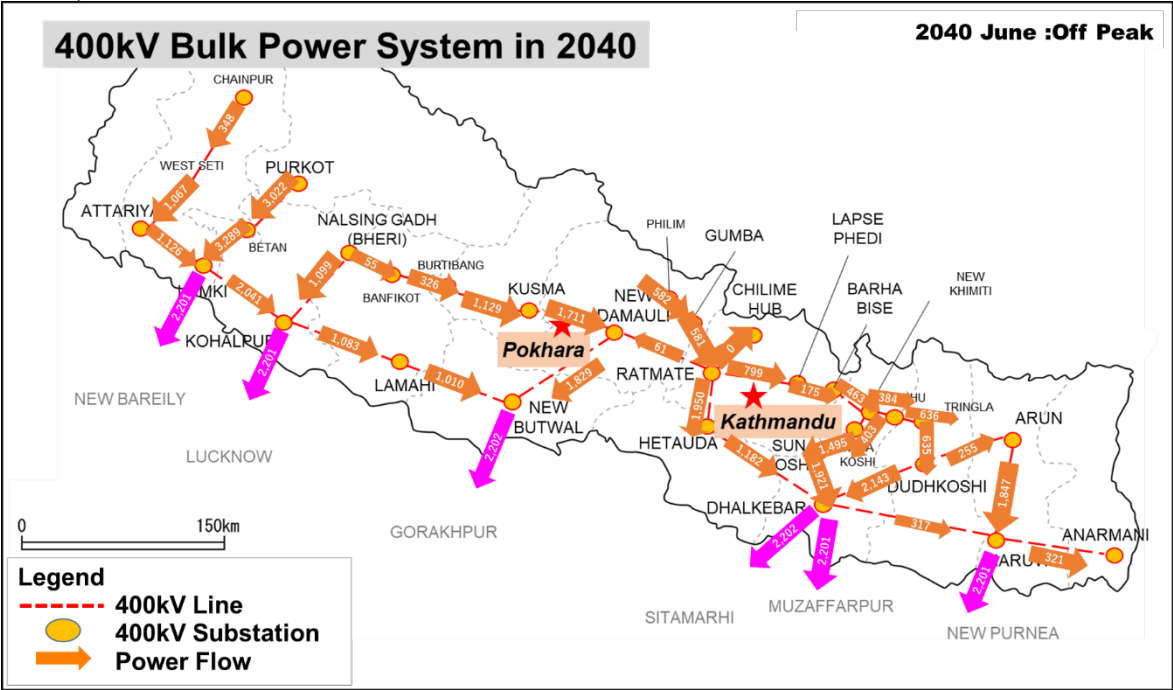


Kusma - New Damauli T/L (max power flow section), Kusam side, 5cycle accident
(Direct Export : 16.66GW (Purkot, Betan, Ratmate, Tamakoshi, Bheri, Arun))

Source: JICA Study Team

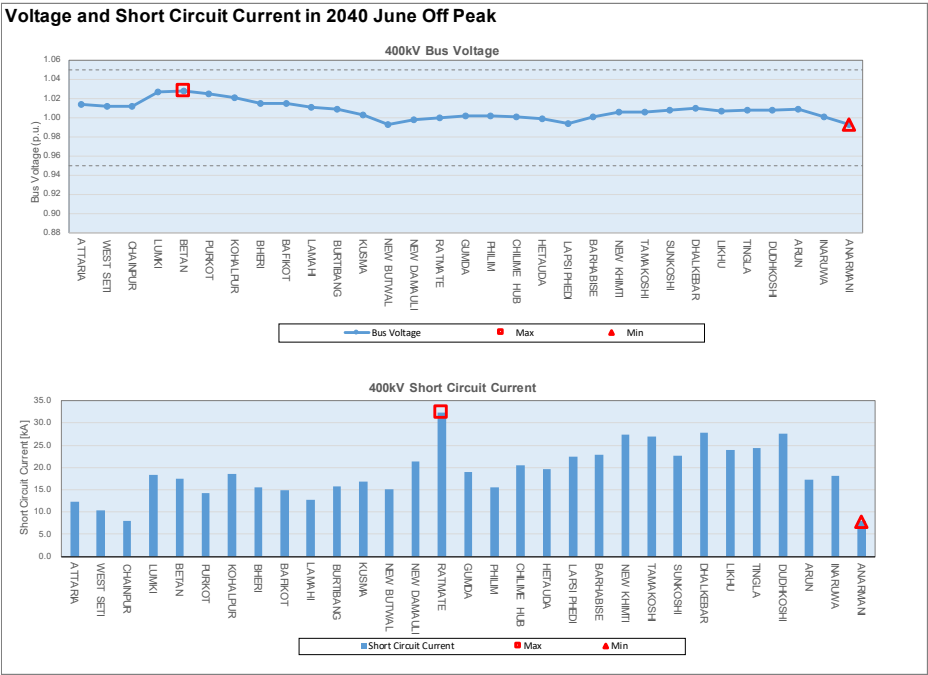
2040 June Peak (system stability)

