Ministry of Power and Renewable Energy (MPRE)
Ceylon Electricity Board (CEB)

Project on Electricity Sector Master Plan Study in Democratic Socialist Republic of Sri Lanka

Final Report

March, 2018

Japan International Cooperation Agency (JICA)

Tokyo Electric Power Company Holdings, Inc. (TEPCO HD)
TEPCO Power Grid, Incorporated (TEPCO PG)
Tokyo Electric Power Services Co., Ltd. (TEPSCO)

Contents

List of Figures

List of Tables

Abbreviations

Abbreviation	Word
3R	Three R - (Reduce, Reuse, Recycle)
AC	Alternating Current
ADB	Asian Development Bank
AFC	Automatic Frequency Control
AFD	Agence Française de Development
AIIB	Asian Infrastructure Investment Bank
AR	Auto Recloser
ATP	Alternative Transient Program (Name of software)
BAU	Business as Usual
B/C	Buyer’s Credit
BEV	Battery Electric Vehicle
B/L	Bank Loan
BMS	Building Management System
BOI	Board of Investment
BOO	Build Own Operate
BOT	Build Operate Transfer
B/S	Balance Sheet
BT	Booster Transformer
CAIDI	Customer Average Interruption Duration Index
CAPEX	Capital Expenditure
CB	Circuit Breaker
CC	Combined Cycle
CCGT	Combined Cycle Gas turbine
CE	Chief Engineer
CEA	Central Environmental Authority
CEB	Ceylon Electricity Board
CIF	Cost, Insurance and Freight
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COP	Conference of Parties
CP	Central Province
CPC	Ceylon Petroleum Corporation
CPS	Country Partnership Strategy
CPSTL	Ceylon Petroleum Storage Terminals Limited
dB	decibel
DC	Direct Current
DD	Distribution Division
DES	Debt Equity Swap
DFR	Draft Final Report
DGM	Deputy General Manager
DOF	Department of Forest
DSCR	Debt Service Coverage Ratio
DS	Divisional Secretary
DSM	Demand Side Management
DT	Distribution Transformer
DWC	Department of Wildlife Conservation

Abbreviation	Word
EBF	Equity Back Finance
ECA	Export Credit Agency
EE	Executive Engineer
EIA	Environmental Impact Assessment
EL	Elevation
EMS	Energy Management System
EMTP	Electro Magnetic Transient Program (Name of software)
EP	Eastern Province
EPC	Engineering, Procurement and Construction
EPZ	Export Processing Zone
ERD	External Resource Department
EV	Electric Vehicle
FEED	Front End Engineering Design
FI	Fault Indicator
FIT	Feed in Tariff
FO	Fuel Oil
FR	Final Report
FS	Feasibility Study
FSRU	Floating Storage and Re-gasification Unit
FSU	Floating Storage Unit
FY	Fiscal Year
GDP	Gross Domestic Product
GNI	Gross National Income
GPRS	General Packet Radio Service
GSS	Grid Substation
GT	Gas turbine
HC	Hydrocarbon
HFO	Heavy Fuel Oil
HPP	Hydro Power Plant
HVDC	High-Voltage Direct Current
HWL	High Water Level
ICR	Inception Report
IDA	International Development Association
IEA	International Energy Agency
IEE	Initial Environmental Examination
IFC	International Finance Corporation
IFRS	International Financial Reporting Standards
IKL	Isokeraunic
INDC	Intended Nationally Determined Contribution
IP	Industrial Park
IPP	Independent Power Producer
IT	Information Technology
ITR	Interim Report
IUCN	International Union for the Conservation of Nature
JBIC	Japan Bank for International Cooperation
JCC	Joint Coordination Committee
JICA	Japan International Cooperation Agency
JST	Joint Study Team
JV	Joint Venture

Abbreviation	Word
LA	Loan Agreement
LAA	Land Acquisition Act
LBS	Load Break Switch
LECO	Lanka Electricity Company
LED	Light Emitting Diode
LGLL	Litro Gas Lanka Limited
LGTLL	Litro Gas Terminal Lanka (Private) Limited
LIBOR	London Interbank Offered Rate
LIOC	Lanka Indian Oil Company
LKAS	Sri Lanka Accounting Standards
LKR	Sri Lanka Rupee
LNG	Liquefied Natural Gas
LOLE	Loss of Load Expectation
LOLP	Loss of Load Probability
LPG	Liquefied Petroleum Gas
LPS	Lakvijaya Power Station
LRMC	Long Run Marginal Cost
LRT	Light Rail Transit
LTGEP	Long Term Generation Expansion Plan
LTTDP	Long Term Transmission Development Plan
LV	Low Voltage
LWL	Low Water Level
MAB	Man and the Biosphere
M/M	Man Month
MOCA	Ministry of Culture & Art Affairs
MOF	Ministry of Finance
MOFARD	Ministry of Fisheries and Aquatic Resources Development
MOFOR	Ministry of Fisheries and Oceanic Resources
MOLLD	Ministry of Land and Land Development
MOMDE	Ministry of Mahaweli Development and Environment
MOPE	Ministry of Power and Energy
MOR	Ministry of Resettlement
MP	Master Plan
MPRD	Ministry of Petroleum Resources Development
MPRE	Ministry of Power and Renewable Energy
MTPA	Million Ton Per Annum
NCP	North Central Province
NCRE	Non-Conventional Renewable Energy
NEA	National Environmental Act
NEAP	National Environment Action Plan
NEPS	National Energy Policy and Strategy
NEXI	Nippon Export and Investment Insurance
NG	Natural Gas
NGO	Non-Governmental Organization
NIRP	National Involuntary Resettlement Policy
NOx	Nitrogen Oxide
NP	Northern Province
NTPC	National Thermal Power Corporation
NWP	North Western Province

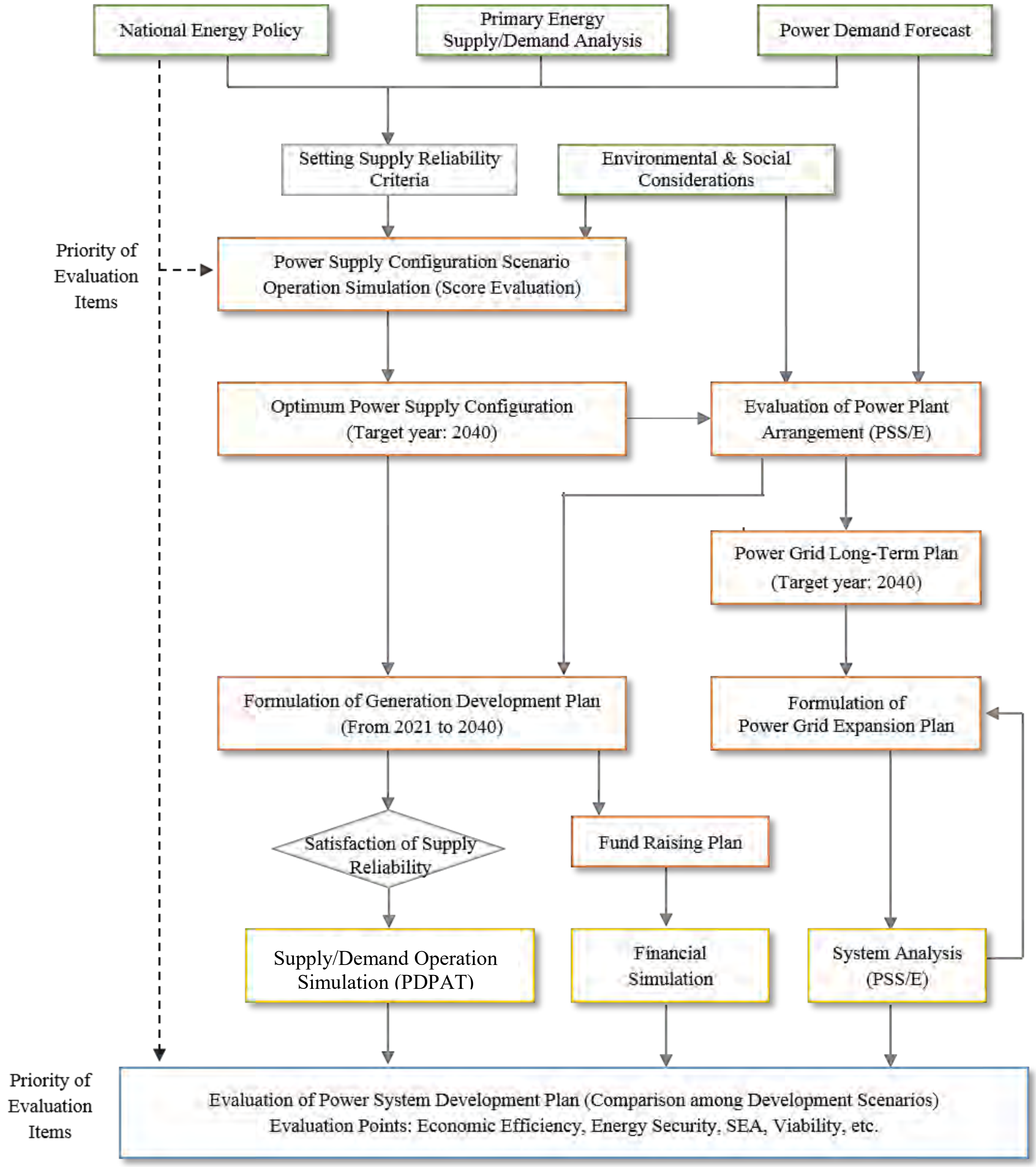
Abbreviation	Word
NWSDB	National Water Supply & Drainage Board
OD	Outer Diameter
ODA	Official Development Assistance
OECD	Organization for Economic Co-operation and Development
O&M	Operation and Maintenance
OPEX	Operating Expenditure
ORV	Open Rack Vaporizer
PAA	Project Approving Agencies
PDPAT	Power Development Planning Assist Tool (Name of software)
PHEV	Plug-in Hybrid Electric Vehicle
PIA	Project Implement Agencies
P/L	Profit and Loss
PLC	Power Line Communication
PM	Particulate Matter
PM_{10}	Particulate Matter 10
PP	Power Plant
PPA	Power Purchase Agreement
PPP	Private Power Producer
PPP	Public Private Partnership
PRDS	Petroleum Resources Development Secretariat
PSPP	Pumped Storage Power Plant
PSS	Primary Substation
PSS/E	Power System Simulator for Engineering (Name of software)
PUCSL	Public Utility Commission of Sri Lanka
ROA	Return on Assets
ROE	Return On Equity
ROR	Return on Revenues
ROW	Right-of-Way
RTS	Rapid Transit System
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SARI/EI	South Asian Regional Initiative for Energy Integration
SBP	Sabaragamuwa Province
SC	Super Critical
SC	Shunt Capacitor
SCADA	Supervisory Control And Data Acquisition
SEA	Sustainable Energy Authority
SEA	Strategic Environmental Assessment
ShR	Shunt Reactor
SLFRS	Sri Lanka Financial Reporting Standards
SOx	Sulphur Oxide
SP	Southern Province
SPBM	Single Point Buoy Mooring
SPC	Special Purpose Company
SPPA	Standardized Power Purchase Agreement
STATCOM	Static Synchronous Compensator
STEEP	Society, Technology, Economy, Environment, Politics
SVC	Static Var Compensator
SVR	Step Voltage Regulator

Abbreviation	Word
TANTRANSCO	Tamil Nadu Transmission Corporation Limited
TEC	Technical Evaluation Committee
TEPCO	Tokyo Electric Power Company
T/L	Transmission Line
TOP	Terms of Payment
TOU	Time of Use
TPCL	Trincomalee Power Company Limited
TPP	Thermal Power Plant
UFLS	Under Frequency Load Shedding
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
UP	Uva Province
USAID	United States Agency for International Development
USC	Ultra-Supercritical
USC	United States Cent
USD	United States Dollar
USEXIM	Export-Import Bank of the United States
VAT	Value Added Tax
VGF	Viability Gap Funding
WACC	Weighted Average Cost of Capital
WASP	Wien Automatic System Planning (Name of software)
WEO	World Energy Outlook
WHO	World Health Organization
WPN	Western Province North
WPS	Western Province South
WRMPP	Western Region Megapolis Planning Project

Chapter 0. Summary

0.1 Viewpoints and Targets of Electricity Sector Master Plan

An outline of the Methodology to formulate the Electricity Sector Master Plan is shown in the below Figure 0-1.



(Source: JICA Survey Team)

Figure 0-1 Flow Chart for Electricity Sector Master Plan

Firstly, the Power supply configuration scenario in the target year of 2040 is established in consideration of the external factors, which are National energy policy, Primary energy analysis, Power demand forecast, and Environmental & Social Considerations. Next, through simulation, evaluation items in every category are calculated in each power supply scenario. Finally, the optimum power supply configuration scenario is established for 2040 by a quantitative comparison in consideration of the importance of every evaluation item.
It is necessary to consider the following key points to formulate a comprehensive electricity sector master plan. However, since some of them have a trade-off relationship with each other, it is determined which point is given priority, taking into consideration superordinate policies such as the national energy policy.

- Economic efficiency (Reduction of power supply cost (generation cost + transmission cost))
- Power supply reliability (Allowable annual power shortage hours, power shortage electric energy, etc.)
- Energy security (Stable supply, Supply cost stability)
- Environmental and social considerations (Environmental evaluation criteria on each development project, Green House Gas emission volumes)

Based on the optimum power supply configuration, the power plant arrangement is evaluated and the power grid long-term plan is then formulated. After the optimum power supply configuration and the formulation of the power grid are confirmed, a generation development plan and power grid expansion plan for each year from the present to the target year are formulated. During this planning and formulating, it is necessary to consider the viability of consensus-building with local residents around project sites, appropriate development lead-time, fund raising, etc.

0.2 Primary Energy

0.2.1 Fuel Price Forecast in WEO2016

The IEA announced the fuel price forecast until 2040 in WEO2016. Based on this forecast, future fuel prices in Sri Lanka are predicted.

(1) Forecasted prices for various fuels
WEO2016 forecasts fuel prices for three scenarios. The forecasted values are shown below.

Table 0-1 Forecasted Prices for various Fuels in WEO2016

	2015	New Policies Scenario			Current Policies Scenario			450 Scenario		
		2020	2030	2040	2020	2030	2040	2020	2030	2040
Crude oil (USD/barrel)	51	79	111	124	82	127	146	73	85	78
Natural gas (USD/MBtu)	10.3	9.6	11.9	12.4	9.9	13.0	14.4	9.0	10.8	10.9
Steam coal (USD/tonne)	72	78	86	89	79	92	98	73	72	67

Natural gas: Japan import price, Steam coal: for Coastal China (Source: WEO2016, IEA)

New Policies Scenario	Voluntary emissions regulations are implemented in each country (central scenario: temperature rise 3.5 °C)
Current Policies Scenario	Do not incorporate large changes (temperature rise 6 °C)
450 Scenario	Keep the atmospheric greenhouse gas concentration to 450 ppm to keep the temperature rise in 2100 less than 2 °C compared with the industrial revolution.

(2) Future forecasts for various fuels in Sri Lanka

Based on the increase rate in the price forecast of the above-mentioned "New Policies Scenario", various fuel prices in 2040 are calculated as follows. The LNG price is calculated based on the above forecasted price. (The cost of handling LNG varies depending on the amount handled, so it is calculated separately as a fixed cost.)

Table 0-2 Fuel Costs for various Power Sources

	Fuel price			Conversion price (USC/Mcal)	
	2015	2040		2015	2040
Auto diesel	124.20	301.98	USD/bbl	8.856	21.533
FO (3%S)	100.20	243.62	USD/bbl	6.509	15.825
FO (2%S)	104.40	253.84	USD/bbl	6.782	16.489
Residual oil	95.20	231.47	USD/bbl	6.184	15.036
Naphtha (local)	93.50	227.33	USD/bbl	7.112	17.291
Naphtha special	108.90	264.78	USD/bbl	8.283	20.139
LNG	--	12.40	USD/MBtu	--	4.920
Gas	--	14.04	USD/MBtu	--	5.571
Coal Puttalam	97.86	120.97	USD/tonne	1.553	1.920
Coal New	89.39	110.50	USD/tonne	1.515	1.873
Coal SC	97.10	120.03	USD/tonne	1.541	1.905

(Source: 2015 prices are derived from Revised LTGEP 2015-2034)

As is apparent from the comparison of conversion prices, coal is the cheapest, LNG (exclusive of domestic fuel handling costs) is more than twice the price of coal, and the price of petroleum is more than eight times that of coal.

0.2.2 Possibility of introducing domestic natural gas and LNG

(1) Domestic natural gas

In Sri Lanka, two natural gas fields (Barracuda and Dorado) were discovered in offshore block M2 (ex-Cairn block) of the Mannar basin in 2012.

(a) Fuel costs

Fuel supply costs (including transportation costs) considering gas field development costs are estimated by PRDS as follows.

・11.5 USD/MMBTU (excluding Royalty, Profit and Tax)
・16.5 USD/MMBTU (including Royalty, Profit and Tax)

(b) Possibility of supply for gas-fired power

The amount of natural gas (300 bcf) in the Dorado gas field covers about 35 years' supply when it is used only for a 300MW CCGT power plant (equipment utilization rate: 50%, thermal efficiency: 50%, Gross calorific value: 13,000kcal/kg).
Currently, it is estimated that the combined reserves of the two gas fields at Barracuda and Dorado are about 2 TCF (about 5.7×10^{10} m^3).
These reserves will cover 8 units (2,400MW) of the 300MW CCGT power plant (equipment utilization rate: 50%, thermal efficiency: 50%), assuming that the power plant's service life is 30 years. If the accuracy of the estimate for these reserves is confirmed, it is expected that the use of domestic natural gas for gas-fired power generation is fully possible.

(2) Possibility of introducing LNG

The fuel supply cost comparison for each type of LNG terminal is shown in Table 0-3.

Table 0-3 Comparison of fuel supply cost to power plant (1200MW)

1. LNG terminal type		Land type	FSRU type
2. Construction Cost for LNG terminal	MUSD	488	170
3. O&M cost for terminal (*1) A typical rental fee for FSRU	MUSD/year	3.9	50(*1)
4. LNG price (CIF)	USD /MMBTU	13.69	13.69
5. Economic life of LNG terminal	years	30	30
6. Total supply amount of heat (Per working years)	MMBTU	1.08E+09	1.08E+09
7. Fuel (natural gas) supply cost	USD /MMBTU	14.25	15.24

Formula : 7. = (2.+ 3. x 5.) / 6. + 4.

(Source: JICA Survey Team)

From this result, it is considered that the land type is more advantageous than the FSRU type in terms of fuel cost. In addition, the land type has better capacity expandability and more stable operation compared to the FSRU type. In consideration of possibility for national gas field development, it is anticipated that usage period of LNG will be shorter than 30 years. The FSRU type is advantageous when usage period of LNG is within 7 years.
However, the Sri Lankan government is hoping to realize the operation of gas-fired power plants as early as possible to mitigate the tight power supply and demand, and the FSRU type is considered to be advantageous in terms of the short construction time. In addition, the FSRU type has lower capital investment than the land type, and the usage period of LNG is unclear at the present time. Therefore, the FSRU type has the advantage that the investment risk is low for the Sri Lankan government.

0.2.3 Renewable Energy

The potential of renewable energy was described in the draft report of the Renewable Energy Master Plan, which is supported by an ADB fund. The potential is shown in Table 0-4.

Table 0-4 Introduction Potential for Renewable Energy

Category	Potential [MW]	Remarks
Mini Hydro	873	Total generation: 3,061GWh
Windpower	5,653	Northern part: 3,070MW
Biomass Power	2,508	Scrub land: 724MW
Solar	6,000	Eastern, Northern, Uva

(Source: Renewable Energy Master Plan)

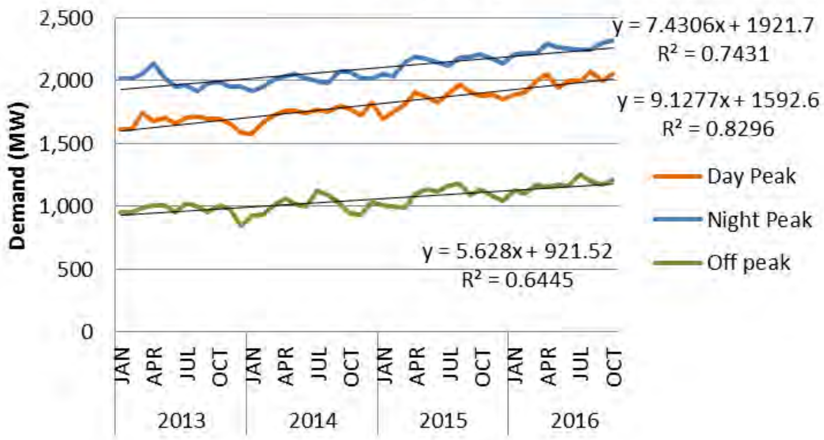
0.3 Demand Forecast up to 2040

0.3.1 Change of Daily Load Profile

(1) Forest of load profile change

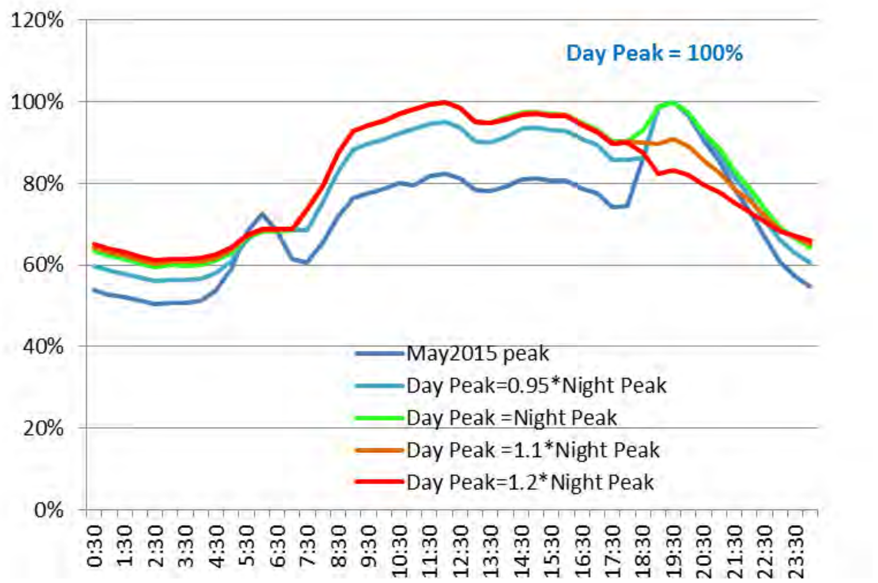
Since the increase in the day peak is significant at the national level, the increase characteristics of the day peak and the night peak are numerically analyzed, and then the daily load profile in the future and load factor is assumed.

Figure 0-2 shows the results of fitting regression equations to the actual records for the night peak, day peak, and off peak in these 4 years. The ratios of the day peak to the night peak up to 2040 are calculated by using regression equations. Therefore, the day peak reaches the night peak in around 2029, and then it becomes gradually prominent.



(Source: JICA Survey Team, based on data provided by CEB)

Figure 0-2 Peak Demand of Whole Country with Regression Equations



(Source: JICA Survey Team, based on data provided by CEB)

Figure 0-3 Change of Load Profile

0.3.2 Recommended Demand Forecast

(1) Demand Forecast based on Historical Records (Past Trend Model)

The future forecast for demand is obtained by adjusting the reduction effect of transmission/distribution loss to the value predicted by the linear regression equation. This model is an extension of past data, which is equivalent to a natural increase that is not reflected in special measures and plans, so this assumption is taken as the Low case.

(2) Demand Forecast considering GDP forecast (GDP Correlation Model)

Since power demand is related to GDP growth, Electric power demand is forecasted based on the forecasted GDP. The central bank of Sri Lanka assumes the future GDP for the four-year period from 2016 to 2019, but no official forecast is made for subsequent years. Therefore, electric power demand was predicted by the following procedure.

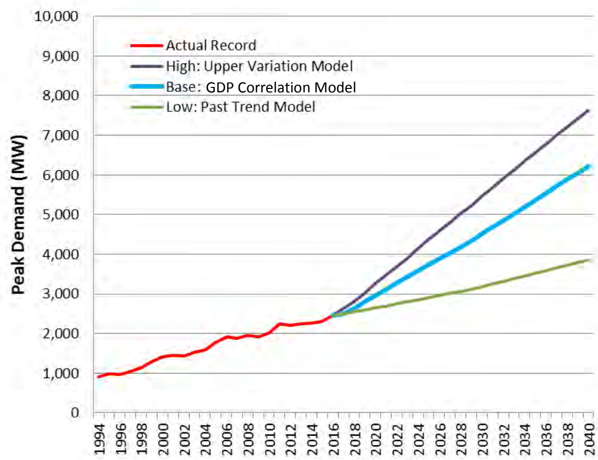
- Until 2019, adopt the central bank's GDP assumption
- Annual GDP growth rate from 2020 to 2040 is assumed to decrease gradually
- GDP elasticity value of electricity demand shall be 1.0

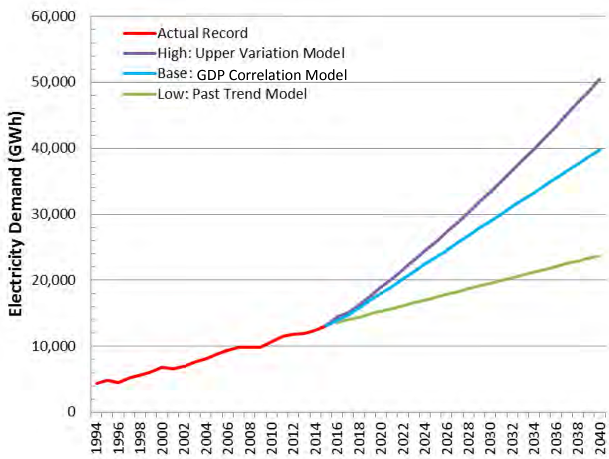
As this forecast reflects the economic development plans etc. for the upcoming years, and the assumptions of the further long-term forecast are based on this extension, this model is taken as the Base case.

(3) Evaluation of Factors Affecting Power Demand Forecast

DSM plan, electrification plan of railways, popularization of EV, and large-scale development plans seem to be factors that are thought to have a significant influence on the future demand. These factors are uncertain both in terms of the realization of their timing and their scale, and they may be delayed considerably depending on various circumstances such as delays in decision making. However, it is desirable to understand the degree of influence of these factors and reflect this in the demand forecast, especially the peak demand forecast. Therefore, an evaluation of the factors that seem to have a large impact is conducted and the JICA Survey Team attempts to reflect this in the forecast model (Upper Variation model; High case), corresponding to the case where electric power demand is beyond the expectation.

The long-term demand forecasts up to 2040 are shown in Figure 0-4.





(Source: JICA Survey Team)

Figure 0-4 Long Term Demand Forecast up to 2040

0.4 Environmental and Social Considerations

Based on SEA, the results of evaluating environmental and social consideration items by power development and described in indicator (environmental impact degree) are shown in the table below.

The power sources in the order of lower negative impacts on the natural and social environment are (i).Mini-hydropower, (ii).Solar, (iii).Wind, (iv).LNG/Heavy Oil, (v).Hydropower, (vi).Biomass, (vii).PSPP, (viii).Coal.

The reasons why the comprehensive impact indicator of PSPP is relatively high are that a lot of households are to be resettled in the candidate site and valuable animals and plants are deemed to grow and inhabit.

The reasons why the comprehensive impact indicator of biomass power generation are that a large-scale of land is to be needed to plant and log a suitable kind of trees repeatedly for ensuring constantly a certain amount of woody fuel and oligopoly of land is needed, and that plant ecological environmental deterioration is expected due to artificial creation of fragile biogeocenosis from the viewpoints of natural environment.

Table 0-5 Environmental Indicators for Each Power Source

Category \ Type of Power	Conventional Energy			Non Conventional Renewable Energy				
	Hydro	Coal	LNG, Oil	Wind	Solar	Mini-Hyd	PSPP	Biomass
Topography & Geology	-1.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0
Soil	-1.0	-2.0	-2.0	0.0	-1.0	-1.0	0.0	0.0
Quality of Water	-0.3	-3.0	-2.0	0.0	-1.0	0.0	0.0	-1.0
Quality of Air	0.0	-2.0	-2.0	0.0	0.0	0.0	0.0	-1.0
Noise/Vibration	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	-1.0
Waste	0.0	-3.0	0.0	0.0	-2.0	0.0	0.0	-2.0
Subsidence	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flora	-1.3	-3.0	0.0	0.0	-2.0	-1.0	-2.3	-3.0
Fauna/Fish/Coral	-2.0	-3.0	-2.0	-3.0	-1.0	-1.0	-3.0	-1.0
Natural Protected Areas	-0.7	0.0	0.0	-0.5	0.0	0.0	0.0	0.0
Natural Environment	-0.63	-1.60	-0.80	-0.45	-0.70	-0.30	-0.63	-0.90
Resettlement	-2.0	0.0	0.0	-0.5	0.0	0.0	-1.7	0.0
Ethnic /Indigenous people	-0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Land use	-1.3	0.0	0.0	-1.0	0.0	-1.0	-2.7	-2.0
Water Use	-1.0	-2.0	-2.0	0.0	0.0	-1.0	-2.7	-1.0
Landscape	0.0	-2.0	0.0	-3.0	-2.0	0.0	0.0	-2.0
Historical Heritage	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Social Environment	-0.89	-0.67	-0.33	-0.67	-0.33	-0.33	-1.17	-0.83
Comprehensive Environmental Indicator	**-0.76**	**-1.13**	**-0.57**	**-0.56**	**-0.52**	**-0.32**	**-0.90**	**-0.87**

(Source: JICA Survey Team)

0.5 Long-term Power Development Plans

0.5.1 Concept of Formulating Long-term Power Development Plans

Based on the following 3 scenarios, a sample of long-term power development plans for each year are made and examined by comparing among them.

(1) Scenario A: Cost is regarded as the important factor

Power development after 2016 is Coal-fired TPP 3.0GW + LNG-fired TPP 0.9GW + Windpower 0.9GW + Solar power 1.5GW.

(2) Scenario B: CO_2 reduction is regarded as the important factor and Renewable energy development is prioritized

Power development after 2016 is LNG-fired TPP 3.0GW + Windpower 3.9GW + Solar power 2.0GW + PSPP 0.6GW. Furthermore, additional coal-fired thermal development is not carried out.

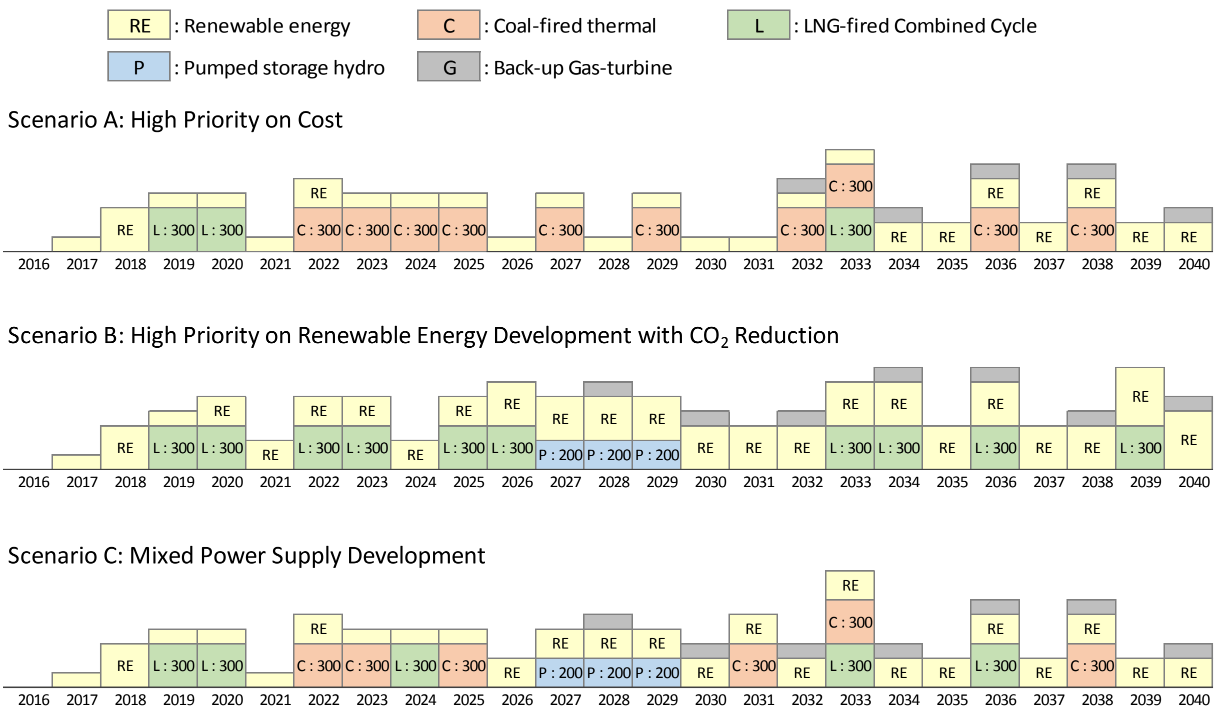
(3) Scenario C: Power development is carried out by combining several fuels

Power development after 2016 is LNG-fired TPP 1.5GW + Coal-fired TPP 1.8GW + Windpower 1.9GW + Solar power 2.0GW + PSPP 0.6GW.

0.5.2 Comparison of Each Scenario

(1) Comparison of Development Plans

A comparison of development plans made based on the concepts in the previous section is as follows.

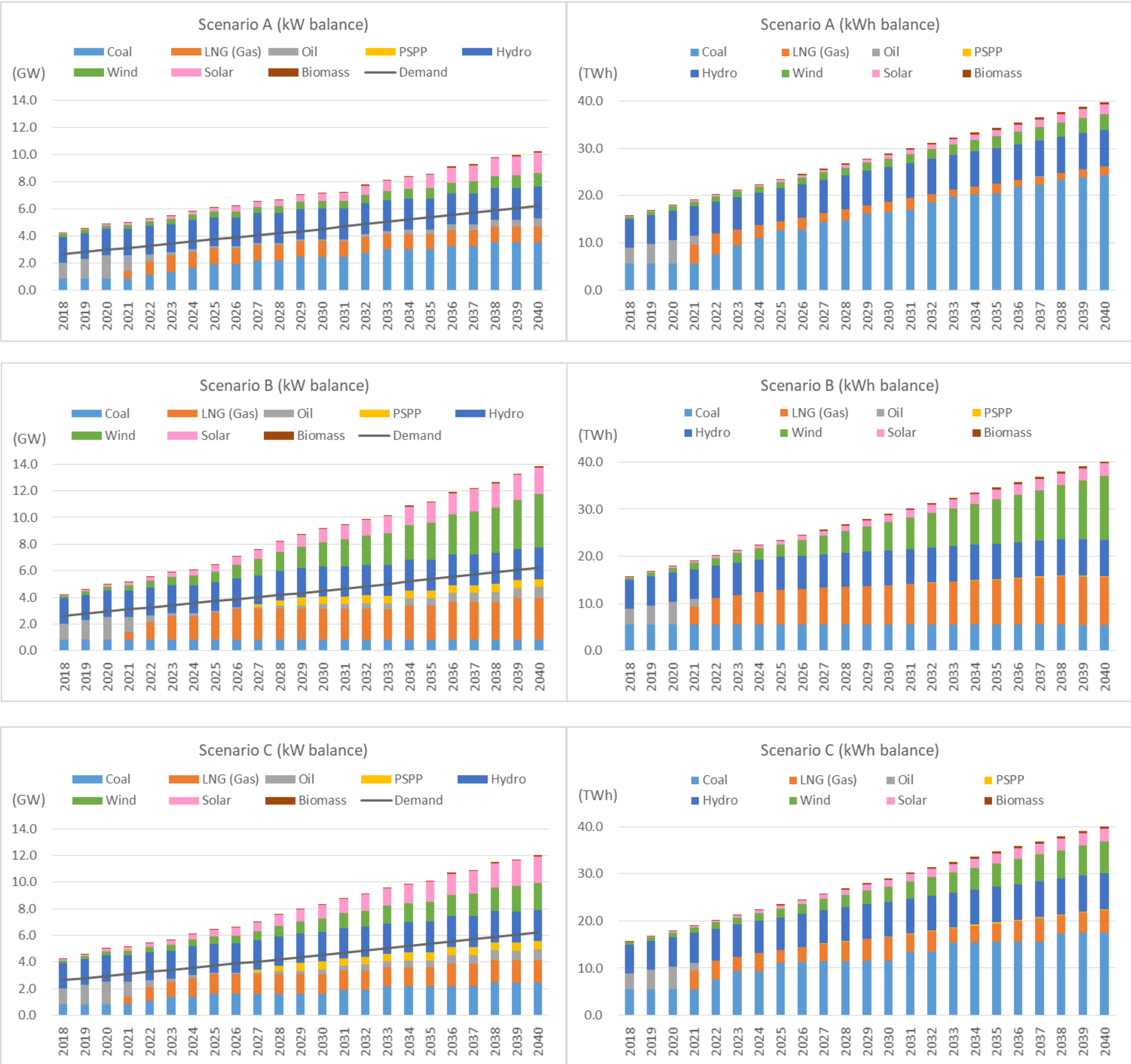


(Source: JICA Survey Team)

Figure 0-5 Development Plans in Each Scenario

The plan to 2020 is assumed to be the same plan except for renewable energy. In addition, LNG-fired TPP in 2019 and 2020 uses petroleum fuel at the beginning of operation and converts it to LNG fuel in 2021.

Changes in installed capacity and power generation amount for each power source in each scenario are shown below.



(Source: JICA Survey Team)

Figure 0-6 Changes in Installed Capacity and Power Generation Amount in Each Scenario

Scenario B, which has a large amount of renewable energy (solar power and wind power) development, has a larger total installed capacity than the other scenarios, and it is more than twice the maximum demand.

(2) Comparison of Generation Costs

A comparison of generation costs in each year is shown below.

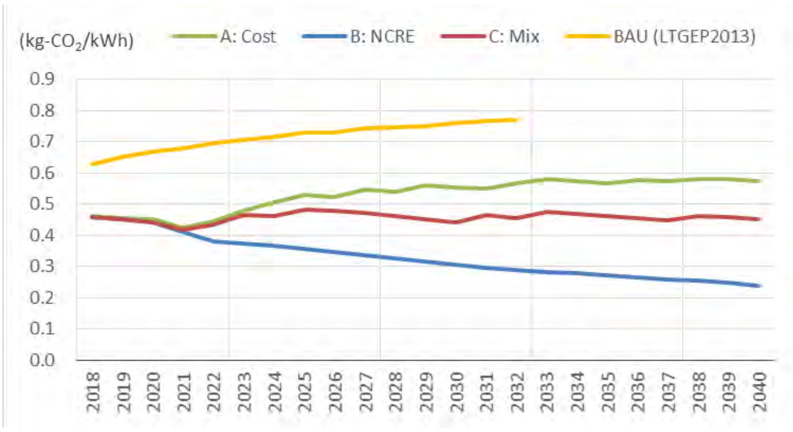
(Source: JICA Survey Team)

Figure 0-7 Comparison of Generation Costs

Generation cost decreases with Coal-fired TPP development because coal-fired TPP is cheap. Regarding the comparison of generation costs, Scenario A, with priority on cost and Coal-fired TPP development, is the cheapest and Scenario B, with priority on renewable energy development, is the most expensive. Scenario C, which is a fuel mix plan, is a little more expensive than Scenario A. Regarding the comparison of generation cost after 2022 and in 2016 in normal hydropower generation, all scenarios cost becomes low. Especially regarding the cost in Scenario A and C approximately 1 USC/kWh becomes low. In 2019 and 2020, since the newly developed combined cycle is operated with petroleum as a fuel, it costs about 13 USC/kWh.

(3) Comparison of CO_2 Emissions

A comparison of CO_2 emissions in each year is shown below.



(Source: JICA Survey Team)

Figure 0-8 Comparison of CO_2 Emissions

As renewable energy development increases, CO_2 emission per kWh decreases slightly and finally becomes 0.4 kg-CO_2/kWh in 2020. In Scenario B, the CO_2 emission per kWh decreases still more and reaches a level lower than 0.24 kg-CO_2/kWh in 2040. Annual CO_2 emissions are approximately 7,000 kton, which is unchanged until 2020, and then increase slightly, but are around 10,000 kton-CO_2 in 2040, and there is no big increase.

In Scenario A, CO_2 emission per kWh increases gradually after 2021 and becomes 0.6 kg-CO_2/kWh in 2040. CO_2 emission increases steadily and reaches 23,000 kton in 2040, which is more than three times that of the current level.

Scenario C, which conducts power development by combining several energy sources, is located between Scenarios A and B, and CO_2 emission per kWh becomes a slightly lower level than the current level.
The Nationally Determined Contributions (NDC) submitted by the Ministry of Mahaweli Development and Environment in September 2016 declared a reduction in greenhouse gas emissions by 20% by 2030 in the energy sector as compared to the Business-as-usual (BAU) scenario. The emissions in the BAU scenario are based on LTGEP 2013 - 2032, submitted in October 2013. In all scenarios, the emissions have been reduced by 30% or more as compared to BAU, and the target value declared in the NDC is sufficiently cleared.

(4) Comparison of Configuration Rates for various Power Sources

In Scenario A, which gives priority to cost, the configuration rate of coal-fired TPP gradually increases and reaches 61% by 2040 in generated energy. On the other hand, in Scenario B, which develops renewable energy as a priority, the configuration rate of coal-fired TPP gradually decreases, and it decreases to 14% in generated energy in 2040.
Up to 2020, the configuration rate of renewable energy is about 50% in installed capacity and about 45% in generated energy in every scenario. In Scenario B, which gives priority to renewable energy, it gradually increases thereafter and reaches 61% in terms of installed capacity and 60% in generated energy in 2040. In Scenario A, which gives priority to cost, from 2021 onwards, the rate in the installed capacity hardly changes, but the rate in the generated energy slightly decreases and reaches 34% in 2040. Scenario C, which is a fuel mix plan, is located between the two, and it increases to 54% in installed capacity in 2040, but the rate in generated energy is almost the same as the present situation.

0.5.3 Recommended Proposal

The JICA Survey Team has comprehensively judged the three perspectives of economics, environmental friendliness and energy security and recommends development per Scenario C.

0.6 Transmission Development Plan

0.6.1 Transmission lines required for each power development scenario

The 400kV and 220kV transmission lines scheduled to be completed by 2020 in CEB's Long Term Transmission Development Plan (2015 - 2024) are shown below.

・220kV Nadukuda-Mannar-New Anuradharapura (2 cct) 155km
・220kV New Habarana-Veyangoda (2 cct) 148km
・220kV Veyangoda-Kirindiwela (2 cct) 17.5km
・400kV Kirindiwela-Padukka (2 cct) 20km (initially 220kV operation)
・220kV Kotmale-New Polpitiya (2 cct) 23km
・220kV New Polpitiya-Padukka-Pannipitiya (2 cct) 70km
・220kV New Polpitiya-Hambantota (2 cct) 150km
・220kV Kerawalapitiya-Port-Wellawatta (UG cable 1cct) 22.5km
・220kV Kelanitissa-Port (UG cable 1cct) 6.5km
・220kV Pannipitiya-Wellawatta (UG cable 1cct) 14km
・220kV Port-Port City (UG cable 2cct) 1.0km

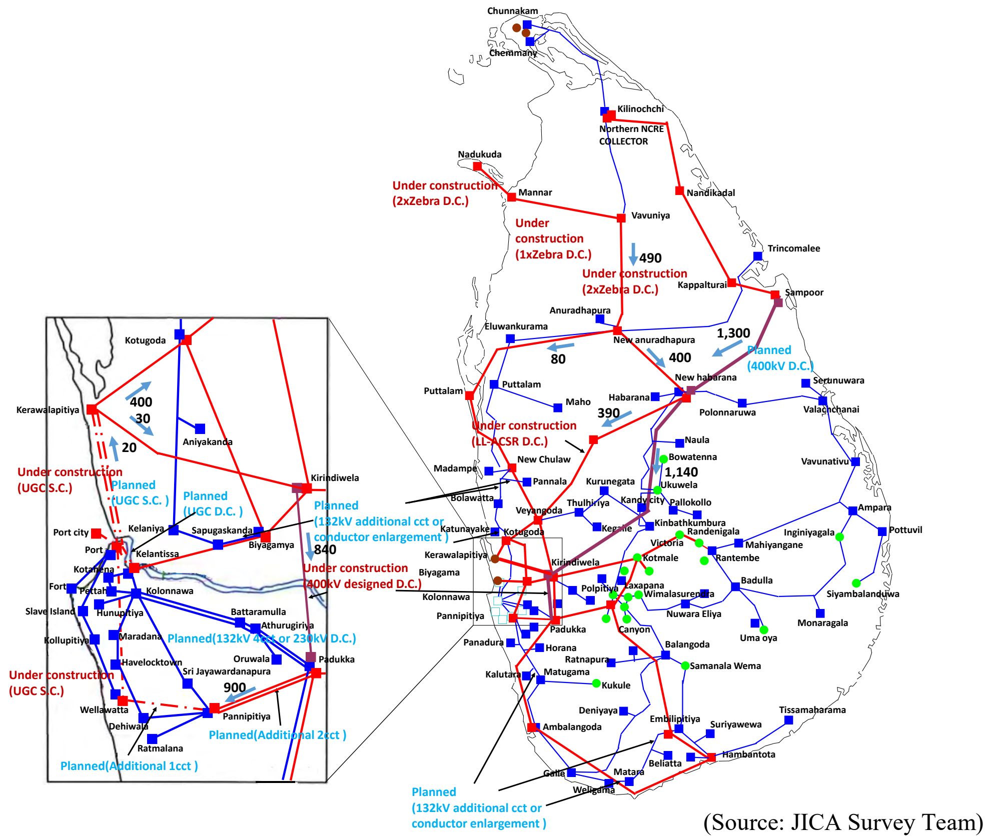
The above transmission lines are necessary for all power development scenarios. In addition to these, the transmission lines required for each power development scenario by 2040 are shown below.

Table 0-6 Transmission lines required for each power development scenario

	Length (km)	Scenario A	Scenario B	Scenario C
400kV Sampoor-New Habarana	95	Y (2 cct)	N	Y (2 cct)
400kV New Habarana-Kirindiwela	165	Y (2 cct)	Y (2 cct)	Y (2 cct)
400kV transmission line (2 cct) total length		260km	165km	260km
220kV Sampoor-New Habarana	95	N	Y (2 cct)	N
220kV Kerawalapitiya-Kirindiwela	30	Y (2 cct)	Y (2 cct)	Y (2 cct)
220kV Pooneryn-Northern NCRE collector	30	N	Y (4 cct)	Y (2 cct)
220kV Northern NCRE collector-Sampoor	180	Y (2 cct)	Y (2 cct)	N
220kV Northern NCRE collector- Vavuniya	75	N	Y (4 cct)	Y (4 cct)
220kV Vavuniya-Sampoor	100	N	N	Y (4 cct)
220kV Vavuniya-New Anuradhapura-New Habarana	105	N	Y (4 cct)	N
220kV New Anuradhapura -Puttalam-New Chulaw	174	N	Y (2 cct)	N
220kV New Chulaw-Veyangoda-Kotugoda	60	N	Y (2 cct)	Y (2 cct)
220kV Biyagama-Kelantissa	12.5	N	Y (2 cct)	N
220kV Padukka-Ambalangoda-Hambantota	220	Y (2 cct)	Y (2 cct)	Y (2 cct)
220kV transmission line (2 cct) total length		430km	1,192km	690km
220kV Kerawalapitiya-Port (UG)	13.5	Y (1 cct)	Y (1 cct)	Y (1 cct)

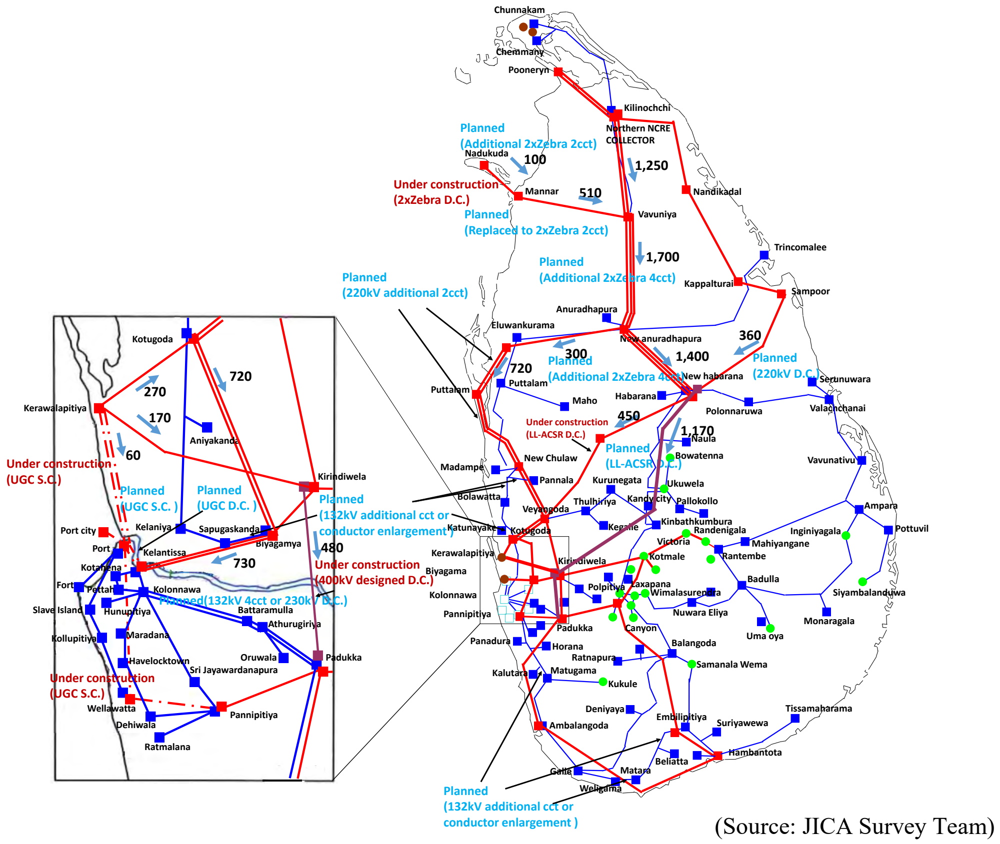
(Source: JICA Survey Team)

In Scenario B, the required length of the 400kV transmission line can be reduced by 95km, but the required length of the 220kV transmission line is about 500km more compared with other scenarios. The construction cost difference for power transmission facilities between Scenario B and Scenario C is about USD 280 million in total by 2040, and the difference in average cost during this period is about 0.04 USC/kWh (0.06 LKR/kWh).



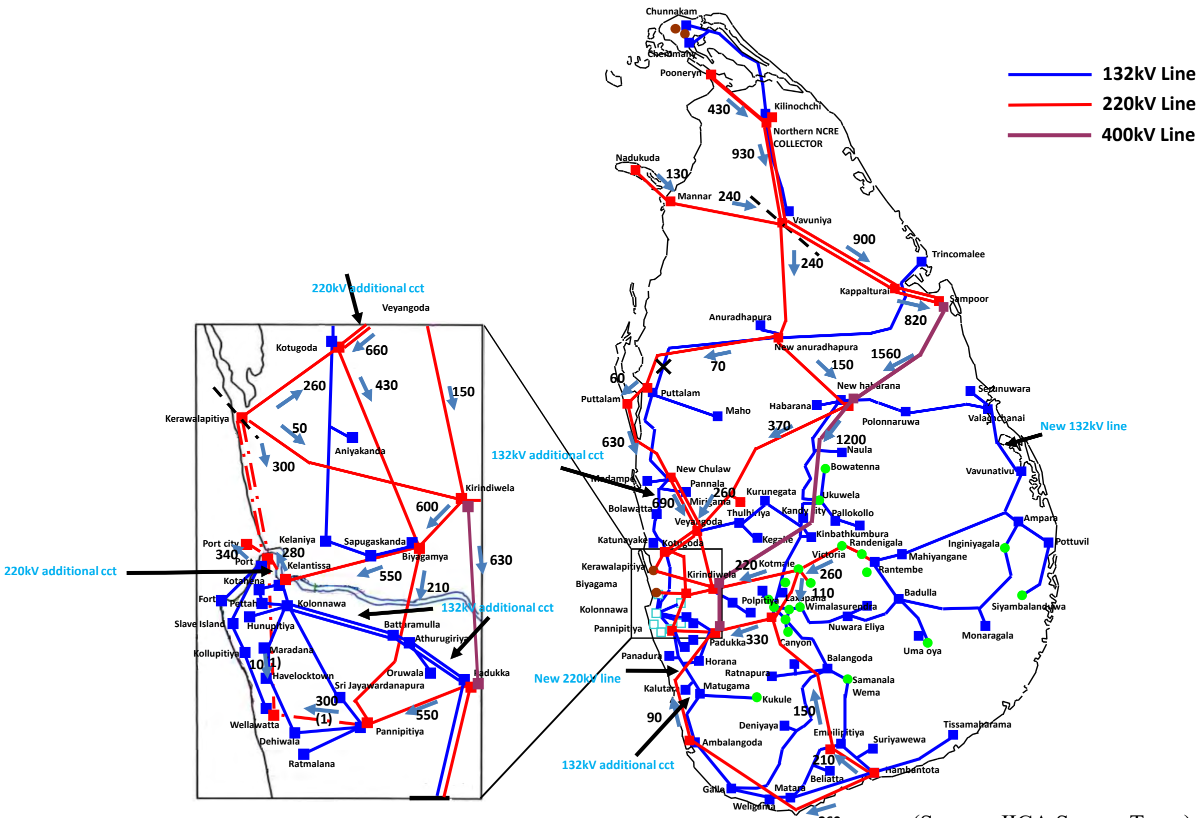
(Source: JICA Survey Team)

Figure 0-9 Transmission Line Map in 2040 (Scenario A)



(Source: JICA Survey Team)

Figure 0-10 Transmission Line Map in 2040 (Scenario B)



(Source: JICA Survey Team)

Figure 0-11 Transmission Line Map in 2040 (Scenario C)

0.6.2 Maximum Capacity of Allowable Generator Trip

Power system characteristics are 10%MW/Hz and allowable frequency range is 1.5Hz. So, the maximum capacity of allowable generator trip is calculated to be 15% of total demand. Maximum demand for 2040 in Sri Lanka is about 6.2GW. Therefore, minimum demand is about 40% of this, or 2.5GW. So, maximum output capacity of a single generator unit is 15% of 2.5GW, or 370MW.

Table 0-7 Maximum output capacity of single generator unit

Item	Amount
Maximum demand in 2040	6.2GW
Minimum demand in 2040	2.5GW
Maximum output capacity of single generator unit in 2040	370MW

(Source: JICA Survey Team)

It may be possible to install generators with over 370MW installed capacity to consider operation in service with output of less than 15% for the maximum during off-peak hours.

When a unit of 600MW generator is installed in the grid, it is necessary to operate it with PSPP in pumping mode during off-peak periods to avoid a big impact on the grid. If a 600MW generator suddenly stops, the PSPP should be shed at once by the protection relay in order to avoid a huge frequency drop.

0.7 Improving Reliability of Distribution System

CEB's distribution companies have been collecting statistics for SAIDI, which is an indicator for evaluating operational performance related to supply reliability, since January 2016. This indicator shows the power outage duration per customer, and efforts to reduce it are required. Conceivable measures for this include suppression of the frequency of outages, early detection and early recovery of faulty points, implementation of construction using uninterruptible power supplies, and other methods. Among these, early detection of faulty points is the most effective method of reducing power outage duration with a small amount of investment. CEB has already introduced a system to detect faulty sections early and separate them. However, since the sections to be separated are wide and the faulty points are mainly found via visual observation, it takes a lot of time. Considering this situation, it is desirable to introduce a system to classify faulty sections in a more subdivided way, and to deploy equipment for early discovery of faulty points in distribution offices.

In Chapter 9, the system and equipment adopted in Japan is described. Based on experience in Japan, the effect of introducing these is considered to be very significant, but the likely effect on Sri Lanka's distribution system is unclear. Therefore, it is preferable to perform a pilot project in limited areas first, and undertake a nationwide roll-out once the effect has been confirmed.

0.8 Proposal of Investment Plan and Financial Plan

Based on the above analysis, the JICA Survey Team proposes options for CEB in order to improve financial position and financial sustainability. It is essential to discuss the following recommendations with PUCSL who determines the Return on Assets level and the electricity tariff level since they require an increase in the electricity tariff.

(1) Increase in own capital for the transmission division via increased return on assets

While CEB’s Generation Division enables avoidance of additional funding for capital investment through greater participation by IPP for the construction of new power generation facilities for the future, its Transmission Division, as a single buyer, needs to make capital investments for the future and ensure funding. The current Return on Assets level of 2% has not been a serious issue so far because concessional loans with low interest rates from JICA and ADB have been utilized for capital investments on the transmission network. However, it is expected that CEB will not use such ODA loans with low interest rates in the near future. On the other hand, CEB needs to implement construction of transmission lines and substations in a timely manner, in accordance with the construction schedules for power generation facilities. Therefore, it is inevitable that CEB’s Transmission Division will implement capital investment using its own capital or take on commercial loans at some point in time.
CEB is required to expand its capital investment in transmission facilities to meet the growing power demand. However, the increase in debt finance for capital investment in transmission facilities, including substations and transmission lines, can increase the financial burden for CEB. Therefore, CEB should prepare a financial source other than loans, which can be costly. Because the current Return on Assets level of 2% on the operational assets has not been sufficient to cover the incremental investment, it is necessary for CEB to increase its own funds.

In order to cover the incremental investment by the own fund, CEB requires to accumulate retained earnings from the appropriate profit margin on the transmission tariff. Based on the simulation above, the profit margin of 3.5% on the operational assets can mostly cover the projected incremental cost and reduce debt finance for the capital investment. If the profit margin of 5% on the operational assets enables CEB to make capital investment by retained earnings after 2026. If the profit margin is set to 3.5% on the operational assets, it is necessary to increase the electricity tariff by about 0.06LKR/kWh over the present level, and when the profit margin on the operational assets is 5%, it is necessary to increase the electricity tariff by about 0.12LKR/kWh. In the case where its own capital increases via the increased Return on Assets, it is expected that the electricity tariff will be reduced in the long-run because of the reduced interest payments on the capital investment in future, though the electricity tariff will increase in the short term.

(2) Necessity of ensuring profit margin to deal with dramatic increase in power supply costs due to drought

As mentioned above, CEB's profitability can be fragile to fluctuation of power supply cost, in particular, by expensive fuel cost for oil-fired power generation in case of water shortage for hydropower generation. Since there is a lag between timing of sharp increase in power generation cost and for revision of electricity tariff and it is not possible to perfectly reflect the increased power generation cost into the tariff, CEB always needs to face financial difficulties to fill the gap between the electricity tariff and the actual power supply cost. CEB requires short-term loans to cover loss by the operation under the situation where the actual power supply cost is higher than the electricity tariff.

In order to avoid or mitigate impacts of fluctuation of power supply cost, in particular by water shortage for power generation, it is proposed to introduce setting a profit margin for preparation of cost escalation by water shortage. The profit margin enables CEB to compensate possible loss by a lag between the electricity tariff and the actual cost when drought occurs. The profit margin can be 7.5% for the period from 2018 to 2021 and 3% afterwards to minimize negative financial impact by drought.
However, in the case where the Return on Assets is increased, the profit margin can be used for purposes other than the increased power supply costs because there are no limits on the use of proceeds. In order to properly manage the use of proceeds, a mechanism to provide for droughts, which is reserved as a cost and used for this limited purpose when a drought occurs, can be considered as an alternative.

0.9 Action Plan and Road Map

This MP is greatly different from the previous MP. The JICA Survey Team proposes a development plan combining various power sources, taking into account the advantage of each. It aims to minimize supply costs, considering environmental and social aspects including the reduction of CO_2 emissions, and the aspect of providing a stable supply of electric power. As a result, issues to be newly addressed which have not been taken into consideration so far, such as responding to a massive introduction of renewable energy, and measures to introduce LNG-fired TPP, are becoming apparent. For promoting this MP in the future, the JICA Survey Team proposes an action plan and road map to address the assumed tasks.

For the action, the road map showing the execution timing and persons in charge of the implementation is shown below.

Table 0-8 Road Map

				2018						2019						2020						2021						Remarks
				1	3	5	7	9	11	1	3	5	7	9	11	1	3	5	7	9	11	1	3	5	7	9	11	
		[Long-term Generation Expansion Plan]																										
1	LTGEP	Direction Selection for Long-term Generation Expansion Plan	MPRE, CEB, PUCSL	■	■	■																						Especially, setting development goals for renewable energy
		[Renewable Energy]																										
1	RE	Introduction of rules enabling requests to suppress the output of RE when supply surplus occurs	PUCSL										■	■	■													Application timing will be after 2030, but it is important to adopt early rules to correct inequality
2	RE	Review of NCRE Three-tier Tariff	PUCSL	■	■	■																						Applicable only to small-scale (1MW or less) facilities
3	RE	System design that allows free entry	PUCSL, SEA, CEB							■	■	■																After establishment of an organization to calculate connection line costs
4	RE	Establishment of an organization to calculate connection line costs	CEB				■	■	■																			Capacity building for CEB staff is required
5	RE	Establishment of an organization to handle disputes	PUCSL	■	■	■																						A mediator for disputes between the developer and CEB
6	RE	Environmental Impact Assessment for RE	SEA	■	■	■																						To prevent environmentally-damaging development, Post-treatment collateral after project completion
7	RE	Confirmation of the response ability for load fluctuation by installing a small capacity battery	CEB, SEA										■	■	■	■	■	■	■	■	■	■	■	■				Establish pilot project in Hambantota About one year is required for manufacturing
		[Pumped Storage Power Plants]																										
1	PSPP	Confirmation of necessity of PSPP	CEB Consultant	■	■	■																						Depends on the configuration, but it is necessary in the case of developing a large amount of renewable energy
2	PSPP	Feasibility Study (including site selection, EIA)	CEB Consultant				■	■	■	■	■	■																Re-identification of good sites (excellent both economically and environmentally) for PSPP
3	PSPP	Detailed design (DD)	CEB Consultant													■	■	■	■	■	■	■	■	■	■	■	■	Needs 5 to 6 years for the construction period after completion of DD
		[LNG Fuel Supply Facilities]																										
1	LNG	Selection of fuel supply method	MPRE, MPRD CEB, CPC	■	■	■																						Considering sufficient domestic gas reserves, FSRU is desirable
2	LNG	Selection of management organization (LNG MO)	MPRE, MPRD CEB, CPC	■	■	■																						Considering load adjustment function, it is desirable that CPC or CEB manages and operates
3	LNG	Feasibility Study (including EIA)	LNG MO Consultant				■	■	■	■	■	■																
4	LNG	Detailed design Procurement contractor	LNG MO Consultant										■	■	■	■	■	■										
5	LNG	Construction (if FSRU type)	LNG MO Contractor																■	■	■	■	■	■	■	■	■	4 to 5 years required for land-based type
6	LNG	Acceleration of activities aimed at early start of commercial operations for domestic gas supply	PRDS	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	To shift from LNG to domestic gas at the stage when domestic gas supply becomes available
		[Coal-fired Thermal Power Plants]																										
1	Coal	Environmental mitigation measures for existing coal-fired TPP	CEB	■	■	■																						Measures to prevent scattering of ash etc. at existing Norocholai power station
2	Coal	Consensus formation for coal-fired TPP development	MPRE, CEB	■	■	■																						It will be reflected in the next LTGEP (April 2019).
3	Coal	Determination of development framework	MPRE, CEB				■	■	■	■	■	■																Comparative evaluation of IPP, JV etc.
		[Transmission Line Plan for Kerawalapitiya TPP]																										
1	T/L	Route selection for 220kV Kerawalapitiya - Kirindiwela Transmission line	CEB				■	■	■																			If it is difficult to secure the route, underground cable will be considered
2	T/L	Feasibility Study (including EIA)	CEB				■	■	■	■	■	■																
		[Inter-connected Transmission Line between Sri Lanka and India]																										
1	T/L	Forming of consensus between two countries	MPRE, CEB	■	■	■																						
2	T/L	Pre-Feasibility Study	CEB				■	■	■	■	■	■																Including survey in Tamil Nadu
		[Distribution Facilities]																										
1	D/L	Nationwide deployment of distribution SCADA system	CEB				■	■	■																			
2	D/L	Introduction and verification of faulty point detection system (pilot project)	CEB, LECO				■	■	■	■	■	■	■	■	■													Selection of supply area for distribution substation near Colombo as pilot project area
3	D/L	Nationwide introduction of faulty point detection system	CEB, LECO													■	■	■	■	■	■	■	■	■				Depending on verification results in pilot project

(Source: JICA Survey Team)

Chapter 1. Introduction

1.1 Background to the Survey

In Sri Lanka, the national electrification rate reached 98% in 2014, and the electricity sales volume is increasing at about 4% a year. Furthermore, the peak power demand recorded 2,453MW in 2016, and is assumed to reach 4,805MW in 2030.
In order to cope with the increasing demand year by year, the government has been working on the development of power sources, but the major hydropower resources have already been developed. As a result, the government is faced with the need to consider the diversification of power sources, development of peaking power plants (pumped-storage hydroelectricity, etc.) and installation of high-efficiency coal-fired power generation. In addition, the transmission and distribution (T&D) network has challenges concerning the improvement of power supply reliability and system losses by diversifying power source.
Under such circumstances, the government of Sri Lanka plans to review the current Electricity Sector Master Plan (ESMP), considering the latest technologies and various circumstances affecting the country (gas field development plans, etc.). Consequently, the government requested the cooperation of JICA in order to update the ESMP.

1.2 Purpose of the Survey

In reviewing the current ESMP by electricity demand forecast, primary energy analysis and an analysis of the data underlying the various power sector development plans in Sri Lanka, this survey aims to provide the strategies and their implementation plans to establish the updated ESMP for construction of the future national power system.

1.3 Area in Which to Conduct the Survey

The whole of Sri Lanka (i.e. the regions where critical power generation and T&D systems are located).

1.4 Conducting Organizations of the Partner Country

Governing agency: Ministry of Power and Renewable Energy (MPRE)
Executing agency: Ceylon Electricity Board (CEB)

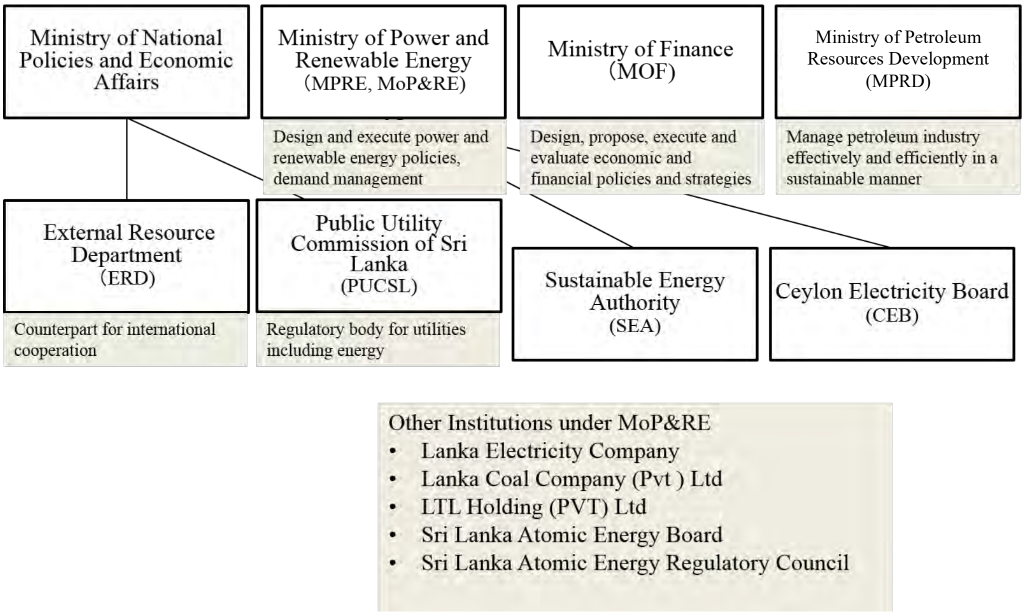
Chapter 2. Energy Sector and Electricity Sector in Sri Lanka

2.1 Energy Sector

Here, key public sector and private sector institutions in the energy sector and their roles are briefly introduced. Public sector and private sector institutions in the power sector are described in 2.2 Power Sector. Ministries have been recently recognized; therefore, relevant ministries prior to and post reorganization are shown.

2.1.1 Public Sector Institutions

Key organizations in the energy sector are the Ministry of Power and Renewable Energy and Ministry of Petroleum Resources Development. Both of them have Affiliated Institutes under their control. The Ministry of Megapolis and Western Development is responsible for urban development and infrastructure development in the Western region, including Greater Colombo; however, it is not in charge of power development plans or energy demand and supply plans.



(Source: JICA Survey Team)

Figure 2-1 Public Sector Institutions in Energy Sector

Ministries were recently recognized; therefore, relevant ministry names prior to and post reorganization are listed below to facilitate comparison with past studies.

Table 2-1 Reorganization of Ministries

Prior to reorganization	Post reorganization
Ministry of Environment and Renewable Energy (MOE&RE)	Ministry of Power and Renewable Energy (MPRE)
Ministry of Power and Energy (MOPE)	
Ministry of Petroleum Industries (MOP)	Ministry of Petroleum Resources Development (MPRD)
Ministry of Finance and Planning (MOF&P)	Ministry of National Policies and Economic Affairs
	Ministry of Finance (MOF)

(Source: JICA Survey Team)

(1) Ministry of Power and Renewable Energy

The Ministry of Power and Renewable Energy of Sri Lanka remains committed to a capacity development strategy maintaining the equilibrium between cost efficiency and the environment, power demand and supply management, and the efficient use of energy. It is responsible for the below eight areas.

1. Formulation of policies, programs and projects, monitoring and evaluation in regard to the subjects of power and renewable energy and those subjects that come under the purview of Departments, Statutory Institutions and Public Corporations under the Ministry of Power and Renewable Energy.
2. Formulation of an appropriate power policy for the control, regulation and utilization of power resources.
3. Investigation, planning, monitoring and development of activities relating to generation of power from sources, such as water, heat, coal and wind.
4. Rural electrification.
5. Management of demand to ensure energy efficiency, and development of renewable power.
6. Development of Renewable Energy.
7. All other subjects that come under the purview of Institutions listed under the Ministry of Power and Renewable Energy.
8. Supervision of the Institutions listed under the Ministry of Power and Renewable Energy.

The Ministry of Power and Renewable Energy has seven Affiliated Institutes.

1. Ceylon Electricity Board (CEB)
2. Lanka Electricity Company (LECO)
3. Lanka Coal Company (Pvt.) Ltd.
4. LTL Holding (Pvt.) Ltd.
5. Sri Lanka Sustainable Energy Authority (SEA)
6. Sri Lanka Atomic Energy Board
7. Sri Lanka Atomic Energy Regulatory Council

CEB and SEA are administrative organizations that are deeply involved in this project, and outlines of them are given below.

- Ceylon Electricity Board was established in November 1969. It is empowered to generate electrical energy, transmit the same and distribute it to reach all categories of consumers and to collect the revenue.
- The Sri Lanka Sustainable Energy Authority (SEA) was established in October 2007. SEA was established to realize the necessity of having an apex institution to drive Sri Lanka towards a new level of sustainability in energy generation and usage, through increasing indigenous energy and improving energy efficiency within the country. SEA's mission is to guide the nation in all its efforts to develop indigenous energy resources and conserve energy resources.

(2) Ministry of Petroleum Resources Development

Recognizing the importance of having a separate policy making body in respect of upstream and downstream petroleum activities, the Ministry of Petroleum and Petroleum Resources Development was established under the Government Extraordinary Gazette No. 1422/22 dated 08/12/2005. Its vision is to make both the upstream and downstream petroleum industries the foremost contributors to the National Economic Development of Sri Lanka. It is responsible for managing the activities of the downstream and upstream petroleum industries effectively and efficiently in a sustainable manner to meet the energy needs of the country and harness the country's petroleum resources to the maximum. It has the below eight objectives.

1. Make Sri Lanka an energy self-sufficient nation by 2030.
2. Optimum production of domestic oil and natural gas by 2030.
3. Meet Sri Lanka's petroleum product demands through the country's own processing by 2030.
4. Upgrade the quality of Diesel and Gasoline to EURO III and EURO IV standards respectively by 2020.
5. Store and distribute fuel more efficiently and safely.
6. Minimize haphazard disposal of plastic waste into the environment by converting it into petroleum fuel.
7. Enhance the quality and reliability of the fuel supply.
8. Promote fuel conservation.

The Ministry of Petroleum Resources Development has four Affiliated Institutes.

1. Ceylon Petroleum Corporation
2. Petroleum Resources Development Company
3. Ceylon Petroleum Storage Terminal Ltd
4. Petroleum Resources Development Secretariat

The most prominent institute is Ceylon Petroleum Corporation; however, other institutes play important roles in petroleum supply and distribution.
The key Affiliated Institutes managed by the Ministry of Power and Renewable Energy and Ministry of Petroleum Resources Development are described below.

(3) Lanka Coal Company
With the commissioning of the first coal plant in Puttalam in 2011, a new company was established under the Ministry of Power and Renewable Energy to streamline the supply of coal required for the plant. This new organization continues to supply coal to the three 300MW power plants, with a supply of 1,606.6 thousand tons in 2014.

(4) Ceylon Petroleum Corporation (CPC)
Established in 1961, CPC imports, refines and distributes petroleum products in the country. CPC owns and operates the only refinery in Sri Lanka, with a daily throughput of 50,000 barrels. The demand for petroleum products has significantly increased, with the sale of all petroleum products for all sectors recording an increase from 3,632.6 kt in 2013 to 4,029.1 kt in 2014.

(5) Ceylon Petroleum Storage Terminals Limited (CPSTL)
With the liberalization of the petroleum industry in the early 2000s, and the entry of Lanka Indian Oil Company, a necessity was felt to share storage infrastructure among downstream vendors. At the time, there was an expectation of a third player entering the downstream petroleum business. A company was incorporated with equal share holdings by CPC, LIOC and the Treasury. CPSTL is now managing the main distribution infrastructure in the country.

(6) Petroleum Resources Development Secretariat (PRDS)
This Secretariat was established in 2003 under the Petroleum Resources Act No. 26 of 2003, to manage the petroleum exploitation activities of the country. PRDS has successfully attracted an oil exploring company to explore petroleum resources in the Mannar offshore region. This Secretariat is not affiliated with any Ministry and functions within the purview of the Presidential Secretariat.

(7) Litro Gas Lanka Limited

The Liquefied Petroleum Gas (LPG) industry was privatized in 1995, when Shell Gas purchased a stake in the previously Government-owned Gas Company, under a five-year concession. Over 1995-2000, Shell Gas purchased LPG available in the CPC refinery and also imported LPG, and marketed it in Sri Lanka. The monopoly status ended in late 2000. The Company markets LPG to all customer segments, in all provinces of the country. Full ownership of Shell Gas Lanka (Pvt) Ltd was handed over to the Government in November 2010, forming Litro Gas Lanka Limited (LGLL). Sri Lanka depends on imported LPG to bridge the growing gap between demand and the limited local production by Ceylon Petroleum Corporation's (CPC) Refinery in Sapugaskanda. To meet this demand, the Government also took steps to purchase the Shell-owned LPG Storage Terminal situated in Kerawalapitiya. The LPG Storage Terminal was re-named Litro Gas Terminal Lanka (Private) Limited (LGTLL). Litro Gas also owns a modernized LPG bottling plant situated in Mabima, Sapugaskanda, which is one of the largest in the region, and a fleet of modernized LPG tanker trucks.

2.1.2 Private Sector Institutions

LAUGFS Gas PLC, part of a large conglomerate, is the key player in the LPG value chain, and Lanka Indian Oil Company and the Sri Lankan subsidiary of Indian Oil Company are major private institutes in the energy sector. According to newspaper reports, British, Indian and two American companies have already submitted requests for approval to the Board of Investment for investment in a new LNG processing, storage and regasification terminal.

(1) LAUGFS GAS PLC

Established in 1995, LAUGFS Holdings is a Sri Lankan diversified business conglomerate covering most of the commercial spectrum of industries. LAUGFS Gas PLC is a subsidiary of LAUGHS Holdings Limited. It plays a key role in the importation, storage filling, distribution and sale of Liquefied Petroleum Gas (LPG) for domestic, industrial and auto gas users. LAUGFS has a state-of-the-art storage and filling facility at Mabima, with a storage capacity of 2,500 tons, and a strong dealer network in the country.

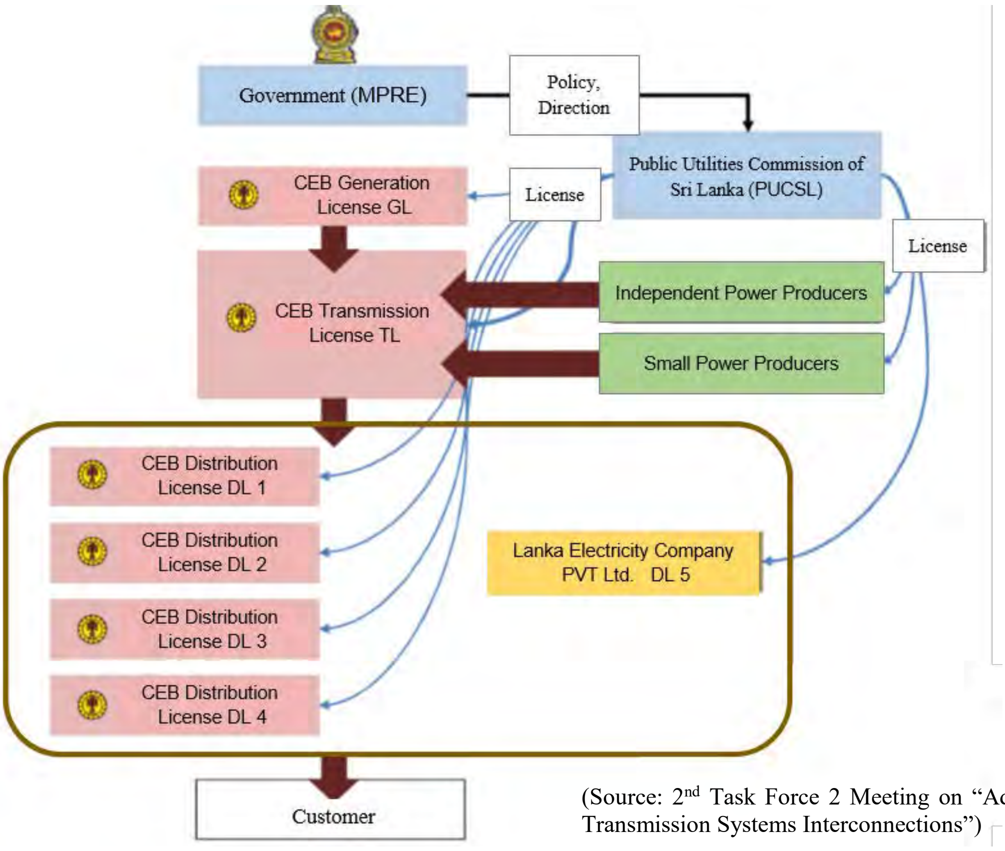
(2) Lanka Indian Oil Company (LIOC)

LIOC is a subsidiary of Indian Oil Company, which is owned by the government of India. It operates about 150 fuel stations in Sri Lanka, and has a very efficient lube oil marketing network. Its major facilities include a storage terminal at Trincomalee, Sri Lanka's largest petroleum storage facility, and an 18,000 tons per annum capacity lubricant blending plant and state-of-the-art fuel and lubricant testing laboratory in Trincomalee.

2.2 Electricity Sector

(1) Electricity Sector in Sri Lanka

The major characteristic in the electricity sector of Sri Lanka is that the Public Utilities Commission of Sri Lanka (PUCSL), which is a neutral organization, has played the role of a licensing authority in implementing issues regarding business licenses, tariff approvals, formulation of technical and safety standards, consumer protection, etc. CEB has divisions for Generation, Transmission and Distribution and has carried out its business by getting business permission from the PUCSL.



(Source: 2nd Task Force 2 Meeting on "Advancement of Transmission Systems Interconnections")

Figure 2-2 Electricity Sector in Sri Lanka

(a) Ceylon Electricity Board (CEB)
CEB was established according to Act of Parliament No. 17 in 1969. CEB has taken over the tasks in its Generation and Transmission division which the Sri Lankan Government managed. CEB owns generating, transmission and distribution facilities and plays an important role in actual power supply in Sri Lanka.

(b) Sri Lanka Sustainable Energy Authority (SEA)
SEA was established in 2007 by enacting Sri Lanka Sustainable Energy Authority Act No. 35. SEA has been working on the promotion of renewable energy development, improvement of energy efficiency, and reserves for energy security.

(2) Roles of Structures

(a) Power Development Planning
CEB submits a power development plan to PUCSL every two years. PUCSL gives permission to CEB after it has reviewed the validity of the plan.

(b) Electricity Tariff

CEB examines the electricity tariff every six months according to actual costs and submits an application to PUCSL. PUCSL gives approval to CEB after it has reviewed the validity of the costs.

(c) Renewable Energy

A developer gets a license for generation from PUCSL and also receives permission for each project development from SEA. Then, the developer undertakes a Small Power Purchase Agreement (SPPA) with CEB and finally starts the development. For small projects with a capacity of less than 10MW, power purchase is not decided by negotiation between CEB and the developer, but by the Feed-in-tariff prescribed by PUCSL.

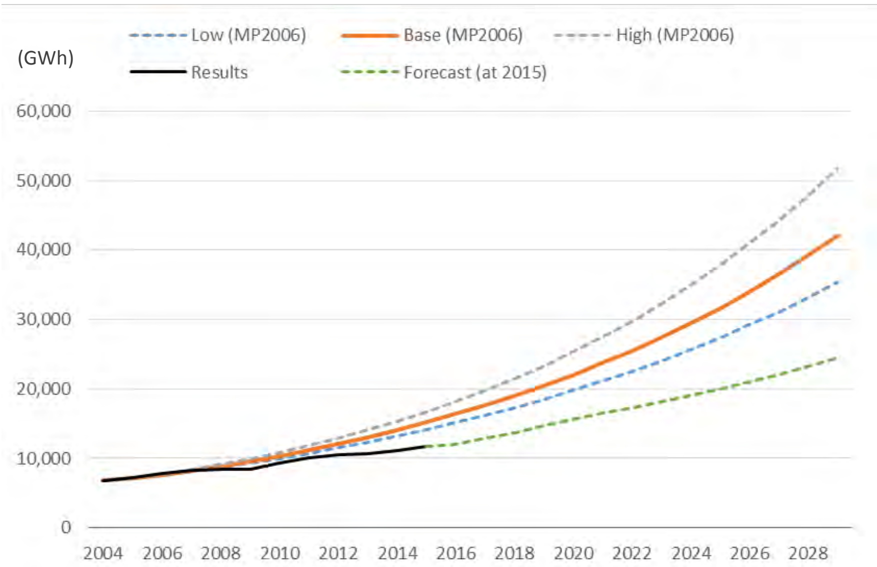
Chapter 3. Viewpoints and Targets of Electricity Sector Master Plan

3.1 Current Status of Electricity Sector

3.1.1 Review of Current Electricity Sector Master Plan (MP2006)

(1) Power Demand Forecast

The power demand forecast (Electricity consumption) in MP2006 and actual power demand after 2006 are shown as follows:



(Source: JICA Survey Team, based on MP2006)

Figure 3-1 Power Demand Forecast (Electricity Consumption) in MP2006

It had been supposed that the annual growth rate of electricity consumption for the 25 years from 2004 to 2029 would be approximately 7.7% in the Base case. It is slightly lower compared to the present situation.

The power demand forecast (maximum power demand) in MP2006 and actual power demand after 2006 are shown as follows:

(Source: JICA Survey Team, based on MP2006)

Figure 3-2 Power Demand Forecast (Maximum Demand) in MP2006

It had been supposed that the annual growth rate of the demand forecast for the 25 years from 2004 to 2029 would be approximately 7.5% in the Base case. It had been anticipated that the annual load factor for the 25 years would be 55.2% constant, and that the annual growth rate of generation would also be approximately 7.7%. However, the actual growth rate for the 11 years from 2004 to 2015 was about 3.5%, which was completely different from the demand forecast.

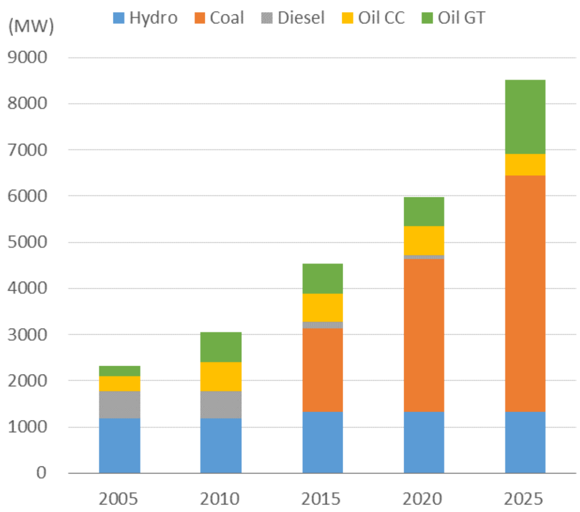
Compared to the electricity consumption, a large difference is occurring. The reason is that the assumption of the annual load factor was uniformly 55.2%, but at present it is increasing to 65%; also, the assumption of the transmission and distribution loss rate was around 14% after 2008, but it is decreasing to 10%.

