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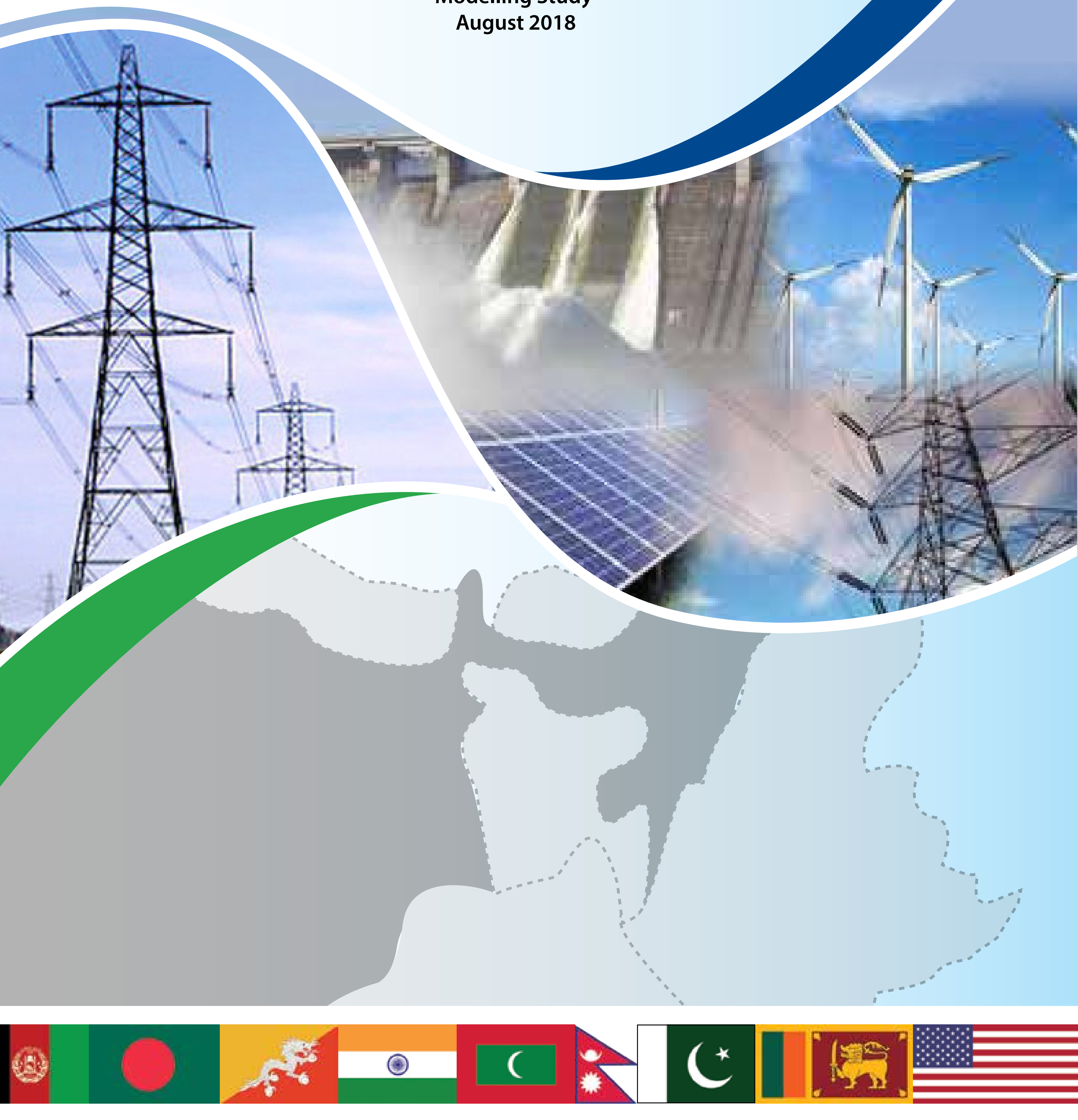
South Asia Regional Initiative for Energy Integration (SARI/EI)

Gains from Multilateral Electricity Trade among BBIN Countries

Modelling Study
August 2018



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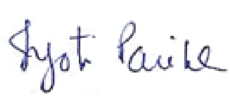
Preface

We are pleased to present the report "Gains from Multilateral Electricity Trade among BBIN Countries", carried out under the South Asia Regional Initiative for Energy Integration (SARI/EI) project supported by USAID. It was felt that long-term modelling in the BBIN (Bangladesh, Bhutan, India and Nepal) region is essential to assess the potential of cross border trade as it has technical and macroeconomic benefits for all the participating countries. Further, long-term projection of gains from multilateral trade helps in building investor confidence and steady planning with progressive streamlined projects among participant countries.

Each country in the BBIN region has its own unique generation and capacity mix. For instance, India and Bangladesh has predominately coal and gas based power capacity mix, respectively, whereas Bhutan and Nepal are having hydro based capacity installation. Moreover, Bhutan and Nepal has a combined hydro potential of more than 73 GW (feasible potential) whereas their combined domestic demand is less than 2 GW. Hence, both the countries have immense potential for development of their domestic hydropower potential for exporting into the BBIN region. Already, bilateral trade between India- Nepal, India-Bhutan and India-Bangladesh is happening but this is more or less negotiated based on government-to-government agreements often at predetermined prices. This needs to progress further based on market principles and countries should come together for enabling more market friendly electricity trade, where the prices follow demand and supply principles.

We had earlier undertaken bilateral trade studies for India-Nepal and India-Bangladesh for which we held many discussions with stakeholders, focussed groups and electricity planners from all the countries. Hence, building on our previous studies we have undertaken the current multilateral study, wherein we integrate the power system model of the bilateral studies. This was a painstaking and novel exercise and it helped us to assess the scope for trade and the resultant gains for countries in the BBIN region. In the multilateral study,the benefits accrue in terms of higher trade volumes, lower installed capacity, reduced CO_2 emissions and lower capital requirements by the power sector in the BBIN region compared to the bilateral study. While the current study gives a long-term trend on an annual basis, simultaneously, we had undertaken another study under USAID that explored day-ahead markets through power exchange in the region. Together, the idea of market friendly multilateral trade model makes a convincing case.

We are grateful to USAID for supporting this path-breaking modelling exercise and extend my gratitude to our colleagues in Bangladesh, Bhutan, India and Nepal. We hope that this study will give a new direction to the South Asia power trade.



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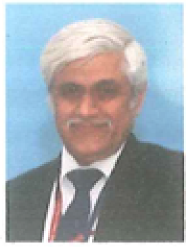
Executive Director
Integrated Research and Action for Development

Pankaj Batra
Chairperson (I/c)

सत्यमेव जयते



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Foreword

Availability of reliable and quality power in South Asia hinders development and economic growth in the region. However, with the common interest of development, nations within the region are working together towards greater energy cooperation. One of such cooperation was the "SAARC Framework Agreement for Energy Cooperation (Electricity)" among the SAARC Member States.

Another such cooperation within the South Asia region is the sub-regional cooperation between Bangladesh, Bhutan, India and Nepal (BBIN) on water resources management, power/hydropower, and on connectivity and transit. Through electricity trade among the BBIN countries, the region looks to harness regional resources such as coal, gas, hydro and solar potential for efficient power generation. Within the BBIN region, India will be a critical partner for electricity trade. Presently, India is having bilateral trade agreements with Bangladesh, Bhutan, Myanmar and Nepal for electricity trade.

IRADe has carried out the study "Gains from Multilateral electricity trade among BBIN countries" that attempts to provide concrete evidence for building consensus to support creation and implementation of multiregional power trade among the BBIN countries. The report is an outcome of consultation held with various stakeholders in all the countries of BBIN region. The study highlights the gains for all partners within the region participating in electricity trade. It captures the importance of trade for enhancing regional power supply balance and utilization of regional hydropower potential. Through regional trade, India gains in terms of lower capacity requirements and supply of peaking power from regional hydro resources. Further, through regional trade India will find bigger market for power export and import. Bhutan and India are already operating in an integrated manner since a long time. Nepal and Bangladesh, which suffer in terms of shortage of power and low per capita consumption, would benefit from higher quantum of power available at a cheaper cost and more reliable supply. Overall, with trade among BBIN region countries, the region gains in terms of higher utilization of regional hydro potential, lower capital investments, reduced CO_2 emissions and efficient utilization of regional assets.

I would like to congratulate IRADe Team for carrying this intensive analytical work applying state-of-the-art modelling tools under SARI/EI/IRADe project. I hope the findings of this report will be actively considered by Energy Utilities/Electricity Regulatory Institutions of BBIN countries for promotion of electricity trade leading to socio-economic benefits.

P. Batra

10 August, 2018

(Pankaj Batra)

FOREWARD

The U.S. Agency for International Development (USAID) has been working for over a decade to enhance regional energy cooperation in South Asia through its South Asia Regional Initiative for Energy (SARI/E) program launched in 2000. The program covers eight countries: Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan, Sri Lanka and the Maldives. The fourth phase of the program, called South Asia Regional Initiative for Energy Integration (SARI/EI), was launched in 2012 to promote regional energy integration by increasing cross-border power trade.

The program aims to create an enabling environment to support establishment of a South Asian electricity market, create consensus on issues related to cross-border power trade and support key decision makers with relevant information and analysis. Towards this, Integrated Research and Action for Development (IRADe), the implementing agency of USAID's SARI/EI program undertook the study "Gains from multilateral electricity trade among BBIN (Bhutan, Bangladesh, India and Nepal) countries." The study quantifies the technological and economic benefits of trade among the BBIN countries. It provides concrete evidence of the potential benefits from regional power trade.

For the study, IRADe used state of the art modeling tool and built on its earlier studies, which were conducted to establish the benefits of bilateral trade between India and Nepal and India and Bangladesh. The integrated study shows that power trade among the BBIN countries is win-win for all countries. While Bangladesh and India will be the importers of power in the region, Bhutan and Nepal will emerge as the big hydropower exporters among the BBIN partners. India's electricity export to Bangladesh increases by 12 percent annually and its imports from Bhutan and Nepal increase by 11 percent and 43 percent respectively from 2015 to 2045. Further, regional power trade will help in reducing the capacity and generation requirements for India and Bangladesh, resulting in lower greenhouse gas (GHG) emissions. Overall, the cumulated capital expenditure of all the three countries (Bangladesh, India and Nepal) together reduces by 17 billion USD because of efficiency gains due to regional integration.

I would like to take this opportunity to acknowledge the excellent work done by IRADe in carrying out such an in-depth analysis. I am confident that the recommendations of this report will be very useful for building trust and creating consensus around power trade in BBIN region.

Thank you

Julia Kennedy
Director (A)
Clean Energy & Environment Office
USAID/India

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We thank members of Nepal Electricity Authority (NEA) for their support in assessing the Nepal power system model (IRADe Nepal Technology model- INTec) results and for validating the model assumptions for appropriately reflecting the features of Nepal's power system in a bilateral India-Nepal study. On the Bangladesh side, we thank members of the Power Cell and Bangladesh Power Development Board (BPDB) for their support in development of the Bangladesh power system model (IRADe Bangladesh Technology model- IBTec).

We also thank Mr Pankaj Batra, chairperson of Central Electricity Authority, India, and its former chairperson, Mr. Ravindra Kumar Verma for their constant support and valuable feedback on the current and previous bilateral studies. We are also thankful to CEA members for their valuable feedback during the development of India power system model (IRADe India Technology- IITec) for the bilateral studies (India- Nepal and India-Bangladesh). We also thank Mr. P.S. Mhaske, Member (Power System) and Mr. S.K. Ray Mohapatra, Chief Engineer (Power System Planning & Project Appraisal) for helping the study team in organising the stakeholder consultations at CEA.