4) 2040 June Off Peak



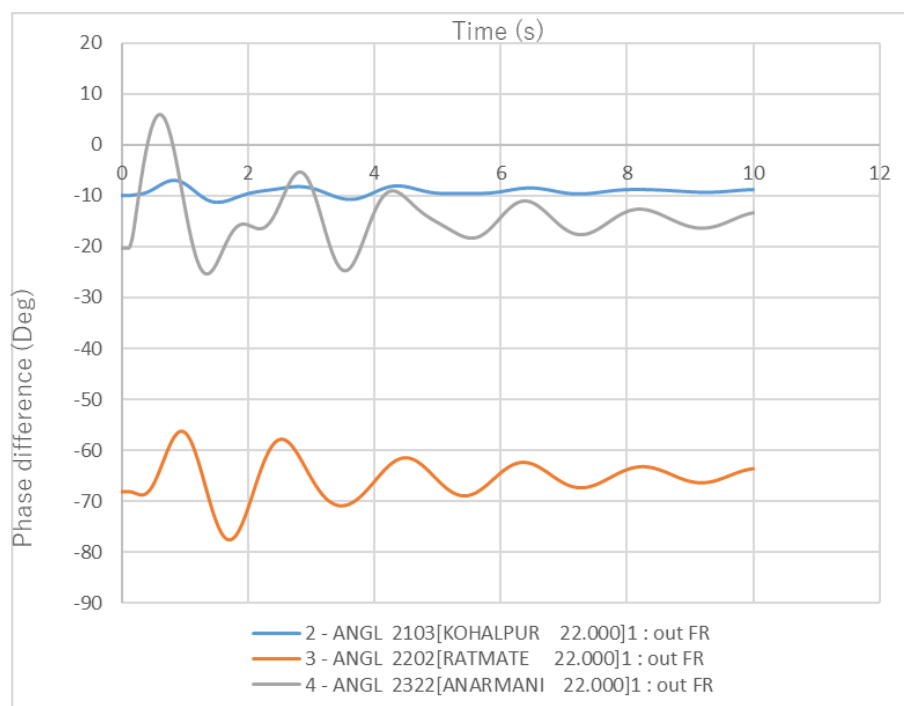
Source: JICA Study Team

2040 June Off Peak (power flow)



Source: JICA Study Team

2040 June Off Peak (voltage, short circuit current)

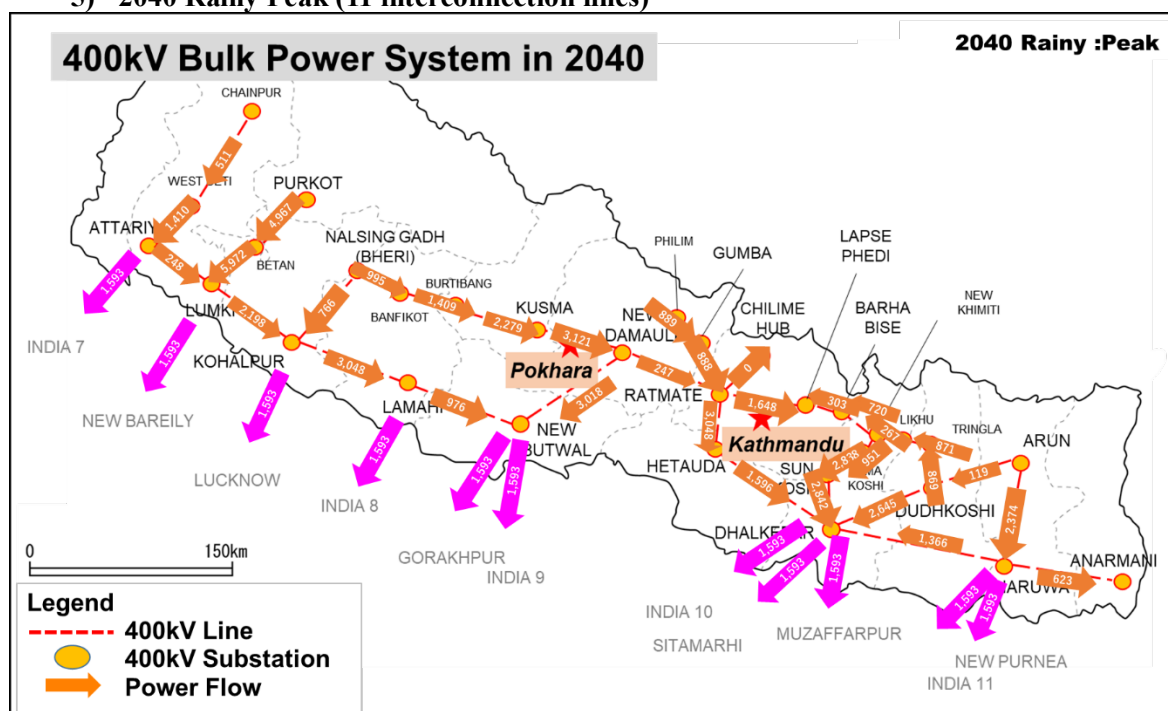


Dudhukoshi - Dhalkebar T/L (max power flow section), Dudhukoshi side, 5cycle accident
(Direct Export : 9.82GW (Purkot, Betan, Ratmate, Tamakoshi, Bheri, Arun))