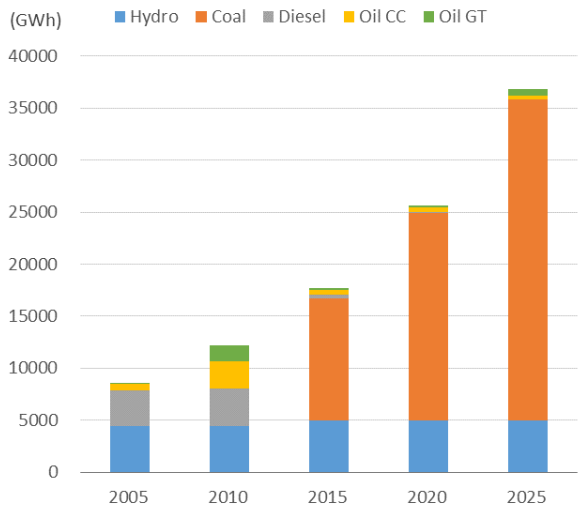
(2) Power Development Plan

The following scenarios are proposed in MP2006 and this fundamental plan is based on “Large scale thermal development scenario”.

(a) Large scale thermal development scenario...............Unconstrained development
(b) Non large scale thermal development scenario......Constrained development (capacity less than 150MW)
(c) Hydro development scenario...................................Promising hydropower development
(d) Natural gas supply scenario……….........................Natural gas supply starts after 2020

These power development plans excluded renewable energy because it was judged that power development plans without renewable energy should be reasonable from such concerns as the project economy, development possibility and unstable generating equipment.





(Source: JICA Survey Team, based on MP2006)

Figure 3-3 Transition of Power Supply Configuration in MP2006

A comparison of power supply configurations in 2015 is described below.

Table 3-1 Comparison of Power Supply Configurations in 2015

	Plan (MP2006)				Actual			
	Installed capacity		Generated energy		Installed capacity		Generated energy	
	MW	%	GWh	%	MW	%	GWh	%
Hydro	1,335	29%	4,994	28%	1,377	36%	4,904	37%
Oil	1,404	31%	1,009	6%	1,115	29%	2,275	17%
Coal	1,800	40%	11,681	66%	900	23%	4,443	34%
NCRE	0	0%	0	0%	455	12%	1,467	11%
Mini hydro	(0)	(0%)	(0)	(0%)	(307)	(8%)	(1,065)	(8%)
Wind	(0)	(0%)	(0)	(0%)	(127)	(3%)	(343)	(3%)
Other	(0)	(0%)	(0)	(0%)	(21)	(1%)	(59)	(0%)
Total	4,539	100%	17,684	100%	3,847	100%	13,090	100%

(Source: JICA Survey Team, based on MP2006)

In the Plan (MP2006), coal-fired TPP is the main power source. Its ratio of installed capacity is 40% and that of generated energy is 66%. For 2015, the actual situation is that the ratio of installed capacity is 23% and that of generated energy is 34%, which is half that of the plan (MP2006). The ratio of NCRE, which is not considered in the plan (MP2006), has increased to approximately 11%.

3.1.2 Current Status of Electricity Sector

The current status of the electricity sector is described in detail in 7.1.

(1) Power Supply Configuration

Power supply configuration in 2015 is also shown in Table 3-1. Power supply configuration accounting for 45% is Hydro, including mini hydro, which is the main power source.

(2) Current Power Development Plan

LTGEP 2015-2034 was submitted to PUCSL on 6 August 2015. This plan was made based on development for mainly coal thermal power plants as proposed by the current master plan. However, the current administration has had questions regarding coal thermal development and has insisted that the priority for development should be renewable energy. Under these circumstances, PUCSL gave CEB a direction to revise this LTGEP. As a result, CEB revised parts of the LTGEP and PUCSL gave approval to CEB on 15 September 2016. The major revised point was that a coal power plant (250MW x 2) which TPCL (Trincomalee Power Company Limited) planned in 2020 was canceled and a construction plan for an LNG thermal power plant (300MW) around Colombo in 2019 was included.

Power supply configuration in the revised LTGEP 2015-2034 is shown as follows:

Table 3-2 Power Supply Configuration in 2034 in revised LTGEP 2015-2034

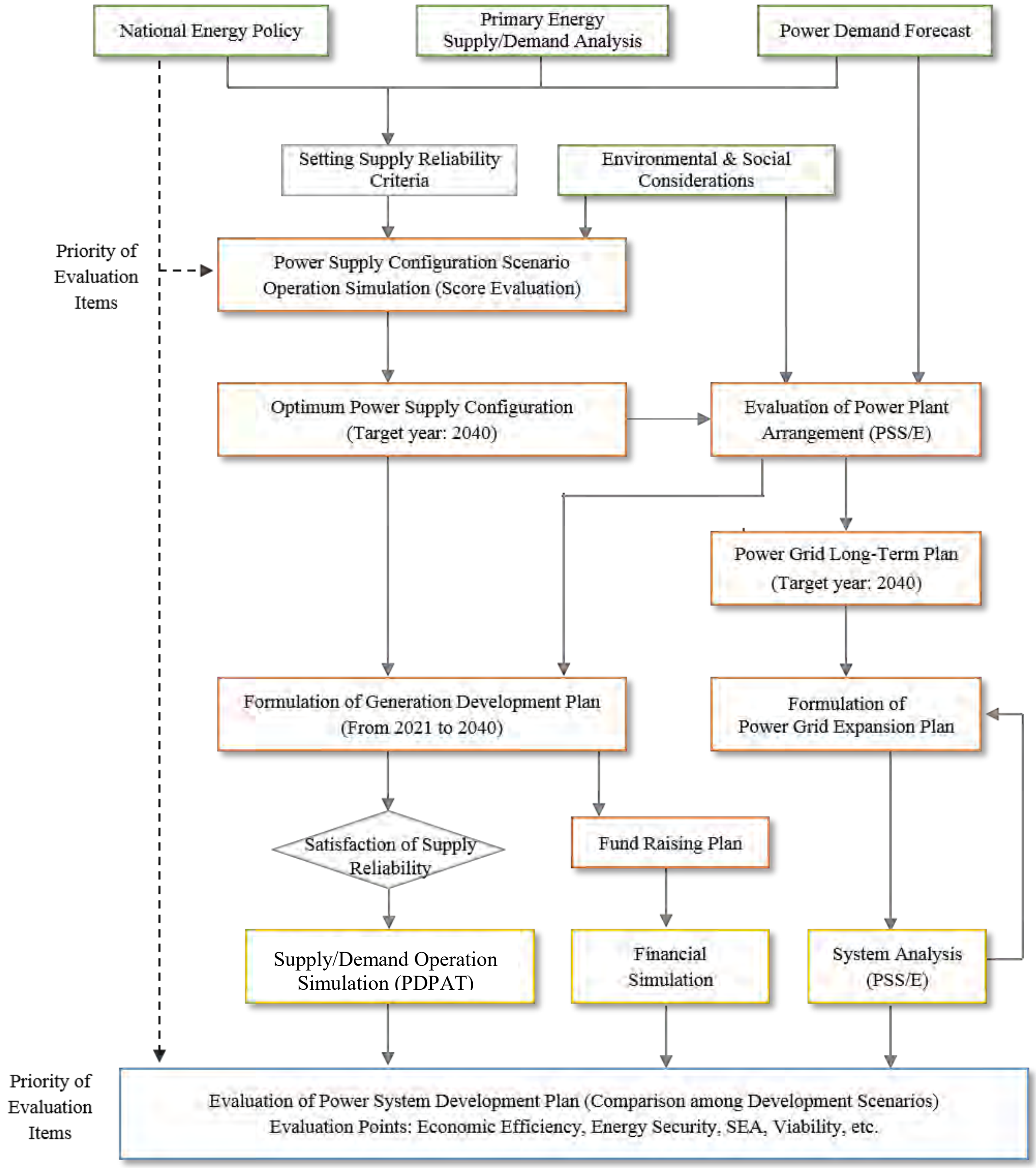
	Installed Capacity (MW)		Generated Energy (GWh)	
Hydro	2,176	25.3%	5,608	16.1%
Coal	3,200	37.2%	18,489	53.0%
LNG (Gas)	1,200	14.0%	4,070	11.7%
Oil	132	1.5%	14	0.0%
NCRE	1,884	21.9%	6,735	19.3%
Mini-hydro	(673)			
Wind	(719)			
Solar	(226)			
Biomass	(266)			
Total	8,592		34,916	

Remarks: Hydro including PSPP (600MW)

(Source: JICA Survey Team, based on revised LTGEP 2015-2034)

3.2 Viewpoints and Targets of Electricity Sector Master Plan

An outline of the Methodology to formulate the Electricity Sector Master Plan is shown in the below Figure 3-4.



(Source: JICA Survey Team)

Figure 3-4 Flow Chart for Electricity Sector Master Plan

Firstly, the Power supply configuration scenario in the target year of 2040 is established in consideration of the external factors, which are National energy policy, Primary energy analysis, Power demand forecast, and Environmental & Social Considerations. Next, through simulation, evaluation items in every category are calculated in each power supply scenario. Finally, the optimum power supply configuration scenario is established for 2040 by a quantitative comparison in consideration of the importance of every evaluation item.
It is necessary to consider the following key points to formulate a comprehensive electricity sector master plan. However, since some of them have a trade-off relationship with each other, it is determined which point is given priority, taking into consideration superordinate policies such as the national energy policy.

- Economic efficiency (Reduction of power supply cost (generation cost + transmission cost))
- Power supply reliability (Allowable annual power shortage hours, power shortage electric energy, etc.)
- Energy security (Stable supply, Supply cost stability)
- Environmental and social considerations (Environmental evaluation criteria on each development project, Green House Gas emission volumes)

Based on the optimum power supply configuration, the power plant arrangement is evaluated and the power grid long-term plan is then formulated. After the optimum power supply configuration and the formulation of the power grid are confirmed, a generation development plan and power grid expansion plan for each year from the present to the target year are formulated. During this planning and formulating, it is necessary to consider the viability of consensus-building with local residents around project sites, appropriate development lead-time, fund raising, etc.

Chapter 4. Primary Energy

4.1 Primary Energy Policy

The Ministry of Power and Energy published "National Energy Policy & Strategies of Sri Lanka", which has nine policy elements, in 2008.

Table 4-1 Nine policy elements of "National Energy Policy & Strategies of Sri Lanka"

Policy Elements	
1. Providing Basic Energy Needs	6. Enhancing Energy Sector Management Capacity
2. Ensuring Energy Security	7. Consumer Protection and Ensuring a Level Playing Field
3. Promoting Energy Efficiency and Conservation	8. Enhancing the Quality of Energy Services
4. Promoting Indigenous Resources	9. Protection from Adverse Environmental Impacts of Energy Facilities
5. Adopting an Appropriate Pricing Policy	

(Source: Ministry of Power and Renewable Energy)

Implementing strategies for the nine policy elements are respectively developed. Furthermore, specific targets, milestones and institutional responsibilities are stated. The key points of the nine policy elements are described as below.

1. Providing Basic Energy Needs:
   Energy requirements to fulfil the basic needs of the people and to enhance their living standards, and opportunities for gainful economic activity will be adequately and continually satisfied at the lowest possible cost to the economy.

2. Ensuring Energy Security:
   Energy resources used in the country will be diversified and the future energy mix will be rationalized.

3. Promoting Energy Efficiency and Conservation:
   Energy supply systems will be efficiently managed and operated while also ensuring efficient utilization and conservation of energy.

4. Promoting Indigenous Resources:
   Indigenous energy resources will be developed to the optimum levels to minimize dependence on non-indigenous resources, subject to resolving economic, environmental and social constraints.

5. Adopting an Appropriate Pricing Policy:
   An appropriate pricing policy for the energy sector will be adopted considering important factors such as cost reflectivity, need for targeted subsidies, and competitiveness of locally produced goods and services in the regional and world markets.

6. Enhancing Energy Sector Management Capacity:
   All measures will be taken to continually enhance the local capacity to develop and manage the energy sector effectively, giving due emphasis to technological developments and good governance in the energy sector.

7. Consumer Protection and Ensuring a Level Playing Field:
   Necessary measures will be taken to safeguard the interests of both present and future consumers while ensuring a level playing field for all the stakeholders in the energy sector.

8. Enhancing the Quality of Energy Services:

The quality of energy services will be ensured through imposition of appropriate quality standards and regulatory interventions.

9. Protection from Adverse Environmental Impacts of Energy Facilities:
Necessary steps will be taken to minimize adverse environmental and social impacts caused by electricity and petroleum sub-sector development and operational activities.

The below twelve targets are set to secure the visibility of progress and achievements regarding the policy elements.

1. Electrification of Households
2. Targeted Subsidies
3. Fuel Diversity and Security
4. Non-Conventional Renewable Energy (NCRE)-Based Electricity in the Grid
5. Electricity Pricing
6. Petroleum sub-sector Regulation and Product Pricing
7. Oil and Gas Exploration
8. Bunkering
9. Supply-side Energy Efficiency
10. Demand-side Energy Efficiency
11. National Energy Database and Integrated National Energy Planning
12. Rural Electrification

"National Energy Policy & Strategies of Sri Lanka" is revised every ten years, and the Ministry of Power and Renewable Energy is drafting a revision in 2018. 2008's "National Energy Policy & Strategies of Sri Lanka" stated nine policy elements. The revision renamed "energy policy elements" to "energy policy" and the below ten policies are reviewed.

Table 4-2 Ten energy policies of "National Energy Policy & Strategies of Sri Lanka"

Energy Policy	
1. Assuring Energy Policy	6. Caring for the Environment
2. Providing Energy Services at the Optimum Cost to the National Economy	7. Enhancing the Share of Renewable Energy
3. Providing Access to Energy Services	8. Strengthening Good Governance in the Energy Sector
4. Enhancing Self Reliance	9. Securing Future Energy Infrastructure
5. Improving Energy Efficiency and Conservation	10. Providing Opportunities for Innovation and Entrepreneurship

(Source: Ministry of Power and Renewable Energy)

The Ministry of Power and Energy published "Sri Lanka Energy sector development plan for a knowledge-based economy 2015-2025" in 2015. This plan stated eight major challenges, fourteen energy sector targets and eight thrust areas which underpin Sri Lanka's economic development.

Table 4-3 Major challenges in "Sri Lanka Energy sector development plan for a knowledge-based economy 2015-2025"

1. High cost of electricity	5. Large investment needed for infrastructure development in the power & energy sector
2. 100% dependency on imported oil for the transport sector	6. Unsustainable consumption patterns
3. Lack of local capacity development, research and technology	7. Energy wastage and losses
4. Traditional institutional setup not geared to meet emerging energy sector challenges	8. Increasing demand trends across all sub-sectors

(Source: Ministry of Power and Renewable Energy)

Fourteen energy sector targets were developed to overcome these challenges and underpin the development of Sri Lanka in its shift to a knowledge-based economy.

1. Make Sri Lanka an energy self-sufficient nation by 2030.
2. Increase the share of electricity generation from renewable energy sources from 50% in 2014 to 60% by 2020 and, finally, meet the total demand from renewable and other indigenous energy resources by 2030.
3. Increase the electricity generation capacity of the system from 4,050MW to 6,400MW by 2025.
4. Generate a minimum of 1,000MW of electricity using indigenous gas resources discovered in the Mannar basin by 2020.
5. Increase generation capacity of low cost thermal power plants fired by natural gas and biomass to 2,000MW to reduce the generation costs and to diversify the generation mix by 2020.
6. Provide affordable electricity coverage to 100% of the population on a continuous basis before the end of 2015.
7. Reduce the technical and commercial losses in the electricity transmission and distribution network from 11% to 8% by 2020.
8. Reduce annual energy demand growth by 2% through conservation and efficient use.
9. Reduce petroleum fuel use in the transport sub-sector by 5% by introducing alternative strategies such as efficient modes of transport and electrification of transport by 2020.
10. Produce the country's total petroleum product demand via its own refinery by 2025.
11. Upgrade quality of Gasoline and Diesel to EURO IV and EURO III respectively by 2018.
12. Further enhance the quality and reliability of the electricity and fuel supply.
13. Broaden energy sector investment windows to include bonds, debentures, public private partnerships and other such novel financial instruments.
14. Reduce the carbon footprint of the energy sector by 5% by 2025.

Eight thrust areas with respective strategies were determined in order to meet these fourteen targets.

1. Integrated National Energy Policy Formulation
2. A cleaner future through green energy
3. Conservation and efficient use of energy - a national priority
4. Customer satisfaction in service and quality
5. Timely development of infrastructure
6. Efficient energy sector institutions and good governance
7. Innovative financing for a diverse energy sector
8. Investment in R&D for cutting-edge product development

4.2 Primary Energy for Power Development

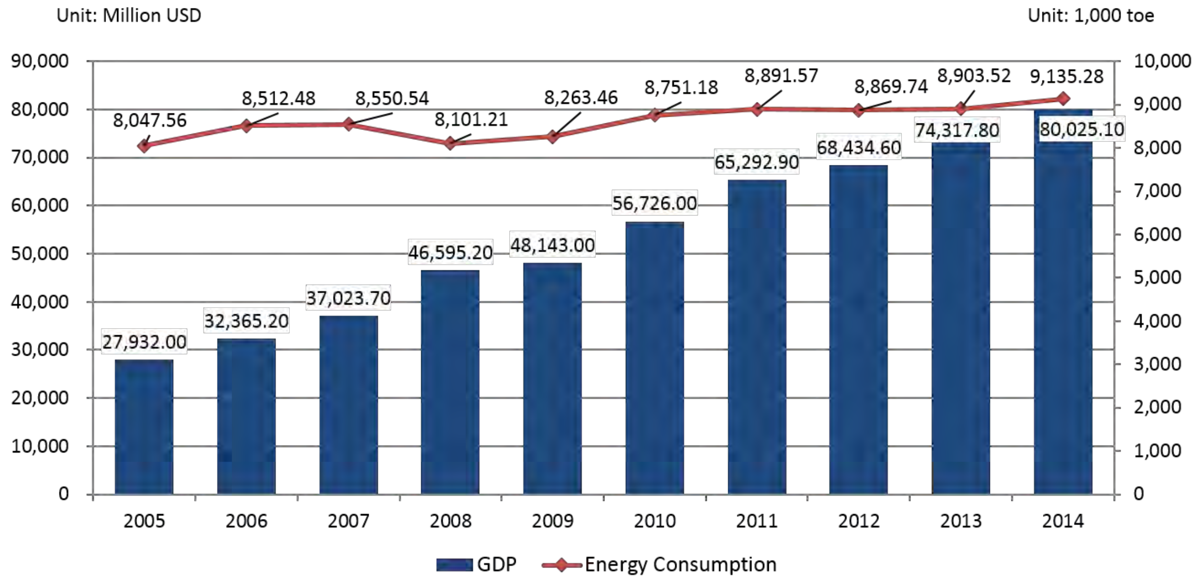
4.2.1 Primary Energy Demand and supply transition

(1) Demand

Sri Lanka recorded high economic growth, growing by 2.9 times, from USD 27,932 million to USD 80,025 million in GDP, in the 10 years from 2005 to 2014. According to the Central Bank of Sri Lanka, Gross National Income (GNI) increased by approximately 1.35 times, from LKR 5,758,104 million in 2010 to LKR 7,817,395 million in 2015. Looking at the growth in GNI by industry, primary, secondary and tertiary industries have grown by approximately 1.24, 1.32 and 1.39 times respectively. Most notably, Growing of Spices, Aromatics, Drug and Pharmaceutical Crops, as well as IT Programming, Consultancy and related Activities, have grown by approximately 2.1 times.

Energy Consumption increased by 1.2 times, from 8,047.56 thousand toe 9,135.28 thousand toe, in the 10 years from 2005 to 2014. Regarding energy consumption structure by sector, the structural comparison of Industry - Transport, Household, Commercial & Others - changed from 25:26:49 in 2005 to 26:29:45 in 2014. GDP elasticity of energy consumption from 2005 to 2014 was 0.4, which indicates that energy demand increased but was below the economic growth rate. With regard to primary energy consumption by sector, the Industry sector increased by 1.2 times from 2,004.07 thousand toe to 2,363.42 thousand toe, Transport increased by 1.3 times from 2,093.45 thousand toe to 2,686.25 thousand toe, and Household, Commercial & Others stayed about the same, increasing from 3,950.04 thousand toe to 4,085.61 thousand toe.

The former Sri Lankan government set the Five (maritime, aviation, commercial, knowledge, and energy) plus One (tourism) hub strategy. Consequently, the IT, Finance and Tourism industries achieved high rates of growth in GNI. Since all of these high-growth industries are in the service sector, energy consumption growth for the Household, Commercial & Others sector remains at approx. 3%. Energy consumption growth in the Transport sector was contributed to by both foreign bunker with naval and maritime development, and gasoline demand growth with motorization. Consumption of foreign bunker has increased by 10 times, and that of gasoline by 1.8 times. The number of vehicle registrations increased by about 1.6 times in the 7 years from 2007 to 2014.



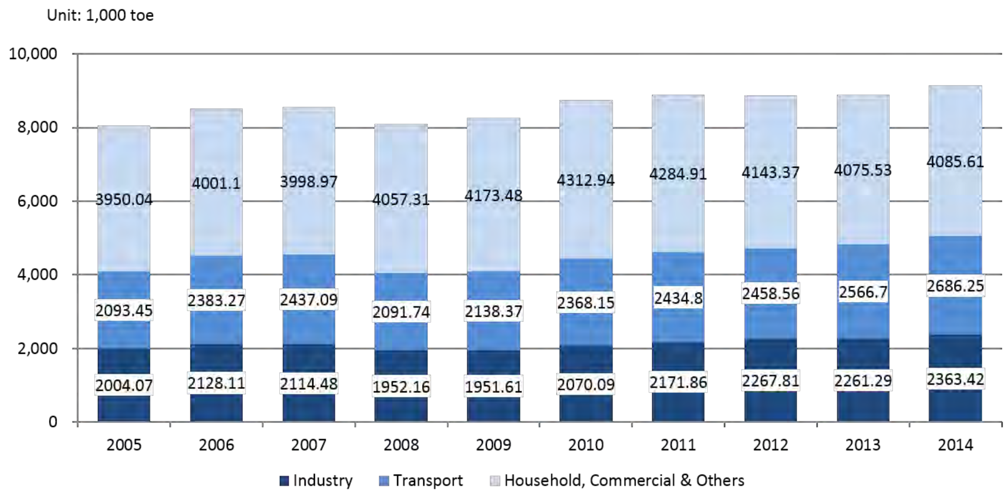
(Source: Sri Lanka Sustainable Energy Authority, Oxford Economics)

Figure 4-1 GDP growth and primary energy consumption trend

Table 4-4 Consumption by Sector (Thousand toe)

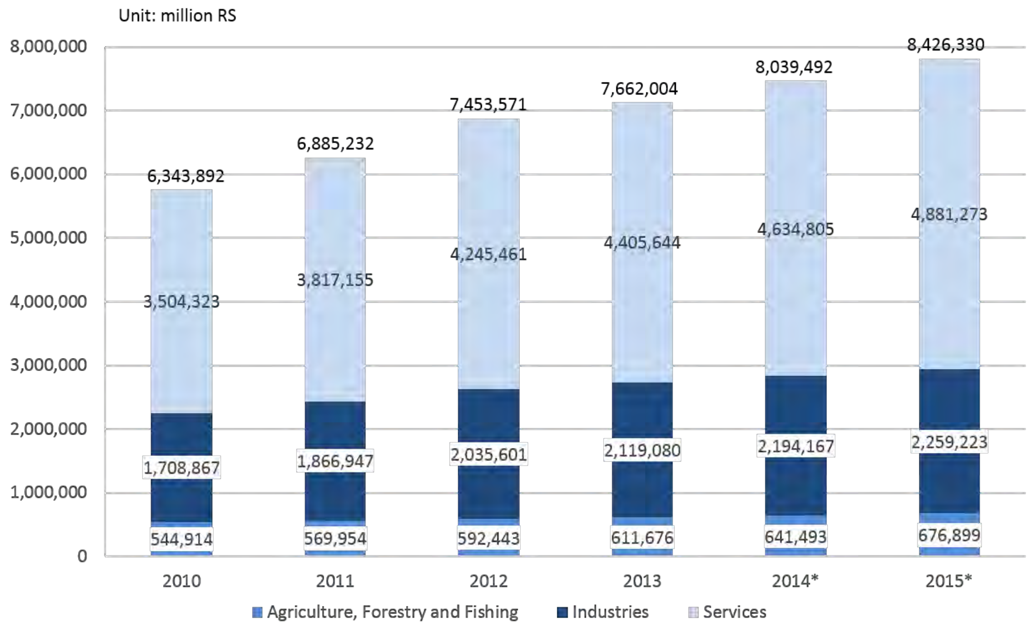
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Industry	2,004.07	2,128.11	2,114.48	1,952.16	1,951.61	2,070.09	2,171.86	2,267.81	2,261.29	2,363.42
Transport	2,093.45	2,383.27	2,437.09	2,091.74	2,138.37	2,368.15	2,434.80	2,458.56	2,566.70	2,686.25
Household, Commercial & Others	3,950.04	4,001.10	3,998.97	4,057.31	4,173.48	4,312.94	4,284.91	4,143.37	4,075.53	4,085.61
Total	8,047.56	8,512.48	8,550.54	8,101.21	8,263.46	8,751.18	8,891.57	8,869.74	8,903.52	9,135.28

(Source: Sri Lanka Sustainable Energy Authority)



(Source: Sri Lanka Sustainable Energy Authority)

Figure 4-2 Consumption by Sector (thousand toe)



(Source: Department of Census and Statistics Annual Report 2015)

Figure 4-3 GNI trends by sector (GNI: Gross National Income)

Table 4-5 GDP elasticity of primary energy consumption

	GDP		Primary Energy Consumption		Energy consumption Increase rate /GDP Growth ratio
	GDP	Year-over-year	Total	Year-over-year	
Unit	Million USD	%	1,000 toe	%	
2004	23,646.5	-	7,324.27	-	-
2005	27,932.0	18.1%	8,047.56	9.9%	0.55
2006	32,365.2	15.9%	8,512.48	5.8%	0.36
2007	37,023.7	14.4%	8,550.54	0.4%	0.03
2008	46,595.2	25.9%	8,101.21	-5.3%	-0.20
2009	48,143.0	3.3%	8,263.46	2.0%	0.61
2010	56,726.0	17.8%	8,751.18	5.9%	0.33
2011	65,292.9	15.1%	8,891.57	1.6%	0.11
2012	68,434.6	4.8%	8,869.74	-0.2%	-0.04
2013	74,317.8	8.6%	8,903.52	0.4%	0.05
2014	80,025.1	7.7%	9,135.28	2.6%	0.34

(Source: JICA Survey Team based on data from Sri Lanka Sustainable Energy Authority, Oxford Economics)

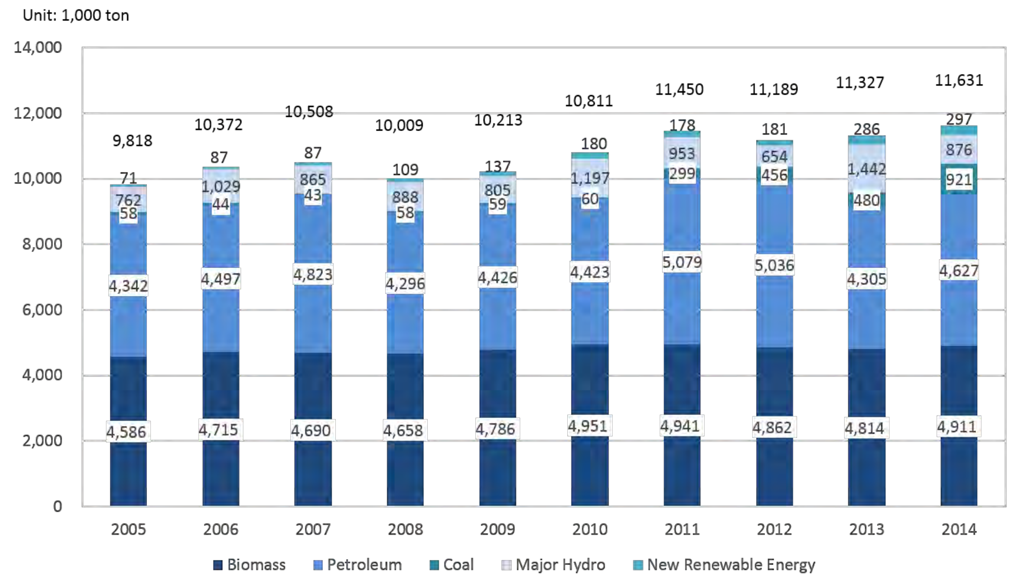
(2) Supply

Energy supply increased by about 1.2 times from 9,818.37 thousand toe to 11,631.37 thousand toe in the 10 years from 2005 to 2014. The structural comparison of biomass, petroleum, coal, major hydro power, and new renewable energy changed from 47:46:0:7:1 in 2005 to 42:40:8:8:3 in 2014. The increases in coal and new renewable energy were significant, at 15.8 and 4.2 times respectively. However, the supply increase for biomass, petroleum and major hydro power remains at 1.1-1.2 times. The coal supply increase was driven by the start of operations of CEB's Puttalam coal-fired power plant (3 x 300MW) in 2011 and 2014. The new renewable energy increase indicates that the establishment of the Sustainable Energy Authority (SEA) in 2007, as well as the start of operations of wind power plants comparable to 10MW in 2010, 2012 and 2014, contributed to the gradual spread of new renewable energy.

Table 4-6 Supply of Energy by Different Sources (Thousand toe)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Biomass	4,585.89	4,714.55	4,689.66	4,658.46	4,786.25	4,951.10	4,940.51	4,861.69	4,814.33	4,911.25
Petroleum	4,341.53	4,497.24	4,823.46	4,295.81	4,425.94	4,422.93	5,078.92	5,035.79	4,304.53	4,626.84
Coal	58.43	43.82	42.75	57.64	58.67	59.93	299.10	455.99	479.70	920.65
Major Hydro	761.52	1,029.46	864.70	888.11	805.34	1,197.24	953.44	654.41	1,442.42	875.93
New Renewable Energy	71.00	87.21	87.11	108.98	136.52	179.75	178.36	181.06	285.55	296.70
Total	9,818.37	10,372.28	10,507.68	10,009.00	10,212.72	10,810.95	11,450.33	11,188.94	11,326.53	11,631.37

(Source: Sri Lanka Sustainable Energy Authority)



(Source: Sri Lanka Sustainable Energy Authority)[1]

Figure 4-4 Supply of Energy by Different Sources (thousand toe)

(3) Handling volume at Port of Discharge and Port Development Plan

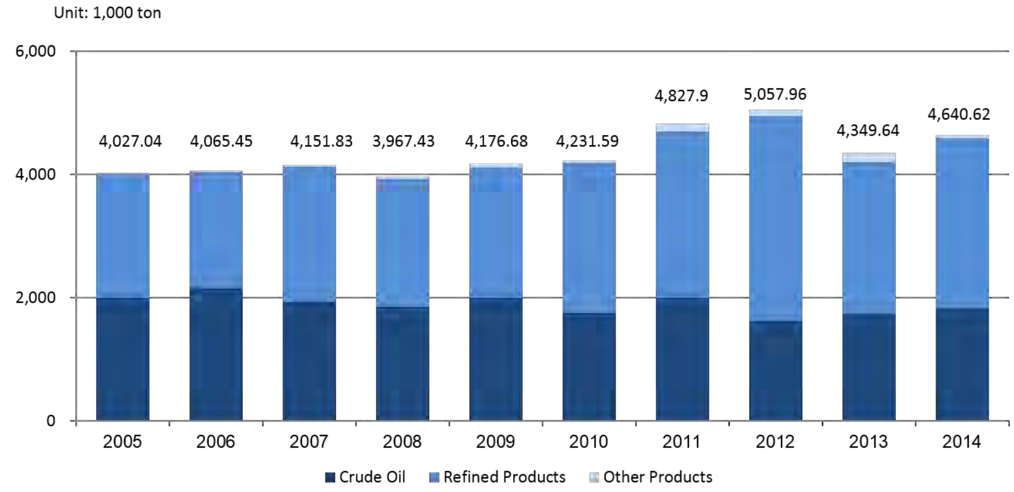
In Sri Lanka, petroleum and petroleum products, and coal, rely on imports. Since there is only one domestic petroleum refinery facility, owned by CPC in Sapugaskanda, the import rate of crude oil is approximately 40% and the remainder is imported as petroleum products. In addition to Colombo port, Galle, Trincomalee, and Kankasanthura ports are equipped with pipeline facilities, while Galle remains inoperative due to damage by a tsunami. Single point buoy mooring (SPBM) is facilitated at Muthurajawela on the west coast, as well as at Colombo.

The Sri Lanka port authority does not publish handling volumes by port. Thus, here is shown the whole import volume. The import volume of petroleum and petroleum products increased by 1.2 times, from 4,027.04 thousand tons to 4,640.62 thousand tons, in the 10 years from 2005 to 2014. The import volume of crude oil decreased from 2,008.41 thousand tons to 1,823.99 thousand tons, while that of petroleum products increased by 1.37 times from 2,009.48 thousand tons to 2,760.42 thousand tons. The import volume of coal increased by more than 17 times, from 92.74 thousand tons to 1606.60 thousand tons, in the 10 years from 2005 to 2014. Coal imports are handled by Lanka Coal Company (Private) Limited under CEB.

According to the Sri Lanka port authority, expansion of Colombo port was completed during 2012 to 2013. Hambantota port is also being expanded in multiple phases and further port development is under

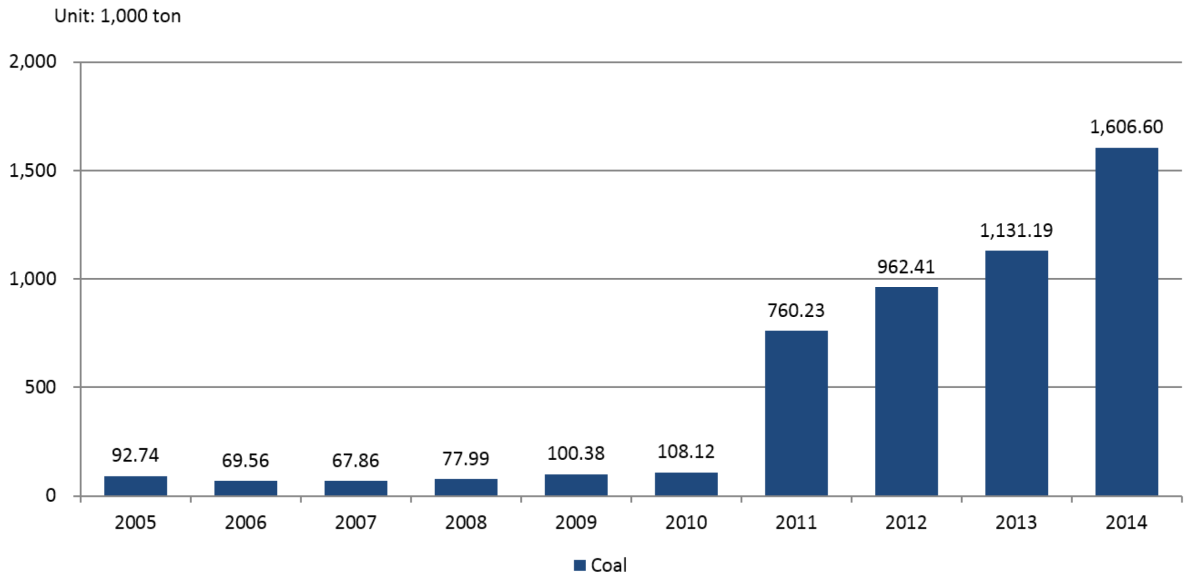
[1] Note: 2014 and 2015 are provisional figures.

way with a water depth of 17 meters[2]. In addition, ADB[3] announced a port development master plan and the conducting of technical assistance in order to support the development plan for Colombo and Trincomalee ports in 2016. The LNG terminal construction plan is described in Section 4.2.3.



(Source: Sri Lanka Sustainable Energy Authority Sri Lanka Energy Balance)

Figure 4-5 Crude petroleum and petroleum products' import trend



(Source: Sri Lanka Sustainable Energy Authority)

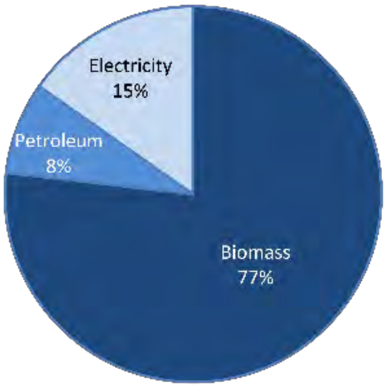
Figure 4-6 Coal Import trend

(4) Current conditions of household energy in city area

Approx. 77% of household energy consumption consists of biomass, followed by 15% electric power and 8% petroleum. While biomass is the main energy supply source for households, an accurate number cannot be ascertained by the Sustainable Energy Authority (SEA) since the number includes distribution channels for in-house production. Approximately 52% (equivalent to 2,376,190kL) of petroleum products' consumption comes from Colombo and Gampaha, an area adjacent to the capital. Household sector energy consumption accounts for 85% of the overall consumption volume. According to the Ministry of Megapolis and Western Development (WRMPP), the west region, consisting of Colombo and Gampaha (north of Colombo) and Kalutata (south of Colombo), covers only 6% of the whole

[2] http://portcom.slpa.lk/port_hambantota.asp?chk=4
[3] https://www.adb.org/projects/50184-001/main#project-pds

territory of Sri Lanka, but is an urban area which accounts for 28% of the population and 42% of GDP. The electrification rate of the west region is 100%, which is preeminent in South Asia. Concerning electric power demand, while the overall domestic demand in 2014 was 2,152MW (12,357GWh), that of the west region was 1,165MW (4,822GWh). The west region is also the center of the IT and naval and maritime industries, so it will be necessary to strengthen the power transmission system especially for the urban areas with a tight electric power supply expected in 2030; it is also getting difficult to secure land.



(Source: Sri Lanka Sustainable Energy Authority)

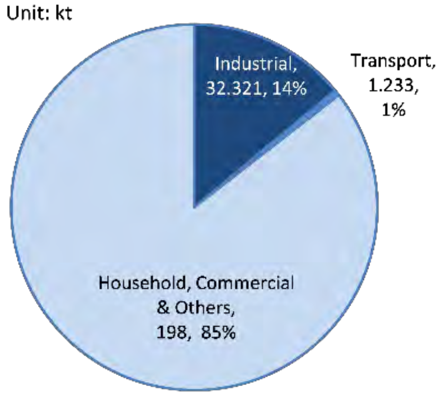
Figure 4-7 Household and commercial sector energy consumption

Table 4-7 Petroleum products demand by district

Unit: KL

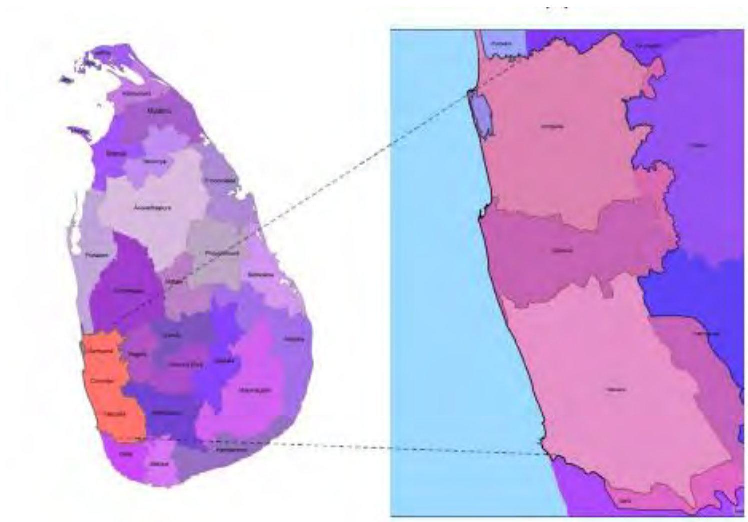
District	Total	District	Total
Kandy	174,258	Kurunegala	251,515
Matale	65,132	Puttalam	146,474
Nuwara Eliya	65,708	Ratnapura	139,368
Batticaloa	46,430	Kegalle	83,462
Ampara	66,660	Galle	139,403
Trincomalee	62,194	Matara	131,980
Anuradhapura	127,044	Hambantota	94,466
Polonnaruwa	61,901	Badulla	82,504
Jaffna	89,894	Moneragala	107,100
Mannar	19,113	Colombo	1,731,295
Mulalativu	21,621	Gampaha	644,895
Vavuniya	31,770	Kalutata	173,681
Kilinochchi	19,029	Total	4,570,188

(Source: Sri Lanka Sustainable Energy Authority)



(Source: Sri Lanka Sustainable Energy Authority)

Figure 4-8 LPG consumption by sectors



(Source: Ministry of Megapolis and Western. Development, Western Region Megapolis Master Plan)

Figure 4-9 Western district of Sri Lanka

(Source: JICA Survey Team)

Figure 4-10 Pictures: Urban Areas

4.2.2 Forecast for future demand

The forecast for primary energy demand for the industry, transport, household and commercial sectors is based on the data investigated in Chapter 4.2.1 according to the trends of primary energy demand in neighboring countries, Thailand, Malaysia and Vietnam which have the almost same population with larger primary energy consumption per person, with the macro-environment, which affects future demand, considered. Moreover, the uncertainty of the future demand will be mentioned in this section.

As mentioned in Chapter 4.2.1, from 2005 to 2014, the consumption of energy grew by 1.2 times, from 8,047.56 thousand toe to 9,135.28 thousand toe. Consumption has increased by 1.2 times in the transport sector, which is the biggest increase across all sectors. GDP elasticity of energy demand in the past 10 years is 0.4; thus, the growth in energy demand is slower than the economy. The STEEP[4] aspects of the macro-environment ("Social", "Technology", "Economy", "Environment", "Politics") are shown as follows.

Table 4-8 Major Factors affecting Macro-environment

Politics	• The civil war ended in 2009. Issues like the rehabilitation of the northern and eastern districts, and reconciliation between ethnic groups still exist, but it is a safe place • President Sirisena entered office in January 2015, and reforms such as constitutional amendment for reduction of the authority of the president, and anti-corruption measures are already being realized • Sri Lanka plans to reform its diplomacy, from excessive dependence on China to balanced relationships with Japan, India and China
Economics	• 5 hub strategies of marine transportation, aviation, commerce, knowledge and energy with tourism hub • Positioned in between Asia and Middle East/Africa, playing a big role in marine transportation • With rich tourism resources such as world heritage sites and beach resorts, major domestic companies and western hotel chains have developed new hotels and the number of tourists has increased by 20% • High level of education and English literacy makes the country noteworthy in the IT industry, finance/accounting, and the outsourcing industry, and as a hub of knowledge
Society	• The population of Sri Lanka is about 20.67 million, and will increase slowly • Western area of the country includes the capital Colombo, with about 30% of the population; there are many people working in the service sector in the civil district
Technology	• Western companies actively come into the market • Although the scale is small, there are wind-power and solar-power generations in the country, and low-carbon technology will spread in the country
Environment	• The establishment of Sri Lanka Sustainable Energy Authority in 2007 • Over 20 CDM projects • 2030 reduction target volume, adoption of the Paris Agreement

(Source: Analyzed by JICA Survey Team)

[4] Society, Technology, Economy, Environment, Politics

Referring to the growth of primary energy demand in semi-developed countries, Thailand, Malaysia and Vietnam, the forecasts for the industry, transport, and household and commercial sectors require the use of the following method. Economic growth is based on Oxford Economics' 2040 Nominal GDP forecast. The "Long Term Generation Expansion Plan 2015-2034" compiled by CEB uses the Annual Report published by the central bank of Sri Lanka, which differs from this forecast.

The first forecast, "GDP scenario", shows what happens if the demand follows GDP growth. Growth rate presupposes the same value as GDP growth year-over-year, as with other countries. Nevertheless, the GDP elasticity of energy demand in the past 10 years is 0.4. The government's economic policy, which focuses more on the service sector instead of energy-intensive sectors, and COP21, signed in 2015 and which urges transition to a low-carbon society, may result in divergence from the forecast.

Regarding this problem, the second case measured the GDP elasticity of the past 10 years to the growth of the primary energy demand; this is the "GDP Elasticity Scenario". In this case, we used the growth rate of the year which recorded the primary energy demand per capita in Thailand, Malaysia and Vietnam, similar to that of Sri Lanka in 2013[5], and the growth rate over 25 years defined in this master plan. For the record, the data for Malaysia which can be acquired from 1980 is larger than that for Sri Lanka in 2013. The data for Vietnam is the most similar to Sri Lanka in 2006. The data of Thailand is subject to reference for 25 years from 1988 to 2013. The service industry in Sri Lanka covers a larger portion than in these 3 countries, so it is not realistic for such a case as the "GDP Scenario", in which the demand is forecasted to grow faster than these 3 countries.

Therefore, in both cases, using the data for the portions of the industry, transport, and household and commercial sectors in 2014, which are 25.9%, 29.4%, and 44.7% respectively, the demand increase in the transport sector is influenced by the development of logistics, as a hub for marine transportation should be considered an uncertainty, as will be mentioned later. It is hard to quantify as of now, but the influence of shifting from fossil fuels to electricity is considered to be slight with the electrification of Panadura-Veyangoda (almost 70km) outside Colombo funded by ADB[6], and with the spread of electric vehicles[7]. Railway electrification will be mentioned later, in Chapter 5.2.5.

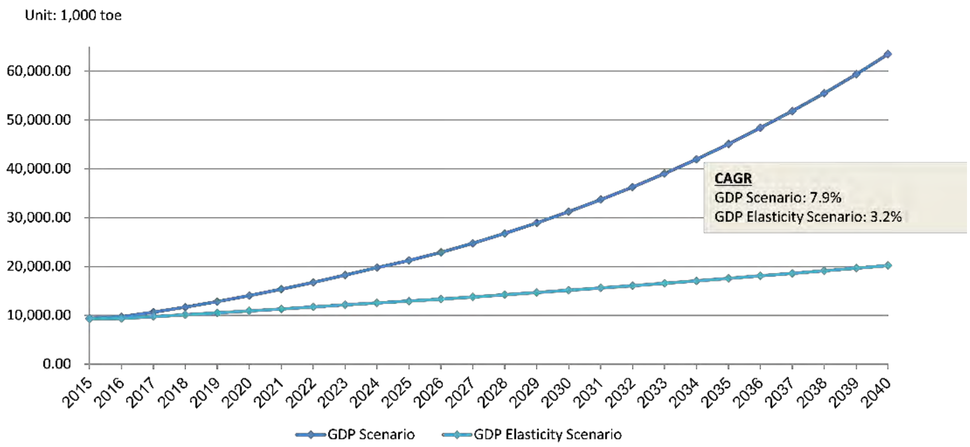
In the "GDP Scenario", the demand for primary energy in 2040 is forecasted to be: 16,419.92 thousand toe in the industry sector, 18,662.78 thousand toe in the transport sector, and 28,384.87 thousand toe in the household and commercial sector, a total of 63,467.57 thousand toe. In the "GDP Elasticity Scenario", it is forecasted to be: 5,225.63 thousand toe in the industry sector, 5,939.42 thousand toe in the transport sector, and 9,033.47 thousand toe in the household and commercial sector, a total of 20,198.52 thousand toe.

[5] The primary energy consumption per capita in 1980 is 0.516ktoe.
[6] According to a meeting with SEA during the first field visit, electrification of the transport sector has not progressed.
[7] SEA commented that there was a pilot project for EV charging infrastructure.

Table 4-9 Nominal GDP forecast (Million USD)

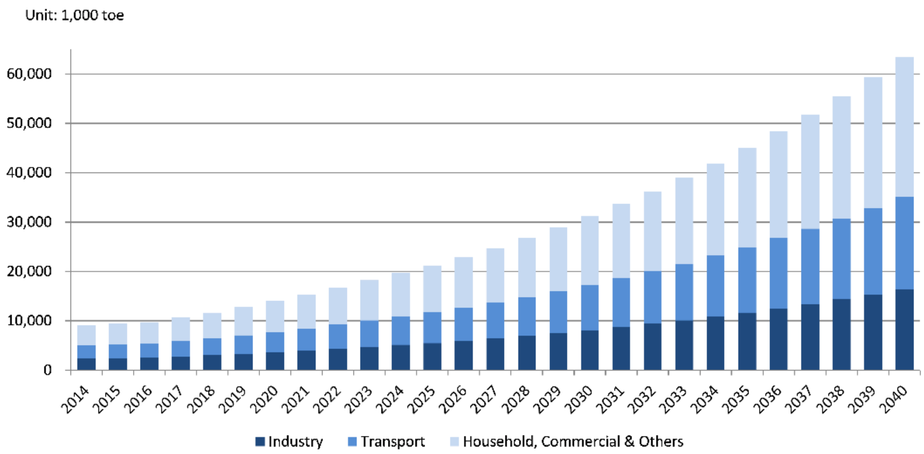
	2016	2017	2018	2019	2020	2021	2022
GDP, nominal	85,222.0	93,262.9	102,243.6	112,091.0	122,781.0	134,317.4	146,653.9
	2023	2024	2025	2026	2027	2028	2029
GDP, nominal	159,655.5	172,951.3	185,954.5	200,475.7	216,847.5	234,434.1	253,223.7
	2030	2031	2032	2033	2034	2035	2036
GDP, nominal	273,382.5	295,032.9	317,599.2	341,668.8	367,314.8	394,662.4	423,784.7
	2037	2038	2039	2040			
GDP, nominal	453,986.9	486,026.1	519,994.8	555976.4			

(Source: Oxford Economics)



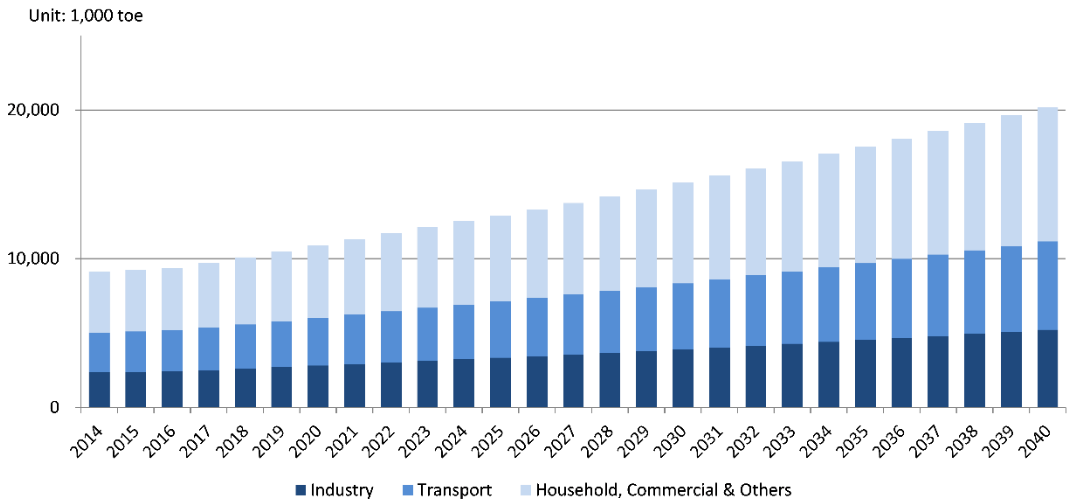
(Source: JICA Survey Team)

Figure 4-11 Forecast of primary energy demand



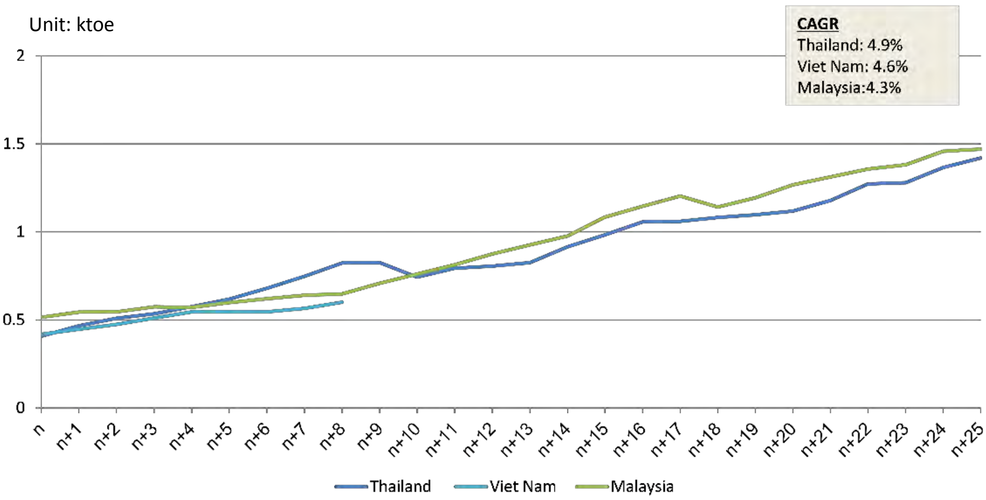
(Source: JICA Survey Team)

Figure 4-12 Forecast of primary energy demand in "GDP Scenario"



(Source: JICA Survey Team)

Figure 4-13 Forecast of primary energy demand in "GDP Elasticity Scenario"



(Source: JICA Survey Team)

Figure 4-14 Demand trends of primary energy demand in Thailand, Malaysia and Vietnam

It is important in the forecasting of energy demand in the medium and long term using the scenario planning method to understand beforehand the uncertainties which cannot be controlled by the Sri Lankan government or CEB.

The volatility of fossil fuel prices and securing of a stable supply, fluctuation in the amount of demand, change in the demand structure, the transition to a low-carbon society, and so on are the uncertainties in this issue. Fossil fuel prices will be mentioned in Chapter 4.2.3. Energy conservation and demand side management are examples of influence factors changing the amount of demand and the demand structure. Sri Lanka Sustainable Energy Authority has raised the target for energy conservation in 2020 to improve the efficiency of air-conditioners, lights and motors in the report "Forecast of Energy Saving Potential and Cost 2014-2039". However, consumers perform energy conservation rather than CEB and the authorities, and this is also considered an uncertainty.

The transition to a low-carbon society is a global movement and considered to be a big impact in the future, since the Paris Agreement was adopted at COP21 in 2015 and ratified in 2016. Sri Lanka submitted National Determined Contributions to UNFCC, with a greenhouse gas emission reduction of 4% in energy-intensive sectors alone and 20% as a conditional target, plus a 3% reduction in non-energy-intensive sectors alone and 10% as an unconditional target. Furthermore, sector understanding was agreed and announced for export credits for coal-fired power plants at the Working Party on Export Credits and Credit Guarantees of OECD in November 2015. Although redemption schedules and scales are restricted, as a blend country in IDA Eligibility, sub-critical of less than 300MW, and super critical of less than 500MW are financed to Sri Lanka, but this would become uncertain after the tightening of regulations before July of 2019. European and American financial institutions are divesting from fossil fuel assets, and this could be an uncertainty too.

Categorizing the uncertainty by the predictability and size of impact, and discussing this in multiple scenarios, is important. It is not essential to choose the best scenario, but to look into the robustness of the uncertainty.

4.2.3 Available amount of fossil fuel imports and power generation

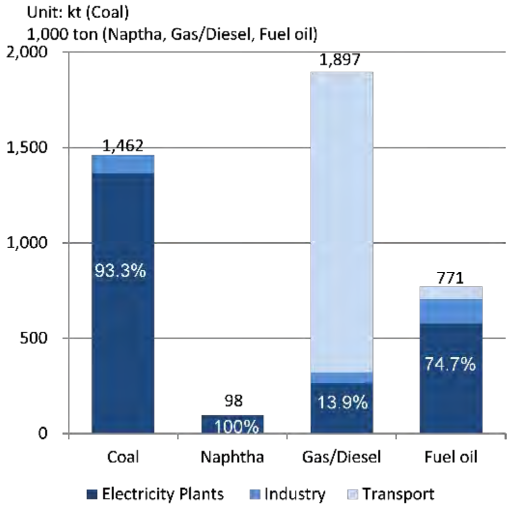
Sri Lanka relies on imports to meet demand for oil and coal in regard to fossil fuel. As for natural gas, as described in section 4.3 Possibility of implementing domestic natural gas and LNG, implementation of the Mannar offshore gas field development and LNG are presently being studied. In studying usable volumes for electricity, it is necessary to consider the overall demand volume inclusive of the Industry and Transport sector, maintenance of import ports and infrastructure restrictions such as petroleum refinery facilities.

However, while the possibility of introducing LNG has been studied since the beginning of the 2000s, infrastructure such as LNG imports, storage and re-gasification facilities have not been established. In June 2016, the Sri Lankan government withdrew a plan to build a coal-fired power plant which was under way in collaboration between National Thermal Power Corporation (NTPC), India and CEB, and proposed the possibility of an LNG thermal power plant. According to a newspaper article, a British company, an Indian company and two US companies submitted natural gas infrastructure investment plans to the Board of Investment (BOI). A recent LNG implementation possibility study[8] indicates that Colombo North Port is ranked as the ideal candidate location for LNG terminal construction, in view of combined cycle thermal power generation refurbishment and its intended purpose with regard to the Industry and Transport sector. Considering the LNG demand volume in Sri Lanka, and the cost and term of an LNG terminal, a Floating Storage and Re-gasification Unit (FSRU) is proposed for Colombo North Port LNG. Selection of the style of the LNG receiving base is discussed from a general viewpoint in 4.3.2, described later. From the perspective of technology, economic efficiency and environmental and social considerations, Kerawalapitiya is a strong candidate for a new LNG gas thermal power plant location. According to the above possibility study, as well as a study by the World Bank, a relatively high carbon price has been set. Despite this there is a challenge in accurately reflecting the LNG price wave, and photovoltaic application cannot by itself absorb the construction cost of an LNG terminal. It is necessary to clarify and prioritize the allocated generation cost of an LNG terminal, a diversified energy sector mix and criteria for electric sector low carbonization, as well as coordination with the Industry and Transport sector, and the decision making process is believed to be beyond CEB and the Ministry of Power and Renewable Energy only.

Since the Sustainable Energy Authority (SEA) does not indicate fossil fuel amount use by purpose, the data shown below is based on IEA Energy Statistics and makes reference to the current consumption

[8] "Energy Diversification Enhancement Project Phase II Feasibility Study for Introducing LNG to Sri Lanka", Oriental Consultants Co., Ltd. (OC), Tokyo Electric Power Services Co., Ltd. (TEPSCO), Consulting Engineers and Architects Associated (Pvt.) Ltd. (CEAA)

volume, conversion, and possibility of usage for electric purposes by 4 sectors. 93.3% of coal and 74.7% of heavy oil is used for power generation. The amount used for power generation with gas and diesel fuel is 13.9%. The main user of gas and diesel fuel is the Transport sector. It is presumed that there is a limited possibility of conflict in securing fossil fuels with the so-called high energy consuming heavy industry, considering that the main Sri Lankan domestic industries are agriculture, services, and light industries such as the sewing and assembly industry.



(Source: IEA[9])

Figure 4-15 Fossil fuel consumption by sector (2014)

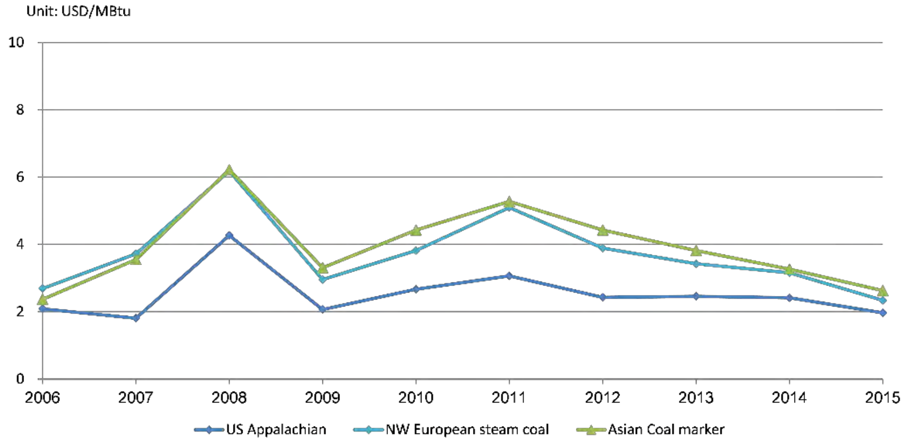
4.2.4 Price forecasts for various types of fuel

While price forecasts for coal, petroleum, natural gas etc. are an important factor in drawing up an electricity master plan, as described in 4.2.2 Future demand forecast, fuel price changes are an uncertainty for the Sri Lankan government and CEB. The following describes the trends of recent price changes and delivery prices at power plants based on IEA (International Energy Agency) and World Bank forecasts.

The prices for coal, petroleum and natural gas have all been on a downward trend since 2011-2012, except for the LNG price for Japan; however, in 2016, power generation prices in the Asian market

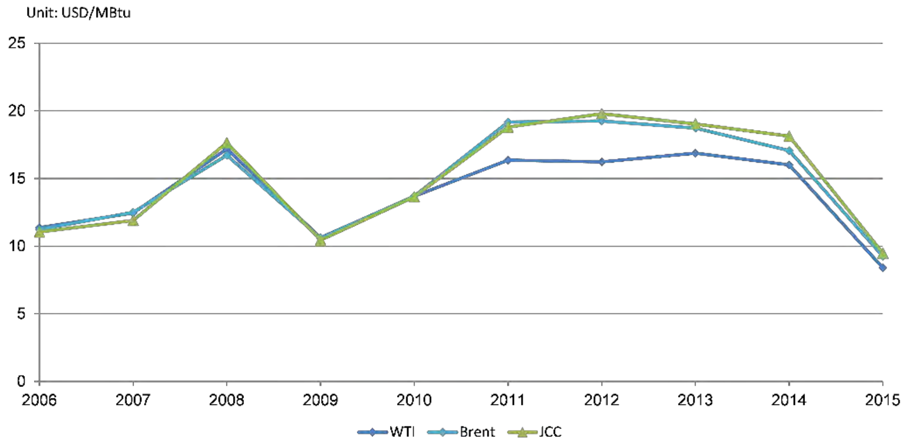
[9] Since consumption of petroleum and petroleum products by sector is not made public by the Sustainable Energy Authority (SEA), IEA data is referred to.

started to soar. In November 2016, the spot price reached a high for the first time in about a year for LNG, and in 4 and a half years for coal. Petroleum prices are on the rise as well.



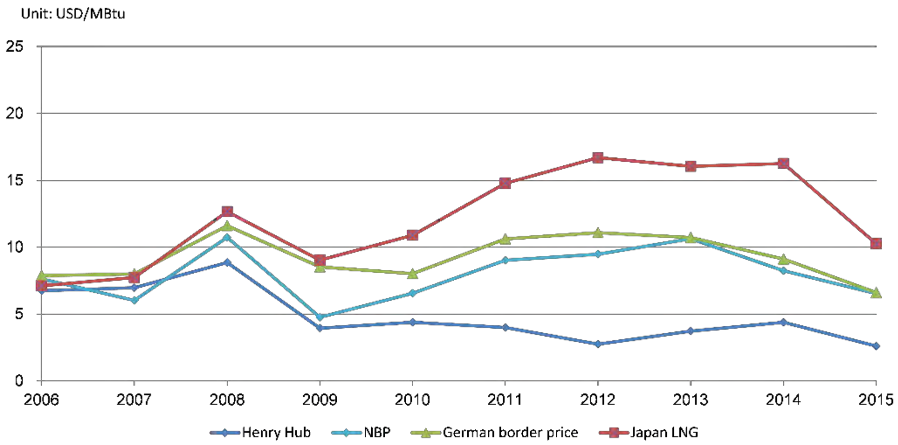
(Source: IEA)

Figure 4-16 Trends of coal prices



(Source: IEA)

Figure 4-17 Trends of petroleum prices



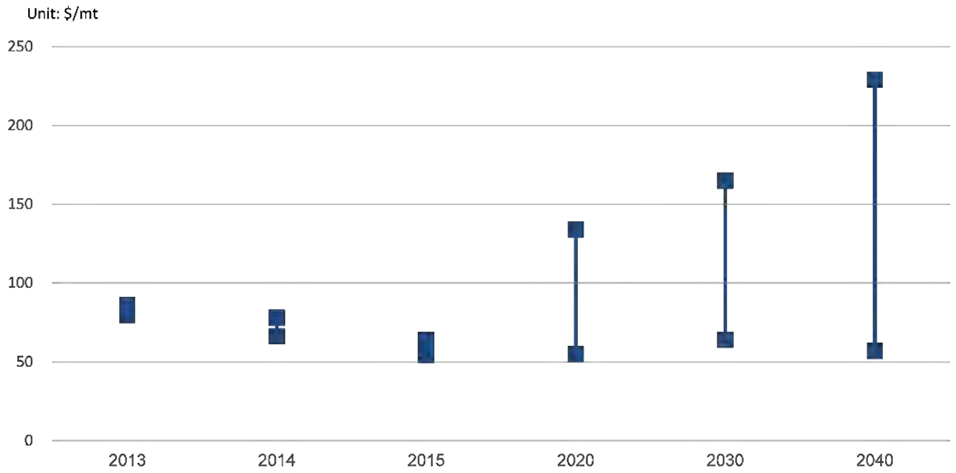
(Source: IEA)

Figure 4-18 Trends of natural gas prices

Future price forecasting is not easy and, in theory, it is established by “a general equilibrium model in which equations for determining demand and equations for determining supply are prepared and supply and demand are balanced through price”, and the simulation of changes in price under different assumptions; however, model construction has a high load. Furthermore, it is not always possible to forecast price with a model formula. A model formula is designed to support a forecast with regard to scenarios of uncertainty, which eventually leads to a pricing forecast. In this electricity master plan, IEA World Energy Outlook[10] and the World Bank Commodity Markets Outlook[11] are referred to. Other than these, price scenarios are indicated or made available by the Energy Information Administration as well as by private research companies. What is common in all these functions is that it takes more than 1 year to formulate a long-term outlook and therefore there is a time lag. In addition, depending on actual demand or factor changes, which are influencers of demand, different forecast prices are calculated even if the prerequisite compound is the same.

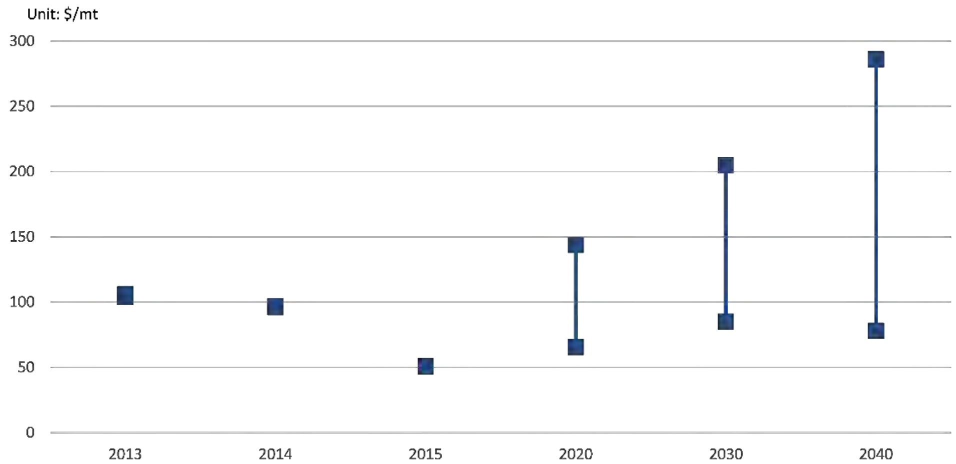
Since fuel prices are an uncertainty which neither the Sri Lankan government nor CEB are able to control, they capture the predicted value of prices with width. Shown below are the widths of forecast prices by IEA World Energy Outlook and the World Bank Commodity Markets Outlook from 2013 through 2016. The forecast for coal by the World Bank for 2020 indicates that 54.8 USD/mt is the minimum, while that of IEA World Energy Outlook 2013 under the current policy scenario indicates that 134.0 USD/mt is the highest. The forecast by IEA World Energy Outlook 2016 under the 450 scenario for 2040 indicates that 57.0 USD/mt is the minimum, while that of IEA World Energy Outlook 2014 under the current policy scenario[12] indicates that 229.0 USD/mt is the highest. The forecast for petroleum by the World Bank for 2020 indicates that 65.6 USD/barrel is the minimum, while that of IEA World Energy Outlook 2013 under the current policy scenario indicates that 144.0 USD/barrel is the highest. The forecast by IEA World Energy Outlook 2016 under the 450 scenario for 2040 indicates that 78 USD/barrel is the minimum, while that of IEA World Energy Outlook 2014 under the current policy scenario indicates that 286 USD/barrel is the highest. The forecast on natural gas for Europe, the US and LNG for Japan is indicated by the IEA and the World Bank, and LNG for Japan is referred to here, having similarities in tanker transporting. The forecast by the World Bank for 2020 indicates that 8.1 USD/Mbtu is the minimum, while that of IEA World Energy Outlook 2013 under the current policy scenario indicates that 17.7 USD/Mbtu is the highest. The forecast by IEA World Energy Outlook 2016 under the 450 scenario for 2040 indicates that 10.9 USD/Mbtu is the minimum, while IEA World Energy Outlook 2014 under the current policy scenario indicates that 31.9USD/ Mbtu is the highest. Even with the same price forecasting model and scenario parameters, forecast prices differ by publication year, which is due to economic growth forecast changes influencing energy demand, transition to a low carbon society and technical progress in shale gas and petroleum. In addition, since Sri Lanka relies on imports for its primary energy, transportation costs have to be considered in the sales price at electricity generation plants. Transportation costs are influenced by the supply and demand balance between reserved ships and freight space, crude oil price changes and foreign currency etc.

[10] The predicted values in IEA World Energy Outlook are for 2020, 2030 and 2040.
[11] The price forecast in the World Bank Commodity Markets Outlook is the predicted value by 2025.
[12] Current Policy Scenario is recognized as if benchmarking other scenarios; therefore, the highest price will be lower than this figure.



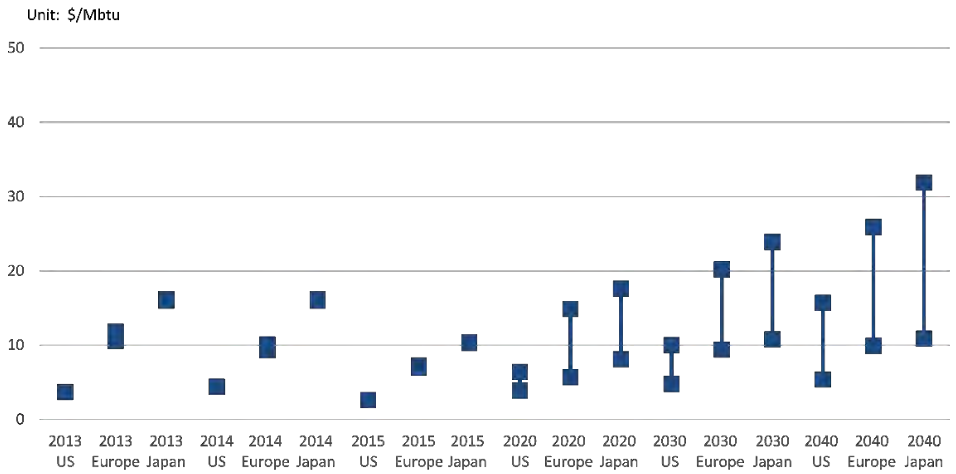
(Source: IEA, and WB)

Figure 4-19 Forecast of coal price



(Source: IEA, and WB)

Figure 4-20 Forecast of petroleum price



(Source: IEA, and WB)

Figure 4-21 Forecast of natural gas price

4.2.5 Fuel Price Forecast in WEO2016

The IEA announced the fuel price forecast until 2040 in WEO2016. Based on this forecast, future fuel prices in Sri Lanka are predicted.

(1) Forecasted prices for various fuels

WEO2016 forecasts fuel prices for three scenarios. The forecasted values are shown below.

Table 4-10 Forecasted Prices for various Fuels in WEO2016

	2015	New Policies Scenario			Current Policies Scenario			450 Scenario		
		2020	2030	2040	2020	2030	2040	2020	2030	2040
Crude oil (USD/barrel)	51	79	111	124	82	127	146	73	85	78
Natural gas (USD/MBtu)	10.3	9.6	11.9	12.4	9.9	13.0	14.4	9.0	10.8	10.9
Steam coal (USD/tonne)	72	78	86	89	79	92	98	73	72	67

Natural gas: Japan import price, Steam coal: for Coastal China (Source: WEO2016, IEA)

New Policies Scenario	Voluntary emissions regulations are implemented in each country (central scenario: temperature rise 3.5 °C)
Current Policies Scenario	Do not incorporate large changes (temperature rise 6 °C)
450 Scenario	Keep the atmospheric greenhouse gas concentration to 450 ppm to keep the temperature rise in 2100 less than 2 °C compared with the industrial revolution.

(2) Future forecasts for various fuels in Sri Lanka

Based on the increase rate in the price forecast of the above-mentioned "New Policies Scenario", various fuel prices in 2040 are calculated as follows. The LNG price is calculated based on the above forecasted price. (The cost of handling LNG varies depending on the amount handled, so it is calculated separately as a fixed cost.)

Table 4-11 Fuel Costs for various Power Sources

	Fuel price			Conversion price (USC/Mcal)	
	2015	2040		2015	2040
Auto diesel	124.20	301.98	USD/bbl	8.856	21.533
FO (3%S)	100.20	243.62	USD/bbl	6.509	15.825
FO (2%S)	104.40	253.84	USD/bbl	6.782	16.489
Residual oil	95.20	231.47	USD/bbl	6.184	15.036
Naphtha (local)	93.50	227.33	USD/bbl	7.112	17.291
Naphtha special	108.90	264.78	USD/bbl	8.283	20.139
LNG	--	12.40	USD/MBtu	--	4.920
Gas	--	14.04	USD/MBtu	--	5.571
Coal Puttalam	97.86	120.97	USD/tonne	1.553	1.920
Coal New	89.39	110.50	USD/tonne	1.515	1.873
Coal SC	97.10	120.03	USD/tonne	1.541	1.905

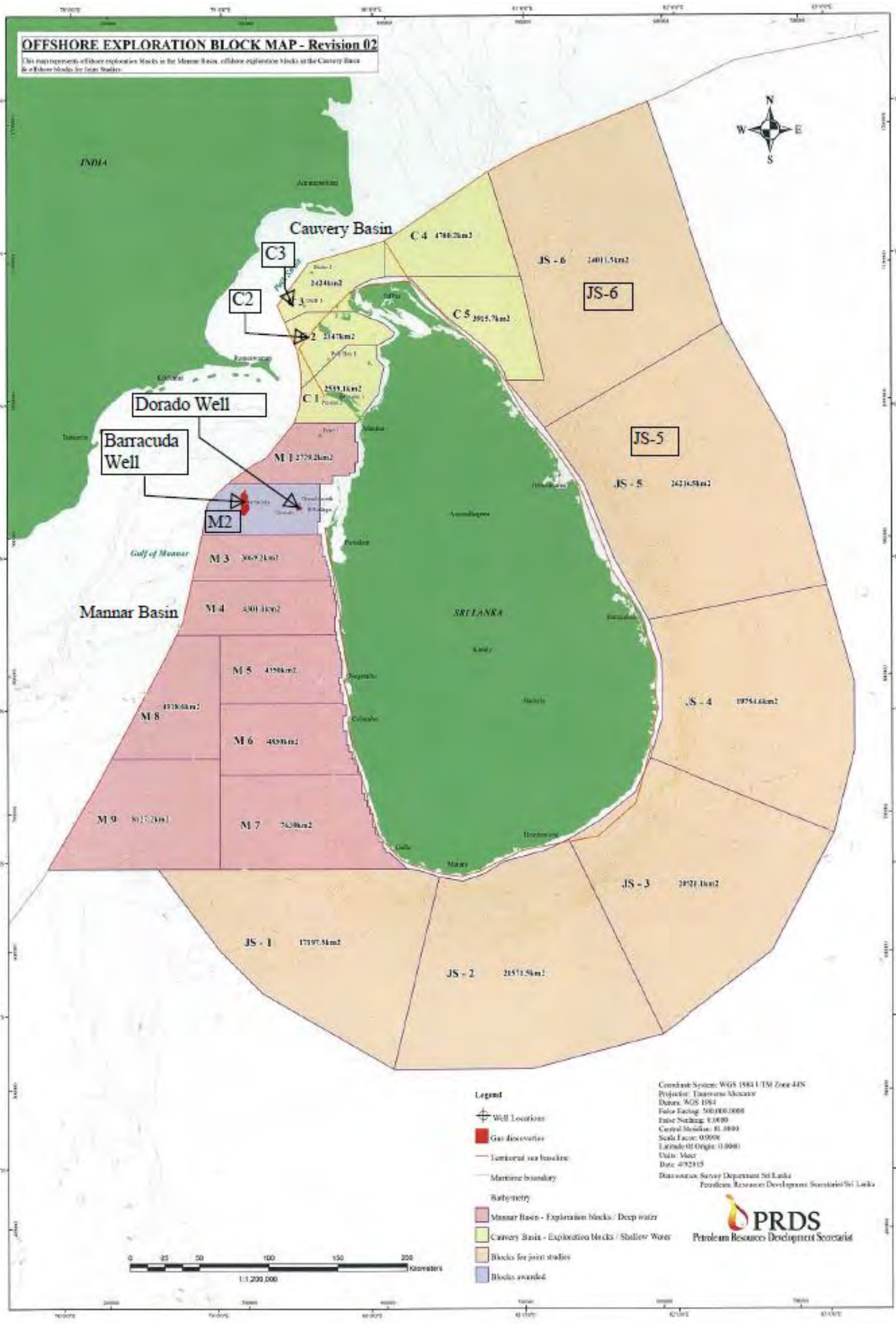
(Source: 2015 prices are derived from Revised LTGEP 2015-2034)

As is apparent from the comparison of conversion prices, coal is the cheapest, LNG (exclusive of domestic fuel handling costs) is more than twice the price of coal, and the price of petroleum is more than eight times that of coal.

4.3 Possibility of introducing domestic natural gas and LNG

4.3.1 Domestic natural gas

With regard to the development manner of offshore natural gas fields, which are expected to serve as domestic energy resources, possible reserves, daily average production, development cost (or fuel production cost), etc. are investigated and the possibility of supply to gas fired power plants is considered. In Sri Lanka, two natural gas fields (Barracuda and Dorado) were discovered in offshore block M2 (ex-Cairn block) of the Mannar basin in 2012 (see Figure 4-22).



(Source: PRDS)

Figure 4-22 Positions of the gas fields

According to PRDS:
"PRDS has already announced an international marketing campaign to select a suitable operator to appraise and develop the two gas discoveries and prospects in the offshore Block M2 (ex-Cairn block) in Mannar Basin. It is hoped that a new license for block M2 will be awarded by the end of 2017.
4-6 test wells are expected to be drilled by 2018 and this may also lead to the drilling of more test wells in 2018/2019 depending on the success of the prospect analysis in the exploration program. In support of commercialization of these identified reserves, PRDS has already taken the initiative to recruit an NG (Natural Gas) consultant and is in the process of preparing an NG policy for Sri Lanka.
The government has already issued a conditional award to Bonavista (bidder - 2013 bid round) to find a suitable business partner and enter into a production sharing agreement for the two blocks C2 and C3 in the Cauvery Basin. If this effort is successful it would lead to a few more test wells being drilled in these two blocks as well.
In the meantime, PRDS is preparing to conduct 2D and 3D seismic surveys in early 2017 in some identified locations off the east and west coasts through a globally reputed seismic company. An airborne Gravity/Magnetic survey is also planned to explore the prospects of the offshore acreage demarcated for oil and gas exploration. All these expensive surveys will be done on a multi-client basis at no cost to the government. PRDS expects to make this data available for the next planned international licensing round tentatively scheduled for Q4 2017 for the remaining blocks of the Mannar and Cauvery Basins.
In addition, PRDS signed a joint Study agreement with an international oil company, Total (of France), in early 2016 and they have already selected a seismic contractor to explore blocks JS5 & JS6 off the east coast."
In this way, comprehensive preparation is underway for domestic natural gas development.

(1) Recoverable Gas Reserves

Recoverable reserves that are currently confirmed are 300 bcf at Dorado gas field. [1]
It is estimated that the combined reserves of the two gas fields at Barracuda and Dorado are about 2 TCF (about 5.7×10^{10} m^3).[2]
In Sri Lanka, further reserves are expected from the prospecting survey that is planned for the future; this will include Mannar basin and Cauvery basin.

(2) Daily average production

At present, development of natural gas with a daily average production of 70 mscfd (about 0.5 mtpa) [1] is planned in the Dorado gas field. The currently confirmed recoverable reserves of the Dorado gas field would be about 10 years at this average daily production.
The average daily production amount needs to be finally decided according to the future power development plan and natural gas demand other than electric power.

(3) Fuel costs

Fuel supply costs (including transportation costs) considering gas field development costs are estimated by PRDS as follows[13].
・11.5 USD/MMBTU (excluding Royalty, Profit and Tax)
・16.5 USD/MMBTU (including Royalty, Profit and Tax)

(4) Possibility of supply for gas-fired power

The amount of natural gas (300 bcf) in the Dorado gas field covers about 35 years' supply when it is used only for a 300MW CCGT power plant (equipment utilization rate: 50%, thermal efficiency: 50%, Gross calorific value: 13,000kcal/kg).

[1] [Revised LGEP2015-2034(CEB)] -4.3.4-(ⅳ)

Currently, it is estimated that the combined reserves of the two gas fields at Barracuda and Dorado are about 2 TCF (about 5.7 $\times 10^{10}$ m^3).
These reserves will cover 8 units (2,400MW) of the 300MW CCGT power plant (equipment utilization rate: 50%, thermal efficiency: 50%), assuming that the power plant's service life is 30 years. If the accuracy of the estimate for these reserves is confirmed, it is expected that the use of domestic natural gas for gas-fired power generation is fully possible.
In terms of price competitiveness with other fuels, if it is developed for use in city gas, such as for civilian or industrial use other than thermal power generation, the discovery of new gas fields in the future will lead to a reduction in the cost of fuel, and it is expected that the availability for thermal power generation will be even greater.
In order to formulate the introduction plan for imported LNG which is currently being studied, an accurate investigation of the reserves of domestically produced gas fields is awaited.

4.3.2 Possibility of introducing LNG

As mentioned in section 4.3.1, accurate recoverable reserves have not been confirmed for domestically produced natural gas at the present time, except for the Dorado gas field. Therefore, if the amount of gas reserves in the domestic gas fields is smaller than the gas supply required for the gas thermal power generation amount in the power development plan, the shortfall will depend on import LNG. Conversely, if domestically produced natural gas production is larger than necessary for gas thermal power generation, imported LNG may be unnecessary.
However, the government of Sri Lanka wants to set up a gas-fired power plant with a small burden on the environment at an early stage in order to mitigate the tight power supply and demand.
Here, we evaluate the fuel supply cost considering the improvement of peripheral infrastructure such as an LNG terminal (importing port facilities, storage facilities) and pipeline, and evaluate the possibility of introducing imported LNG to thermal power plants.

(1) LNG import port facilities

(a) Candidate sites:
At the moment, Colombo North Port[14] is scheduled as the best candidate for an LNG import terminal. Kerawalapitiya[3] is also planned as the optimum construction site for a new gas-fired power plant using LNG as fuel, taking into consideration technical, economic, social and environmental aspects.
These candidate sites are considered reasonable locations at a reasonable distance for constructing a fuel transport gas pipeline network to the power plant.

(b) LNG import terminal:
For LNG import terminals, land type and floating type (Floating Storage and Regasification Unit (FSRU)) are generally considered.
The following table shows a general comparison of land type and floating type (FSRU) LNG terminals (based on land-type LNG terminal).

[14] Energy diversification enhancement by introducing Liquefied Natural Gas operated power generation option in Sri Lanka. – Phase IIA

Table 4-12 Comparison of land type and floating type (FSRU) LNG Terminals

Item	Land type LNG terminal	Floating type (FSRU) LNG terminal
Construction cost	Base	Lower
Construction/procurement period	Base (4~5 years)	Shorter (1~3 years)
Environmental impact	Base	Lower
Influence of weather and sea conditions	No impact	Influence of waves
Move/Remove	Difficult	Easy
Operating cost	Base	Comparatively high
Facility expandability	Relatively easy High degree of freedom	Number of ships Low degree of freedom

(Source: JICA Survey Team)

As shown in the above table, the FSRU type is superior to the land type in the construction cost and period, and movement and removal easiness. However, there are disadvantages, such as poor expandability of facilities, higher operation costs, and operation being affected by meteorological and oceanic conditions. Therefore, the FSRU type is effective when LNG is used in the short term/medium term or when it is desired to introduce LNG at an early stage. If LNG is used for a long period or permanently, land type is considered to be advantageous.
The final judgment should be made according to the required amount, required time and procurement period for LNG.