We are grateful to the project team of SARI-EI and the project director Mr. V. K. Kharbanda for their inputs and valuable suggestions. We also thank the IRADe administration for their efforts in organising meetings and workshops related to the project.

Last, but not the least, we sincerely thank the USAID, Ms. Julia Kennedy, Director (Acting), Clean Energy & Environment Office, USAID, Mr. Padu S. Padmanabhan, Strategic Energy, Water & Environment Expert and the programme officer of the SARI/EI project, Ms. Monali Zeya Hazra for supporting this research study.

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Abbreviations

APT	Accelerated Power Trade Scenario
BBIN	Bangladesh-Bhutan-India- Nepal
BPDB	Bangladesh Power Development Board, Bangladesh
CBET	Cross Border Electricity Trade
CEA	Central Electricity Authority, India
CO2	Carbon Dioxide
DCA	Delayed Capacity Addition Scenario
GW	Gigawatt
GWh	Gigawatt Hour
IBINET	IRADe Bangladesh-India-Nepal Electricity Trade
IBTec	IRADe Bangladesh Technology
IITec	IRADe India Technology
INTec	IRADe Nepal Technology
IRADe	Integrated Research and Action for Development
ITS	Integrated Trade Scenario
JICA	Japan International Cooperation Agency
kWh	Kilowatt Hour
MW	Megawatt
NEA	Nepal Electricity Authority, Nepal
PSMP	Power System Master Plan
REF	Reference Scenario
SARI/EI	South Asia Regional Initiative for Energy Integration
SREDA	State Renewable Energy Development Agency, Bangladesh
TIMES	The Integrated MARKAL-EFOM System model
TRADE-30	TRADE-30 scenario
USAID	US Agency for International Development
USD	United States Dollar

Executive Summary

The Bangladesh, Bhutan, India and Nepal (BBIN) region has sufficient energy resources such as coal, hydro and renewables. However, these resources are unevenly distributed within the region. One possibility of utilizing this unevenly distributed energy resources is through cross border electricity trade among the BBIN countries. Within the BBIN region, countries such as Nepal (139 kWh per person[1]) and Bangladesh (310 kWh per person[1]) has very low per capita electricity consumption compared to the world average of (3,128 kWh per person[1]). Due to frequent power outages, many industrial and commercial businesses depend on inefficient and expensive alternatives of generating electricity, such as burning imported diesel or oil in both Bangladesh and Nepal. Already the small quantity of electricity import from India to Bangladesh and Nepal has given some temporary relief to deal with acute power shortages that cause economic losses and difficulties in daily life.

The current study "Gains from Multilateral Electricity Trade among BBIN Countries" is developed from the experience of past studies based on the models developed by IRADe for assessing a) Economic Benefits from Nepal- India Electricity Trade (Released in January 2017) and b) Economic Benefits of Bangladesh- India Electricity Trade (Released in January 2018). These studies are undertaken under the USAID's program South Asia Regional Initiative for Energy Integration (SARI/EI) currently in its fourth phase (2012- 2018) for which IRADe is the implementing partner.

While the earlier studies examined bilateral trade at a time, in the current study we try to see trade in a unified manner and focus on the integration at a regional level of the power sectors of Bangladesh, Bhutan, India and Nepal (BBIN region) together. We assess the potential for electricity trade among the regional partners. However, due to the limitation of time and complexity of the modelling system interaction this study focuses only on the power system and not on the macroeconomic impacts of the power trade as we had done for the bilateral trade studies. Key questions examined in this study are:

- Power supply strategies (capacity, generation, technology, import/export, investment, fuel, power supply cost and so on) in BBIN region with regional power trade among the BBIN partners
- The optimal level of trading agreeable to both buyer and seller
- Change in per capita electricity consumption
- Environmental benefits

Since the interest is primarily in understanding the consequences of regional trade, only one scenario is selected for the study that is the Integrated Trade Scenario (ITS) wherein the four regions Bangladesh-Bhutan-India-Nepal can trade electricity among each other. This trade has to be through India and we assume that India will facilitate this as it has already announced to permit trade between Nepal and Bangladesh. The power system modelling framework for Bangladesh, India and Nepal are taken from IRADe's previous studies. For Bhutan, since many of the needed power sector details were not available, levels of electricity exports for different years are specified using National Electricity Plan of India prepared by Central Electricity Authority, India.

The power system model for each country is modelled as a least-cost, dynamic linear programming model representing the physical aspects and functioning of the energy (power) system with technological details and options. Alternative technologies of power generation include sub-critical coal, super critical coal, nuclear, gas, hydro (three types -reservoir, run of the river and run of the river with pondage) and renewables such as solar and wind with and without storage. The model provides the least-cost solution for meeting the requirement electricity demand for each sub-period of a year, taking into account potential supply options (resource, technology, various costs, etc.) in the country. ***Since, electricity demand varies from hour to hour and month to month and so does electricity availability from hydro, wind and solar plants, sub-periods are taken as hours of an average day for each month to balance supply, demand and trade.*** Answer TIMES is the software used for this study.

[1] For year 2014 from World Bank Indicators.

The Indian and Bangladesh power systems are heavily dependent on fossil fuel based generation such as coal in India and Gas in Bangladesh, whereas the Bhutan and Nepal power system are primarily hydropower based. For assessing the change in the three power systems under the multilateral trade (Integrated Trade Scenario) we compared the Nepal power system results with the bilateral trade scenario (BASE scenario[2] where electricity trade is fixed at current level and APT scenario[3] where trade is unrestricted) of the 'Economic Benefits from Nepal-India Electricity Trade' study. Similarly, for comparing Bangladesh and India power system multilateral trade scenario results, we used the bilateral trade scenario (REF scenario[4] where electricity trade is fixed at current level and TRADE30 Scenario[5] where electricity imports up to 30% of total supply is permitted) of the 'Economic Benefits from Bangladesh-India Electricity Trade' power trade takes place in an accelerated manner.

Results show that the direction of trade for Nepal and Bangladesh remains same in the multilateral trade as was in the bilateral trade. Nepal continues to be a net exporter and Bangladesh continues to be an importer of electricity. Nepal's export to India increases by 12 per cent and 18 per cent by 2030 and 2045, respectively, in the multilateral trade compared to bilateral trade. However, Bangladesh's imports from India remain more or less same in both bilateral and multilateral trade due to 30 per cent trade restriction assumption. It is to be noted that in the India-Bangladesh bilateral study, India was exporting electricity to Bangladesh from its own generation sources increasing output from coal based plants, whereas in multilateral trade, India's exports to Bangladesh are lower than its imports from Bhutan and Nepal together. Therefore, it can be assumed that in the future India can easily export electricity to Bangladesh without increasing its own generation capacity, as sufficient imports are available for its domestic consumption.

Further, the net electricity imports of India (Imports– Exports) increase under multilateral trade (Integrated Trade Scenario) as compared with the bilateral trade models of India- Nepal (APT scenario) and India- Bangladesh (TRADE30 scenario) since the multilateral trade model chooses exports and imports in more optimal way such that the regional resources are used efficiently. The study also captures the impact of multilateral trade at hourly level.

The higher electricity exports by Nepal and higher imports by India in the multilateral trade will have impact on their installed capacity. Hence, Nepal installed capacity increases from 34 GW to 37 GW by 2045 under the multilateral trade compared to bilateral trade. In addition to this, the multilateral trade supports higher installation of pondage run of river based hydropower capacity, which has more flexible generation than run of river plants. For India, the installed capacity reduces by 5 per cent and 4 per cent by 2030 and 2045, respectively, in the multilateral trade compared to bilateral trade. This reduction in installed capacity reduces CO_2 emission as well as capital requirements for the Indian power sector. However, for Nepal increase in installed capacity in the multilateral trade increases its capital requirements by USD 5 billion at 2011-12 price level (increase by 7 per cent) for cumulated period 2012 to 2045 compared to bilateral trade. Nevertheless, on the regional level, due to multilateral trade the capital requirements for power sector reduce by USD 77 billion at 2011-12 price level (decrease by 4 per cent).

To summarize multilateral electricity trade over bilateral trade increases level of trade, reduces generation capacity in India and Bangladesh, reduces use of fossil fuel and hence CO_2 emissions. It also reduced capital requirement for investment in power sector.

[2] The BASE scenario is taken from 'Economic Benefits from Nepal-India Electricity Trade' study. The BASE scenario assumes no increased interconnections across India and Nepal beyond what are currently in place (CBET as in 2011–12) or are already committed to be built. In this scenario, each country independently makes its own capacity investments to satisfy its projected demand profile.

[3] The APT scenario is taken from 'Economic Benefits from Nepal-India Electricity Trade' study. The Accelerated Power Trade (APT) scenario allows the model to utilize full potential of electricity trade between India and Nepal.

[4] The REF scenario is taken from 'Economic Benefits of Bangladesh-India Electricity Trade' study. The REF scenario assumes no increased interconnections between India and Bangladesh beyond what are currently in place in year 2015 (600 MW) and are under construction (500 MW). In this scenario, each country independently makes its own capacity investments to satisfy its projected demand profile.

[5] The TRADE-30 scenario is taken from 'Economic Benefits of Bangladesh-India Electricity Trade' study. The TRADE-30 scenario allows electricity import up to 30 percent of the total electricity supply by 2040. While the supply of electricity from coal in this scenario is capped, other sources are free so that the import option will substitute the sources for power generation on least-cost basis.

1 Background

As power sector becomes more and more capital intensive and complex, many regions of the world are taking power pooling initiatives to create efficient regional power grids to boost the reliability of supply, lower infrastructure investment and supply costs. Examples of regional power pools include Southern Africa Power Pool, West African Power Pool, Greater Mekong Sub-Region Power Trade Organization, Central American Electrical Interconnection System, and so on.

Countries in the South Asian region are some of the poorest ones. Availability of reliable and adequate electricity is a major challenge that hampers economic development of the region. Though the region has significant energy resources like coal, hydro and renewables, this potential is unevenly distributed. A combined hydro potential of 350 GW in the region offers a huge scope for tapping the clean energy and addressing the chronic problems of electricity supply shortage. Electricity trade could exploit the resources, and provide electricity at lower costs to all. The additional export revenue will further the economic growth and development, improve energy security and promote environment-friendly socio-economic development by sharing energy resources, energy infrastructure and capacity reserves. Current electricity trade in the region is limited to about 2300 MW, whereas the total installed capacity at the end of 2017 was around 342 GW.

The South Asia Regional Initiative for Energy Integration (SARI/EI) phase IV, launched in 2012, is the USAID (US Agency for International Development) programme. The programme started in the year 2000 and has since created an enabling environment in the region through building capacity, raising awareness, undertaking focused studies and providing technical assistance. SARI/EI aims to further the regional energy integration through Cross Border Electricity Trade (CBET).

Integrated Research and Action for Development (IRADe) is the implementing partner of the fourth phase of the programme through a cooperative agreement with the USAID. It adopts a bottom-up approach by working through the three inter-governmental task forces with representatives nominated by the government of each participating country to promote cross-border electricity trade. Under this programme, IRADe has also undertaken analytical studies focusing on macro-economic benefits from electricity trade in South Asian countries. Studies on Nepal-India and Bangladesh- India electricity trade have been completed. The focus of this report is on Bhutan-Bangladesh-India-Nepal (BBIN) electricity trade.

The per capita electricity consumption in Nepal (139 kWh per person [6]) and Bangladesh (310 kWh per person[7]) is the lowest among the BBIN countries compared to world average (3,128 kWh per person[8]). Only Bhutan (2,799 kWh per person[9]) had somewhat higher consumption. Socio-economic development of both Bangladesh and Nepal is constrained by energy supply. Due to frequent power outages, many industrial and commercial businesses depend on inefficient and expensive alternatives of generating electricity, such as burning imported diesel or oil in both Bangladesh and Nepal. A small quantity of electricity import by Bangladesh and Nepal from India has given these countries some temporary relief in acute power shortage that causes economic losses and difficulties in daily life.