Source: JICA Study Team

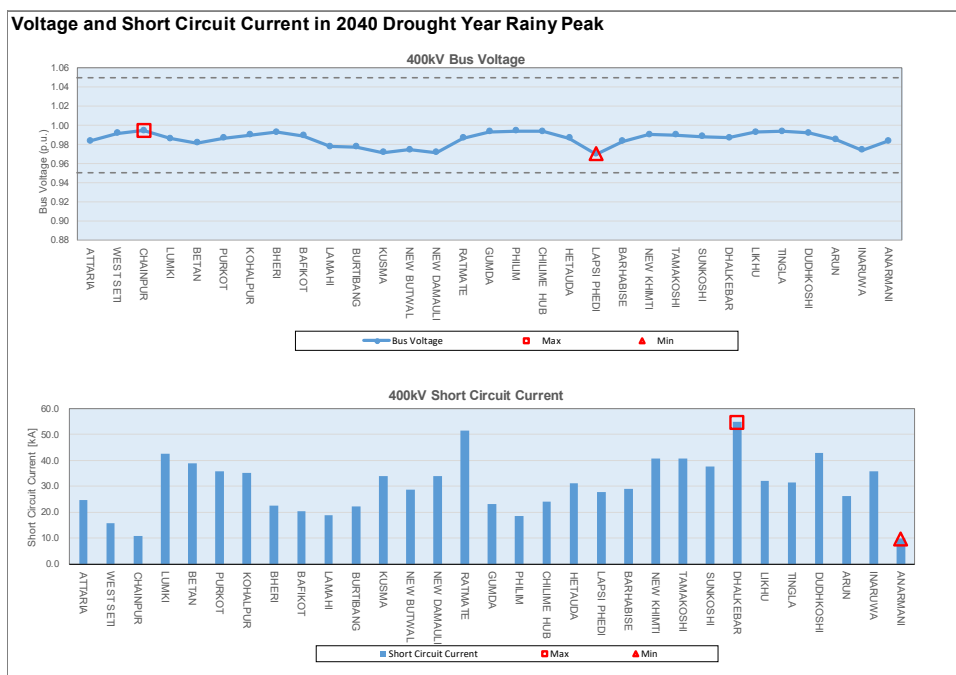
2040 June Off Peak (system stability)

5) 2040 Rainy Peak (11 interconnection lines)



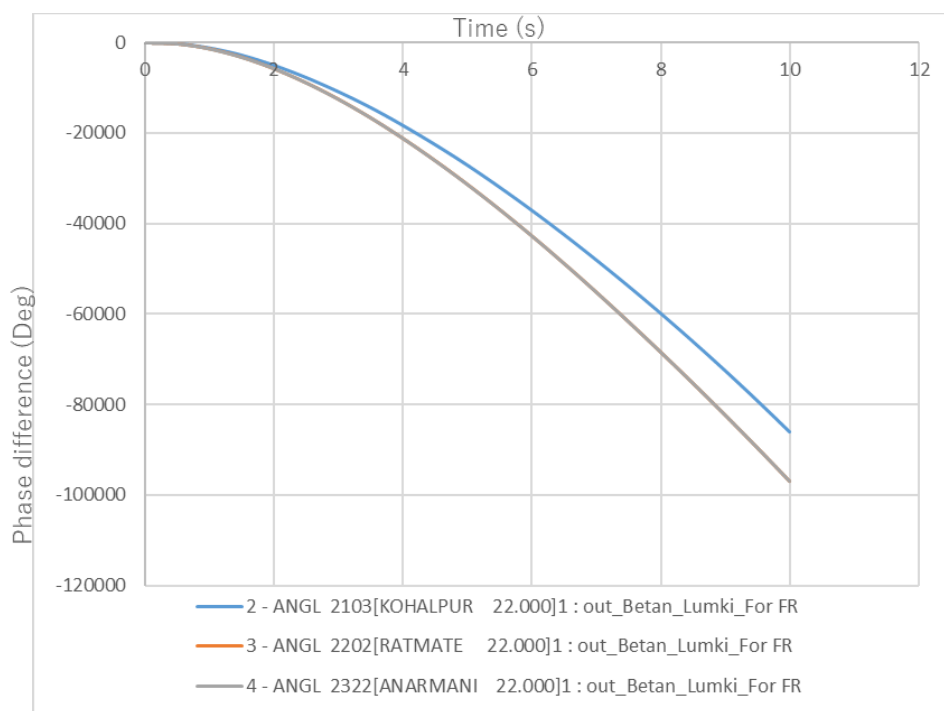
Source: JICA Study Team

2040 Rainy Peak (11 interconnection lines) (power flow)



Source: JICA Study Team

2040 Rainy Peak (11 interconnection lines) (voltage, short circuit current)



Betan - Lumki T/L (max power flow section), Betan side, 5cycle accident

Source: JICA Study Team

2040 Rainy Peak (11 interconnection lines) (system stability)