(c) Capacity of facilities:
The necessary capacity of LNG terminal facilities is estimated from the power development plan in "Revised LGEP 2015-2034".
Table 4-10 shows the trends in the annual LNG consumption of gas-fired thermal power plants (CCGT) in the Power Development Plan (Revised Base Case - 2015) in "Revised LGEP 2015-2034 (CEB)".
Here, the calculation conditions for LNG consumption are assumed as follows.
· Thermal efficiency of LNG power generation equipment: 50%
· LNG calorific value: 13,000 kcal/kg

Table 4-13 Trends in LNG consumption of gas-fired power generation facilities in the Power Development Plan (Revised Base Case - 2015)

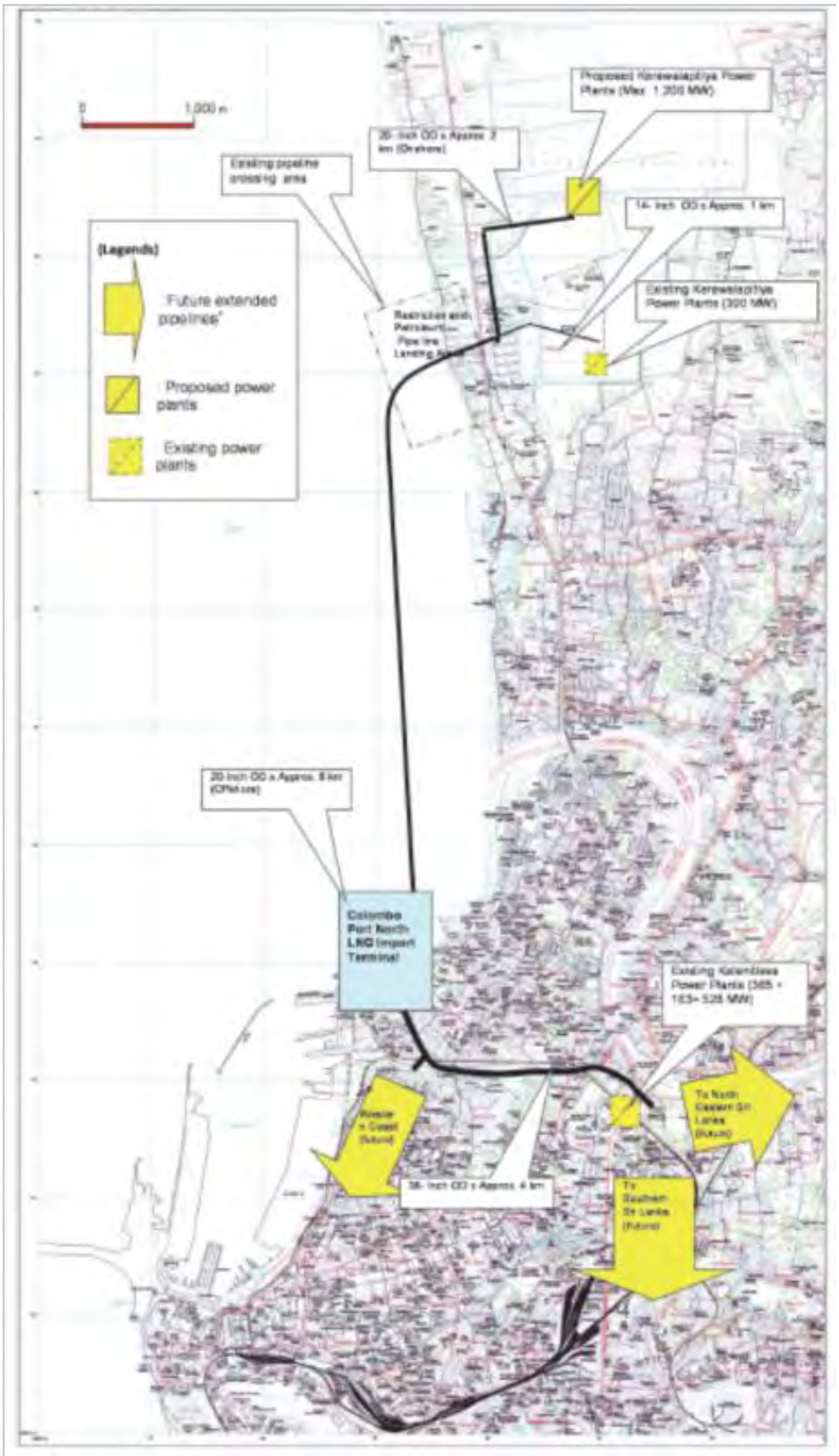
Year	2019	2020	2021	2022	2023	2024	2025	2026
Annual power generation amount (GWh)	885	2,434	2,145	2,073	2,418	2,188	2,627	3,002
LNG consumption (MMBTU/y)	6.04E+0.6	1.66E+07	1.46E+07	1.41E+07	1.65E+07	1.49E+07	1.79E+07	2.05E+07
LNG consumption (MTPA)	0.12	0.32	0.28	0.27	0.32	0.29	0.35	0.40
Year	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Annual power generation amount (GWh)	3,370	3,101	3,567	3,303	3,112	2,930	3,015	4,070
LNG consumption (MMBTU/y)	2.30E+07	2.12E+07	2.43E+07	2.25E+07	2.12E+07	2.00E+07	2.06E+07	2.78E+07
LNG consumption (MTPA)	0.45	0.41	0.47	0.44	0.41	0.39	0.40	0.54

(Source: Revised LTGEP 2015-2034 (CEB); Ad 5: Energy Balance for the Revised Base Case - 2015 is used)

From Table 4-13, annual LNG consumption in the case of "Revised Base Case - 2015" is approximately 0.3 to 0.5 MTPA from the minimum value of 0.12 MTPA in 2019, which is the LNG introduction year, to the maximum value of 0.54 MTPA in 2034. The facility utilization rate is considered to be about 30 to 50%.
Therefore, considering only use for power generation plants, 1 MTPA is deemed appropriate for the capacity of LNG terminal facilities considering the margin.

(2) Development of peripheral infrastructure such as pipelines

In order to use natural gas as a fuel for a gas-fired power plant, it is necessary to develop infrastructure such as a pipeline for supplying fuel from the LNG terminal to the thermal power plant.
If the LNG terminal is built at the presently-proposed candidate of Colombo North Port, the development of a pipeline (Underwater piping: about 6 km, Onshore piping: about 3 km) to supply natural gas to the existing gas-fired power plant (converted to NG) and the currently planned new gas-fired power plant in Kerawalapitiya is necessary. In addition, it is necessary to develop an Onshore pipeline (about 4 km) to the existing power plant (converted to NG) located in Kelanitissa (see Figure 4-23).
The distance of these pipelines is considered to be a reasonable length for the transport distance of natural gas.



(Source: Energy Diversification Enhancement Project Phase IIA Feasibility Study for Introducing LNG to Sri Lanka - Volume III - 3.5.3, Figure 3-40)

Figure 4-23 Natural Gas Transmission Lines to the Proposed and Existing Power Plants

(3) Construction period

The construction period for an LNG terminal is generally considered to be about 4 to 5 years for the land type and about 1 to 3 years for the FSRU type.

(After awarding of EPC contract)

(4) LNG terminal construction cost (including storage facilities, vaporization equipment, transportation equipment)

Table 4-14 shows a comparison of LNG terminal (1 MTPA) costs for land type and FSRU type.

Table 4-14 Construction cost comparison for 1MTPA LNG terminal

Terminal type	CAPEX	OPEX
Land-based terminal	**488 million USD**	1) Fixed O&M cost: 2.1 million USD/year*1) 2) Variable O&M cost: 1.8 million USD/year*2)
FSRU	**170 million USD** (145 million USD for marine structures and port facilities, 13 million USD for natural gas pipelines and 12 million USD for relocation of sewer pipelines)	**50 million USD/year** (approx.)*3)

Notes:
*1) Assumed to be 1% of EPC cost of LNG storage tank and terminal facilities (219 million USD).
*2) Assumed to be 1.8 USD/ton.
*3) A typical rental fee of FSRU for 10-year lease period (Source: Cruacao CNG-LNG Terminal Feasibility Study)
(Source: Energy diversification enhancement by introducing Liquefied Natural Gas operated power generation option in Sri Lanka. – Phase IIA)

(5) Cost of fuel supply to power plant by LNG terminal type

The cost of the fuel supply to a gas-fired power plant is estimated from the LNG terminal construction costs for the land type and FSRU type and the imported LNG cost.

・Conditions for estimating fuel supply cost

1) 1 MTPA LNG terminal Construction cost (MUSD): Use construction costs in Table 4-14
2) O&M cost (MUSD/year): Use O&M costs in Table 4-14
3) Imported LNG price (at Colombo CIF): Use price of 13.69 USD/MMBTU in 2015 (Revised LTGEP2015-2034(CEB))
   (Assuming there is no price fluctuation)
4) Lifetime of LNG terminal: Assumed as 30 years
5) Fuel supply cost is calculated by adding LNG terminal construction cost and O&M cost (30 years' worth) to LNG price. However, interest rates etc. are not considered.
6) For the configuration of gas thermal power generation facilities, the following numbers are used based on "Revised Base Case - 2015" of "Revised LGEP 2015-2034 (CEB)".

・Power generation equipment configuration: Use 2034 case (300MW x 4 units = 1200MW)
・Facility utilization rate: Assumed as 50%
・Power generation efficiency: Assumed as 50%
・LNG calorific value: Assumed as 13,000kcal/kg

The fuel supply cost comparison for each type of LNG terminal is shown in Table 4-15 based on the above conditions.

Table 4-15 Comparison of fuel supply cost to power plant (1200MW)

1. LNG terminal type		Land type	FSRU type
2. Construction Cost for LNG terminal	MUSD	488	170
3. O&M cost for terminal (*1) A typical rental fee for FSRU	MUSD/year	3.9	50(*1)
4. LNG price (CIF)	USD /MMBTU	13.69	13.69
5. Economic life of LNG terminal	years	30	30
6. Total supply amount of heat (Per working years)	MMBTU	1.08E+09	1.08E+09
7. Fuel (natural gas) supply cost	USD /MMBTU	14.25	15.24

Formula : 7. = (2.+ 3. x 5.) / 6. + 4.

(Source: JICA Survey Team)

Fuel supply costs estimated from Table 4-15 are as follows.
・Land type LNG terminal: 14.25 USD/MMBTU
・FSRU type LNG terminal: 15.24 USD/MMBTU
From this result, it is considered that the land type is more advantageous than the FSRU type in terms of fuel cost. In addition, the land type has better capacity expandability and more stable operation compared to the FSRU type. In consideration of possibility for national gas field development, it is anticipated that usage period of LNG will be shorter than 30 years. The FSRU type is advantageous when usage period of LNG is within 7 years.
However, the Sri Lankan government is hoping to realize the operation of gas-fired power plants as early as possible to mitigate the tight power supply and demand, and the FSRU type is considered to be advantageous in terms of the short construction time. In addition, the FSRU type has lower capital investment than the land type, and the usage period of LNG is unclear at the present time. Therefore, the FSRU type has the advantage that the investment risk is low for the Sri Lankan government.

(6) Economic evaluation

(a) Comparison of fuel prices for LNG and coal
When comparing the fuel cost per unit of power generation amount in a coal-fired power generation facility and an LNG thermal power generation facility, LNG is 2.5 to 3 times more expensive than coal, which is economically disadvantageous. (Table 4-11.)
Although it is expensive, the development of a gas-fired power plant accompanying the introduction of LNG has another advantage regarding the environmental impact, such as no SOx and lower NOx and CO_2 emissions compared with a coal-fired power plant.

(b) Comparison of fuel supply price by LNG and domestic gas field
Fuel supply costs including transportation costs from domestic gas fields are estimated as follows. (See 4.3.1 - (3).)
・11.5 USD/MMBTU (excluding Royalty, Profit and Tax)
・16.5 USD/MMBTU (including Royalty, Profit and Tax)
The fuel supply cost for imported LNG (including the added amount of 0.635 USC/Mcal due to LNG terminal construction cost) is calculated as follows. (See Revised LTGEP2015-2034(CEB) and Table 4-11.)
・Price in 2015: 15.29 USD/MMBTU (5.432+0.635=6.067 USC/Mcal)
・Price in 2040: 16.51 USD/MMBTU (5.916+0.635=6.551 USC/Mcal)
The fuel supply cost for domestic gas fields of 16.5 USD/MMBTU (including Royalty, Profit and Tax) is higher than the imported LNG price in 2015, but it is almost equal to the LNG price in 2040.

However, since the fuel supply cost for domestic gas fields is the price including the government's profit etc., price reduction due to the government's energy policy is expected.
Furthermore, if more gas field reserves are confirmed in the future, it is expected that not only the price reduction due to scale merit but also the stable supply of fuel will be advantageous compared with imported LNG.

4.3.3 Use of natural gas (NG) other than for power generation

Natural gas has a high calorific value and has the feature that emissions of carbon dioxide, nitrogen oxides and sulfur oxides at the time of combustion are less than those of petroleum and coal.
For this reason, natural gas is attracting worldwide attention as an environmentally friendly clean energy resource.
Currently, in countries that implement greenhouse gas reduction policies, natural gas is being utilized in a wide range of fields such as the Cogeneration system for buildings and homes (conducting electricity supply, air conditioning, hot water supply, etc. at the same time) and fuel for automobiles.
In Sri Lanka, city gas and automobile fuel are considered the main usage targets other than power generation.

(1) Utilization for city gas

Utilization as a city gas raw material is the most representative application.
Due to the temperate climate of Sri Lanka throughout the year, there is no heating gas demand and the main gas demand is considered to be for the kitchen and hot water supply. And compared with electricity tariff, air-conditioning by city gas seems to be cheaper, there are possibilities such as cogeneration (absorption type chiller) with electric power utilizing city gas and gas cooling engine and cold heat demand. It is also expected that demand will be large in urban areas where the population or large-scale hotels are concentrated locally.

However, the following problems can be considered.
・It is necessary to develop infrastructure, such as gas pipelines from the gas supply source to the supply destination. In particular, improvement of gas pipelines in urban areas such as Colombo is expected to require a long period of time due to the great influence of interference with other infrastructure projects.
・It is necessary to compromise with existing energy markets such as the liquefied petroleum gas (LPG) market.

(2) Use as automobile fuel

Natural gas vehicles emit less amounts of carbon dioxide (CO_2), nitrogen oxides (NOx) and hydrocarbons (HC) than gasoline and diesel vehicles, and black smoke and particulate matter (PM) are hardly discharged. Therefore, it is expected to be widely used as fuel for automobiles in terms of the prevention of global warming and improvement of the atmospheric environment.

However, the following problems can be considered.
・Infrastructure improvement, such as natural gas stands, is necessary.
・Vehicles becomes more expensive than gasoline cars.

In order to realize the utilization of natural gas as city gas or automobile fuel, further investigation and examination in the future is necessary.

(3) Demand Forecasts Other than for Power Generation

As described in (1) and (2) above, demand forecasts for LNG in the consumer sector and transportation sector, other than for electricity generation, in Sri Lanka were not easy to calculate, and attempts were also made to predict them from the LNG demands of other countries with a similar economic environment. However, there are limits in terms of data availability and so on. With this proviso, we predict the demand of LNG in Sri Lanka in 2040 for household and business use in the large Colombo area (Western Province, which includes Colombo and Gampaha prefectures), where the population and economic activities are concentrated.

Nearly 30% of the total population is concentrated in Western Province, with about 1.5 million households (source: Population of Sri Lanka by district, 2012, Department Census and Statistics, Sri Lanka). Similar to this number of households, reference is made to gas sales volume data for 2015 of Saibu Gas, which supplies 1.1 million households in northern Kyushu, Japan.

Table 4-16 Saibu gas sales volumes in 2015

Categories	m^3 (in thousands)
Households	257,496
Business*	536,262
Total	793,758
Wholesale supply	98,735
Total sales volume	892,493

*Business: Commercial, industrial, official, medical use
(Source: Saibu Gas website, http://www.saibugas.co.jp/index.htm)

As shown in Table 4-16, the volume sold to 1.1 million households in 2015 was about 900 million m3. Seibu gas also supplies natural gas stands. Among the sales volume the ratio is low, but sales to natural gas vehicles (transport sector) are included. Although it is difficult to predict the demand for the whole country, about 1,000 million cubic meters is presented as an example reference value for the demand forecast for city gas (home use and business use) and the transportation sector in the large Colombo area.

Demand except generation increases as fuel supply infrastructure grows, and is much smaller than demand for the generation for the time being. For this reason, it is necessary to improve fuel supply facility for generation only without expecting demand except generation. However, when there is demand except generation, it is necessary to develop the demand positively in order to expect generation cost reduction effect by allocating facility investment for fuel supply.

4.4 Renewable Energy

At the United Nations Climate Change Conference, COP21, in Paris, France, the Paris agreement was adopted as a climate agreement by all the nations of the world. The Paris agreement doesn't include obligations for CO_2 reduction, but all countries are to submit national goals and updates, reports and reviews every five years. In consideration of the worldwide movement regarding global warming and the environment, the introduction of renewable energy has been discussed positively in Sri Lanka.
Renewable energy is generally defined as an energy used permanently, such as Hydropower, Windpower, Biomass, Solar, Geothermal power, etc. In this report, Hydropower (less than 10MW), Windpower, Biomass and Solar are described as renewable energy, because these energies are already used and are expected to be used.

In this project, in consideration of promoting indigenous energy which is one of the Sri Lanka's policy, the renewable energy is treated as one of the important power source. It is judged that renewable energy potential is limitation of the development. Development plan of the renewable energy is examined in consideration of power demand and LTGEP in point of view of economy, environment and energy security.

4.4.1 Introduction of Renewable Energy

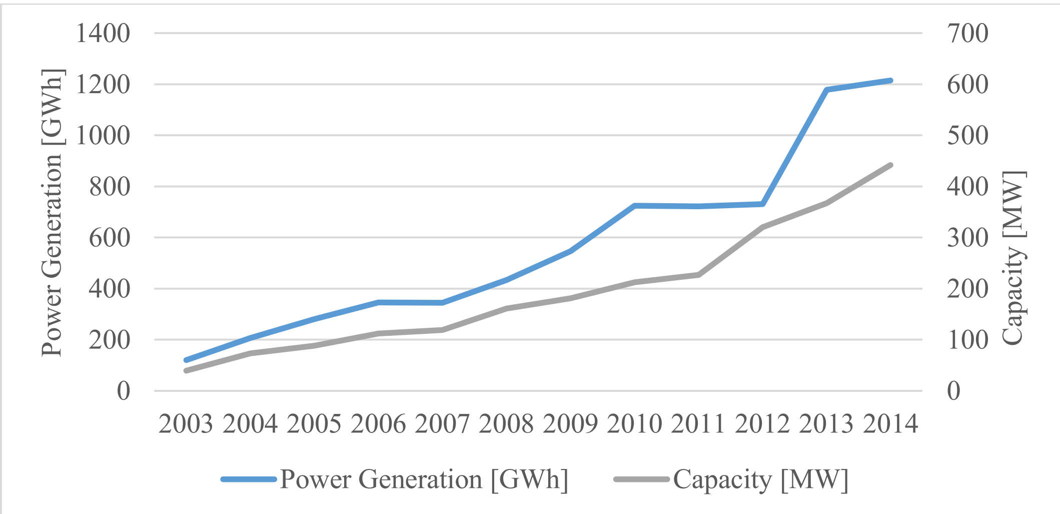
On-grid Renewable Energy in Sri Lanka is shown in Table 4-17. As of February 2017, mini hydro and windpower account for 90% or more of the renewable energy.

Table 4-17 On-grid Renewable Energy in Sri Lanka (as of February 2017)

Category	Mini Hydro	Windpower	Biomass power	Solar	Total
Output	350MW	128MW	24MW	41MW	543MW

(Source: JICA Survey Team)

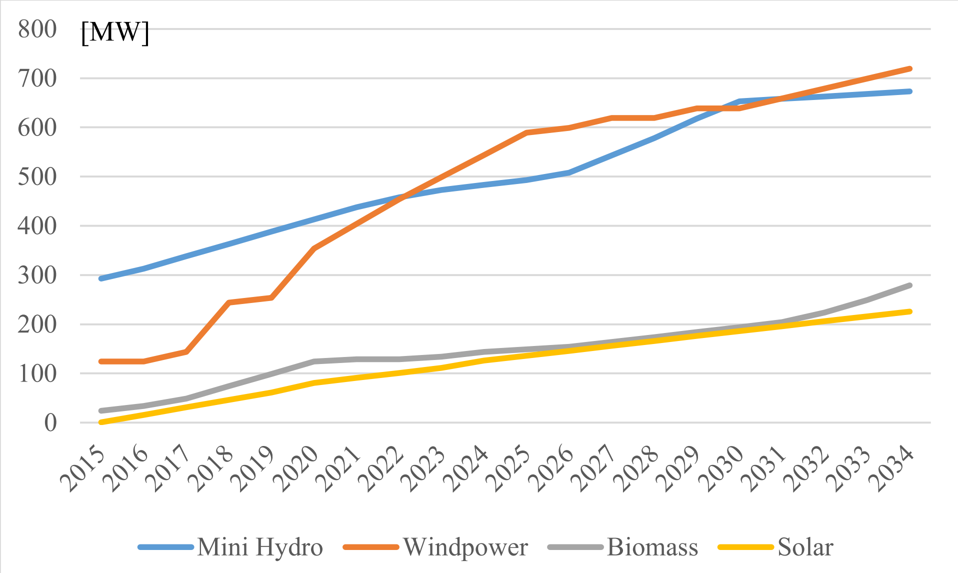
To begin with, CEB played the main role in introducing renewable energy, but a private company including foreign investors is taking on the task of introducing it at present. Introduction data for renewable energy from 2003 to 2014 is shown in Figure 4-24. 39MW of renewable energy had been introduced as of 2003, and the energy was then gradually developed. Though some mini hydros were introduced from 2010 to 2012, the power generation during this period doesn't increase so much due to drought in 2011 and 2012. As of February 2017, on-grid renewable energy accounts for approximately 543MW, which is 14% of all power sources.



(Source: JICA Survey Team)

Figure 4-24 Renewable Energy Introduction Amounts

Introduction targets for renewable energy mentioned in LTGEP 2015-2034 are shown in Figure 4-25. Rates for biomass and solar are lower than that for mini hydro, but all renewable energy is increasing gradually. In particular, windpower development is rapidly increasing and it is expected that it will become almost the same capacity as mini hydro in 2030.



(Source: JICA Survey Team based on LTGEP 2015-2034)

Figure 4-25 Introduction Targets for Renewable Energy

4.4.2 Introduction Policies and Structure for Renewable Energy

The following policies are conducted to introduce renewable energy.

• Sustainable Energy Authority Act

The Sustainable Energy Authority Act, a law related to renewable energy, was enacted in 2007. At the same time, the Sustainable Energy Authority (SEA) was established in order to introduce and supervise renewable energy, and to enhance energy efficiency and reliability. In the Sustainable Energy Authority Act, the role of SEA and development policy for renewable energy are prescribed.

• Non-Conventional Renewable Energy Tariff

The Non-Conventional Renewable Energy Tariff has already been adopted in order to expedite the introduction of renewable energy. The non-conventional renewable energy tariff is described in Table 4-18. This tariff consists of a fixed rate, operation & maintenance cost, and fuel cost. The fixed rate decreases in three tiers as time goes by.

Table 4-18 Non-Conventional Renewable Energy Tariff

(Unit: LKR/kWh)

Technology/Source	Scalable Base O&M Rate (years 1-20)	Scalable Base Fuel Rate (years 1-20)	Non-scalable (fixed rate)		
			Tier 1: Years 1-8	Tier 2: Years 9-15	Tier 3: Years 16-20
Mini-hydro	1.83	None	15.56	5.98	3.40
Mini-hydro-local	1.88	None	15.97	6.14	3.49
Wind	1.30	None	22.05	8.48	4.82
Wind-local	1.33	None	22.60	8.69	4.94
Biomass	1.52	12.25	9.67	3.72	2.11
Biomass, 16th yr onwards	1.90	-	-	-	-
Agro & Industrial waste	1.52	6.13	9.65	3.71	2.11
Agro & Indus., 16th yr onwards	1.90	-	-	-	-
Waste Heat	0.48	None	9.14	3.52	2.00
Escalation rate for year 2013	5.16%	3.44%			

(Source: Renewable Energy Master Plan)

• Oversight Sub-Committee on Power and Renewable Energy of the Parliament of Sri Lanka

As of August 2016, the introduction policy has been examined by the Oversight sub-committee on power and renewable energy of the parliament of Sri Lanka for the following targets.

- Make Sri Lanka an energy self-sufficient nation by 2030
- Increase the share of electricity generation from renewable energy sources to 60% by 2020 and, finally, meet the total demand from renewable and other indigenous energy resources by 2030

4.4.3 Introduction Potential for Renewable Energy

The potential of renewable energy was described in the draft report of the Renewable Energy Master Plan, which is supported by an ADB fund. The potential is shown in Table 4-19. From 4.4.4, the power-wise potential is described.

Table 4-19 Introduction Potential for Renewable Energy

Category	Potential [MW]	Remarks
Mini Hydro	873	Total generation: 3,061GWh
Windpower	5,653	Northern part: 3,070MW
Biomass Power	2,508	Scrub land: 724MW
Solar	6,000	Eastern, Northern, Uva

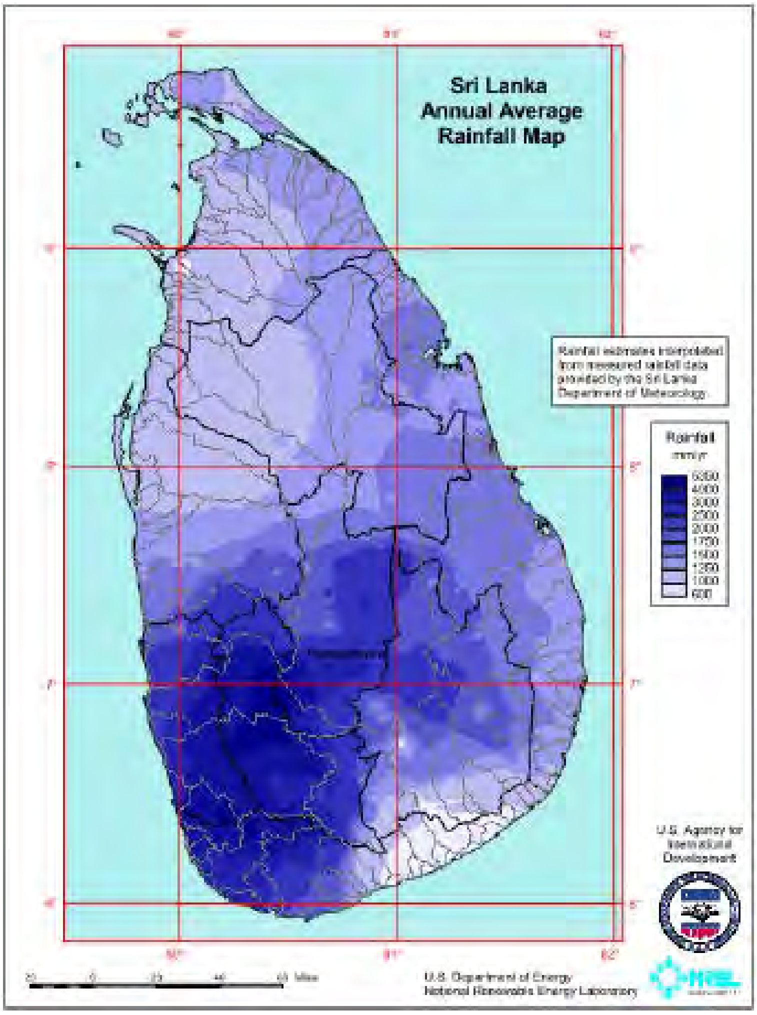
(Source: Renewable Energy Master Plan)

4.4.4 Introduction Potential for Hydropower

Hydropower has been utilized in Sri Lanka since the 1950s and there are many hydropower plants. Hydropower was the main power source before thermal power generation supplanted it in the 2000s. There are flat lands in the northern area and mountains in the center of the southern area in Sri Lanka. Therefore, many hydropower plants are located around Kandy, which is the main city in the southern area. Victoria Hydropower plant (210MW), which is the largest hydropower plant, has started operation and an expansion project has already been planned. A location for additional generation equipment has been secured and part of the civil structure has been completed.

The annual precipitation map for Sri Lanka is shown in Figure 4-26. The climate is tropical and the precipitation fluctuates with the Southwest monsoon and Northeast monsoon. The Southwest monsoon occurs from May to September, and is blocked by the mountains in the central area, leading to a large amount of rainfall in the Southwest area. The Northeast monsoon arises from November to March and leads to rainfall in the Northeast area and a small amount of rainfall in the Southwest. The Wet zone is the area from the mountain area to the Southwest area, and an annual precipitation of 3,000 to 4,000 mm is expected there. Hydropower potential is very high in the Wet zone.

A geographical map of Sri Lanka is shown in Figure 4-27. 2,000m-class mountains are located in the central area, and many rivers run radially from the central highlands to the ocean. Many hydropower plants have already been developed around the mountain area.



(Source: Renewable Energy Master Plan)

Figure 4-26 Annual Precipitation Map of Sri Lanka

(Source: Renewable Energy Master Plan)

Figure 4-27 Geographical Map of Sri Lanka

River-wise potential for Hydropower is shown in Table 4-20. The Mahaweli River is the longest river in Sri Lanka and has already had some hydropower plants. However, there still seems to be great potential for hydropower in this river.

Table 4-20 Potential for Hydropower

River	Capacity [MW]	Generation [GWh]
Kelani	139	487
Kalu	163	571
Gin	24	85
Nilwala	2	9
Walawe	72	253
Kirindi Oya	21	73
Menik	10	35
Kumbukkan Oya	9	31
Gal Oya	5	19
Mahaweli	420	1,473
Maha Oya	5	16
Deduru Oya	2	7
Attanagalu Oya	1	1
Total	873	3,061

(Source: Renewable Energy Master Plan)

4.4.5 Introduction Potential for Windpower

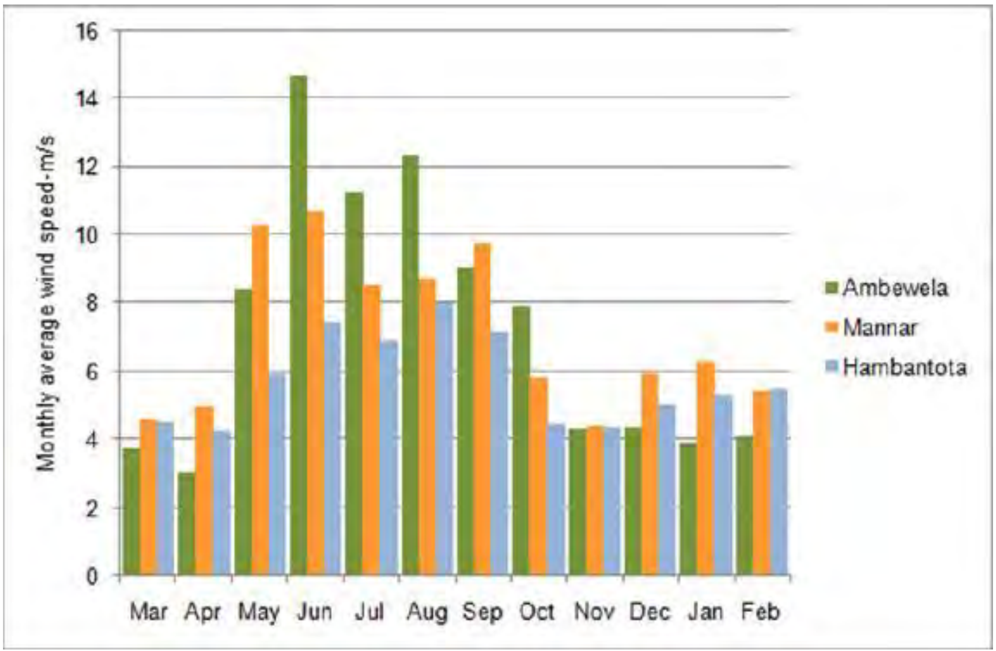
Many windpower projects have been implemented since a pilot windpower project was carried out in 1999. A list of windpower plants in Sri Lanka (as of 2015) is shown in Table 4-21. Many windpower plants have been constructed in the northwest area (Puttalam and Uppudaluwa), where the wind conditions are excellent. In addition, a 100MW class wind farm is planned to be constructed on Mannar Island, located in the northern area. In the future, it is expected that more windpower plants will be constructed in the north and northeast areas.

Table 4-21 List of Windpower Plants

Power plant	Location	Capacity	Commissioning year
Hambantota	Hambantota	3MW	1999
Mampuri-I	Puttalam	10MW (8 x 1.25MW)	2010
Seguwantivu & Vidatamunai	Puttalam	20MW (25 x 0.8MW)	2010
Nirmalapura	Puttalam	10.5MW (7 x 1.5MW)	2011
Uppudaluwa	Uppudaluwa	10.5MW (7 x 1.5MW)	2011
Madurankuliya	Puttalam	12MW (8 x 1.5MW)	2012
Ambewela Aitken Spence	Ambewela	3MW (12 x 0.25MW)	2012
Nala Danavi	Puttalam	4.8MW (6 x 0.8MW)	2014
Pollupalai & Vallimunai	Pachchilaipalli	24MW (16 x 1.5MW)	2014
Mampuri-II, III	Puttalam	21MW (10 x 2.1MW)	-
Pawan Danavi	Puttalam	10.2MW (12 x 0.85MW)	-
Willwind	Bithugalgama	0.85MW (7 x 0.121MW)	-
(Mannar Island)	(Mannar Island)	(100MW)	(2018)

(Source: JICA Survey Team)

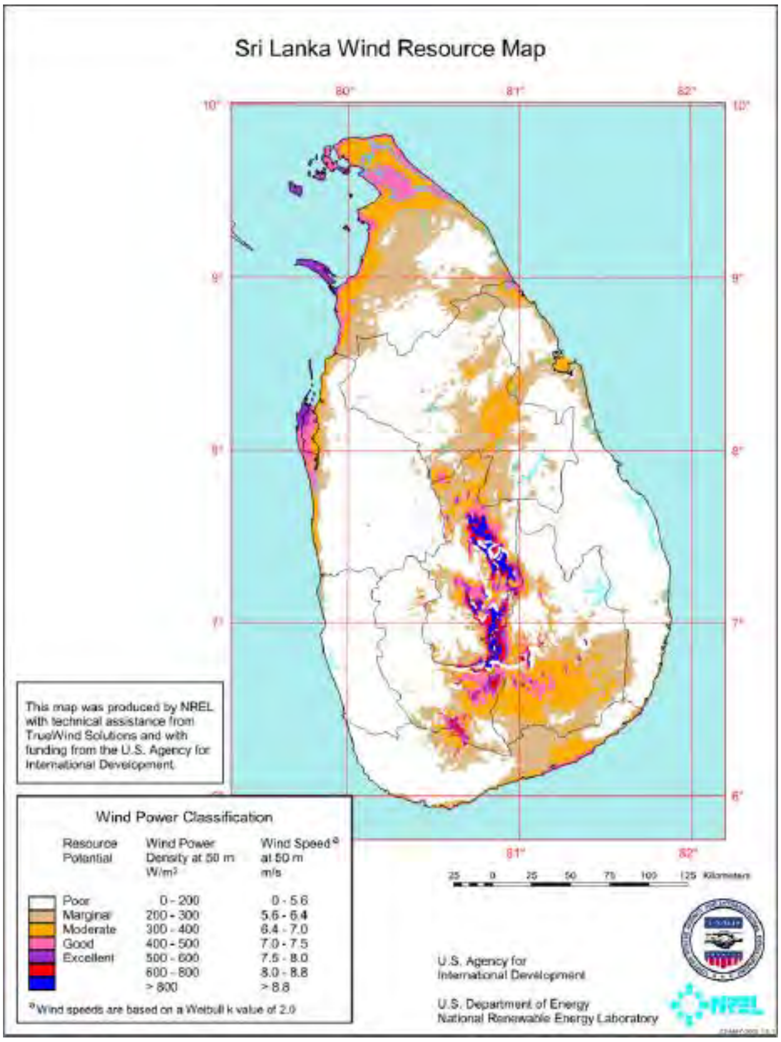
Wind velocity conditions in the northern (Mannar), central (Ambewela) and southern (Hambantota) areas are shown in Figure 4-28. Wind velocity trends are a little different from location to location, but the annual trend is similar. High availability is expected if a suitable place for the windpower is selected. There is abundant wind power from May to September, but there is not much windpower from November to April. Therefore, wind fluctuation for the whole year should be paid attention to in order to determine the optimum introduction amount for windpower.



(Source: Renewable Energy Master Plan)

Figure 4-28 Wind velocity conditions of the northern, central and southern areas

The potential map for windpower is shown in Figure 4-29. There is high potential in the northwest and central areas due to the excellent wind conditions. Many wind farms have already started operation in the northwest area, and availability seems to be approximately 30%. Wind farms have not been developed so much in the central area, which has mountains, due to transport limitations. The northwest coastal area is flat and suitable for wind farm construction because shipping transportation is available.



(Source: Renewable Energy Master Plan)

Figure 4-29 Potential Map for Windpower

In the Renewable Energy Master Plan, potential for windpower is estimated in Table 4-22. The potential in the northern area is approximately 3,000MW, and additional windpower development is expected in the future.

Table 4-22 Potential for Windpower

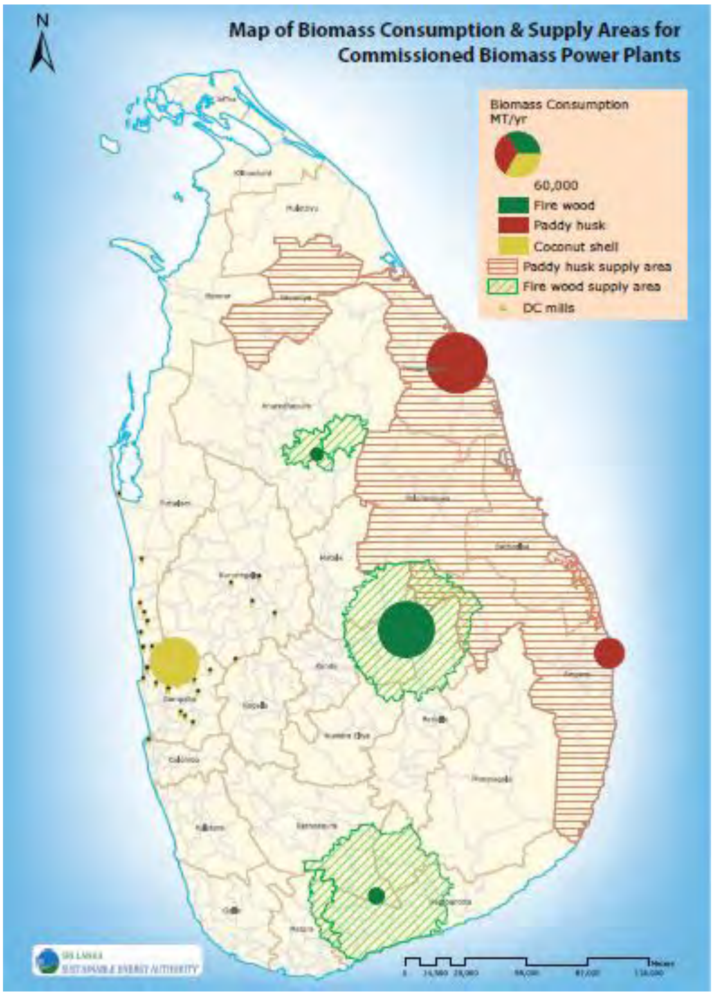
Province	Potential for Windpower [MW]						
	Tea	Chena	Grassland	Scrubland	Sand	Others	Total
Central	447	20	8	312	0	91	878
Eastern	0	3	0	59	0	0	62
North Central	0	0	0	78	0	9	87
North Western	0	10	1	247	90	6	355
Northern	0	20	61	1,614	623	752	3,070
Sabaragamuwa	67	251	19	42	0	8	387
Southern	40	74	0	52	54	6	227
Uva	229	111	8	160	0	80	587
All provinces	783	490	97	2,564	767	952	5,653

(Source: Renewable Energy Master Plan)

At present, a micro-grid pilot project including windpower is being carried out. A 100MW wind farm is scheduled to be constructed in the Mannar islands, and further development is expected.

4.4.6 Introduction Potential for Biomass Power

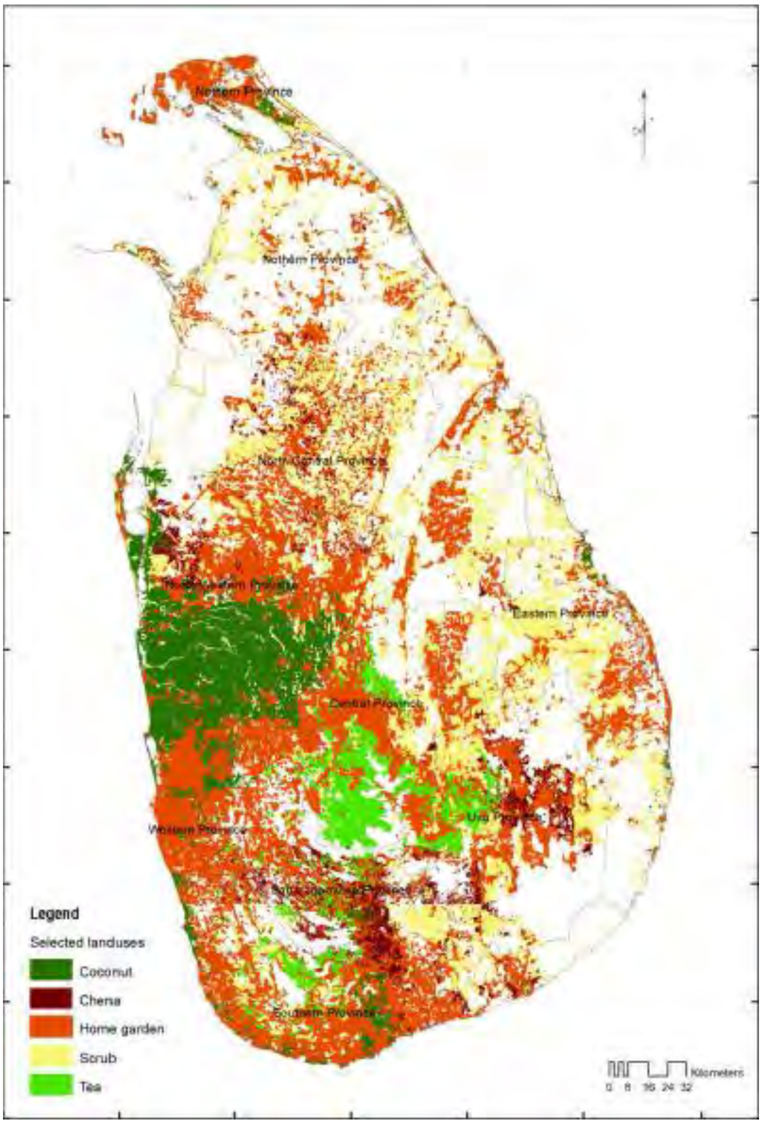
Biomass power, unlike windpower and solar, is not affected by weather changes and can supply stable electricity. Biomass power is attractive in Sri Lanka. The numbers of applicants for dendro and agriculture waste were 88 and 16 respectively from 2007, when SEA was established, to June 2015. Three dendro power plants, two paddy husk power plants and one waste power plant have started operation in Sri Lanka as of 2015. A map of Biomass consumption & supply areas for commissioned biomass power plants is shown in Figure 4-30. Power generation depends on a secured consumption area, but securing continuous fuel should be considered taking into account transportation routes and cost.



(Source: Assessment & Mapping of Biomass Consumption in Sri Lankan Industries)

Figure 4-30 Map of Biomass Consumption & Supply Areas for Commissioned Biomass Power Plants

Firewood, residues, wastes, etc. are kinds of biomass. Some biomass is used for home fuel in Sri Lanka, but the amount for power generation is small. In this chapter, potential for biomass power is described. An energy plantation map is shown in Figure 4-31. Potential for biomass power is diversified all over Sri Lanka, and great potential is located in the southwest area relatively. When it is assumed that 500ha of land should produce 1MW over 1 year, the estimated potential result is shown in Table 4-23. There is approximately 2,400MW of potential for biomass power, and the great majority is Chena, Scrub Land and Home garden.



(Source: Renewable Energy Master Plan)

Figure 4-31 Energy Plantation Map

Table 4-23 Potential for Biomass

[MW]

Province	Chena	Scrubland	Home garden	Coconut	Tea
Central	12	55	79	5	78
Eastern	17	175	48	4	0
North Central	94	148	65	1	0
North Western	63	52	78	180	0
Northern	25	83	55	7	0
Sabaragamuwa	160	14	59	14	18
Southern	44	46	89	21	20
Uva	165	143	81	0	30
Western	15	8	74	41	3
Subtotal	595	724	629	273	148
Total	2369				

(Source: Renewable Energy Master Plan)

It has been considered that Gliricidia sepium can be utilized as biomass energy. Gliricidia sepium is native to South and Central America, and it is said that it entered Southeast Asia in the 1600s by way of the Caribbean and Central Africa. Gliricidia sepium entered Sri Lanka from Western India and was used for sunshades in tea gardens in the 1700s. It is often used for fences in tea and coconut gardens at present, because it has hard branches and remains sturdy in bad weather.

The Sri Lankan government declared Gliricidia sepium the fourth plantation crop other than major plantation crops such as tea, rubber and coconuts. Gliricidia sepium grows naturally all over Sri Lanka and it is often used for sunshades in tea gardens and as fertilizer for nitrogen fixation. Furthermore, its leaves are utilized as feed for cows and goats.

Gliricidia sepium grows rapidly and takes 18 months from planting to reaping. The reaping period is 6-9 months. Therefore, it can be used as biomass energy for biomass generation. However, it is necessary to plant it systematically to secure a certain amount of biomass energy continuously. It is difficult to say that biomass generation with Gliricidia sepium is economical compared to solar generation, the panels for which are cheaper when considering periodic plantation, fuel processing, transportation, etc. It is unwise for SEA and CEB to expand the biomass generation business.

4.4.7 Introduction Potential for Solar Power

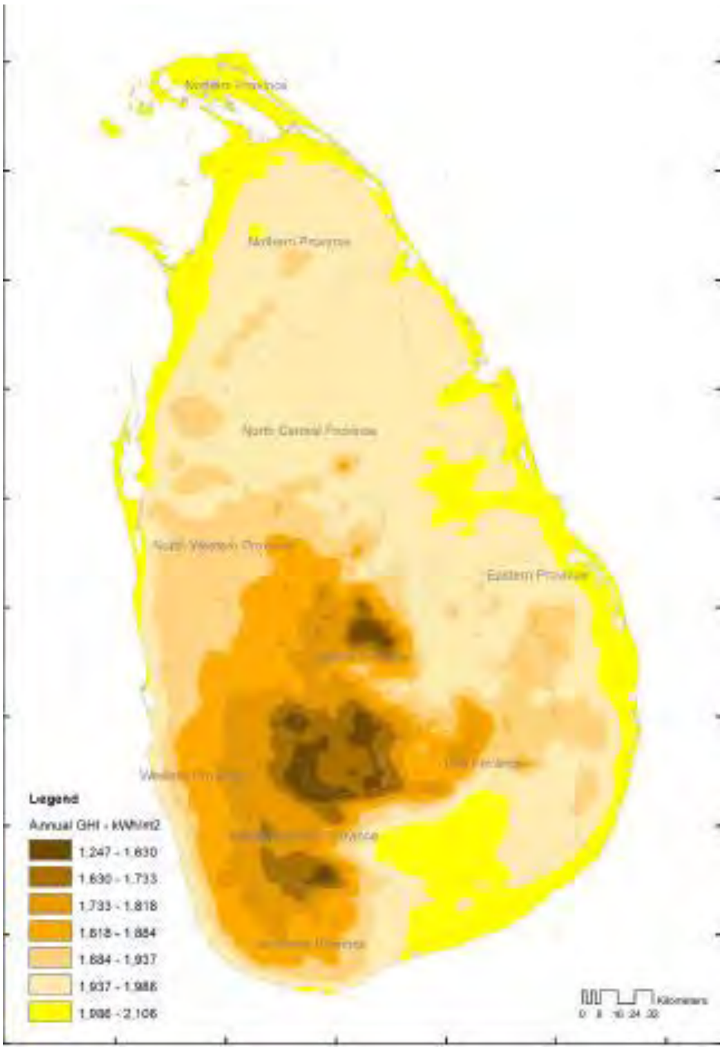
There are six on-grid solar power plants, as shown in Table 4-20. The largest solar power plant (10MW) was commissioned in Hambantota in October 2016. This power plant is connected to a 33kV distribution line, and an additional 20MW solar power plant was constructed.

Table 4-24 List of Solar Power plants

Power plant	Capacity [kW]	Location
-	10,000 x 3	Hambantota
-	10,000	Welikanda
Buruthakada Solar Park	1,237	Hambantota
Thirappane	123	Thirappane

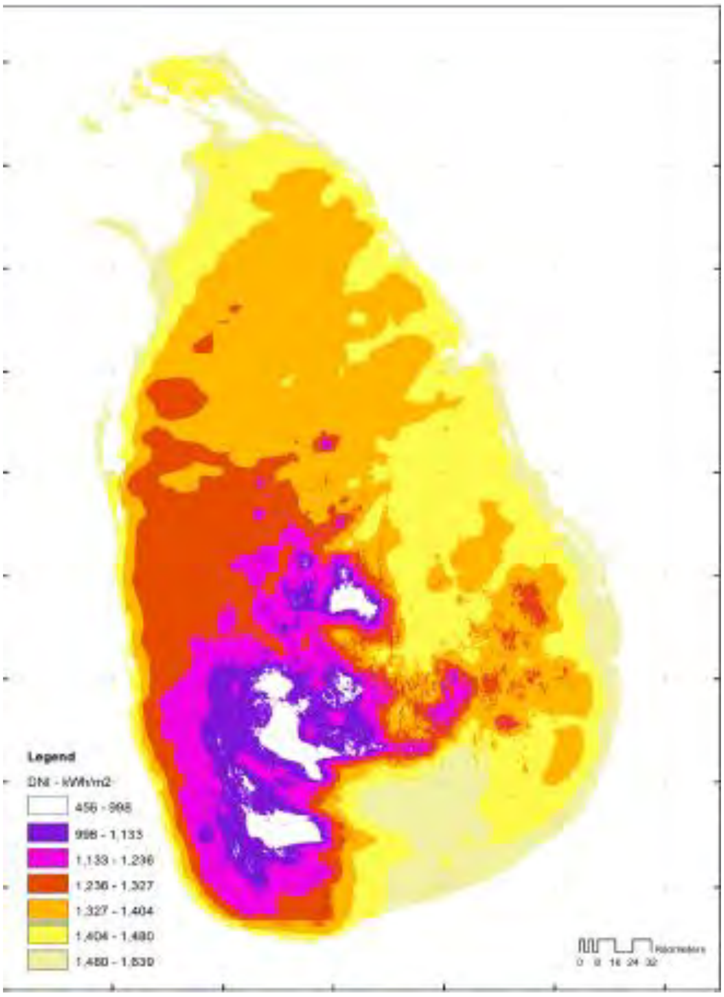
(Source: JICA Survey Team)

Potential maps for Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI), which are related to solar generation, are shown in Figure 4-32 and Figure 4-33 respectively. GHI and DNI are classified as shown in Table 4-25. Hambantota, where a solar power plant is commissioned, has high potential and the northern and eastern areas also have potential. Therefore, there is still some room for development.



(Source: Renewable Energy Master Plan)

Figure 4-32 GHI Map of Sri Lanka



(Source: Renewable Energy Master Plan)

Figure 4-33 DNI Map of Sri Lanka

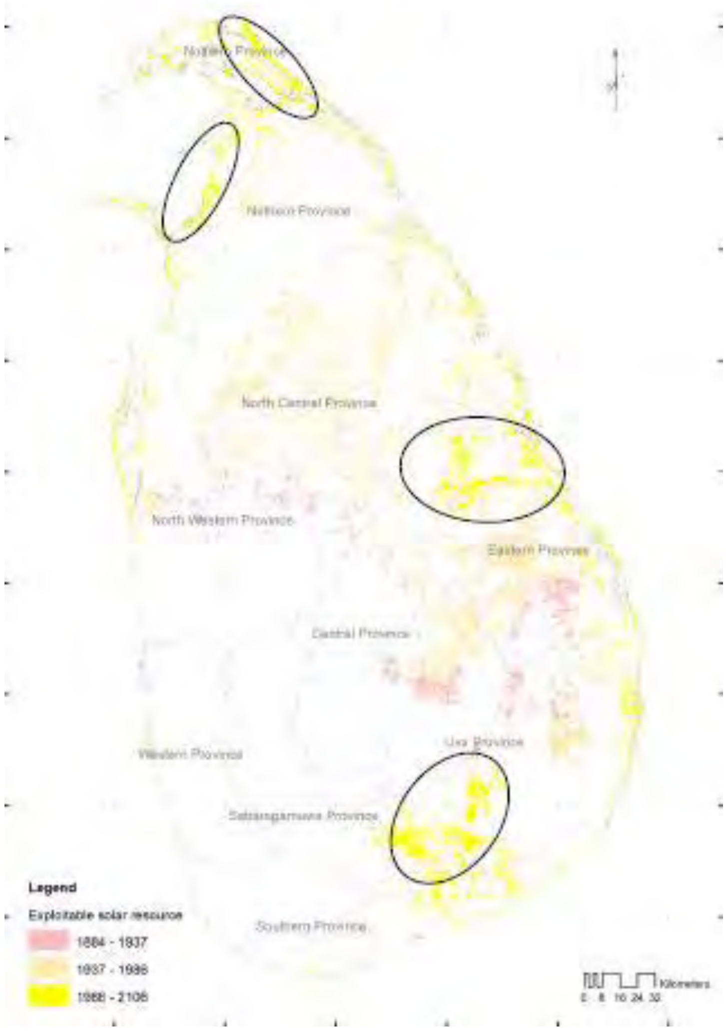
Table 4-25 Classification for GHI and DNI

(Unit: kWh/m²/year)

Class	1	2	3	4	5	6	7
GHI	1,247-1,630	1,630-1,733	1,733-1,818	1,818-1,884	1,884-1,937	1,937-1,966	1,966-2,106
DNI	456-998	998-1,133	1,133-1,236	1,236-1,327	1,327-1,404	1,404-1,480	1,480-1,639

(Source: Renewable Energy Master Plan)

There are some protected and limited areas regarding development. Excluding these protected and limited areas, a potential map for class 5-7 solar areas is shown in Figure 4-34. Promising areas are divided into the northern, eastern and southern areas. In Figure 4-34, the most promising areas, which are class 7 and suitable for large solar power plants, are circled. The total capacity of these is 3,000MW to 6,000MW.

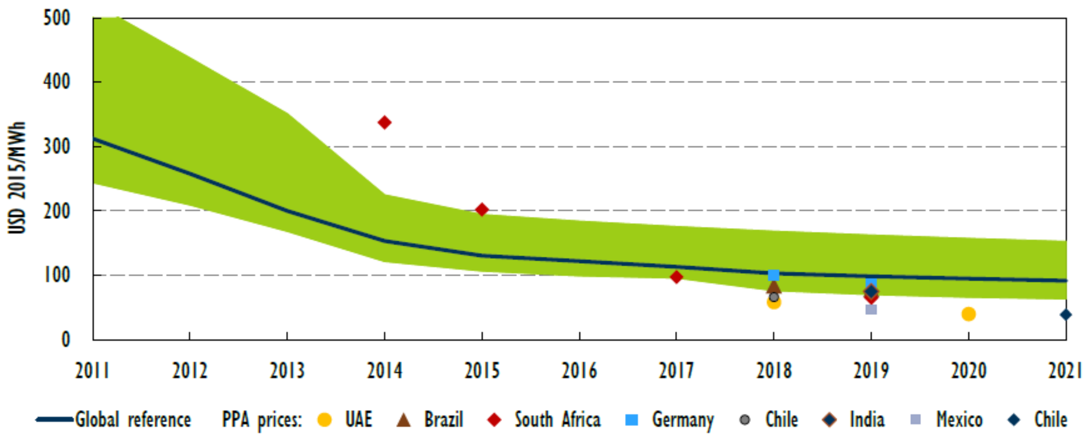


(Source: Renewable Energy Master Plan)

Figure 4-34 Potential Map for Solar (Promising Candidate Sites)

Without subsidiaries, the actual results for LCOE (Levelised Costs of Electricity) from 2011 to 2015 and forecast from 2016 are shown in Figure 4-35. There are some ranges of costs from country to country. Detailed costs are mentioned, but the cost is relatively high in America and Japan, and it is low in China and India. In 2011, the cost was still 250-500 USD/MWh and this decreased dramatically to 100-200 USD/MWh. The cost seems to reduce gradually and it is considered that it will become approximately 90 USD/MWh.

Dots in Figure 4-35 indicate the actual cost in PPA for each country. In Mexico and Peru, PPA has already been contracted under the condition of cost less than 50 USD/MWh (5 cents/kWh). It is predicted that equipment made in Sri Lanka and imported items will reduce in the same way, and many solar power plants will be established in Sri Lanka from now on.



(Source: Renewable Energy Medium-Term Market Report 2016)

Figure 4-35 Actual and Forecasted costs for Solar Power Project

4.4.8 Supply Capacity for Renewable Energy

It is most difficult for power system staff to control windpower and solar, which are affected by climate conditions, of all renewable energy. In addition, as the introduction rate of windpower and solar goes up, it becomes very hard to implement stable power system control without sufficient frequency adjustment capacity. Therefore, it is considered that there is a limit to the introduction amount of renewable energy, but it is possible to increase this by adopting pumped storage power plants, and an output suppression scheme for windpower and solar.

Reforming Systems Related to the Introduction of Renewable energy in Japan

Recently in Japan some power companies suspended the answer for the application of renewable energy as the number of applicants increases. For this reason, the committee of the Ministry of Economy, Trade and Industry considered the problem and countermeasures, and reformed systems related to the introduction of renewable energy.
In the past, there was a rule enabling one to restrict windpower and solar (more than 500kW) to a maximum of 30 days in one year. At present, the following rules are in effect, and as a result the amount of renewable energy in Japanese power companies increases.

(1) Expansion of Output Suppression Days (Maximum of 60 days in one year)
Maximum Output suppression days for new windpower and solar (more than 500kW) extend to 60 days in one year.

(2) Time Management for Output Suppression
Output suppression for new windpower and solar (more than 500kW) is managed by time unit. The maximum suppression time is 720 hours for windpower and 360 hours for solar in one year.

(3) Range Expansion of Output Suppression (New applications (less than 500kW))
Maximum output suppression days for new windpower and solar is 30 days in one year, regardless of equipment capacity.

(4) Range Expansion of Output Suppression (Including existing)
Maximum output suppression days including existing windpower and solar is 30 days in one year.

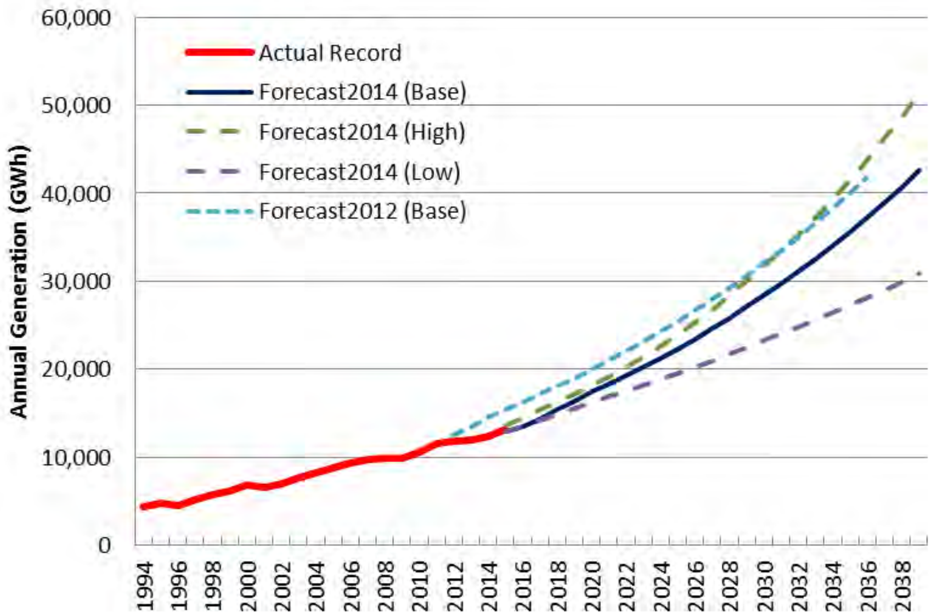
(5) Utilization of Interconnection Line

Chapter 5. Demand Forecast

5.1 Current Demand Forecast in Current Plan

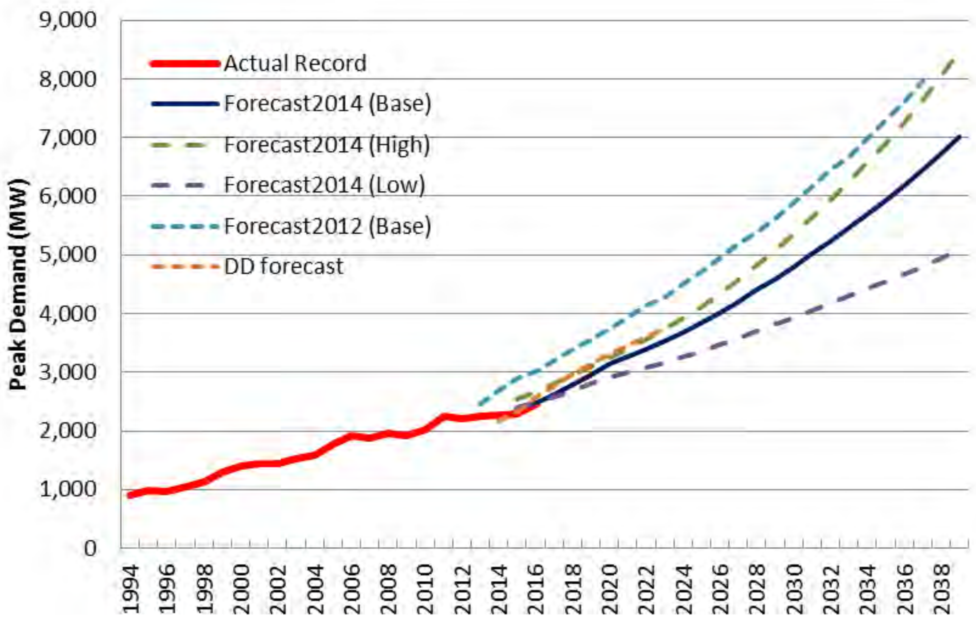
5.1.1 Current Demand Forecast

The electric power demand forecast in Sri Lanka is updated every two years. The latest update was implemented in 2014 and assumed demand until 2039. This result is reflected in the Long Term Generation Expansion Plan (LTGEP) 2015-2034, approved in September 2016.
Forecasted demand and actual records of demand are shown in Figure 5-1 and Figure 5-2. Actual demand in 2015 is almost the same as the forecast; therefore, the accuracy of the forecast seems good.
The other peak demand forecast, which was conducted by the Distribution divisions of CEB and LECO in 2015 based on specific customers' expansion plans and which expected an increase in electricity demand in the near future, is also shown in Figure 5-2. This forecast is near to the high case of CEB's forecast, so it seems reasonable since the forecasting method of the distribution divisions seems to be the larger forecast.



(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-1 Latest Demand Forecast (Energy)



(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-2 Latest Demand Forecast (Peak Demand)

5.1.2 Validity of and Issues regarding Current Power Demand Forecast

CEB's current demand forecast is conducted by using econometoric models for each sector: residential, industrial, commercial and others. A multiple regression equation is used for the econometric model, and a statistically high correlation is obtained. However, as shown by the previous forecast in 2012, in Figure 5-1 and Figure 5-2, the actual demand does not grow as much as the forecast.

It is practically difficult to forecast electric power demand accurately, as is the case in other countries. Therefore, it is worth adopting a simple assumption instead of a sophisticated forecasting method that requires a lot of effort and time, and update it as necessary while monitoring the actual demand increase.

5.2 Related Information on Electric Power Demand Forecast

5.2.1 Actual Records

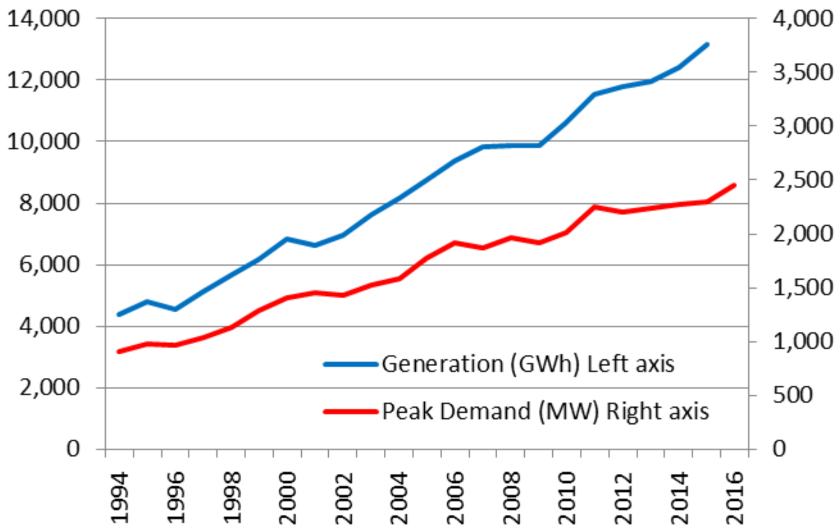
(1) Trends in Nationwide Electric Power Demand

The actual records of demand for the whole country in recent years are shown in Figure 5-3, and the trend of the annual load factor is shown in Figure 5-4. Generally, the electricity demand is calculated based on the electricity transmission amount from the substations (or the electricity generation amount of the power generation stations). However, since renewable energy (NCRE) directly connected to a distribution system of 33 kV or 11 kV supplies electricity directly to customers, it is not counted in the amount of power supply from the substations, and the counted demand is less than the actual.

In recent years, generation of NCRE and its influence have been increasing. In response to this, CEB decided to change the calculation methods to consider the peak supply of NCRE and reflect this from April 2015. For this reason, in order to compare historical demand results under the same conditions, the actual demand before March 2015 was adjusted based on the actual amounts in the NCRE monthly power generation records.

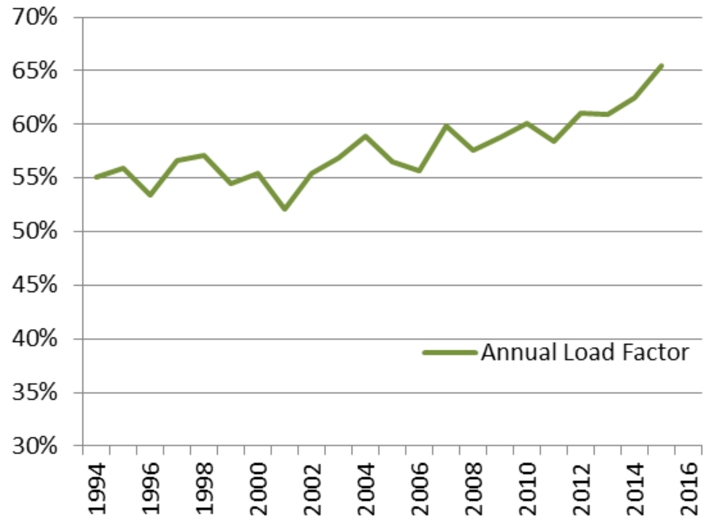
Electricity demand has been increasing constantly in both electricity generation and peak power.

Although there was stagnation in the demand increase around 1995, 2000 and 2008, a generally constant increase of electricity demand in both electricity and peak electric power is recognized. In addition, the annual load factor continues to gradually increase.



(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-3 Actual Records of Electric Power Demand

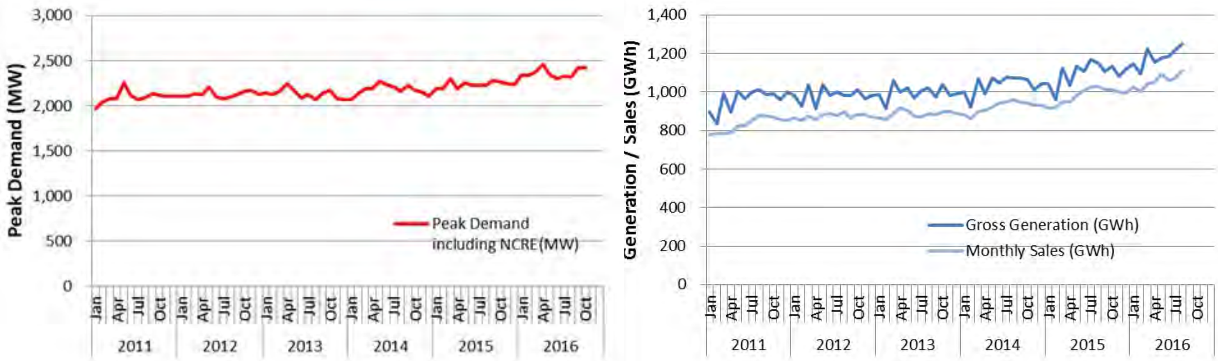


(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-4 Trend of Annual Load Factor

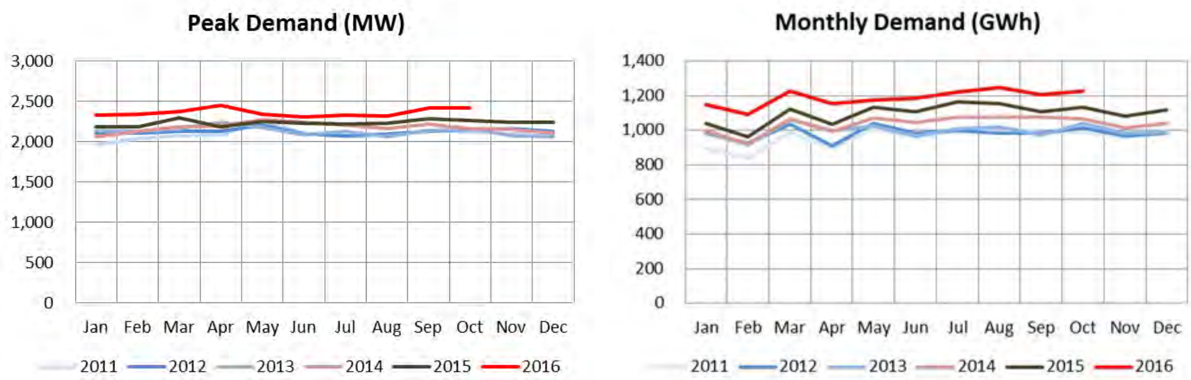
(2) Fluctuation in a year

Changes in the peak demand and energy for each month in recent years are shown in Figure 5-5 and Figure 5-6. In addition, the ratio of the peak demand for each month to the maximum power for the year is shown in Figure 5-7. Electricity demand in recent years is steadily increasing, and is surpassing the peak electricity of the previous year in almost all months. In addition, the ratio of the peak of each month to the annual peak is approximately 90% or more of the year's maximum, and the annual variation is relatively small.



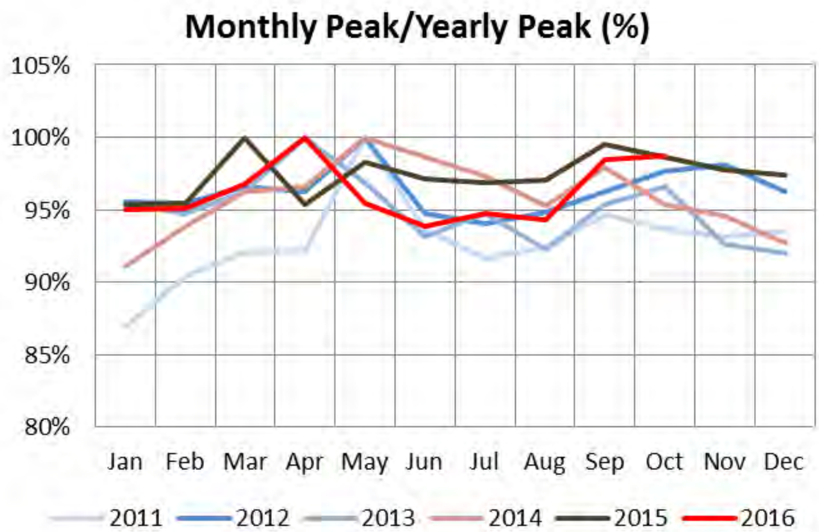
(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-5 Trends of Peak Demand and Generation in a Month (1)



(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-6 Trends of Peak Demand and Generation in a Month (2)



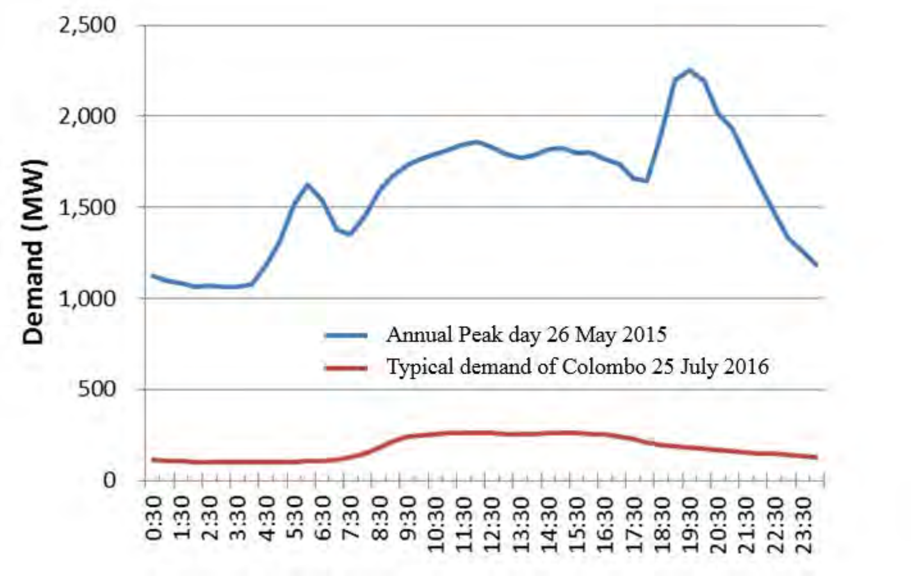
(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-7 Ratio of Peak of Each Month to Annual Peak (Annual Peak: 100%)

(3) Load profile

Nationwide load profiles for the annual peak day (May 2015) and for a typical day in Colombo City are shown in Figure 5-8.

There are three peaks, namely morning peak, day peak and night peak, appearing in the nationwide load profile. Maximum demand in a day is observed at 19:30. However, the load profile of Colombo City is different from that of nationwide, and the peak only appears in the daytime.

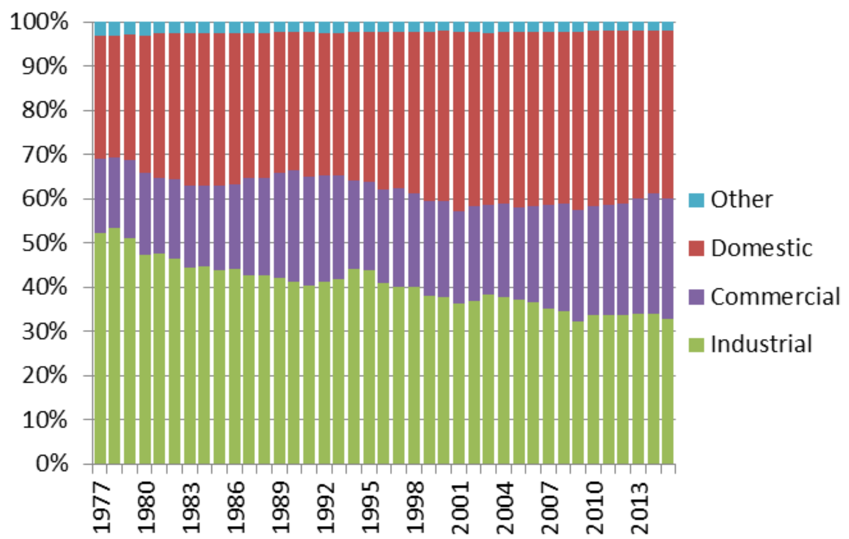


(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-8 Example of Actual Load Profile

(4) Electricity demand by category

Figure 5-9 shows the trends of electric power demand by tariff category. In the long term, the share of industrial demand has decreased and the share of commercial has increased, but in recent years the share of these categories is stable and an almost constant ratio, as shown in the Figure.

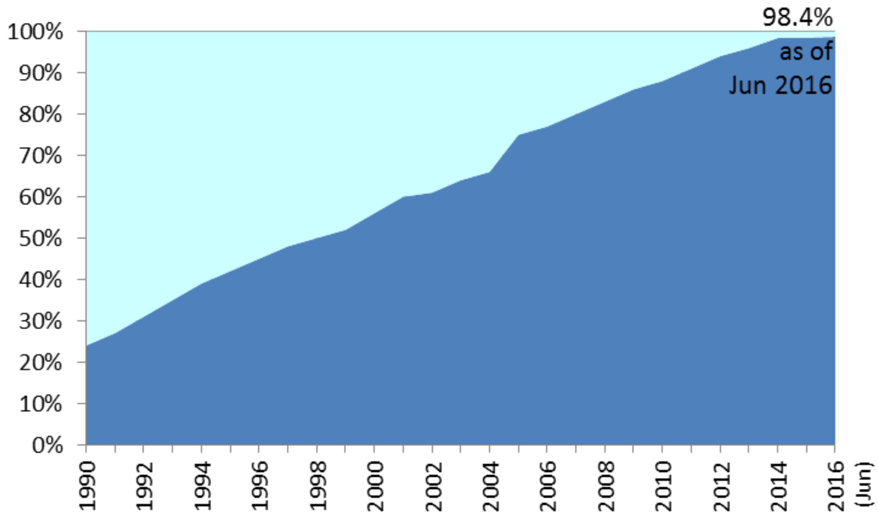


(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-9 Electric Power Demand by Sector

(5) Progress of Rural Electrification

Rural electrification is progressing year after year, and the electrification rate in Sri Lanka has already reached 98.4% as of June 2016.



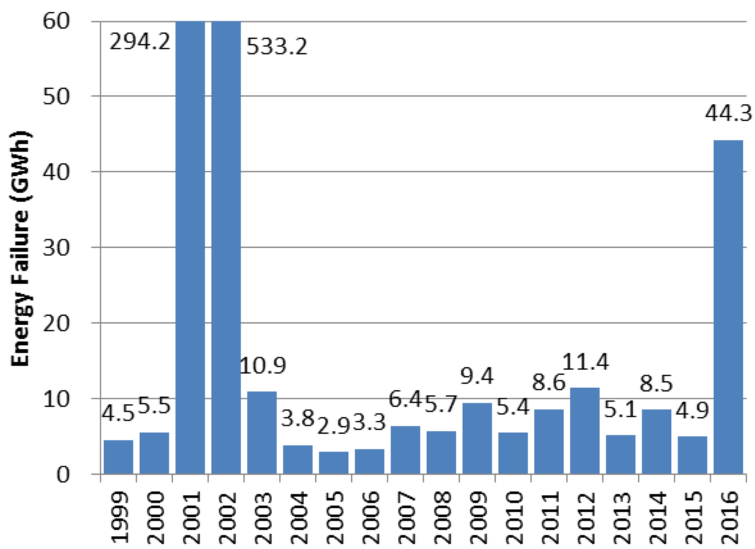
(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-10 Progress of Rural Electrification

(6) Power Cuts

Power supply obstacles were relatively small since 2002, as shown in Figure 5-11, but increased due to the accidents at Lakvijaya thermal power plant that occurred in September 2015, February and March 2016.

CEB classifies energy failure records by causes. The actual data on energy failures caused by lack of generation are shown in Table 5-1. Supply obstacles due to lack of generation in recent years have improved and remained at a low rate but supply shortages occurred in 2016 with the above accidents.



(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-11 Historical Records of Power Cuts

Table 5-1 Reduction of Power Cuts

Year	Power cut (GWh)	Generation (GWh)	Ratio (%)
2001	291.22	6,625	4.40%
2002	524.59	6,946	7.55%
2003	0.00	7,612	0.00%
2004	0.00	8,159	0.00%
2005	0.01	8,769	0.00%
2006	0.01	9,385	0.00%
2007	0.35	9,811	0.00%
2008	0.55	9,893	0.01%
2009	0.59	9,856	0.01%
2010	1.03	10,628	0.01%
2011	6.42	11,528	0.06%
2012	5.67	11,801	0.05%
2013	2.01	11,962	0.02%
2014	5.05	12,418	0.04%
2015	0.06	13,154	0.00%
2016	30.23	14,250	0.21%

(Generation level)

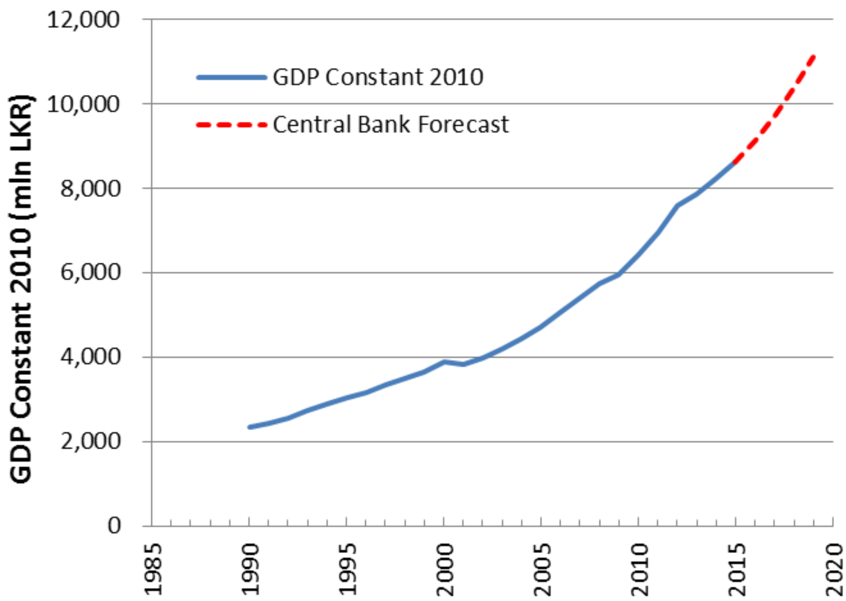
(Source: JICA Survey Team, based on data provided by CEB)

5.2.2 Economic Policy (GDP Growth Rate), Population/Growth Rate Forecast

(1) Actual GDP performance and Forecast by Central Bank of Sri Lanka

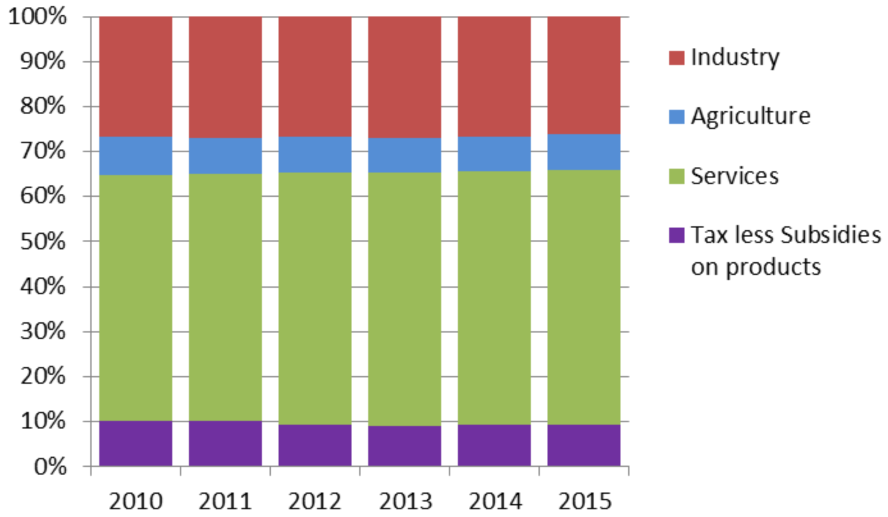
The actual GDP performance and the forecast for GDP by the Central Bank of Sri Lanka (2015 version) are shown in Figure 5-12. There is a steadily increasing trend in the actual results although there is GDP stagnation around 2001. According to the central bank's assumption of GDP (4 years from 2016-2019), the annual growth rate is assumed to be a relatively high rate of 5.8-7.0%.

In addition, Figure 5-13 shows the GDP share by industry, but there are no major changes observed in recent years.



(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-12 Actual GDP Performance and Forecast by Central Bank of Sri Lanka

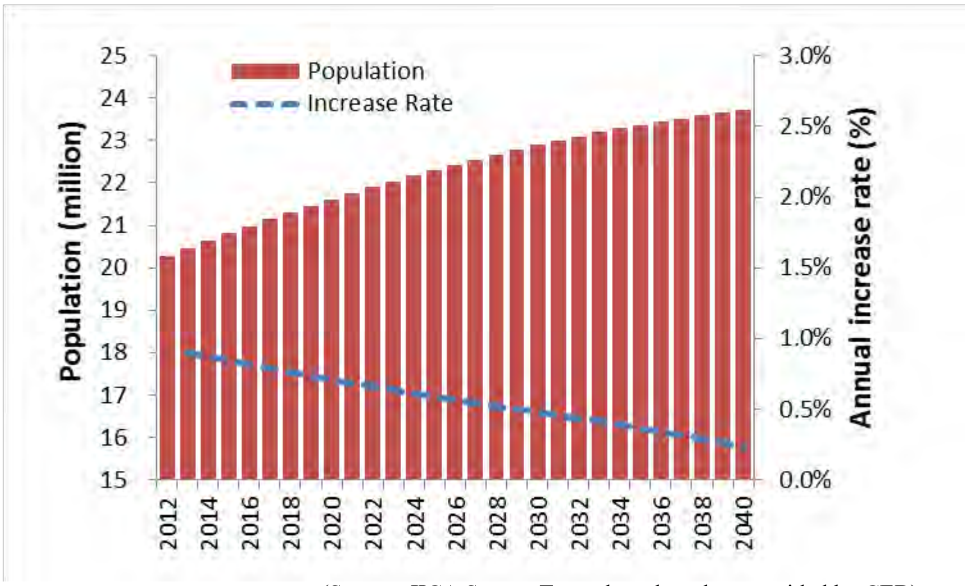


(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-13 Share of GDP

(2) Population

The population projection in Sri Lanka provided by CEB is shown in Figure 5-14. Although the population of Sri Lanka is increasing moderately, the rate of increase is low, at less than 1% in the 2012 survey, and is expected to gradually decrease in the future. Since CEB does not estimate the population in 2040, the survey team assumed it based on the trend until 2039.

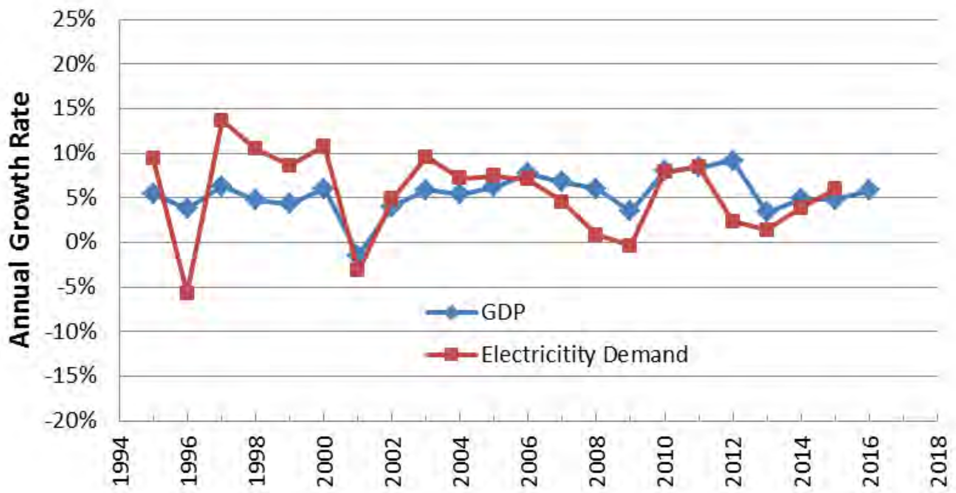


(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-14 Population Projection for Sri Lanka

(3) Growth rate of GDP and Electric Power Demand

Figure 5-15 shows the annual growth rate of GDP and electric power demand. Although the annual growth rate of electric power demand fluctuates more than GDP, the movements of both are generally quite similar.