6 For year 2014 from World Bank Indicators.

7 For year 2014 from World Bank Indicators.

8 For year 2014 from World Bank Indicators.

9 Bhutan Statistical Year Book 2015

2 IRADe's Previous Studies on Cross Border Electricity Trade

2.1 Study on Economic Benefits from Nepal- India Electricity Trade (Released in January 2017)

Through Nepal-India electricity trade, Nepal can gain by developing its hydropower potential, its major electricity resource, for which India will provide a ready market. The export earnings from electricity trade with India will boost Nepal's economy and human development. India, on the other hand, can promote renewable energy sources like solar and wind power whose intermittency can be balanced by hydropower import from Nepal. The study assessed the time-dependent power trade potential for the period 2012–2045, balancing supply and demand on an hourly basis, consistent and sustainable with the country's macroeconomic framework. It also quantifies and analyses the socioeconomic benefits of CBET (arising from investment, export revenue, reduced electricity price) for India and Nepal taking into account its macroeconomic response.

The study developed a modelling system, which deploys two types of models with a 30-year perspective: power system models that balance demand and supply on an hourly basis and a macroeconomic model that factor in the impact on various sectors of the economy and its development. The iterative linkage between these models produces consistent solutions with the availability of resources for investment and the changing structure of the production economy. This modelling system was used to analyse three scenarios. The BASE scenario assumed no increased interconnections across countries beyond what was currently in place in 2011–12, and each country independently makes its own capacity investments to satisfy its projected demand profile. The *Accelerated Power Trade (APT) scenario* allowed the full potential of electricity trade. Another scenario, *Delayed Capacity Addition (DCA),* was also included for Nepal. It captured the impact of delay in hydropower project implementation by five years in Nepal as the delay may not only postpone the earning from exports but may even increase the imports until the projects are implemented. The study highlighted multiple benefits for both Nepal and India. The study focussed on electricity trade between the two countries only and didn't account for the impact of trade among all the BBIN (Bangladesh, Bhutan, India and Nepal) countries.

2.2 Study on Economic Benefits of Bangladesh- India Electricity Trade (Released in January 2018)

The Bangladesh-India study follows a strategy very similar to the Nepal-India study. In this study, too, a modelling system comprising of two technology models and two macroeconomic models was developed to assess the time-dependent power trade potential for the period 2012–2045. The modelling system was used to analyse three scenarios. The Reference (REF) scenario assumes interconnections across countries to stay at the level of 2018 (1100 MW) and each country independently makes its own capacity investments to satisfy its projected demand profile. The PSMP scenario based on Bangladesh's Power Sector Master Plan (PSMP) 2016, prepared by JICA and the Bangladesh Government, recommended the Bangladesh Power Development Board (BPDB), under the guidance of Ministry of Energy, to adopt an energy security framework for the expansion of the power sector based on diversification of sources of power supply. Accordingly, shares of supply based on coal, natural gas, nuclear, electricity imports, hydro and renewables are fixed respectively at 35%, 35%, 12%, 16%, and 1% of total electricity supply in the country by 2041. To accommodate the 2015-2021 renewables target of the State Renewable Energy Development Agency (SREDA), the share of liquid fuel was reduced to less than one per cent. The TRADE-30 scenario is based on electricity import of up to 30 per cent of the total electricity supply by 2040. While the import of electricity in this scenario is capped, sources of domestic generation are free so that import option will substitute the sources for power generation on least cost basis. The study provides evidence-based technical and macroeconomic benefits both for Bangladesh and India to undertake electricity trade. However, it did not include the possibilities of BBIN regional trade, which could further increase the trade volumes and benefits for all countries.

2.3 Current Study

While the earlier studies examined the bilateral electricity trade potential and mutual benefits to the respective countries, in the current study we try to see them in a unified manner and focus on power sector integration at Bangladesh-Bhutan-India-Nepal (BBIN region) regional level. In this context, the present study attempts to assess the potential for electricity trade among the regional partners. However, due to the limitation of time and complexity of the modelling system interaction, this study focuses only on the power system and not on the macroeconomic impacts of the power trade. The positive impact of cross border trade on the economy was already established in the past studies undertaken by IRADe.

At the regional level, Bhutan and Nepal have high export potential, whereas Bangladesh and India have import requirements. However, as observed in our previous study, "Economic Benefits from Nepal-India Electricity Trade," Nepal will continue to import electricity from India in the early years and from 2025 onwards, it will start exporting electricity to India. This regional electricity trade among the four countries will impact their installed capacity, generation, fuel mix, emissions, and investments, etc.

2.3.1 Objectives

The primary objective of this study is to improve energy cooperation among the BBIN countries by strengthening their policy and decision-making with necessary information on the scope and benefits of CBET for the region. The study attempts to produce evidence for the policy and decision makers to build consensus among countries and within countries through informed dialogues and negotiations to support the creation and implementation of the CBET.

2.3.2 Key questions to be answered

The study informs policy makers/planners of the BBIN region on power supply strategies, the role of electricity import and its implications for the power sector. Key questions examined in this study are:

- Power supply strategies (capacity, generation, technology, import/export, investment, fuel, power supply cost and so on) in BBIN region with regional power trade among the BBIN partners
- The optimal level of trading agreeable to both buyer and seller
- Change in per capita electricity consumption
- Environmental benefits

2.3.3 Scope

To our knowledge, this is the first study that attempts to assess the impact of electricity trade on Bangladesh, India and Nepal through a detailed power system technology model. The period of the analysis is 2012–2045. The scope of the study is as follows:

- Analytical work to assess
  - Electricity supply scenario with electricity trade as option
  - Impact of CBET on BIN countries with focus on their power system development

2.4 The Report Structure

The report is structured as follows:

- Chapter 3 –the approach and methodology
- Chapter 4 –the results and analysis
- Chapter 5 – key messages and way forward

[5] http://www.moen.gov.np/pdf_files/SAARC-Framework-Agreement.pdf

[6] http://www.irade.org/IRADe-SARI-EI-Regional%20Regulatory-Guidelines%20(July%202015)-.pdf

[7] http://www.irade.org/IRADe-SARI-EI-Regional%20Regulatory-Guidelines%20(July%202015)-.pdf

[8] World Bank-South Asia Economic Focus Spring 2015

3 Approach and Methodology

3.1 Approach

IRADe developed the modelling framework for analysing the trade potential between Bangladesh, Bhutan, India and Nepal. Since the primary interest of the study was to analyse the consequences of the regional trade, the Integrated Trade Scenario (ITS) wherein all four countries in the region Bangladesh-Bhutan-India-Nepal could trade electricity among each other was picked for the study analysis. This trade has to be through India and we assume that India will facilitate this. The power system technology modelling framework for Bangladesh, India and Nepal was taken from the previous studies conducted by IRADe as explained in Chapter 1. Since many of the needed power sector details for Bhutan were not available, its electricity exports for different years were specified using the National Electricity Plan of India prepared by Central Electricity Authority, India.

3.2 Model

The physical power systems of each of the three countries are modelled separately using energy system modelling software TIMES . TIMES is a technology-rich, least-cost, dynamic linear programming model representing the physical aspects and functioning of the energy (power) system. It quantifies new investment needs in generation and grid, including interconnection, cost of generating electricity to meet the requirement for each time-period and sub-periods. The demand is specified for each hour assuming that for a given month hourly demand remains the same. Thus 24 hours for 12 months give us 288 sub-periods of each year over the period 2012–2045. This captures the variation in demand and supply across the hours of the day and across the months of the year. The model provides the least-cost solution for meeting the requirement for each sub-period taking into account potential supply options (resource, technology, various costs, etc.) in the country. These three models are named as IBTec (IRADe Bangladesh Technology) model for Bangladesh, IITec (IRADe India Technology) model for India and INTec (IRADe Nepal Technology) model for Nepal.

Since, electricity demand varies from hour to hour and month to month and so does electricity availability from hydro, wind and solar plants, sub-periods are taken as hours of an average day for each month to balance supply, demand and trade.

Although the power system of each country is modelled separately in the TIMES model generator, the ANSWER -TIMES software allows integration of three national power system models into one. The integrated model gives the quantity of electricity trade for each sub-period and price along with investment on new capacity in each system in each period, which minimises the net present value of the total power system costs taking all the three countries together. This integrated model is named as integrated IBBINET (IRADe Bangladesh-Bhutan-India-Nepal Electricity Trade) model depicted in Figure 3.1.

These models are based on a number of assumptions on domestic energy resource availability, fuel imports, scheduled construction of power projects, available technology options and their respective technical and economic performances, fuel prices, cost of capital (discount rate), energy and environment policies, macroeconomic policies, development in productivity and savings rate over a period of 40 years. Experts in the respective countries were consulted for these assumptions, which were listed in our previous report series.

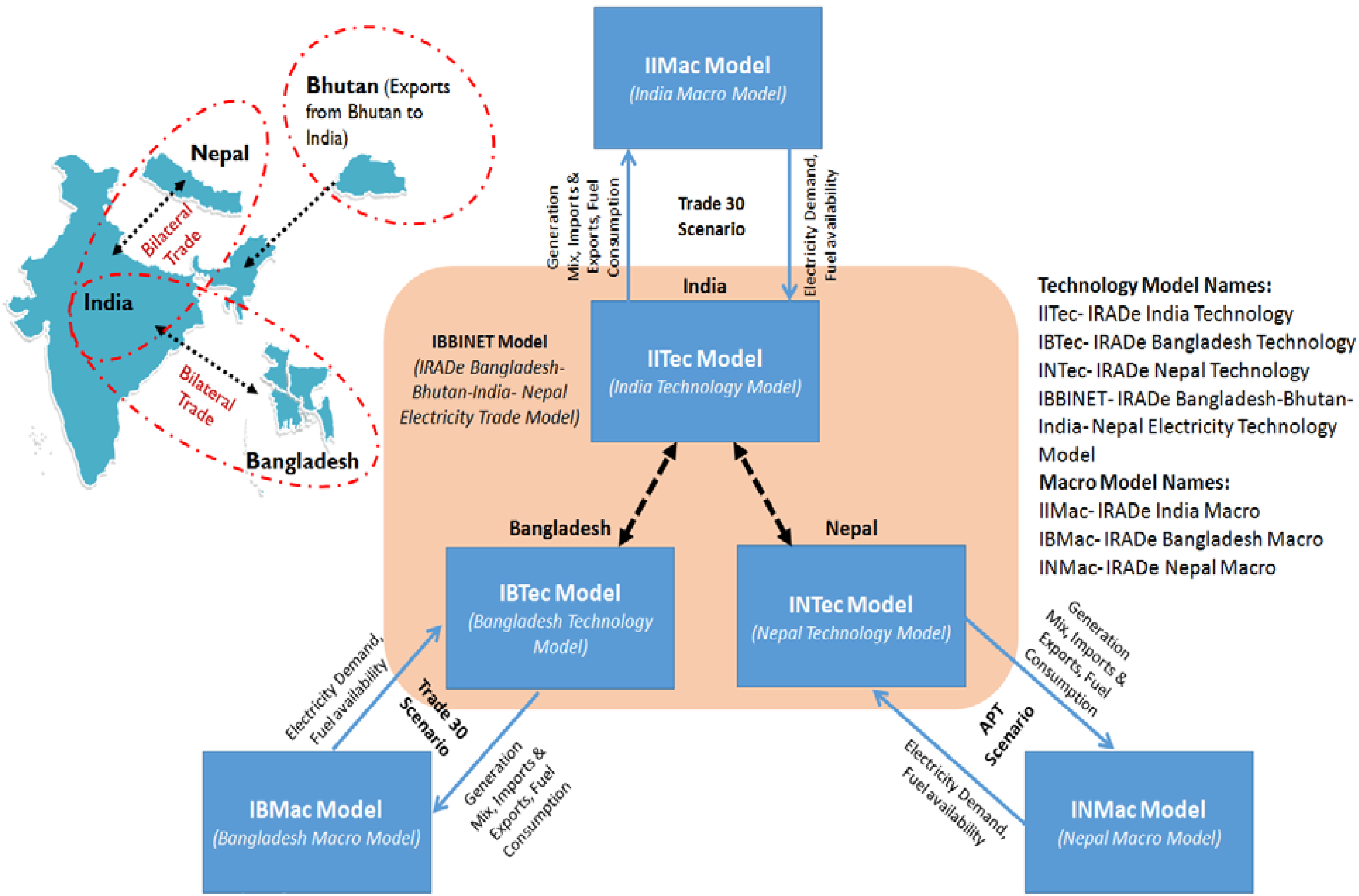


Figure 3.1 Integrated IBBINET (IRADe Bangladesh-Bhutan-India-Nepal Electricity Trade) modelling system