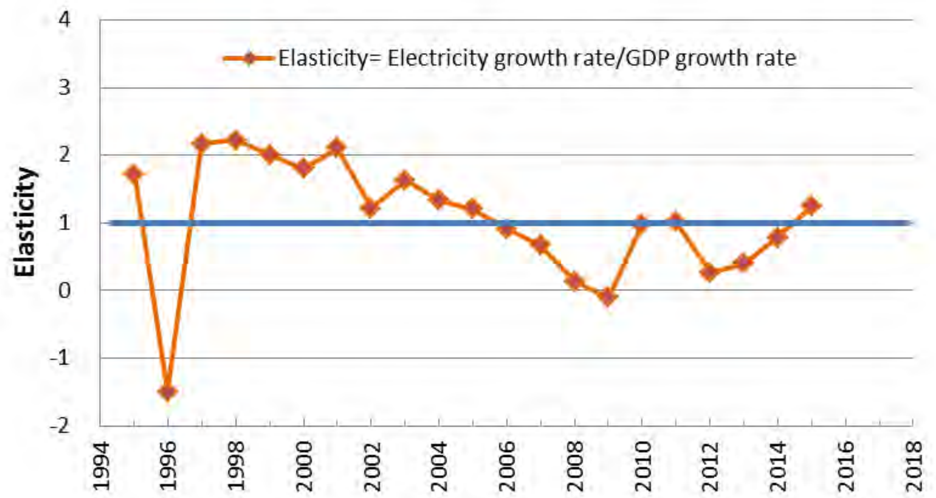


(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-15 Growth Rate of GDP and Electric Power Demand

(4) GDP Elasticity of Electric Power Demand

Figure 5-16 shows the GDP elasticity of electric power demand. Although the GDP elasticity value continued to decrease during the period from 1998 to 2009, it has been fluctuating widely since it recovered to more than 1 in 2015. It is quite difficult to assume a certain numerical value, but it fluctuates mainly around 1. Therefore, in this survey, it is assumed that the GDP elasticity used for the electric power demand forecast described later is 1.



(Source: JICA Survey Team, based on data provided by CEB)

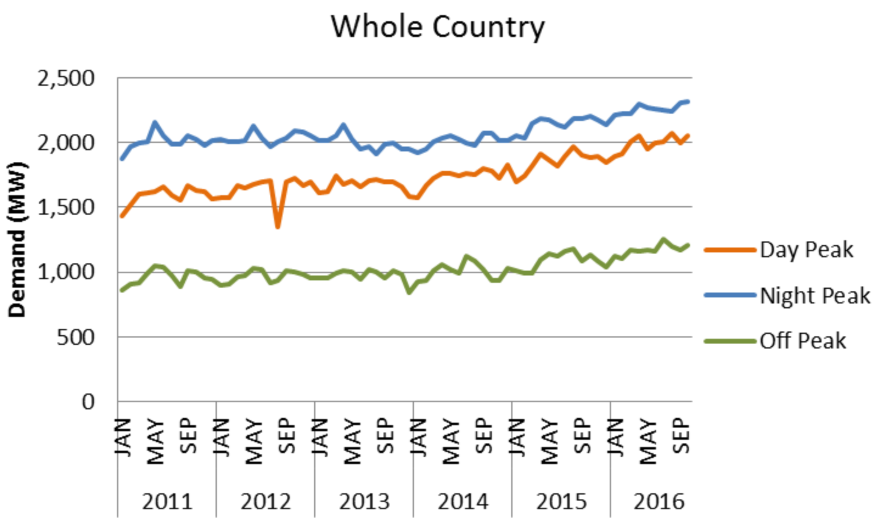
Figure 5-16 GDP Elasticity of Electric Power Demand

5.2.3 Characteristics of Demand by Province and Trends of Increase

(1) Peak Demand for Whole Country and Regions

As indicated in 5.2.1 (3), the demand in the whole country has occurred at night time, whereas the peak is daytime in Colombo City, where urbanization is advanced; therefore, the shape of its load profile is different.

Figure 5-17 shows the actual monthly records for the night peak, the day peak, and the off peak, which is the lowest demand in a day. Night peak, day peak, and off peak demand are increasing every year, but in particular the increase in day peak is larger than the increase in night peak, so the shape of the daily load profile gradually changes. It is expected that in the near future the day peak will increase to the same level as the night peak and the day peak will then become dominant.



(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-17 Peak Demand for Whole Country

(2) Peak Demand by Region

The actual records for the night peak, day peak, and off peak for each province are sorted in the same manner. Although there are differences depending on the province, it generally seems that the increase in day peak is somewhat larger than the increase in night peak.

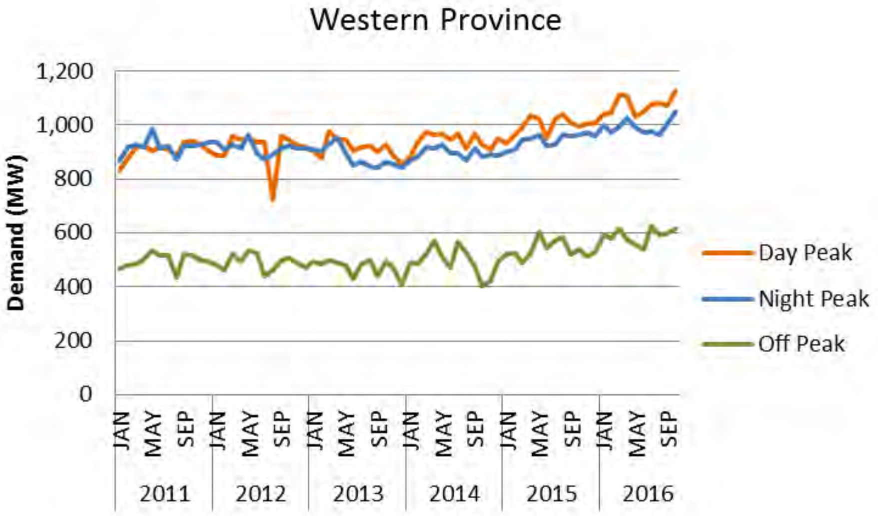
Among them, Western Province and Northern Province show different characteristics from the others. The day peak in Western Province is already larger than the night peak. In Northern Province, the power demand has been increasing rapidly since 2014 in both night peak and day peak; this seems to reflect the progress in the improvement of power plants and transmission lines to improve the power supply to Northern Province.

Based on the above, other states were divided into two groups according to the size of GDP. They were consolidated into the following four groups and their historical records are shown in figures.

a) Western Province (Figure 5-18)
b) North-Western/Central/South Provinces (Figure 5-19)
c) North-Central/Sabaragamuwa/Uva/Eastern Provinces (Figure 5-20)
d) Northern Province (Figure 5-21)

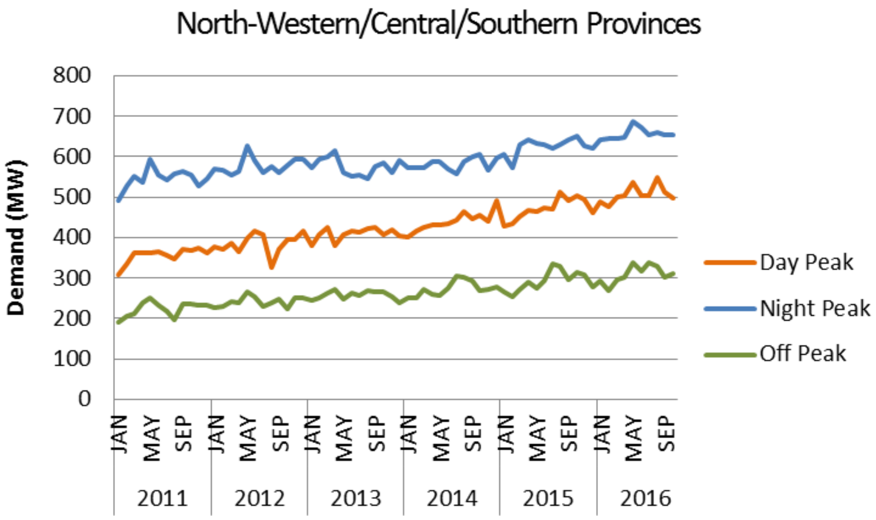
As shown in the figures, therefore, the rising trend of the day peak at the national level is considered to reflect the characteristics of each region.[15]

[15] Upon arranging peak demand results for each province, a decreasing trend in the day peak appears only in Uva province. However, due to the low demand, the impact on the national level evaluation is minimal.



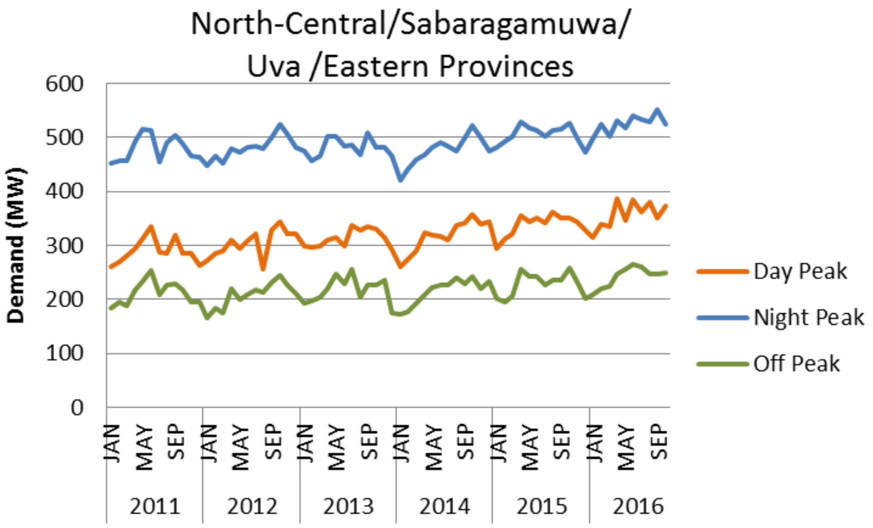
(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-18 Peak Demand of Western Province



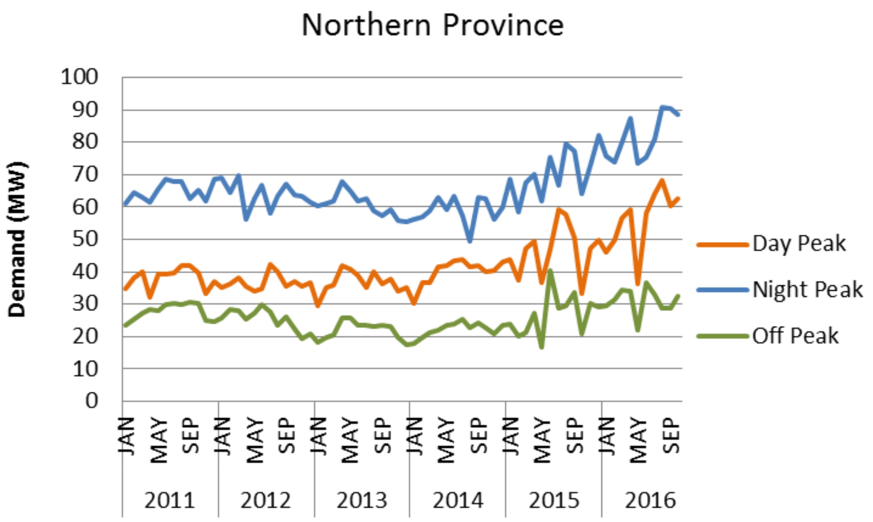
(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-19 Peak Demands of North-Western/Central/Southern Provinces



(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-20　Peak Demands of North-Central/Sabaragamuwa/Uva/Eastern Provinces

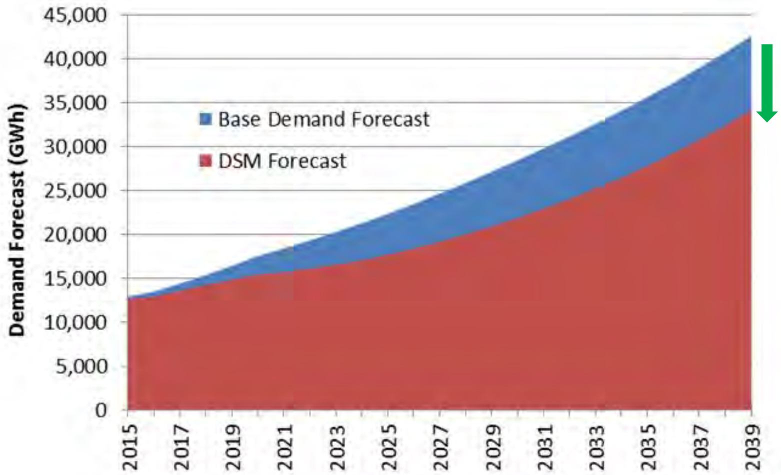


(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-21　Peak Demand of Northern Province

5.2.4　Demand Side Management

Demand side management (DSM) has been planned and conducted by Sri Lanka Sustainable Energy Authority (SEA) in collaboration with relevant organizations. According to the Long Term Generation Expansion Plan (LTGEP 2015-2034) approved in 2016, measures for the introduction and expansion of DSM were planned and about 7,600GWh of electricity saving was expected in 2039.



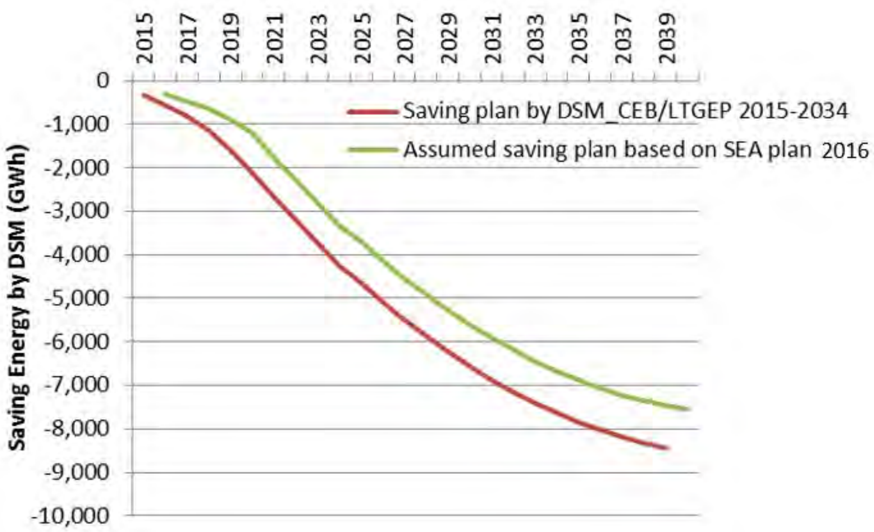
(Source: JICA Survey Team, based on LTGEP 2015-2034)

Figure 5-22 Demand Forecast (LTGEP 2015-2034, Base case and DSM case; Generation)

(1) Current plan and expectations

SEA compiled the National Energy Management Action Plan 2016-2020 in 2016, and a DSM promotion plan was indicated. This plan provides for 1,104 GWh of energy saving in 5 years up to 2020 by promoting energy conservation measures, including improvement of efficiency for air conditioning, lighting, refrigerators, etc. It will require about 100 Billion LKR, including investment and technical support expenses. In this plan, demand reduction via DSM by 2020 is about 800 GWh smaller than the previous plan in LTGEP 2015-2034. This seems to be the result of narrowing down the measures that are highly likely to be realized, following evaluation of the market situations and technical issues.

SEA is considering further DSM, such as cold heat storage technology and electric vehicles, as a countermeasure against peak shift, but it has not yet concluded a specific implementation plan. Therefore, swift progress is desired.



(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-23 Expected Energy Saving via DSM (Generation Level)

Based on the above, the effect of the introduction of DSM up to the year 2040 is assumed reflecting the DSM plan in LTGEP 2015-2034 and the energy saving plan by 2020. This is converted to generation at the sending end considering loss improvement in the future. If the DSM is implemented as planned, about 7,500GWh of electricity reduction in 2040 is expected, as shown in Figure 5-23.

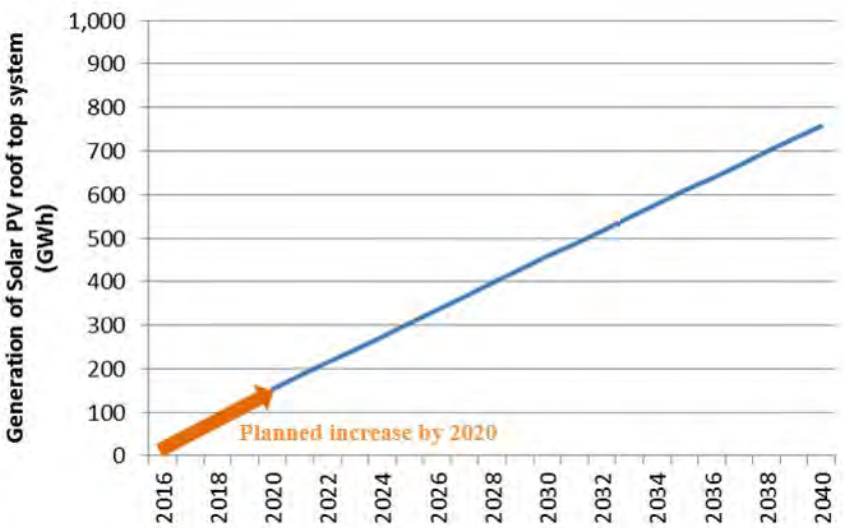
(2) Introduction Plans for Smart Home with Roof-top PV system

SEA has also compiled a promotion plan for smart homes with solar power panels installed on the roofs of private houses. According to the aforementioned National Energy Management Action Plan 2016-2020, small-scale photovoltaic power generation installed on the roof-top of a private house and connected to the power system via the metering system, is expected to introduce 100MW by 2020, and generate 139 GWh of electricity. About 22 Billion LKR is expected as the cost necessary for introduction.

This plan greatly exceeds the previous CEB plan reflected in LTGEP 2015-2034; the previous target was 13.4MW, 19.9 GWh by 2039, which was ten times larger than the actual records in 2013. This is due to the adoption of a policy to introduce larger quantities of smaller scale (1 kW) panels with lower cost burden.

In this system, when the roof-top solar power generation exceeds the demand of the private house, the surplus power is supplied to the electric power system, and when the electric power runs short because the solar power cannot generate enough, the system supplies the shortfall amount. Therefore, with the increase in solar power generation due to the introduction of roof-top smart homes, the power generation amount of CEB's electric power system will decrease. As described in section 5.3.1, the peak demand will shift from the night peak to the day peak, when solar power can generate. Accordingly, when this situation occurs, it is expected that reducing the power supply capacity of CEB's power system might be viable. However, the nationwide total for electricity demand will not reduce by introducing smart homes.

A specific promotion plan for roof-top smart homes after 2021 is not fixed yet, but further expansion, along with the cost reduction of solar panels, is expected. When assuming the future increase to be the same as the current plan, generation from smart homes will be 500MW, 760 GWh in 2040 (converted to the sending end of CEB's electric power system taking the loss improvement effect into consideration).



(Source: JICA Survey Team, based on data provided by CEB)

Figure 5-24 Increase in Solar Power Generation of Roof-Top Smart Homes

5.2.5 Railway Electrification

This section describes how the demand for electricity will increase after railway electrification in Sri Lanka is completed in the future. Because it will only focus on how much electricity volume will be needed, budget, time and possibility of electrification are not considered.

(1) Information from Sri Lanka Railway

In Sri Lanka, Sri Lanka Railway Authority (hereinafter referred as SLR) is responsible for railway development, operation and service provision and no domestic line is privatized. Among a total of 1380km, no section has been electrified so far.

Before considering the electricity demand increase due to railway electrification, the JICA team interviewed SLR in order to confirm the development status and plans for the railways.

(a) Points from interview with SLR (9th August 2016)

- Plans for Railway Electrification
  - SLR doesn't have any concrete electrification project covered by their own budget at present, but other international partners have proposed projects to SLR.
  - Utilizing some partners' schemes, SLR wishes to start electrification within 30-40km of Colombo central as a first step.
  - However, the railway sector has to implement other infrastructure development at the moment. Installing an electrified system is not considered a high priority.
- Recent Operations
  - Peaks for people transportation are from 6AM to 9AM, and 16:00 to 19:00.
  - It runs 220 trains per day in the Colombo area. (24h operation)

(b) Official Data of SLR (Administration Report 2014)

The below table shows track lengths of existing lines as of the end of 2014.

Table 5-2 Existing Lines in Sri Lanka (2014)

		Length (km)	Frequency	Stations
1	Main Line & Matale Line	324	137	98
2	Puttalam Line with Airport Spur	173	49	24
3	Northern Line	322	34	44
4	Talaimannar Line	43	0	52
5	Batticaloa Line	211	10	3
6	Trincomalee Line	70	6	34
7	Coast Line	159	114	68
8	Kelani Valley Line	59	21	30
9	Mihintale Line	15	0	0
10	Kolonnawa Spur	2	4	2
11	Harbour Spur	2	0	0
	Total	1380	375	355

Frequency: Number of trains running on weekdays in 2014

(Source: SLR Administration Report 2014)

(2) Advantages and Disadvantages of railway electrification

Although electrification is not the most prioritized policy as mentioned above, SLR has a desire to electrify their lines. However, even if electrification progresses as much as possible in the future, the length of electrified track is going to be limited because of the below mentioned reasons. Electrification of a railway has both advantages and disadvantages such as:

(a) Advantages

- Less restriction on railway operation because refueling is not necessary.
- High energy efficiency compared with internal combustion engine or steam engine.
- Weight reduction without fuel or any other power source on the train.

(b) Disadvantages

- Significant capital expenditure for development and maintenance of facilities such as substations, transmission lines and so on.
- Low profitability for low use lines.

Generally, busy lines enjoy the merits of electrification, but lines with fewer trains are not suitable to be electrified because of a lack of economic efficiency. In Sri Lanka, there are some lines running very few trains in a day according to Table 5-2. Even if customers increase in the future, these lines can be considered as not suited to electrification.

(3) Assumptions for Electrified Lines

In order to calculate the volume of electricity demand increase, the length of the electrified lines has to be designated. Thus, the below 2 cases will be assumed for possible electrification length in the future:

(a) Low Case: Electrification within Colombo metropolitan area

According to Transport Master Plan for Western Region Megapolis Planning Project (WRMPP), which was released in October 2016 by the Ministry of Megapolis and Western Development, the below new and existing lines are recommended to be electrified as the result of a study. The total length of these lines is assumed as the Low Case which will be electrified by 2040.

Table 5-3 Lines and Sections to be Electrified (Low Case)

Route	Section	Length
Main Line, Coast Line	Panadura - Veyangoda - Polgahawela	110 km
Puttalam Line with Airport Spur	Ragama – Negombo with Airport Spur	26 km
Kelani Valley Line	(all sections)	59 km
(New Line)	Kottawa to Horana	22 km
(New Line)	Kelaniya to Kosgama via Biyagama, and Dompe	30 km
	Total	247 km

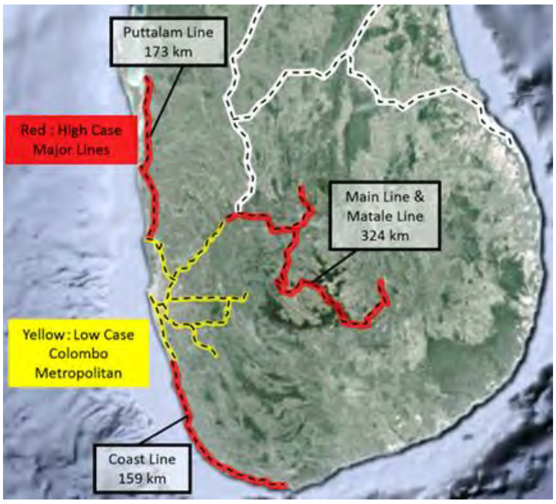
(Source: JICA Survey Team)

(b) High Case: Electrification of all major lines

Electrification for major lines, even for the 247 km mentioned above, requires considerable budget and time. However, this study assumes another case that includes a greater length, as a High Case.

The High Case covers 767 km, the total length of 4 major lines and 2 new lines: 1. Main Line & Matale Line, 2. Puttalam Line, 7. Coast Line and 8. Kelani Valley Line, N1. Kottawa to Horana, N2. Kelaniya to Kosgama via Biyagama, and Dompe. Other lines which have low usage are not considered for electrification because of the information mentioned above.

Total Length: 767 km (High Case)



(Source: JICA Survey Team)

Figure 5-25 Map of Major Lines

Table 5-4 Lines and Sections to be Electrified (High Case)

Route	Length (km)	Frequency per day	Stations
Main Line & Matale Line	324	137	98
Puttalam Line with Airport Spur	173	49	24
Coast Line	159	114	68
Kelani Valley Line	59	21	30
(New Line) - Kottawa to Horana	22	-	-
(New Line) - Kelaniya to Kosgama via Biyagama, and Dompe	30	-	-
Total	**767**	**321**	**220**
(Example) Joban-Line, Japan [16]	350	200※2	80

*1 the entire route of the Low case is included in the High case route
*2 total number of train stops at TSUCHIURA station on Joban-Line during weekdays in Dec. 2016

(Source: JICA Survey Team)

(4) Estimation of Electricity Demand

There are several possible ways to think about demand increasing, but this study considers the number of train substations required and the electricity demand for each.

In order to feed enough power to locomotives, substations at regular intervals are required, but the interval distance is different depending on the voltage and current (DC or AC) flow to the locomotive. A DC feeding system requires comparatively many substations because the power sent from substations can only reach a short distance due to limitations of voltage and transmission losses. (The DC system can save the cost of manufacturing the locomotive itself.) On the other hand, an AC feeding system can use substations with longer intervals because it can send high voltage power.

Because experience shows that the distance between substations is about 5km – 10km for a DC feeding system, and 20km – 50km for an AC feeding system (DC-BT feeding system), the number of substations required is as below.

[16] Joban Line data is shown as a comparison example because operation length is similar to Main Line in Sri Lanka.

Table 5-5 Number of Substations by Feeding System

			Number of Substations	
Feeding System	Voltage	Interval	Low: 248km	High: 767km
DC	1.5 kV	Approx. 5 km	51	157
AC	20 kV	Approx. 20 km	15	39

(Source: JICA Survey Team)

Assuming that each substation requires 2MW for DC and 10MW for AC, total demand for railway electrification is calculated as follows:

Table 5-6 Demand Increase Estimation

Feeding System	Low: 248km	High: 767km
DC	Approx. 102MW	Approx. 314MW
AC	Approx. 150MW	Approx. 390MW

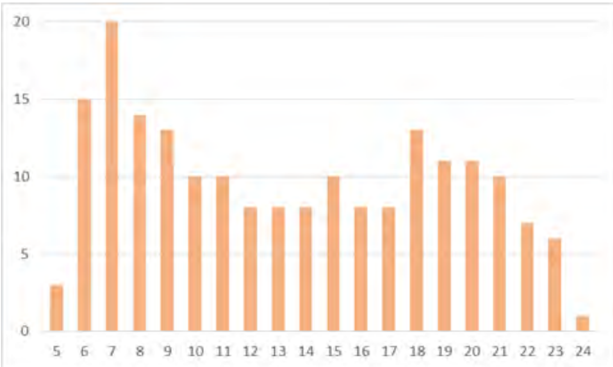
(Source: JICA Survey Team)

(5) Conclusion

In general, a DC feeding system needs higher investment for ground installations but the cost for locomotives can be saved compared with an AC feeding system. Whichever the Sri Lankan government installs in the future, it can be said that:

Low Case: Less than 150MW increase estimated in case of electrification within Colombo metropolitan area.
High Case: Less than 400MW increase in case of electrification for all major lines

Basically, railway electricity demand follows closely the amount of trains that run in the day. In Sri Lanka, in common with other countries, the peaks for trains appear in the morning and evening hours. This means that the peak for railway electricity demand is not always the same as the daily peak demand in an urban area.



(Source: JICA Survey Team)

Figure 5-26 Typical number of trains run

(Weekday at Tsuchiura-station, Joban-Line, Japan)

5.2.6 Introduction of Rapid Transit System (RTS)

As well as the Railway, Transport Master Plan for WRMPP recommends development of a Rapid Transit System, which is relatively light carrying system of urban transport. According to the Master Plan, the below lines and sections are considered suitable for RTS development.

Table 5-7 Development Plan for RTS

	Line	Length	Section
1	Green Line (RTS1)	15km	Fort–Kollupitiya-Bambalapitiya-Borella-Union Place- Maradana
2	Yellow Line (RTS2)	11.5km	Fort- Maradana- Mattakkuliya/Peliyagoda
3	Red Line (RTS3)	10km	Dematagoda-Borella-Narahenpita-Kirulapone-Havelock City- Bambalapitiya
4	Purple Line (RTS4)	10km	Borella–Rajagiriya–Battramulla-Malabe
5	Pink Line (RTS5)	9.6km	Malabe – Kottawa
6	Olive Line (RTS6)	6km	Malabe - Kaduwela
7	Ash Line (RTS7)	13km	Peliyagoda - Kadawatha
	Total	75.1km	

(Source: JICA Survey Team)

In the development of an RTS, a Monorail System and/or Light Rail Transit (LRT) System can be considered as the vehicle type. Whichever system is selected, vehicles run with electricity fed from outside and total electricity demand can be calculated by the same method as the Railway. Basically, the feeding system for an RTS is DC type because RTS operation length is relatively shorter than a railway.

Table 5-8 Electricity Demand of RTS

Feeding System	Length	Number of Substations	Electricity Demand
DC	75.1 km	Approx. 17	Approx. 34MW

(Source: JICA Survey Team)

5.2.7 Popularization of Electric Vehicles

Recently, the development and deployment of Electric Vehicles (EV)[17] has improved rapidly in the transportation sector. Development of long-run capacity and mass-production batteries has enabled EVs to attain equal operational quality with conventional gasoline vehicles. In addition, the lower CO_2 emissions aspect spurs a high growth of sales amid raised environmental consciousness among consumers today. Amid this trend, many of the industrial car companies, research institutes and government agencies have released forecasts for the growth of EV sales for their own purposes and almost all say that more than 20% of the total number of vehicles will be replaced by EVs by the 2030s. If this is achieved, total electricity demand for EVs cannot be ignored.

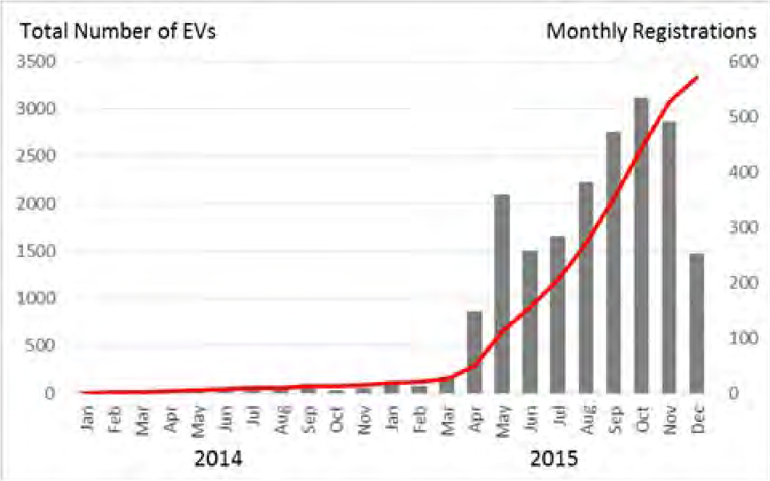
In this section, future electricity demand for EVs is assumed from forecasts for vehicle sales in Sri Lanka. Because this section only focuses on the electricity demand increasing, utilizing an EV battery as an emergency power source and DSM are not considered here.

(1) Method

In Sri Lanka, almost of the domestic use vehicles are imported from other countries because there is no large car factory within the country. In June 2010, just after the end of the civil war, a reduction of import taxes for second-hand vehicles triggered the flow of many imported vehicles into the domestic market and pushed the car ownership ratio up. After tax rises other than for EVs in January 2015, the

[17] Electric Vehicle (EV) includes Battery Electric Vehicle (BEV) and Plug-in Hybrid Electric Vehicle (PHEV).

number of EVs in the Sri Lankan vehicle market started to increase (Figure 5-27). Today, many EVs and quick charging stations can be seen in Colombo city and more are expected in the future as per the global trend.



(Source: Department of Motor and Traffic)

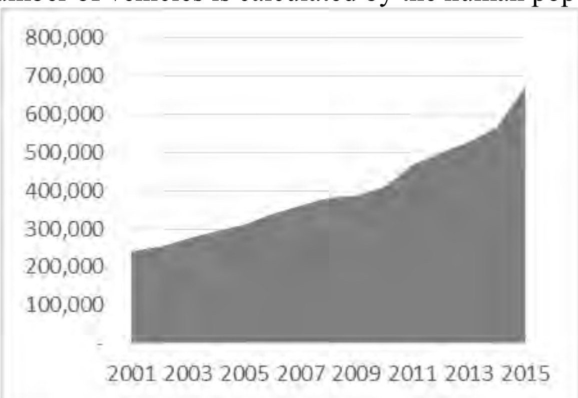
Figure 5-27 Total Number of EV Registrations in Sri Lanka

In order to promote EVs in Sri Lanka, various schemes have been prepared by the public sector. For example, CEB launched a prepaid e-Card for quick charging stations[18]. However, a concrete long-term target for EV deployment by the government in consideration of environmental measures has not been confirmed via research by the JICA team for this Master Plan. Rather, by raising import taxes for all types of vehicles including EVs in November 2015, the government seems to want to limit the number of vehicles in order to reduce traffic congestion.

Thus, in order to consider the electricity demand for EV charging in 2040, the overall vehicle type population and EV ratio in that year have to be calculated.

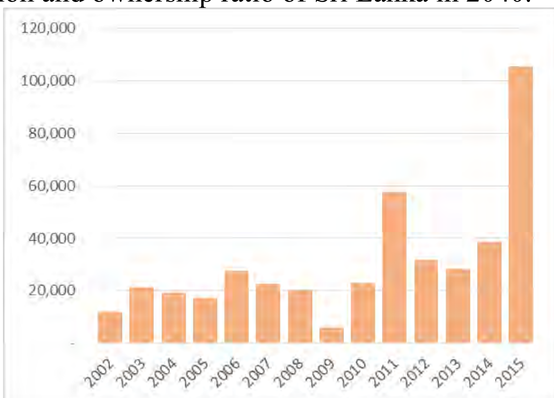
(2) Total number of vehicles in 2040

Firstly, the number of all types of vehicles, including not only EVs but also conventional internal-combustion vehicles, hybrid vehicles and so on is considered. As mentioned above, the number of imported second-hand vehicles has been rising drastically since 2010 and this has continued. However, the annual increase volume is not that stable due to the government tax policy changing. In these circumstances, forecasting until 2040 from past trends is difficult. Therefore, in this section, the total number of vehicles is calculated by the human population and ownership ratio of Sri Lanka in 2040.



(Source：Department of Motor and Traffic)

Figure 5-28 Total Number of Vehicles in Sri Lanka



(Source：Department of Motor and Traffic)

Figure 5-29 New Registrations by Year

18 http://www.ceb.lk/launching-of-prepaid-ceb-e-card/

The population of Sri Lanka in 2040 is shown as 23.7 million in the above-mentioned Figure 5-14. Ownership ratio in 2015 is 32/thousand people[19], and this is assumed to be 100/thousand people[20], almost 3 times higher, in 2040. The total number of vehicles is therefore assumed as 2.37 million in 2040.

(3) Future EV share

As mentioned above, many industrial car companies, research institutes and government agencies released forecasts for the growth of EV sales with their own views, such as a measurement to prevent global warming, BAU (Business As Usual) base, commercial base and so on. Analyzing these forecasts one by one is not the purpose of this section but some examples are shown in the below Table 5-9. From these assumptions, it can be said that almost 20–30% of vehicles will be replaced by EVs by 2040.

Table 5-9 Examples of EV Penetration Forecasts

	2030	2035	2040	2050	Assumption base
International Agency (IEA)[21]	10%	-	(25%)	40%	Environment
Energy Company	-	6%	-	-	Market Trend
Industrial Car Company	15%	-	-	-	Sales Target
Private Think Tank A	-	-	25%	-	Market Trend
Private Think Tank B	15%	-	-	-	Market Trend

(Source: JICA Survey Team)

Because Sri Lanka does not have concrete political targets for EV and vehicle supply relies on imports as mentioned above, the EV and other vehicle markets in Sri Lanka are easily influenced by global trends. Therefore, it can be considered that EV penetration in the country will reach 20–30% by 2040.

(4) The electricity demand for EVs

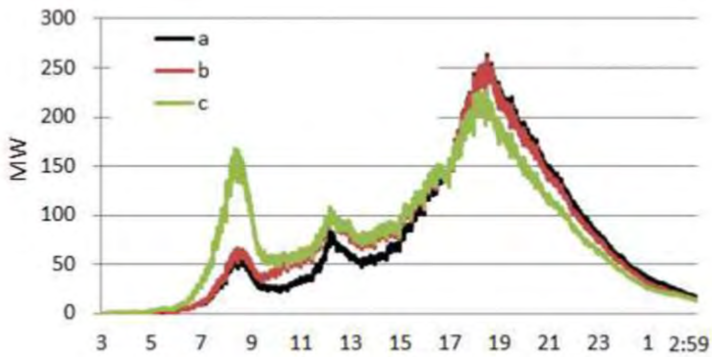
When the electricity demand for EVs is calculated, it requires some pattern data for EV owners' actual usage conditions, such as how much and when the owner charges in a day as well as the charging load of the EV. However, deriving pattern data requires large-scale investigation of EV owners. Without implementing such a large-scale investigation, this section cites existing research, "An Estimation of Electric Vehicle Load Profiles in Service Areas of Ten Electric Power Companies in Japan", conducted by Central Research Institute of Electric Power Industry (CRIEPI) in 2014, in order to survey electricity demand in 2040.

This study aims to estimate the daily load profiles for EV charging in the service areas of the ten regional electric power companies in Japan, with the running/parking patterns obtained from a large-scale owner interview investigation in 2005. This estimation is based on 30% EV penetration among all vehicle types as well as the figures in Sri Lanka for 2040 as mentioned above.
Because the total number of vehicles in Hokkaido (2.717 million), among the ten regions, is similar to that of Sri Lanka in 2040 (2.370 million), this assumption refers to Hokkaido's figures and data[22]. The below

19 Population: 20.8 million, total vehicle number: 672,502 in 2015, Sri Lanka
20 JICA team estimated by comparing with other countries' figures.
21 Global EV Outlook 2016, International Energy Agency
22 In Japan, there are various climate conditions from south to north and since Hokkaido is located in the northernmost part its climate is relatively cold. However, no difference in EV active pattern and demand curb due to climate and temperature was confirmed, so the EV active pattern in Sri Lanka is considered similar to that of Hokkaido.

Figure 5-30 shows the daily charging load based on several parking and charging scenarios for a weekday in Hokkaido[23]. Each line shows the load profile as below:

Black Line (a): Charging at Household only
Red Line (b): (a) + Shopping mall, Commercial building
Green Line (c): (b) + Place of Work

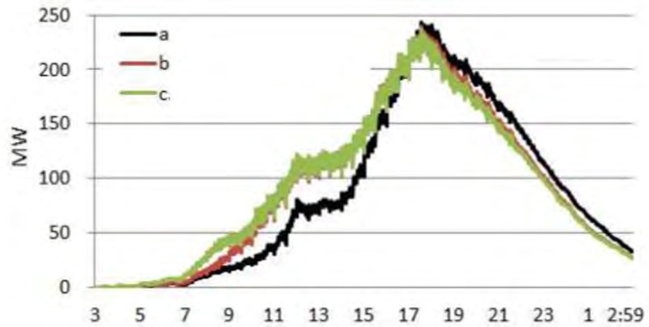


(Source: CRIEPI)

Figure 5-30 Daily Charging Load of a Weekday in Hokkaido

Load profile hits the peak around 7 PM, since the owner of the EV tends to connect the battery charger immediately after returning home. Peak demand in Hokkaido is around 260MW in (a) case. Because this case is estimated based on Hokkaido's vehicle numbers, which are 15% higher than Sri Lanka in 2040, the peak demand for Sri Lanka is assumed to be around less than 220MW. The day peak is assumed to be around less than 95MW, which has the potential to affect the overall grid demand in the daytime.

The below Figure 5-31 shows the case of a holiday in Hokkaido. This load profile shows a mound shape without work trip usage and it hits a peak of 240MW around 6 PM (Hokkaido).

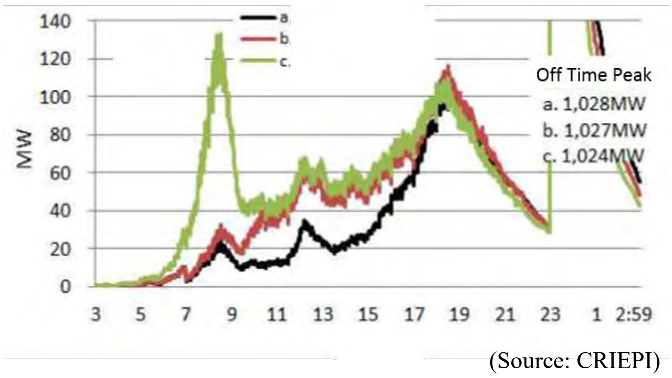


(Source: CRIEPI)

Figure 5-31 Daily Charging Load of a Holiday in Hokkaido

In the study, charging load in the case of electricity tariff discount during the night is estimated as well. If the discount starts at 11 PM, the use of many chargers at the same time causes a precipitous peak of around 1,000MW.

[23] The EV battery consumption and capacity is assumed as: 11.3km/kWh (16kWh/unit) for light-vehicles, 9.5km/kWh (24kWh/unit) for normal vehicles. Charging Power is 3kW/unit.



(Source: CRIEPI)

Figure 5-32 Daily Charging Load of a Weekday in Hokkaido with Midnight Tariff Discount

In order to encourage the use of EVs and avoid peak time charging, CEB has already determined a new tariff menu that has three time blocks for meter and charging separately, as per the below Table 5-10[24]. This menu sets the Off Peak time tariff as around one fourth. Obviously, if more EVs are connected just after 22:30, a more precipitous peak demand will appear, like that shown in Figure 5-32. This will require a countermeasure, such as separating the starting time of Off Peak to avoid severe problems in the power system due to this steep peak.

Table 5-10 New Tariff Menu Released in September 2015

Time of Use (TOU)	Energy Charge (Rs/kWh)	Fixed Charge (Rs/month)
Off Peak (22:30 – 05:30 hrs)	13.00	540.00
Day (05:30 – 18:30 hrs)	25.00	
Peak (18:30 – 22:30 hrs)	54.00	

(Source: CEB)

(5) Conclusion

Although the overall Sri Lankan day peak demand is predicted to be more than night peak in 2040, the night peak at around 7 PM will still remain slightly less than maximum demand (see Figure 5-42) and charging demand for EVs has the potential to push this peak up more. Thus, appropriate countermeasures such as a new tariff system and/or EV-side management, which shifts the charging load into another off peak time, will be required (the method of how to avoid the precipitous demand increase shown in Figure 5-32 is not considered in this Master Plan).
Considering the influence on the whole power system, peak electricity demand is predicted to be less than 60MW in the daytime, and 100MW in the night-time, in Sri Lanka in 2040.

5.2.8 Demand Increase in Large Scale Development Plans and Large Customers' Plans

(1) Large Scale Development Projects

(a) Western Region Megapolis Planning Project (WRMPP)
WRMPP, which was announced by the Ministry of Megapolis and Western Development, is a large scale project for developing not only Colombo city but the surrounding Western Province, aiming to provide comprehensive development such as:
- Transportation, water and electricity infrastructure,
- Airports, sea ports and other logistics hubs,
- Tourism, culture, environmental facilities and so on.

24 http://www.ceb.lk/launching-of-prepaid-ceb-e-card/

Since the Master Plan for WRMPP was combined and released in 2016, there is a high possibility of development in the region following this. However, it is still difficult to say how much will actually be developed because there are few projects under construction today[25].

(b) Port, Harbor and surrounding area development

As a huge development project, the former Sri Lankan government and China formulated a Colombo harbor and surrounding area development plan, the 'Port City' project. After signing the new agreement between the Sri Lankan and Chinese governments, the project launched with the name 'Colombo International Finance City'.

In addition, large-scale expansion projects such as at Colombo International Airport, Hambantota Port and so on are planned.

(c) Export Processing Zones

The Board of Investment of Sri Lanka (BOI) has set up more than ten Export Processing Zones (EPZ) in the country and prepared tax reductions and financial support in order to create a good business environment for domestic/international investors. EPZs are located near Colombo, such as Mirigama-EPZ and Horana-EPZ, and the development plans are included in the WRMPP Master Plan.

(2) Electricity Demand Increase

Although there have been many development projects which were going to have a high electricity demand in the country, some of these were not implemented or constructed well despite grand designs and high targets. Therefore, forecasting future electricity demand from such a big development project is quite difficult due to its unclear feasibility. Since this Master Plan is aiming to evaluate long-term electricity demand, it has to avoid any influence due to the success or failure of a specific project.

This section evaluates the whole electricity demand for large-scale developments by calculating the total of individual construction plans. Even for a large-scale development, every project consists collectively of individual construction plans.

In order to make their own distribution network improvements, each distribution division in Sri Lanka surveys and formulates a large-scale construction plan by private and public sectors in their business region and the JICA team obtained these lists. According to the lists, approximately 200 large-scale constructions were planned in 2015, and most initial demand will appear within 4 years, with total demand increasing at an average of 123MW/year. This section assumes that this increasing volume will appear continuously every year until 2040.

For example, large-scale construction plans ascertained by distribution companies are:

- New construction and expansion plans for Airports, Sea ports and surrounding area
- Infrastructure development for electricity, telecommunications, water, transportation, etc.
- Setting up the EPZ, and factories of private companies
- Large residential/commercial buildings at Colombo and other regional cities
- Hotel construction
- New development of science and technology city

5.2.9 Air Temperature

Generally, the electric power consumption for air conditioning equipment increases as the temperature rises. Figure 5-33 shows the relationship between peak demand and maximum air temperature of a day during 19 Nov 2013 to 19 Jul 2016 in Colombo City, where air conditioners are increasingly popular. In this figure, weekdays/Sundays/Saturdays/Poyaday/public holidays other than Poyaday are shown separately.

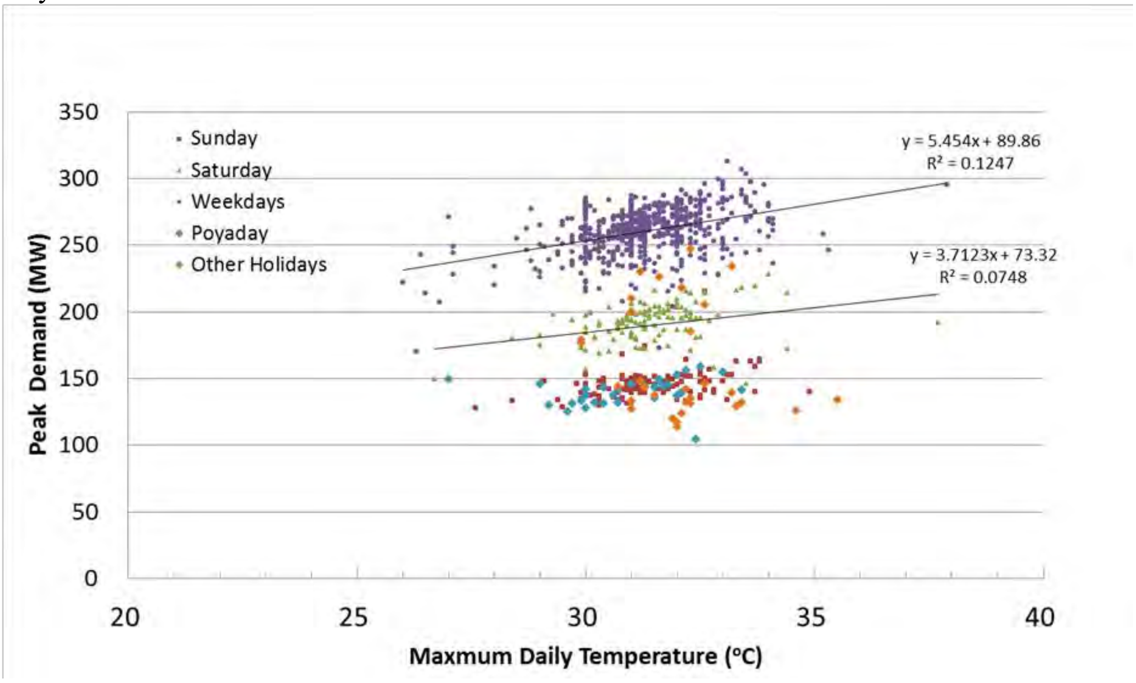
According to this figure,

(i) The maximum demand is high when the temperature is high on weekdays,

(ii) There is little influence from the temperature on Sunday and Poyadays

[25] The same kind of project was planned more than 10 years ago but not implemented due to a change of administration.

(iii) Saturday is intermediate sensitivity between the weekdays and holydays including Sunday. There is a large variance in the data. In order to determine quantitative indicators, it is necessary to accumulate and analyze data in the future. At present, therefore, it is assumed that the fluctuation on weekdays is around 50MW.



(Source: JICA Survey Team)

Figure 5-33 Relationship between Peak Demand and Maximum Temperature of a Day

5.3 Demand Forecast up to 2040

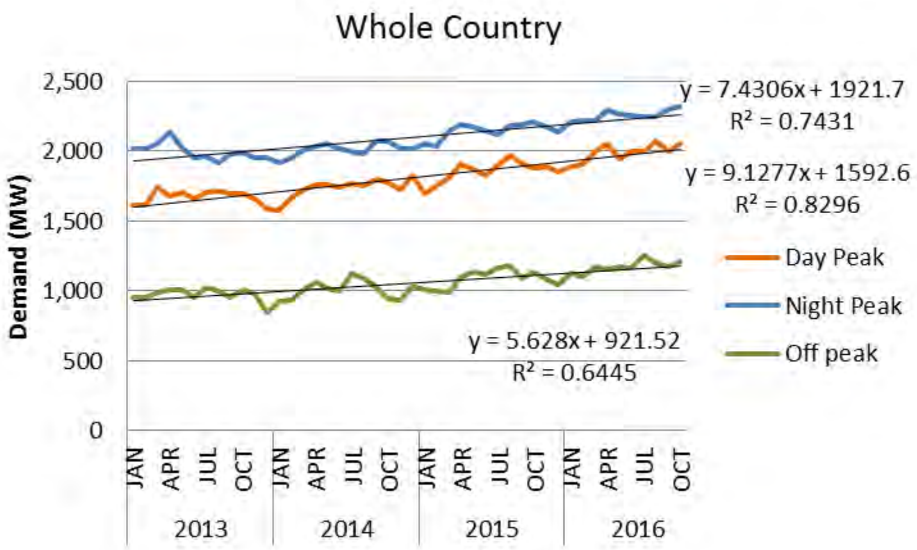
5.3.1 Change of Daily Load Profile

(1) Forest of load profile change

As described in section 5.2.3, since the increase in the day peak is significant at the national level, the increase characteristics of the day peak and the night peak are numerically analyzed, and then the daily load profile in the future and load factor is assumed.

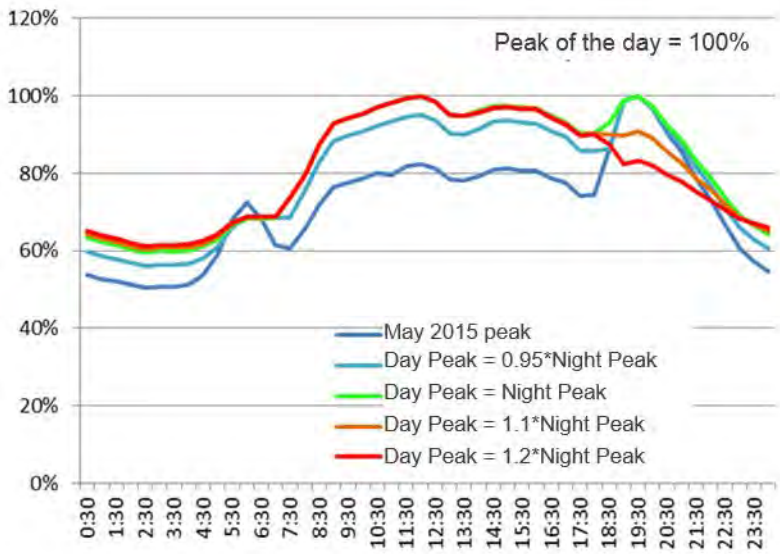
Figure 5-34 shows the results of fitting regression equations to the actual records for the night peak, day peak, and off peak in these 4 years. The ratios of the day peak to the night peak up to 2040 are calculated by using regression equations. Therefore, the day peak reaches the night peak in around 2029, and then it becomes gradually prominent.

The shape of the load profile, which will change when the ratio of the peaks of the day and night changes, is forecasted considering changes for day, night and off peak in accordance with the change in the ratio of the peaks. The load profile (H3) in May 2015, when the annual maximum demand was recorded, is used for the base of this forecast. The estimated load profiles are shown in Figure 5-35.



(Source: JICA Survey Team)

Figure 5-34 Peak Demand of Whole Country with Regression Equations



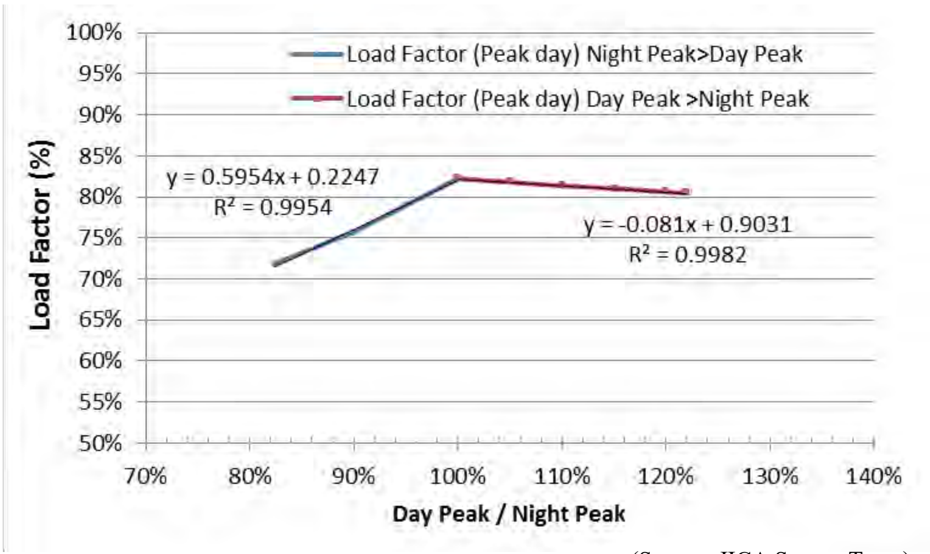
(Source: JICA Survey Team)

Figure 5-35 Change of Load Profile

(2) Forecast of Annual Load Factor

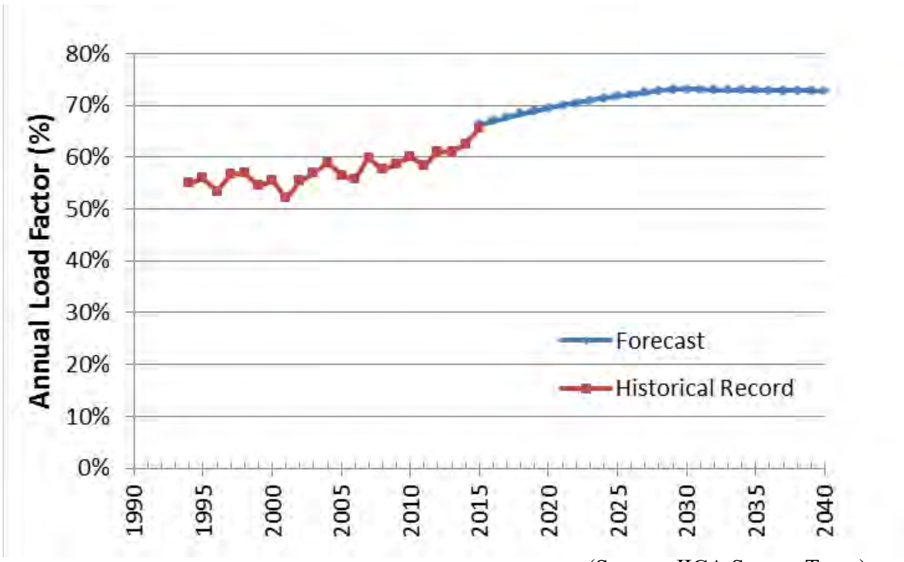
The load factor varies depending on the shape of the daily load profile. The load factor becomes higher in the situation where both night and day peaks appear. In the case of a shape where one peak is sharpened (that is, either the night or the day peak is dominant), the load factor is lower as the sharpening progresses. Figure 5-36 shows the relationship between the ratio of the day and night peak demands and the load factor of the peak day.

Based on the above, the forecasted result of the annual load factor up to 2040 is shown in Figure 5-37. The conversion rate from the load factor of the annual peak day to the annual load factor was fixed at the actual result (89.3%) in recent years.



(Source: JICA Survey Team)

Figure 5-36 Relationship between Ratio of the Day and Night Peak Demands and Load Factor of the Peak Day



(Source: JICA Survey Team)

Figure 5-37 Annual Load Factor up to 2040

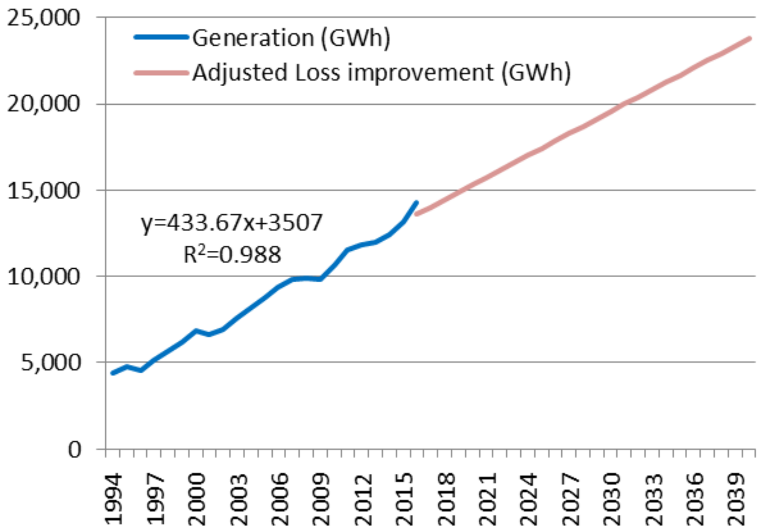
5.3.2 Electric Power Demand (Energy) Forecast

(1) Demand Forecast based on Historical Records (Past Trend Model)

The result of fitting a linear regression equation based on the demand records between 1994 and 2016 is shown in Figure 5-38. The coefficient of determination for the regression equation is 0.99, and it can be said that the linear regression reflects the actual records well.

The future forecast for demand is obtained by adjusting the reduction effect of transmission/distribution loss to the value predicted by the linear regression equation. The results are shown in Figure 5-38 and Table 5-11.

This model is an extension of past data, which is equivalent to a natural increase that is not reflected in special measures and plans, so this assumption is taken as the Low case.



(Source: JICA Survey Team)

Figure 5-38 Demand Forecast (Past Trend Model)

Table 5-11 Demand Forecast (Energy) (Past Trend Model)

Year	Loss Reduction plan (%)	Demand forecast (GWh)	
		Before adjustment	Adjusted
2017	9.9%	13,915	14,016
2018	9.9%	14,349	14,444
2019	9.8%	14,782	14,871
2020	9.8%	15,216	15,298
2021	9.8%	15,650	15,725
2022	9.7%	16,083	16,151
2023	9.7%	16,517	16,577
2024	9.6%	16,951	17,003
2025	9.6%	17,384	17,428
2026	9.6%	17,818	17,853
2027	9.5%	18,252	18,278
2028	9.5%	18,685	18,702
2029	9.4%	19,119	19,126
2030	9.4%	19,553	19,549
2031	9.4%	19,986	19,973
2032	9.3%	20,420	20,395
2033	9.3%	20,854	20,818
2034	9.2%	21,287	21,240
2035	9.2%	21,721	21,662
2036	9.2%	22,155	22,083
2037	9.1%	22,588	22,504
2038	9.1%	23,022	22,925
2039	9.0%	23,456	23,346
2040	9.0%	23,889	23,766

(Source: JICA Survey Team)

(2) Demand Forecast considering GDP forecast (GDP Correlation Model)

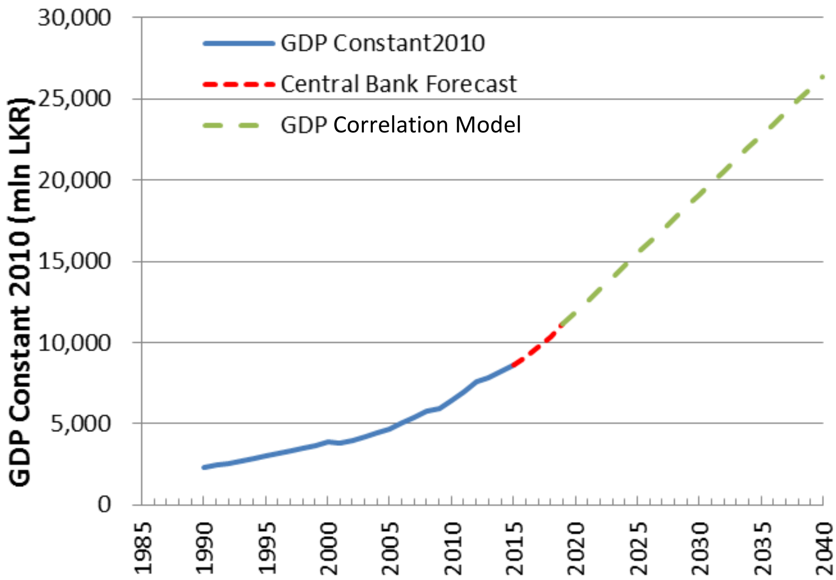
Since power demand is related to GDP growth as shown in section 5.2.2, Electric power demand is forecasted based on the forecasted GDP.

As shown in Figure 5-12, the central bank of Sri Lanka assumes the future GDP for the four-year period from 2016 to 2019, but no official forecast is made for subsequent years. Therefore, electric power demand was predicted by the following procedure.

- Until 2019, adopt the central bank's GDP assumption
- Annual GDP growth rate from 2020 to 2040 is assumed to decrease gradually
- GDP elasticity value of electricity demand shall be 1.0
- The demand forecast value for each year obtained by the above is adjusted based on the reduction plan for the transmission and distribution losses, finally deriving the forecasted demand

Since the increase in electricity demand due to future population increase is included in the GDP increase, no adjustment is made.

As this forecast reflects the economic development plans etc. for the upcoming years, and the assumptions of the further long-term forecast are based on this extension, this model is taken as the Base case.



(Source: JICA Survey Team)

Figure 5-39 GDP Forecast Used for Demand Forecast

Table 5-12 Demand Forecast (Energy) (GDP Correlation Model)

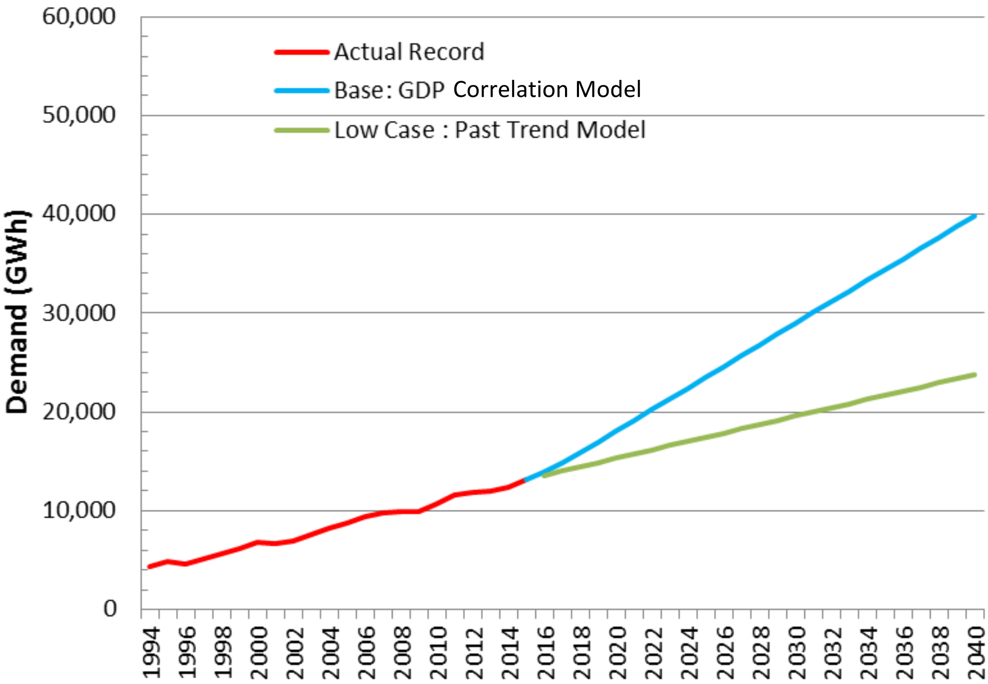
Year	Loss Reduction plan (%)	Demand forecast (GWh)	
		Before adjustment	Adjusted
2017	9.9%	14,794	14,782
2018	9.9%	15,830	15,811
2019	9.8%	16,938	16,911
2020	9.8%	18,046	18,010
2021	9.8%	19,154	19,108
2022	9.7%	20,262	20,205
2023	9.7%	21,370	21,302
2024	9.6%	22,478	22,397
2025	9.6%	23,586	23,492
2026	9.6%	24,694	24,586
2027	9.5%	25,802	25,679
2028	9.5%	26,911	26,771
2029	9.4%	28,019	27,862
2030	9.4%	29,127	28,952
2031	9.4%	30,235	30,041
2032	9.3%	31,343	31,130
2033	9.3%	32,451	32,217
2034	9.2%	33,559	33,304
2035	9.2%	34,667	34,390
2036	9.2%	35,775	35,475
2037	9.1%	36,883	36,559
2038	9.1%	37,991	37,642
2039	9.0%	39,099	38,724
2040	9.0%	40,208	39,805

(Source: JICA Survey Team)

(3) Comparison of the Forecasted Demand (Energy)

The demand prediction results via the past trend model (Low case) and the GDP correlation model (Base case) are shown in Figure 5-40.

The forecasted demand via the GDP correlation model has reached about 40,000 GWh in 2040, which is 1.7 times' the forecast in the past trend model.



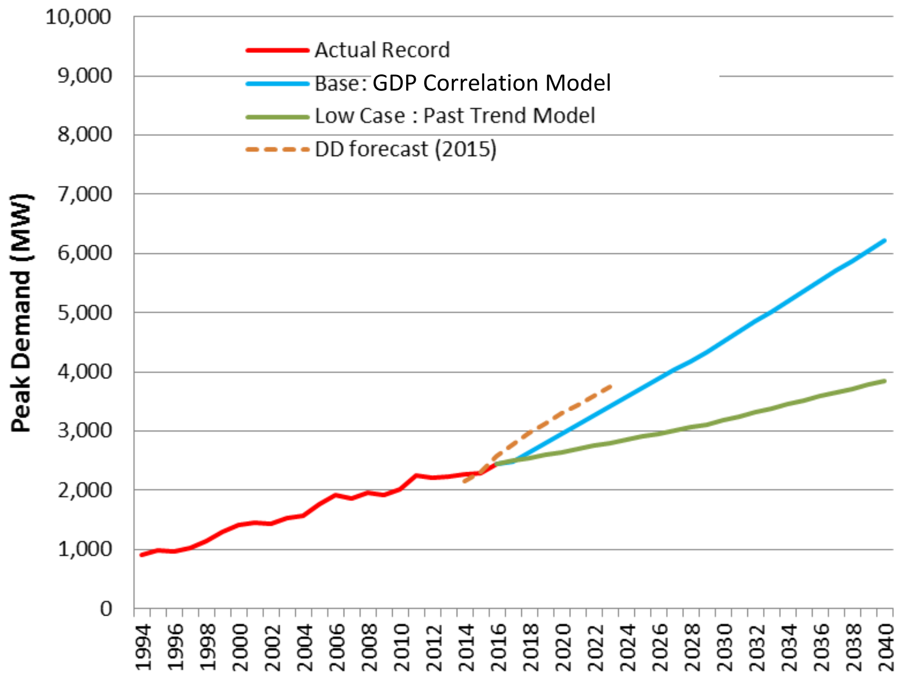
(Source: JICA Survey Team)

Figure 5-40 Forecasted Demand (Energy)

5.3.3 Peak Demand Forecast

The peak demand is forecasted from the forecast demand (energy) and the assumed annual load factor. The peak demands forecasted by the past trend model (Low case) and the GDP correlation model (Base case) are shown in Table 5-13 and Figure 5-41. As a result of forecasting by the GDP correlation model, it is expected that the peak demand will reach about 7,000MW in 2040. The forecast of the GDP correlation model is slightly lower than the prediction value of the distribution department, as shown in the figure.

Since the peak demand of a day will gradually shift from night peak to day peak in the near future and the shape of the load profile will also change, as shown in Figure 5-42, the peak demand forecast takes this change into consideration.



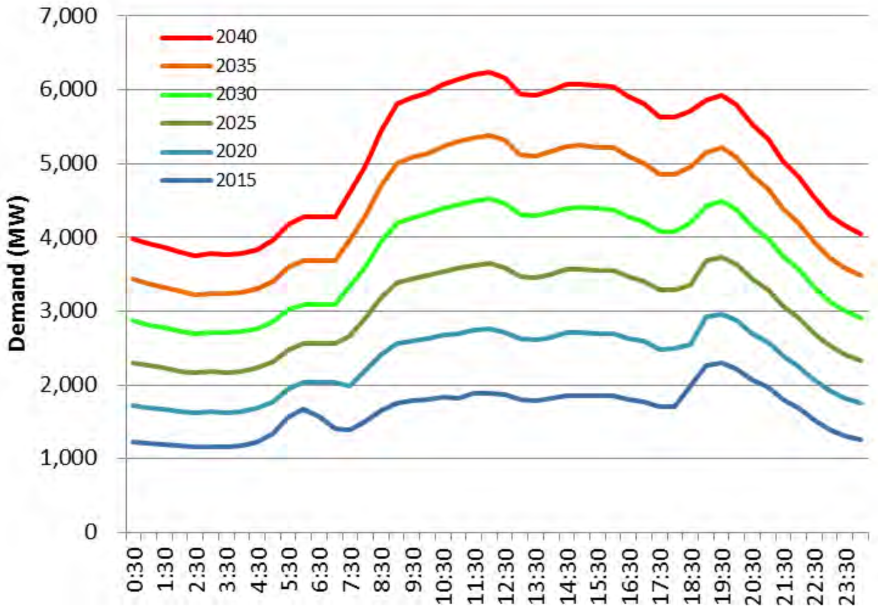
(Source: JICA Survey Team)

Figure 5-41 Forecasted Demand (Peak)

Table 5-13 Demand Forecast (Peak)

Year	Load Factor (%)	Demand forecast (MW)	
		Past trend model	GDP correlation model
2017	68%	2,501	2,491
2018	68%	2,550	2,639
2019	69%	2,599	2,798
2020	70%	2,649	2,955
2021	70%	2,700	3,112
2022	71%	2,751	3,267
2023	71%	2,802	3,422
2024	71%	2,854	3,577
2025	72%	2,906	3,730
2026	72%	2,959	3,883
2027	73%	3,011	4,035
2028	73%	3,064	4,187
2029	73%	3,113	4,333
2030	73%	3,181	4,505
2031	73%	3,249	4,677
2032	73%	3,316	4,849
2033	73%	3,384	5,021
2034	73%	3,451	5,193
2035	73%	3,518	5,365
2036	73%	3,585	5,536
2037	73%	3,653	5,708
2038	73%	3,720	5,879
2039	73%	3,787	6,051
2040	73%	3,854	6,222

(Source: JICA Survey Team)



(Source: JICA Survey Team)

Figure 5-42 Change of Load Profile (GDP Correlation Model)

5.3.4 Evaluation of Factors Affecting Power Demand Forecast

There seem to be factors that are thought to have a significant influence on the future demand, as described in sections 5.2.4 to 5.2.9. These factors are uncertain both in terms of the realization of their timing and their scale, and they may be delayed considerably depending on various circumstances such as delays in decision making.

However, it is desirable to understand the degree of influence of these factors and reflect this in the demand forecast, especially the peak demand forecast. Therefore, in this section, an evaluation of the factors that seem to have a large impact is conducted and we attempt to reflect this in the forecast model (Upper Variation model; High case), corresponding to the case where electric power demand is beyond the expectation.

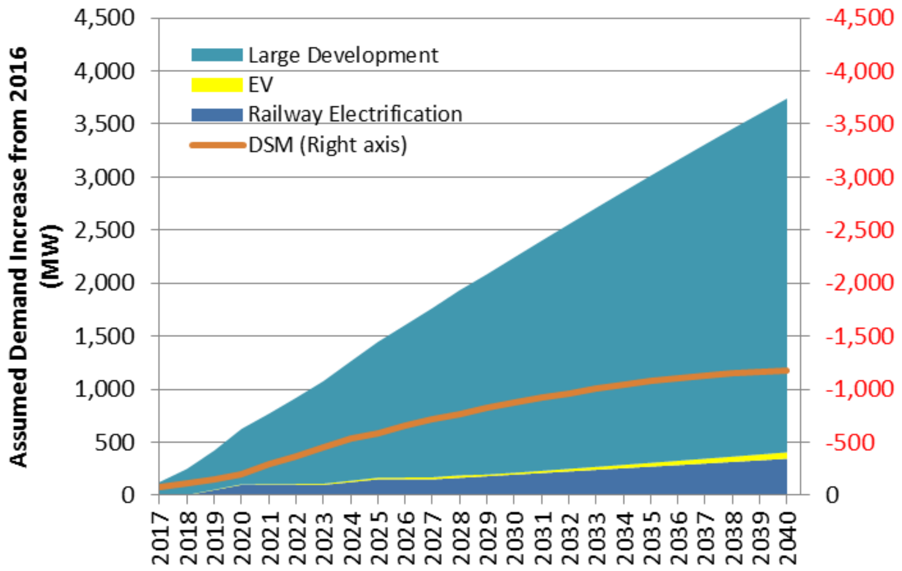
(1) Evaluation of the impact on the peak demand

The results of the evaluation of each factor to the peak demand are summarized and shown in Table 5-14 and Figure 5-43, and the assumptions for the evaluation of each factor are shown in the following (a) to (e). Here, influence of air temperature is not counted in the calculation since it is not directly related to the demand increase via development.

Table 5-14 Evaluation Results for Impact to Peak Demand (MW)

Factor		2020	2030	2040
(a)	Demand Side Management (DSM)	▲200	▲870	▲1,180
(b)	Electrification of Railways	100	200	350
(c)	Introduction of RTS	0	30	30
(d)	Popularization of Electric Vehicles	10	20	60
(e)	Large-scale Development Plans and Large Customers' Plans	520	2,030	3,330
	Subtotal (increase)	**630**	**2,270**	**3,770**
	Total	**430**	**1,400**	**2,590**

(Source: JICA Survey Team)



(Source: JICA Survey Team)

Figure 5-43 Assumed Peak Demand Increase (MW)

(a) Demand Side Management (DSM)

As described in section 5.2.4, it is expected that the amount of electricity will reduce by about 7,500 GWh by 2040, since this is mainly dependent on energy saving measures. Since the deviation due to the time zone is considered to be small, it is converted into the peak demand by the load factor. As a result, a peak reduction of about 1,200MW is expected in 2040.

In addition, introduction of solar power via roof-top smart homes, the scale of which is 500MW in 2040, is planned. If this is realized as planned, it is expected that up to 500MW of electric power will be supplied to CEB's electric power system through the distribution lines, and the required capacity for CEB's peaking power supply can be reduced. However, since the electricity demand itself does not decrease in total, it is not included in the peak demand reduction amount.

(b) Electrification of Railways

Necessary peak demand for the railway electrification is estimated based on the evaluation described in 5.2.5, considering the plans in the Transport Master Plan for WRMPP.

The assumption for the requirements of electric power demand for the railway is: the electrification project in the Colombo Metropolitan area, which was designated as a low case in the future, will be completed in 2027, and after that, electrification will continue at the same pace. (That is, High case: completion of electrification of the main line will not be completed by 2040, but after 2042.)

150MW of peak demand for railway electrification in the metropolitan area is adopted as the safety side assumption, though the peak demand for the railway and the power system might not occur at the same time.

(c) Introduction of RTS

Similar to the impact evaluation for the railway, peak demand increase due to the development of 7 new RTS routes (34MW in total), as mentioned in section 5.2.6, is assumed considering the plans in the Transport Master Plan for WRMPP.

(d) Popularization of Electric Vehicles

As described in section 5.2.7, it is assumed that the share of electric vehicles will gradually increase in the future, and the maximum charging loads in 2040 for daytime and night-time are assumed to be about 60MW and 100MW respectively.

Introducing electric vehicles and encouraging off-peak charging is expected to be a good measure for improving load factor by increasing off-peak demand. Taking measures to avoid concentration of the charging demand is vital, and it is desirable to take action to increase off-peak demand. Therefore, the case where an off-peak tariff is applied is adopted as an assumption for the peak demand estimation.

(e) Large-scale Development Plans and Large Customers' Plans

As described in section 5.2.8, the increase in power demand accompanying large-scale developments in recent years is about 123MW per year on average.

The future demand increase due to large-scale developments, including the Megapolis plan, is assumed considering this incremental amount.

Regarding large-scale developments, in particular, it is extremely difficult to specify the realization timing of the plans, and demand may suddenly increase in the completion year; therefore, an average increase is adopted for the base in the estimation of the demand increase.

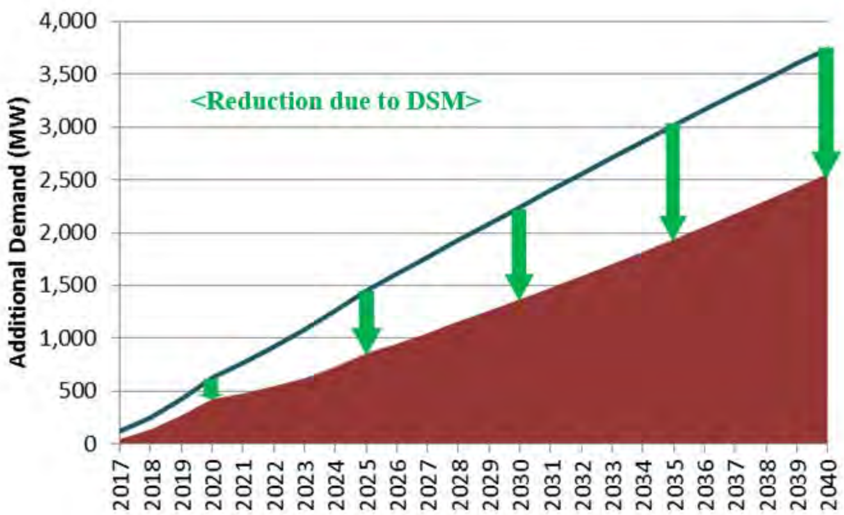
(2) A Model for demand beyond the expectation (Upper Variation model)

In 5.3.4(1), Figure 5-43 shows the positive or negative effect on the peak power. Figure 5-44 shows the additional demand, which is an increment of the peak demand that needs to be secured when these plans and reduction measures are realized.

Figure 5-45 shows the above-mentioned additional demand, two cases that are with/without considering DSM effects, added to the low case of demand forecast corresponding to the case where special measures are not taken into consideration.

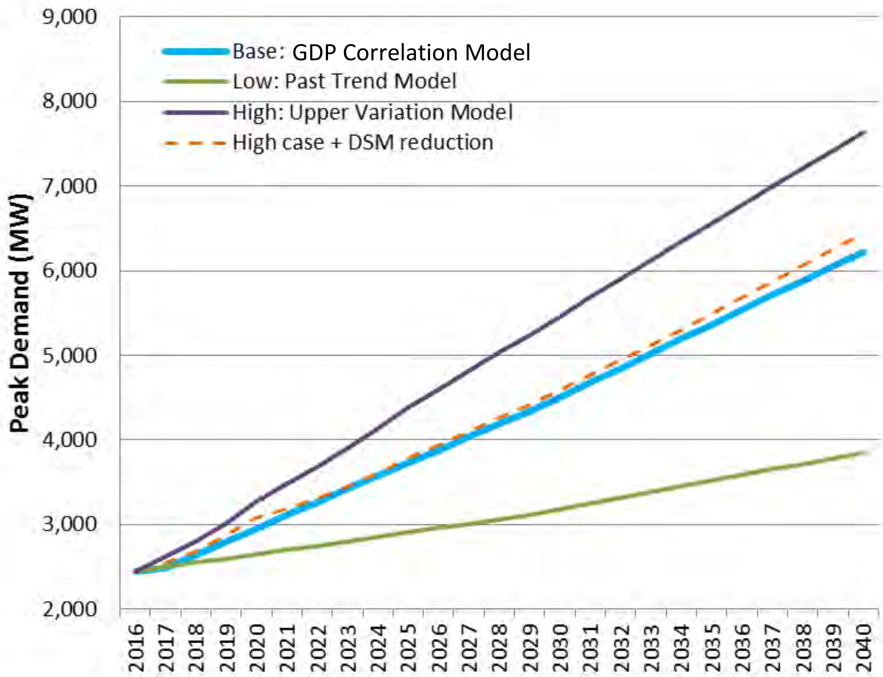
As shown in this figure, the demand, which is considered additional demand including large development plans except for DSM reduction, the forecasted demand reaches about 7,600MW in 2040, which is about 1,400MW larger than the Base case. Therefore, this forecast case is set as the High case for the demand forecast.

The demand, which is considered the reduction effect due to DSM, is quite close to the Base case of forecasted demand. This means that the demand reduction due to DSM is very important for keeping the Base case demand. Therefore, it is highly desirable to promote DSM as planned.



(Source: JICA Survey Team)

Figure 5-44 Additional Demand Required to be Supplied



(Source: JICA Survey Team)

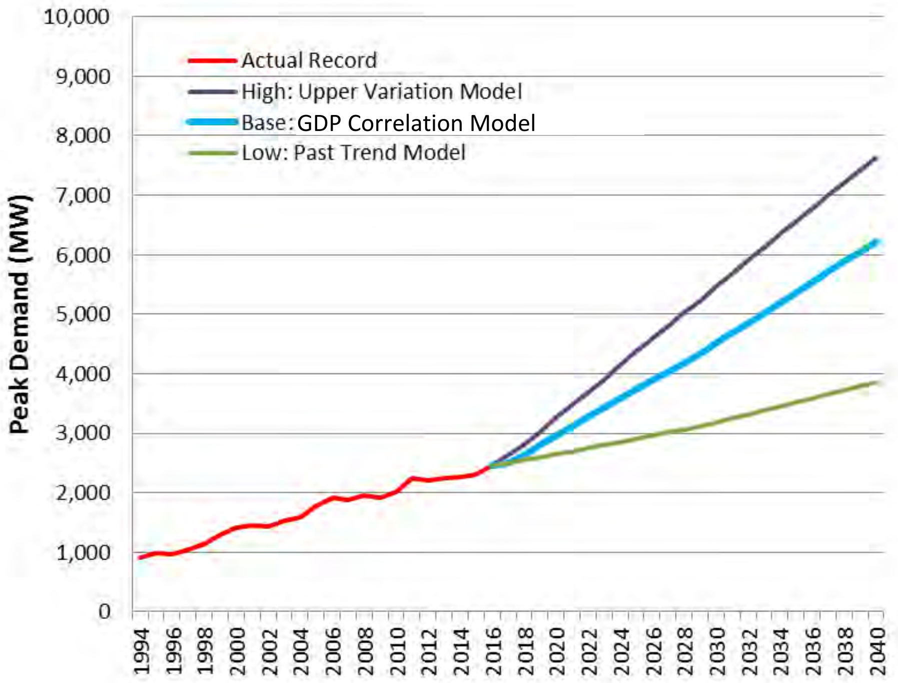
Figure 5-45 High case and DSM reduction

5.3.5 Recommended Demand Forecast

In this section, the recommended long-term power demand forecast is shown as the conclusion to the study results discussed in this chapter.

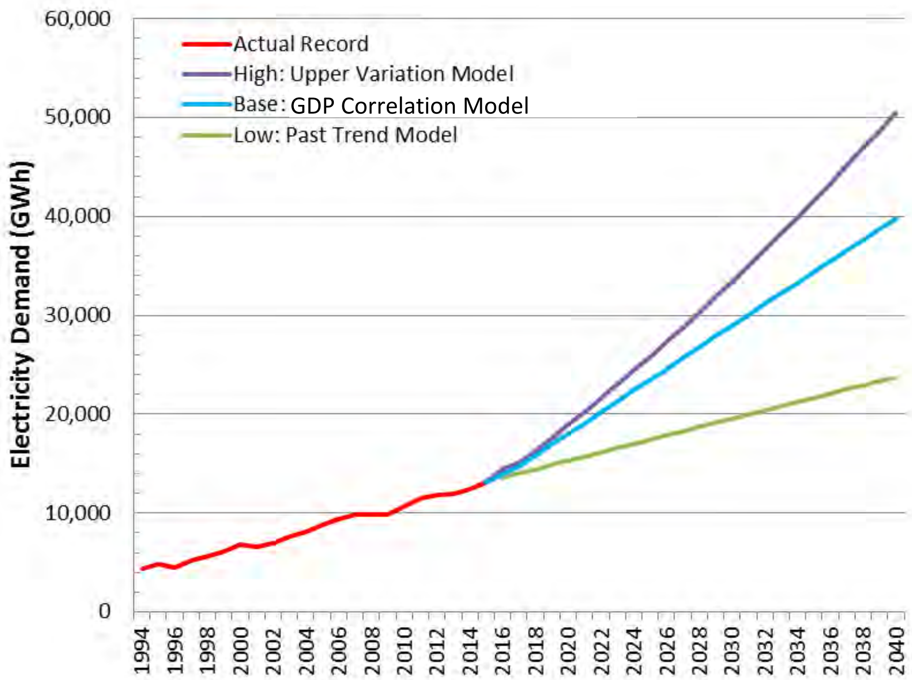
The long-term demand forecasts (Base case, High case, Low case) up to 2040 are shown in Figure 5-46 (Peak), Figure 5-47 (Energy), and Table 5-15.

Here, the demand forecast (Energy) of the High case is calculated from the forecasted peak demand and the load factor shown in Table 5-13.



(Source: JICA Survey Team)

Figure 5-46 Long Term Demand Forecast up to 2040 (Peak)



(Source: JICA Survey Team)

Figure 5-47 Long Term Demand Forecast up to 2040 (Energy)

Table 5-15 Recommended Demand Forecast up to 2040

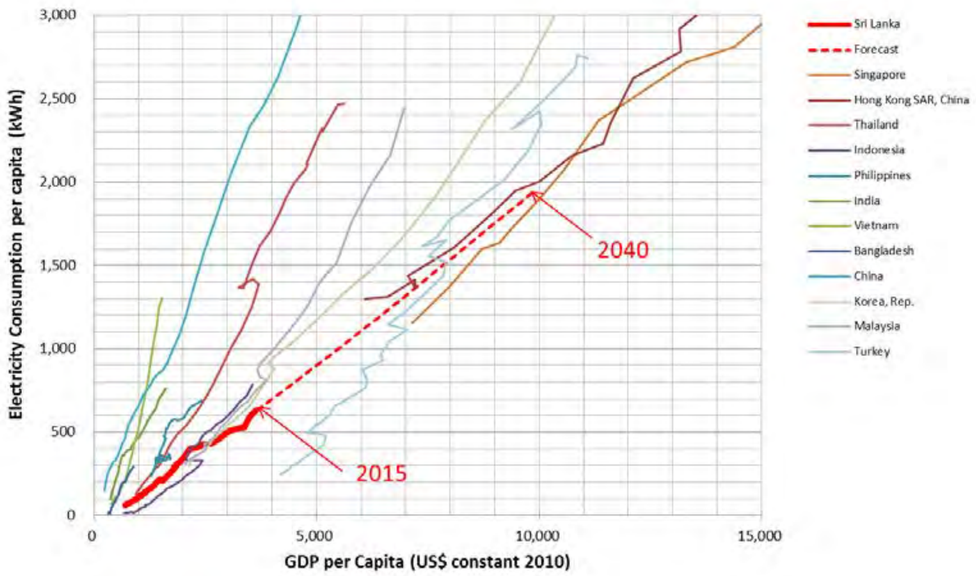
Year	Load Factor (%)	Forecasted Demand					
		Base case		Low case		High case	
		GDP correlation model		Past trend model		Upper variation model	
		(GWh)	(MW)	(GWh)	(MW)	(GWh)	(MW)
2017	68%	14,782	2,491	14,016	2,501	15,580	2,625
2018	68%	15,811	2,639	14,444	2,550	16,764	2,798
2019	69%	16,911	2,798	14,871	2,599	18,257	3,020
2020	70%	18,010	2,955	15,298	2,649	19,957	3,275
2021	70%	19,108	3,112	15,725	2,700	21,366	3,480
2022	71%	20,205	3,267	16,151	2,751	22,759	3,681
2023	71%	21,302	3,422	16,577	2,802	24,264	3,898
2024	71%	22,397	3,577	17,003	2,854	25,922	4,139
2025	72%	23,492	3,730	17,428	2,906	27,588	4,380
2026	72%	24,586	3,883	17,853	2,959	29,113	4,598
2027	73%	25,679	4,035	18,278	3,011	30,610	4,810
2028	73%	26,771	4,187	18,702	3,064	32,167	5,031
2029	73%	27,862	4,333	19,126	3,113	33,637	5,231
2030	73%	28,952	4,505	19,549	3,181	35,071	5,457
2031	73%	30,041	4,677	19,973	3,249	36,496	5,682
2032	73%	31,130	4,849	20,395	3,316	37,909	5,905
2033	73%	32,217	5,021	20,818	3,384	39,311	6,127
2034	73%	33,304	5,193	21,240	3,451	40,703	6,347
2035	73%	34,390	5,365	21,662	3,518	42,083	6,565
2036	73%	35,475	5,536	22,083	3,585	43,452	6,781
2037	73%	36,559	5,708	22,504	3,653	44,809	6,996
2038	73%	37,642	5,879	22,925	3,720	46,156	7,209
2039	73%	38,724	6,051	23,346	3,787	47,481	7,419
2040	73%	39,805	6,222	23,766	3,854	48,806	7,629

(Source: JICA Survey Team)

5.3.6 Macro-evaluation of Demand Forecast Results

To confirm the validity of the demand forecast results, a study comparing with the actual demand of neighboring countries is conducted. Figure 5-48 shows the actual records and the demand forecast results (the base case of the GDP correlation model) for Sri Lanka, on a relationship chart of GDP per capita and electric power consumption per capita during 1973 to 2013.

According to this figure, the relationship between GDP and electricity consumption differs depending on the country, reflecting the different electricity usage conditions due to the differences in climate, industrial structure, and so on. However, the lines of each country in the figure increase almost linearly. Forecasted demand for Sri Lanka up to 2040 is an extension of the previous records and looks to extend linearly, the same as the actual records of the neighboring countries. Therefore, it seems that the demand forecasting method is reasonable.



(Source: JICA Survey Team)

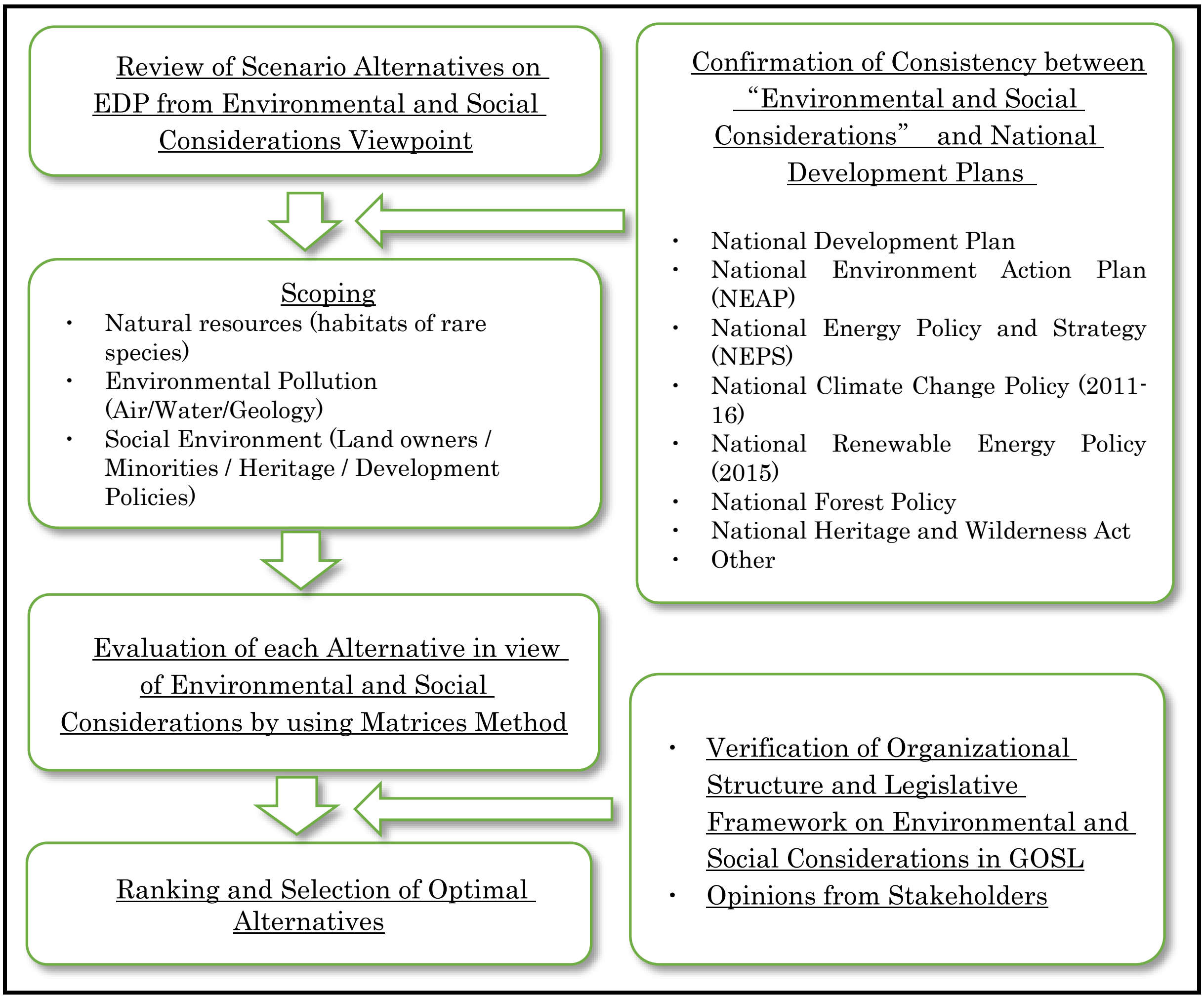
Figure 5-48 Relationship Chart of GDP per Capita and Electric Power Consumption

Chapter 6. Evaluation of Environmental and Social Considerations

6.1 Outline of Strategic Environmental Assessment

Currently, SEA is widely introduced in many developed countries as a tool to integrate Environmental and Social Considerations into a decision-making process but there is no single approach to SEA that can be applied to all cases and no internationally recognized definition of SEA, since there are differences in the scope, comprehensiveness, duration and degree of association to policies, plans and programs.

Amid this situation, the JICA survey team conducted an SEA from the viewpoint of environmental and social considerations, concerning development of various power sources to be considered in the alternative scenario draft plans in "Power development plan/power transmission system reinforcing plan" using the method shown in Fig. 6-1, for evaluations on each type of generation development. The team quantitatively assessed the environmental load and ranked this from the viewpoint of environmental conservation.



(Source: JICA Survey Team)

Figure 6-1 SEA Approach Method for Evaluation on Generation Development Plan

The detailed methodology is described below.

i) Selection of scoping items and indicators

From the viewpoint of environmental and social considerations, in order to analyze and evaluate each power generation development plan, scoping with the natural and social environments as the evaluation items is implemented.

ii) Evaluation on scoping items

A quantitative evaluation is to be carried out on the scoping items used by the evaluation criteria, the score for which covers 4 levels, from 0 to -3.

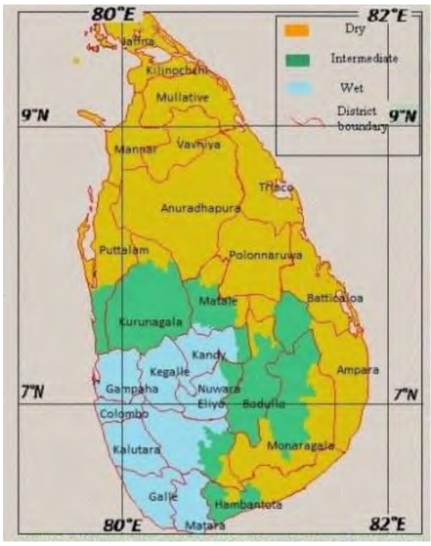
iii) Matrix Evaluation concerning each power generation development plan

A matrix evaluation on each power generation is to be carried out to grasp quantitatively their impacts on the environment.

6.2 Overview of the Present State of the Proposed Project Area

(1) Natural Environment

Sri Lanka Democratic Socialist Republic is an island country with a land area of 65,610 km^2, in the southeast of the Indian sub-continent. The country belongs to the equatorial subtropical zone and is affected by monsoons. Due to the Northeast monsoon there are rainy seasons from December to January in the northern and eastern parts, and due to the southwest monsoon, the western part, the southern part and the central part experience a rainy season from May to July. 19,400 km^2, which is about 29.5% of the land area, is covered with forests. In addition, the climate zone of the country is divided into three types, a wetland in the southwestern part, a dry region in the northeast to the southwestern part, and an intermediate part in between, and such a unique climate contributes to the existence of various vegetation, and a variety of animals that make it their habitat.



(Source: Malaria Journal, Uni. Colombo)

Figure 6-2 Climate Zone

(a) Current status of biodiversity

Sri Lanka is the country with the highest number of animals (mammals, reptiles, amphibians, freshwater fishes) and plants (flowering plants) per unit area inhabiting and breeding in the Asian region, which makes it one of the richest countries in biodiversity with 3,209 animals and 3,154 plants (angiosperms).

Table 6-1 Species Diversity of Sri Lanka's Fauna and Flora

Taxon	Number	Taxon	Number
Land snails	253 (205)	Freshwater fish	91 (50)
Dragonflies	118 (47)	Amphibians	111 (95)
Bees	130 (?)	Reptiles	193 (124)
Ants	194 (33)	Birds	693 (35)
Carabid beetles	525 (?)	Mammals	95 (21)
Butterflies	245 (26)	Total (Fauna)	3,209 (943)
Spiders	510 (257)	Angiosperms	3,154 (894)
Freshwater crabs	51 (50)	Total (Flora)	3,154 (894)

(Source: Sri Lanka's Fifth National Report to the Convention on Biological Diversity 2014)

(b) Designation and management status of protected areas

Outstanding nature in Sri Lanka is protected by two different administrative agencies, "Protective Forest" designated and managed by the Forest Department based on the Forest Law, and "Protected Areas", designated and administered by the Department of Wildlife Conservation under the Environment Protection Act.

The protected area designated and controlled by both administrative agencies covers about 35% of the nation, with a total area of about 2,267,966 ha (using the figures in the Forest Department and Department of Wildlife Conservation's data accumulated by IUCN) (refer to the table and figure below). In addition, a Ramsar area of 198,172 ha (as of 2016) is designated at 6 places based on international treaties (conventions on wetlands of international importance as a waterfowl habitat).

Table 6-2 Number and Extent of Protected Areas

Protected Area Category and Number / Area (ha)			
(Under **Forest Department**)		(Under **Department of Wildlife Conservation**)	
Wilderness Area (1)	11,427	National Park (22)	535,182
Conservation Forest (75)	118,759	Nature Reserve (5)	64,585
Reserved Forest (371)	1,044,009	Sanctuary (65)	376,943
Forest Plantation	75,557	Strict Natural Reserve (3)	31,574
Mangrove (15)	1,153	Jungle Corridor (1)	8,777
Sub Total	1,250,905	Sub Total	1,017,061
Total	**2,267,966**		

(Source: Sri Lanka's Fifth National Report to the Convention on Biological Diversity 2014)

(Source: CEA)

Figure 6-3 Protected Areas administered by Department Wildlife Conservation

(Source: DoF)

Figure 6-4 Protected Areas administered by Forest Department

Table 6-3 Ramsar Sites

No.	Name	Area (ha)	Designation
1	Vankalai Sanctuary	4,839	2010
2	Wilpattu Ramsar Wetland Cluster	165,800	2013
3	Kumana Wetland Cluster	19,011	2010
4	Bundala	6,210	1990
5	Annaiwilundawa Tanks Sanctuary	1,397	2001
6	Maduganga	915	2003
Total		198,172	

(Source: CEA)

(Source: JICA Survey Team)

Figure 6-5 Ramsar Sites

(Source: CEA)

Figure 6-6 Protected Mangrove Areas

(2) Social Environment

(a) Ethnic composition and living area

The population of Sri Lanka is 20,277 thousand (2012), and is roughly divided into four ethnic groups: Sinhalese (74.9%), Sri Lanka/Tamil (11.2%), India/Tamil (4.1%), Moore (9.3%), and other Peoples (Vedicians, Burgher).

Due to their historical background, these ethnic groups are settled together. The Sinhalese are all over the southern region, and the Sri Lanka/Tamil people are in the Batticaloa district in northern Jaffna and eastern provinces. India/Tamil people are mainly settled in Kandy, Matale, and the Muwara District of the Central Highlands, and Moore people are commonly found in the Mannar district on the northwest coast and Ampara district in the eastern province.

(b) Type of Land Use

Approximately 35% of the country is agricultural land, approximately 31% is forests and wildlife protected areas, and the remaining 34% is tea fields, pastures and urban areas. Details of land use are as shown in the table below.

Table 6-4 General Land Balance Sheet as of 1996

Type of land use	Area (ha, %)
Utilized land (agricultural and urban)	2,635,000 (40)
Forests, wildlife and catchment areas	2,000,000 (31)
Sparsely utilized land (under tea, patana, etc.)	728,800 (11)
Reserved land (reservoirs, streams, roads etc.)	585,300 (9)
Steep land (sloping to excess for agriculture)	380,000 (6)
Barren land (rock, sand, poor vegetation cover)	77,000 (1)
Land over 5000 feet/1500 m altitude	76,400 (1)
Mangroves and marshes	70,000 (1)
Total land area	6,552,500 (100)

(Source: Planning sustainable management of land resources in Sri Lanka)

6.3 Review of Frameworks for Environmental and Social Considerations in Sri Lanka

6.3.1 Legal and Regulatory Frameworks for Environmental and Social Considerations

(1) Regulatory Framework for Strategic Environmental Assessment

Strategic Environmental Assessment (SEA) is still not a mandatory requirement in NEA (No. 47, 1980), which was amended in 2000. However, the Cabinet of Ministers has approved implementation of SEA for policies, programs and plans, and all Ministries, Departments and Authorities who are responsible for implementing a new policy, plan or program are expected to carry out an SEA prior to its implementation. Moreover, the Cabinet of Ministers directed the CEA to prepare simple guidelines on what SEA is, and how to carry out an SEA for Policy, Plan or Program.

Based on the above request of the Cabinet of Ministers, CEA has prepared “A simple Guide to Strategic Environmental Assessment” since 2008, and also established an environmental unit responsible for implementation of SEA in CEA in 2008.

CEA has implemented SEA on the following projects as case studies based on its guidelines.

(a) Trincomalee Development Plan (2008)
(b) Hambantota Development Plan (2010)
(c) Northern Province Development Plan (2011)

However, there are few instances of SEA being carried out universally in every Ministry, Department and Authority as the following note is attached in “A simple Guide to Strategic Environmental Assessment” prepared by CEA.

> ***Note:***
> *A copy of the SEA report should be sent to the Central Environmental Authority for review and comments, if any. It should be noted that unlike in the case of project level EIA reports there is no legal requirement for obtaining CEA approval for SEAs at present.*

In addition, since CEA has revealed its views that compilation and submission of an SEA for “The Project of Electricity Sector Master Plan” are commended to CEB’s discretion (in interviews with CEA and JICA), the SEA for the project will not be complied and submitted to the CEA as aforementioned based on the discussion with CEB.

(2) Related Laws and Regulations on Strategic Environmental Assessment (SEA)

The key laws and regulations that should be given consideration for implementation of SEA are listed in the below table.

Table 6-5 Key laws and regulations concerning Environmental and Social Considerations

Law/Regulation	Outline	Responsible Authority
Constitution of Sri Lanka, 1978	Specify protection of the environment (nature, life) that is the responsibility and regulation of the people.	—
National Environmental Act, 1980, 1988、2000ammended.	Law as the basis of environmental conservation. Provide the authority, functions, responsibilities etc. of the Central Environment Agency (CEA).	CEA
National Environmental Action Plan 1992-1996	Specify environmental measures for the 21st century and measures to be taken for each sector (classified into 9 sectors).	MoMDE
（Order based on NEA） ● A Simple Guide to Strategic Environmental Assessment ,CEA, 2008） ● Guidance for Implementing the Environmental Impact Assessment Process, CEA, 2006）	Specify EIA approval agency, scoping method etc.	CEA
(Regulation based on NEA) ● National Environmental Act, 1990	Specify environmental standards and measurement methods concerning air quality, noise and water quality.	CEA
Forest Act,1966	Specify designation and management policy concerning forest development, deforestation, use of forest products and forest protection.	DOF
Fauna and Flora Protection Act, 1937	Specify restrictions on commercial transactions of animals and plants, regulation of growth and habitat of animals and plants.	CEA
National Heritage and Wilderness Areas Act, 1988	Specify protection and management of unique ecosystems, genetic resources, rare animals and plants from the viewpoint of protecting the natural environment and protecting wildlife.	CEA MoCA DOF
Fisheries and Aquatic Resources Act, 1996	Specify protection and management of fishery resources on the inner water surface.	MoFARD
Monuments and Archaeological Sites and remains Act, 1958	Specify designation and management of historical culture and natural heritage.	CEA MoCA DOF
Coastal Conservation Act No. 57/1981	Specify regulations for coastal zone administrative framework and regulations.	MoFOR
Land Acquisition Act, 1986	Specify provisions on land acquisition and compensation etc.	MoLLD
（Draft of Law） National Involuntary Resettlement Policy (NIRP)	Mainly specifies guidelines for settlement planning for involuntary immigrants.	MoR

(Source: JICA Survey Team)

(3) International treaties/conventions concerning SEA

International treaties/conventions ratified by Sri Lanka that need to be considered in implementing SEA are as follows.

Table 6-6 International Treaties/Conventions Concerning SEA in Sri Lanka

Name of Convention	Outline	Ratification
International Plant Protection Convention	Control pests and diseases affecting plants and plant products.	1952
UNESCO "Human and Biosphere" (MAB) Plan	Biosphere reserves are areas comprising terrestrial, marine and coastal ecosystems. Each reserve promotes solutions reconciling the conservation of biodiversity with its sustainable use.	1970
International Trade in Endangered Species of Wild Fauna and Flora	Its aim is to ensure that international trade in specimens of wild animals and plants does not threaten the survival of the species in the wild, and it accords varying degrees of protection to more than 35,000 species of animals and plants.	1975
Convention concerning the Protection of World Cultural and Natural Heritage	Aimed at preventing the deterioration or disappearance of items of cultural or natural heritage in nations around the world.	1964
Convention on Wetlands of International Importance especially as Waterfowl Habitats	Parties designate important waters for flora and fauna, especially birds, and the designated places are registered in the secretariat's register. Parties summarize and implement plans on the proper use and preservation of designated areas.	1975
Convention on the species of mobile wild animals	Purpose of protecting species of wild animals moving across borders.	1983
Convention on Biological Diversity	Promote conservation of biodiversity, its sustainable use, benefits arising from utilization of genetic resources, appropriate access to genetic resources and appropriate technology transfer and financing.	1993

(Source: JICA Survey Team)

(4) Related Global Actions on Climate Change (INDC of Sri Lankan)

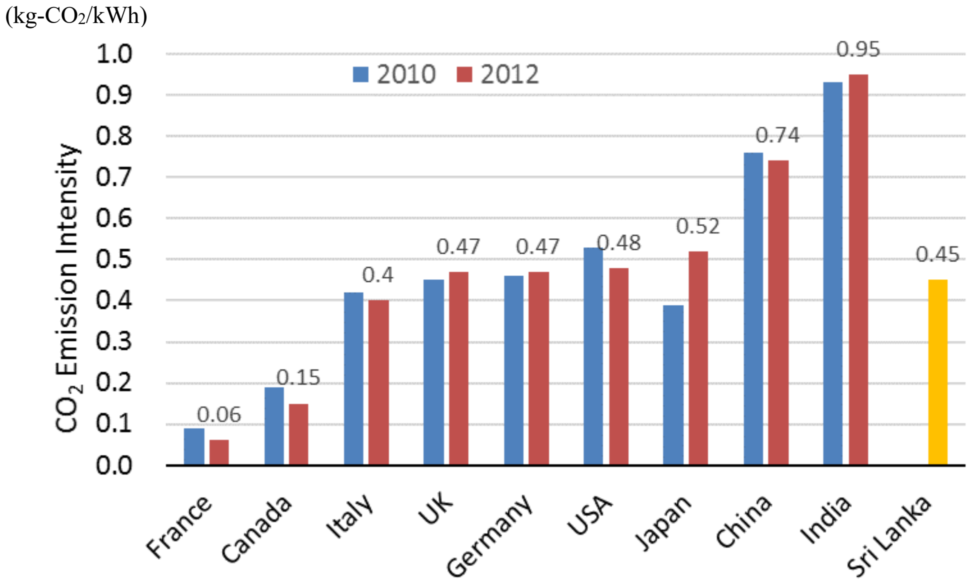
The Ministry of Mahaweli Development and Environment in Sri Lanka, as the National Focal Point to the United Nations Framework Convention on Climate Change (UNFCCC), submitted its Intended Nationally Determined Contributions (INDC) in accordance with Decision CP-20 in November 2015 and adopted by the Paris Agreement in December 2015. Sri Lanka’s INDCs adopted by the Paris Agreement aim to reduce the Greenhouse gas (GHG) emissions against the Business-As-Usual (BAU) scenario by 20% in the energy sector (4% unconditionally and 16% conditionally) and by 10% in other sectors (transport, industry, forests and waste), 3% unconditionally and 7% conditionally, by 2030.
Table 6-7 shows the projects or policies which are listed in the INDCs to ensure emission targets for GHG.

Table 6-7 Projects or Policies Listed in INDCs to Ensure Emission Targets

	Energy Sector	Installed Capacity
1	Development of large scale wind power farms (This could replace the equivalent of energy generation from the planned thermal power plants)	514MW
2	Development of solar power plants	115MW
3	Development of biomass power plants (fuel wood, municipal waste, industrial waste and agricultural waste)	104.62MW (targeted by 2025)
4	Development of Mini-hydropower plants	176MW
5	Promotion of Demand Side Management (DSM) activities and Building Management Systems (BSM)	-
6	Energy saving policy in line with the promotion of RE policies (more than 50% share of the total energy)	-
	Total Installed Capacity	**909.62MW**

(Source: Intended Nationally Determined Contributions, Ministry of Mahaweli Development and Environment)

In view of COP21, the total CO_2 emission volume and CO_2 emission intensity (kg-CO_2/kWh) for each alternative power development scenario is to be estimated and each alternative scenario is evaluated numerically, in reference to the CO_2 emission intensity in the power sector of each country as shown in Figure 6-7.



Remarks: Sri Lanka's data is actual result in 2015

(Source: The Federation of Electric Power Companies of Japan)

Figure 6-7 Country-wise CO_2 Emission Intensities in Power Sector

6.3.2 Differences between JICA Guidelines and Sri Lanka Regulations (SEA Guidelines)

The differences between the JICA Guidelines and Sri Lanka SEA Guidelines are summarized in Table 6-8.

Table 6-8 Differences between JICA Guidelines and Sri Lanka SEA Guidelines

Items	JICA Guidelines	Sri Lanka Regulations	Key differences
Implementation of SEA	JICA applies an SEA when conducting Master Plan or Feasibility Study.	SEA is still not a mandatory requirement in National Environmental Act. However, the Cabinet of Ministers has approved implementation of SEA for policies, programs and plans since 2006 and all Ministries, Departments and Authorities who are responsible for implementing a new policy, plan or program are expected to carry out an SEA prior to its implementation.	Guidelines on SEA adopted by Cabinet require that following items are included in SEA. 1. Information to be cleared. ➢ What are the goals and objectives of the policy, plan or program? ➢ What are the feasible options for the policy, plan or program? ➢ What are the most pronounced environmental issues (both positive and negative) associated with each of the preferred options? ➢ How significant are these environmental effects? ➢ What can be done to avoid or lessen the negative effects and enhance the positive effects? 2. Key items to be mentioned ➢ The existing situation in the particular sector and/or region. ➢ The major goals and objectives of the policy, plan or program. ➢ The most pronounced Environmental issues (adverse as well as positive) of the preferred options. ➢ The significance of these environmental effects. ➢ What can be done to avoid or lessen the negative effects and enhance the positive effects? ➢ Details of consultations with any stakeholders including internal meetings with other sections as well as with external agencies and how the outcomes of these consultations were integrated into the policy, plan, or program.
	(specifies) Specific technical guidelines for implementing SEA have not been established yet.	Specific technical guidelines for implementing SEA have not been established yet.	No gaps
EIA Report	For projects that are expected to have serious adverse environmental impact, EIA report is requested.	Based on NEA (National Environmental Act), projects needing EIA/IEE report are specified.	No gaps

Items	JICA Guidelines	Sri Lanka Regulations	Key differences
Alternative examination	Examination of available alternatives is mandated.	Examination of available alternatives is mandated by EIA Guideline.	No gaps
Environmental checklist	Environmental checklist specific to EIA is provided.	No.	Gap existence
Resettlement Action Plan （RAP）	The project proponent is obligated to prepare a RAP. In the case that number of resettled households is small (e.g. one household), the RAP can be simplified. -The RAP is firstly prepared as a part of the EIA Report.	In the case that number of resettled households is more than 20, NIRP requires a RAP.	Not so big difference. RAP is obligated to prepare, although number of resettled households is different.
Land compensation	It is compensated by replacement cost as much as possible.	In NIRP, it is described that it is compensated by replacement cost including transaction cost. On the other hand, in LAA, it is described that the compensation cost is estimated based on the market price.	Not so big difference. It is stipulated to be compensated by replacement cost in the policy except LAA.
Monitoring/ Mitigation measures	Implementation of Monitoring and mitigation is obliged.	Implementation of Monitoring and mitigation is obliged.	No gaps
Disclosure information	EIA report is to be disclosed 120 days prior to concluding agreement documents.	Based on NEA, EIA is to be disclosed to public.	No gaps

(Source: JICA Survey Team)

6.3.3 Organizations and Their Roles regarding Environmental and Social Considerations

Environmental and social considerations are a key evaluation point for formulating a comprehensive electricity sector master plan. In JICA’s Guidelines for Environmental and Social Considerations from 2010, JICA officially stipulates integration of the concept of SEA into the electricity sector master plan in order to carry out environmental and social considerations assessments from an early phase of the development plan to the monitoring phase.

The Cabinet of Ministers in Sri Lanka has approved the implementation of SEA for policies, programs and plans but there are few instances of SEA being carried out universally in each Ministry, Department and Authority.

As aforementioned, the current environmental law (National Environmental Act No. 47, 1980) does not stipulate any provisions concerning SEA, therefore, implementation of SEA is commended to the discretion of each competent ministries based on the Cabinet decision, and CEA's independent involvement has been eliminated. On the contrary, the CEA is preparing a revision of the current environmental law (NEA) so that implementation of SEA is to be legislated.

As environmental and social considerations for SEA are currently being prepared by CEA and have not been published yet, organizations, their roles and detailed items for EIA/IEE are to be described here instead of in SEA documents.

(1) Organization framework for Environmental and Social Considerations (Role of central government and its executing agency)

CEA was established in 1980 as a policy-making and coordination agency based on NEA. After this, in 1988, its role differed as the executing agency for the implementation of environmental protection policy, with environmental management policy being covered by the Mahaweli Development & Environment Ministry until 1988.

The legal framework for the EIA/IEE process in Sri Lanka was laid down in the amended National Environmental Act (NEA) in 1988 and its amended law casts a duty on CEA to manage EIA/IEE procedure.

The amended law also states that the EIA process is implemented through designated “Project Approving Agencies (PAA)” led by CEA, and that guidelines necessary for PAA to evaluate EIA/IEE should be prepared by CEA.

The PAAs designated by CEA are EIA/IEE administrative agencies that are responsible for steering the EIA/IEE for projects and for issuing EIA approvals or rejections.

(2) Key items implemented through environmental and social considerations

(a) Projects requiring implementation of EIA/IEE

Projects (designated project, Prescribed Project) that require IEE/EIA are those to be conducted outside the Coast Conservation Law Designated Area. 52 projects are designated based on Circular No. 772/22, 1992. Among them, the electric power related projects which are thought to be related to this master plan are shown in the table below.

Table 6-9 Projects Requiring Implementation of EIA/IEE related to Electrical Generation

Projects requiring implementation of EIA/IEE	Scale requirement for EIA
(2) Reclamation of Land/wetland	Exceeding 4ha
(5) Clearing of Land	Exceeding 50ha
(8) Port and Harbour Development	Construction of Ports (All) Construction of Harbors (All)
(9) Power generation plants	Construction of hydroelectric power stations (Exceeding 50MW) Construction of thermal power plants (Exceeding 25MW) Construction of nuclear power stations (All) All renewable energy (Exceeding 50MW)
(10) Transmission lines	Exceeding 50kV and Exceeding 10km
(12) Resettlement	Involuntary resettlement (Exceeding 100 families)
(14) Pipelines	Laying of gas and liquid pipelines (Exceeding 1km)

Note: The number in parentheses is the number attached to the Circular.

(Source: JICA Survey Team)

(b) The EIA/IEE process involves the following 6 major steps:

1) Items to be implemented

The main items concerning environmental and social considerations implemented in the EIA/IEE procedures are the following six items.

Table 6-10 Items and Timing for Each Step in EIA/IEE Process

Item	Term	
	EIA	IEE
(1) Screening	6 days	6 days
(2) Scoping	30 days	14 days
(3) Preparation of the EIA/IEE report	no time limit	no time limit
(4) Review of the report by the public and the PAA	30 days	21 days*
(5) Approval with terms and conditions or rejection with reasons	30 days after submission	6 days after submission
(6) Post approval monitoring	N/A	N/A

*: Technical review only (Source: JICA Survey Team)

a) Screening

The implementer of the project submits prior information on the planned designated project to the PAA as soon as possible. Based on this prior information, the PAA performs screening as to whether IEE or EIA implementation is necessary.

b) Scoping

Based on the prior information submitted in (1), PAA will implement scoping based on the opinions of relevant stakeholders including administrative agencies, resident representatives and NGOs.

c) Preparation of the EIA/IEE report

Project executors prepare a report in Sinhalese (Tamil and English if requested by residents) and submit it to PAA.

d) Review of the report by the public and the PAA

PAA makes the submitted report available to the public for 30 days and seeks opinions. PAA and CEA hold a meeting if the following negative issues are submitted regarding the EIA report.

- If a proposed prescribed project is highly controversial, or if more expressions of public views are essential to make a decision
- If the proposed prescribed project might cause unusual national or regional impacts
- If it might threaten a nationally important environmentally sensitive area
- If a formal request for a public meeting has been requested by an interested party

e) Approval with terms and conditions or rejection with reasons

Based on the opinions in the meeting, the PAA consults the Technical Committee (TEC) on the examination of EIA/IEE and, based on that opinion, the PAA notifies proponents that the project is approved or disapproved within 30 days of the EIA or, for an IEE, within 21 days.

f) Post approval monitoring

Since monitoring is a component of EIA, project developers are obliged to implement monitoring in line with approval of EIA, and are obliged to report it to CEA and PAA. Monitoring of air quality and water quality is usually carried out based on the environmental standards specified by the government, but environmental standards concerning water quality are currently not yet established, so air quality (PM_{10}, $PM_{2.5}$, NO_2, SO_2, O_3, CO) and standards on noise are promulgated.

Table 6-11 Air Quality Standards in Sri Lanka

Air Quality	Environmental Standard	WHO Guideline
NO_2	0.13 ppm (1h)	0.20 ppm (1h)
SO_2	0.08 ppm (24h)	0.02 ppm (24h)
O_3	0.1 ppm (8h)	0.160 ppm (8h)
CO	26 ppm	-
Particulate Matter (PM_{10})	100 µg/m^3	50 µg/m^3 (24h)
Particulate Matter ($PM_{2.5}$)	50 µg/m^3	25 µg/m^3 (24h)

(Source: Government Notifications on Air Quality, No.1562/22, 2008, WHO Guideline, 2008)

Table 6-12 Air Quality Standards (Noise) in Sri Lanka

Areas	Standard (dB)		Standard (IFC)	
	Day	Night	Day	Night
Rural Residential	55	45	55	45
Urban Residential	60	50		
Noise Sensitive	50	45		
Mixed Residential	63	55	70	70
Commercial	65	55		
Industrial	70	60		

(Source: Government Notifications on Air Quality, No.924/12, 1996, IFC Guideline, 2007)

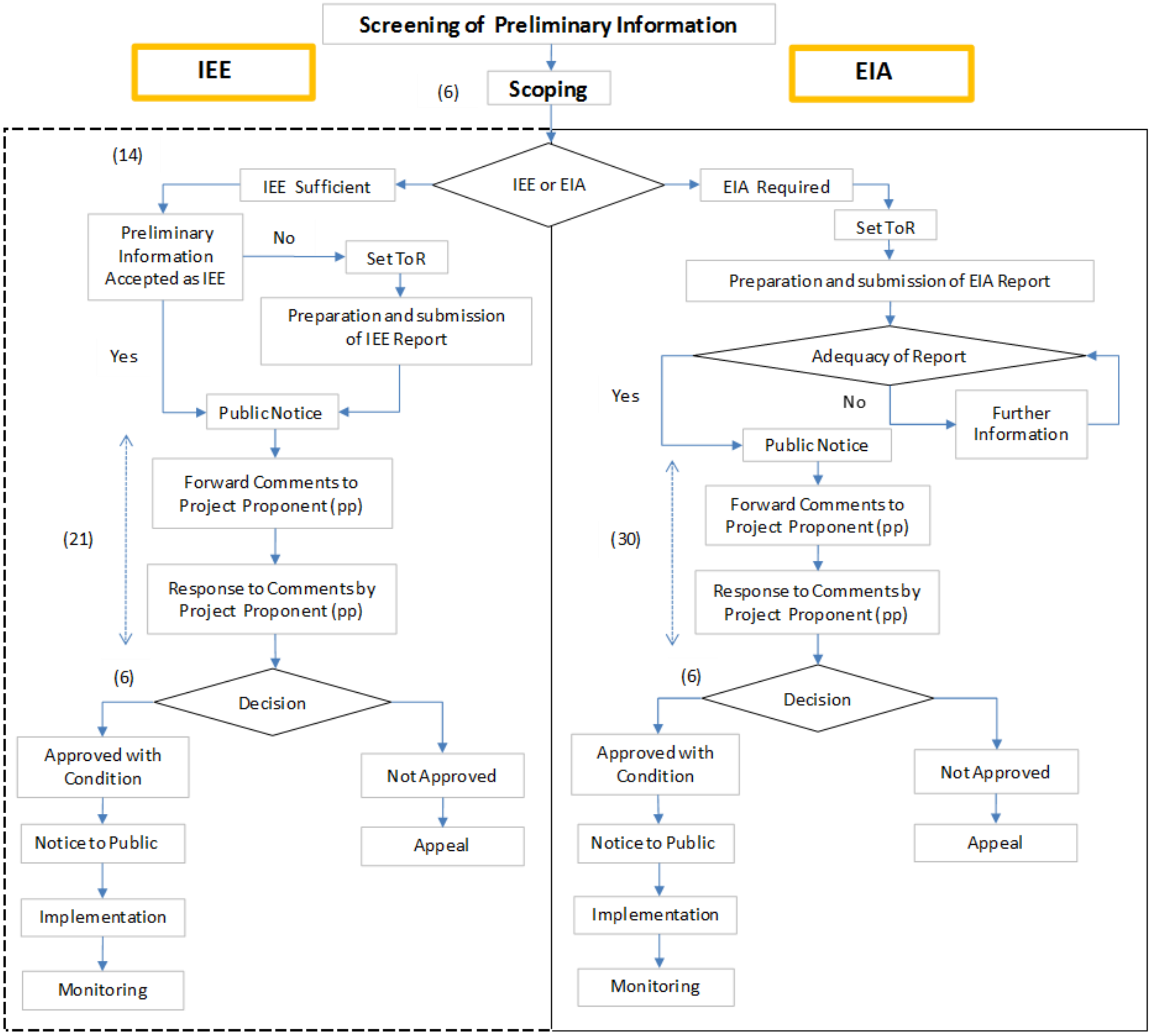
Table 6-13 Air Emission Standard Values of Coal Fired Plant at end of Stack in Sri Lanka

Pollutant Type	Ambient Air Quality (µg/m3)				Proposed Stack Emission (mg/MJ)	
	Annual level	24 hour level	8 hour level	1 hour level	Coal	Liquid Fuel
NO_2	-	100	150	250	300	130
SO_2	-	80	120	200	520	340
PM_{10}	50	100	-	-	-	-
$PM_{2.5}$	25	50	-	-	-	-
TSP	-	-	-	-	40	40

(Source: Government Notifications on Air Quality)

2) Implementation procedure for IEE/EIA

The implementation procedure for IEE/EIA is shown in the below figure.



Note: In parentheses is the maximum number of days required for the procedure.

(Source: "Central Environmental Authority: Guidance for Implementing the Environmental Impact Assessment (EIA) Process, No. 2: A General Guide for Conducting Environmental Scoping" is summarized by JICA Survey Team)

Figure 6-8 Procedure for IEE/EIA in Sri Lanka

At the stage of SEA, the size, location, etc. of the facility are uncertain, so here it will describe the handling of domestic law concerning land acquisition and resettlement that may occur when CEB conducts the project based on the SEA in the future.

a) Land acquisition

When land is required for a public purpose including electricity generation, transmission, and distribution, the head of the relevant department forwards an acquisition proposal to the Secretary of the Ministry of Land and Land Development via the Secretary to the Ministry whose purview it falls under. After confirming the accuracy of the proposal, the acquisition procedure is commenced upon approval of the Minister of Land and Land Development. Land and other assets are acquired under the provisions of the Land Acquisition Act (LAA) No. 9 of 1950 and its amendments. Compensation and interest are paid to the land owners accordingly.

According to the LAA, the market value of land shall be the perceived amount which the land might be expected to have realized, if sold by a willing seller in the open market, as a separate entity on the date of publication as notified in the gazette.

The amount of compensation to be paid shall be based on the market value of the land where the compensation is for the acquisition or servitude over the land. It shall be proportionate to the persons' interest in that land. No additional compensation shall be allowed, considering the compulsory nature of the acquisition. The resident is notified of the amount of compensation for the land to be paid by the Project Implementing Agency (PIA) through the Divisional Secretariat (DS) office where the land is located.

b) Resettlement

The National Involuntary Resettlement Policy (NIRP) was developed and approved by the Cabinet in May 2001 in Sri Lanka. Before NIRP became effective, the LAA only provided for compensation for land, structures, and crops. Other issues were not addressed, like the exploration of alternative project options, compensation for those without land titles, consultation with affected people and their hosts on resettlement options, provision of successful social and economic integration of the affected people and their hosts, or full rehabilitation of the project affected persons (PAPs).

The NIRP has established a framework for project planning and implementation to ensure that the PAPs are treated in a fair and equitable manner, and that they are not impoverished in the process. This indicates that a comprehensive resettlement action plan is required where 20 or more families are affected.

6.4 Comparison of Alternatives (including Zero Options)

The following three scenarios are drafts from the viewpoint of the optimum power supply plan in the power master plan with the final target year of 2040 (refer to Chapter 7).

(a) Scenario A plan: High Priority on Coal Thermal Development in consideration of Cost
(b) Scenario B plan: High Priority on Renewable Energy Development with CO_2 Reduction
(c) Scenario C plan: Mixed Power Supply Development

In addition, "zero option"[26] is to be left out in this report, since it is unrealistic to prepare measures and plans which can achieve the master plan aiming at the best fuel mix in the targeted year of 2040, other than via the implementation of the various power developments.

Furthermore, when implementing various power developments, the power development scenario which has lower environmental indicators (that is, the negative impact is low) is to be placed at a higher priority from the viewpoint of SEA, since the environmental impact degrees (natural environment, social environment and global environment) differ according to the differences in power source, location, fuel type and the development scale (MW).

6.5 Scoping Items and Proposed TOR on Environmental and Social Considerations Survey

"Best Practicable Environmental Option" is selected and ranked through comparison among scenario alternatives in the proposed electricity sector master plan. Based on this evaluation, the major survey items for the environmental and social considerations in the implementing stage of the project are proposed.

(1) Selection of scoping items and indicators

In order to analyze and evaluate each development scenario plan (power development) from the viewpoint of environmental and social considerations, and JICA Survey Team selected the evaluation items related to various power development projects to be considered at the master plan stage in reference to the JICA guidelines (checklist).

[26] It is defined based on the regulation of Japanese Government (Ministry of Environment in JAPAN) on "Strategic Environment Assessment Guideline" 2007.

Table 6-14 Scoping Item Selection for SEA

Type		Items	Conventional			Renewable Energy				
			Hydro	Coal	LNG, Oil	Wind	Solar	Mini-Hydro	PSPP	Biomass
Pollution Control	**1**	**Air Quality**	**B**	**A**	**B**	**B**	**B**	**B**	**B**	**B**
	2	**Water Quality**	**B**	**B**	**B**	C	**B**	**B**	**B**	C
	3	**Soil Quality**	D	**B**	C	D	D	D	D	B
	4	Sediment	D	D	D	D	C	C	C	D
	5	**Noise and Vibration**	**B**	**B**	**B**	**B**	**B**	**B**	**B**	**B**
	6	Odor	D	C	C	D	D	D	D	C
	7	**Waste**	C	**A**	C	D	**A**	D	D	**A**
	8	**Subsidence**	**B**	**B**	**B**	D	D	D	**B**	**B**
Natural Environment	**9**	**Protected areas**	**A**	D	D	**A**	D	**A**	**B**	D
	10	**Ecosystem**	**A**	D	D	**A**	D	**A**	**B**	D
	11	**Topography and Geology**	**A**	C	C	D	D	**A**	**A**	D
Social Environment	**12**	**Land acquisition**	**A**	**A**	**B**	C	C	**B**	**A**	C
	13	Disturbance to Poor People	C	D	D	D	D	D	D	D
	14	**Disturbance to Ethnic Minority Groups and Indigenous People**	**A**	**B**	**D**	**D**	**D**	**A**	**A**	**D**
	15	Deterioration of Local Economy such as Losses of Employment and Livelihood Means	C	C	C	C	C	C	C	C
	16	**Land Use and Utilization of Local Resources**	**A**	**B**	**B**	**B**	**B**	**B**	**B**	**B**
	17	**Disturbance to Water Usage, Water Rights, etc.**	A	A	A	D	D	**A**	**B**	D
	18	Disturbance to the Existing Social Infrastructure and Services	C	C	C	C	C	C	C	C
	19	Social Institutions such as Social Infrastructure and Local Decision-making Institutions	C	C	C	C	C	C	C	C
	20	Misdistribution of Benefits and Compensation	C	C	C	C	C	C	C	C
	21	Local Conflicts of Interest	C	C	C	C	C	C	C	C
	22	**Cultural Heritage**	C	C	D	D	D	C	C	D
	23	**Landscape**	**B**	C	C	**A**	**B**	C	C	D
	24	Gender	D	D	D	D	D	D	D	D
	25	Children's Rights	D	D	D	D	D	D	D	D
	26	Infectious Diseases such as HIV/AIDS	C	C	C	C	C	C	C	C
	27	Work Environment (including Work Safety)	C	C	C	C	C	C	C	C
Other	28	Accidents	C	C	C	C	C	C	C	C
	29	**Cross-boundary Impact and Climate Change**	C	**A**	**B**	D	D	D	D	D

Note: A+/-: Significant positive/negative impact is expected
B+/-: Positive/negative impact is expected to some extent
C+/-: Positive/negative impact is unknown (further examination is needed, and the impact may be clarified as the study progresses) and evaluation is not to be done at the stage of SEA
D: No impact is expected and evaluation is not to be done at the stage of SEA

(Source: JICA Survey Team)

Table 6-15 Selected Scoping Items and Impact Evaluation Indicators

Category	Items	Indicators
Natural (10)	Topography & Geology	Destruction of ground
	Soil	Erosion, Disposal, Leakage of toxic substances, Peeling off of top soil
	Quality of Water	Pollution due to water-diverting/sedimentation of toxic substances
	Quality of Air	Emission of pollutants from facilities
	Noise/Vibration	Noise/Vibration from facilities or operation activities
	Waste	Domestic or Industrial waste from facilities
	Subsidence	Use of underground water by facilities
	Flora	Deforestation (including mangrove), Peeling of vegetation, changing of flora ecosystem
	Fauna/Fish/Coral	Destruction of habitat/ecosystem of animals, adverse impact on migratory fish or birds
	Natural Protected Areas	Impacts on strict natural protected areas such as National Parks
Social (6)	Resettlement	Involuntary resettlement/Loss of means of livelihood
	Ethnic minorities / Indigenous people	Adverse impacts on vulnerable people
	Land Use	Confliction of land use
	Water Use	Confliction of water use
	Landscape	Destruction of landscape
	Historical Heritage	Loss of local heritage

(Source: JICA Survey Team)

(2) Impact evaluation method for scoping items

A quantitative evaluation for each project listed in the scenario is to be carried out based on the impact evaluation criteria, the scores for which vary over 4 levels from 0 to -3, as shown in Table 6-16.
The scores for the impacts of each alternative development scenario are to be summed up and the total score is to be used for prioritization of each scenario from the viewpoint of environmental and social considerations.

Table 6-16 Impact Evaluation Criteria

Score (E.C.I)*	Evaluation Criteria
- 3	Significant direct-negative impact is expected and mitigation cannot be expected.
-2	Significant direct-negative impact is expected and mitigation is expected.
-1	Minor direct-negative impact is expected and mitigation is expected.
0	Minor indirect-negative impact is expected and mitigation is not needed.

*: Environmental Contribution Indicator (Source: JICA Survey Team)

(3) Proposed TOR on Environmental and Social Considerations Survey

Based on the above evaluation, the major survey items for environmental and social considerations to be carried out in the implementing stage of the project are as shown in the table below.

Table 6-17 Survey Items and Methods

Environmental Items	Survey Items	Survey Method
Air Quality	- Relevant environmental standards - Meteorological Information - Current status of Ambient Atmosphere	- Obtain ambient air quality standards, - Measure the air pollutants (TSP), SO_2, NO_2, CO, PM10, etc.
Water Quality	- Relevant environmental standards - Current status of Water Quality	- Obtain water quality standards and effluent standards. - Measure the existing reservoir and river water quality (temperatures, salinity, COD, and nutrients, etc.)

Environmental Items	Survey Items	Survey Method
Soil Quality	- Relevant environmental standards	- Measure for soil quality and any contamination.
Sediment (bottom of dam)	- Current status of Water Quality and sediments	- Measure the dam water quality (temperatures, salinity, COD, and heavy materials).
Noise and Vibration	- Relevant environmental standards - Current status of noise and vibration	- Obtain noise level standards - Measure the noise levels (background)
Odor	- Relevant environmental information	- Obtain environmental countermeasures for smell sources (odor).
Waste	- Relevant environmental standards	- Obtain waste handling standards/manuals/ guidelines.
Subsidence	- Current status of soil conditions	- Geological survey
Protected Areas	- Current status of Protected Areas	- Collect relevant laws and regulations, information on Protected Areas
Ecosystem	- Current habitat status of flora, mammal , birds, reptiles, amphibians, fish, precious species (migrant birds)	- Survey the distribution of flora and fauna.
Topography and Geology	- Geological conditions	- Obtain geological information
Land acquisition / Resettlement	- Confirm who the affected people are and negative impacts caused by the project. - Confirm assets of the affected people - Identify livelihoods of the affected people	- Collect relevant laws and regulations, information on relevant cases - Conduct population census - Conduct asset inventory survey - Conduct household socioeconomic survey
Disturbance to Poor People	- Identify poor people among the affected people	- Collect relevant laws and regulations, information on relevant cases - Conduct population census - Conduct asset inventory survey - Conduct household socioeconomic survey
Disturbance to Ethnic Minority Groups and Indigenous People	- Identify Ethnic Minority Groups and Indigenous people among the affected people	- Collect relevant laws and regulations, information on relevant cases - Conduct population census - Conduct asset inventory survey - Conduct household socioeconomic survey
Deterioration of Local Economy such as Losses of Employment and Means of Livelihood	- Identify jobs and livelihoods of the affected people	- Collect information on the employment and income in the affected area - Interview the households
Land Use and Utilization of Local Resources	- Identify the present land use - Identify jobs and livelihoods of the affected people	- Collect information on the employment and income in the affected area - Interviews with the households
Disturbance to Water Usage, Water Rights, etc.	- Identify the present water use for day-to-day life and agricultural activities.	- Household socioeconomic survey - Interview the households
Disturbance to Existing Social Infrastructure and Services	- Identify the present facilities of infrastructure	- Collect official data
Misdistribution of Benefits and Compensation	- Identify jobs and livelihoods of the affected people	- Collect information on the employment and income in the affected area - Interview the households
Local Conflicts of Interest	- Identify jobs and livelihoods of the affected people	- Collect information on the employment and income in the affected area - Interview the households
Gender	- Identify gender among the project affected people - Identify access to medical institutions	- Collect relevant laws and regulations, information on relevant cases - Conduct population census - Conduct asset inventory survey - Conduct household socioeconomic survey

Environmental Items	Survey Items	Survey Method
Children's Rights	- Identify number of children among the project affected people - School attendance rates - Identify access to medical institutions	- Collect relevant laws and regulations, information on relevant cases - Conduct population census - Conduct household socioeconomic survey
Infectious Diseases	- Disease rate	- Collect official data
Work Environment (Including Work Safety)	- Accident rate	- Collect official data
Accidents	- Accident rate	- Recording accident cases
Cross-boundary Impact and Climate Change	- Identify the present air quality	- Measure CO_2 emitted from construction vehicles and heavy machines.

(Source: JICA Survey Team)

6.6 Results of Evaluation on Environmental Impact Assessment for Each Project

The results evaluated for each power supply type using the above scoping and evaluation method are shown in the below table.

Since the number of evaluation items of the natural environment and the social environment are 10 and 6 respectively, the effect degrees are evaluated on the average respectively in order to be weighted equally. In addition, since environmental contribution indicators for multiple similar projects are evaluated and the average value of each item is set as the final score, the every score is rounded off to the first decimal place.

(1) Hydropower Plant

A report on the Intergovernmental Panel on Climate Change (the Third Working Group, Renewable Energy Sources and Special Report on Climate Change Mitigation, Hydropower) and EIA on hydropower projects were conducted in the past, and these are shown for reference in the table below. Scoping is conducted on the general impact of hydropower projects on the natural and social environments in Sri Lanka.

Table 6-18 EIA Report on Hydropower Projects Referred to for Scoping

	Hydropower Project	Location	Type	MW	EIA Approval
1	Uma Oya	Uva	Pondage	120	2011/4
2	Broadlands	Sabaragamuwa	Run of River	35	2006/11
3	Moragolla	Central	Pondage	98	2013/8

(Source: JICA Survey Team)

Table 6-19 Results of Scoping (Hydropower)

		Item	Indicator	Score	Basis of Score
Natural	1	Topography & Geology	Destruction of ground	-1.0	Alterations accompanying excavation, explosion work, etc. are expected, but mitigation measures (stabilization of slope, planting on slope) are possible.
	2	Soil	Erosion, Disposal, Leakage of toxic substances, Peeling of top soil	-1.0	The occurrence of soil erosion due to excavation, scraping and storage of surface soil is expected. Also, on steep slopes, soil erosion is expected, but in any case mitigation measures (bare land / slope planting) are possible.

	3	Quality of Water	Pollution due to water-diverting/sedimentation of toxic substances	-0.3	Water pollution and muddy water generation due to excavation work and facility construction are expected, but the effect is temporary, and mitigation measures (purification in the sand pond) are possible.
	4	Quality of Air	Emission of pollutants from facilities	0.0	Impacts that require mitigation measures are not expected.
	5	Noise/Vibration	Noise/Vibration from facilities or operation activities	0.0	Impacts that require mitigation measures are not expected.
	6	Waste	Domestic or Industrial waste from facilities	0.0	Impacts that require mitigation measures are not expected.
	7	Subsidence	Use of underground water by facilities	0.0	Impacts that require mitigation measures are not expected.
	8	Flora	Deforestation (including mangrove), Peeling of vegetation, changing of flora ecosystem	-1.3	As dams and weirs are constructed, logging of trees is expected, but mitigation measures (plant transplantation, planting etc.) are possible.
	9	Fauna/Fish/Coral	Destruction of habitat/ecosystem of animals, adverse impact on migratory fish or birds	-2.0	With the construction of dams and weirs, significant negative direct effects such as division of the habitat of the animals, inhibition of upstream migratory fish migration, changes of the surrounding ecosystems due to the appearance of reservoirs, etc. are expected. Mitigation Measures (installation of fishway, corridor) are possible.
	10	Natural Protected Areas	Impacts on strict natural protected areas such as National Parks	-0.7	If being located around buffer zones away from the core zones, the impact is expected to be small.
	Impact Indicator for Natural Resources			**-0.63**	
Social	1	Resettlement	Involuntary resettlement/Loss of means of livelihood	-2.0	Mitigating measures (securing alternative sites, etc.) are possible, although serious negative direct impacts due to resettlement of residents are expected.
	2	Ethnic minorities/Indigenous people	Adverse impacts on vulnerable people	-0.7	Scattered houses (ethnic minorities) are expected, but their scale is not large to form a community. Since the rights are respected, impacts that require mitigation measures are rarely expected. If infringement of rights arises, mitigation measures by securing alternative lands are possible.
	3	Land Use	Confliction of land use	-1.3	Land submergence is expected, but mitigation measures (securing alternative sites) are possible.
	4	Water Use	Confliction of water use	-1.0	Mitigation measures (securing maintenance release, etc.) are possible, although the impacts on water use (irrigation, daily water, tourism use etc.) in the downstream area due to the decrease in flow rate is expected.
	5	Landscape	Destruction of landscape	0.0	Impacts that require mitigation measures are not expected.
	6	Historical Heritage	Loss of local heritage	-0.3	Scattered houses (ethnic minorities) are expected, but little impact on tangible / intangible heritage etc. which requires mitigation measures is hardly expected.
	Impact Indicator for Social Resources			**-0.89**	
Comprehensive Impact Indicator				**-0.76**	

(Source: JICA Survey Team)

(2) Coal Fired Thermal Power Plant

In reference to the EIA report on the coal thermal power generation project in the table below and the "An Environmental and Fisheries Profile of the Puttalam Lagoon System (IUCN, 2011)" report, the Scoping of a coal-fired thermal power project in Sri Lanka was implemented.

Table 6-20 EIA Report on Thermal Power Projects Referred to for Scoping

	Thermal Project	Location	MW	EIA Approval
1	Lakvijaya (Norocholai)	North Western	300 600	1999/1 (F-I) 2013/5 (F-II, III)
2	Trincomalee	Eastern	500	2015/1

(Source: JICA Survey Team)

Table 6-21 Results of Scoping (Coal Fired Thermal Power)

		Item	Indicator	Score	Basis of Score
Natural	1	Topography & Geology	Destruction of ground	0.0	Impacts that require mitigation measures are not expected.
	2	Soil	Erosion, Disposal, Leakage of toxic substances, Peeling of top soil	-2.0	Soil contamination due to the loss of heavy metals from coal ash treatment facilities is expected, but mitigation measures (installation of water barrier walls) are possible.
	3	Quality of Water	Pollution due to water-diverting/sedimentation of toxic substances	-3.0	Rising in the water temperature is expected due to a large amount of thermal effluent to the ocean or river, and in the case of large capacity, mitigation measures are impossible.
	4	Quality of Air	Emission of pollutants from facilities	-2.0	Pollution of air quality (NO_2, SO_2, PM 10, etc.) due to smoke is expected; mitigation measures (introduction of high combustion efficiency boiler, installation of denitration/desulfur, dustproof devices) are possible.
	5	Noise/Vibration	Noise/Vibration from facilities or operation activities	0.0	Impacts that require mitigation measures are not expected.
	6	Waste	Domestic or Industrial waste from facilities	-3.0	Coal ash is continuously discharged; effective mitigation measures (implementation of 3R) are possible, but drastic mitigation measures are difficult.
	7	Subsidence	Use of underground water by facilities	0.0	Impacts that require mitigation measures are not expected.
	8	Flora	Deforestation (including mangrove), Peeling of vegetation, changing of flora ecosystem	-3.0	Rising in the water temperature is expected due to a large amount of thermal effluent to the ocean or river, and the influence on plants (mangrove, marine plants) is assumed. In the case of large capacity, mitigation measures are impossible.
	9	Fauna/Fish/Coral	Destruction of habitat/ecosystem of animals, adverse impact on migratory fish or birds	-3.0	Rising in water temperature of discharge destination due to a large amount of thermal effluent to the ocean and river, and influence on animals (coral, fish) is assumed. In the case of large capacity, mitigation measures are impossible.
	10	Natural Protected Areas	Impacts on strict natural protected areas such as National Parks	0.0	Impacts that require mitigation measures are not expected.

	Impact Indicator for Natural Resources			**-1.60**	
Social	1	Resettlement	Involuntary resettlement/Loss of means of livelihood	0.0	Impacts that require mitigation measures are not expected.
	2	Ethnic minorities/Indigenous people	Adverse impacts on vulnerable people	0.0	Impacts that require mitigation measures are not expected.
	3	Land Use	Confliction of land use	0.0	Impacts that require mitigation measures are not expected.
	4	Water Use	Confliction of water use	-2.0	Competition for water use due to intake from peripheral rivers as cooling water is assumed, but mitigation measures (introduction of air cooling system) are possible.
	5	Landscape	Destruction of landscape	-2.0	Construction of huge artificial facilities may negatively and directly affect the flat sandbar scenery, but it is possible to mitigate (construction position is sufficiently retracted from the coastline).
	6	Historical Heritage	Loss of local heritage	0.0	Impacts that require mitigation measures are not expected.
	Impact Indicator for Social Resources			**-0.67**	
Comprehensive Impact Indicator				**-1.13**	

(Source: JICA Survey Team)

(3) Thermal Power Plant (LNG, Oil)

With reference to the thermal power plant operating in the Kerawalapitiya (IPP) area near Colombo (Yugadanavi, 300MW, combined cycle) and site survey of the candidate LNG plant sites, Scoping for thermal (LNG, Oil) was carried out.

Table 6-22 Results of Scoping (Thermal Power - LNG, Oil)

		Item	Indicator	Score	Basis of Score
Natural	1	Topography & Geology	Destruction of ground	0.0	Impacts that require mitigation measures are not expected.
	2	Soil	Erosion, Disposal, Leakage of toxic substances, Peeling of top soil	-2.0	Along with the pipeline installation, soil erosion is assumed, because the topsoil is peeled linearly over a long section, but mitigation measures (planting on the raised/cutting ground) are possible.
	3	Quality of Water	Pollution due to water-diverting/sedimentation of toxic substances	-2.0	Rising in the water temperature due to thermal effluent to the ocean and the river is expected, but mitigation measures (air cooling method, cooling tower method introduction) are possible.
	4	Quality of Air	Emission of pollutants from facilities	-2.0	Contamination of air quality (NO_2, SO_2, PM 10, etc.) is assumed, but mitigation measures (introduction of high efficiency boilers, installation of denitrification/desulfur, dustproof devices) are possible.
	5	Noise / Vibration	Noise/Vibration from facilities or operation activities	0.0	Impacts that require mitigation measures are not expected.
	6	Waste	Domestic or Industrial waste from facilities	0.0	Impacts that require mitigation measures are not expected.
	7	Subsidence	Use of underground water by facilities	0.0	Impacts that require mitigation measures are not expected.

	8	Flora	Deforestation (including mangrove), Peeling of vegetation, changing of flora ecosystem	-1.0	Adverse influence on plants (mangrove, marine plant) is assumed due to thermal effluent to the ocean and the river, but mitigation measures (introduction of cooling tower system, air cooling system) are possible.
	9	Fauna / Fish / Coral	Destruction of habitat/ecosystem of animals, adverse impact on migratory fish or birds	-1.0	Adverse influence on fauna (coral, fish) is assumed due to thermal effluent to the ocean and the river, but mitigation measures (introduction of cooling tower system, air cooling system) are possible.
	10	Natural Protected Areas	Impacts on strict natural protected areas such as National Parks	0.0	Impacts that require mitigation measures are not expected.
	Impact Indicator for Natural Resources			**-0.80**	
Social	1	Resettlement	Involuntary resettlement/Loss of means of livelihood	0.0	Impacts that require mitigation measures are not expected.
	2	Ethnic minorities / Indigenous people	Adverse impacts on vulnerable people	0.0	Impacts that require mitigation measures are not expected.
	3	Land Use	Confliction of land use	0.0	Impacts that require mitigation measures are not expected.
	4	Water Use	Confliction of water use	-2.0	Competition for water use due to intake from peripheral rivers as cooling water is assumed, but mitigation measures (introduction of air cooling system) are possible.
	5	Landscape	Destruction of landscape	0.0	Impacts that require mitigation measures are not expected.
	6	Historical Heritage	Loss of local heritage	0.0	Impacts that require mitigation measures are not expected.
	Impact Indicator for Social Resources			**-0.33**	
Comprehensive Impact Indicator				**-0.57**	

(Source: JICA Survey Team)

(4) Wind Power Plant

Referencing the following 3 reports, Scoping was carried out:

(a) Environmental Assessment and Environmental Management Plan (2014) on the "Mannar Wind Power Development Zone",

(b) Environment Assessment and Social Assessment report (2013), and

(c) "An Environmental and Fisheries Profile of the Puttalam Lagoon System (IUCN, 2011)".

Table 6-23 Results of Scoping (Wind Power)

		Item	Indicator	Score	Basis of Score
Natural	1	Topography & Geology	Destruction of ground	0.0	Impacts that require mitigation measures are not expected.
	2	Soil	Erosion, Disposal, Leakage of toxic substances, Peeling of top soil	0.0	Impacts that require mitigation measures are not expected.
	3	Quality of Water	Pollution due to water-diverting/sedimentation of toxic substances	0.0	Impacts that require mitigation measures are not expected.
	4	Quality of Air	Emission of pollutants from facilities	0.0	Impacts that require mitigation measures are not expected.

	5	Noise/Vibration	Noise/Vibration from facilities or operation activities	-1.0	Windmill noise is assumed, but mitigation measures (construction in remote areas) are possible.
	6	Waste	Domestic or Industrial waste from facilities	0.0	Impacts that require mitigation measures are not expected.
	7	Subsidence	Use of underground water by facilities	0.0	Impacts that require mitigation measures are not expected.
	8	Flora	Deforestation (including mangrove), Peeling of vegetation, changing of flora ecosystem	0.0	Impacts that require mitigation measures are not expected.
	9	Fauna/Fish/Coral	Destruction of habitat/ecosystem of animals, adverse impact on migratory fish or birds	-3.0	The occurrence of bird strike accidents is assumed. Even adopting mitigation measures to avoid migratory birds' flight routes, it is difficult to eradicate this.
	10	Natural Protected Areas	Impacts on strict natural protected areas such as National Parks	-0.5	Influence on the flight and ecology of waterfowl species' habitats in protected areas (Ramsar areas) is assumed but mitigation measures (construction in areas far from protected areas) are possible.
	Impact Indicator for Natural Resources			**-0.45**	
Social	1	Resettlement	Involuntary resettlement/Loss of means of livelihood	0.0	Impacts that require mitigation measures are not expected.
	2	Ethnic minorities/Indigenous people	Adverse impacts on vulnerable people	0.0	Impacts that require mitigation measures are not expected.
	3	Land Use	Confliction of land use	-1.0	Land competition is assumed, but mitigation (securing of substitute) is possible.
	4	Water Use	Confliction of water use	0.0	Impacts that require mitigation measures are not expected.
	5	Landscape	Destruction of landscape	-3.0	Huge artificial structures appear at the foot of mountains, in the wilderness, etc., so there is concern about serious influence on the surrounding environment, and mitigation measures are difficult.
	6	Historical Heritage	Loss of local heritage	0.0	Impacts that require mitigation measures are not expected.
	Impact Indicator for Social Resources			**-0.67**	
Comprehensive Impact Indicator				**-0.56**	

(Source: JICA Survey Team)

(5) Solar power Plant

Based on the results of interviews with CEB on environmental problems related to Hambantota Solar Park (Phase-I-737 kW-, Phase-II-500 kW) and Scoping is carried out in reference to the "Renewable Energy Master Plan (SLSEA)" report,

Table 6-24 Results of Scoping (Solar Power)

		Item	Indicator	Score	Basis of Score
Natural	1	Topography & Geology	Destruction of ground	0.0	Impacts that require mitigation measures are not expected.

	2	Soil	Erosion, Disposal, Leakage of toxic substances, Peeling of top soil	-1.0	Soil collapse, top soil release, and soil erosion under the panel mount due to rainwater is assumed, but mitigation measures (paving, stabilization of foundation soil by gravel bed) are possible.
	3	Quality of Water	Pollution due to water-diverting/sedimentation of toxic substances	-1.0	Occurrence of muddy flow due to soil erosion is assumed, but mitigation measures (construction of adjustment reservoirs and installation of drainage channels) are possible.
	4	Quality of Air	Emission of pollutants from facilities	0.0	Impacts that require mitigation measures are not expected.
	5	Noise/Vibration	Noise/Vibration from facilities or operation activities	0.0	Impacts that require mitigation measures are not expected.
	6	Waste	Domestic or Industrial waste from facilities	-2.0	A large amount of waste (solar cell modules, storage batteries, power conditioners, etc.) is assumed after reaching the end of its life, but mitigation measures (promotion of 3R) are possible.
	7	Subsidence	Use of underground water by facilities	0.0	Impacts that require mitigation measures are not expected.
	8	Flora	Deforestation (including mangrove), Peeling of vegetation, changing of flora ecosystem	-2.0	There is a concern about serious impacts on vegetation due to the bare ground under the panels, but mitigation measures (planting of shade-tolerant plants under the panels) are possible.
	9	Fauna/Fish/Coral	Destruction of habitat/ecosystem of animals, adverse impact on migratory fish or birds	-1.0	There is a concern about the influence of large-scale facilities on the movement routes of animals, but mitigation measures (establishment of a detour route) are possible.
	10	Natural Protected Areas	Impacts on strict natural protected areas such as National Parks	0.0	Impacts that require mitigation measures are not expected.
	Impact Indicator for Natural Resources			**-0.70**	
Social	1	Resettlement	Involuntary resettlement/Loss of means of livelihood	0.0	Impacts that require mitigation measures are not expected.
	2	Ethnic minorities/Indigenous people	Adverse impacts on vulnerable people	0.0	Impacts that require mitigation measures are not expected.
	3	Land Use	Confliction of land use	0.0	Impacts that require mitigation measures are not expected.
	4	Water Use	Confliction of water use	0.0	Impacts that require mitigation measures are not expected.
	5	Landscape	Destruction of landscape	-2.0	Huge artificial structures appear at the foot of mountains, in the wilderness, etc., and there is concern about serious impact on the surrounding environment, but mitigation measures (tree planting around the facility) are possible.
	6	Historical Heritage	Loss of local heritage	0.0	Impacts that require mitigation measures are not expected.
	Impact Indicator for Social Resources			**-0.33**	
Comprehensive Impact Indicator				**-0.52**	

(Source: JICA Survey Team)

(6) Mini-Hydro Power Plant

In reference to the report on the Intergovernmental Panel on Climate Change (The Third Working Group, Renewable Energy Sources and Special Report on Climate Change Mitigation, Hydroelectric) and EIA report on Naya Ganga mini hydropower project, Scoping was conducted.

Table 6-25 Results of Scoping (Mini-Hydropower)

		Item	Indicator	Score	Basis of Score
Natural	1	Topography & Geology	Destruction of ground	0.0	Impacts that require mitigation measures are not expected.
	2	Soil	Erosion, Disposal, Leakage of toxic substances, Peeling of top soil	-1.0	Soil erosion due to drilling, scraping and storage of surface soil is assumed, and soil erosion is assumed on steep slopes, but in any case, mitigation measures (bare land/steep slope planting) are possible.
	3	Quality of Water	Pollution due to water-diverting/sedimentation of toxic substances	0.0	Impacts that require mitigation measures are not expected.
	4	Quality of Air	Emission of pollutants from facilities	0.0	Impacts that require mitigation measures are not expected.
	5	Noise/Vibration	Noise/Vibration from facilities or operation activities	0.0	Impacts that require mitigation measures are not expected.
	6	Waste	Domestic or Industrial waste from facilities	0.0	Impacts that require mitigation measures are not expected.
	7	Subsidence	Use of underground water by facilities	0.0	Impacts that require mitigation measures are not expected.
	8	Flora	Deforestation (including mangrove), Peeling of vegetation, changing of flora ecosystem	-1.0	As dams and weirs are constructed, logging of trees is assumed, but mitigation measures (plant transplantation, planting etc.) are possible.
	9	Fauna/Fish/Coral	Destruction of habitat/ecosystem of animals, adverse impact on migratory fish or birds	-1.0	Adverse impacts on the migration of fish and the surrounding ecosystem accompanying the appearance of a reservoir are assumed, but mitigation measures (installation of fish way and corridor) are possible.
	10	Natural Protected Areas	Impacts on strict natural protected areas such as National Parks	0.0	Impacts that require mitigation measures are not expected.
	Impact Indicator for Natural Resources			**-0.30**	
Social	1	Resettlement	Involuntary resettlement/Loss of means of livelihood	0.0	Impacts that require mitigation measures are not expected.
	2	Ethnic minorities / Indigenous people	Adverse impacts on vulnerable people	0.0	Impacts that require mitigation measures are not expected.
	3	Land Use	Confliction of land use	-1.0	Land submergence is assumed, but mitigation measures (securing alternative sites) are possible.
	4	Water Use	Confliction of water use	-1.0	Influence on water use (irrigation, daily water, tourism use etc.) in the downstream area is assumed, but mitigation measures (maintenance release) are possible.
	5	Landscape	Destruction of landscape	0.0	Impacts that require mitigation measures are not expected.
	6	Historical Heritage	Loss of local heritage	0.0	Impacts that require mitigation measures are not expected.
	Impact Indicator for Social Resources			**-0.33**	
Comprehensive Impact Indicator				**-0.52**	

(Source: JICA Survey Team)

(7) Pumped Storage Power Plant (PSPP)

In reference to the environmental information on nature and society for the three candidate sites (Halgran 3, Maha 2, Maha 3) described in the JICA report for pumped-storage power stations (The Project for Development Planning on Optimal Power Generation for Peak Demand in Sri Lanka), Scoping was conducted.

Table 6-26 Results of Scoping (PSPP)

		Item	Indicator	Score	Basis of Score
Natural	1	Topography & Geology	Destruction of ground	-1.0	Alterations accompanying excavation and explosion work, etc. are assumed, but mitigation measures (stabilization of slope, planting on slope) are possible.
	2	Soil	Erosion, Disposal, Leakage of toxic substances, Peeling of top soil	0.0	Impacts that require mitigation measures are not expected.
	3	Quality of Water	Pollution due to water-diverting/sedimentation of toxic substances	0.0	Impacts that require mitigation measures are not expected.
	4	Quality of Air	Emission of pollutants from facilities	0.0	Impacts that require mitigation measures are not expected.
	5	Noise/Vibration	Noise/Vibration from facilities or operation activities	0.0	Impacts that require mitigation measures are not expected.
	6	Waste	Domestic or Industrial waste from facilities	0.0	Impacts that require mitigation measures are not expected.
	7	Subsidence	Use of underground water by facilities	0.0	Impacts that require mitigation measures are not expected.
	8	Flora	Deforestation (including mangrove), Peeling of vegetation, changing of flora ecosystem	-2.3	Mitigation via plant transplantation and planting are available. However, from the viewpoint of regional vegetation conservation, serious negative influence is assumed.
	9	Fauna/Fish/Coral	Destruction of habitat/ecosystem of animals, adverse impact on migratory fish or birds	-3.0	Adverse impacts on the migration of fish and the surrounding ecosystem accompanying the appearance of a reservoir are assumed. Although mitigation measures (installation of fish way and corridor) are partially possible, inevitable disturbance of mountain ecosystems caused by the artificial reservoir (upper dam) occurs.
	10	Natural Protected Areas	Impacts on strict natural protected areas such as National Parks	0.0	Impacts that require mitigation measures are not expected.
	Impact Indicator for Natural Resources			**-0.63**	
Social	1	Resettlement	Involuntary resettlement/Loss of means of livelihood	-1.7	A serious negative direct impact due to resettlement of residents is assumed, but mitigation measures (recovery of living base after relocation, securing alternative place etc.) are possible.
	2	Ethnic minorities/ Indigenous people	Adverse impacts on vulnerable people	0.0	Impacts that require mitigation measures are not expected.
	3	Land Use	Confliction of land use	-2.7	Changes in land use over a wide area due to submergence of land at several places (upper/lower dam) are assumed. Limitations are expected via mitigation measures to secure alternative sites.

	4	Water Use	Confliction of water use	-2.7	Competition between pumped water in the dry season and the already-acquired water interests (water reservoir of lower dam) are expected. Limitations are expected via mitigation measures.
	5	Landscape	Destruction of landscape	0.0	Impacts that require mitigation measures are not expected.
	6	Historical Heritage	Loss of local heritage	0.0	Impacts that require mitigation measures are not expected.
	Impact Indicator for Social Resources			**-1.17**	
Comprehensive Impact Indicator				**-0.90**	

(Source: JICA Survey Team)

(8) Biomass power Plant

In reference to the reports on biomass power generation "Assessment & Mapping of Biomass Consumption in Sri Lankan Industries (SLSEA)", and "Promoting Sustainable Biomass Energy Production and Modern Bio-Energy Technologies in Sri Lanka (UNDP)", Scoping was conducted.

Table 6-27 Results of Scoping (Biomass Power)

		Item	Indicator	Score	Basis of Score
Natural	1	Topography & Geology	Destruction of ground	0.0	Impacts that require mitigation measures are not expected.
	2	Soil	Erosion, Disposal, Leakage of toxic substances, Peeling of top soil	0.0	Impacts that require mitigation measures are not expected.
	3	Quality of Water	Pollution due to water-diverting/sedimentation of toxic substances	-1.0	Leakage of polluted water from the collection materials is expected, but mitigation measures (drainage canals, construction of purification ponds) are possible.
	4	Quality of Air	Emission of pollutants from facilities	-1.0	Contamination of air quality (NO_2, SO_2, PM 10, etc.) is assumed, but mitigation measures (introduction of high efficiency boilers, installation of denitrification/sulfur, dustproof device) are possible.
	5	Noise/Vibration	Noise/Vibration from facilities or operation activities	-1.0	Noise due to vehicles and heavy machinery used for loading materials, discharging waste, etc. are assumed, but mitigation measures (low noise vehicles, maintenance of vehicles at regular intervals, etc.) are possible.
	6	Waste	Domestic or Industrial waste from facilities	-2.0	A serious negative direct impact is assumed when securing the disposal site for waste (combustion residues, etc.), but mitigation measures (promotion of 3R etc.) are possible.
	7	Subsidence	Use of underground water by facilities	0.0	Impacts that require mitigation measures are not expected.
	8	Flora	Deforestation (including mangrove), Peeling of vegetation, changing of flora ecosystem	-3.0	When treating timber as the main resource for biomass power generation, destruction or rapid changes in ecosystems caused by local plants are assumed due to simultaneous planting (forestation) with a single tree species. Biodiversity is lost and mitigation measures become impossible.

	9	Fauna/Fish/Coral	Destruction of habitat/ecosystem of animals, adverse impact on migratory fish or birds	-1.0	Changes in animal ecosystems due to the appearance of vegetation zones of single tree species are expected over a vast area, but mitigation measures (establishment of animal route by corridor etc.) are possible.
	10	Natural Protected Areas	Impacts on strict natural protected areas such as National Parks	0.0	Impacts that require mitigation measures are not expected.
	Impact Indicator for Natural Resources			**-0.90**	
Social	1	Resettlement	Involuntary resettlement/Loss of means of livelihood	0.0	Impacts that require mitigation measures are not expected.
	2	Ethnic minorities / Indigenous people	Adverse impacts on vulnerable people	0.0	Impacts that require mitigation measures are not expected.
	3	Land Use	Confliction of land use	-2.0	Competition for land use between existing land use and the developing of vast plantation grounds for biomass material is assumed, but mitigation measures (securing alternative site) are possible.
	4	Water Use	Confliction of water use	-1.0	Competition for water use due to intake from peripheral rivers as cooling water is assumed, but mitigation measures (introduction of air cooling system) are possible.
	5	Landscape	Destruction of landscape	-2.0	Repetition of forest and bare land has a serious direct impact on landscape unique to the area, but mitigation measures (leveling at the time of felling, introduction of selective cutting method) are possible.
	6	Historical Heritage	Loss of local heritage	0.0	Impacts that require mitigation measures are not expected.
	Impact Indicator for Social Resources			**-0.83**	
Comprehensive Impact Indicator				**-0.87**	

(Source: JICA Survey Team)

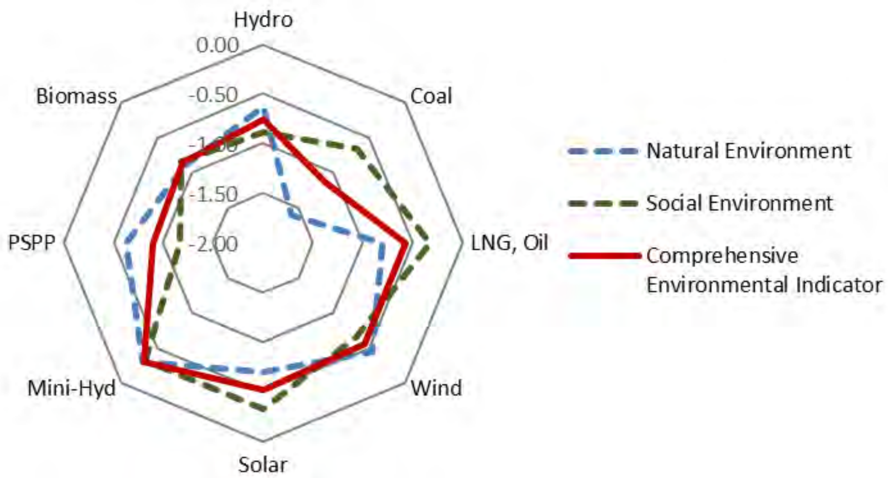
6.7 Matrix Evaluation for Each Power Source Development Plan

Based on SEA, the results of evaluating environmental and social consideration items by power development and described in indicator (environmental impact degree) are shown in the table below.
The power sources in the order of lower negative impacts on the natural and social environment are ① Mini-hydropower ②Solar ③Wind ④LNG/Heavy Oil ⑤Hydropower ⑥Biomass ⑦PSPP ⑧Coal. The reasons why the comprehensive impact indicator of PSPP is relatively high are that a lot of households are to be resettled in the candidate site and valuable animals and plants are deemed to grow and inhabit.
The reasons why the comprehensive impact indicator of biomass power generation are that a large-scale of land is to be needed to plant and log a suitable kind of trees repeatedly for ensuring constantly a certain amount of woody fuel and oligopoly of land is needed, and that plant ecological environmental deterioration is expected due to artificial creation of fragile biogeocenosis from the viewpoints of natural environment.

Table 6-28 Environmental Indicators for Each Power Source

Category \ Type of Power	Conventional Energy			Non Conventional Renewable Energy				
	Hydro	Coal	LNG, Oil	Wind	Solar	Mini-Hyd	PSPP	Biomass
Topography & Geology	-1.0	0.0	0.0	0.0	0.0	0.0	-1.0	0.0
Soil	-1.0	-2.0	-2.0	0.0	-1.0	-1.0	0.0	0.0
Quality of Water	-0.3	-3.0	-2.0	0.0	-1.0	0.0	0.0	-1.0
Quality of Air	0.0	-2.0	-2.0	0.0	0.0	0.0	0.0	-1.0
Noise/Vibration	0.0	0.0	0.0	-1.0	0.0	0.0	0.0	-1.0
Waste	0.0	-3.0	0.0	0.0	-2.0	0.0	0.0	-2.0
Subsidence	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flora	-1.3	-3.0	0.0	0.0	-2.0	-1.0	-2.3	-3.0
Fauna/Fish/Coral	-2.0	-3.0	-2.0	-3.0	-1.0	-1.0	-3.0	-1.0
Natural Protected Areas	-0.7	0.0	0.0	-0.5	0.0	0.0	0.0	0.0
Natural Environment	-0.63	-1.60	-0.80	-0.45	-0.70	-0.30	-0.63	-0.90
Resettlement	-2.0	0.0	0.0	-0.5	0.0	0.0	-1.7	0.0
Ethnic /Indigenous people	-0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Land use	-1.3	0.0	0.0	-1.0	0.0	-1.0	-2.7	-2.0
Water Use	-1.0	-2.0	-2.0	0.0	0.0	-1.0	-2.7	-1.0
Landscape	0.0	-2.0	0.0	-3.0	-2.0	0.0	0.0	-2.0
Historical Heritage	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Social Environment	-0.89	-0.67	-0.33	-0.67	-0.33	-0.33	-1.17	-0.83
Comprehensive Environmental Indicator	**-0.76**	**-1.13**	**-0.57**	**-0.56**	**-0.52**	**-0.32**	**-0.90**	**-0.87**

(Source: JICA Survey Team)



(Source: JICA Survey Team)

Figure 6-9 Environmental Indicators for Each Power Generation Development Plan

The load index (comprehensive environmental indicator x 0.2 + CO_2 emission ratio x 0.8) to the environment by power source is multiplied with each configuration ratio and summed up. And those indexes are normalized so that the scenario with highest score is 10 point and the scenario with lowest score is 0.0 point.

In the scenario B plans, the scenario plan with the highest score (the lowest negative influence on the environment) is B-C3-084 (LNG-fired TPP 3.6 GW, Coal-fired TPP 0.9 GW, PSPP 0.0 GW, Wind Power 4.0 GW, Solar Power 2.0GW).

(For details, refer to Section 7.4.4 Evaluation Method for Power Supply Configuration Scenarios).