3.3 Scenario

To assess the power trade among Bangladesh, Bhutan, India and Nepal (BBIN region), we developed a scenario called **Integrated Trade Scenario (ITS).** This scenario integrates power system models of Bangladesh and Nepal with India's power system model in TIMES through bilateral trade links. India's imports from Bhutan were specified as mentioned earlier. All the system parameters for the three power system models (for system model assumptions refer Annexure A,B,C & D) such as electricity demand, fuel availability, generation potentials, capacity expansion plans, trade constraints, among others were taken from the trade scenario of our previous studies. Hence, for India and Bangladesh power systems, the parameters were taken from **TRADE-30**[12] of the 'Economic Benefits of Bangladesh-India Electricity Trade' study and for Nepal power system, the power system parameters were taken from the **APT scenario**[13] of the 'Economic Benefits from Nepal-India Electricity Trade' study.

Further, to account for India's hydroelectricity import from Bhutan, we have assumed the import capacity and capacity factor as per the Draft National Electricity Plan (Vol-II) Transmission, published in December 2016 by CEA, India. The plan provides for 4336 MW and 26336 MW of import capacity in 2022 and 2036, respectively, as shown in Table 3.1. In addition to this, the plan also assumed the capacity factor for this import capacity to be 50%, 65%, 50% and 40% for Q1, Q2, Q3 and Q4, respectively, for a year as shown in Figure 3.2. For modelling India's hourly import pattern from Bhutan for these capacities, we assumed that these capacities will be run-of- river type hydropower plants and will be having a flat generation varying over the quarter of a year. The average price of India's electricity import from Bhutan is INR 2.07 per kWh based on the price for FY 2014-15 at constant price, as no information is available for the future price of electricity imports.

Table 3.1 India's Expected Hydroelectricity Import Capacity from Bhutan (in MW)

Period	2021-22	2026-27	2031-32	2035-36
Import Capacity	4336	14336	26336	26336

Source: Draft National Electricity Plan (Vol-II) Transmission, CEA, India

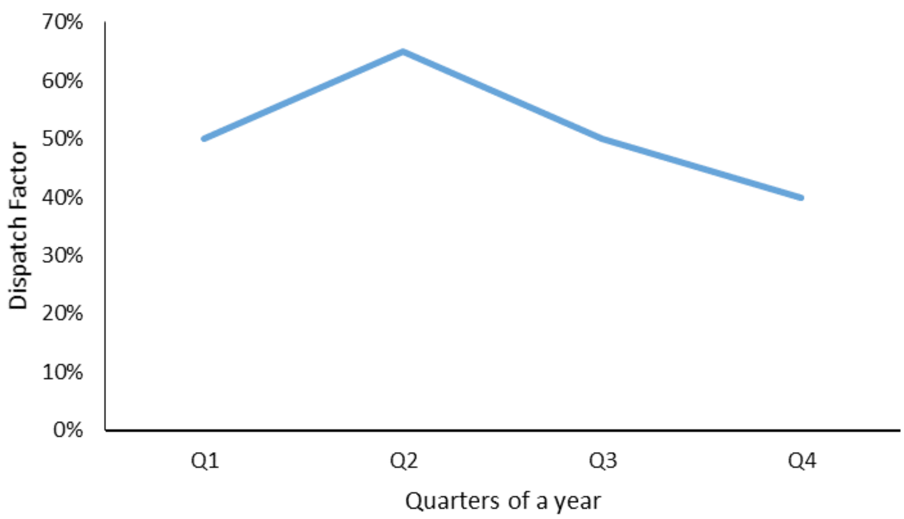


Figure 3.2 Bhutan's Hydroelectricity Import Capacity Dispatch Factor

Source: Draft National Electricity Plan (Vol-II) Transmission, CEA, India

[12] The TRADE-30 scenario is taken from 'Economic Benefits of Bangladesh-India Electricity Trade' study. The TRADE-30 scenario allows electricity import up to 30 percent of the total electricity supply by 2040. While the supply of electricity from coal in this scenario is capped, other sources are free so that the import option will substitute the sources for power generation on least-cost basis.

[13] The APT scenario is taken from 'Economic Benefits from Nepal-India Electricity Trade' study. The Accelerated Power Trade (APT) scenario allows the model to utilize full potential of electricity trade between India and Nepal.

4 Result and Analysis

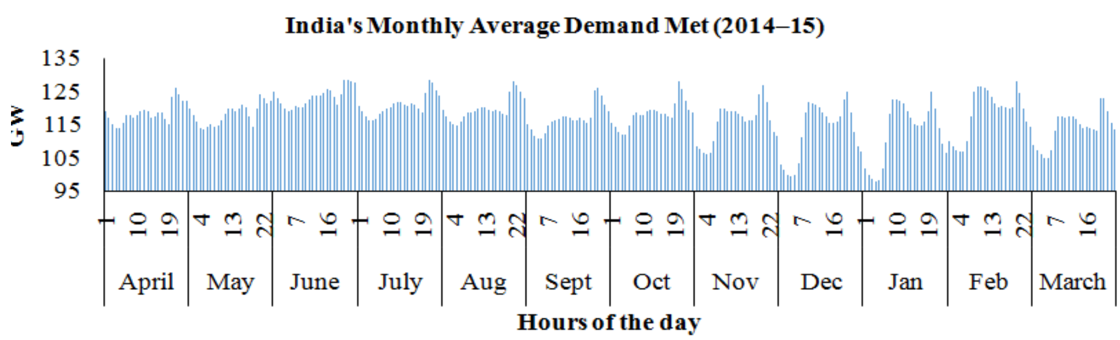
Electricity demand in India is the highest among the three countries Bangladesh, India and Nepal. For India, the peak demand in FY 2016-17 was 1,59,542 MW[14] (demand met was 1,56,934 MW) whereas the peak demand for Bangladesh and Nepal was 12,644 MW and 1,444 MW, respectively (as shown in Table 4.1). Although all the three countries face power shortages, power shortages in Nepal are the most severe followed by Bangladesh. Both Bangladesh and Nepal import power from India, which provides some relief and this scale of import is expected to increase in future (for limited time in case of Nepal). In the future, both Bhutan and Nepal will become net exporters of hydropower as they possess huge untapped hydro potential. The governments of both the countries are working to tap this potential.

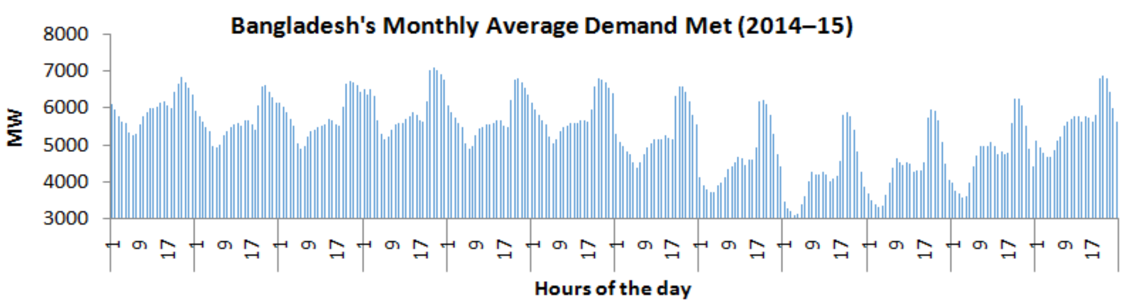
Table 4.1 Peak Demand and Met Demand for FY 2016-17 (in MW)

Country	Peak Demand (MW)	Peak Demand Met (MW)
India	159,542	156,934
Bangladesh	12,644	9,479
Nepal	1,444	950

Source: CEA Executive Summary, BPDB Annual Report and NEA Annual Report

Electricity consumption is variable over season and time of day. Figure 4.1 provides the hourly demand variation during different months of a year for Bangladesh, India and Nepal. It is noted that the low demand months for both Bangladesh and India are typically winter months of November, December and January. The variation in monthly demand for India remains within the range of 15 to 20 per cent of the peak demand, however, for Bangladesh it ranges from 15 to 50 per cent of the peak demand. Demand for Nepal is estimated based on the past data, which was verified through stakeholder consultations with Nepal Electricity Authority (NEA), Nepal. Further, it was observed that hourly demand pattern for Nepal is more or less same in all the months as Nepal faces significant power shortages and seasonal variation is reflected in varying shortage (in some seasons shortages were as high as 14 hours a day in the year 2011-12).





[14] CEA Monthly Executive Summary, March 2017

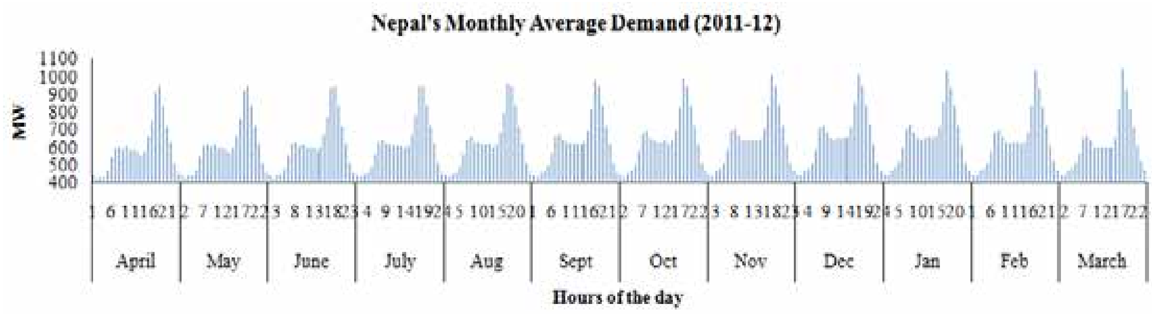


Figure 4.1 Hourly demand variation among different months of a year for Bangladesh, India and Nepal

India has the largest installed capacity followed by Bangladesh and Nepal among the three countries as shown in Table 4.2. Further, the three countries have a variety of fuel in their capacity mix; for instance, the Indian power system is predominantly coal-based whereas Bangladesh uses gas as a major fuel for electricity generation. Nepal, a Himalayan country, majorly has hydro-based installed capacity. Hydroelectricity accounts 94 per cent of its total capacity mix. Similarly, Bhutan has 1614 MW installed hydropower capacity and about 24 GW of hydropower potential. Considering the low level of domestic demand in both Bhutan and Nepal in comparison to their hydro-potential, they have the potential to be key hydropower exporter in the SAARC region.