Table 6-29 Evaluation Scores in Scenario B Plans from Viewpoints of Regional Environment

	Installed capacity (GW)					Generating cost (USC/kWh)	CO_2 emissions (kg/kWh)	Normalized Score			
	LNG	Coal	PSPP	Wind	Solar			Economy	Environ-ment	Energy security	Total
B-C3-084	3.6	0.9	0.0	4.0	2.0	9.41	0.241	2.9	10.0	3.1	16.0
B-B3-086	3.3	0.9	0.0	4.0	3.0	9.37	0.229	3.3	9.9	2.0	15.2
B-C3-064	3.6	0.9	0.0	3.0	2.0	9.44	0.273	2.7	9.8	3.6	16.0
B-A3-088	3.0	0.9	0.0	4.0	4.0	9.37	0.218	3.2	9.8	1.2	14.2
B-93-08A	2.7	0.9	0.0	4.0	5.0	9.40	0.208	3.1	9.7	0.0	12.7
B-C3-066	3.6	0.9	0.0	3.0	3.0	9.44	0.259	2.7	9.6	3.1	15.4
B-B3-068	3.3	0.9	0.0	3.0	4.0	9.35	0.245	3.4	9.6	3.3	16.3
B-B3-184	3.3	0.9	0.6	4.0	2.0	9.44	0.239	2.7	9.6	4.8	17.2
B-A3-186	3.0	0.9	0.6	4.0	3.0	9.41	0.227	2.9	9.6	3.8	16.2
B-D3-044	3.9	0.9	0.0	2.0	2.0	9.67	0.308	0.7	9.3	4.0	14.1
B-C3-046	3.6	0.9	0.0	2.0	3.0	9.59	0.295	1.4	9.3	3.8	14.5
B-B3-048	3.3	0.9	0.0	2.0	4.0	9.50	0.281	2.1	9.3	4.0	15.4
B-A3-188	3.0	0.9	0.6	4.0	4.0	9.51	0.216	2.1	9.3	2.0	13.3
B-C3-164	3.6	0.9	0.6	3.0	2.0	9.60	0.273	1.3	9.2	4.0	14.5
B-B3-166	3.3	0.9	0.6	3.0	3.0	9.51	0.260	2.0	9.2	3.6	14.8
B-A3-168	3.0	0.9	0.6	3.0	4.0	9.43	0.246	2.8	9.1	3.9	15.9
B-93-18A	2.7	0.9	0.6	4.0	5.0	9.52	0.207	2.0	9.1	1.2	12.3
B-C3-144	3.6	0.9	0.6	2.0	2.0	9.75	0.309	0.0	8.9	4.3	13.2
B-B3-146	3.3	0.9	0.6	2.0	3.0	9.67	0.295	0.7	8.9	4.0	13.5
B-B3-148	3.3	0.9	0.6	2.0	4.0	9.68	0.282	0.7	8.7	4.1	13.4

(Source: Citing from Table-7-18 in Chapter 7)

6.8 Expected Mitigation Measures

The optimal power configuration to meet electric power demand in 2040 is evaluated numerically in the project "Electricity Sector Master Plan with the final target year of 2040". The development of each project to materialize various power developments (location, scale, plot plan etc.) is excluded. Accordingly, since concrete mitigation measures against the environmental impacts caused by each power development project are impossible to quantify at this stage of the survey (SEA level), the general mitigation measures to be considered for each power development project are described in the table below.

Table 6-30 Expected Mitigation Measures for Each Power Source

	Expected mitigation measures (avoidance, reduction, compensation)
Hydropower	・Prioritize the adoption of “Run-of River Type” and reduce the impact on the natural and social environment (resettlement of residents). ・Select preferentially an alternative that can avoid resettling residents. ・Release river maintenance flow to avoid the influence on the natural and social environments (drink water supply, irrigation, tourism use) in the downstream area due to water reduction. ・By installing fish passes, avoid influence on migratory fish due to installation of dam / intake weir. ・Prevent fish from passing into turbines by using nets, barriers or screens. ・Discharge at various elevations of the dam to avoid outflow of anoxic or cold water. ・In principle, adopt a “embedded type” for a penstock, and if inevitable, adopt “open type”. ・In the case of the “ground surface type” or “semi-underground type” power house, design the building in a harmonious manner with the surrounding landscape.

Thermal (Coal)	・Avoid new alteration of the land by locating in a place where existing infrastructure can be used. ・By adopting a cooling tower system, avoid influence by heated effluent. ・To reduce greenhouse gas emissions and fuel costs, introduce a high-efficiency thermal power generation (IGCC, IGFC). ・By mixing biomass fuels, reduce carbon dioxide emissions. ・Install de-NOx equipment to reduce nitrogen oxide emissions. ・Set equipment which generates noise / vibration apart from the residence as far as possible. ・Proaccelerating to make effective use of coal ash.
Thermal (LNG, Oil)	・Avoid new alteration of the land by locating in a place where existing infrastructure can be used. ・By adopting the cooling tower system, avoid influence by heated effluent. ・Set equipment which generates noise / vibration apart from the residence as far as possible.
Wind	・Use blades to suppress the generation of noise and very low frequency sound. ・Avoid flight routes of migratory birds and avoid bird strike. ・To avoid shadow flicker, locate it apart from the residential area as far as possible. ・Avoid the influence of fish by electromagnetic waves in the case of offshore wind power generation. ・Develop batteries that can be simply disposed as waste. ・Design in harmony with the surrounding landscape
Solar	・Develop batteries that can be simply disposed as waste. ・Design in harmony with the surrounding landscape by planting around facility.
Mini-hydro	・Prioritize the adoption of "Run-of River Type" and reduce the impact on the natural and social environment (resettlement of residents). ・Select preferentially an alternative that can avoid resettling residents. ・Release river maintenance flow to avoid the influence on the natural and social environments (drink water supply, irrigation, tourism use) in the downstream area due to water reduction. ・By installing fish passes, avoid influence on migratory fish due to installation of dam / intake weir. ・Prevent fish from passing into turbines by using nets, barriers or screens. ・Design the building in a harmonious manner with the surrounding landscape.
PSPP	・Avoid the influence on the body of water by installing a bypass channel around the upper reservoir. ・Select preferentially an alternative that can avoid resettling residents. ・In principle, adopt a "embedded type" for a penstock, and if inevitable, adopt "open type". ・Prevent fish from passing into turbines by using nets, barriers or screens.
Biomass	・Avoid new alteration of the land by locating in a place where existing infrastructure can be used. ・By adopting the cooling tower system, avoid influence by heated effluent. ・Set equipment which generates noise / vibration apart from the residence as far as possible. ・Promote making effective use of combustion residue.

(Source: JICA Survey Team)

6.9 Implementation of Monitoring Plan

Based on the same reason as the background described in Section 6.8 Mitigation Measures, the preparation and implementation of the monitoring plan shall be considered in the EIA at the project implementation stage.

In this section, general monitoring items to be considered are described in the table below when monitoring in time-series the appropriate implementation of mitigation measures proposed in the power development project.

Table 6-31 Common Monitoring Items for Power Development Project

	Main Monitoring Items		
Power Development Project	Anti-Pollution measures	Air Quality	SO_2, NO_2, CO, O_3, Soot, Dust, Suspended particulate matter (PM10, PM2.5), Coarse particulate
		Water Quality (Surface) (Ground)	pH, Suspended solids (SS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Total nitrogen, Total phosphorus, Heavy metals, etc.
		Waste (Industrial) (Domestic)	Types, Volume, Implementation of 3R
		Noise Vibration	Level of noise (dB) and vibration
		Odors	Specific bad smell material
		Soil	Content of heavy metals
		Sedimentation	Sedimentation volume
	Natural Environment	Ecosystem	Threatened species, Endemic species
		Topography Geology	Erosion, Land slide or collapse
	Social Environment	Resettlement	Impacts due to resettlement Adequate payment of compensation cost
		Living Livelihood	Adverse impacts on the livelihood of inhabitants
	Globe Environment	Air Quality	GHG (CO_2) emission

(Source: JICA Survey Team)

6.10 SEA Concerning Transmission Reinforcement Plans

(1) Outline of project

SEA was conducted on the planned transmission line system (2 routes) below.
For these proposed transmission lines with 400kV undermentioned, from the viewpoint of SEA, scoping on environmental and social consideration items that are expected to be affected was carried out and the influence was evaluated.

Table 6-32 Proposed Transmission Lines

	Name of Power Grid	Circuit x kV	Length (km)	Route
1	Kirindiwela-Padukka-Ambalangoda-Hambantota	2 x 400kV	213.0	Figure 6-10
2	Sampoor-New Habarana	2 x 400kV	83.5	Figure 6-11
3	Kirindiwela SWS-Kerawalapitiya PG	2 x 400kV	33.4	Figure 6-12

(Source: JICA Survey Team)

(2) Analysis of Alternatives (including without project)

Three alternative routes are selected for the above proposed three transmission lines as shown in Figure 6-10, Figure 6-11, and Figure 6-12, respectively.
Every route of alternative-II is planned to connect from the power plants to the substations putting priority on economic efficiency such as distance and topographic conditions. Every route of alternative-I is planned putting priority on avoidance of negative environmental impacts on densely-populated places and protected areas.
Regarding each planned route of transmission line reinforcement, scoping is carried out to evaluate quantitatively environmental items having a serious negative direct impact, and the environmentally desirable transmission line plan is presented.

A method for quantitatively evaluating environmental impact has not yet been scientifically proven. Therefore, the JICA team focused on alternative qualitative differences here, divided them into the following four stages and quantified them (0 to -3).

0: No impact
-1: Not serious but a small impact
-2: Serious impact but not irreversible
-3: Huge serious irreversible impact

From the viewpoint of environmental and social considerations, the following table shows a quantitative comparison of the impact of "alternative-I," and "alternative-II," for each transmission line route.

Table 6-33 Comparison of Alternative Routes

Name of route / Items	Kirindiwela-Padukka--Ambalangoda-Hambantota		Sampoor-New Habarana		Kirindiwela SWS-Kerawalapitiya PG	
	Alternative-I	Alternative-II	Alternative-I	Alternative-II	Alternative-I	Alternative-II
Protected area	0	0	0	-3	0	0
Topography & Geology*	-2	-1	-2	-1	-2	-1
Resettlement**	0	-3	0	-1	0	-3
Evaluation	**-2**	**--4**	**-2**	**-5**	**-2**	**-4**

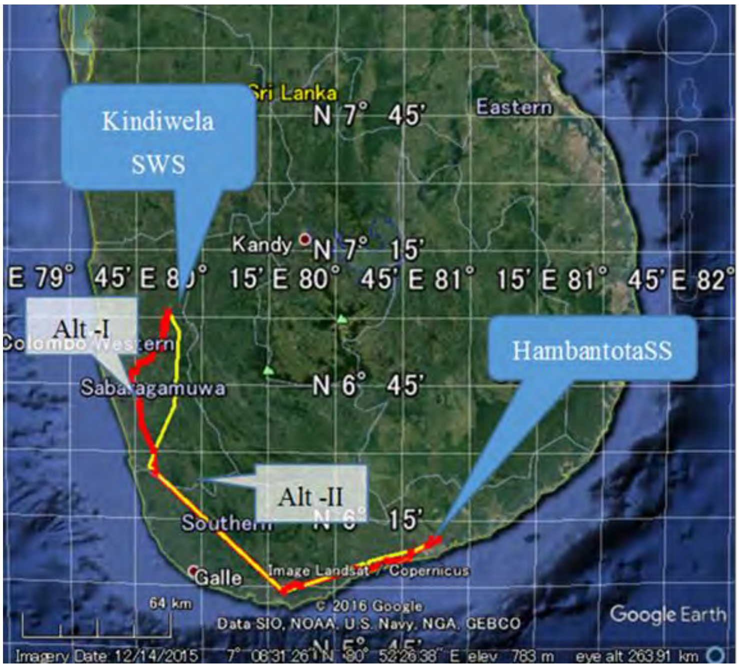
* : Destruction area means altered area by construction of steel tower: Large; -2, Small; -1, Nil.; 0.
** : Resettlement : Large scale (over 11); -3, Medium scale (6-10); -2, Small scale (1-5); -1, Nil.; 0.

(Source: JICA Survey Team)

Therefore, the load on the environment is -2 for all alternative-Is; alternative-IIs are -4 and -5 respectively.

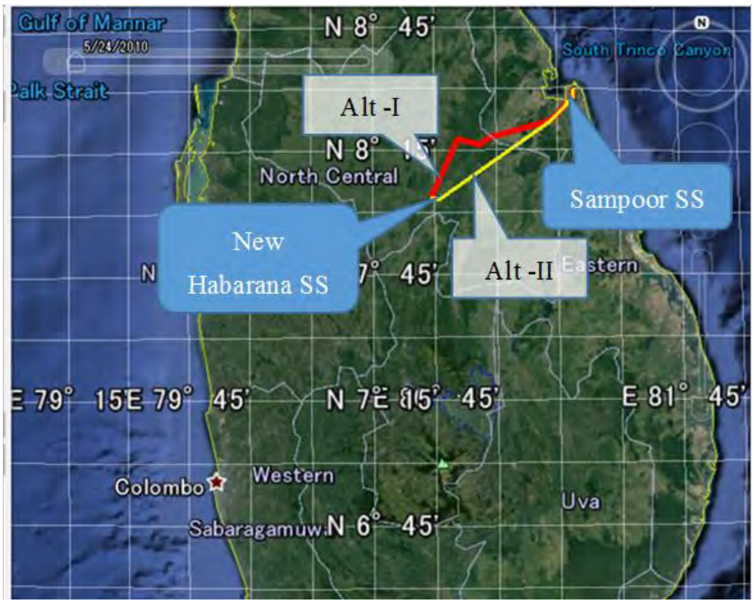
Based on the above evaluation results, all routes adopted "Alternative-I," as the environmentally preferable route.

The examination of the zero option is not considered at the SEA stage, since no practical and concrete project plan to transmit electricity, other than the construction of the transmission line, can be assumed. Zero option would be considered at the F/S stage or EIA, where various investigations on the natural and social environments will be conducted.



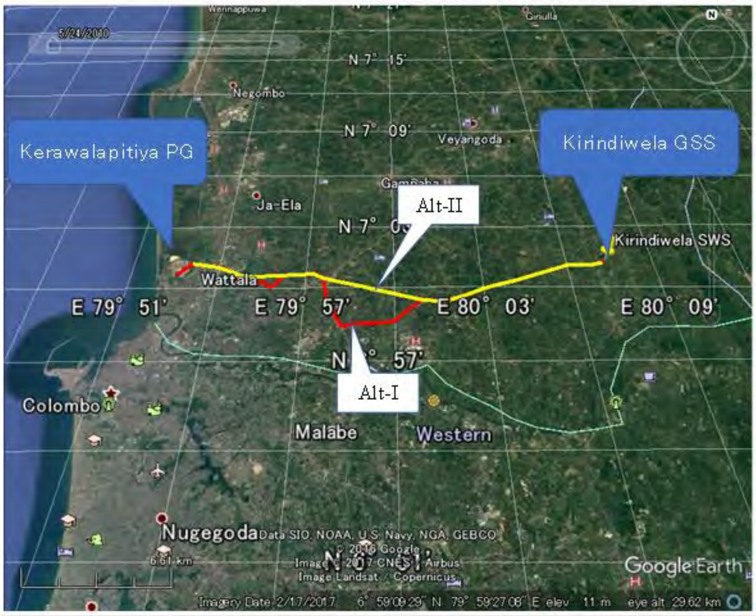
(Source: JICA Survey Team)

Figure 6-10 Alternatives for Transmission Line between Kirindiwela-Padukka-Ambalangoda-Hambantota



(Source: JICA Survey Team)

Figure 6-11 Alternatives for Transmission Line between Sampoor-New Habarana



(Source: JICA Survey Team)

Figure 6-12 Alternatives for Transmission Line between Kerawalapitiya and Kirindiwela

(3) Scoping

The scoping for Alternative-I for Kirindiwela-Padukka-Ambalangoda-Hambantota Transmission Line is shown in the table below.

Table 6-34 Scoping for Alternative-I for Kirindiwela-Padukka-Ambalangoda-Hambantota Transmission Line

Item		Impact	Rating	Results
Pollution Control	1	Air Quality	D	There is no specific negative impact anticipated.
	2	Water Quality	D	There is no specific negative impact anticipated.
	3	Soil Quality	D	There is no specific negative impact anticipated.
	4	Sediment (bottom of dam)	D	There is no specific negative impact anticipated.
	5	Noise and Vibration	D	There is no specific negative impact anticipated.
	6	Odor	D	There is no specific negative impact anticipated.
	7	Waste	D	There is no specific negative impact anticipated.
	8	Subsidence	D	There is no specific negative impact anticipated.
Natural	9	Protected Areas	D	There is no specific negative impact anticipated.
	10	Ecosystem	A	Bird strikes of power transmission line are assumed.
	11	Topography and Geology	B	Depending on the geology, there is a possibility of soil erosion around the towers.
Social Environment	12	Land acquisition and Resettlement	C	Confirm the existence of private land on the transmission line land (ROW) and the usage situation. Furthermore, the actual condition of settlements and other residences on the route has not been confirmed, but occurrence of involuntary resettlement relating to the construction of transmission lines is not assumed.
	13	Poor People	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time.

Item		Impact	Rating	Results
	14	Ethnic Minority Groups and Indigenous People	D	There is no specific negative impact anticipated.
	15	Local Economy such as Losses of Employment and Livelihood Means	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time
	16	Land Use and Utilization of Local Resources	C	Impact is unknown from existing documents. This item will be evaluated after collecting information and analyzing it through social surveys in the field.
	17	Water Usage, Water Rights, etc.	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time
	18	Existing Social Infrastructure and Services	D	There is no specific negative impact anticipated.
	19	Social Institutions such as Social Infrastructure and Local Decision-making Institutions	D	There is no specific negative impact anticipated.
	20	Misdistribution of Benefits and Loss	D	There is no specific negative impact anticipated.
	21	Local Conflicts of Interest	D	There is no specific negative impact anticipated.
	22	Cultural Heritage	D	There is no specific negative impact anticipated.
	23	Landscape	D	There are no scenic spots in and around the site.
	24	Gender	D	There is no specific negative impact anticipated.
	25	Children's Rights	D	There is no specific negative impact anticipated.
	26	Infectious Diseases such as HIV/AIDS	C-	The extent of the influence associated with the construction of the transmission line is unknown at the present time
	27	Work Environment (including Work Safety)	B-	Accidents may occur in the construction site. Workers may get involved in accidents during maintenance work.
Other	28	Accidents	B-	Accidents may occur in the construction site. Increase of traffic volume may cause traffic accidents
	29	Cross-boundary Impact and Climate Change	D	There is no specific negative impact anticipated.

(Source: JICA Survey Team)

Table 6-35 Scoping for Alternative-II for Kirindiwela-Padukka-Ambalangoda-Hambantota Transmission Line

Item		Impact	Rating	Results
Pollution Control	1	Air Quality	D	There is no specific negative impact anticipated.
	2	Water Quality	D	There is no specific negative impact anticipated.
	3	Soil Quality	D	There is no specific negative impact anticipated.
	4	Sediment (bottom of dam)	D	There is no specific negative impact anticipated.
	5	Noise and Vibration	D	There is no specific negative impact anticipated.
	6	Odor	D	There is no specific negative impact anticipated.
	7	Waste	D	There is no specific negative impact anticipated.
	8	Subsidence	D	There is no specific negative impact anticipated.

Item		Impact	Rating	Results
Natural	9	Protected Areas	D	There is no specific negative impact anticipated.
	10	Ecosystem	A	Bird strikes of power transmission line are assumed.
	11	Topography and Geology	C	Depending on the geology, there is a possibility of soil erosion around the towers.
Social Environment	12	Land acquisition and Resettlement	A	Actual conditions of settlements and other residences on the route are confirmed and occurrence of involuntary resettlement due to the construction of transmission lines is assumed.
	13	Poor People	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time.
	14	Ethnic Minority Groups and Indigenous People	D	There is no specific negative impact anticipated.
	15	Local Economy such as Losses of Employment and Livelihood Means	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time
	16	Land Use and Utilization of Local Resources	C	Impact is unknown from existing documents. This item will be evaluated after collecting information and analyzing it through social surveys in the field.
	17	Water Usage, Water Rights, etc.	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time
	18	Existing Social Infrastructure and Services	D	There is no specific negative impact anticipated.
	19	Social Institutions such as Social Infrastructure and Local Decision-making Institutions	D	There is no specific negative impact anticipated.
	20	Misdistribution of Benefits and Loss	D	There is no specific negative impact anticipated.
	21	Local Conflicts of Interest	D	There is no specific negative impact anticipated.
	22	Cultural Heritage	D	There is no specific negative impact anticipated.
	23	Landscape	D	There are no scenic spots in and around the site.
	24	Gender	D	There is no specific negative impact anticipated.
	25	Children's Rights	D	There is no specific negative impact anticipated.
	26	Infectious Diseases such as HIV/AIDS	C-	The extent of the influence associated with the construction of the transmission line is unknown at the present time
	27	Work Environment (including Work Safety)	B-	Accidents may occur in the construction site. Workers may get involved in accidents during maintenance work.
Other	28	Accidents	B-	Accidents may occur in the construction site. Increase of traffic volume may cause traffic accidents
	29	Cross-boundary Impact and Climate Change	D	There is no specific negative impact anticipated.

(Source: JICA Survey Team)

Table 6-36 Scoping for Alternative-I for Sampoor-New Habarana Transmission Line

Item		Impact	Rating	Results
Pollution Control	1	Air Quality	D	There is no specific negative impact anticipated.
	2	Water Quality	D	There is no specific negative impact anticipated.
	3	Soil Quality	D	There is no specific negative impact anticipated.
	4	Sediment (bottom of dam)	D	There is no specific negative impact anticipated.
	5	Noise and Vibration	D	There is no specific negative impact anticipated.
	6	Odor	D	There is no specific negative impact anticipated.
	7	Waste	D	There is no specific negative impact anticipated.
	8	Subsidence	D	There is no specific negative impact anticipated.
Natural	9	Protected Areas	D	There is no specific negative impact anticipated.
	10	Ecosystem	A	Bird strikes of power transmission line are assumed.
	11	Topography and Geology	B	Depending on the geology, there is a possibility of soil erosion around the towers.
Social Environment	12	Land acquisition and Resettlement	C	Confirm the existence of private land on the transmission line land (ROW) and the usage situation. Furthermore, the actual condition of settlements and other residences on the route has not been confirmed, but occurrence of involuntary resettlement relating to the construction of transmission lines is not assumed.
	13	Poor People	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time.
	14	Ethnic Minority Groups and Indigenous People	D	There is no specific negative impact anticipated.
	15	Local Economy such as Losses of Employment and Livelihood Means	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time
	16	Land Use and Utilization of Local Resources	C	Impact is unknown from existing documents. This item will be evaluated after collecting information and analyzing it through social surveys in the field.
	17	Water Usage, Water Rights, etc.	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time
	18	Existing Social Infrastructure and Services	D	There is no specific negative impact anticipated.
	19	Social Institutions such as Social Infrastructure and Local Decision-making Institutions	D	There is no specific negative impact anticipated.
	20	Misdistribution of Benefits and Loss	D	There is no specific negative impact anticipated.
	21	Local Conflicts of Interest	D	There is no specific negative impact anticipated.
	22	Cultural Heritage	D	There is no specific negative impact anticipated.
	23	Landscape	D	There are no scenic spots in and around the site.
	24	Gender	D	There is no specific negative impact anticipated.
	25	Children's Rights	D	There is no specific negative impact anticipated.
	26	Infectious Diseases such as HIV/AIDS	C-	The extent of the influence associated with the construction of the transmission line is unknown at the present time

Item		Impact	Rating	Results
	27	Work Environment (including Work Safety)	B-	Accidents may occur in the construction site. Workers may get involved in accidents during maintenance work.
Other	28	Accidents	B-	Accidents may occur in the construction site. Increase of traffic volume may cause traffic accidents
	29	Cross-boundary Impact and Climate Change	D	There is no specific negative impact anticipated.

(Source: JICA Survey Team)

Table 6-37 Scoping for Alternative-II for Sampoor-New Habarana Transmission Line

I		Impact	Rating	Results
Pollution Control	1	Air Quality	D	There is no specific negative impact anticipated.
	2	Water Quality	D	There is no specific negative impact anticipated.
	3	Soil Quality	D	There is no specific negative impact anticipated.
	4	Sediment (bottom of dam)	D	There is no specific negative impact anticipated.
	5	Noise and Vibration	D	There is no specific negative impact anticipated.
	6	Odor	D	There is no specific negative impact anticipated.
	7	Waste	D	There is no specific negative impact anticipated.
	8	Subsidence	D	There is no specific negative impact anticipated.
Natural	9	Protected Areas	A	Transmission line is planned to across protected area.
	10	Ecosystem	A	Bird strikes of power transmission line are assumed.
	11	Topography and Geology	C	Depending on the geology, there is a possibility of soil erosion around the towers.
Social Environment	12	Land acquisition and Resettlement	A	Actual conditions of settlements and other residences on the route are confirmed and occurrence of involuntary resettlement due to the construction of transmission lines is assumed.
	13	Poor People	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time.
	14	Ethnic Minority Groups and Indigenous People	D	There is no specific negative impact anticipated.
	15	Local Economy such as Losses of Employment and Livelihood Means	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time
	16	Land Use and Utilization of Local Resources	C	Impact is unknown from existing documents. This item will be evaluated after collecting information and analyzing it through social surveys in the field.
	17	Water Usage, Water Rights, etc.	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time
	18	Existing Social Infrastructure and Services	D	There is no specific negative impact anticipated.
	19	Social Institutions such as Social Infrastructure and Local Decision-making Institutions	D	There is no specific negative impact anticipated.
	20	Misdistribution of Benefits and Loss	D	There is no specific negative impact anticipated.
	21	Local Conflicts of Interest	D	There is no specific negative impact anticipated.

I		Impact	Rating	Results
	22	Cultural Heritage	D	There is no specific negative impact anticipated.
	23	Landscape	D	There are no scenic spots in and around the site.
	24	Gender	D	There is no specific negative impact anticipated.
	25	Children's Rights	D	There is no specific negative impact anticipated.
	26	Infectious Diseases such as HIV/AIDS	C-	The extent of the influence associated with the construction of the transmission line is unknown at the present time
	27	Work Environment (including Work Safety)	B-	Accidents may occur in the construction site. Workers may get involved in accidents during maintenance work.
Other	28	Accidents	B-	Accidents may occur in the construction site. Increase of traffic volume may cause traffic accidents
Other	29	Cross-boundary Impact and Climate Change	D	There is no specific negative impact anticipated.

(Source: JICA Survey Team)

Table 6-38 Scoping for Alternative-I for Kirindiwela-Kerawalapitiya Transmission Line

Item		Impact	Rating	Results
Pollution Control	1	Air Quality	D	There is no specific negative impact anticipated.
Pollution Control	2	Water Quality	D	There is no specific negative impact anticipated.
Pollution Control	3	Soil Quality	D	There is no specific negative impact anticipated.
Pollution Control	4	Sediment (bottom of dam)	D	There is no specific negative impact anticipated.
Pollution Control	5	Noise and Vibration	D	There is no specific negative impact anticipated.
Pollution Control	6	Odor	D	There is no specific negative impact anticipated.
Pollution Control	7	Waste	D	There is no specific negative impact anticipated.
Pollution Control	8	Subsidence	D	There is no specific negative impact anticipated.
Natural	9	Protected Areas	A-	There is no specific negative impact anticipated.
Natural	10	Ecosystem	A-	Bird strikes of power transmission line are assumed.
Natural	11	Topography and Geology	C	Depending on the geology, there is a possibility of soil erosion around the towers.
Social Environment	12	Land acquisition and Resettlement	D	Confirm the existence of private land on the transmission line land (ROW) and the usage situation. Furthermore, the actual condition of settlements and other residences on the route has not been confirmed, but occurrence of involuntary resettlement relating to the construction of transmission lines is not assumed.
Social Environment	13	Poor People	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time.
Social Environment	14	Ethnic Minority Groups and Indigenous People	D	There is no specific negative impact anticipated.
Social Environment	15	Local Economy such as Losses of Employment and Livelihood Means	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time
Social Environment	16	Land Use and Utilization of Local Resources	C	Impact is unknown from existing documents. This item will be evaluated after collecting information and analyzing it through social surveys in the field.
Social Environment	17	Water Usage, Water Rights, etc.	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time
Social Environment	18	Existing Social Infrastructure and Services	D	There is no specific negative impact anticipated.

Item		Impact	Rating	Results
	19	Social Institutions such as Social Infrastructure and Local Decision-making Institutions	D	There is no specific negative impact anticipated.
	20	Misdistribution of Benefits and Loss	D	There is no specific negative impact anticipated.
	21	Local Conflicts of Interest	D	There is no specific negative impact anticipated.
	22	Cultural Heritage	D	There is no specific negative impact anticipated.
	23	Landscape	D	There are no scenic spots in and around the site.
	24	Gender	D	There is no specific negative impact anticipated.
	25	Children's Rights	D	There is no specific negative impact anticipated.
	26	Infectious Diseases such as HIV/AIDS	C-	The extent of the influence associated with the construction of the transmission line is unknown at the present time
	27	Work Environment (including Work Safety)	B-	Accidents may occur in the construction site. Workers may get involved in accidents during maintenance work.
Other	28	Accidents	B-	Accidents may occur in the construction site. Increase of traffic volume may cause traffic accidents
	29	Cross-boundary Impact and Climate Change	D	There is no specific negative impact anticipated.

(Source: JICA Survey Team)

Table 6-39 Scoping for Alternative-II for Kirindiwela-Kerawalapitiya Transmission Line

Item		Impact	Rating	Results
Pollution Control	1	Air Quality	D	There is no specific negative impact anticipated.
	2	Water Quality	D	There is no specific negative impact anticipated.
	3	Soil Quality	D	There is no specific negative impact anticipated.
	4	Sediment (bottom of dam)	D	There is no specific negative impact anticipated.
	5	Noise and Vibration	D	There is no specific negative impact anticipated.
	6	Odor	D	There is no specific negative impact anticipated.
	7	Waste	D	There is no specific negative impact anticipated.
	8	Subsidence	D	There is no specific negative impact anticipated.
Natural	9	Protected Areas	D	There is no specific negative impact anticipated.
	10	Ecosystem	A	Bird strikes of power transmission line are assumed.
	11	Topography and Geology	C	Depending on the geology, there is a possibility of soil erosion around the towers.
Social Environment	12	Land acquisition and Resettlement	A	Densely populated areas are confirmed on the route, and large-scale involuntary resettlement due to the construction of transmission lines is assumed.
	13	Poor People	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time.
	14	Ethnic Minority Groups and Indigenous People	D	There is no specific negative impact anticipated.
	15	Local Economy such as Losses of Employment and Livelihood Means	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time

Item		Impact	Rating	Results
	16	Land Use and Utilization of Local Resources	C	Impact is unknown from existing documents. This item will be evaluated after collecting information and analyzing it through social surveys in the field.
	17	Water Usage, Water Rights, etc.	C	The extent of the influence associated with the construction of the transmission line is unknown at the present time
	18	Existing Social Infrastructure and Services	D	There is no specific negative impact anticipated.
	19	Social Institutions such as Social Infrastructure and Local Decision-making Institutions	D	There is no specific negative impact anticipated.
	20	Misdistribution of Benefits and Loss	D	There is no specific negative impact anticipated.
	21	Local Conflicts of Interest	D	There is no specific negative impact anticipated.
	22	Cultural Heritage	D	There is no specific negative impact anticipated.
	23	Landscape	D	There are no scenic spots in and around the site.
	24	Gender	D	There is no specific negative impact anticipated.
	25	Children's Rights	D	There is no specific negative impact anticipated.
	26	Infectious Diseases such as HIV/AIDS	C-	The extent of the influence associated with the construction of the transmission line is unknown at the present time
	27	Work Environment (including Work Safety)	B-	Accidents may occur in the construction site. Workers may get involved in accidents during maintenance work.
Other	28	Accidents	B-	Accidents may occur in the construction site. Increase of traffic volume may cause traffic accidents
	29	Cross-boundary Impact and Climate Change	D	There is no specific negative impact anticipated.

Note: A+/-: Significant positive/negative impact is expected
B+/-: Positive/negative impact is expected to some extent
C+/-: Extent of positive/negative impact is unknown (further examination is needed, and the impact may be clarified as the study progresses)
D: No impact is expected

(Source: JICA Survey Team)

(4) Proposed TOR on survey to collect data

Based on the above evaluation, surveys on major environmental and social consideration items to be carried out at the implementation stage of the project are as shown in the table below.

Table 6-40 Survey Items and Methods

Environmental Items	Survey Items	Survey Method
Air Quality	- Relevant environmental standards - Meteorological information - Current status of ambient atmosphere	- Obtain ambient air quality standards, - Measure the air pollutants (TSP), SO_2, NO_2, CO, O_3, PM_{10}, $PM_{2.5}$.
Water Quality	- Relevant environmental standards - Current status of water quality	- Obtain water quality standards and effluent standards. - Measure the existing reservoir and river water quality (temperatures, salinity, COD, and nutrients, etc.)

Environmental Items	Survey Items	Survey Method
Soil Quality	- Relevant environmental standards	- Measure for soil quality and any contamination.
Noise and Vibration	- Relevant environmental standards - Current status of noise and vibration	- Obtain noise level standards - Measure the noise levels (background)
Waste	- Relevant environmental standards	- Obtain waste handling standards / manuals / guidelines.
Subsidence	- Current status of soil conditions	- Geological survey
Protected Areas	- Current status of Protected Areas	- Collect relevant laws and regulations, information on Protected Areas
Ecosystem	- Current habitat status of flora, mammal , birds, reptiles, amphibians, fish, precious species (migrant birds)	- Survey the distribution of flora and fauna.
Topography and Geology	- Geological conditions	- Obtain geological information
Land acquisition / Resettlement	- Confirm who the affected people are and negative impacts caused by the project. - Confirm assets of the affected people - Identify livelihoods of the affected people	- Collect relevant laws and regulations, information on relevant cases - Conduct population census - Conduct asset inventory survey - Conduct household socioeconomic survey
Disturbance to Ethnic Minority Groups and Indigenous People	- Identify ethnic minority groups and indigenous people among the affected people	- Collect relevant laws and regulations, information on relevant cases - Conduct population census - Conduct asset inventory survey - Conduct household socioeconomic survey
Land Use and Utilization of Local Resources	- Identify the present land use - Identify jobs and livelihoods of the affected people	- Collect information on the employment and income in the affected area - Interviews with the households
Disturbance to Water Usage, Water Rights, etc.	- Identify the present water use for day-to-day life and agricultural activities.	- Household socioeconomic survey - Interviews with the households
Cultural Heritage	- Current status of Cultural Heritage Areas	- Collect relevant laws and regulations, information on Heritage Areas
Landscape	- Current status of outstanding scenery	- Collect relevant laws and regulations, information on outstanding scenery
Cross-boundary Impact and Climate Change	- Identify the present air quality	- Measure CO_2 emitted from construction vehicles and heavy machines.

(Source: JICA Survey Team)

(5) Environmental Impact Assessment

From the results of the examination and evaluation of scoping and alternative plans for both transmission lines, Kirindiwela-Padukka-Ambalangoda-Hambantota line and Sampoor-New Habarana line, the negative influence on the environment due to alternative-I is judged to be less than that of alternative-II.

(6) Expected Mitigation Measures

The JICA Survey Team proposed a transmission line route that avoids protected areas designated by domestic law and minimizes the resettlement of residents.

Mitigation measures are to be considered by combining features of power transmission lines and pylons weather conditions, and topography / geology along the route and sites. Accordingly, since concrete mitigation measures against the environmental impacts caused by a transmission line expansion project are impossible to quantify at this stage of the survey (SEA level), the general mitigation measures to be considered for a transmission line expansion project are described in the table below.

Table 6-41 Expected Mitigation Measures for Transmission Line

	Expected mitigation measures (avoidance, reduction, compensation)
Transmission line	・Optimization of transmission line route with respect to avian migration corridors. ・Installation of anti-perching devices or platforms specially designed to encourage birds to perch or nest in safer places. ・Placing fluttering banners and brightly-colored (orange, yellow, white) spirals on transmission lines. ・Use of plant screens or other types of screens close to transmission lines to force birds to increase their flight altitude. ・Avoiding conservation units in habitats that have good wildlife potential.

(Source: JICA Survey Team)

(7) Implementation of Monitoring Plan

Based on the same reason as the background described in Section 6.8 Mitigation Measures, the preparation and implementation of the monitoring plan shall be considered in the EIA at the project implementation stage.

In this section, general monitoring items to be considered are described in the table below when monitoring in time-series the appropriate implementation of mitigation measures proposed in the transmission expansion project.

Table 6-42 Common Monitoring Items for Transmission Line Expansion Project

	Main Monitoring Items		
Transmission Line	Anti-Pollution measures	Air Quality	SO_2, NO_2, CO, O_3, Soot, Dust, Suspended particulate Matter (MP_{10},$PM_{2.5}$), Coarse particulate
		Water Quality Surface (Ground)	pH, Suspended solids (SS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Total Nitrogen, Total Phosphorus, Heavy Metals, etc.
		Waste (Industrial) (Domestic)	Types, Volume, Implementation of 3R
		Noise Vibration	Level of noise (dB) and vibration
		Odors	Specific bad smell material
		Soil	Including of heavy metals
	Natural Environment	Ecosystem	Threatened species, Endemic species Grasping of bird strike accidents
		Topography Geology	Erosion, Land slide
	Social Environment	Resettlement	Impacts of Resettlement Adequate explanation on compensation
		Living Livelihood	Adversely affects to the living conditions of inhabitants, recovery of means of livelihood.
	Global Environment	Air Quality	Emission of GHG (CO_2)

(Source: JICA Survey Team)

6.11 Stakeholder Meeting

The second workshop was held at The Bandaranaike Memorial International Conference Hall (BMICH) in Colombo on June 1, 2017, in which the environmental part positioned as stakeholder meeting, and SEA survey results was reported including questions and answers on SEA.
The numbers of participants were about 50 people including the JICA study team members.
The major participating organizations are CEB departments, Lanka Electricity Company, the Forest Ministry (Department of Forest Conservation, Department of Wildlife Conservation), the Central Environmental Authority (Environmental Management and Environment Assessment Division), and the Ministry of Electricity and Renewable Energy (Environmental Management Center).
The stakeholder meeting was held for the main purpose of providing the following two items to stakeholders.

- Evaluation results of the proposed power source development plan (proposed development scenario) reflecting the comments obtained at the SEA survey stage
- The degree of influence that each development scenario plan has on the environmental and social considerations.

The main questions and comments on the survey-outcomes were as follows.

Table 6-43 Questions and Answers in Stakeholder Meeting

Questions and Comments	Answers
➢ Mitigation measures on the negative impacts are considered when giving points to each type of power source	➢ JICA Survey Team gives point to each type of power source on the premise that the current environmental conservation measure technologies are to be applied. In the case that irreversible influence is assumed to occur even if applying current technology, high (minus) score is marked.
➢ Regarding mini hydropower, since various environmental problems occur in Sri Lanka and there are campaigns against project implementation, such environmental problems should also be evaluated.	➢ Regarding mini hydropower, since information on environment is limited, JICA Survey Team evaluated mini hydropower based on IEE / EIA of the existing small hydropower projects in Sri Lanka.
➢ On comparing the impacts on the social environment between mini hydropower and pumped storage power, do mini hydropower projects have more negative impacts such as water decline area than pumped-storage power project?	➢ JICA Survey Team analyzed social environmental impacts by pumped storage power project based on the existing study report “Development Planning on Optimal Generation for Peak Demand in Sri Lanka”. The score of social environment by pumped storage power project is lower than that of the mini hydropower plant, because pumped storage power project sites have larger scale of resettlement amount and land acquisition area than that of the existing small hydropower project.

6.12 Evaluation Methods of Environmental and Social Considerations for Projects

Evaluation of environmental and social considerations concerning the main projects reviewed / proposed in this master plan was conducted by the following method.

Table 6-44 Evaluation Method for Reviewed/Proposed Projects

Type of Plan	Outline	Evaluation-Method
Optimum Generation Configuration	The following three scenario drafts as the best mix (optimization) plan for power supply configuration are prepared; ① Scenario A: High Priority on Cost ② Scenario B: High Priority on Renewable Energy Development with CO_2 Reduction ③ Scenario C: Mixed Power Supply Development	Scoping was carried out on each generation type to evaluate its effects to the environmental and social conditions.
Transmission Expansion Plan according to the Optimum Power Development Scenario	Transmission development plan which coping with the scenario on optimum power development plan was discussed about the following three expansion plans; ① Kirindiwela-Padukka-Ambalangoda-Hambantota ② Sampoor-New Habarana ③ Kerawalapitiya PG-Kirindiwela GS	By conducting scoping based on secondary information such as literature, aerial photograph (Google Earth) etc., evaluation of its effects to the environmental and social conditions was carried out.

(Source: JICA Survey Team)

Chapter 7. Power Development Plan

7.1 Review of Current Power Development Plans

7.1.1 Current Power Demand and Supply Situation

(1) Operational Data

The past five years' records for installed capacity and generated energy by power sources from 2011 to 2015 are shown in Table 7-1.

The power development records and the configuration of the installed capacity by power sources in 2015 is shown in Figure 7-1 and the actual data and configuration of generated energy by power sources in 2015 is shown in Figure 7-2.

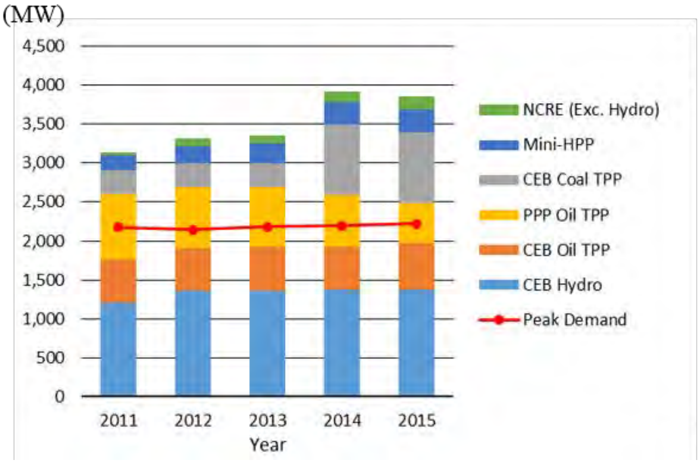
The installed capacity has increased 706MW from 2011 to 2015. Coal thermal has increased 600MW. Mini-hydro and wind power have increased 209MW and 95MW, respectively. Six oil fired thermal PPs of 281MW were retired. The ratio of CEB's installed capacity and the ratio of generated energy of the power plants owned by CEB are 75% and 79%, respectively.

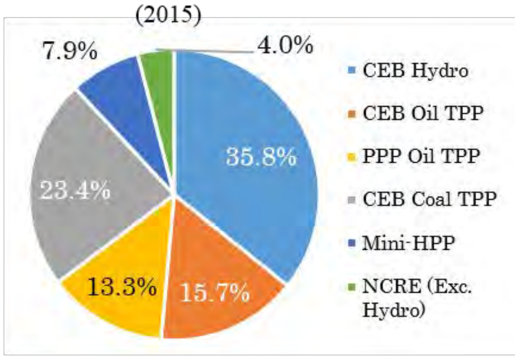
The ratio of both installed capacity and generated energy from fossil fuel fired TPPs and non-fossil fuel PPs is almost 50:50 in 2015. Accordingly, the CO_2 emission intensity in the power sector in Sri Lanka is 0.45kg-CO_2/kWh, which is at the same level as those of developed countries.

Table 7-1 Installed Capacity and Generated Energy by Power Sources

Year		2011			2012			2013			2014			2015		
		No.	MW	GWh	No.	MW	GWh	No.	MW	GWh	No.	MW	GWh	No.	MW	GWh
CEB	Total	24	2,064	6,553	25	2,214	6,162	25	2,228	8,744	25	2,824	8,532	26	2,884	10,399
	Hydro	16	1,207	4,018	17	1,357	2,727	17	1,361	5,990	17	1,377	3,632	17	1,377	4904
	Thermal - Oil	6	554	1,494	6	554	2,029	6	564	1,283	6	544	1,696	7	604	1050
	Thermal - Coal	1	300	1,038	1	300	1,404	1	300	1,469	1	900	3,202	1	900	4443
	Wind	1	3	3	1	3	2	1	3	2	1	3	2	1	3	2
I.P.P	Total	111	1,081	4,973	134	1,098	5,639	156	1,132	3,153	171	1,102	3,825	184	967	2,691
	Hydro - Small	91	194	601	109	227	565	131	264	916	144	288	902	154	303	1,065
	Thermal	11	842	4,254	8	784	4,906	7	771	1,977	6	671	2,610	4	511	1,225
	Wind	4	33	89	10	73	144	10	78	232	12	118	270	15	128	342
	Biomass	2	10.5	27.6	4	12.5	22	5	17.5	26.4	6	23.5	41	8	23.6	57
	Solar	3	1.36	1.0	3	1.36	1.8	3	1.36	1.7	3	1.36	1.5	3	1.36	1.9
Total		135	3,145	11,526	159	3,312	11,801	181	3,360	11,897	196	3,926	12,357	210	3,851	13,090

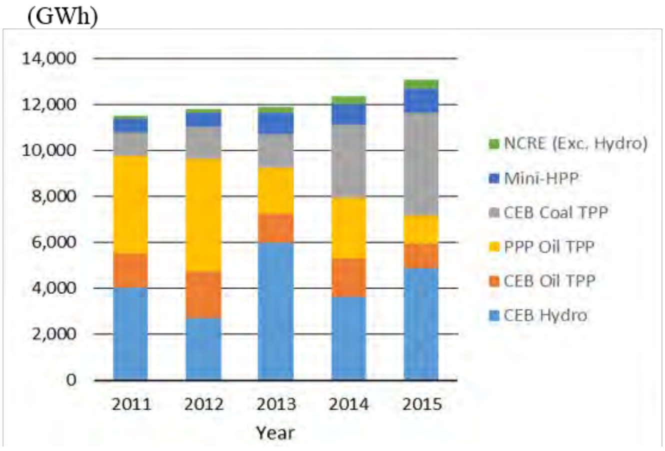
(Source: CEB Statistics Data)

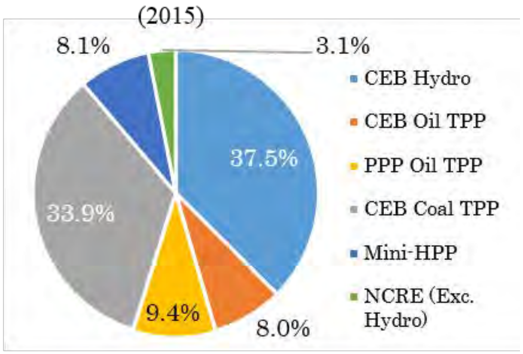




(Source: JICA Survey Team)

Figure 7-1 Configuration of Installed Capacity by Power Sources

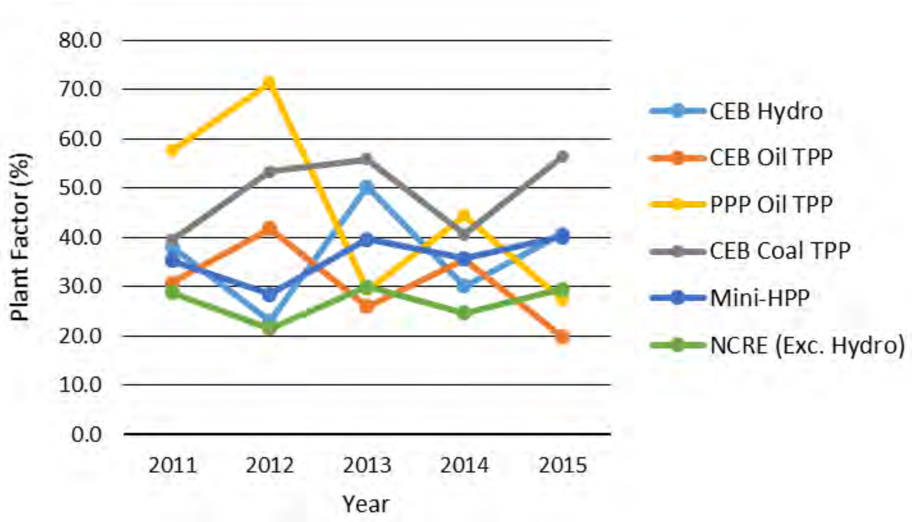




(Source: JICA Survey Team)

Figure 7-2 Configuration of Generated Energy by Power Sources

The plant factor results for each power source from 2011 to 2015 are shown in Figure 7-3. The role of oil fired TPPs belonging to Independent Power Producers (IPP) has drastically changed from base supplier to peak supplier in line with development of coal fired TPP. Since the plant factor of coal fired TPP is as low as 55% in comparison to the common value of over 70%, the forced outage rate is deemed rather high.



(Source: JICA Survey Team)

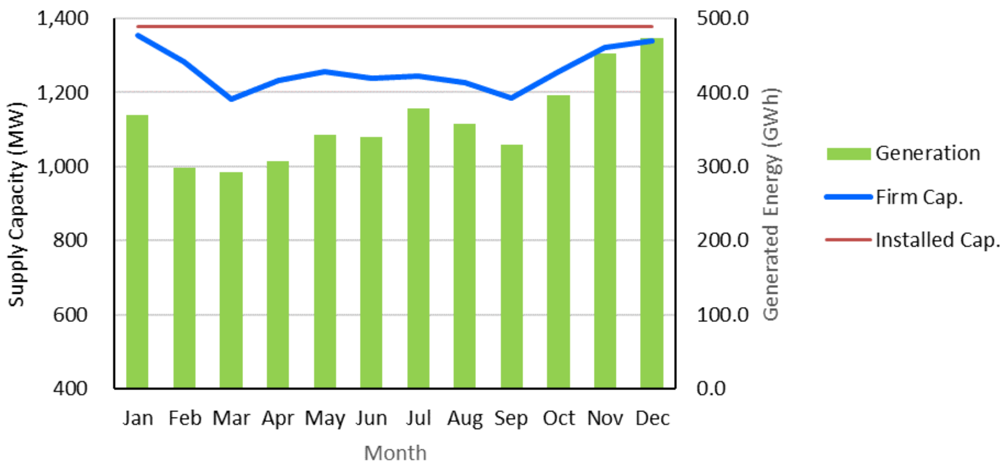
Figure 7-3 Plant Factor of Each Power Source (2011-2015)

(2) Features of Existing Power Plants

(a) CEB Hydropower Plants

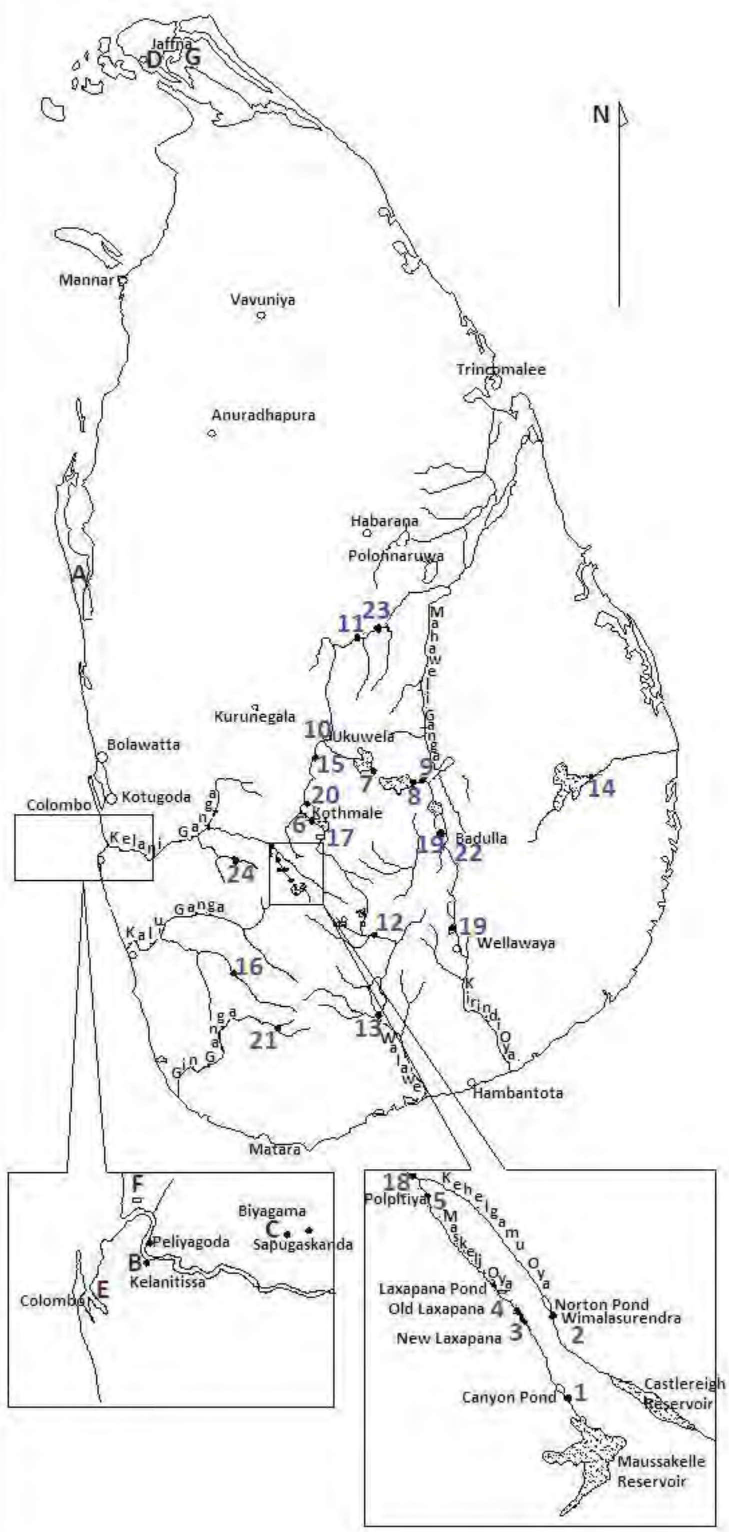
The locations of the power plants owned by CEB (existing and commissioned) are shown in Figure 7-5.

The installed capacity of the existing hydropower plants is 1,377MW as of the end of 2015. The mean monthly generated energy by CEB hydropower plants from 2000 to 2016 is shown in Figure 7-4, and the seasonal deviation is not so remarkable. In addition, all CEB hydropower plants are reservoir type, which can adjust the output though the year, or pondage type, which can adjust the output on a daily basis or weekly basis; therefore, since the supply capacity (firm peak capacity) of reservoir type depends only on the water head in line with seasonal variation of the water level of the reservoir, the supply capacity of reservoir type is determined as the mean monthly maximum output recorded from 2011 to 2015. The supply capacity of pondage type is determined as four times' the 90% probability monthly output recorded from 2005 to 2015 assuming that the peak duration is 6 hours. Accordingly, the lowest total supply capacity of hydropower plants remains at 1,184MW (86% of the installed capacity) in September, the end of the dry season.



(Source: JICA Survey Team)

Figure 7-4 Mean Monthly Generated Energy and Supply Capacity of CEB Hydropower



No.	Power Plant	Capacity (MW)
	Hydro Power Plants (Existing)	
1	Canyon	60
2	Wimalasurendra	50
3	New Laxapana	116
4	Old Laxapana	53.5
5	Polpitiya	75
6	Kotmale	201
7	Victoria	210
8	Randenigala	122
9	Rantambe	49
10	Ukuwela	40
11	Bowatenna	40
12	Samanalawewa	120
13	Udawalawe	6
14	Inginiyagala	11.25
15	Nilambe	3.2
16	Kukule	70
17	Upper Kotmale	150
	Hydro Power Plants (Committed)	
18	Broadlands	35
19	Uma Oya	120
20	Moragolla	31
	Hydro Power Plants (Candidate)	
21	Gin Ganga	20
22	Thalpitigala	15
23	Moragahakanda	25
24	Seethawaka	20
	Thermal Power Plants	
A	Puttalam Coal	900
B	Kelanithissa PP, AES PP	543
C	Sapugaskanda PP, Asia Power	211
D	Uthuru Janani	27
E	CEB Barge	64
F	West Coast PP	300
G	Northern Power	38

(Source: JICA Survey Team, revised based on LTGEP 2015-2034)

Figure 7-5 Locations of Existing and Commissioned Power Plants

Table 7-2 Lists of Existing Hydropower Plants

Plant Name	Units x Capacity	Capacity (MW)	Expected Annual Avg. Energy (GWh)	Active Storage (MCM)	Rated Head (m)	Year of Commissioning
Canyon	2 x 30	60.0	160	107.9 (Moussakelle)	204.2	1983 - Unit 1
Wimalasurendra	2 x 25	50.0	112	53.6 (Castlereigh)	225.6	1965
Old Laxapana	3x 9.5+ 2x12.5	53.5	286	0.245 (Norton)	472.4	1950
New Laxapana	2 x 58	116.0	552	0.629 (Canyon)	541.0	Unit 1 1974 Unit 2 1974
Polpitiya	2 x 37.5	75.0	453	0.113 (Laxapana)	259.1	1969
Laxapana Total		**354.5**	**1,563**			
Upper Kotmale	2 x 75	150.0	409	0.8	473.1	2012
Victoria	3 x 70	210.0	865	688.0	190.0	Unit 1 - 1985 Unit 2 - 1984 Unit 3 - 1986
Kotmale	3 x 67	201.0	498	154.0	201.5	Unit 1 - 1985 Unit 2&3 - '88
Randenigala	2 x 61	122.0	454	558.0	77.8	1986
Ukuwela	2 x 20	40.0	154	4.1	75.0	Unit 1&2 - '76
Bowatenna	1 x 40	40.0	48	18.0	51.0	1981
Rantambe	2 x 24.5	49.0	239	4.4	32.7	1990
Mahaweli Total		**812.0**	**2,667**			
Samanalawewa	2 x 60	120.0	344	168.2	320.0	1992
Kukule	2 x 35	70.0	300	1.7	180.0	2003
Small hydro		20.45				
Samanala Total		**210.5**	**644**			
Existing Total		**1377.0**	**4874**			
Committed						
Broadlands	2x17.5	35.0	126.0	-	57.0	2017
Moragolla	2x15.5	31.0	97.6	-	69.0	2020
Multi-Purpose Projects						
Uma Oya	2x60	120.0	231.0	0.7	704.0	2017
Gin Ganga	2x10	20.0	66.0	0.2	-	-
Thalpitigala	2x7.5	15.0	52.4	11.42	93.0	-
Moragahakanda	2x5 +7.5 +7.5	25.0	114.5	430	38 34 34	Unit 1-2017 Unit 2-2020 Unit 3-2022
Total		**246.0**	**687.5**			

(Source: JICA Survey Team, revised based on LTGEP 2015-2034)

Upgrade and/or expansion plans for the hydropower plants are as follows:

- New Laxapana HPP and Old Laxapana HPP (Stage-1) were upgraded from 2011 to 2014
- Polpitiya HPP is being upgraded now and the 1st unit is planned to be commissioned in Jun. 2017

- Polpitiya HPP (75MW (37.5MW x 2 units)) has an upgrade plan which increases the installed capacity to 87MW. The installed capacity per unit is 45MW; however, due to constraints of conduit tunnel discharge capacity, the total capacity will be limited to 87MW
- Victoria HPP has an expansion plan for 228MW, for which a Feasibility Study has already been done. However, it is economically unfeasible in consideration of the change in daily load curve in the future, since there is little increase in generated energy (refer to section 7.4.8)
- There are some upgrade plans (idea stage), as follows:
  - Old Laxapana HPP (Stage-2): the existing 12.5MW x 2 units are converted to one unit, and civil structure is also altered to increase design discharge
  - Canyon HPP: conduit tunnel is altered to increase net head and design discharge
- There is little potential for hydropower over 10MW
- There are no retirement plans

(b) Thermal Power Plants

The existing thermal power plants are listed in Table 7-3. The total installed capacity of CEB thermal power plants is 1,511MW as of the end of 2015, and Colombo Power (64MW) was bought out by CEB after terminating a contract period of 15 years.

The total supply capacity of CEB TPPs is 1,389MW and is around 10% less than the installed capacity due mainly to the station's own use. The total installed capacity and supply capacity of IPP TPPs are 552MW and 514MW, respectively.

Meanwhile, the supply capacity of thermal power plant and/or biomass power plant is defined as the installed capacity minus power station own use and outage for inspection, if power facilities are sound and there is no hindrance of fuel supply.

The total supply capacity of the major hydropower and thermal power is 3,087MW as of 2015; accordingly, the reserve margin is as large as 39%.

Table 7-3 Lists of Existing Thermal Power Plants

	Plant Name	Location	Type	Commissioning Year	No. x Unit Cap. (MW)	Installed Capacity (MW)	Dependable Capacity (MW)	Fuel Type
CEB	Puttalam	Puttalam	Steam	2011, 2014	3 x 300	900	3 x 275	Coal
	Kelanitissa	Colombo	GT	1981-82 1997	4 x 20 1 x 115	195	4 x 16.3 1 x 113	Auto Diesel
			CCGT	2002	1 x 165	165	1 x 161	Naphtha
	Sapugaskanda	Colombo	Diesel	1984 1997, 1999	4 x 20 8 x 10	160	4 x 17.4 8 x 8.7	Res. Oil
	Uthuru Janani	Jaffna	Diesel	2013	3 x 8.9	27	3 x 8.67	Fuel Oil
	Colombo Power	Colombo	GT	2000	1 x 64	64	1 x 60	Auto Diesel
Sub-total						1,511	1,389	
IPP	Asia Power	Colombo	GT	1998	1 x 51	51	1 x 50.8	Auto Diesel
	AES Kelanitissa	Colombo	CCGT	2003	1 x 163	163	1 x 163	Auto Diesel
	West Coast	Colombo	CCGT	2010	1 x 300	300	1 x 270	Auto Diesel
	Northern Power	Colombo	Diesel	1999	1 x 38	38	1 x 30	Fuel Oil
Sub-total						552	514	
Total						2,063	1,903	

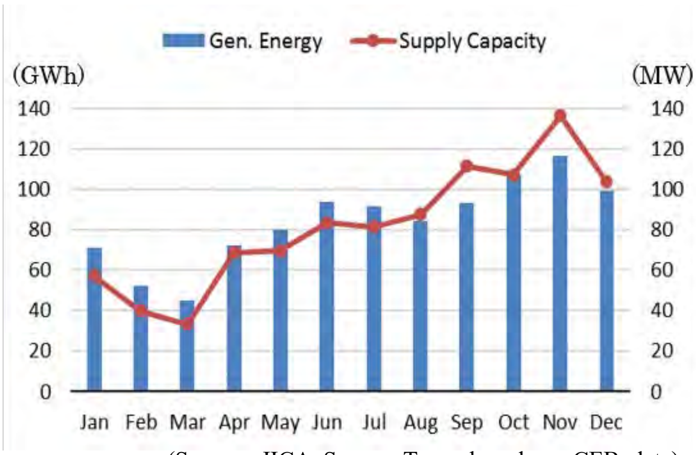
(Source: JICA Survey Team, revised based on LTGEP 2015-2034)

Reserve capacity and reserve margin are defined as follows.

<Reserve capacity>
Reserve capacity = total supply capacity of all power plants – kW power demand (at sending end)
<Reserve margin>
Reserve margin = reserve capacity / kW power demand (at sending end)

(c) Mini-hydropower Plants

Run-of-river type hydropower plants of less than 10MW developed by IPPs are called mini-hydropower plants. They are a sort of NCRE, and have been developed since the 1990s.
The total installed capacity is 303MW as of the end of 2015. The mean monthly generated energy from 2011 to 2015 and the supply capacity (firm capacity), are shown in Figure 7-6. Since only the monthly generated energy data are available, the supply capacity (firm capacity) was calculated as the monthly mean output minus monthly standard deviation of the mean output from 2011 to 2015, for which the value probability is 83%.
Generated energy in Feb. and Mar. is less, around 20% of the monthly plant factor; however, the monthly plant factors during Oct. and Dec. are more than 50%.

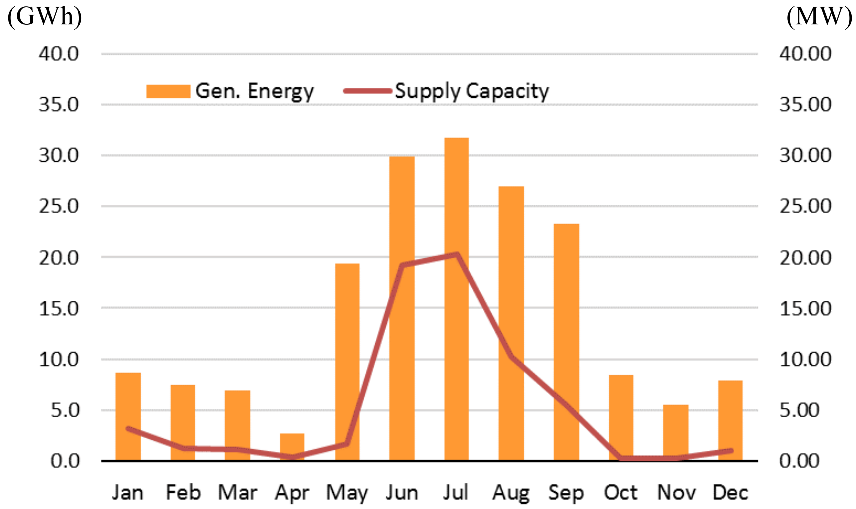


(Source: JICA Survey Team based on CEB data)

Figure 7-6 Mean Monthly Generated Energy and Supply Capacity

(d) Wind Power Plants

Wind power plants have been sequentially developed and the installed capacity (excl. CEB Hambantota WP (3MW)) is 124MW as of the end of 2015; the total generated energy of WPPs is 342GWh in 2015. All existing WPPs are located in the Puttalam area.
The generation records of Norechcole WPP (65MW) in 2014 and 2015, which is a representative wind power plant in the Puttalam area, were analyzed. The mean monthly generated energy and the supply capacity (90% probability) are shown in Figure 7-7. Monthly deviation is significantly large. Monthly plant factors for 4 months from Jun. to Sep. are more than 50%; however, those for 7 months from Oct. to Apr. are distinctly small at around 15%.
Therefore, in the configuration rate for wind power plants, it should be considered that a decrease in supply capacity for 7 months from Oct. to Apr. needs to be complemented, taking into account the large seasonal deviation of generated energy and supply capacity.
In addition, although the annual plant factor of WPPs in the Puttalam area is 31.4%, that in the Mannar area is expected to be 42.3% according to the LTGEP 2015-2034.



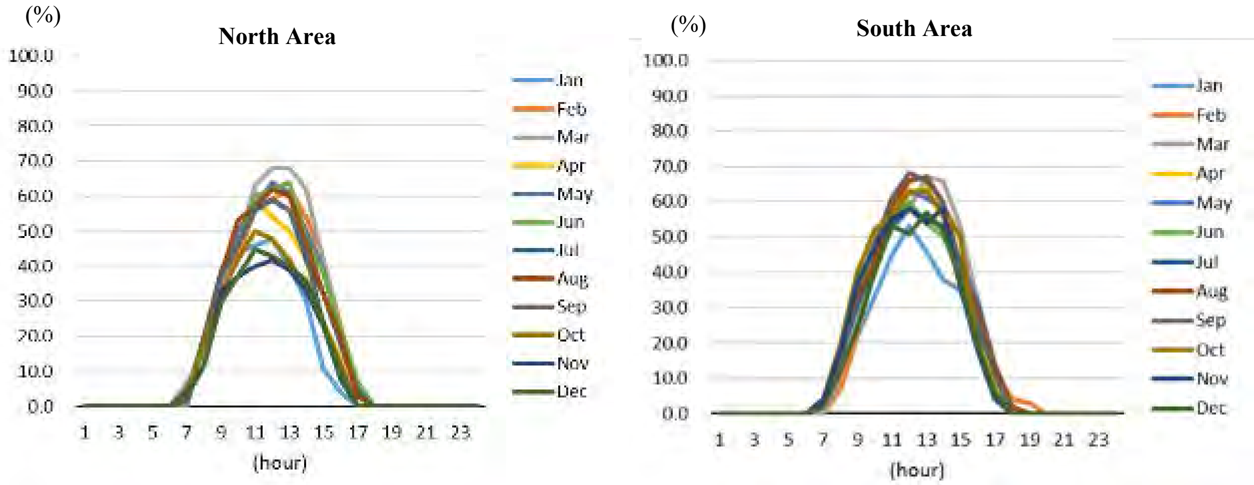
(Source: JICA Survey Team based on CEB data)

Figure 7-7 Mean Monthly Generated Energy and Supply Capacity of Norechcole WP

(e) Solar Power Plants

Only 3 solar power plants had been developed, and the total installed capacity is as little as 1.36MW as of the end of 2015. Using data from the LTGEP 2015-2034, the monthly mean outputs in the north area (Kilinochchi Solar) and in the south area (Hambantota Solar) are shown in the below figure. The peak outputs for 4 months from Oct. to Jan. are 10-20% less than those of the other months, which are 60%. In addition, the annual plant factors in the north area and in the south area are expected to be 14.8% and 16.7%, respectively.

Furthermore, since there are few actual generation records for SPPs in Sri Lanka, the supply capacity (90% probability) is assumed as 50% of the above monthly mean output.



(Source: JICA Survey Team based on LTGEP 2015-2034)

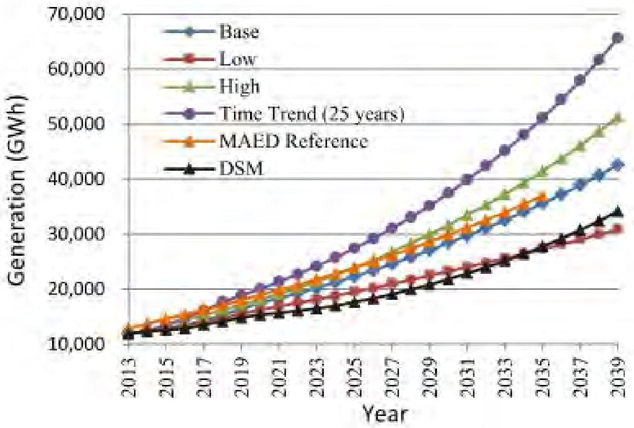
Figure 7-8 Monthly Mean Output of Solar Power Plants

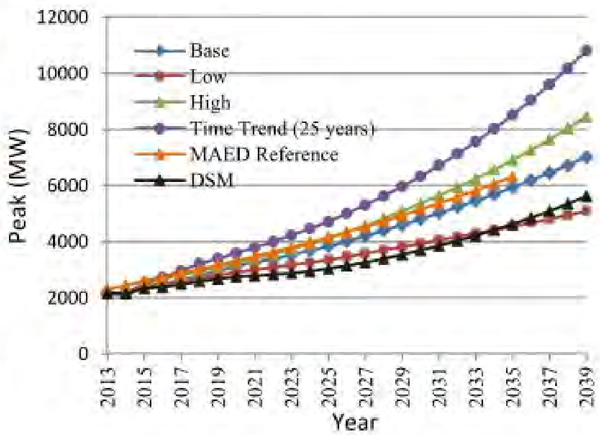
7.1.2 Review of LTGEP 2015-2034

The Long Term Generation Expansion Plan (LTGEP) (2015-2034), which is revised every two years, was approved by the Government in September 2016.

(1) Power Demand Forecasts

Power demand scenarios for high case, base case and low case are forecasted by econometric methods, multi-variety analyses with variables such as GDP, population and average electricity tariff as shown in the below figure. Annual maximum demand and generated energy in 2039 for the High case and Base case are forecasted as 8,461MW (51,362GWh) and 7,013MW (42,571GWh), respectively.





(Source: LTGEP 2015-2034)

Figure 7-9 Power Demand Forecast for Each Case

(2) Power Development Plan

So as to ensure supply capacity which can meet the above power demand and to make the annual generation cost the minimum, a power development plan (Base case) was prepared. However, the LTGEP 2015-2034 was approved on September 15th 2016 with the condition that a total of 900MW of coal fired TPPs, including Trincomalee coal fired TPP of NTPC (India), should be canceled and replaced by other power sources such as LNG C/C TPP.

The approved power development plan is shown in Table 7-5. It targets development of NCRE so as to account for 20% of the overall generated energy from the viewpoints of environment and energy security.

Table 7-4 Development Plan for NCRE (Base Case) (2015-2034)

Year	Cumulative Mini hydro (MW)	Cumulative Wind (MW)	Cumulative Biomass (MW)	Cumulative Solar (MW)	Cumulative Total (MW)	Total Generation (GWh)	Share of NCRE Generation (%)
2016	313	124	34	16	487	1,677	12.5
2018	363	244	74	46	727	2,561	16.7
2020	413	354	124	81	972	3,496	20.0
2022	458	454	129	101	1,142	4,047	21.0
2024	483	544	144	126	1,297	4,553	21,4
2026	508	599	154	146	1,407	4,906	20.9
2028	578	619	174	166	1,537	5,371	20.8
2030	653	639	194	186	1,672	5,853	20.6
2032	663	679	224	206	1,772	6,240	20.0
2034	673	719	279	226	1,897	6,801	20.0

(Source: LTGEP 2015-2034)

Table 7-5 Power Development Plan (Base Case) (2015-2034)

YEAR	RENEWABLE ADDITIONS (MAJOR HYDRO)	THERMAL ADDITIONS	THERMAL RETIREMENTS	LOLP %
2015	-	4x15 MW CEB Barge Power Plant	4x15 MW Colombo Power Plant 14x7.11 MW ACE Power Embilipitiya°	0.298
2016	-	-	-	0.496
2017	-	**100 MW Furnace Oil fired Power Plant 1†** **70 MW Furnace Oil fired Power Plant 2†** **(Southern Region)**	-	0.383
2018	*35 MW Broadlands HPP* *120 MW Uma Oya HPP*	**2x35 MW Gas Turbine**	8x6.13 MW Asia Power 4x17 MW Kelanitissa Gas Turbines	0.280
2019	-	**1x35 MW Gas Turbine** **1x300 MW Natural Gas fired Combined Cycle Power Plant – Western Region+**	4x18 MW Sapugaskanda diesel	0.180
2020	**15 MW Thalpitigala HPP**		6x5 MW Northern Power	0.394
2021	-	**1x250 MW Coal Power Plant** *	-	0.211
2022	*31 MW Moragolla HPP* **20 MW Seethawaka HPP** **20 MW Gin Ganga HPP**	**1x250 MW Coal Power Plant** *	100 MW Furnace Oil fired Power Plant 1† 70 MW Furnace Oil fired Power Plant 2†	0.239
2023	-	*163 MW Combined Cycle Power Plant (KPS–2)* • **1x300 MW New Coal Power Plant Phase I** **	163 MW AES Kelanitissa Combined Cycle Plant • 115 MW Gas Turbine 4x9 MW Sapugaskanda Diesel Ext.	0.201
2024	-	**1x300 MW New Coal Power Plant Phase I** **	-	0.094
2025	**1x200 MW Pump Storage Power Plant**	-	4x9 MW Sapugaskanda Diesel Ext. 4x15 MW CEB Barge Power Plant	0.101
2026	**1x200 MW Pump Storage Power Plant**	-	-	0.076
2027	**1x200 MW Pump Storage Power Plant**	-	-	0.056
2028	-	**1x300 MW New Coal Power Plant - Southern Region** ***	-	0.041
2029	-	-	-	0.144
2030	-	**1x300 MW New Coal Power Plant - Southern Region** ***	-	0.106
2031	-	**1x300 MW New Coal Power Plant Phase II** **	-	0.085
2032	-	**1x300 MW New Coal Power Plant Phase II** **	-	0.067
2033	-	**1x300 MW Natural Gas fired Combined Cycle Power Plant -Western Region**	165 MW Combined Cycle Plant (KPS) 163 MW Combined Cycle Plant (KPS- 2)	0.368
2034	-	**1x300 MW Natural Gas fired Combined Cycle Power Plant -Western Region**		0.247
Total PV Cost up to year 2034, **US$ 13,550.06 million** [LKR 1,782.52 billion]				

NOTES:

* This project was proposed to be implemented as a Joint Venture between CEB/NTPC at Sampur. Presently, a policy directive is awaited from the Government of Sri Lanka to proceed or new location/alternative arrangement to be made.

** These power plants are to be developed at Sampur, if permission is granted by the Government of Sri Lanka. Otherwise new location is to be found.

*** These power plants are proposed to be developed in Southern Region, if permission is granted by the Government of Sri Lanka.

† Due to the immediate requirement, 170 MW power plants are proposed with initial operation by FO/Diesel. Retirement year of these plants should be reviewed based on major thermal plant availability and possibility of conversion to Natural Gas. Once the plants are retired, those could be utilized as standby power plants.

+ Grid integration of 1x300 MW Natural Gas fired Combined Cycle Power Plant would be possible once the Kerawalapitiya- Port 220kV cable is available in June 2018.

• AES Kelanitissa is scheduled to be retired in 2023 will be operated as a CEB Natural Gas fired power plant from 2023 to 2033 with the conversion. West Coast and Kelanithissa Combined Cycle plant are converted to Gas in 2020 with the development of LNG based infrastructure.

○ ACE Embilipitiya Power Plant operates from March 2016 for a period of one year on short term contract.

✓ Committed plants are shown in Italics. All plant capacities are given in gross values.

✓ Thalpitigala and Gin Ganga multipurpose hydro power plants proposed by Ministry of Irrigation are forced considering secured Cabinet approval for the implementation of the Projects.

✓ Seethawaka HPP and PSPP units are forced in 2022, 2025, 2026 and 2027 respectively.

✓ Moragahakanda HPP will be added in to the system by 2017, 2020 and 2022 with capacities of 10 MW, 7.5 MW and 7.5 MW respectively.

✓ LNG terminal cost of 487.8 million USD and Coal jetty cost of 115 million USD are included in the above total cost.

✓ Renewable Development Cost (excluding large hydro) of 1527.9 million USD is included in the above cost.

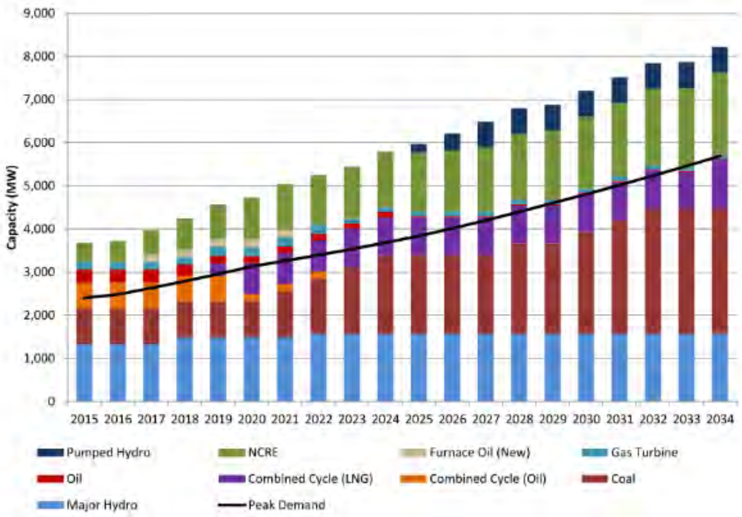
(Source: Revised LTGEP 2015-2034)

The power development plan for every 5 years by power source (Base case) is shown in Table 7-6. And the installed capacity and the generated energy by power sources (2015-2034) are shown in Figure 7-10 and Figure 7-11, respectively.

Table 7-6 Power Development Plan by Power Sources (Base Case) (2015-2034)

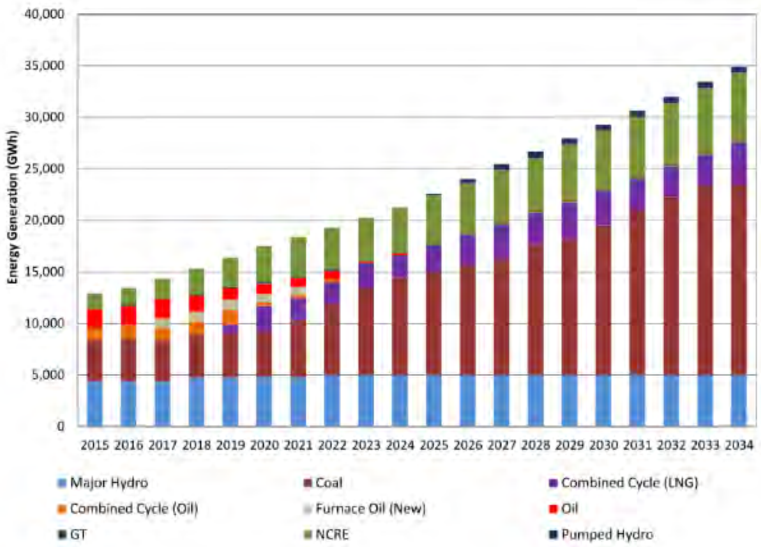
Type of Plant	2015-2019 (MW)	2020-2024 (MW)	2025-2029 (MW)	2030-2034 (MW)	Total Capacity Additions (MW)	(%)
Gas Turbine	105				105	1.8
LNG C/C	300			600	900	15.5
Major Hydro	155	86			241	4.2
Pumped storage			600		600	10.4
Coal		1,100	300	900	2,300	39.7
Oil Fired TPP	170				170	2.9
NCRE	382	495	320	280	1,477	25.5
Total	1,112	1,681	1,220	1,780	5,793	100

(Source: Revised LTGEP 2015-2034)



(Source: Revised LTGEP 2015-2034)

Figure 7-10 Installed Capacity by Power Sources (2015-2034)



(Source: Revised LTGEP 2015-2034)

Figure 7-11 Generated Energy by Power Sources (2015-2034)

7.2 Past Study Reports

The following existing reports are referred for preparing power development plan and for preparing SEA as a concrete power development project.

7.2.1 Pumped Storage Power Plants

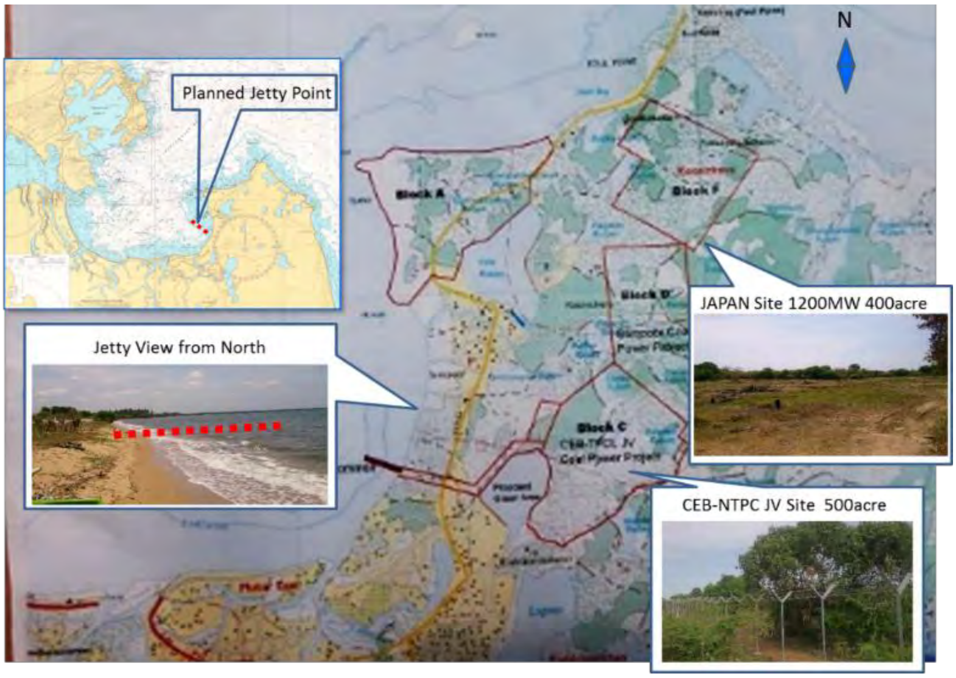
In the report "Development Planning on Optimal Generation for Peak Demand in Sri Lanka (JICA, Feb. 2015)", the Maha 3 PSPP site was nominated as the most likely PSPP site and a conceptual design and IEE study were conducted. However, since the estimated construction unit cost is as much as 1,063USD/kW (excl. IDC), which is far higher than the 500USD/kW of GT TPP, it is hard to make it economical except for the fact that pumping energy comes from any power source with a cheap fuel cost such as coal fired TPP.

In terms of issues regarding environmental and social considerations for the Maha 3 PSPP site, 25 houses (29 families) and 96 people will have to be resettled, homes and tea gardens of 19ha will be inundated and aliment of livelihood will be lost in the upper dam site. In addition, 8 houses (9 families) and 27 people will have to be resettled, home gardens and gum plantations of 17ha will be inundated and aliment of livelihood will be lost in the lower dam site.

Furthermore, a landslide or slope failure has occurred near the Maha 3 PSPP site; therefore, the local people have great concerns that landslides may occur in line with the construction of open civil structures, such as access roads and construction work roads.

7.2.2 Coal Fired TPP

As shown in the below figure, "Sampur Coal Fired Thermal Power Project Pre-FS (NEDO, 2012)" was prepared. It reports the plan that a coal fired TPP of 1,200MW is developed at the north end of Sampur, Block F, which is at the north of Block C of the other coal fired TPP, a CEB-NTPC JV. The jetty for unloading coal is planned to be located at the place where around 20m deep under the sea so that large size tankers (60 thousand class) can be berthed. The unloaded coal is planned to be transported with a belt conveyer to the coal fired TPPs. Accordingly, since there is no need to develop large-scale port facilities, the projects are economical.



(Source: JICA Survey Team based on CEB data)

Figure 7-12 Coal Fired Thermal Power Projects in Trincomalee

7.2.3 LNG TPP

"Energy Diversification Enhancement Project Phase IIA Feasibility Study for Introducing LNG to Sri Lanka VOLUME III LNG Import Terminal and Natural Gas Pipeline (CEB, June 2014)" was carried out. It examined an LNG terminal being constructed in the northern area of the Colombo port and gas pipelines being installed from the terminal to Kerawalapitiya, and an LNG combined cycle power project of upmost 1,200MW being developed in Kerawalapitiya. The rough estimates of the Project cost for the LNG import terminal and Gas pipelines are shown in Table 7-7. The estimated costs of the 2 MTPA (Mil. ton/annum) case and 3 MTPA case are 68.6 bill. Yen and 79.2 bill. Yen, respectively.

Table 7-7 Project Costs for LNG Import Terminal (2020 Constant Price)

(Unit: Mil. JPY)

	2 MTPA	3 MTPA
1. Marine Structure and Port Facilities	18,096	20,756
2. LNG Storage Tank	9,402	9,402
3. Procurement of Major Equipment and facilities	5,665	7,225
4. Installation and Construction of Terminal Facilities	15,019	19,155
5. Gas Pipeline	1,310	1,310
6. Relocation of Sewage Pipe	1,200	1,200
7. Consultant Services	2,782	2,782
8. Contingency and others	15,000	17,000
Total	68,573	79,244

(Source: CEB Report, June 2014)

7.2.4 Non-Conventional Renewable Energy (NCRE)

The potential for NCRE, such as mini-hydro, wind, solar and biomass, is reported in "Draft Final Report of Renewable Energy Master Plan (ADB, Mar. 2014)". The contents are described in detail in section 4.4.

7.3 Supply Reliability and Reserve Margin

7.3.1 Criteria for Supply Reliability

CEB has adopted LOLP (Loss of Load Probability) as the criteria for supply reliability and set the target as less than 1.5%. This target admits supply being lower than demand during a total of 5.5 days (131.4 hours) in one year and power supply shortages occurring during a total of 5.5 days in one year.

However, national loss increases due to power supply shortages as the economy develops. As a result, it is desirable to pursue much higher supply reliability in 2040, which is the target year in this MP, in order to prevent high national loss. At a concrete level, it is considered appropriate to aim for LOLP of less than 0.3% (LOLE (Loss of Load Expectation: Expected value for shortage time for one year) of 24 hours for one year), which is adopted in Thailand, Malaysia, Viet Nam, etc.

7.3.2 Supply Capacity of Renewable Energy

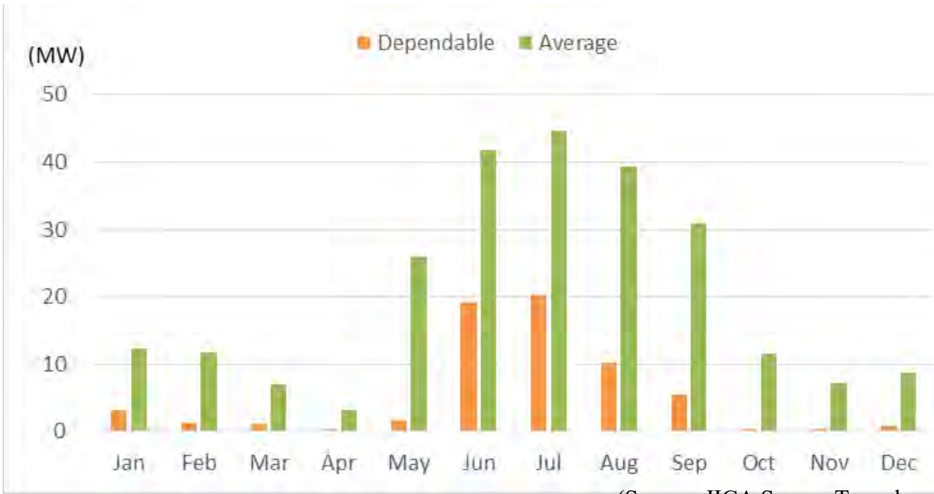
In general, supply capacity is defined as generated energy which each power plant is able to supply at more than 90% probability. A thermal power plant and biomass power plant can always supply 100% power if the power plant is in good condition and can receive fuel, and the supply capacity is generated energy except for house power consumption. However, expected supply capacity for renewable energy is not a large amount because the generated energy for hydropower, windpower and solar power is affected by natural conditions.

(1) Hydropower

Almost all hydropower plants owned by CEB are reservoir type and can supply 100% output because they can store energy. However, it is necessary to consider a decrease in maximum output due to a decrease in the effective head by lowering the water level at the reservoir dam.

(2) Windpower

Actual generated energy of Norechcole Wind in 2014 and 2015 is shown below.



(Source: JICA Survey Team based on data supplied by CEB)

Figure 7-13 Actual Generation Results of Norechcole Wind

As per Figure 7-13, dependable generated energy at more than 90% probability from June to September is approximately half of the average value. In the other months, the supply capacity is not expected.

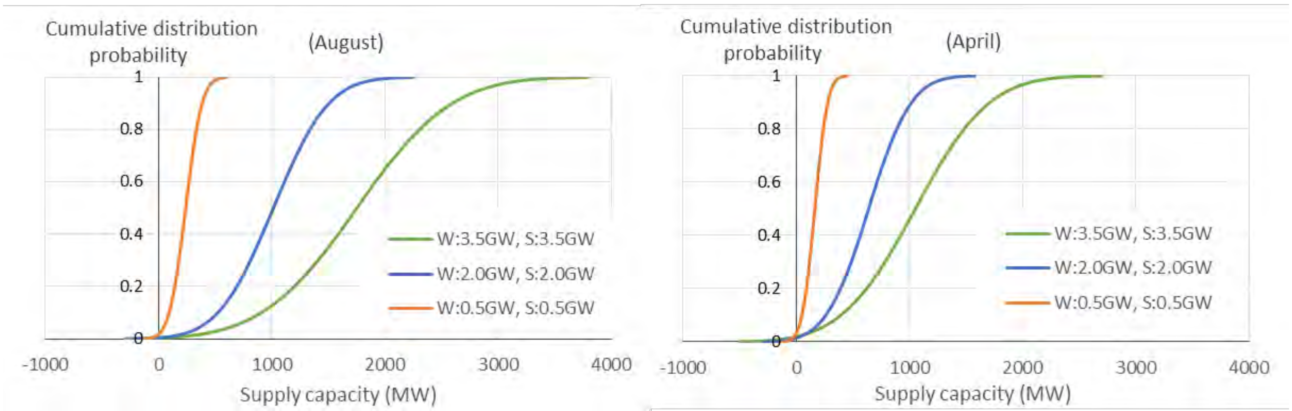
(3) Solar Power

Expected supply capacity is not clear because actual generation results for large scale solar power are not available to the public, but it is predicted to be half of the average generated energy. It is necessary

to revise the expectation if the actual generated energy of large scale solar power becomes available to the public. Generated energy from solar power is expected to serve as peak time supply capacity because the peak time of generated energy from solar power overlaps with the peak time of power demand.
However, the amount of solar power generation is greatly influenced by the weather, and in the event of bad weather nationwide, there is a possibility that it will become highly unreliable as supply power. When the quantity of solar power plants is small, it is possible to deal within the range of supply reserve capacity. However, as the quantity of solar power plants increases, it will be impossible to respond within the range of supply reserve capacity, so a backup power supply like a gas turbine becomes necessary.

7.3.3 Relationship between LOLE and Reserve Capacity

It is very important to predict how large renewable energy is in order to confirm the relationship between LOLE and reserve capacity. Supply capacities of windpower and solar power are expected to be supplied at the probability of 90% at individual power plants. That is, at a given time, supply capacity is the output that can be expected with a 90% chance. For this reason, with a 10% chance, there is also the possibility that it will be less than the expected supply capacity. However, total capacity is underestimated in the case of estimating total capacity via each power plant because average generated energy is larger than expected supply capacity. In other words, in situations where many power plants are scattered, the possibility that all power plants can output only the expected supply power at the same time is extremely low. It is possible to carry out an evaluation in consideration of the actual situation by evaluating the supply capacity of renewable energy with variable probability.
Cumulative distribution probability for the supply capacity of renewable energy is shown below.

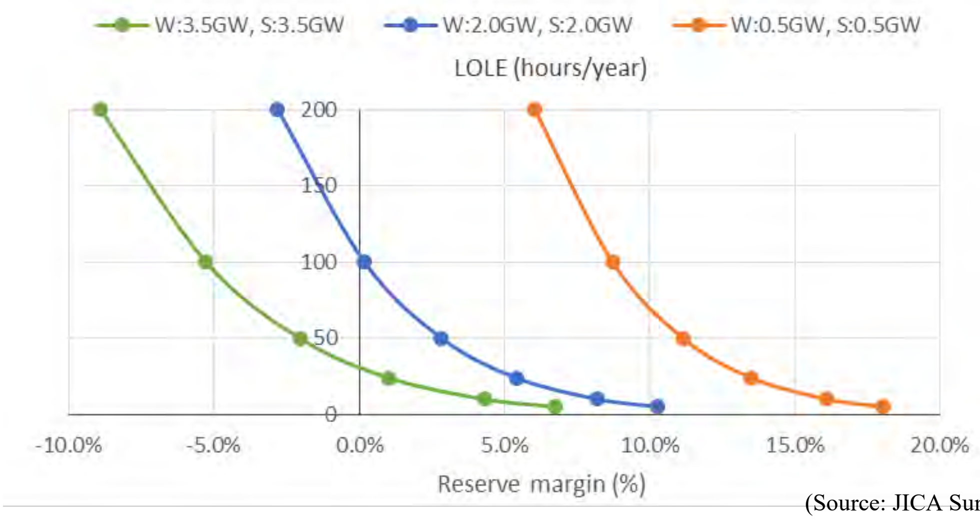


(Source: JICA Survey Team)

Figure 7-14 Cumulative distribution probability for Supply Capacity of Renewable Energy

Supply capacity 0 in Figure 7-14 is the total value which combines the supply capacity of each power plant. For example, with windpower of 2.0GW and solar power of 2.0GW, the total value which combines the supply capacity of each power plant is 1.0GW in August, and 0.6GW in April. However, it is expected that there will be approximately 1.0GW of additional supply capacity in August, and 0.7GW in April. In a more developed case of renewable energy, an increase in additional supply capacity is expected.

In consideration of these variable probabilities, the calculated relationship between LOLE and reserve capacity is shown below.



(Source: JICA Survey Team)

Figure 7-15 Relationship between LOLE and Reserve Capacity

Reserve capacity to satisfy the target (LOLE: 24 hours) is different depending on the development scale of renewable energy. In the case of small development (windpower 0.5GW and solar power 0.5GW), necessary reserve margin is approximately 13%, but in the case of windpower 3.5GW and solar power 3.5GW, it is almost 1%. Because the expected value of the supply power added to the power generation output expected as the supply power increases in the high development case, LOLE can be secured if reserve margin is minus.

The necessary reserve margin is greatly affected by the development scale of renewable energy. In this MP, whether LOLE is secured is not judged from reserve margin, but from whether LOLE which is calculated in each case satisfies the target.

7.4 Optimum Generation Configuration in Target Year

7.4.1 Prerequisites for Optimum Power Supply Configuration Study

The final target year for the Electricity Sector Master Plan (ESMP) is set to be 2040. However, it is difficult to accurately forecast the maximum demand at the target year, so the study is carried out based on the case where the maximum demand in 2040 is 6.2 GW as per the target system described in Chapter 5. In the demand forecast in Chapter 5, it is assumed that the time when the maximum demand reaches 6.2 GW is around 2040, but if the demand growth is larger than expected it will be reached earlier than 2040, and if the demand growth is smaller it will be reached after 2040.

(1) Electricity power demand forecast

The power demand forecast is described in detail in Chapter 5. Though the maximum demand occurs around 19 o'clock at present, it will gradually shift to the daytime zone, and the maximum demand in 2040 will be during the daytime zone.

The annual load factor is 65.9% in the actual results for 2014, and it gradually increases in the trend in the nearest 10 years, but it is assumed that the annual load factor will decrease after the peak time for power demand shifts to the daytime zone; the annual load factor in 2040 is 73.0% (the annual electric energy demand is 39,805GWh).

(2) Power supply configuration in 2040

Although the power supply configuration in 2040 will be presented in this study, power plants not to be retired by 2040 among the existing facilities in 2015 and gas-fired TPP and conventional hydro PP included in the current plan will be treated as existing power plants in 2040. Regarding renewable energy (NCRE), it is assumed that a composition ratio of at least 20% in terms of installed capacity is maintained. Specifically, the following facilities are targeted.

Table 7-8 Fixed Power Generation Plants in 2040

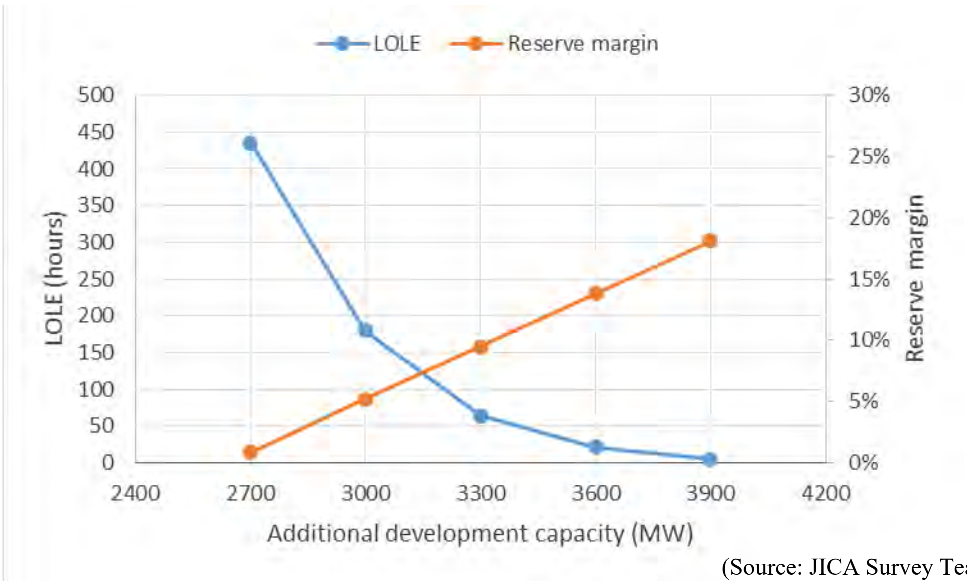
(Unit: MW)

	Existing capacity (as of the end of 2015)	Minimum development capacity (2016 - 2040)	Fuel conversion capacity (2016 - 2040)	Retirement capacity (2016 - 2040)	Fixed capacity in 2040
Hydro	1,377	199			1,576
Coal	900	0			900
LNG (Gas)	0	900	300		1,200
Oil	1,121	105	- 300	- 821	105
NCRE	452	1,359			1,811
Mini-hydro	(303)	(400)			(703)
Wind	(124)	(380)			(504)
Solar	(1)	(499)			(500)
Biomass	(24)	(80)			(104)
Total	3,850	2,563	0	- 821	5,592

(Source: JICA Survey Team)

(3) Facilities requiring additional development by 2040

The relationship between the amount of power generation capacity to be developed additionally and the supply reliability after fixing the power generation plants shown above is shown below. For supply reliability, LOLE value (Loss of load expectation: expected value of time when supply power is insufficient in one year) is used. In this calculation, all the additional power generation plants to be developed are LNG-fired thermal power with 300MW unit capacity.



(Source: JICA Survey Team)

Figure 7-16 Relationship between Additional Development Capacity and Supply Reliability

The amount of additional development varies depending on the degree of supply reliability criterion. The standard currently used by CEB is 1.5% or less in the LOLP value (Loss of load probability), and if it is converted to the LOLE value, it is less than 131.4 hours. In order to satisfy this criterion, it is sufficient to develop an additional 3,300MW (11 units of 300MW class LNG-fired TPP).

However, since the national loss caused by power shortages increases with economic development and high supply reliability will be required in 2040, which is the target year of this MP, the pursuit of higher supply reliability is desired. On a concrete level, it is appropriate to aim for the LOLE value adopted in Thailand, Malaysia, Vietnam, etc., which is less than 24 hours (0.3% in terms of LOLP value). In order to satisfy this supply reliability, further development of 300MW is necessary, and it is necessary to develop 3,600MW in total (12 units of 300MW class LNG-fired TPP).

(4) Specifications for Economic Evaluation

The numerical values used for economic evaluation basically adopt the numerical values described in LTGEP 2015-2034 after evaluating their validity for this MP.

(a) Unit construction costs for various power sources

The unit construction costs for various power sources as used for the economic evaluation is shown below.

Table 7-9 Unit Construction Costs for various Power Sources

	Net capacity (MW)	Unit construction cost (USD/kW)	Construction cost (million USD)
GT (auto-diesel)	35	737	26
GT (auto-diesel)	105	501	53
C/C (auto-diesel)	144	1,056	152
C/C (auto-diesel)	288	854	246
New coal	270	1,788	483
SC Coal	564	1,915	1,080
C/C (LNG)	288	1,109	319
C/C (LNG with fuel terminal)	288	1,517	437
Dendro	5	1,685	8

(Source: Revised LTGEP 2015-2034)

Since interest during construction varies depending on the source of funds, it is excluded.

The construction cost for LNG thermal power, including fuel supply facilities such as an LNG base, is calculated assuming that the construction costs for fuel supply facilities (USD 484 million (see Table 4-14)) are allocated to 1,200MW.

(b) Fuel costs for various power sources

For the prices of various fuels used for the economic evaluation, the price estimation from the New Policies Scenario in WEO2016 assumed by the IEA, shown in 4.2.5, is used. (See Table 4-11)

(c) Operation and maintenance cost (O&M cost)

The O&M costs for various power sources are as follows.

Table 7-10 O&M Costs for various Power Sources

	Fixed (USD/kW/month)	Variable (USC/kWh)
35MW GT	0.690	0.557
105MW GT	0.530	0.417
150MW C/C	0.549	0.470
300MW C/C	0.414	0.355
300MW Coal Trinco	2.920	0.560
300MW New coal	4.470	0.590
600MW Coal SC	4.500	0.590
300MW LNG C/C	0.381	0.497
Diesel	9.210	0.203

(Source: Revised LTGEP 2015-2034)

(d) Power generation costs for various power sources

1) Specifications of the newly developed TPP

The specifications of the newly developed TPP are shown below.

Table 7-11 Specifications of the Newly Developed TPP

	Capacity MW	Construction cost USD/kW	Life years	Fixed O&M USD/kW/mo.	Variable O&M USC/kWh	Heat rate kcal/kWh	Efficiency
Oil C/C	300	853.7	30	0.414	0.355	1785	48.2%
LNG C/C	300	1108.8	30	0.381	0.497	1785	48.2%
Coal ST	300	1788.0	30	4.470	0.590	2241	38.4%

(Source: JICA Survey Team)

The construction cost for the LNG terminal (ground base) is 484.3 million USD (handling volume is 1 million tons per year), Fixed O&M cost is 2.1 million USD per year, and Variable O&M cost is 1.8 million USD per year.
These costs are allocated to four 300MW machines. (If four 300MW machines operate at a plant factor of around 70%, the annual LNG fuel consumption is one million tons.)

2) Generation costs for the newly developed TPP

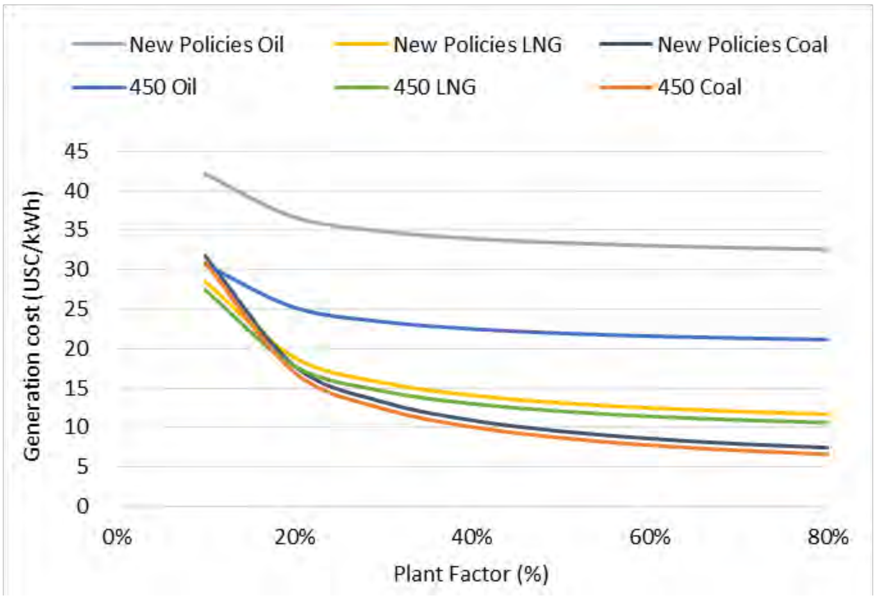
Based on the above specifications and the fuel price forecast shown in Chapter 4, the calculation results for the generation costs for the newly developed TPP are as below.

Table 7-12 Generation Costs for the Newly Developed TPP

	Fixed cost (USD/kW/year)		Variable cost (USC/kWh)		Generation cost (USC/kWh)		
	Capital cost	O&M cost	Fuel cost	O&M cost	P.F.=10%	P.F.=40%	P.F.=70%
Oil C/C	90.6	5.0	30.86	0.36	42.12	33.95	32.78
LNG C/C	117.6	4.6	8.78	0.50	28.49	14.08	12.02
LNG terminal	42.8	3.3					
Coal ST	189.7	53.6	4.20	0.59	32.56	11.73	8.75

Note: Interest rate on capital cost is 10%, Salvage value 0%, P.F.: Plant Factor

(Source: JICA Survey Team)

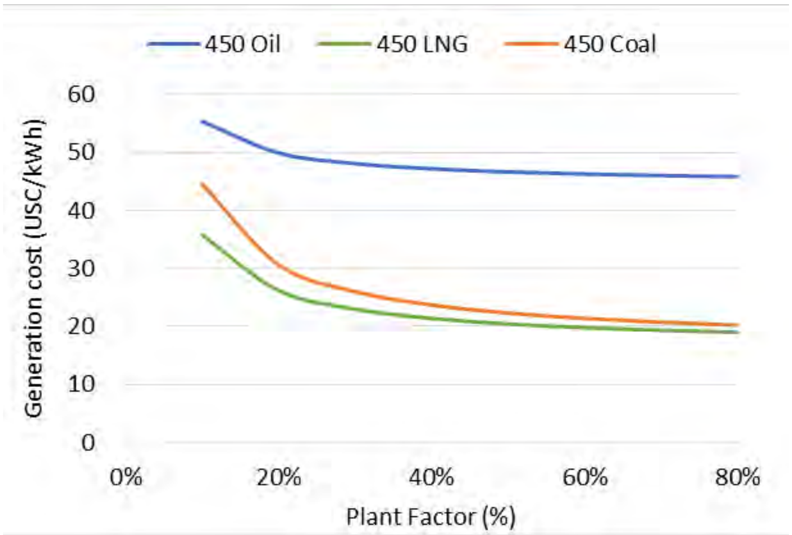


(Source: JICA Survey Team)

Figure 7-17 Generation Costs for the Newly Developed TPP

As for LNG-fired TPP and coal-fired TPP, there is no big difference between "New Policies Scenario" and "450 Scenario", and LNG-fired TPP is cheaper when the plant factor becomes about 20% or less.

In WEO 2016, CO_2 price is also forecasted, and it is forecasted to become 140 USD/tonne in 2040 in "450 Scenario". The generation costs for the newly developed TPP using this CO_2 price are calculated as follows.



(Source: JICA Survey Team)

Figure 7-18 Generation Costs for the Newly Developed TPP (Considering CO_2 price)

Considering that the CO_2 price becomes 140 USD/tonne, LNG-fired TPP is cheaper than coal-fired TPP.

(e) Cost of renewable energies

CEB has been purchasing renewable energy of 10MW or less with a standardized power purchase agreement (SPPA) at the price determined by PUCSL. (Refer to Table 4-18 for purchase price.)

PUCSL also calculates the actual price for various renewable energies. The actual prices and the average purchase prices leveled between the useful life-time are shown below.

Table 7-13 Comparison between Actual Price and Purchase Price of Renewable Energies

	Life-time averaged tariff based on three tier tariff		Actual price	
	LKR/kWh	(USC/kWh)	LKR/kWh	(USC/kWh)
Biomass	24.87	18.91	18.58	14.12
Solar	23.10	17.56	15.24	11.58
Wind	18.37	13.96	9.73	7.40
Mini-hydro	14.21	10.80	9.56	7.27

(Source: CEB document)

The actual price is much lower than the purchase price, and CEB plans to purchase renewable energy by bidding in the near future. In this MP, the study is made based on the actual price as a base case, and examination at the purchase price is carried out as sensitivity analysis. Regarding solar power generation, recent prices have further declined as shown in Chapter 4, and based on the latest actual price, the study is conducted at 6.0 USC/kWh.

(f) Comparison of generation cost considering construction cost

Generation cost considering the construction period of each power source is shown below.

Table 7-14 Generation cost considering Construction period of each power source

	Construction		Fuel cost (USC/kWh)	O&M cost (USD/kW/Yr.)	Levelised cost (USC/kWh)	Plant factor (%)
	Cost (USD/kW)	Period (Year)				
Coal (SC)	1,788	5	4.2	95.0	8.9	80
LNG CC	1,512	3	8.8	42.7	11.9	80
Wind	1,820	1	--	32.9	7.4	38
Solar	700	1	--	7.4	6.0	17

(Source: JICA Survey Team)

Difference of generation cost between coal-fired TPP and LNG TPP is approximately 3.0 USC/kWh by reducing the difference, nearly 0.4 USC/kWh.

(5) CO_2 emissions

CO_2 emissions are calculated from the fuel used and the thermal efficiency of the power plant. CO_2 emissions per kWh at the maximum output of major power plants are shown below.

Table 7-15 CO_2 Emissions per kWh of Major Power Plants

	Fuel		Efficiency	CO_2 Emissions Factor
West coast	Diesel oil	74.1 g-CO_2/MJ	44.6%	0.599 kg-CO_2/kWh
Gas turbine	Diesel oil	74.1 g-CO_2/MJ	28.1%	0.949 kg-CO_2/kWh
Puttalam	Coal	94.6 g-CO_2/MJ	36.2%	0.942 kg-CO_2/kWh
Trinco India	Coal	94.6 g-CO_2/MJ	33.1%	1.030 kg-CO_2/kWh
Trinco SC	Coal	94.6 g-CO_2/MJ	41.3%	0.824 kg-CO_2/kWh
Kerawalapitiya	LNG	56.1 g-CO_2/MJ	48.2%	0.419 kg-CO_2/kWh

(Source: Created by JICA Survey Team based on the revised LTGEP 2015-2034)

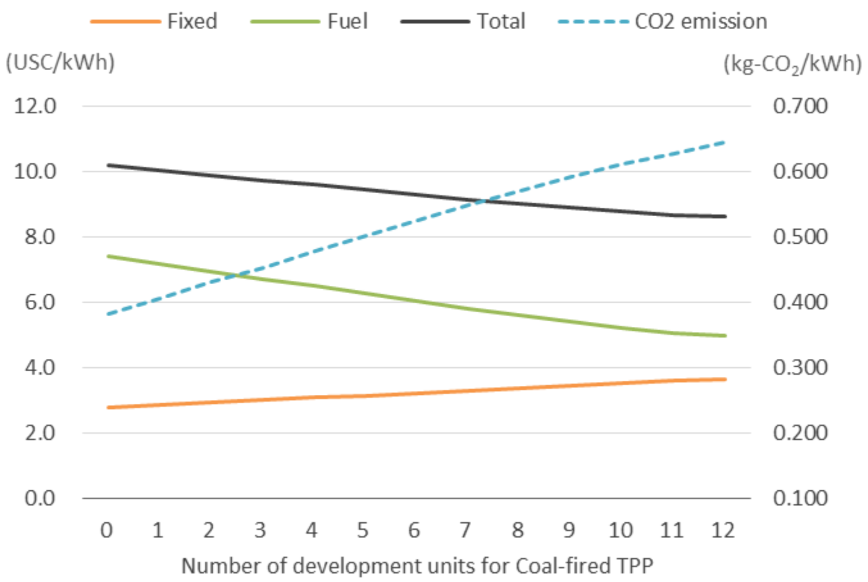
In terms of fuel used, the amount of CO_2 emissions per unit of calorific value is the largest in coal, and LNG is about 60% of coal. Among coal-fired TPPs, the SC (super critical) machine has a high thermal efficiency of 41.3%, and the CO_2 emissions are less than those of the existing Puttalam TPP and Trinco India. In addition, CO_2 emissions per kWh are smaller than GT fueled by oil (Diesel oil) which is planned to be developed in 2018.
In addition to the fact that CO_2 emissions per unit of calorific value are smaller than those of other fuels, LNG-fired TPP has higher thermal efficiency than other TPPs because of introducing a combined cycle machine, and the CO_2 emissions per kWh are less than half of coal-fired TPP.

7.4.2 Outline Study by Paired Comparison

LNG-fired TPP is positioned as the main power source for the future power development plan and each power source is compared with LNG-fired TPP and its characteristics identified. As described in section 7.4.1, considering the fixed generation capacity shown in Table 7-8, the development capacity that can be changed by 2040 is 3,600MW (12 units of 300MW class LNG-fired TPP). Regarding this changeable amount of development, comparison studies are carried out in case alternative power sources are developed instead of LNG-fired TPP.

(1) Comparison between LNG-fired TPP and coal-fired TPP

In order to keep the supply reliability constant, a comparison between supply cost and CO_2 emissions for the case of developing the same amount of coal-fired TPP as an alternative to LNG-fired TPP is shown below. The total number of coal-fired TPP and LNG-fired TPP is 12, and the number of LNG-fired TPPs is decreasing as the number of coal-fired TPPs increases.



(Source: JICA Survey Team)

Figure 7-19 Comparison of Supply cost and CO_2 emission between LNG-fired TPP and Coal-fired TPP

As shown in Table 7-9, the construction cost of coal-fired TPP per unit is USD 165 million higher than that of LNG-fired TPP and the O&M expenses of coal-fired TPP are also higher than those of LNG-fired TPP. Therefore, the annual fixed cost increases by USD 30 million (0.08 USC/kWh) if the development of coal-fired TPP increases by one unit. On the other hand, as shown in Table 7-12, the fuel cost of coal-fired TPP is 5.3 USC/kWh cheaper than that of LNG-fired TPP, so the annual fuel cost decreases by USD 90 million (0.23 USC/kWh) if the development of coal-fired TPP increases by one unit.

When the number of coal-fired power units is 10 or more, the fuel cost reduction effect is reduced, and the total cost becomes the lowest when the number of coal-fired power units to be developed is 12 units. The reason for this is that as the number of coal-fired TPPs increases, the plant factor of coal-fired TPP will decrease and a surplus will be generated during low-demand hours.

Looking at the CO_2 emissions, the CO_2 emissions per kWh also increase as the development of coal-fired TPP increases. The cost comparison when considering the surcharges due to CO_2 emissions is shown below.

(Source: JICA Survey Team)

Figure 7-20 Supply Cost Comparison when considering Surcharges due to CO_2 Emissions

When the surcharges due to CO_2 emissions increase to about USD 60/ton-CO_2, the cost of LNG-fired TPP becomes comparable to coal-fired TPP.

(2) Comparison between LNG-fired TPP and NCRE

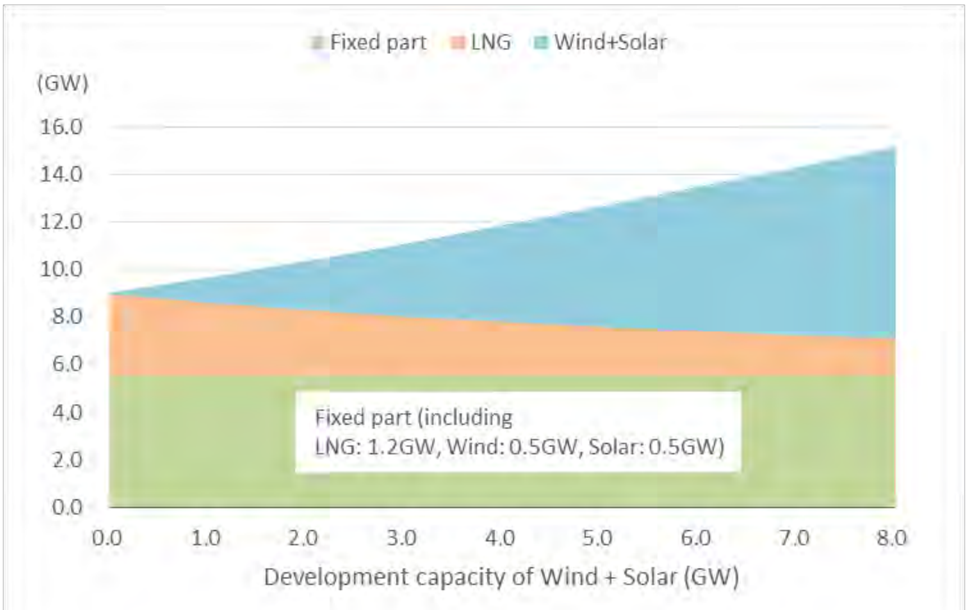
Among renewable energies, the total capacity of small hydro PP is expected to be 700MW (including those existing and being developed until 2040) in 2040, and it has already reached a level close to the potential level, so further development cannot be expected. With respect to biomass power generation, fuel can be stored and operation can be performed according to the magnitude of demand, so there are few problems in system operation. However, in the conventional method using agricultural residues etc., in addition to being used for applications other than power generation, accumulation of fuel is a problem. Significant development cannot be expected except for plantation type methods that grow plants exclusively for biomass power generation and utilize the resources.

There is much potential for solar power generation and wind power generation, and further development can be expected in the future, but the output is influenced by natural conditions and cannot be controlled by the system operator. Since solar power generation uses sunlight as an energy source, the output changes suddenly due to the movement of clouds above the sky. However, this change is an event in a very narrow area, and as the output of the whole of Sri Lanka becomes larger, a smoothing effect will occur, so there is little probability that a sudden change will occur, meaning that it is not a big problem in system operation.

It is considered that solar power and wind power, which have the same capacity respectively, are to be developed and LNG-fired TPP is to be canceled as far as possible.

(a) Transition of Total Generation Capacity

The following figure shows the relationship between additional development capacity of wind power and solar power and total generation capacity.



(Source: JICA Survey Team)

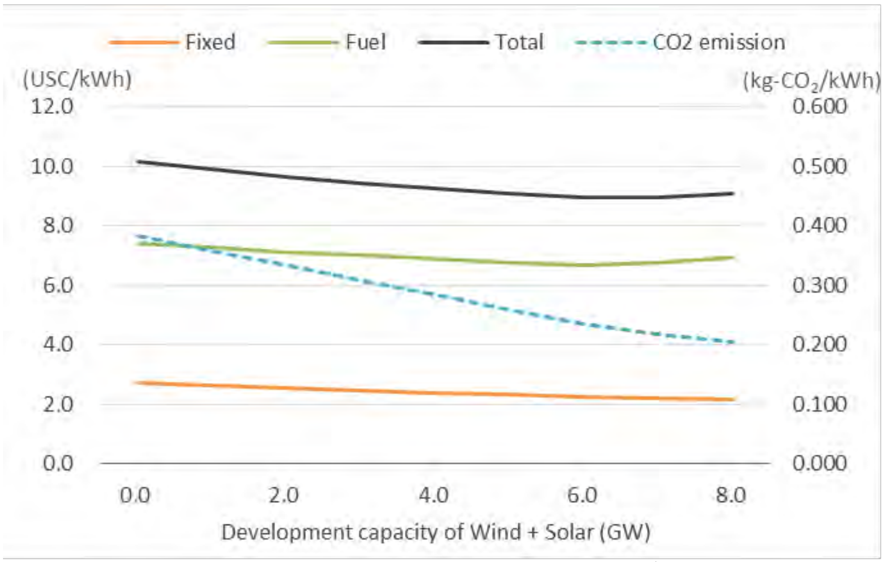
Figure 7-21 Relationship between Additional Renewable Energy Development and Total Generation Capacity

More generation capacity is required in order to keep the same supply reliability as the generation capacity of renewable energy becomes large, because available generation time is limited for solar power and wind power as mentioned in the previous section. LOLE = 24 hours is used for power supply reliability for this calculation.

Approximately 9GW of generation capacity is required for 6.2GW of power demand in the case of additional development with LNG-fired TPP only. Some volume of LNG-fired TPP development is required to secure power supply capacity during low generation of renewable energy, even if additional development of renewable energy becomes large. For this reason, the larger the total generation capacity is, the larger the additional development of renewable energy is. With additional development of 6GW of renewable energy (3GW solar power and 3GW wind power), 13GW of total generation capacity, which is twice as large as the 6.2GW power demand, is required.

(b) Comparison of Generation Costs

A generation cost comparison is shown below.



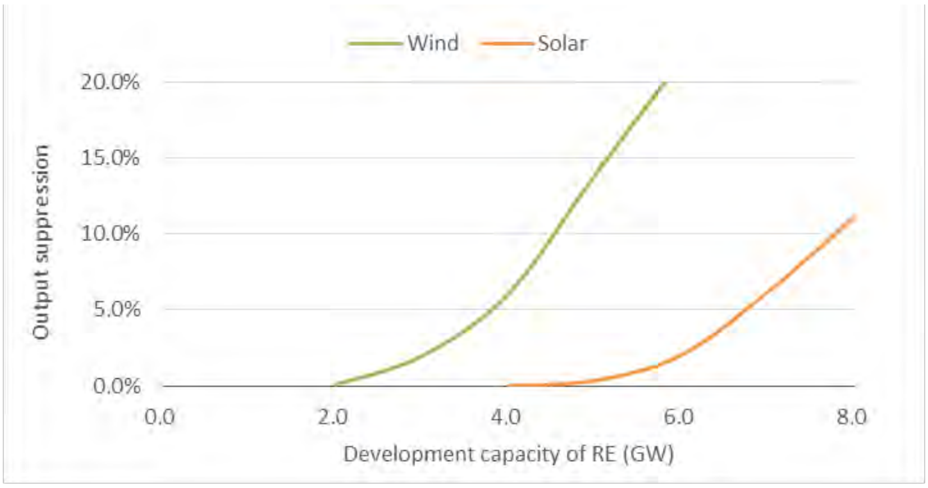
(Source: JICA Survey Team)

Figure 7-22 Comparison of Supply cost and CO_2 emission between Renewable Energy and LNG-fired TPP

Generation cost decreases gradually as renewable energy development becomes larger, because the actual cost of renewable energy is cheaper than that of LNG-fired TPP. However, when the amount of renewable energy development exceeds 6 GW, the amount of power generation suppression increases, so the cost increases as the development of renewable energy increases.

(c) Output Suppression Amount

It will be necessary to suppress the output of renewable energy when large amounts of energy are generated if renewable energy development becomes large and power supply becomes larger than demand. The relationship between the development capacity of renewable energy and output suppression is shown below.



(Source: JICA Survey Team)

Figure 7-23 Development Capacity of Renewable Energy and Output Suppression

Approximately 2GW of additional wind power is developed in the case of wind power development only, and output is suppressed during the off-peak period in June and July. Approximately 20% of generated energy should be required in the case of 6GW of additional development. On the other hand, in the case of development of solar power only, output suppression hardly arises because a large area of the generation period and demand peak period overlaps. However, with additional development of 5 GW, power generation suppression starts to occur during the daytime of holidays.

7.4.3 Summary Evaluation for Each Type of Power Supply[27]

(1) Coal-fired TPP

[Economy]
- O Generation cost is the cheapest if the plant factor is more than 80%.

[Environment]
- X CO_2 emission per kWh is large even if high efficiency equipment is adopted.
- X Emissions of NOx, SOx, dust, ash, etc. are large.

[Energy Security]
- O Fuel cost is comparatively stable.
- O There is a large amount of fuel storage, and possibility of supply disruption is low.
- X There is low flexibility in minimum output, propriety of stopping at night, output adjustment speed, etc. and small capacity for frequency adjustment.

(2) LNG-fired TPP

[Economy]
- X Generation cost is expensive compared with coal-fired TPP, but cheaper than coal-fired TPP in the case of a plant factor lower than 20%.

[Environment]
- O CO_2 emission per kWh is less than half that of coal-fired TPP.
- O There are NOx emissions, but no emissions of SOx, dust, ash, etc.

[Energy Security]
- X There is a possibility of large fluctuations in fuel cost.
- X There is a possibility that supply is disrupted due to low fuel storage.
- O There is high flexibility in operation and frequency adjustment capacity is large.

(3) Wind power

[Economy]
- O Actual generation cost is cheaper than that of coal-fired TPP.

[Environment]
- O No CO_2 emissions.
- X There are some problems with bird-strikes, noise, etc.

[Energy Security]
- O Cost is stable when the cost at the contract is applied.
- X No flexibility in operation.
- X It is difficult to forecast the generated energy.

(4) Solar Power

[Economy]
- O Actual cost is higher than that of coal-fired TPP, but it is possible to decrease the cost in the future.

[Environment]
- O No CO_2 emissions.
- X Vast land is required.

27 Since the details of environmental aspects are described in Chapter 6, only an outline is described here.

[Energy Security]

- O Cost is stable when the cost at the contract is applied.
- X No flexibility in operation.
- X It is difficult to forecast the generated energy.

7.4.4 Evaluation Method for Power Supply Configuration Scenarios

Power supply configuration scenarios are evaluated by scoring them from the viewpoints of Economy, Environmental performance, and Energy security.

(1) Economy

Economy is evaluated by supply cost in the case of optimum operation in the existing power plants, and the score has been normalized with the lowest cost at 10 and the highest cost at 0.

(2) Environmental performance

Environmental performance is evaluated by total score for the CO_2 emission factor and harmful effects from a regional environmental aspect. Regarding the harmful effects for the regional environment, since it is assumed that the impact can be mitigated to some extent by the introduction of mitigation measures during power plant construction, for the weighting, the evaluation of the CO_2 emissions is set at 80%, and the evaluation of the harmful effects from the viewpoint of the regional environment is set at 20%.

(a) CO_2 emission factor

The score has been normalized with the lowest emission factor at 10 and the highest at 0.

(b) Harmful effects from viewpoint of regional environmental aspect

Evaluation of harmful effects from the viewpoint of the regional environmental aspect for each power source is as described in Chapter 6. The numerical values are re-listed as follows.

Table 7-16 Evaluation Scores from Viewpoint of Regional Environmental Aspect

Source	LNG-fired TPP	Coal-fired TPP	Windpower	Solar power	PSPP
Evaluation score	- 0.57	- 1.13	- 0.56	- 0.52	- 0.90

(Source: JICA Survey Team)

The points above are integrated for every 1 GW of installed capacity of each power source, and the total is evaluated. The score has been normalized with the smallest minus score at 10 and the largest minus score at 0.

(3) Energy Security

Energy security is evaluated via the following three items from the viewpoints of securing a stable power supply and stable generating cost, and the total score is checked.

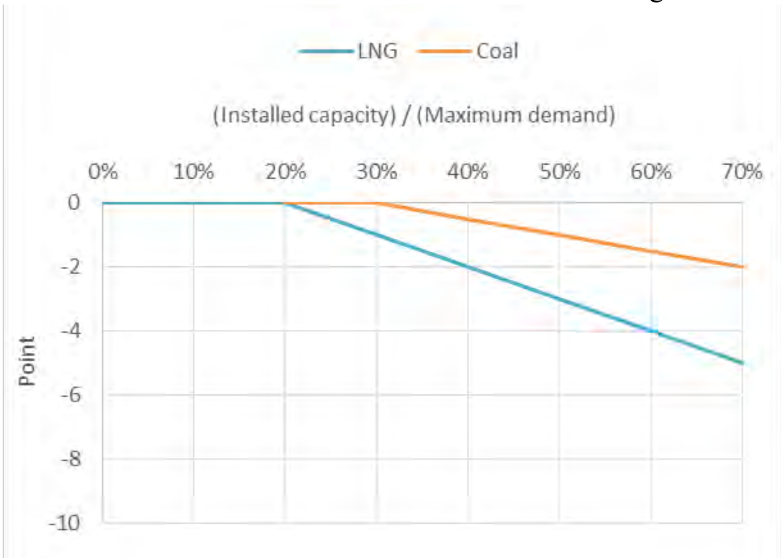
- Risk of Fuel Procurement Impossibility
- Risk of Fuel Price Increase
- Risk of Generating Capacity Fluctuation

With regard to the weighting, taking into consideration the frequency of the occurrence of risk and the impact caused by the risk, the evaluation of the risk of supply fluctuation that may occur every day is set to 60%, and the evaluations of the other two risks are both set to 20%. Decrease of generating capacity due to a plant accident is a kind of risk that prevents stable power supply, but this risk is not included in this evaluation, because measures are taken to secure supply reliability and sufficient reserve margin in each scenario.

(a) Risk of Fuel Procurement Impossibility

Fuel procurement for coal and LNG-fired TPPs depends on imports from overseas. For this reason, there is a risk of fuel procurement impossibility due to long term unseasonable weather and deterioration of relationships with the trade country. This risk probability seems to be very low, but should be examined in consideration of the large impact caused by its occurrence.

In general, even if fuel cannot be procured, the impact is very small in the case of a small amount of fuel. A coal-fired TPP has no trouble generating for approximately one month with fuel procurement impossibility, because there is a coal storage yard in a coal-fired TPP. However, there is a possibility of an LNG-fired TPP not being able to supply electricity in the case of a one month fuel procurement impossibility, because the plant doesn't have a large fuel storage capacity. This risk is evaluated by the ratio of installed capacity to the maximum demand (6.2GW), and scored via the following figure. The score has been normalized with the smallest minus score at 10 and the largest minus score at 0.

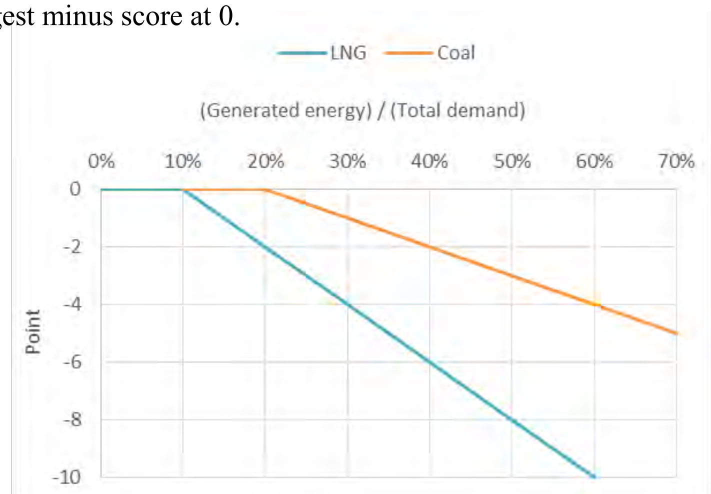


(Source: JICA Survey Team)

Figure 7-24 Evaluation Method for Risk of Fuel Procurement Impossibility

(b) Risk of Fuel Price Increase

Fuel for coal and LNG-fired TPPs has been procured from the global market. As shown in historical data, there is a possibility that fuel prices may rise sharply. Oil price fluctuation is particularly large, and LNG price fluctuation linked to the oil price is larger than the coal price fluctuation. Fuel cost rises lead to an increase in total cost. It is necessary to consider fuel price increase as a risk because it causes instability of finances. This risk is evaluated by the ratio of generated energy to total demand (39,805 GWh), and scored via the following figure. The score has been normalized with the smallest minus score at 10 and the largest minus score at 0.



(Source: JICA Survey Team)

Figure 7-25 Evaluation Method for Risk of Fuel Price Increase

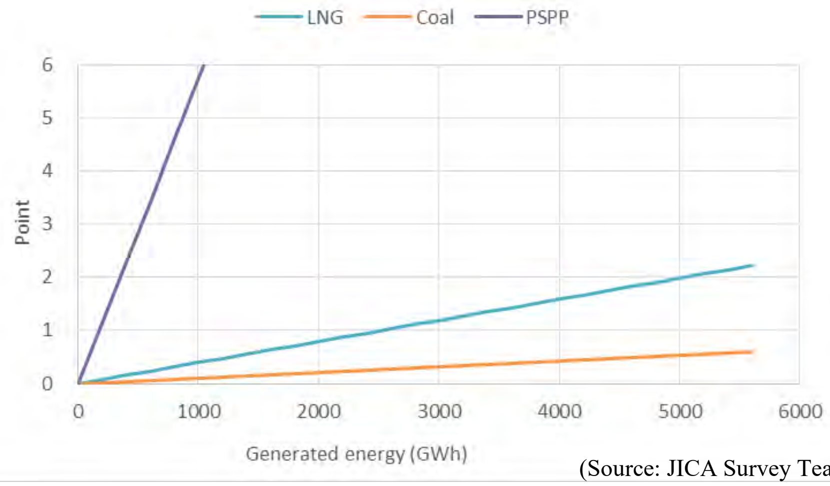
(c) Risk of Generating Capacity Fluctuation

In solar power and wind power plants, producing renewable energy, output fluctuates rapidly according to the natural conditions. It is necessary to keep the frequency constant by balancing demand and supply amid these fluctuations via adjustment by hydropower and thermal power plants. However, the frequency becomes unstable and the quality of the electricity gets much worse with a shortage of hydropower and thermal power plants which can perform adjustment operations. There is concern about the shortage of frequency adjustment capacity during the off-peak period, during which many reservoir type hydropower plants stop. Solar power plants operate during the daytime only and stop completely during the night when the power demand is low. However, the influence of the risk becomes large because wind power plants operate all day long. In general, the rate of viability decreases due to a leveling effect as the introduction amount of renewable energy increases. This risk is evaluated by installed capacity and scored via the following figure.

(Source: JICA Survey Team)

Figure 7-26 Evaluation Method for Risk of Generating Capacity Fluctuation

In general, it is necessary to maintain a frequency adjustment capacity which is approximately 2% of total demand in order to secure a stable power supply. The risk of generating capacity fluctuation can be avoided via the frequency adjustment capacity of hydropower and thermal power plants. The output adjustment range of LNG-fired TPP is wide and the speed is fast, compared with those of coal-fired TPP. Pumped storage power plants have a wider range of adjustment and the speed is also faster than an LNG-fired TPP. In addition, adjustable speed PSPP have a frequency adjustable capacity even during pumping operation and are effective for off-peak time amid a shortage of frequency adjustable capacity and time for surplus power supply. However, the effect of the frequency adjustment capacity is fully anticipated if availability of the PSPP is more than 5% and those of coal-fired and LNG-fired TPP are more than 40%, and the score will be discounted in the case of low availability. In consideration of these items, frequency adjustment capacity is evaluated by generated energy, and the points evaluated are regarded as positive points for canceling the risk of generating capacity fluctuation.



(Source: JICA Survey Team)

Figure 7-27 Evaluation Method for Frequency Adjustment Capacity

Surplus supply occurs on a holiday or at midnight when power demand decreases as the introduction amount of renewable energy becomes large. The balance between demand and supply is kept so as not to receive power from renewable energy in this situation, when the surplus supply power still occurs though PSPPs and battery systems are utilized as much as possible in order to absorb the surplus power. Under these circumstances, all operating hydropower and thermal power plants are generating at minimum output. As a result, a situation arises which makes the electricity quality worse because the response capacity for power supply fluctuations is shortened. This risk is evaluated by the ratio of surplus energy to total demand (39,805GWh) and scored via the following Figure.

(Source: JICA Survey Team)

Figure 7-28 Evaluation Method for Risk of Surplus Generating Capacity

Risk of generating capacity fluctuation is evaluated at three points in total: risk of supply power fluctuation from solar power plants and wind power plants, offset of risk due to frequency adjustment ability, and risk due to supply surplus occurrence. The score has been normalized with the smallest minus score at 10 and the largest minus score at 0.

In addition, in the event of bad weather throughout the country, there is a possibility that solar power generation will become highly unreliable as supply power. If the amount of solar power plants exceeds 500MW, additional development of gas turbine TPP equivalent to 50% of excess is required as a backup power supply and it is added to the supply cost as a factor deteriorating economy. This backup power supply is operated when conditions are such that demand is very large, there is almost no power generation from solar power due to bad weather throughout the country, and there is almost no wind power generation. For this reason, operation hours are only 30 per year and fuel cost is added accordingly.

(4) Normalization of Score

The aim of scoring is to evaluate each scenario relatively. Economy, environment and energy security are evaluated in every category with the highest score at 10 and the lowest score at 0, and the score is normalized. It is determined depending on evaluation criteria based on national energy policy which category is stressed. Decision makers can extract the optimum plan by weighting the normalized score according to the important categories based on the national energy policy.[28]

28 Studies with varying weights for each evaluation category are carried out in section 7.4.6.

7.4.5 Extraction of Optimum Power Supply Configuration

(1) Scenario A: High Priority on Cost

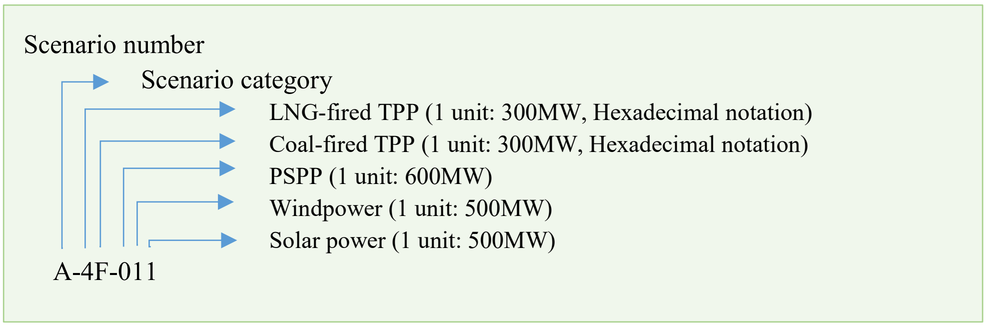
A high priority is given to cost and supply cost is reduced as much as possible.

Table 7-17 Evaluation Results for Every Scenario in Scenario A

	Installed capacity (GW)					Generation cost (USC/kWh)	CO_2 emissions (kg/kWh)	Normalized Score			
	LNG	Coal	PSPP	Wind	Solar			Economy	Environ-ment	Energy security	Total
A-4F-011	1.2	4.5	0.0	0.5	0.5	8.65	0.646	9.5	0.3	8.4	18.1
A-6D-011	1.8	3.9	0.0	0.5	0.5	8.78	0.612	8.3	1.4	8.7	18.4
A-4E-022	1.2	4.2	0.0	1.0	1.0	8.66	0.596	9.4	1.3	7.8	18.4
A-6C-022	1.8	3.6	0.0	1.0	1.0	8.74	0.563	8.7	2.4	8.9	19.9
A-4D-023	1.2	3.9	0.0	1.0	1.5	8.59	0.573	10.0	1.9	7.9	19.8
A-4D-024	1.2	3.9	0.0	1.0	2.0	8.63	0.563	9.6	1.9	7.3	18.8
A-4D-033	1.2	3.9	0.0	1.5	1.5	8.69	0.546	9.1	2.3	6.9	18.3
A-4C-034	1.2	3.6	0.0	1.5	2.0	8.62	0.522	9.7	2.9	7.1	19.7
A-4C-044	1.2	3.6	0.0	2.0	2.0	8.73	0.496	8.8	3.3	6.1	18.1
A-4E-111	1.2	4.2	0.6	0.5	0.5	8.72	0.646	8.8	0.0	8.7	17.5
A-6C-111	1.8	3.6	0.6	0.5	0.5	8.97	0.598	6.7	1.5	8.8	17.0
A-4D-122	1.2	3.9	0.6	1.0	1.0	8.82	0.591	8.0	1.1	9.4	18.5
A-6B-122	1.8	3.3	0.6	1.0	1.0	8.94	0.549	7.0	2.5	9.6	19.1
A-4D-123	1.2	3.9	0.6	1.0	1.5	8.75	0.579	8.6	1.1	9.4	19.2
A-4C-124	1.2	3.6	0.6	1.0	2.0	8.71	0.555	9.0	1.8	9.5	20.2
A-4C-133	1.2	3.6	0.6	1.5	1.5	8.73	0.536	8.8	2.3	8.9	20.0
A-4C-134	1.2	3.6	0.6	1.5	2.0	8.77	0.525	8.4	2.3	8.2	18.9
A-4B-144	1.2	3.3	0.6	2.0	2.0	8.76	0.482	8.5	3.4	8.1	20.0

(Source: JICA Survey Team)

Every scenario has a high score for Economy and Energy security but a low score for Environment. The score becomes higher as renewable energy development increases in place of coal-fired thermal development. If there is a large amount of renewable energy facilities, there is a tendency that the score will be higher if the amount of PSPP increases. As a result, A-4C-124 (LNG-fired TPP 1.2GW + Coal-fired TPP 3.6GW + PSPP 0.6GW + Windpower 1.0GW + Solar power 2.0GW) has the highest score.



(2) Scenario B: High Priority on Renewable Energy Development with CO_2 Reduction

A high priority is given to renewable energy development to prevent CO_2 emissions. Regarding the introduction of solar power and wind power for renewable energy, it is necessary to consider energy security because the output of solar power and wind power fluctuates suddenly due to natural conditions. In this Scenario, coal-fired TPP is not developed since CO_2 reduction is the top priority.
Actual study results are shown below.

Table 7-18 Evaluation Results for Every Scenario in Scenario B

	Installed capacity (GW)					Generating cost (USC/kWh)	CO_2 emissions (kg/kWh)	Normalized Score			
	LNG	Coal	PSPP	Wind	Solar			Economy	Environ-ment	Energy security	Total
B-D3-044	3.9	0.9	0.0	2.0	2.0	9.67	0.308	0.7	9.3	4.0	14.1
B-C3-046	3.6	0.9	0.0	2.0	3.0	9.59	0.295	1.4	9.3	3.8	14.5
B-B3-048	3.3	0.9	0.0	2.0	4.0	9.50	0.281	2.1	9.3	4.0	15.4
B-C3-064	3.6	0.9	0.0	3.0	2.0	9.44	0.273	2.7	9.8	3.6	16.0
B-C3-066	3.6	0.9	0.0	3.0	3.0	9.44	0.259	2.7	9.6	3.1	15.4
B-B3-068	3.3	0.9	0.0	3.0	4.0	9.35	0.245	3.4	9.6	3.3	16.3
B-C3-084	3.6	0.9	0.0	4.0	2.0	9.41	0.241	2.9	10.0	3.1	16.0
B-B3-086	3.3	0.9	0.0	4.0	3.0	9.37	0.229	3.3	9.9	2.0	15.2
B-A3-088	3.0	0.9	0.0	4.0	4.0	9.37	0.218	3.2	9.8	1.2	14.2
B-93-08A	2.7	0.9	0.0	4.0	5.0	9.40	0.208	3.1	9.7	0.0	12.7
B-C3-144	3.6	0.9	0.6	2.0	2.0	9.75	0.309	0.0	8.9	4.3	13.2
B-B3-146	3.3	0.9	0.6	2.0	3.0	9.67	0.295	0.7	8.9	4.0	13.5
B-B3-148	3.3	0.9	0.6	2.0	4.0	9.68	0.282	0.7	8.7	4.1	13.4
B-C3-164	3.6	0.9	0.6	3.0	2.0	9.60	0.273	1.3	9.2	4.0	14.5
B-B3-166	3.3	0.9	0.6	3.0	3.0	9.51	0.260	2.0	9.2	3.6	14.8
B-A3-168	3.0	0.9	0.6	3.0	4.0	9.43	0.246	2.8	9.1	3.9	15.9
B-B3-184	3.3	0.9	0.6	4.0	2.0	9.44	0.239	2.7	9.6	4.8	17.2
B-A3-186	3.0	0.9	0.6	4.0	3.0	9.41	0.227	2.9	9.6	3.8	16.2
B-A3-188	3.0	0.9	0.6	4.0	4.0	9.51	0.216	2.1	9.3	2.0	13.3
B-93-18A	2.7	0.9	0.6	4.0	5.0	9.52	0.207	2.0	9.1	1.2	12.3

(Source: JICA Survey Team)

All scenarios have a high score on Environment, but low score on Economy and Energy security. It cannot be said that every scenario has a high score when checking the total scores for Economy, Environment and Energy security. As a result, B-B3-184 (Windpower 4.0GW + solar power 2.0GW) has the highest score.

(3) Scenario C: Mixed Power Supply Development

Optimum power supply development is studied by balancing every power supply in consideration of economy, environment, and energy security.

Table 7-19 Evaluation Results for Every Scenario in Scenario C

	Installed capacity (GW)					Generating cost (USC/kWh)	CO_2 emissions (kg/kWh)	Normalized Score			
	LNG	Coal	PSPP	Wind	Solar			Economy	Environ-ment	Energy security	Total
C-98-033	2.7	2.4	0.0	1.5	1.5	9.09	0.450	5.7	5.4	7.9	19.0
C-7A-033	2.1	3.0	0.0	1.5	1.5	8.84	0.494	7.9	4.0	8.1	19.9
C-5C-033	1.5	3.6	0.0	1.5	1.5	8.69	0.532	9.1	2.8	7.3	19.2
C-97-044	2.7	2.1	0.0	2.0	2.0	9.08	0.402	5.8	6.4	7.1	19.3
C-79-044	2.1	2.7	0.0	2.0	2.0	8.84	0.446	7.9	5.0	7.2	20.0
C-5B-044	1.5	3.3	0.0	2.0	2.0	8.74	0.481	8.7	3.8	6.5	19.0
C-96-055	2.7	1.8	0.0	2.5	2.5	9.07	0.353	5.8	7.4	6.1	19.3
C-78-055	2.1	2.4	0.0	2.5	2.5	8.87	0.397	7.6	6.0	6.3	19.8
C-5A-055	1.5	3.0	0.0	2.5	2.5	8.79	0.432	8.2	4.8	5.7	18.7
C-88-133	2.4	2.4	0.6	1.5	1.5	9.18	0.452	4.9	5.0	8.4	18.3
C-6A-133	1.8	3.0	0.6	1.5	1.5	8.91	0.500	7.2	3.5	10.0	20.7
C-4C-133	1.2	3.6	0.6	1.5	1.5	8.73	0.536	8.8	2.3	8.9	20.0
C-87-144	2.4	2.1	0.6	2.0	2.0	9.16	0.403	5.1	5.9	7.7	18.8
C-69-144	1.8	2.7	0.6	2.0	2.0	8.91	0.451	7.3	4.5	9.1	20.8
C-4B-144	1.2	3.3	0.6	2.0	2.0	8.76	0.482	8.5	3.4	8.1	20.0
C-96-155	2.7	1.8	0.6	2.5	2.5	9.24	0.356	4.4	6.7	6.9	18.0
C-78-155	2.1	2.4	0.6	2.5	2.5	9.02	0.396	6.3	5.4	7.1	18.8
C-5A-155	1.5	3.0	0.6	2.5	2.5	8.93	0.428	7.0	4.3	7.3	18.6

(Source: JICA Survey Team)

As a result, C-69-144 (LNG-fired TPP 1.8GW + Coal-fired TPP 2.7GW + PSPP 0.6GW + Windpower 2.0GW + Solar power 2.0GW) has the highest score. Therefore, it is considered that the optimum power supply development is around C-69-144.

(4) Scenario O: Search for Optimum Scenario

It is considered that the optimum power supply configuration exists around the above-mentioned C-69-144, and this is searched for.

Table 7-20 Evaluation Results for Every Scenario in Scenario O

	Installed capacity (GW)					Generating cost (USC/kWh)	CO_2 emissions (kg/kWh)	Normalized Score			
	LNG	Coal	PSPP	Wind	Solar			Economy	Environ-ment	Energy security	Total
O-5B-133	1.5	3.3	0.6	1.5	1.5	8.80	0.521	8.1	2.8	9.9	20.8
O-78-144	2.1	2.4	0.6	2.0	2.0	9.03	0.428	6.2	5.2	8.7	20.0
O-69-144	1.8	2.7	0.6	2.0	2.0	8.91	0.451	7.3	4.5	9.1	20.8
O-5A-144	1.5	3.0	0.6	2.0	2.0	8.83	0.466	7.9	3.9	8.1	19.9
O-79-143	2.1	2.7	0.6	2.0	1.5	8.99	0.458	6.5	4.4	9.3	20.1
O-6A-143	1.8	3.0	0.6	2.0	1.5	8.89	0.476	7.4	3.8	8.5	19.6
O-5B-143	1.5	3.3	0.6	2.0	1.5	8.85	0.492	7.7	3.2	8.4	19.3
O-79-134	2.1	2.7	0.6	1.5	2.0	9.05	0.469	6.0	4.1	9.0	19.1
O-6A-134	1.8	3.0	0.6	1.5	2.0	8.91	0.492	7.2	3.4	9.3	19.9
O-5B-134	1.5	3.3	0.6	1.5	2.0	8.82	0.510	8.0	2.8	8.3	19.1
O-87-154	2.4	2.1	0.6	2.5	2.0	9.10	0.386	5.6	6.1	8.3	19.9
O-78-154	2.1	2.4	0.6	2.5	2.0	9.00	0.406	6.5	5.4	7.7	19.6
O-69-154	1.8	2.7	0.6	2.5	2.0	8.94	0.422	7.0	4.9	7.7	19.6
O-87-145	2.4	2.1	0.6	2.0	2.5	9.17	0.397	5.0	5.8	7.6	18.4
O-78-145	2.1	2.4	0.6	2.0	2.5	9.03	0.421	6.2	5.1	8.2	19.5
O-69-145	1.8	2.7	0.6	2.0	2.5	8.92	0.440	7.2	4.4	7.9	19.5

(Source: JICA Survey Team)

O-69-144 (LNG-fired TPP 1.8GW + Coal-fired TPP 2.7GW + PSPP 0.6GW + Windpower 2.0GW + Solar power 2.0GW) has the highest score.

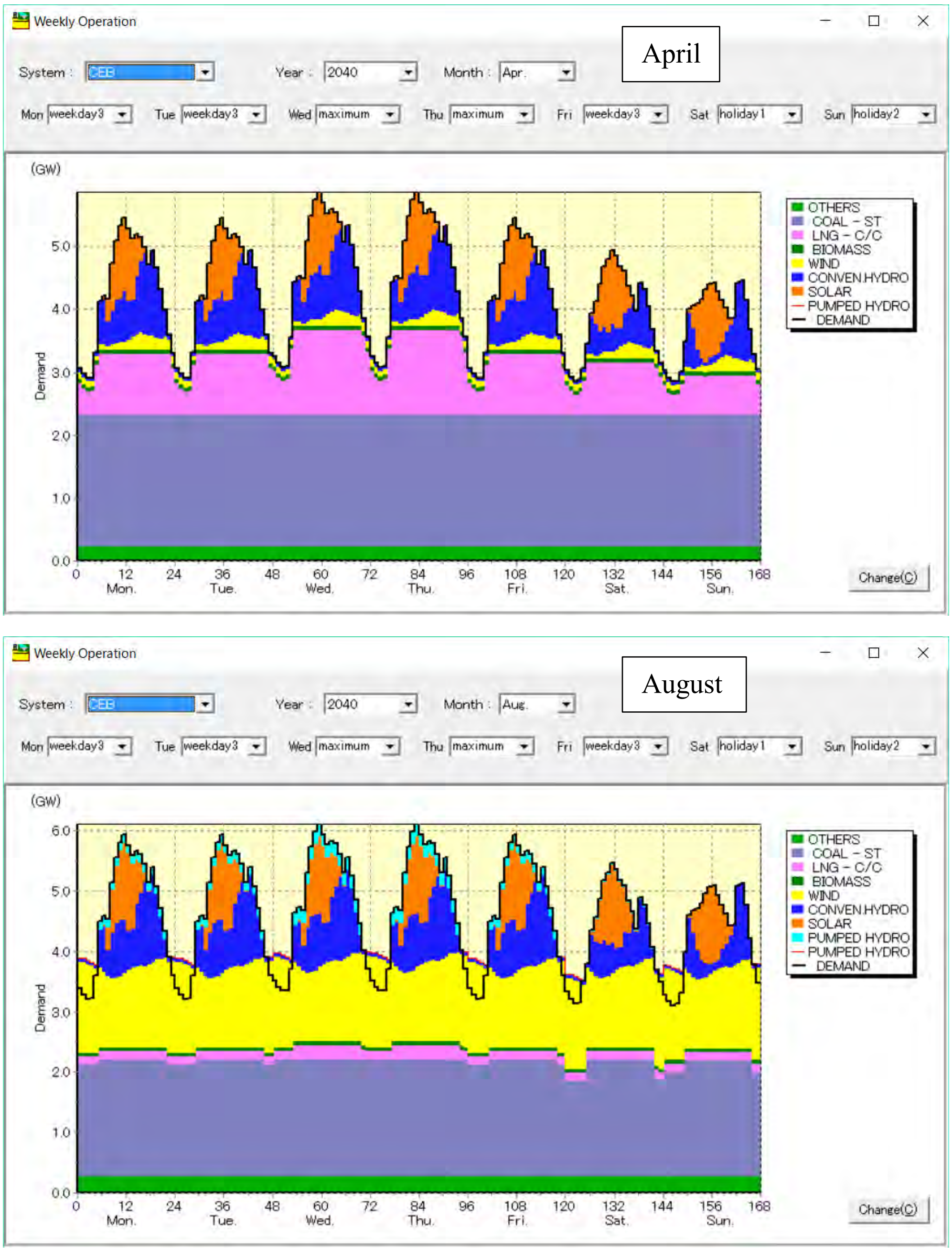
Regarding O-69-144, the installed capacity and generated energy are as follows:

Table 7-21 Power Supply Configuration of Optimum Plan

	Installed capacity		Generated energy		Plant factor
	GW	%	TWh	%	
Hydro	1.6	14.1%	5.3	13.2%	36.9%
Coal	2.7	23.2%	17.5	43.6%	74.0%
LNG (Gas)	1.8	15.4%	4.7	11.7%	29.8%
Oil	0.1	0.9%	0.0	0.0%	0.0%
PSPP	0.6	5.1%	0.3	0.6%	4.9%
NCRE	4.8	41.3%	12.4	30.9%	29.4%
Mini-hydro	0.7	6.0%	2.3	5.8%	37.9%
Wind	2.0	17.2%	6.7	16.7%	38.3%
Solar	2.0	17.2%	2.8	6.9%	15.8%
Biomass	0.1	0.9%	0.6	1.4%	62.8%
Total	11.7	100.0%	40.2	100.0%	39.3%

(Source: JICA Survey Team)

Installed capacity and generated energy accounting for renewable energy including hydropower is 55% in installed capacity and 45% in generated energy. The ratio of installed capacity in coal-fired thermal is about 23%, but the ratio of generated energy is about 44%. The ratio of installed capacity in LNG-fired thermal is about 15%. The ratio of generated energy in LNG-fired thermal is approximately 12%, because an LNG-fired TPP has a role in middle and peak power supply and the plant factor is low at approximately 30%. The plant factor for PSPP is 4.9%, but is more than 10% during the period when a PSPP operates by using mainly the surplus generated energy of windpower, from May to September. Operation status for one week in April and August in O-69-144 is shown below.



(Source: JICA Survey Team)

Figure 7-29 Operation Status for One Week

In April, the PSPP doesn’t operate at all because the generated energy of windpower is very low and surplus power doesn’t occur. However, in August, the PSPP operates due to surplus power at night. Therefore, the LNG-fired TPP doesn’t operate much. Looking at the coal-fired TPP operation status, in August, there is a large amount of windpower-generated energy, and part of the coal-fired TPP stops due to periodic inspection and the others operate at partial load.

7.4.6 Sensitivity Analysis

The above-mentioned optimum power supply configuration is calculated under conditions in which the three items (Economy, Environment and Energy security) are of the same importance. The optimum power supply configuration changes if the conditions, such as importance of these items, change.

Based on all the above-mentioned scenarios, the evaluation results when changing the importance of the three items are shown below.

Table 7-22 Sensitivity Analysis for Every Scenario

	Installed capacity (GW)					Normalized score			Eco: 1 Env: 1 Sec: 1	Eco: 60% Env: 20% Sec: 20%	Eco: 20% Env: 60% Sec: 20%	Eco: 20% Env: 20% Sec: 60%
	LNG	Coal	PSPP	Wind	Solar	Economy (Eco)	Environ-ment (Env)	Energy security (Sec)				
A-4D-023	1.2	3.9	0.0	1.0	1.5	10.0	1.9	7.9	19.8	23.9	14.1	21.3
A-4D-024	1.2	3.9	0.0	1.0	2.0	9.6	1.9	7.3	18.8	22.8	13.5	20.0
A-4D-033	1.2	3.9	0.0	1.5	1.5	9.1	2.3	6.9	18.3	22.0	13.7	19.3
A-4C-034	1.2	3.6	0.0	1.5	2.0	9.7	2.9	7.1	19.7	23.5	15.3	20.3
A-4D-123	1.2	3.9	0.6	1.0	1.5	8.6	1.1	9.4	19.2	21.9	12.9	22.8
A-4C-124	1.2	3.6	0.6	1.0	2.0	9.0	1.8	9.5	20.2	22.9	14.3	23.5
A-4C-133	1.2	3.6	0.6	1.5	1.5	8.8	2.3	8.9	20.0	22.5	14.7	22.7
A-4C-134	1.2	3.6	0.6	1.5	2.0	8.4	2.3	8.2	18.9	21.5	14.1	21.2
B-B3-068	3.3	0.9	0.0	3.0	4.0	3.4	9.6	3.3	16.3	13.9	21.3	13.8
B-C3-084	3.6	0.9	0.0	4.0	2.0	2.9	10.0	3.1	16.0	13.1	21.6	13.3
B-B3-086	3.3	0.9	0.0	4.0	3.0	3.3	9.9	2.0	15.2	13.0	21.0	11.6
B-A3-168	3.0	0.9	0.6	3.0	4.0	2.8	9.1	3.9	15.9	12.9	20.5	14.2
B-B3-184	2.4	0.9	0.6	4.0	2.0	2.7	9.6	4.8	17.2	13.5	21.9	16.1
B-A3-186	2.1	0.9	0.6	4.0	3.0	2.9	9.6	3.8	16.2	13.2	21.2	14.3
C-7A-033	2.1	3.0	0.0	1.5	1.5	7.9	4.0	8.1	19.9	21.4	16.8	21.7
C-79-044	2.1	2.7	0.0	2.0	2.0	7.9	5.0	7.2	20.0	21.4	17.9	20.6
C-78-055	2.1	2.4	0.0	2.5	2.5	7.6	6.0	6.3	19.8	21.0	19.0	19.4
C-6A-133	1.8	3.0	0.6	1.5	1.5	7.2	3.5	10.0	20.7	21.0	16.6	24.4
C-69-144	1.8	2.7	0.6	2.0	2.0	7.3	4.5	9.1	20.8	21.2	17.8	23.3
C-78-155	2.1	2.4	0.6	2.5	2.5	6.3	5.4	7.1	18.8	18.8	17.8	19.8
O-5B-133	1.5	3.3	0.6	1.5	1.5	8.1	2.8	9.9	20.8	22.2	15.8	24.3
O-69-144	1.8	2.7	0.6	2.0	2.0	7.3	4.5	9.1	20.8	21.2	17.8	23.3
O-6A-143	1.8	3.0	0.6	2.0	1.5	7.4	3.8	8.5	19.6	20.6	16.3	22.0
O-6A-134	1.8	3.0	0.6	1.5	2.0	7.2	3.4	9.3	19.9	20.6	16.0	23.1
O-78-154	2.1	2.4	0.6	2.5	2.0	6.5	5.4	7.7	19.6	19.5	18.3	21.0
O-78-145	2.1	2.4	0.6	2.0	2.5	6.2	5.1	8.2	19.5	19.1	17.8	21.5

(Source: JICA Survey Team)

(1) Economy

The optimum power supply configuration becomes A-4D-023 when economy points increase by three times. This plan includes LNG-fired TPP 1.2GW + Coal-fired TPP 3.9GW + PSPP 0GW +Wind power 1.0GW + Solar power 1.5GW, and has a higher ratio of Coal-fired TPP and a lower ratio of LNG-fired TPP than the original optimum configuration.

(2) Environment

The optimum power supply configuration becomes B-B3-184 when environment points increase by three times. This plan includes LNG-fired TPP 3.3GW + Coal-fired TPP 0.9GW + PSPP 0.6GW +Wind power 4.0GW + Solar power 2.0GW. In this plan, development of Renewable energy and LNG-fired TPP increases very much and the coal-fired TPP development is canceled.

(3) Energy Security

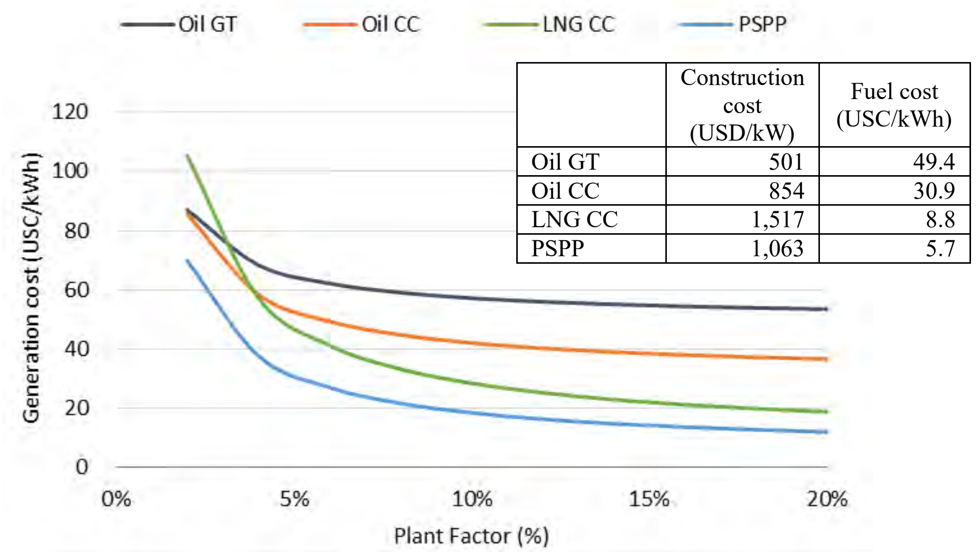
The optimum power supply configuration becomes C-6A-133 when energy security points increase by three times. This plan does not differ much from the original optimum configuration.

7.4.7 Economic Evaluation of Pumped Storage Power Plants (PSPP)

(1) Value of PSPP

(a) Economy

In general, it is said that PSPP is economical as a peak supply power corresponding to areas with low plant factor of approximately 10%. The power generation costs for various power sources in a low plant factor area are shown below. This is calculated assuming that the pumping energy for PSPP is supplied by coal fired TPP. However, when utilizing the surplus electric power of wind power, the energy charge for pumping becomes unnecessary, which makes it even cheaper.



	Construction cost (USD/kW)	Fuel cost (USC/kWh)
Oil GT	501	49.4
Oil CC	854	30.9
LNG CC	1,517	8.8
PSPP	1,063	5.7

(Source: JICA Survey Team)

Figure 7-30 Power Generation Costs for various Peak Supply Power Sources

As shown in the above figure, PSPP is more economical than other peak supply power. However, in order to ensure sufficient economic efficiency, it is necessary to satisfy the following two conditions.

- Enables cheap pumping energy
- Can always be expected as a supply power during peak time period

Thus, the economic efficiency of PSPP varies greatly depending on the shape of demand and the configuration of power sources.

(b) Energy security

The availability of a load following function (ancillary services) for a variety of peaking power plants is described below.

Table 7-23 Load Following Functions of Various Peaking Power Plants

	Frequency Control (Primary & Secondary reserve)		Stand-by operation (Secondary & Tertiary reserve)
	Peak period	Off-peak period	
Conventional-type PSPP	Possible	Impossible (at pumping operation)	Possible
Adjustable Speed-PSPP (AS-PSPP)	Possible	Possible (at pumping operation)	Possible
Reservoir-type hydro	Possible	Uneconomical (basically stop)	Possible
Battery	Possible	Possible	Possible
Gas turbine (GT)	Possible	Uneconomical (basically stop)	Possible (slower than hydro)
Buying power from other countries	Possible	Possible	Possible (dependent on other countries)
Combined cycle (C/C) thermal	Possible but uneconomical with partial load operation		Possible (slower than GT)

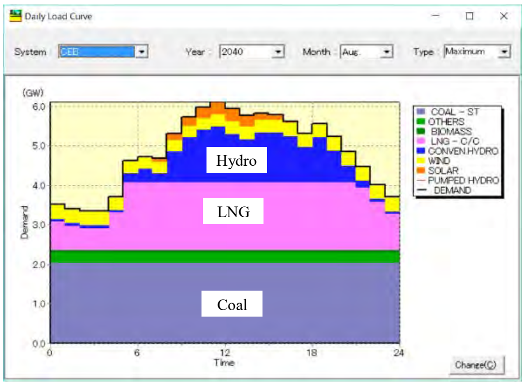
(Source: JICA Survey Team)

Different peaking power plants have very similar load following functions, but only AS-PSPP, battery and buying power from other countries have the frequency control function during off-peak periods. Reservoir-type hydro also has frequency control during off-peak periods, but it is very uneconomical to operate during hours with low marginal cost. Combined-cycle thermal power plants can make frequency adjustments, but the response speed is much slower than hydro power plants.

(2) Possibility of PSPP in Sri Lanka

(a) Possibility as Peak Supply Power

It is assumed that peak demand occurs during daytime in 2040 and the peak time period is long. In the Sri Lankan system, since there is sufficient reservoir type hydropower even in 2040, there is sufficient peak supply power. Hydropower adjusts output according to the demand curve, and as a result the peak time period is approximately 16 hours. In consideration of the function of PSPP, which generates the water during daytime and pumps up it during night, it is difficult to secure 100% supply power at all times even if the PSPP is introduced.



(Source: JICA Survey Team)

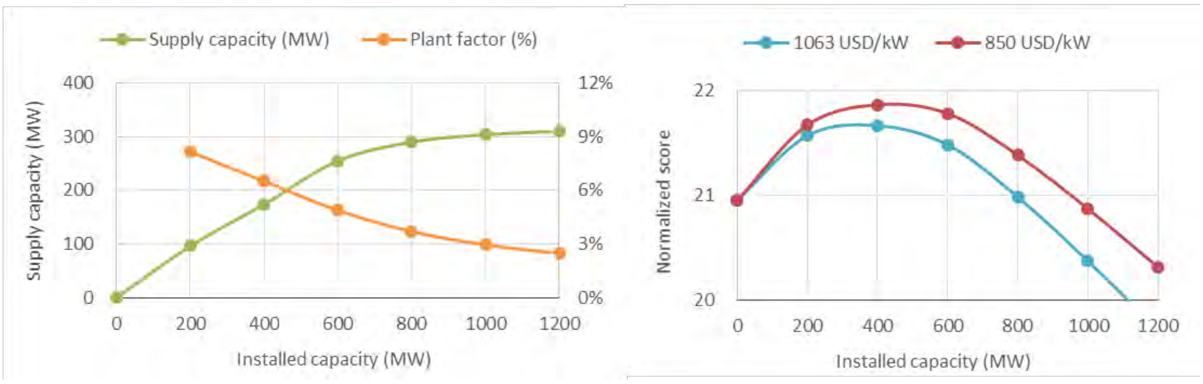
Figure 7-31 Operation Situation of Reservoir Type Hydro

(b) Load following function for energy security
In the Sri Lankan system, since there is sufficient reservoir type hydropower even in 2040, frequency adjustment during peak time periods is no problem at all. However, frequency adjustment at off-peak times is currently carried out by the limited power sources that can control output, operating the reservoir type hydro PP despite this being uneconomical. In future, when PSPP (adjustable speed type) is introduced into the system and it supplies frequency adjustment at off-peak periods, it will be possible to avoid the uneconomical operation of reservoir type hydro PP. However, the frequency control function cannot be supplied in the absence of cheap pumping power, Possibility to secure the cheap pumping power depends on the future demand trend at off-peak periods and development trend of coal-fired TPP and windpower.

(c) Possibility to secure cheap pumping power
Surplus generation is shown in Figure 7-23 when a large amount of renewable energy is introduced. It is necessary to suppress generation output in absence of PSPP or battery. The surplus generation occurs when windpower development exceeds 2GW. The surplus generation comes into 5% of power generation when the windpower development is 4GW. Regarding solar power development, the surplus generation occurs when the development is beyond 5GW, and the surplus generation comes into 5% of power generation when the development is 7GW. Therefore, a large amount of surplus generation occurs when windpower development becomes more than 4GW or the solar power development becomes more than 7GW. As a result, it is possible to secure the cheap pumping power.
It is possible to secure the cheap pumping power when a large amount of coal-fired TPP is introduced, because fuel cost of coal-fired TPP is cheaper than that of LNG fired TPP.

(3) Optimum Development of PSPP
Since the optimum development volume of PSPP greatly varies depending on the development trends of coal-fired PP and wind power, it is examined for the three power supply configuration scenarios. As the method of study, with an increase in the development volume of PSPP, the amount of development of LNG combined cycle TPP is reduced on the premise that the supply reliability is satisfied. As for the construction cost of PSPP, 1,063 USD/kW at Maha-3, which is regarded as the most promising candidate as a result of the PSPP MP survey, is used, but as a reference the case when construction cost decreases by 20% and becomes 850 USD/kW is also calculated.

(a) Scenario to develop various power sources
As a scenario to develop various power sources, the results of studying a case with coal-fired TPP of 2.7 GW, windpower of 2.0 GW, and solar power of 2.0 GW are shown below.

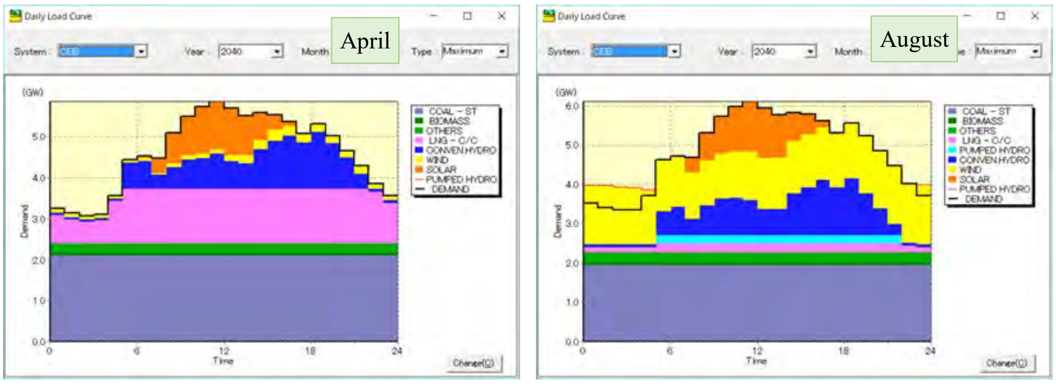


(Source: JICA Survey Team)

Figure 7-32 Optimum Development of PSPP (Scenario to develop Various Power Sources)

Supply capacity that is increased with the development of PSPP is about half of the amount of development. When the development volume of PSPP is less than 600MW, Plant Factor is over 5%, indicating that there is some cheap pumping energy. In terms of normalized score, a plan to develop about 400 to 600MW of PSPP is a high score. From the viewpoint of economy, according to the increase in development volume of PSPP, although the increase in supply capacity is small, it has the effect of reducing fuel cost up to about 600MW development. In addition, because the amount of renewable energy developed is relatively high, the value of the ability to cope with load fluctuations in terms of energy security increases.