Table 4.2 Installed Capacity & Generation Mix for FY 2016-17 for Bangladesh, India and Nepal

FY 2016-17	India				Bangladesh				Nepal			
Technology	Installed Capacity (GW)		Generation (BU)		Installed Capacity (GW)		Generation (BU)		Installed Capacity (GW)		Generation (BU)	
Coal	192	(59%)	945	(76%)	0.25	(2%)	1	(2%)	0	(0%)	0	(0%)
Gas	25	(8%)	49	(4%)	9	(68%)	38	(72%)	0	(0%)	0	(0%)
Diesel	1	(0.3%)	0.3	(0.02%)	4	(28%)	13	(24%)	0.05	(6%)	0.0004	(0%)
Nuclear	7	(2%)	38	(3%)	0	(0%)	0	(0%)	0	(0%)	0	(0%)
Hydro	44	(14%)	122	(10%)	0.23	(2%)	1	(2%)	0.91	(94%)	4.1	(100%)
Renewable	57	(18%)	86	(7%)	0	(0%)	0	(0%)	0	(0%)	0	(0%)
Total	327		1240		13		53		0.97		4	
Electricity Import	-		6		-		5		-		2	
Electricity Export	-		7		-		0		-		0.003	

Source: CEA Executive Summary, BPDB Annual Report and NEA Annual Report

For assessing the change in the three power systems under the Integrated Trade Scenario we compared the Nepal power system results with the **BASE case**[15] of the 'Economic Benefits from Nepal-India Electricity Trade' study. Similarly, for comparing Bangladesh and India power system ITS scenario results, we used the **REF scenario**[16] of the 'Economic Benefits from Bangladesh-India Electricity Trade' study.

[15] The BASE scenario is taken from 'Economic Benefits from Nepal-India Electricity Trade' study. The BASE scenario assumes no increased interconnections across India and Nepal beyond what are currently in place (CBET as in 2011–12) or are already committed to be built. In this scenario, each country independently makes its own capacity investments to satisfy its projected demand profile.

[16] The REF scenario is taken from 'Economic Benefits of Bangladesh-India Electricity Trade' study. The REF scenario assumes no increased interconnections between India and Bangladesh beyond what are currently in place in year 2015 (600 MW) and are under construction (500 MW). In this scenario, each country independently makes its own capacity investments to satisfy its projected demand profile.

4.1 Trade Potential and Hourly Trade

The integrated IBBINET (IRADe Bangladesh-Bhutan-India-Nepal Electricity Trade) modelling system was run with ITS to assess the impact of trade on Bangladesh, India and Nepal power systems. The long-term trade potential among the four countries is provided in Table 4.3 and Table 4.4. It is evident from the trade results that Bangladesh continues to import electricity from India, whereas, Bhutan and Nepal export power to India. India's exports to Bangladesh are expected to increase by 12 per cent from 2015 to 2045 considering the Bangladesh import restriction of 30 per cent under TRADE30 scenario. Bhutan and Nepal electricity exports to India will increase by 11 per cent and 43 per cent, respectively, from 2015 to 2045 as both the countries plan to add significant hydro capacities in the coming decades. Bhutan is already a power surplus country (except for dry season) and Nepal is expected to be power surplus by 2025 and thereafter will be exporting significant volumes of electricity to India.

Table 4.3 India's Trade Potential with Bangladesh, Bhutan and Nepal (in GWh)

Year	India's Exports to (in GWh)			India's Imports from (in GWh)		
	Bangladesh	**Bhutan**	**Nepal**	**Bangladesh**	**Bhutan**	**Nepal**
2015	3380	158	1370	0	4998	3
2020	9619	0	828	0	15392	1890
2025	24841	0	1453	0	46459	40371
2030	27896	0	0	345	96807	72478
2035	50710	0	75	0	118383	99043
2040	72801	0	224	0	118383	126050
2045	103870	0	564	0	118383	135680
CAGR 2015-45	12%	-	-3%	-	11%	43%

Table 4.4 India's Maximum Hourly Electricity Trade Potential with Bangladesh, Bhutan and Nepal (in GW)

	2020	2025	2030	2035	2040	2045
India's Export to (in GW)						
Bangladesh	1.1	6	7	12	17	25
Nepal	1.4	1.9	0.0	2.4	4	8
India's Import from (in GW)						
Bhutan	2.4	7	14	17	17	17
Bangladesh	0	0	1.4	0	0	0
Nepal	1.2	11	16	20	28	34

India's hourly trade with Bangladesh, Bhutan and Nepal for year 2030 and 2040 is provided in the Figure 4.2. During the winter months of November, December, January and February electricity demand in India is lower as compared to the rest of the year. On the generation side, November to March is a typical dry season for hydropower plants in both Bhutan and Nepal due to reduced water flow in rivers resulting in reduced plant output with monthly plant load factor in the range of 40 to 50 per cent. This results in the reduction of export volumes to India from both Bhutan and Nepal. Figure 4.3 and Figure 4.4 show electricity import and export of Bangladesh and Nepal respectively. Further, it is noted that in the India-Bangladesh bilateral study, India was exporting electricity to Bangladesh from its own generation sources, whereas in ITS India's exports to Bangladesh are lower than its imports from Bhutan and Nepal together. Therefore, it can be assumed that in the future India can easily export electricity to Bangladesh without increasing its own generation capacity, as sufficient imports are available for its domestic consumption.

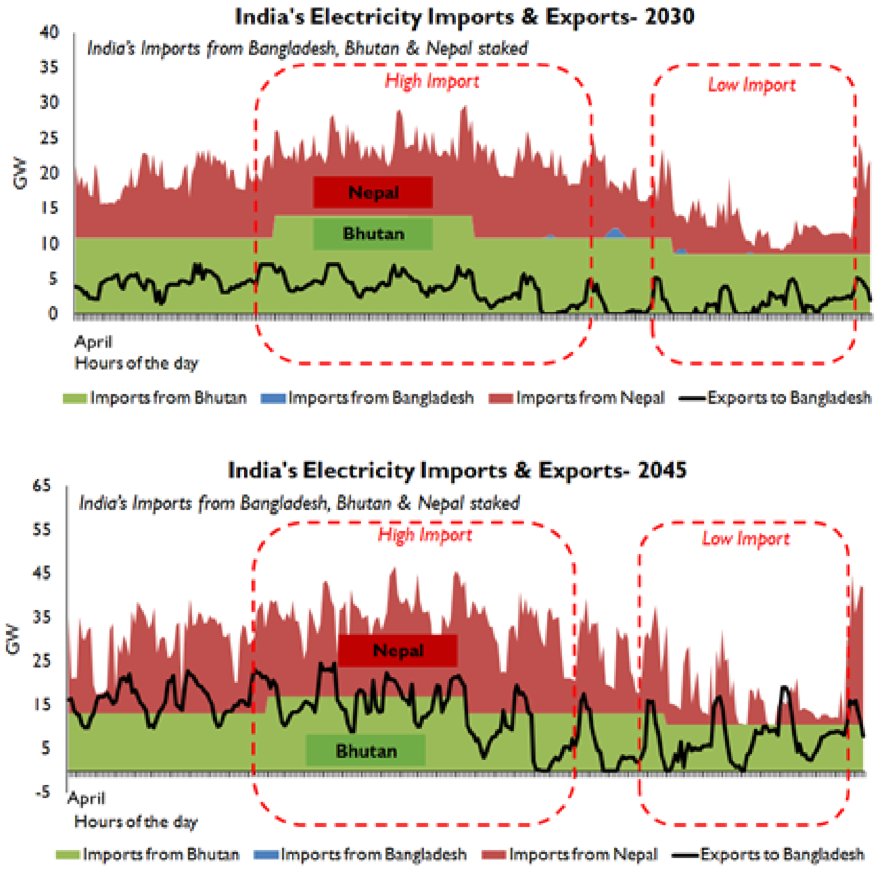


Figure 4.2 India's Hourly Trade with Bangladesh, Nepal and Bhutan for Selected Year 2030 and 2045