The operation situations on the maximum demand day in April and August are shown below.

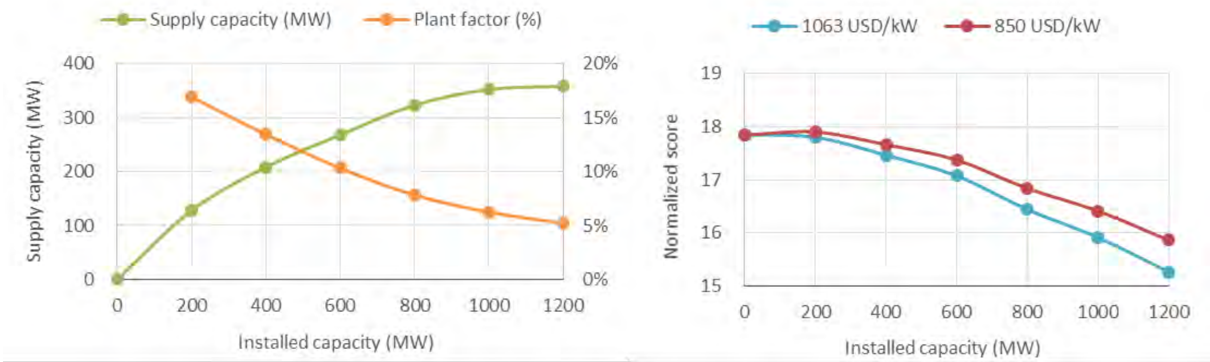


(Source: JICA Survey Team)

Figure 7-33 Operation Situations (Scenario to develop Various Power Sources)

In April, windpower generation is very small and there is no cheap pumping energy, so there is little operation of PSPP. On the other hand, in August, since windpower generation is large, surplus power is generated at off-peak times, and pumping is carried out by using the surplus. In the peak time period, PSPP is operating for about 14 hours at constant output, approximately 250MW.

(b) Scenario to develop many coal-fired TPPs
As a scenario to develop many coal-fired TPPs, the results of studying a case with coal-fired TPP of 3.9 GW, windpower of 0.5 GW, and solar power of 0.5 GW are shown below.

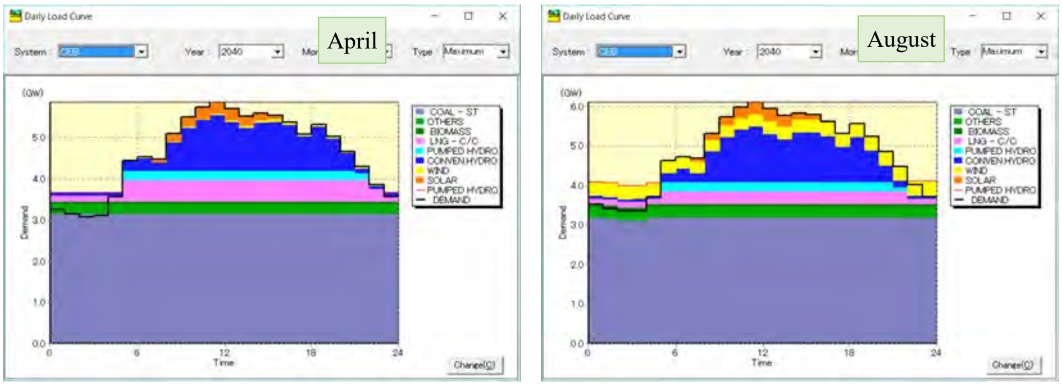


(Source: JICA Survey Team)

Figure 7-34 Optimum Development of PSPP (Scenario to develop many Coal-fired TPPs)

Supply capacity that is increased with the development of PSPP is about half of the amount of development. When the development volume of PSPP is less than 600MW, Plant Factor is over 10%, indicating that there is much cheap pumping energy. However, in terms of normalized score, it is better not to develop PSPP. From the viewpoint of economy, according to the increase in development volume of PSPP, although it has the effect of reducing fuel cost up to about 600MW development, the increase in supply capacity is small. In addition, because the amount of renewable energy developed is very small, the value of the ability to cope with load fluctuations in terms of energy security is not so high.

The operation situations on the maximum demand day in April and August are shown below.



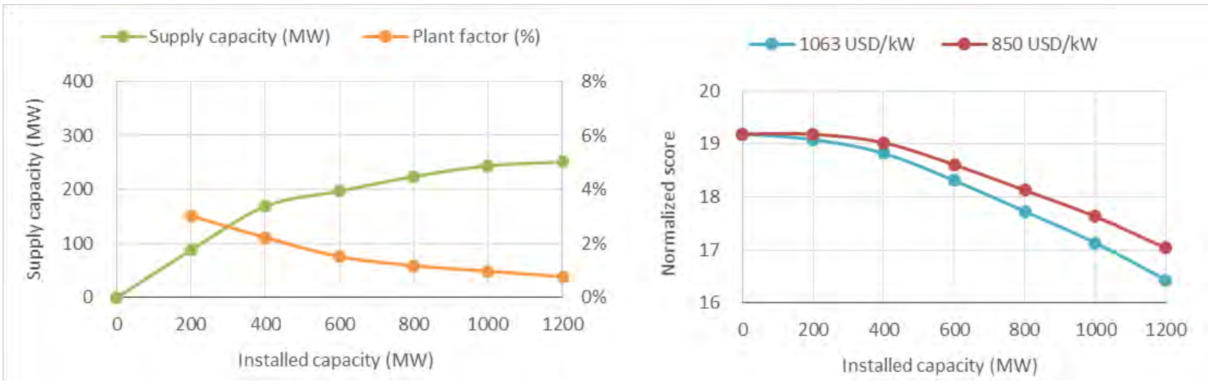
(Source: JICA Survey Team)

Figure 7-35 Operation Situations (Scenario to develop many Coal-fired TPPs)

There is not much difference between April and August. In the peak time period, PSPP is operating for about 14 hours at constant output, approximately 250MW.

(c) Scenario to develop many RE

As a scenario to develop many RE, the results of studying a case with coal-fired TPP of 0.9 GW, windpower of 3.0 GW, and solar power of 4.0 GW are shown below.

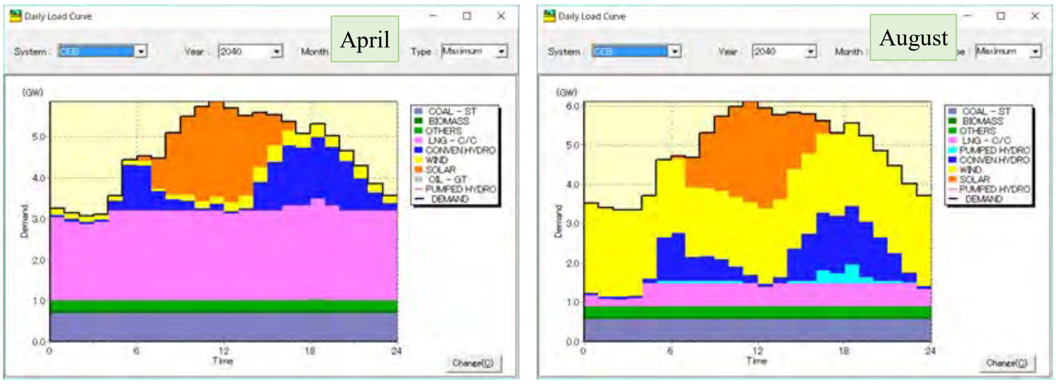


(Source: JICA Survey Team)

Figure 7-36 Optimum Development of PSPP (Scenario to develop many RE)

Supply capacity that is increased with the development of PSPP is about half of the amount of development. Plant Factor is 3% or less, indicating that there is very little cheap pumping energy. In terms of normalized score, it is better not to develop PSPP. Because of the large amount of renewable energy development, the value of the ability to cope with load fluctuations in terms of energy security is high. However, because the amount of cheap pumping energy is very little, the value of the economic aspect becomes lower with the development of PSPP.

The operation situations on the maximum demand day in April and August are shown below.



(Source: JICA Survey Team)

Figure 7-37 Operation Situations (Scenario to develop many RE)

In April, windpower generation is very small and there is no cheap pumping energy, so there is little operation of PSPP. On the other hand, in August, since windpower generation is large, surplus power is generated at off-peak times such as holidays, and pumping is carried out by using the surplus. PSPP is operating in the evening, which becomes the peak time after dispatching solar power output.

(4) Conclusion

(a) Case of peak demand during daytime

Value of PSPP as peak supply power is not high because more than half of supply power increasing with PSPP development cannot be expected. It is not necessary to store power generation and to construct PSPP when solar power development is less than 5GW, because peak time period and generation time of solar power are overlapped. Therefore, optimum PSPP development amount depends heavily on development amount of coal-fired TPP and windpower.

1) Development plan by mixing several fuels

Windpower development is 2GW and value of PSPP as load following function at off-peak period is high. Coal-fired TPP development is being conducted and a large amount of surplus occurs during high season for windpower generation Therefore, optimum PSPP development is 400MW to 600MW.

2) Many coal-fired TPP development plan

Reduction effect of fuel cost is a little expected by developing PSPP, but value of PSPP as load following function is low due to a small amount of renewable energy development. Therefore, optimum PSPP development is less than 200MW.

3) Many renewable energy development plan

Windpower development is 3GW and value of PSPP as load following function at off-peak period is high. However, cheap pumping power cannot be expected because coal-fired TPP is not developed and surplus power generation is very low. Therefore, optimum PSPP development is less than 200MW.

Surplus power increases and cheap pumping power can be expected, when windpower development increases and becomes more than 4GW. As a result, the optimum PSPP development increases. In addition, cheap pumping power is expected and then the optimum PSPP development increases when solar power development exceeds 7GW and surplus energy increases.

(b) Current case of peak demand for approximately 2hours at 7pm

The same amount of supply power as development can be expected and value of PSPP as peak supply power is high when PSPP development is less than 600MW. Peak for 2hours at 7pm gets larger in case of many solar power development because period of peak time and solar power generation are not overlapped. Therefore, same amount of supply power as development can be expected even if PSPP development becomes more than 600MW. It is reasonable that approximately 600MW PSPP is developed at any case because the PSPP can be expected as peak supply power.

(c) Possibility of introduction of battery

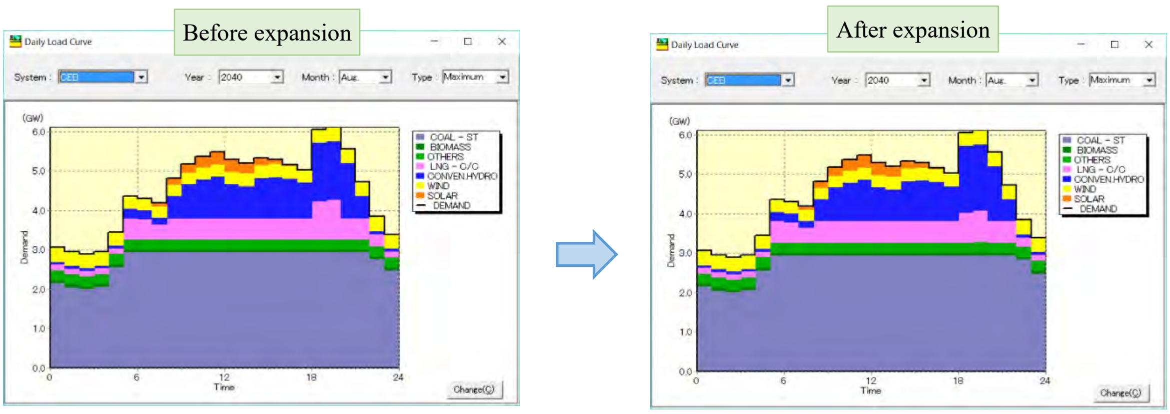
Battery like PSPP has the function to store surplus supply power, and has faster load following function than PSPP. In this way, the function of battery is equal to or greater than that of PSPP. When the battery cost is the same as PSPP cost, the above result holds true. However, current cost per kWh is approximately 3 to 5 times as much as the PSPP cost. The battery is less economical than PSPP. It the future, cost reduction will be conducted by mass production, but it is estimated that it is difficult to reduce the battery cost at the same level of PSPP without a large technical breakthrough. It takes approximately 10 years for PSPP to start operation from decision making, but battery can start operation within 2 years from the decision making. This is large advantage for the battery.

7.4.8 Evaluation of Victoria Hydropower Expansion Plan

The Victoria hydropower expansion plan aims to increase the output of 228MW, by installing two 114MW generators adjacent to the existing power plant. As with the existing power plants, because the electricity is generated using the water of the Victoria lake reservoir, the increment of electric energy is only the avoidance of ineffective discharge at times of flooding, and it is estimated to be 27 GWh per year. Although the power generation's possible time duration differs depending on the monthly available water amount, it is possible to operate for about 8 hours at full output on weekdays at this moment. After completion of expansion, almost doubling the installed capacity, it will be able to increase supply power by 4 hours of only peak time by operating all generators at full output. In other words, it aims to increase the supply power during the peak time period by increasing the power generation amount, and it is considered economical as peak supply power.

According to the results of the FS survey conducted in 2009, the construction cost is expected to be USD 222 million at October 2008 prices. When calculating the power generation cost based on this construction cost, it is around 35 USC/kWh at a Plant Factor of 5%, which is about the same as the PSPP. As shown in Figure 7-30, if supply capacity of the same amount as the increasing installed capacity can be expected, the Victoria hydropower expansion plan will be economical as peak supply capacity.
However, as shown in the previous section, it is necessary for 10 hours or more as the peak supply power at the demand shape used for the current demand forecast. Therefore, even if the installed capacity increases by 228MW, there is almost no increase in supply capacity. The situation before and after the implementation of the Victoria Hydropower Expansion Plan has hardly changed, so it is not economical.

In the case of a shape where almost 2 hours of peak demand occurs around 19 o'clock as in the present situation, the situation before and after implementation of the Victoria Hydropower Expansion Plan is shown below.



(Source: JICA Survey Team)

Figure 7-38 Operation Situation for Victoria Hydropower Expansion Plan

Since the duration required for the peak period is about 2 hours, if the installed capacity is increased by 228MW, the supply capacity increment is obtained at the same level as the capacity enhancement, and the development amount of the LNG-fired TPP can be suppressed correspondingly. Furthermore, since it is possible to reduce the amount of thermal power energy burnt with high cost fuel during the peak time period and to expect the effect of reducing fuel costs, the Victoria hydropower expansion plan is economical.

7.5 Long-term Power Development Plans

7.5.1 Concept of Formulating Long-term Power Development Plans

Based on the following scenario mentioned in the previous section, a sample of long-term power development plans for each year are made and examined by comparing among them.

(1) Scenario A: Cost is regarded as the important factor
(2) Scenario B: CO_2 reduction is regarded as the important factor and Renewable energy development is prioritized
(3) Scenario C: Power development is carried out by combining several fuels

The long-term power development plan in each scenario is made based on the following concepts.

- Change ratio of power supply configuration so that the power supply configuration every year is close to that in the target year
- Consider realistic feasibility such as lead time for development
- Satisfy the criteria for LOLE in each year
- Decommissioning and fuel conversion plan for the existing plants is based on revised LTGEP

(1) Scenario A: Cost is regarded as the important factor

A-4D-023 is selected as the Scenario in 2040 in order to reduce supply cost as much as possible. Power development after 2016 is Coal-fired TPP 3.0GW + LNG-fired TPP 0.9GW + Windpower 0.9GW + Solar power 1.5GW. This plan to 2034 is the same as the revised LTGEP and the coal-fired thermal development is mainly carried out after 2035.

(2) Scenario B: CO_2 reduction is regarded as the important factor and Renewable energy development is prioritized

B-B3-184 is selected as the Scenario in 2040 in order to introduce as much renewable energy as possible in consideration of energy security. Power development after 2016 is LNG-fired TPP 3.0GW + Windpower 3.9GW + Solar power 2.0GW + PSPP 0.6GW. Furthermore, additional coal-fired thermal development is not carried out.

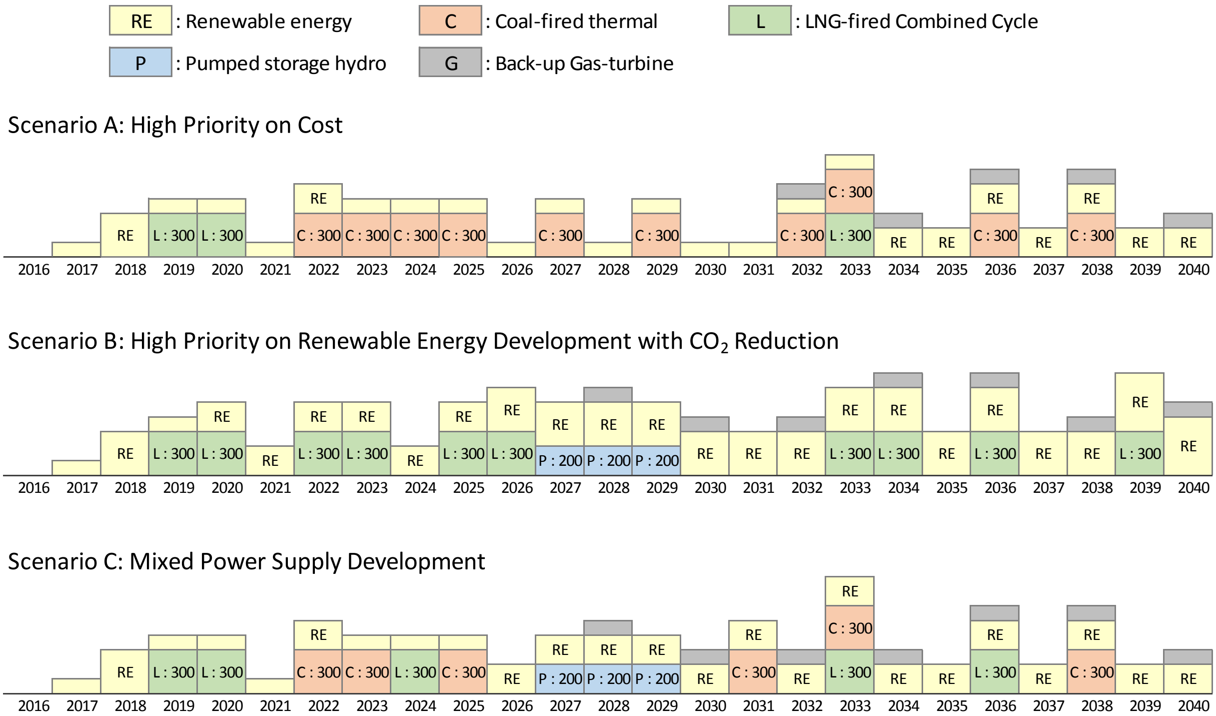
(3) Scenario C: Power development is carried out by combining several fuels

O-69-144 is selected as the Scenario in 2040 in order to make a well-balanced plan by combining Economy, Environment and Energy security. Power development after 2016 is LNG-fired TPP 1.5GW + Coal-fired TPP 1.8GW + Windpower 1.9GW + Solar power 2.0GW + PSPP 0.6GW.

7.5.2 Comparison of Each Scenario

(1) Comparison of Development Plans

A comparison of development plans made based on the concepts in the previous section is as follows.

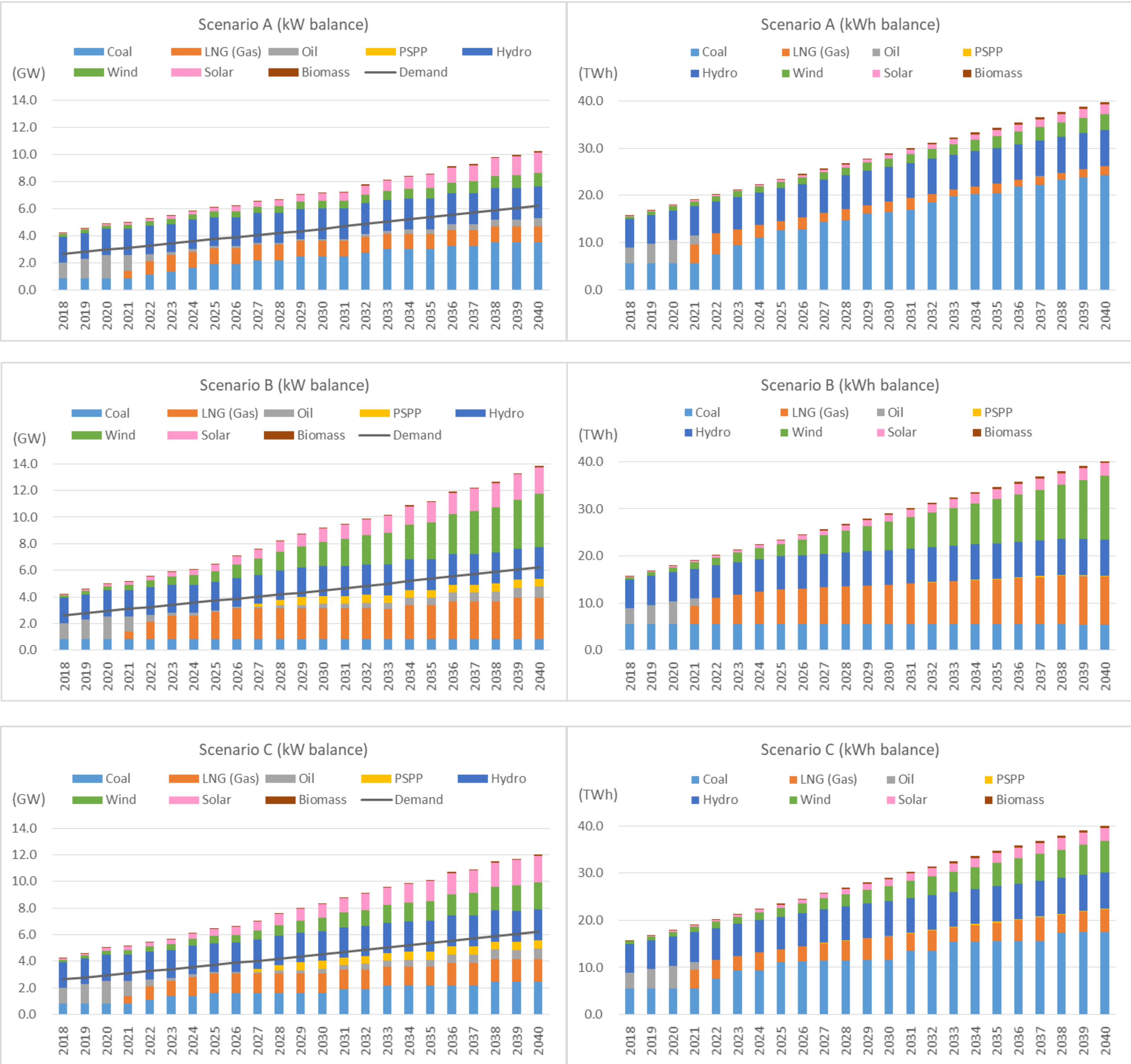


(Source: JICA Survey Team)

Figure 7-39 Development Plans in Each Scenario

The plan to 2020 is assumed to be the same plan except for renewable energy. In addition, LNG-fired TPP in 2019 and 2020 uses petroleum fuel at the beginning of operation and converts it to LNG fuel in 2021.

Changes in installed capacity and power generation amount for each power source in each scenario are shown below.



(Source: JICA Survey Team)

Figure 7-40 Changes in Installed Capacity and Power Generation Amount in Each Scenario

Scenario B, which has a large amount of renewable energy (solar power and wind power) development, has a larger total installed capacity than the other scenarios, and it is more than twice the maximum demand.

A comparison of detailed development plans is shown below. It is assumed that decommissioning plans for the existing plants and fuel conversion plans are the same in every scenario.

The above proposed plan shows the development plans for various power sources, and does not specify specific sites. However, in order to prepare the transmission system development plan, it is necessary to identify the specific sites. In order to aim for economic planning together with the power development plan and the transmission system development plan, the location area for the power development site is specified by the following idea. Regarding coal-fired TPP and LNG-fired TPP, the standard capacity size of one site is 1,200MW (four 300MW machines).

(a) Coal-fired TPP
The possible location sites are the eastern and southern areas. In the case that about 1,200MW of power plants are developed in one site, construction of a new 400kV transmission line will be necessary. Regarding the transmission lines in the eastern area, construction of a 220kV transmission line will be required in the near future, in response to increased demand in the eastern area. If the development of coal-fired TPP is to be carried out in the eastern area, construction beforehand with 400kV design will reduce the amount of investment in transmission and transformation facilities required at the start of operation of the power plant. In consideration of this point, priority is given to development in the eastern area.

(b) LNG-fired TPP
The Colombo area and southern area are available as sites, but in any case, new construction of LNG supply facilities is necessary. In order to improve the operation efficiency of the newly constructed LNG supply facilities, it is effective to use much LNG by converting the existing oil-fired TPP to LNG-fired TPP. Therefore, Kerawalapitiya in the Colombo area is developed as a priority.

(c) PSPP
Since the potential site is a mountainous area, the power plants have to be in the central area.

(d) Renewable energy
As for the mini-hydropower, it is thought that development will progress mainly in the central area as in the present situation. Wind power will be developed mainly in the Mannar area where wind conditions are good and a high utilization rate can be expected, but development is expected to progress even in the Puttalam area and the northern area, where wind conditions are relatively good. Solar will be mainly developed in the southern area and the southeastern area, where a rich amount of solar radiation can be secured, but development in small amounts is expected to progress in other areas as well.
The introduction ratio for each area is shown below.

Table 7-24 Area-wise Introduction Ratio of Renewable Energy

	M Hydro	Wind	Solar	Biomass
North		15%	15%	
Mannar		50%	5%	10%
North East		5%	10%	20%
Puttalam		20%	5%	15%
West	15%		10%	10%
Central	78%	5%	10%	30%
South	7%	5%	25%	10%
South East			20%	5%
	100%	100%	100%	100%

(Source: JICA Survey Team)

Table 7-25 Development Plan in Scenario A

(MW, hours)

	Hydro		Coal		LNG (Gas)		Oil		LOLE
2015		1377		900		0		1121	
2016									16.87
2017							Diesel (South)	170	12.45
2018	Broadland	35					Gas Turbine	70	24.71
	Uma Oya	120					Asia Power	(49)	
							Kelanitissa GT	(68)	
2019							Gas Turbine	35	16.42
							C/C (Colombo)	300	
							Sapugaskanda	(72)	
2020							C/C (Colombo)	300	9.03
	Thalpitigala	15					Northern Power	(30)	
2021					C/C (Colombo)	300	C/C (Colombo)	(300)	26.41
					C/C (Colombo)	300	C/C (Colombo)	(300)	
2022	Moragolla	31	Coal (East)	300			Diesel (South)	(170)	23.38
	Seethawaka	20			West coast C/C	300	West coast C/C	(300)	
	Gin Ganga	20			KPS C/C	165	KPS C/C	(165)	
2023			Coal (East)	300	KPS-2 C/C	163	AES C/C	(163)	21.52
							Gas Turbine	(115)	
							Sapugaskanda	(36)	
2024			Coal (East)	300					11.80
2025			Coal (East)	300			Sapugaskanda	(36)	9.45
							Barge power	(60)	
2026									26.42
2027			Coal (South)	300					13.25
2028									15.43
2029			Coal (South)	300					6.15
2030									11.36
2031									25.26
2032			Coal (South)	300			GT	100	8.93
2033			Coal (South)	300	C/C (Colombo)	300			5.79
					KPS-2 C/C	(163)			
					KPS C/C	(165)			
2034							GT	100	11.07
2035									18.08
2036			Coal (East)	300			GT	100	8.40
2037									15.18
2038			Coal (East)	300			GT	100	7.33
2039							Chunnakam	(27)	12.73
2040							GT	100	23.47

<Renewable Energy>

(MW)

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
M-hydro	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Wind	0	10	50	50	30	30	30	30	30	30	30	30	30	30	30
Solar	0	40	20	20	20	40	40	40	40	40	50	50	50	50	50
Biomass										20					20

	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
M-hydro	10	10	10	10	10	10	10	10	10	10	400
Wind	30	30	30	50	50	50	50	50	50	50	880
Solar	50	100	100	100	100	100	100	100	100	100	1500
Biomass					20					20	80

(Source: JICA Survey Team)

Table 7-26 Development Plan in Scenario B

(MW, hours)

	Hydro		Coal	LNG (Gas)		Oil		LOLE
2015		1377	900		0		1121	
2016								16.87
2017						Diesel (South)	170	12.45
2018	Broadland	35				Gas Turbine	70	24.27
	Uma Oya	120				Asia Power	(49)	
						Kelanitissa GT	(68)	
2019						Gas Turbine	35	15.36
						C/C (Colombo)	300	
						Sapugaskanda	(72)	
2020						C/C (Colombo)	300	8.04
	Thalpitigala	15				Northern Power	(30)	
2021				C/C (Colombo)	300	C/C (Colombo)	(300)	19.18
				C/C (Colombo)	300	C/C (Colombo)	(300)	
2022	Moragolla	31		C/C (Colombo)	300	Diesel (South)	(170)	17.19
	Seethawaka	20		West coast C/C	300	West coast C/C	(300)	
	Gin Ganga	20		KPS C/C	165	KPS C/C	(165)	
2023				C/C (Colombo)	300	AES C/C	(163)	15.25
				KPS-2 C/C	163	Gas Turbine	(115)	
						Sapugaskanda	(36)	
2024								36.96
2025				C/C (South)	300	Sapugaskanda	(36)	24.49
						Barge power	(60)	
2026				C/C (South)	300			11.10
2027	PSPP	200						13.82
2028	PSPP	200				GT	100	6.81
2029	PSPP	200						7.88
2030						GT	100	12.62
2031								16.15
2032						GT	100	23.86
2033				C/C (South)	300			41.74
				KPS-2 C/C	(163)			
				KPS C/C	(165)			
2034				C/C (South)	300	GT	100	19.15
2035								25.34
2036				C/C (Colombo)	300	GT	100	9.92
2037								17.15
2038						GT	100	26.78
2039				C/C (Colombo)	300	Chunnakam	(27)	13.58
2040						GT	100	17.28

<Renewable Energy>

(MW)

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
M-hydro	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Wind	0	10	50	50	70	100	100	100	100	100	200	200	200	200	200
Solar	0	40	50	50	50	50	50	50	60	100	100	100	100	100	100
Biomass										20					20

	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
M-hydro	10	10	10	10	10	10	10	10	10	10	400
Wind	200	200	200	200	200	200	200	200	300	300	3880
Solar	100	100	100	100	100	100	100	100	100	100	2000
Biomass					20					20	80

(Source: JICA Survey Team)

Table 7-27 Development Plan in Scenario C

(MW, hours)

	Hydro		Coal		LNG (Gas)		Oil		LOLE
2015		1377		900		0		1121	
2016									16.87
2017							Diesel (South)	170	12.45
2018	Broadland	35					Gas Turbine	70	24.27
	Uma Oya	120					Asia Power	(49)	
							Kelanitissa GT	(68)	
2019							Gas Turbine	35	15.36
							C/C (Colombo)	300	
							Sapugaskanda	(72)	
2020							C/C (Colombo)	300	8.04
	Thalpitigala	15					Northern Power	(30)	
2021					C/C (Colombo)	300	C/C (Colombo)	(300)	20.28
					C/C (Colombo)	300	C/C (Colombo)	(300)	
2022	Moragolla	31	Coal (East)	300			Diesel (South)	(170)	17.38
	Seethawaka	20			West coast C/C	300	West coast C/C	(300)	
	Gin Ganga	20			KPS C/C	165	KPS C/C	(165)	
2023			Coal (East)	300	KPS-2 C/C	163	AES C/C	(163)	17.09
							Gas Turbine	(115)	
							Sapugaskanda	(36)	
2024					C/C (Colombo)	300			9.46
2025			Coal (East)	300			Sapugaskanda	(36)	6.80
							Barge power	(60)	
2026									17.60
2027	PSPP	200							27.50
2028	PSPP	200					GT	100	11.51
2029	PSPP	200							14.64
2030							GT	100	23.48
2031			Coal (East)	300					9.11
2032							GT	100	15.66
2033			Coal (South)	300	C/C (Colombo)	300			9.74
					KPS-2 C/C	(163)			
					KPS C/C	(165)			
2034							GT	100	17.03
2035									23.60
2036					C/C (South)	300	GT	100	10.15
2037									15.55
2038			Coal (South)	300			GT	100	7.92
2039							Chunnakam	(27)	17.19
2040							GT	100	22.84

<Renewable Energy>

(MW)

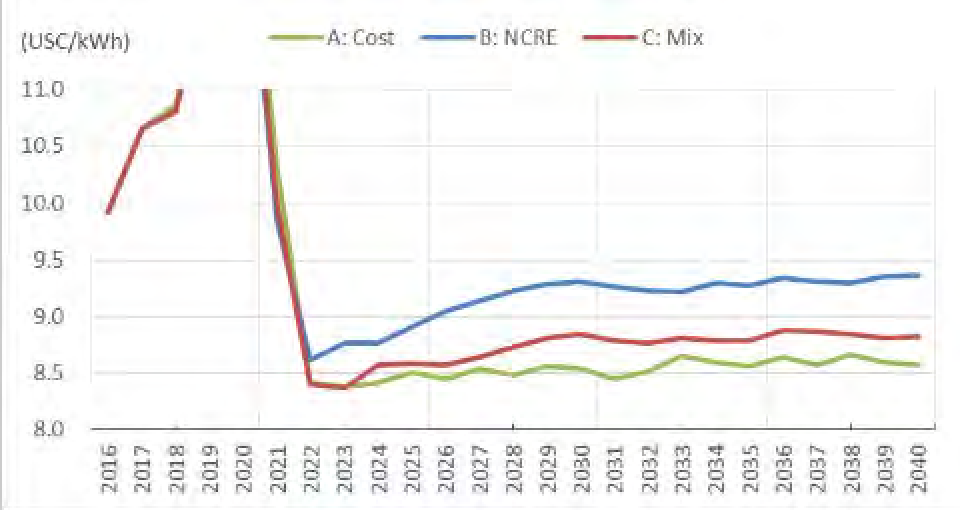
	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
M-hydro	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Wind	0	10	50	50	70	50	50	50	50	50	50	100	100	100	100
Solar	0	40	50	50	50	50	50	50	60	100	100	100	100	100	100
Biomass										20					20

	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
M-hydro	10	10	10	10	10	10	10	10	10	10	400
Wind	100	100	100	100	100	100	100	100	100	100	1880
Solar	100	100	100	100	100	100	100	100	100	100	2000
Biomass					20					20	80

(Source: JICA Survey Team)

(2) Comparison of Generation Costs

A comparison of generation costs in each year is shown below.



(Source: JICA Survey Team)

Figure 7-41 Comparison of Generation Costs

Generation cost decreases with Coal-fired TPP development because coal-fired TPP is cheap. Regarding the comparison of generation costs, Scenario A, with priority on cost and Coal-fired TPP development, is the cheapest and Scenario B, with priority on renewable energy development, is the most expensive. Scenario C, which is a fuel mix plan, is a little more expensive than Scenario A. Regarding the comparison of generation cost after 2022 and in 2016 in normal hydropower generation, all scenarios cost becomes low. Especially regarding the cost in Scenario A and C approximately 1 USC/kWh becomes low. In 2019 and 2020, since the newly developed combined cycle is operated with petroleum as a fuel, it costs about 13 USC/kWh.

The results of comparing the present value (2015 price) for 25 years' expenses from 2016 to 2040 are as follows. Since the cost until 2020 is high and has little difference among Scenarios, the smaller the discount rate, the clearer the difference among Scenarios is and the lower the overall cost.

Table 7-28 Comparison of the Present Value (2015 price) for 25 Years' Expenses

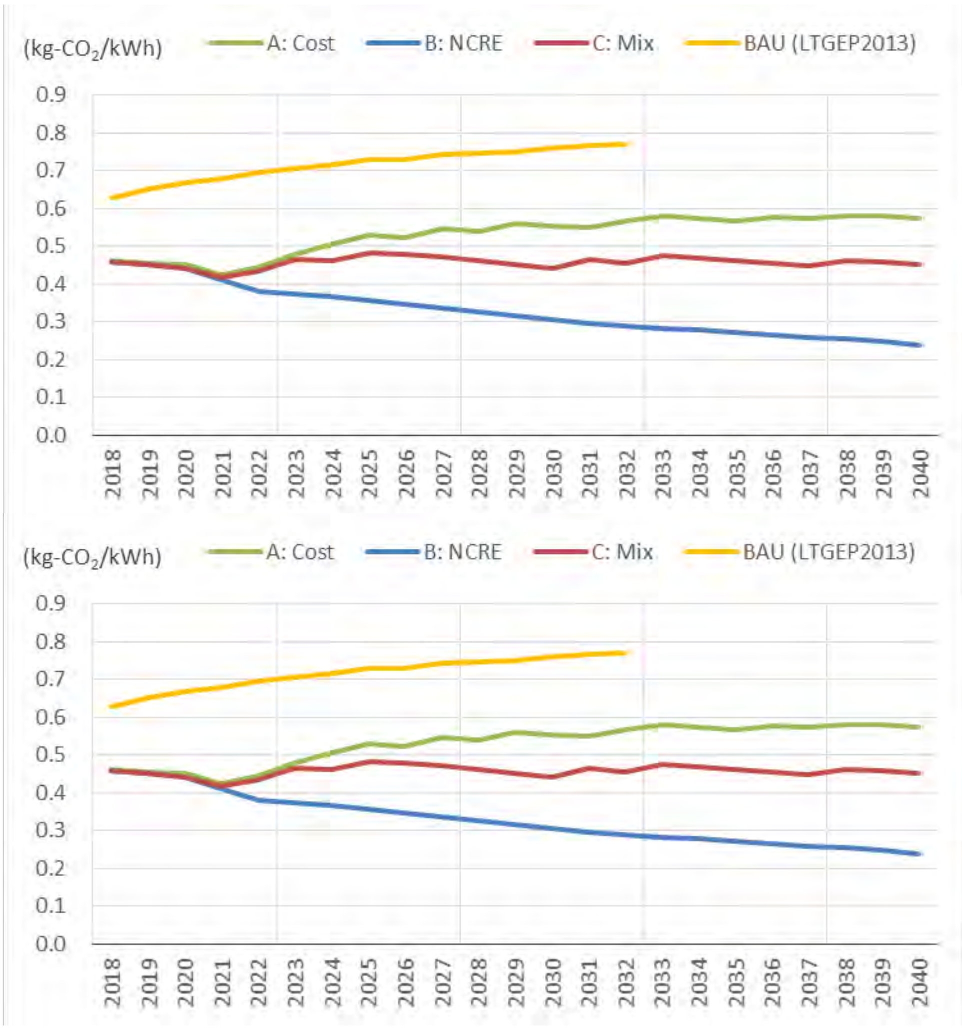
	Discount rate = 10%		Discount rate = 5%	
	million USD	USC/kWh	million USD	USC/kWh
Scenario A	18,714	9.45	31,133	9.18
Scenario B	19,371	9.78	32,606	9.61
Scenario C	18,852	9.52	31,510	9.29

(Source: JICA Survey Team)

A comparison of detailed costs (Comparison of financial position of CEB) is described in Chapter 12.

(3) Comparison of CO_2 Emissions

A comparison of CO_2 emissions in each year is shown below[29].



(Source: JICA Survey Team)

Figure 7-42 Comparison of CO_2 Emissions

As renewable energy development increases, CO_2 emission per kWh decreases slightly and finally becomes 0.4 kg-CO_2/kWh in 2020. In Scenario B, the CO_2 emission per kWh decreases still more and reaches a level lower than 0.24 kg-CO_2/kWh in 2040. Annual CO_2 emissions are approximately 7,000 kton, which is unchanged until 2020, and then increase slightly, but are around 10,000 kton-CO_2 in 2040, and there is no big increase.

In Scenario A, CO_2 emission per kWh increases gradually after 2021 and becomes 0.6 kg-CO_2/kWh in 2040. CO_2 emission increases steadily and reaches 23,000 kton in 2040, which is more than three times that of the current level.

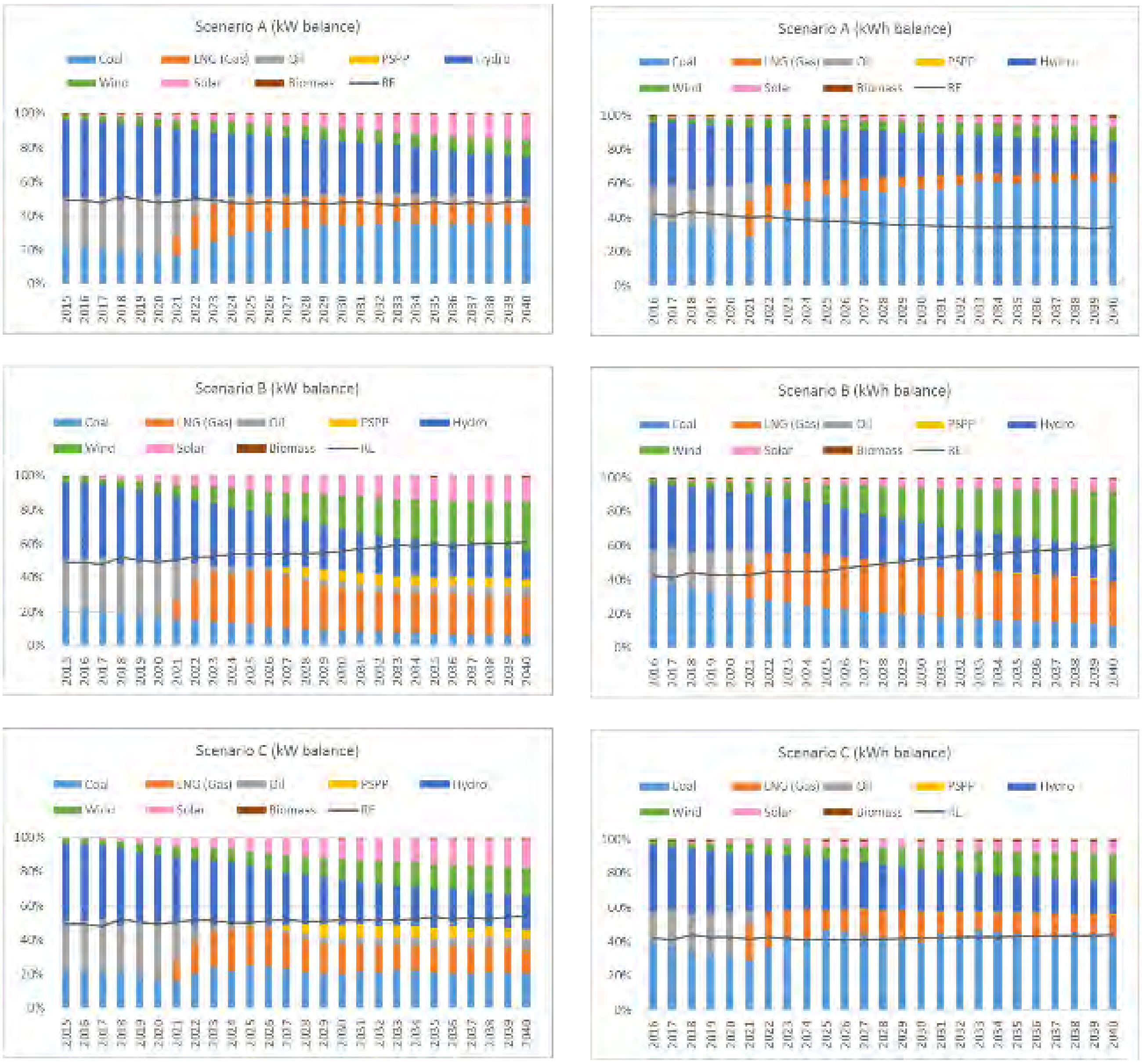
[29] In 2016, the amount of thermal power generation increased drastically due to a serious drought, so the annual CO_2 emissions were 11,895.8 kton-CO_2 and the CO_2 emissions per kWh were very high at 0.8199 kg-CO_2/kWh.

Scenario C, which conducts power development by combining several energy sources, is located between Scenarios A and B, and CO_2 emission per kWh becomes a slightly lower level than the current level.

The Nationally Determined Contributions (NDC) submitted by the Ministry of Mahaweli Development and Environment in September 2016 declared a reduction in greenhouse gas emissions by 20% by 2030 in the energy sector as compared to the Business-as-usual (BAU) scenario. The emissions in the BAU scenario are based on LTGEP 2013 - 2032, submitted in October 2013. In all scenarios, the emissions have been reduced by 30% or more as compared to BAU, and the target value declared in the NDC is sufficiently cleared.

(4) Comparison of Configuration Rates for various Power Sources

A comparison of configuration rates for various power sources in each year is shown below.



(Source: JICA Survey Team)

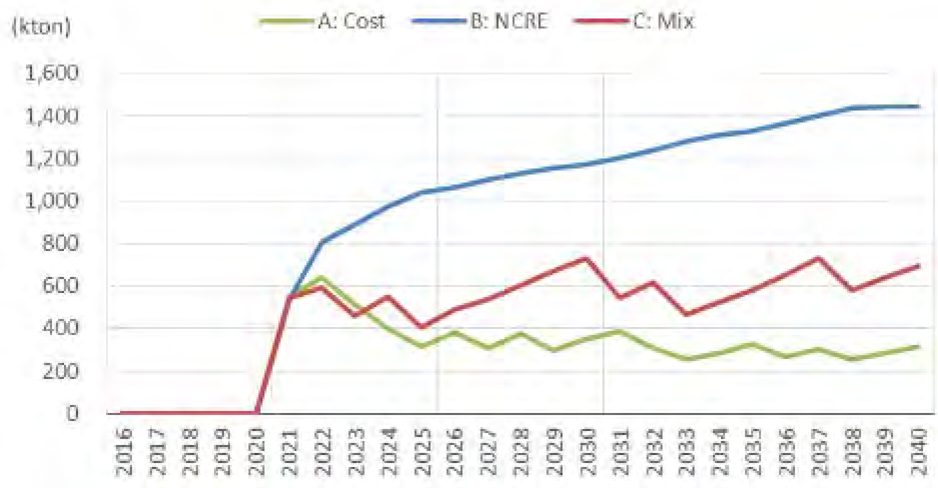
Figure 7-43 Comparison of Configuration Rates for various Power Sources

In Scenario A, which gives priority to cost, the configuration rate of coal-fired TPP gradually increases and reaches 61% by 2040 in generated energy. On the other hand, in Scenario B, which develops renewable energy as a priority, the configuration rate of coal-fired TPP gradually decreases, and it decreases to 14% in generated energy in 2040.

Up to 2020, the configuration rate of renewable energy is about 50% in installed capacity and about 45% in generated energy in every scenario. In Scenario B, which gives priority to renewable energy, it gradually increases thereafter and reaches 61% in terms of installed capacity and 60% in generated energy in 2040. In Scenario A, which gives priority to cost, from 2021 onwards, the rate in the installed capacity hardly changes, but the rate in the generated energy slightly decreases and reaches 34% in 2040. Scenario C, which is a fuel mix plan, is located between the two, and it increases to 54% in installed capacity in 2040, but the rate in generated energy is almost the same as the present situation.

(5) Comparison of LNG Fuel Consumption

A comparison of LNG fuel consumption in each year is shown below.



(Source: JICA Survey Team)

Figure 7-44 Comparison of LNG Fuel Consumption

The introduction of LNG fuel will begin in 2021, and it is about 0.6 million tons per year at the beginning of introduction. Since price of LNG fuel is higher than coal, LNG fuel consumption tends to decrease with the development of coal-fired TPP. In Scenario B, which develops renewable energy as a priority, since coal-fired TPP is not developed at all, annual LNG fuel consumption gradually increases and reaches 1.4 million tons in 2040.

7.5.3 Recommended Proposal

The JICA Survey Team has comprehensively judged the three perspectives of economics, environmental friendliness and energy security and recommends development per Scenario C.

7.6 Possibility for Carbon Neutral

According to the National Energy Policy and Strategies of Sri Lanka which the Sri Lankan government will announce, the government aims to achieve carbon neutral[30] by 2050. In order to achieve carbon neutral, the possibility of supplying 100% renewable energy for all power demand is examined from a technical point of view.

7.6.1 Requirements for high quality power supply

(1) Securing of Power Demand and Supply Balance

It is always necessary to maintain a balance between power demand and supply even though the generating time of solar and windpower is limited. Therefore, it is essential to install power storage facilities like batteries or PSPP when a large amount of renewable energy is introduced.

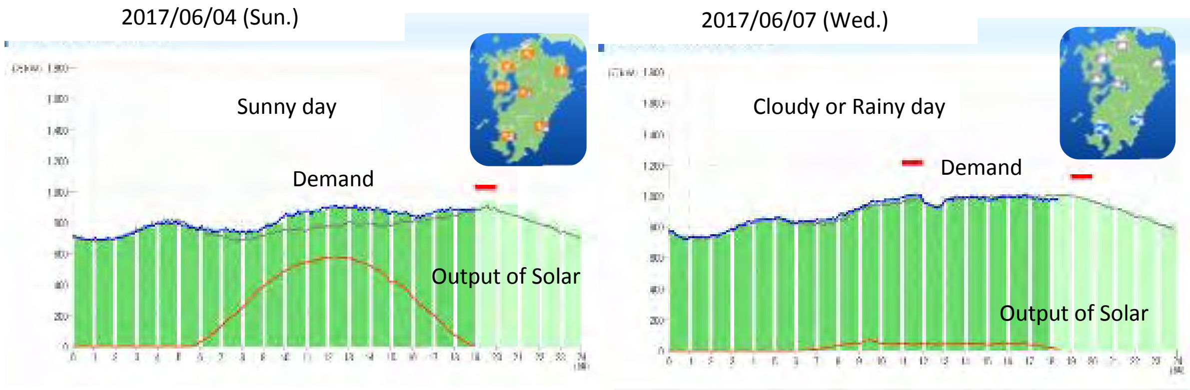
(2) Frequency Control Function

It is a concern that frequency will fluctuate due to an imbalance between power demand and supply because the output of solar and wind power varies depending on the weather. Batteries have a function to maintain the balance between power demand and supply by adjusting the charging/discharging amount. In this case, it is not necessary to install facilities for frequency control. However, a generating facility for setting the standard frequency is necessary because the output of solar and wind power is DC power and this is converted to AC power. In particular, at least several units of rotating facility (Victoria and Kotmale hydropower plants, etc.), which can supply AC power directly to the power network, should be operating.

(3) Reserve Capacity

It is necessary to secure reserve capacity to satisfy power demand at all times even if the output of solar and wind power reduces due to a change in weather. In order to examine the necessary amount of reserve capacity, the impact of weather on solar power output in the Kyushu area, which covers 36,749km^2, equal to 56% of the area of Sri Lanka, is investigated.

Solar power generation results for the Kyushu area, Japan are shown below.



(Source: http://www.kyuden.co.jp/power_usages/pc.html)

Figure 7-45 Solar Power Generation Results in Kyushu Area, Japan

Approximately 7GW of solar power plants have been introduced to the Kyushu area as of June 2017. Maximum power generation is approximately 6GW when it is sunny all over the Kyushu area. However, the power generation is 1GW or less when it is cloudy or rainy all over the area. In this way, the output of solar power depends greatly on the day's weather.

[30] This is a concept whereby the carbon absorbing amount is equivalent to the carbon emissions amount when producing something and implanting a series of artificial actions. (Wikipedia)

It is unlikely that solar power can't generate at all during the daytime on cloudy or rainy days nationwide because the area of Sri Lanka is approximately twice as large as Kyushu, but many customers would not receive power at all hours of the day and night in the absence of a preliminary power storage facility. To avoid such a situation, it is assumed that a preliminary power storage facility is installed so that sufficient power can be supplied even if approximately 20% of average output is supplied for five days in a row.

(4) Expansion of Transmission and Substation Facilities

Solar power plants and batteries are installed nationwide, and no large current flows into interregional transmission lines due to the balancing of power demand and supply at each area. However, in the case of a sunny day at a particular area only, a large current flows into other areas. Therefore, 400kV transmission lines are constructed nationwide and interregional transmission should be expanded.

7.6.2 Study Conditions

(1) Power Demand

It is assumed that power demand in 2050 is 7.5GW and 48.0TWh, with day-peak like power demand in 2040.

(2) Purchase Cost of Renewable Energy

It is supposed that the purchase cost of renewable energy in 2050 is the same as the cost in 2040, as follows.

Table 7-29 Purchase Cost of Renewable Energy

	(USC/kWh)
Biomass	14.1
Solar	6.0
Wind	7.4
Mini-hydro	7.3

(Source: JICA Survey Team)

(3) Cost of Power Storage Facilities

Batteries and PSPP are considered as power storage facilities. Power storage capacity depends on battery type, and construction cost per kWh is generally used. In this MP, cost comparison is implemented on the assumption that the storage capacity of a battery is 6 hours, like PSPP. The cost comparison is shown below.

Table 7-30 Cost Comparison of Power Storage Facilities

	Battery	PSPP
Construction cost	3,000 USD/kW	1,000 USD/kW
Life	10 years	40 years
O&M expenses	5 USD/kW/year	5 USD/kW/year
Storage Efficiency	80%	70%
Life-time cost	56.3 USC/kWh	15.9 USC/kWh

Remarks: Life-time cost is the value at 10% capacity factor.
It is assumed that cost for power storage is zero because surplus power is stored.

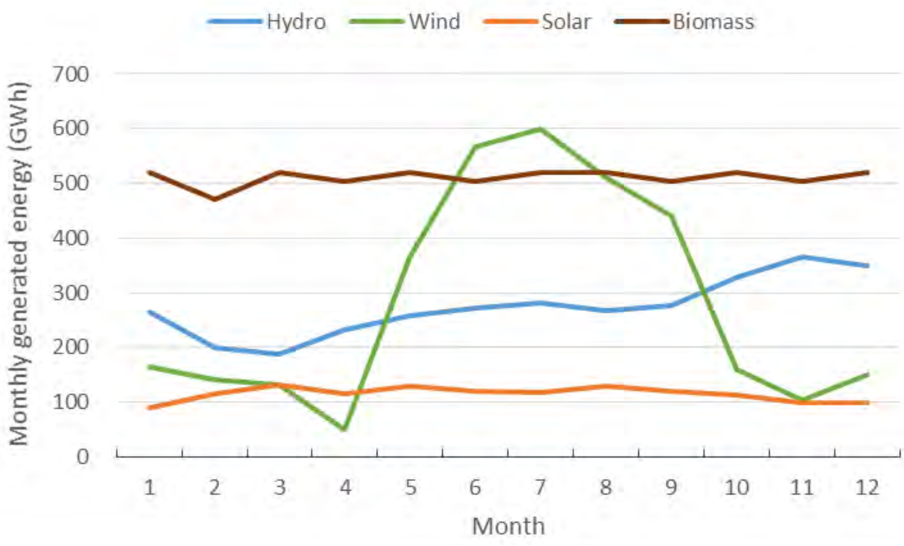
(Source: JICA Survey Team)

Construction cost for batteries is the cheapest at present and there are actual cases in which the cost is approximately 1,000 USD/kWh (6,000 USD/kW in the case of a 6 hour power storage battery).

It is assumed that the maximum development of PSPP is 5GW in consideration of land limitations.

(4) Seasonal Fluctuation of Renewable Energy

Monthly generation for each 1GW of renewable energy is shown below.



(Source: JICA Survey Team)

Figure 7-46 Monthly Generation of Renewable Energy

In consideration of seasonal fluctuations in renewable energy and future development potential, the possibility of renewable energy becoming the main power source to achieve carbon neutral was evaluated.

(a) Windpower

It is necessary to install more than 1,000GWh of batteries per 1GW of windpower to store surplus power from June to August and to levelize the monthly generation each month because seasonal windpower generation fluctuation is very large. In this case, batteries can basically charge/discharge once a year. This is not efficient, and not realistic in consideration of battery storage costs.[31]

(b) Hydropower

Hydropower can store power via the dam reservoir. From the point of view of the electricity sector, it is efficient if hydropower stops and stores water for generation during the high season for windpower, and generates during the off season for windpower. However, water in the dam reservoir is mainly used for irrigation, so it can't be used preferentially for generation during insufficient power supply seasons. In addition, hydropower is not expected to become the main power source in the future, because much of the potential has already been developed.

(c) Solar

Solar is the most promising candidate for the main power source to implement carbon neutral because seasonal variation is small and there is potential nationwide. However, generated energy from November to January is smaller than that of other months. It is predicted that power demand and supply from November to January will be relatively tight when a large amount of solar power is introduced.

[31] During low windpower generation from November to April, it is necessary to supply a shortage amount from batteries, and more than 10,000 GWh of batteries is necessary. Even if the battery costs halve, the investment is still approximately 3,000 billion USD and supply cost is more than 500 USC/kWh.

(d) Biomass

Biomass power plants can supply a fixed amount of power when the fuel can be secured, and adjust output to some extent according to the system operator's instructions. For this reason, Biomass power is a promising candidate to become the main power source for carbon neutral, if it is possible to secure the fuel. However, it is difficult to envisage agricultural residue as a stable fuel because much of it is already used for several purposes, including generation, at present and the supply period is limited to harvest time. For this reason, biomass would start by improving idle land and coppices to provide the fuel, and then biomass fuel can be secured through the biomass fuel business.

In the renewable energy master plan, it is predicted that 500ha ($5km^2$)[32] of land is necessary for a 1MW power plant in the case of land improvement for biomass fuel even if a single crop like coconuts is grown. Therefore, in order to implement 1GW of biomass generation, it is necessary to secure $5,000km^2$ of land, which is equivalent to approximately 8% of Sri Lanka. It is difficult to expect more than 1GW of biomass generation in consideration of the realistic effective land use.

(5) Installed Capacity for Each Power Source

In consideration of the above mentioned status, it is assumed that solar power is the main power source and other renewable energy is set as follows. With regard to solar power and power storage facilities, necessary installed capacity to satisfy power demand is examined in the next section.

Table 7-31 Installed Capacity for Each Power Source

	Capacity (GW)	Energy (TWh)	Remarks
Hydro	2.6	8.3	Existing power plants (1.6GW) + Small hydro (1.0GW)
Windpower	2.0	6.7	Installed capacity in 2040 (Scenario C)
Biomass	1.0	6.1	Forest is improved to produce fuel

Remarks: It is assumed that plant factor of biomass is 70%.

(Source: JICA Survey Team)

[32] There is a report that states that 400ha ($4km^2$) is enough for 1MW of power generation in the case of rapidly grown gliricidia sepium.

7.6.3 Study Results

(1) Necessary Capacity of Solar Power and Power Storage Facilities

Necessary installed capacity is examined in January and April, when power demand and supply is very tight. Study results for the maximum demand day in January and April are shown below.

Table 7-32 Study Results for the Maximum Demand Day in January and April

		January		April	
	Capacity (GW)	Energy (GWh)	Plant factor	Energy (GWh)	Plant factor
Demand		133.9		134.1	
Hydro	2.6	23.5	38.4%	21.6	35.3%
Windpower	2.0	10.6	22.0%	3.4	7.0%
Biomass	1.0	22.8	95.0%	22.8	95.0%
Shortage		77.0		86.4	

(Source: JICA Survey Team)

Necessary capacity is examined in the case of supplying the generation shortage via solar power and power storage facilities. Of the shortage amount, 40% is the shortage during the daytime and this can be supplied by solar power, but 60% is supplied from power storage facilities by using storage power. For this reason, it is necessary to supply 1.2 times' the shortage power generation from solar power when storage efficiency in storage facilities is 75%. When it is assumed that the plant factor of solar power is 12.2% in January and 16.0% in April and that the forced outage rate of solar power and storage facilities is 5%, necessary installed capacity of solar power and power storage facilities in January and April is examined as follows.

Table 7-33 Necessary Capacity of Solar Power and Power Storage Facilities

		January	April
Shortage Capacity per day	GWh	77.0	86.4
Plant Factor of Solar		12.2%	16.0%
Necessary Capacity of Solar	GW	33.2	28.4
Necessary Capacity of Power Storage Facilities	GWh	48.6	54.6

(Source: JICA Survey Team)

The shortage amount can be supplied by 33.2GW of solar power and 54.6GWh of power storage facilities in the case of an average sunny day.

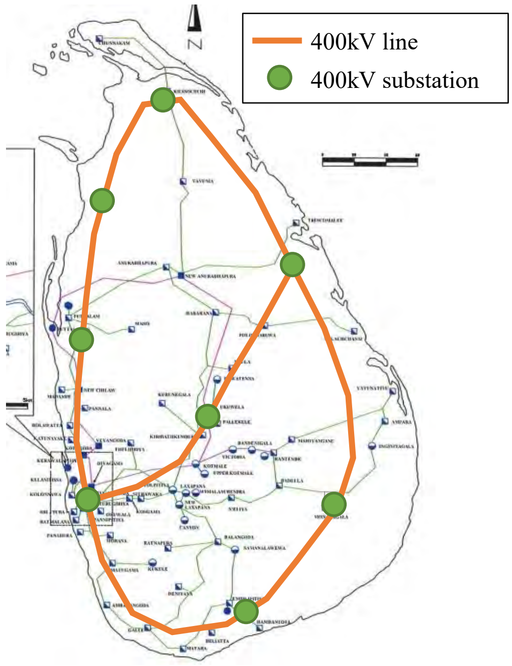
(2) Necessary Capacity of Power Storage Facilities in Consideration of Lack of Sunshine

The case is considered in which a day with approximately 20% of average output continues for five days in a row due to a shortage of sunshine. Under these circumstances, little windpower generation is expected and the shortage amount is the maximum in April. As shown in Table 7-33, the shortage amount in April is 86.4GWh. 25.5GWh is forecasted when solar power generation is 20% of average output and, as a result, the shortage of supply amount per day is 60.9GWh. When such a day continues for 5 days in a row, it is necessary to install 304.4GWh of preliminary power storage facilities. 359.0GWh of power storage facilities is needed when necessary capacity under normal conditions is added.

(3) Necessary Capacity and Cost of Transmission Line Equipment

It is necessary to install 33.2GW of solar power plants for the maximum demand (7.5GW) when a large amount of renewable energy is introduced. A large power flow spreads from solar power in a specific area to other areas nationwide when it is a sunny day in the area. For this reason, it is necessary to improve the 400kV transmission line and inter-regional network.

It is assumed that the 400kV transmission line and substations are improved as shown in Figure 7-47. Transmission line length is approximately 1,500km and the number of substations is 8. Total construction cost is 1,947 million USD, using a transmission cost of 0.87 million USD/km and substation cost of 80.3 million USD/site. Annual expense is 209 million USD/year when the durable years of transmission line and substations is 40 years and the interest rate of return is 10%. Annual expense is 313 million USD/year when it is assumed that the improvement cost for a 220kV or less transmission lines and substations around a 400kV substation is 50% of the above mentioned total construction cost. Impact for expense is calculated based on this expense, and supply cost increases by 0.7 USC/kWh according to additional transmission and substation facilities.



(Source: JICA Survey Team)

Figure 7-47 400kV Transmission Planning

(4) Supply Cost

Supply cost is calculated below. Of energy storage facilities, 5GW (30GWh) is for PSPP and the remaining facilities are batteries with a 1 hour storage capacity.

Table 7-34 Supply Cost

		Capacity (GW)	Annual energy (GWh)	Cost (million USD/year)		
				Fixed cost	Purchase cost	Total
Wind		2.0	6,765		501	501
Biomass		1.0	6,132		865	865
Hydro		1.6	5,340	347		347
Mini-hydro		1.0	3,322		243	243
Solar		33.2	43,467		2,608	2,608
Energy storage	PSPP	5.0		536		536
	Battery-main	24.6		2,024		2,024
	Battery-reserve	304.4		25,078		25,078
Transmission line				313		313
Total			65,026	28,298	4,216	32,514

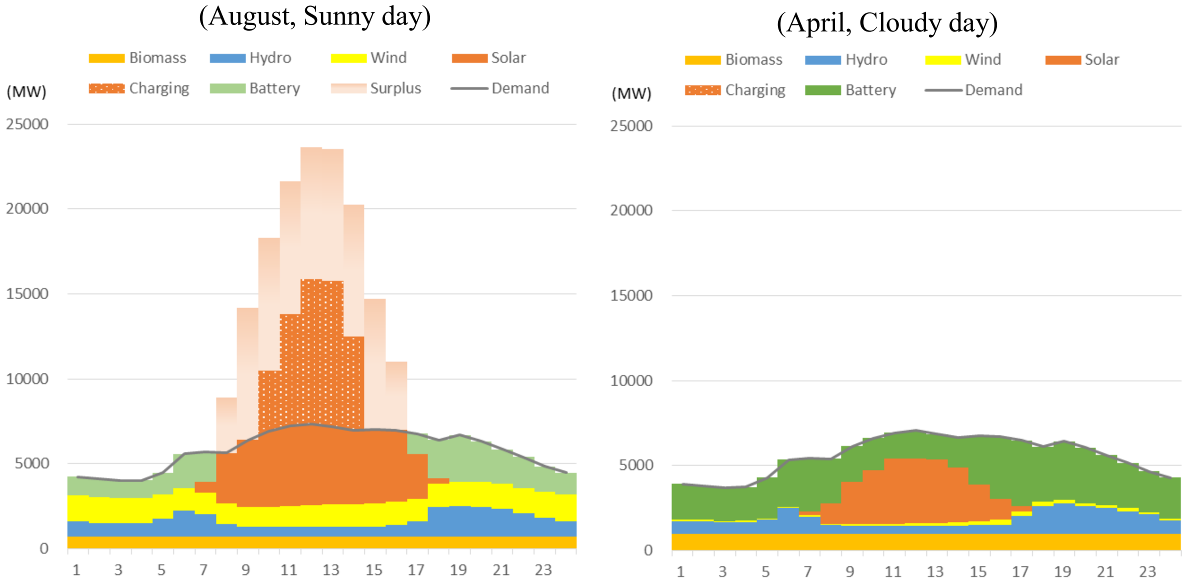
(Source: JICA Survey Team)

Annual power demand is 48.0TWh and supply cost is 67.8 USC/kWh. This value is almost 8 times as large as 8.8 USC/kWh, the supply cost in 2040. The majority of supply cost is preliminary battery cost, which is 52.3 USC/kWh. In other words, when preliminary battery can be replaced with another method, supply cost becomes 15.5 USC/kWh plus substitute cost.

Cost reduction of batteries is expected due to future technological innovations. When the battery cost decreases to half (250 USD/kWh) that used for this calculation, supply cost decreases to 39.5 USC/kWh. However, this lower cost is still 4.5 times as large as supply cost in 2040.

(5) Illustration of Demand and Supply Operation

An illustration of power demand and supply on a sunny day in August, when renewable energy output is large, and on a cloudy day in April, when it is small, is shown below.



(Source: JICA Survey Team)

Figure 7-48 Illustration of Demand and Supply Operation

On a sunny day in August, surplus output occurs during the daytime because windpower generation is large. During the night-time, power is supplied from batteries charged during the daytime. On a cloudy day in April, power is supplied from preliminary batteries because demand cannot be satisfied with renewable energy itself.

(6) Study on Installation Area

(a) Solar

Installation area for solar power is 45MW/km^2 according to the renewable energy master plan. When 33.2GW of solar power is installed, it is necessary to have an area of 738km^2, which is equal to approximately 1% of Sri Lanka.

(b) Batteries

Installation areas for major large batteries installed in Japan are shown below.

Table 7-35 Installation Area for Major Large Batteries

Name	Type	Capacity	Volume	Area	m^2/MWh
Minami-Hayakita	Redox-Flow	15MW	60MWh	5,000m^2	83.3
Minami-Soma	Li-ion	40MW	40MWh	8,500m^2	212.5
Buzen	NAS	50MW	300MWh	14,000m^2	46.7

(Source: JICA Survey Team)

Installation area per MWh is different by battery type. It is assumed that the average installation area for a Li-ion battery is 100m^2/MWh because it is forecasted that batteries will become more compact due to future technological innovations. An area of 35.9km^2 is necessary for installation of 359GWh of batteries.

(7) Necessary Amount for Generating Suppression

It is necessary to suppress power generation because a large amount of surplus power occurs when a lot of power is generated by solar and windpower and all this surplus power cannot be stored in power storage facilities. Generation suppression occurs mainly during the daytime in the Monsoon season from May to September and comes to 30% of total generation of solar and windpower.

(8) Impact of Electric Vehicles

EVs have been introduced in Sri Lanka, and it is thought that their number will increase explosively in the future. It is possible to reduce the necessary capacity of preliminary batteries by using batteries installed in EVs effectively during cloudy or rainy days.

It is possible to secure 250GWh of fully charged batteries when it is assumed that 5 million EVs (one vehicle in five persons) are in use in Sri Lanka and battery capacity per one vehicle becomes 50kWh, which is twice as large as the present capacity. When it is assumed that some EVs are not used on cloudy or rainy days and 30% of all EVs are utilized to supply power to the power system, preliminary battery capacity can be reduced by 75GWh. In consideration of this point, supply cost becomes 54.9 USC/kWh by reducing by 12.9 USC/kWh.

7.6.4 Sensitivity Analysis

As shown in the previous section, supply cost is 67.8 USC/kWh. The factor pushing up the cost is the large amount of batteries introduced for back up during cloudy or rainy days. The possibility of reducing the supply cost is examined.

(1) Additional Introduction of Biomass power

When biomass power capacity increases from 1GW to 2GW, the supply power shortage reduces and development amount of solar and power storage facilities can be decreased. As a result, supply cost becomes 52.4 USC/kWh, and decreases to 31.9 USC/kWh if battery cost halves.

However, it is necessary to secure an area of 5,000km^2 per 1GW for supplying fuel. When biomass power capacity is 2GW, it is necessary to develop a land area that is approximately 15% of the country of Sri Lanka. However, if it is possible to store biomass fuel, 5,000km^2 of land satisfies 2GW of biomass capacity by storing the biomass fuel during the monsoon season, when windpower can supply a lot of power, and by using biomass power plants during the seasons when windpower cannot supply enough power.

In addition, if Sri Lanka imports biomass fuel from neighboring countries, it is expected that this can increase the amount of biomass power without utilizing the country’s land. However, there is a security risk because fuel supply will depend on other countries.

(2) Additional Introduction of Windpower

The necessary amount for solar reduces a little when installed windpower capacity is increased from 2GW to 10GW. Power storage facility development is unchanged, because batteries for back-up should be secured for during cloudy or rainy days in April, when windpower generation is not expected. Under this consideration, supply cost becomes 69.7 USC/kWh, and 41.9 USC/kWh when the battery cost halves. This cost is higher than that in the low case of windpower development. This is why a large amount of power suppression during the monsoon season, from May to September, occurs and this comes to 45% of the total power generation of solar and windpower.

(3) Inter-connected Transmission Line with India

An inter-connected transmission line with India is constructed and depends on power interchange from India as a countermeasure for a shortage of supply power due to lack of sunshine. An inter-connected transmission line with a capacity of 4GW is necessary under the most severe conditions. Annual plant factor is approximately 5% if it is assumed that a supply shortage occurs, on average, for 3 days (72 hours) in one month and the power is purchased from India. It is supposed that the cost for a 1GW inter-connected transmission line with India, including domestic line arrangement around the connection point, is 1,500 million USD. It is thought that Sri Lanka will bear all construction costs, including those in India, because this construction is implemented due to Sri Lanka's needs. Power purchase from India is for a lack of power supply and the cost is assumed to be 15 USC/kWh including transmission loss, because it is necessary to set the purchase cost higher than the market price to receive power preferentially. On the other hand, when surplus power occurs in Sri Lanka, the power is supplied to India within the transmission capacity without suppressing the power in Sri Lanka. In this case, the selling price to India including transmission loss is 3 USC/kWh, as it is necessary to set the cost cheaper than the market price.

Under these conditions, supply cost decreases to 16.6 USC/kWh, and 14.5 USC/kWh if the battery cost halves. However, in this case, supply power to compensate for the lack of supply power during the daytime depends on India. Therefore, outages may continue for a long time if there is insufficient surplus power in India.

(4) Introduction of Nuclear Power

This is no different from the concept of 100% renewable energy, but from the viewpoint of carbon neutral, introduction of Nuclear Power is one of the countermeasures. In LTGEP 2015-2034, construction cost of a 600MW class nuclear power plant is 4,609 USD/kW, fixed costs are 554 USD/kW/year, and variable costs are 4.6 USC/kWh. Supply cost decreases to 37.1 USC/kWh by using the above-mentioned values, and 24.4 USC/kWh when the battery cost halves.

(5) Introduction of Back-up Gas turbines

The introduction of gas turbines (oil fuel) for back-up during shortages of supply power due to lack of sunshine is examined, though 100% renewable energy cannot be implemented with this measure. Under the maximum severe case, it is necessary to secure 4GW of gas turbines for back-up. Annual plant factor is approximately 5% if it is assumed that a supply shortage occurs for an average of 3 days (72 hours) every month and the gas turbines should be operated. It is supposed that the construction cost of a gas turbine is set to 500 USD/kW and fuel cost is 30 USC/kWh.

Under these conditions, supply cost decreases to 17.1 USC/kWh, and 15.0 USC/kWh if the battery cost halves. However, this case is not carbon neutral due to gas turbine operation, and approximately 1,600 kton of CO_2 emissions (0.03kg-CO_2/kWh) occurs every year.

A summary of the sensitivity analysis is shown below.

Table 7-36 Summary of Sensitivity Analysis

		Normal	Battery Half-price	Problems
	Base Case	67.8	39.5	Cost is expensive
(1)	Biomass 2GW	52.4	31.9	15% of country's land is needed for biomass fuel
(2)	Wind 10GW	69.7	41.9	Cost is more expensive than Base Case
(3)	Interconnection with India 4GW	16.6	14.5	Large-scale power outage occurs without surplus power in India
(4)	Nuclear 2GW	37.1	24.4	Carbon neutral is implemented, but 100% renewable energy is not
(5)	Back-up Gas-turbine 4GW	17.1	15.0	100% renewable energy cannot be implemented and a small amount of CO_2 (0.03kg-CO_2/kWh) is emitted

(Source: JICA Survey Team)

7.6.5 Conclusion

Supply cost is 67.8 USC/kWh in the base case, and 39.5 USC/kWh even if battery cost halves. Compared with an 8.8 USC/kWh supply cost in 2040, this cost, 39.5 USC/kWh, is 30.7 USC/kWh more expensive. Compared with development of a mixed plan, it is necessary to bear an additional annual cost of approximately 15,000 million USD in order to implement 100% renewable energy. It would be necessary to raise tariffs sharply to recover the cost and this would lead to a heavy burden on the Sri Lankan people. Considering this, a 100% renewable energy policy should be implemented on the premise of achieving a national consensus.

The main factor in the additional cost is the introduction of a large amount of batteries for back-up during cloudy and rainy days. Considering this, the possibility of reducing the supply cost is examined by the sensitivity analysis. As a result, it is judged that the additional annual cost would be approximately 3,000 million USD if interconnection with India and/or back-up gas turbines is adopted. 95% renewable energy can be implemented, though it is difficult to say that 100% renewable energy can be achieved with either measure. In this way, considering that it will cost a lot of money to achieve the last one mile, it is realistic to select 80-90% power from renewable energy though the target is to implement 100% renewable energy.

7.7 Scenario Consistent with the approved LTGEP 2018-2037

CEB submitted a draft of the Long-Term Power Development Plan (LTGEP 2018-2037) to PUCSL on May 5, 2017. The content of this was planned to be developed by combining coal-fired TPP, LNG-fired TPP and renewable energy in accordance with Scenario C recommended by this MP.

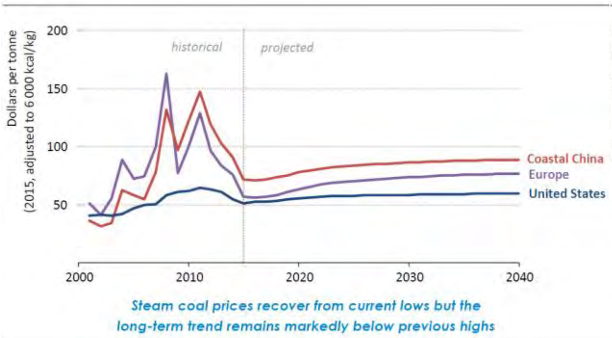
In addition, PUCSL published "Decision on Least Cost Long Term Generation Expansion Plan 2018-2037" on July 20, 2017, and approved 242MW of Major Hydro, 215MW of Mini Hydro, 1389MW of Solar, 1205MW of Wind, 85MW of Biomass, 4800MW of Natural Gas, 330MW of furnace oil-based power and 105MW of Gas Turbine power (not including Coal-fired TPP) to be added to the electricity generation system in a 20 year period. The reason provided by PUCSL is that, recently, fuel prices for coal and LNG have been coming closer to parity, and considering the environmental damage cost, LNG-fired TPP is cheaper than coal-fired TPP, so PUCSL has concluded that it is more economical to develop LNG-fired TPP instead of coal-fired TPP.

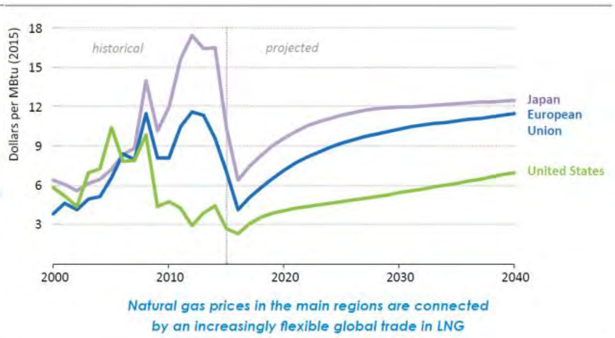
In this MP, taking into consideration the three important planning decision factors - cost, environment and energy security - the JICA Survey Team recommends Scenario C as a balanced plan for these decision factors. However, Scenario B is also examined as a plan that emphasizes the environmental aspect, where coal-fired TPP is not developed at all. It could be assumed that the Government of Sri Lanka placed more emphasis on the environment based on the PUCSL decision. If this is considered government policy then the Scenario B presented in this MP can be considered the base case. However, with regard to this decision by PUCSL, there are issues concerning the following points. It is desirable to create LTGEP 2020-2039, which is the next rolling plan (to be submitted by April 30, 2019), after studying these issues in more detail.

(1) Future Fuel Price Forecasts

Since power generation facilities operate for a long period of more than 20 years, when formulating a long-term power generation plan it is important to accurately ascertain future fuel price forecasts, not only those from recent years. However, it is very difficult to forecast future fuel prices, so it is desirable to obtain long-term forecasts from authoritative organizations such as the IEA and the US EIA (Energy Information Administration), and formulate a plan based on these forecasts.

The JICA Survey Team uses the fuel price forecasts from World Energy Outlook 2016, released by the IEA, in this MP survey. Price predictions for coal and LNG in the New Policies Scenario are shown below.





(Source: World Energy Outlook 2016, IEA)

Figure 7-49 Fuel Price Forecasts in World Energy Outlook 2016

The coal price in 2040 does not fluctuate greatly, being from 1.2 to 1.3 times' the present price, but the LNG price will be about twice the current price in 2040.

(2) Environmental Externality (Damage) Cost

In "Decision on LTGEP 2018 - 2037", PUCSL has requested inclusion of the cost of environmental damage on thermal power generation. Basically, when constructing a thermal power plant, it is requested that the emission of air pollutants should be reduced to a level sufficiently lower than the regulation value by implementing mitigation measures for environmental damage to the extent possible.
In particular, in the development of coal-fired power plants, developers install state-of-the-art de-SOx equipment, de-NOx equipment and dust precipitators as environmental countermeasures, and install high stacks to diffuse discharged matter and reduce the landing concentration. Developers also implement countermeasures to prevent the diffusion of coal dust and ash to the surrounding area by constructing a managed type coal storage and ash dumping station (enclosing it indoors or surrounding it with a fence) in the power station. With such appropriate measures, impact on the surrounding environment by emissions other than CO_2 can be reduced to a level comparable to LNG-fired TPP.

It is necessary to set various conditions in order to calculate the environmental externality (damage) cost, and the calculated cost varies greatly depending on these. Therefore, rather than comparing the negative impacts on the environment and society caused by thermal power generation, such as health damage, by environmental damage costs that are converted into monetary values, it is desirable to carry out a realistic analysis by using the costs of advanced environmental measures taken in developed countries.

As for the ash storage area of the existing Norocholai power plant that is actually creating a negative impact on the environment, measures to prevent scattering, such as installing a fence, must be taken as soon as possible. CEB will take the necessary measures for the problem that is currently occurring and should explain to the stakeholders that it is possible to avoid causing a negative environmental impact and prevent CO_2 emissions by introducing the above-mentioned environmental measures in an appropriate manner, even if coal-fired TPP is used. It is necessary to dispel the negative image of coal-fired TPP and leave room for its consideration as one of the important power sources.

However, with regard to CO_2 emissions, it is difficult to mitigate these at the current technology level, so emissions per kWh from coal-fired TPP are about twice as large as those from LNG-fired TPP. In the actual data from 2015, the CO_2 emissions per kWh are 0.45 kg/kWh on average for all power generation facilities, which is almost the same low level as developed countries. In Scenario C, recommended by this MP, development of not only LNG thermal power but also coal-fired power is carried out, but development of renewable energy is also carried out at the same time, so the CO_2 emissions per kWh in future will be almost the same as the present situation. According to the NDC submitted by the Sri Lankan government in September 2016, the energy sector is planning to reduce greenhouse gases by 20% compared to BAU by 2030, but a reduction in 2030 of about 40% compared to BAU is possible.

(3) Securing Energy Security

CEB proposes a least cost plan as the optimum plan according to the request based on the idea of PUCSL's optimal plan, which is to evaluate all factors by the monetary value and minimize cost. When converting all the factors to monetary values and comparing the candidate plans upon formulating the optimum plan, it is necessary to pay attention to the possibility that there may be no authorized method for conversion, where the unit price to be adopted for conversion can be arbitrarily selected.

However, it is vital to consider energy security risk in formulating a long-term generation expansion plan to achieve a stable power supply. This decision by PUCSL is overly dependent on LNG, where fuel stockpiling is difficult. Even in Japan, stockpiling of LNG is for around 20 days. If the fuel supply from overseas stops for more than 20 days, it will hinder the fuel supply to LNG-fired TPP, which could lead to a shortage of supply capacity. In Sri Lanka especially, there is no way to secure additional supply capacity as there is no interconnection with other countries, so it is necessary to take into consideration the fact that great economic confusion will occur if there is a long-term supply shortage. Energy security is evaluated by the amount of damage in risk events that may have a large impact on the financial and system operations of CEB even though the probability of occurrence is low. In general, it is evaluated by an expected value, which is calculated by multiplying the amount of damage and the probability of occurrence. However, it is extremely difficult to accurately ascertain the probability of occurrence of risk and to explain its validity. Even if the probability of occurrence is extremely low, if the amount of damage at the time of occurrence is enormous, power utility companies will take measures to minimize this amount of damage by bearing some cost. Based on such a viewpoint, it is desirable to secure energy security by diversifying energy sources in order to avoid excessive dependence on one source.

(4) Uncertainty of Renewable Energy

Out of the various types of renewable energy, the generation amount of solar power depends greatly on the weather. If the weather on the day is cloudy or rainy, it will only generate electricity of less than 10% of installed capacity, which means it can hardly be relied upon for supply capacity. In this way, it is very difficult to handle in the software that simulates the power development plan because the amount of solar power generation fluctuates greatly every day and the timing of these output fluctuations is unclear.

Since WASP, currently adopted by CEB, cannot optimize plans that include renewable energy with uncertainties, CEB will introduce OPTGEN and study the optimal plan using this in the future. It is necessary to evaluate the validity of the simulation method by accurately understanding the simulation algorithm used by OPTGEN for unpredictable solar operation.

(5) Supply Reliability Criteria

For the supply reliability criteria, CEB adopts LOLP = 0.5%, which is the lower limit value of the planning code set by PUCSL, but it has been pointed out that using the lower limit may result in over investment. However, considering the current situation of entrusting the development of all thermal power generation facilities to IPPs, due to delays in the procedures for IPP selection, development delays due to IPPs, withdrawal of IPPs, etc., power plants cannot start operation as planned, and there is a risk of power shortages. Therefore, it is necessary to secure some planning margin, and it is considered reasonable to plan with LOLP = 0.5%, the lower limit value of the planning code. This value also needs to be further assessed considering the development of more renewable energy in the future.

(6) Planning for LNG Fuel Supply Facilities and Possibility of Domestic Gas Supply

In the case of constructing many LNG-fired TPP, if all the facilities are constructed around Colombo and the Colombo area is seriously damaged by an earthquake, typhoon or other natural disaster, there is a possibility that a long-term shortage of power will occur. In view of energy security, it is desirable to arrange these TPP in a distributed manner. For this reason, it is necessary to formulate a plan to appropriately arrange fuel supply facilities such as receiving ports, storage tanks, re-gasification facilities and pipelines.

Many reserves of domestic gas have been confirmed, but at present it is assumed that they will be a higher price than LNG, so development of the gas fields is not proceeding. However, if it becomes possible to supply domestic gas, it will then be possible to convert all LNG-fired TPP to domestic gas-fired TPP by laying a pipeline from gas field to power plant. In this situation, all the equipment for fuel supply, except for the pipeline, will be unnecessary. Therefore, in formulating the fuel supply facility plan, it is necessary to thoroughly evaluate the expected supply time for domestic gas and proceed with the formation of less wasteful facilities. Also, when entering into contracts for LNG fuel, it is important to determine the contract years and the contract quantity with the possibility of converting to domestic gas in the future in mind.