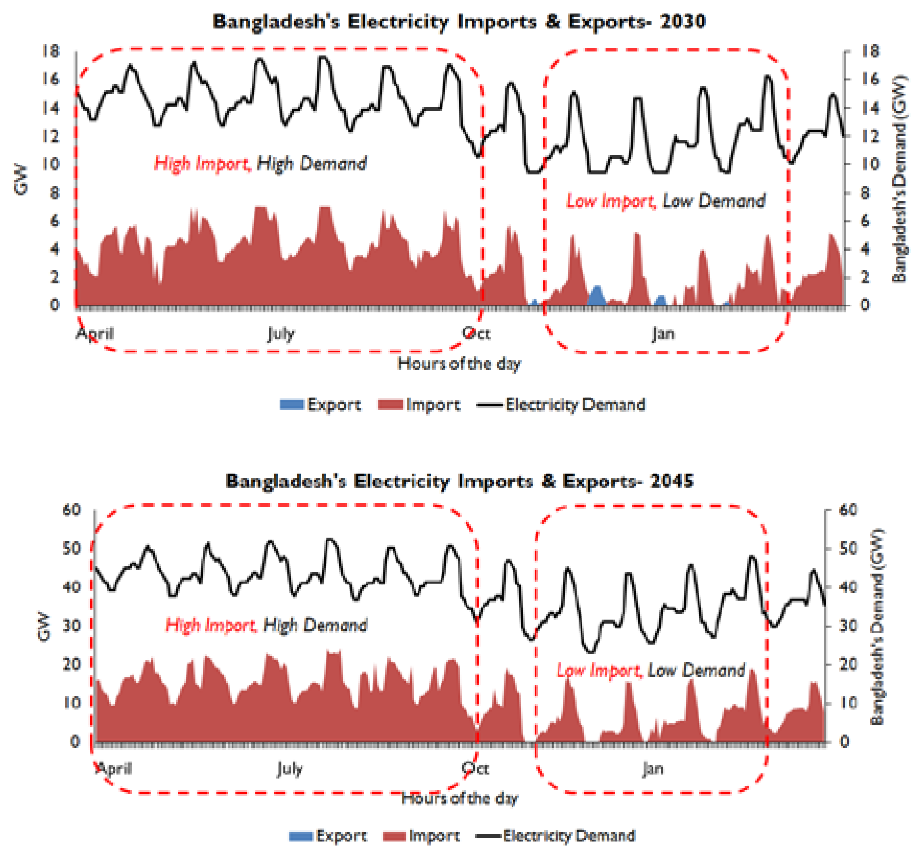


Figure 4.3 Bangladesh's Hourly Trade with India for Selected Year 2030 and 2045

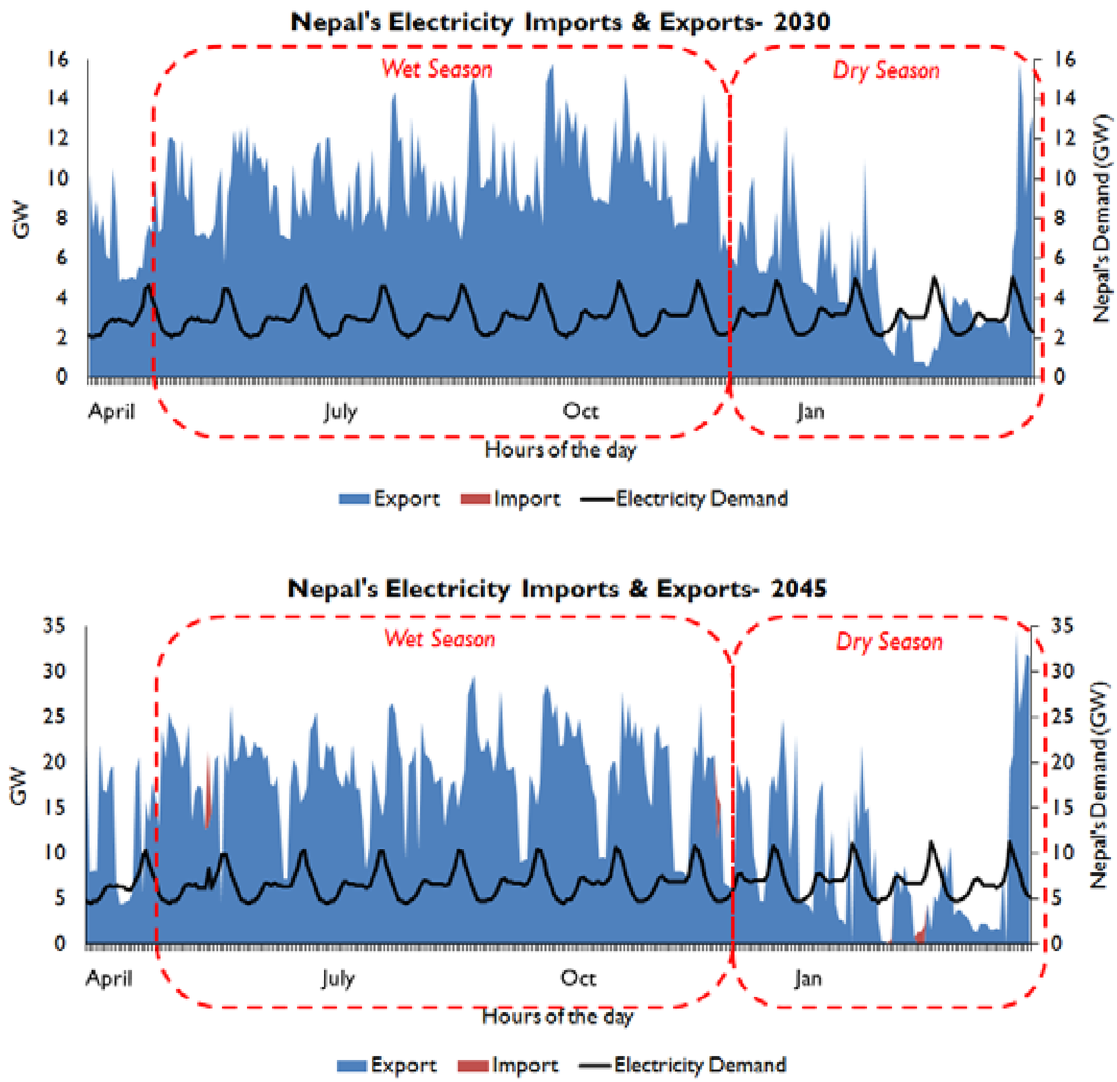
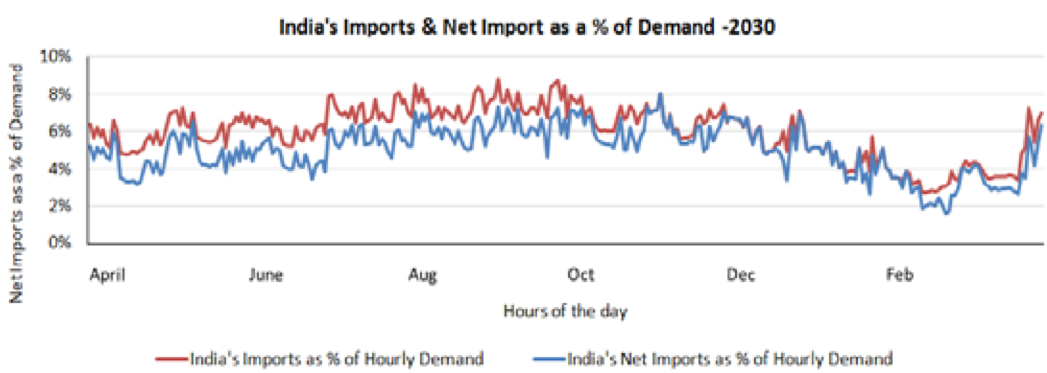


Figure 4.4 Nepal's Hourly Trade with India for Selected Year 2030 and 2045

The electricity import-export volumes might seem to be large for 2030 and 2045. However, the net imports of India in comparison to its total demand are observed to be within the range of two to eight per cent in year 2030 and has a highest share of 5 per cent in year 2040 as shown in Figure 4.5.



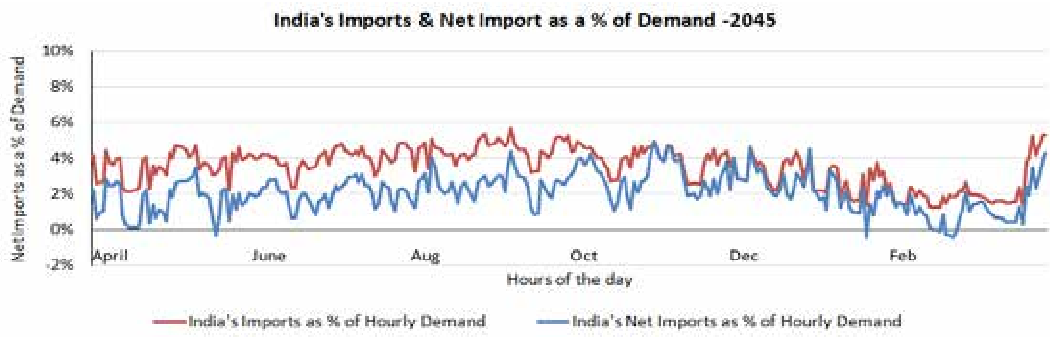


Figure 4.5 India's Imports and Net Imports as a Percentage of Hourly Demand for Year 2030 and 2045

**Net Imports= All Imports – All Exports*

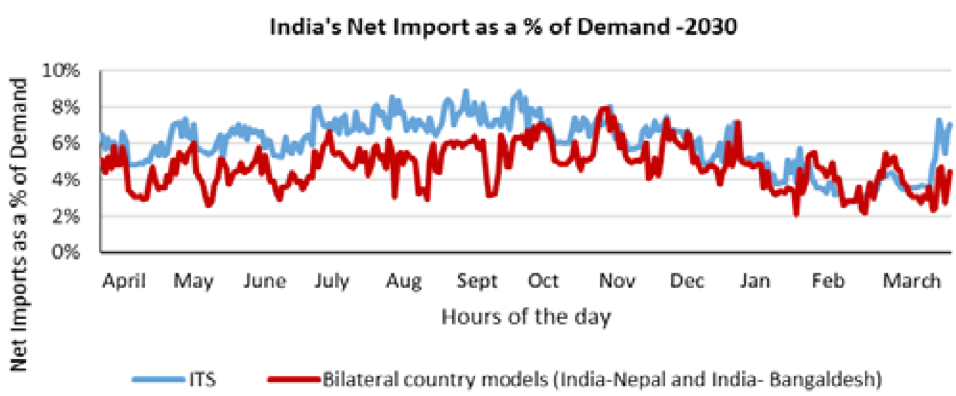
Section Highlights:

- At present, both Bangladesh and Nepal face power shortages and they both import electricity from India
- India's exports to Bangladesh are set to increase by 12 per cent annually from 2015 to 2045 (with Bangladesh import restriction of 30% under the TRADE30 scenario)
- Annual electricity exports from Bhutan and Nepal to India will increase by 11 per cent and 43 per cent, respectively, from 2015 to 2045 as both the countries plan to add significant hydro capacities in the coming decades
- November to March is a typically dry season for hydropower generation. The winter period also has lower demand for electricity in India and Bangladesh. This results in reduced exports- imports during this time as compared to the rest of the months in a year.
- At present, Indian power system with an installed capacity of 316 GW is much larger compared with that of Bangladesh (< 11 GW), Bhutan (<2 GW) and Nepal (< 1 GW). In future also, the Indian power system will be the largest in the BBIN region. Its import volume will be in the range of five to eight per cent of India's electricity demand.

4.2 Trade Comparison: Multilateral versus Bilateral Trade Models

4.2.1 India's Net Imports: Multilateral (ITS) versus Bilateral Trade Models

The net electricity imports of India (Imports– Exports) increase under ITS (Integrated Trade Scenario) as compared with the bilateral trade models of India- Nepal and India- Bangladesh. In ITS, the power systems of Nepal and Bangladesh are connected with India through bilateral trade links, and imports from Bhutan to India is modelled exogenously. Hence, in ITS the regional model chooses the exports and imports in a more optimal way such that the regional resources are used efficiently. Therefore, India's net electricity import as a percentage of demand increases in the ITS scenario compared to bilateral trade model as is shown in Figure 4.6 below.



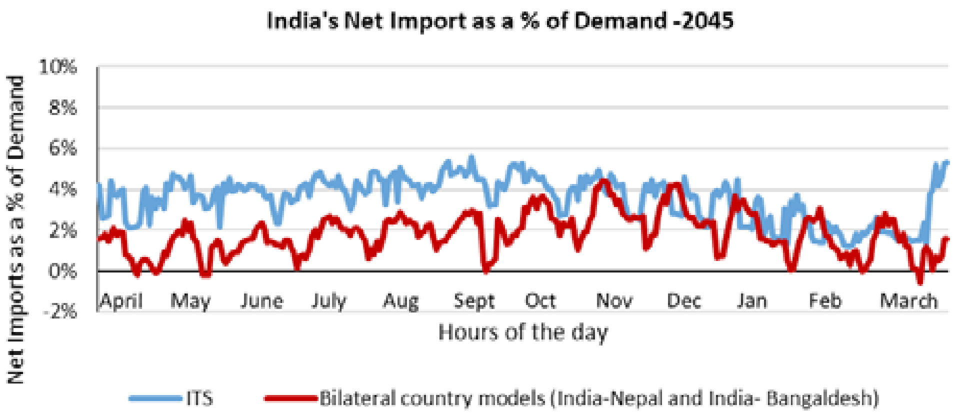


Figure 4.6 Comparison of India's Net Import between ITS and Bilateral Country Models for 2030 and 2045

4.2.2 Impact on Hourly Exports: Multilateral (ITS) versus Bilateral Country Models (such as India- Nepal and India- Bangladesh Bilateral Trade)

Integrated Trade Scenario will have more impact on electricity exports from Nepal to India compared to bilateral trade model (India- Nepal). As shown in Figure 4.7, for August 2030 and 2045, electricity exports from Nepal to India are higher in the ITS scenario compared to India-Nepal bilateral trade model. Similarly, in the month of December 2030 and 2045 electricity exports from Nepal to India are higher for ITS in comparison to bilateral trade model. Overall, Nepal's electricity export to India increase under ITS compared to the APT scenario of bilateral India-Nepal model as shown in Figure 4.8. Nepal exports under ITS scenario are around 15 per cent higher than the APT scenario.

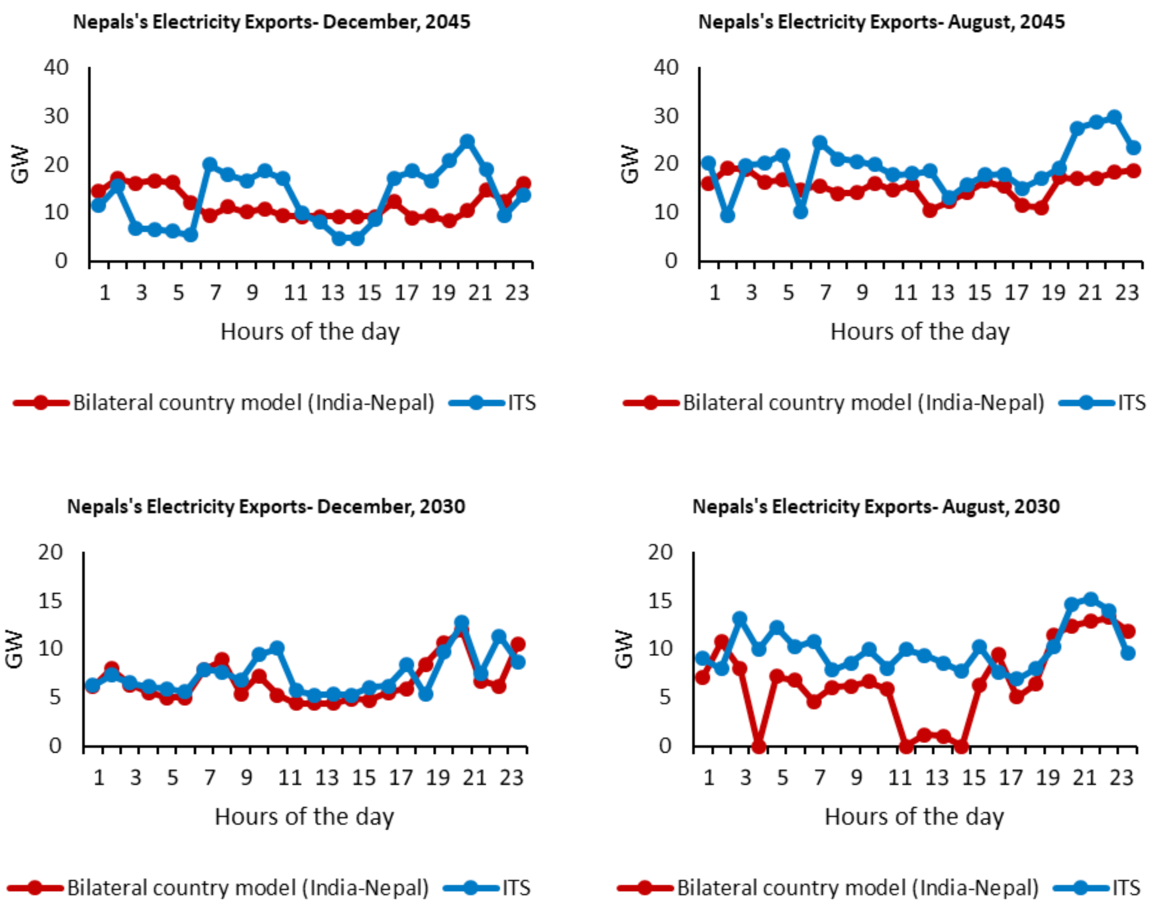


Figure 4.7 Typical Hourly Electricity Export in Selected Month from Nepal to India for 2030 and 2045

**Considering Nepal's Export from the APT scenario of Bilateral India-Nepal Model.*

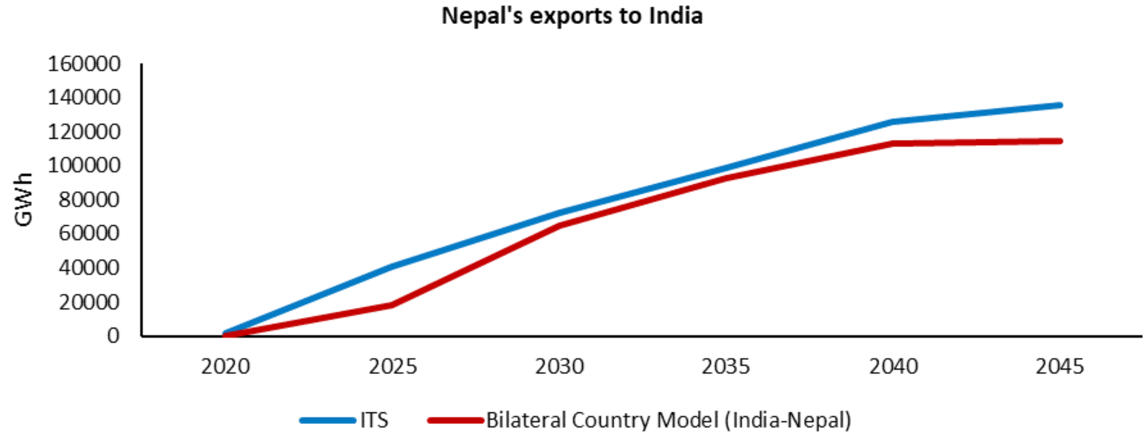


Figure 4.8 Nepal's Exports to India: ITS versus Bilateral Trade Models (India-Nepal)

**Considering Nepal's Exports from the APT scenario of Bilateral India-Nepal Model*

The impact of ITS on Bangladesh's imports from India was not as significant as it was in the case of Nepal given the 30 per cent import cap for Bangladesh power system under TRADE30 scenario of bilateral India-Bangladesh study. Figure 4.9 shows the impact of ITS on Bangladesh's electricity import from India.

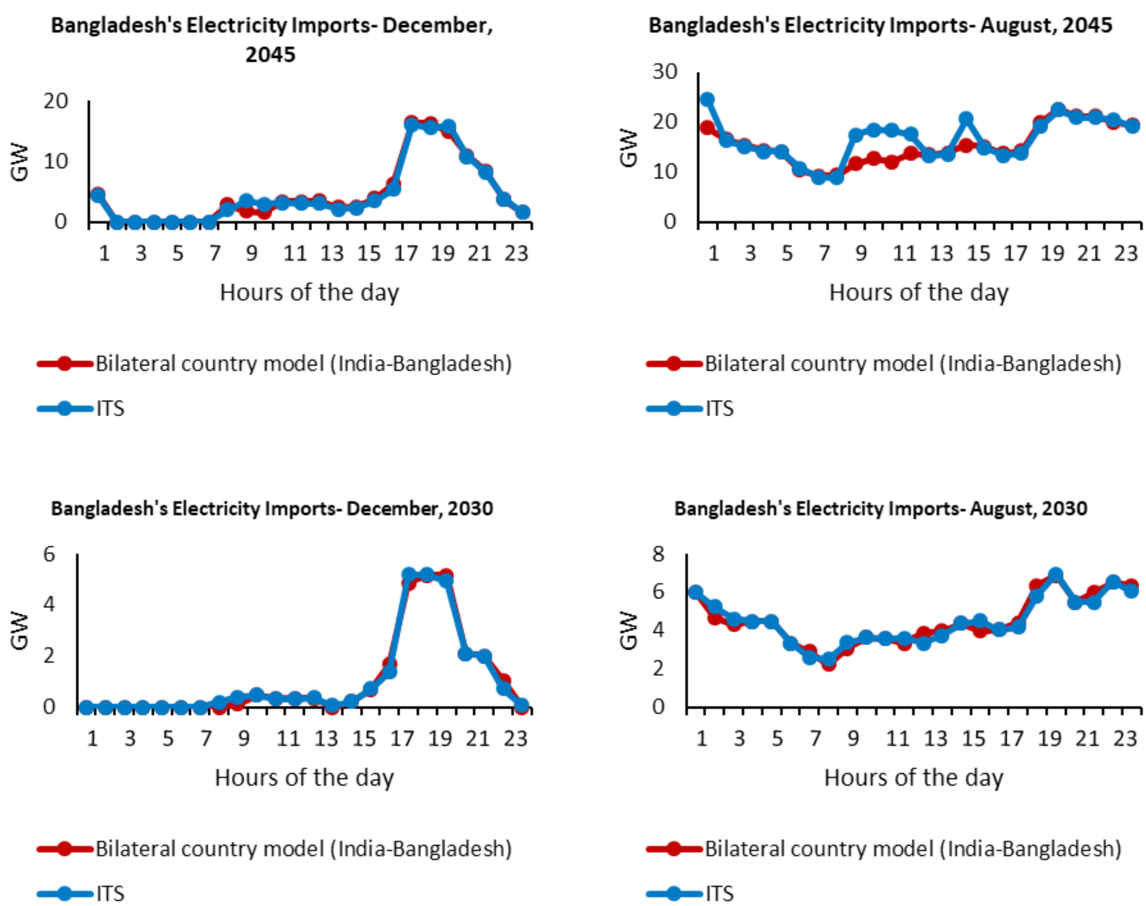


Figure 4.9 Typical Hourly Electricity Import in Selected Month by Bangladesh from India for 2030 and 2045

**Considering Bangladesh's Import under TRADE30 scenario of Bilateral India-Bangladesh Model.*

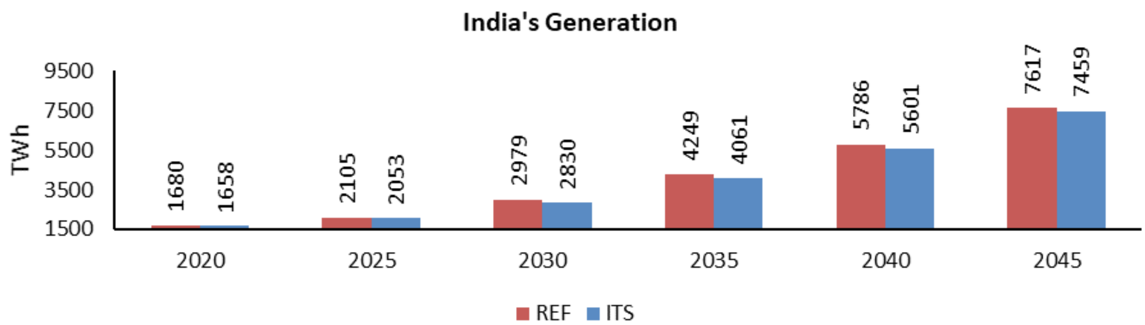
Section Highlights:

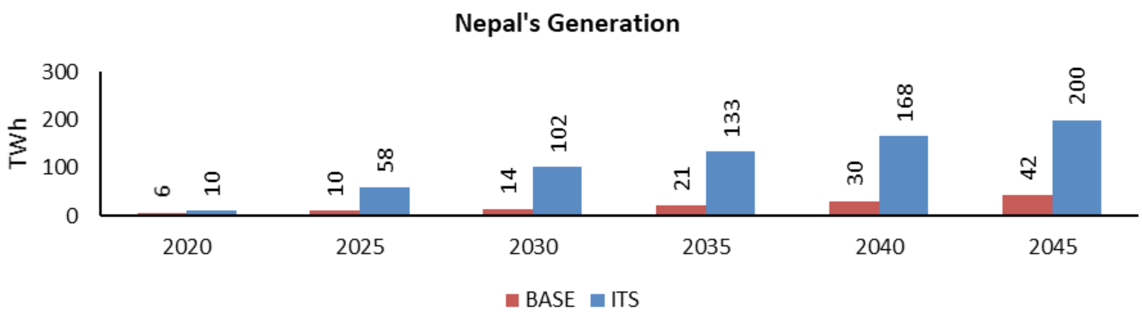
- India's net electricity import as a percentage of demand is higher in the integrated ITS scenario compared to bilateral trade models. This happens on account of more efficient use of regional resources
- Under ITS, Nepal electricity exports to India increases by around 15 per cent as compared to the optimal trade under bilateral India-Nepal model
- For Bangladesh, the integrated trade scenario does not have any impact as Bangladesh imports are capped at 30 per cent of the electricity availability as per TRADE30 scenario assumption

4.3 Impact on Generation

Integrated Trade Scenario will have a greater impact on electricity generation compared to the REF[17] (trade-restricted scenario under bilateral India-Bangladesh study) or BASE[18] (trade-restricted scenario under bilateral India-Nepal study) case for both Bangladesh and Nepal. Since India will be a net importer of electricity, its generation requirement will reduce under ITS scenario by five per cent and two per cent in 2030 and 2045, respectively, compared to the REF case. Due to relatively much larger electricity demand of India in comparison of its imports from Bhutan and Nepal, the net reduction in generation requirement from trade appears low. Figure 4.10 shows the impact of ITS scenario on generation for Bangladesh, India and Nepal compared to BASE/REF scenario. Further, India also exports electricity to Bangladesh while importing from Bhutan and Nepal.

Electricity exports to India will have a significant impact on Nepal's economy as its electricity generation is expected to increase by 624 per cent and 372 per cent by 2030 and 2045, respectively, compared to the BASE case. On the other hand, electricity imports by Bangladesh from India helps Bangladesh in reducing its generation requirements by 22 per cent and 31 per cent by 2030 and 2045, respectively, compared to the REF scenario.





[17] The REF scenario is taken from 'Economic Benefits of Bangladesh-India Electricity Trade' study. The REF scenario assumes no increased interconnections between India and Bangladesh beyond what are currently in place in year 2015 (600 MW) and are under construction (500 MW). In this scenario, each country independently makes its own capacity investments to satisfy its projected demand profile.

[18] The BASE scenario is taken from 'Economic Benefits from Nepal-India Electricity Trade' study. The BASE scenario assumes no increased interconnections across India and Nepal beyond what are currently in place (CBET as in 2011–12) or are already committed to be built. In this scenario, each country independently makes its own capacity investments to satisfy its projected demand profile.

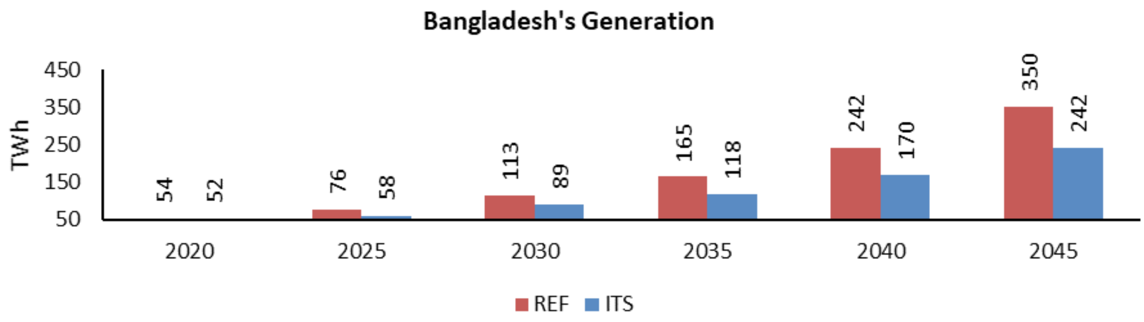


Figure 4.10 Impact of ITS scenario on Generation

The power generation reduction in India will impact its consumption of fuel-mix. The reduced demand for power generation under ITS in comparison to REF is provided in Table 4.5. By 2030 and 2045, India's power generation from coal will see the maximum reduction. On Bangladesh side, the total generation reduction in ITS scenario will be 24 TWh and 108 TWh compared to REF scenario by 2030 and 2045, respectively. Wherein, by 2030, gas-based electricity generation will reduce by 17 TWh followed by nuclear (reduction of 7 TWh) and diesel (reduction of 1 TWh) in ITS compared to REF scenario. By 2045, the highest reduction of 62 TWh will be in coal generation followed by gas (30 reduction of TWh), nuclear (reduction of 13 TWh) and diesel (reduction of 3 TWh) in integrated ITS compared to REF scenario.

Table 4.5 Change in India's Generation Mix in ITS over REF

Fuel Type	2030		2045	
	REF (TWh)	% Reduction in ITS over REF (TWh)	REF (TWh)	% Reduction in ITS over REF (TWh)
Coal	2054	-4% (-90)	5495	-2% (-105)
Gas	200	-16% (-31)	102	-27% (-27)
Diesel	0	0% (0)	0	0% (0)
Hydro	192	-10% (-18)	373	+1% (+3)
Nuclear	129	0% (0)	296	0% (0)
Biomass	79	-2% (-2)	79	0% (0)
SHP	25	-29% (-7)	73	0% (0)
Solar	158	0% (0)	415	-7% (-29)
Wind	141	0% (0)	784	0% (0)
Total	2979	-5% (-149)	7617	-2% (-158)

Section Highlights:

- For India, ITS will lead to two to five per cent reduction in power generation requirement compared to the REF scenario as the volume of import from Bhutan and Nepal are comparatively smaller than the total demand of India
- In India, the highest reduction in generation by volume will be observed for coal-based generation in 2030 and 2045
- For Bangladesh, imports from India will help it to reduce its own generation by 22 to 31 per cent (considering the 30 per cent import restriction) compared to REF scenario
- On the Nepal side, the integrated ITS scenario will help Nepal to export more electricity resulting in increase in its own generation from hydropower resources
- Reduced generation will have impact on installed capacity requirements

4.4 Impact on Capacity

Electricity trade will influence the generation requirements of the participating countries, which will further influence the installed capacity requirements for each country. With imports of electricity from both Bhutan and Nepal, India's capacity requirement will reduce by 4.3 per cent and 2.4 per cent by 2030 and 2045, respectively, compared to the REF scenario (trade-restricted scenario from bilateral India-Bangladesh study). It is noted that although India simultaneously exports electricity to Bangladesh, it is a net importer of electricity; trade reduces its installed capacity requirement. On the other hand, trade will increase Nepal's installed capacity by 586 per cent and 315 per cent by 2030 and 2045 compared to the BASE (trade-restricted scenario from bilateral India-Nepal study) case with increase in electricity exports to India.

Further, electricity imports by Bangladesh from India will help Bangladesh in reducing its capacity requirements by 12 per cent and 42 per cent by 2030 and 2045, respectively, compared to the REF scenario. Figure 4.11 shows the impact of Integrated Trade Scenario (ITS) on generation for Bangladesh, India and Nepal compared to BASE/REF scenario.

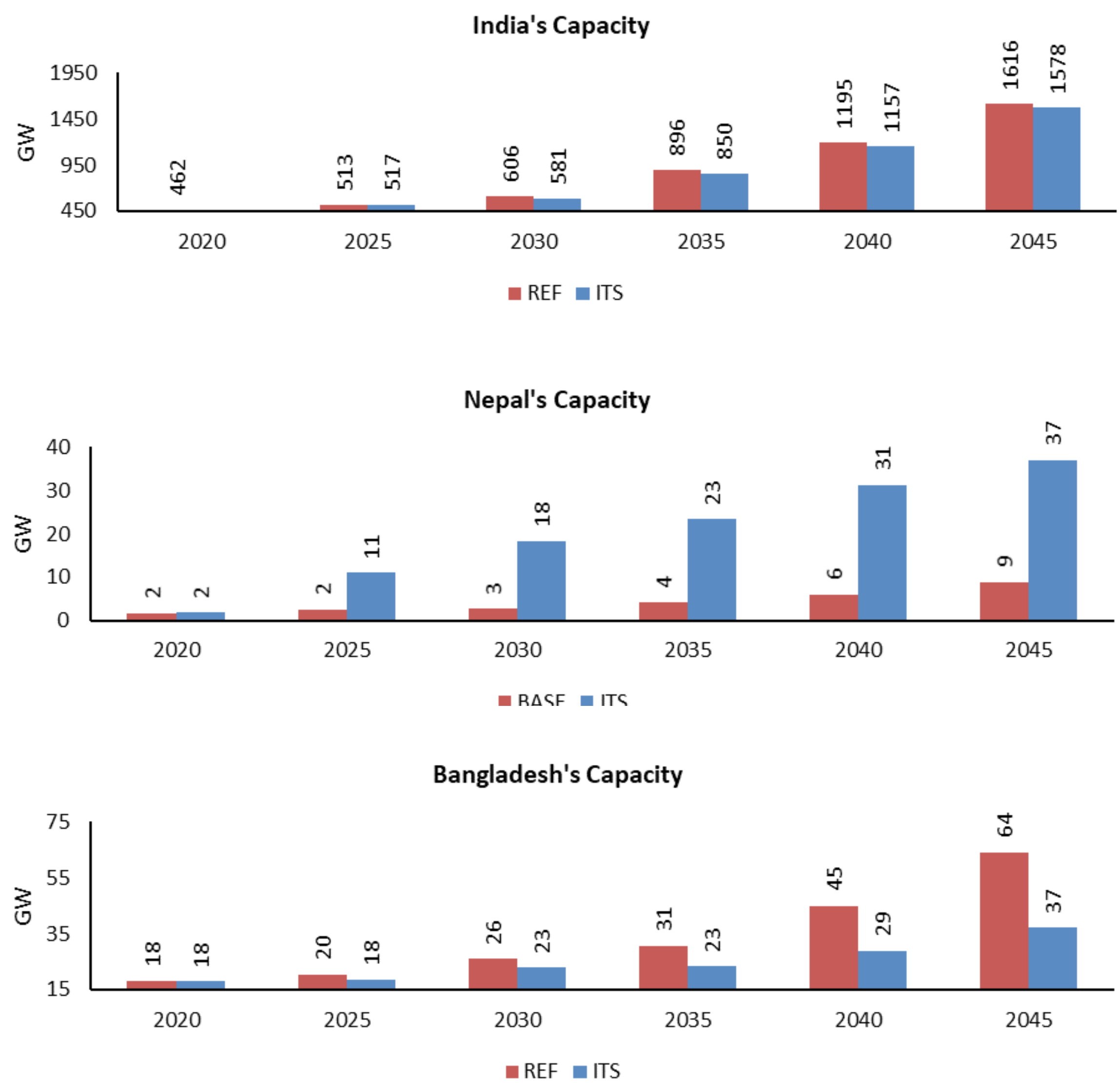


Figure 4 11 Impact of ITS on Capacity Requirements

ITS will have an impact on India's installed capacity mix. Table 4.6 shows the change in India's capacity by fuel type in ITS over the REF scenario for 2030 and 2045. It is to be noted that by 2030 the highest capacity reduction will be in coal-based capacities, and by 2045 the reduction will be seen in coal as well as solar capacities.

For Bangladesh, ITS will majorly impact the installation of coal and gas capacities; need for these capacities will reduce by 12 GW and 11 GW, respectively, by 2045 compared to REF scenario, with minor reduction in nuclear fuel-based capacities. The overall capacity reduction for Bangladesh by 2045 is 27 GW in ITS compared to REF scenario. Further, Bangladesh capacity mix does not change under ITS scenario in comparison to bilateral study trade scenario (TRADE30) as the electricity imports are restricted to 30 per cent both in TRADE30 scenario as well as ITS.

Table 4.6 Change in India's Installed Capacity in ITS over REF Scenario

Fuel Type	2030		2045	
	REF (GW)	% Reduction in ITS over REF (GW)	REF (GW)	% Reduction in ITS over REF (GW)
Coal	314	-4% (-14)	833	-2% (-16)
Gas	31	-13% (-4)	19	-21% (-4)
Diesel	1	0% (0)	0	0% (0)
Hydro	54	-10% (-5)	105	+1% (+1)
Nuclear	18	0% (0)	41	0% (0)
Biomass	18	-2% (-0.4)	18	0% (0)
SHP	7	-29% (-2)	20	0% (0)
Solar	100	0% (0)	262	-7% (-18)
Wind	64	0% (0)	319	0%
Total	606	-4% (-25)	1616	-2% (-37)

Section Highlights:

- Under ITS, India's installed capacity requirements will reduce in the range of two to five per cent compared to the REF scenario. By 2030 India will see the maximum reduction in its coal capacities, and by 2045 the reduction will be observed both in coal and solar capacities
- On Bangladesh side, ITS will result in reduction of installed capacity in the range of 12 to 42 per cent compared to REF scenario
- For Nepal, the installed capacity will increase to support higher electricity exports to India

Impact on Nepal's Installed Capacity: Multilateral Trade (ITS) versus Bilateral Trade Model (India- Nepal)

Under ITS, the installed capacity mix in Nepal changes significantly. However, the overall installed capacity increases marginally as shown in Figure box1. In ITS, the installation of PROR capacities increases and ROR capacities decreases as compared to APT scenario of the bilateral India-Nepal study. On the other hand, requirement of storage capacities increases marginally under ITS.

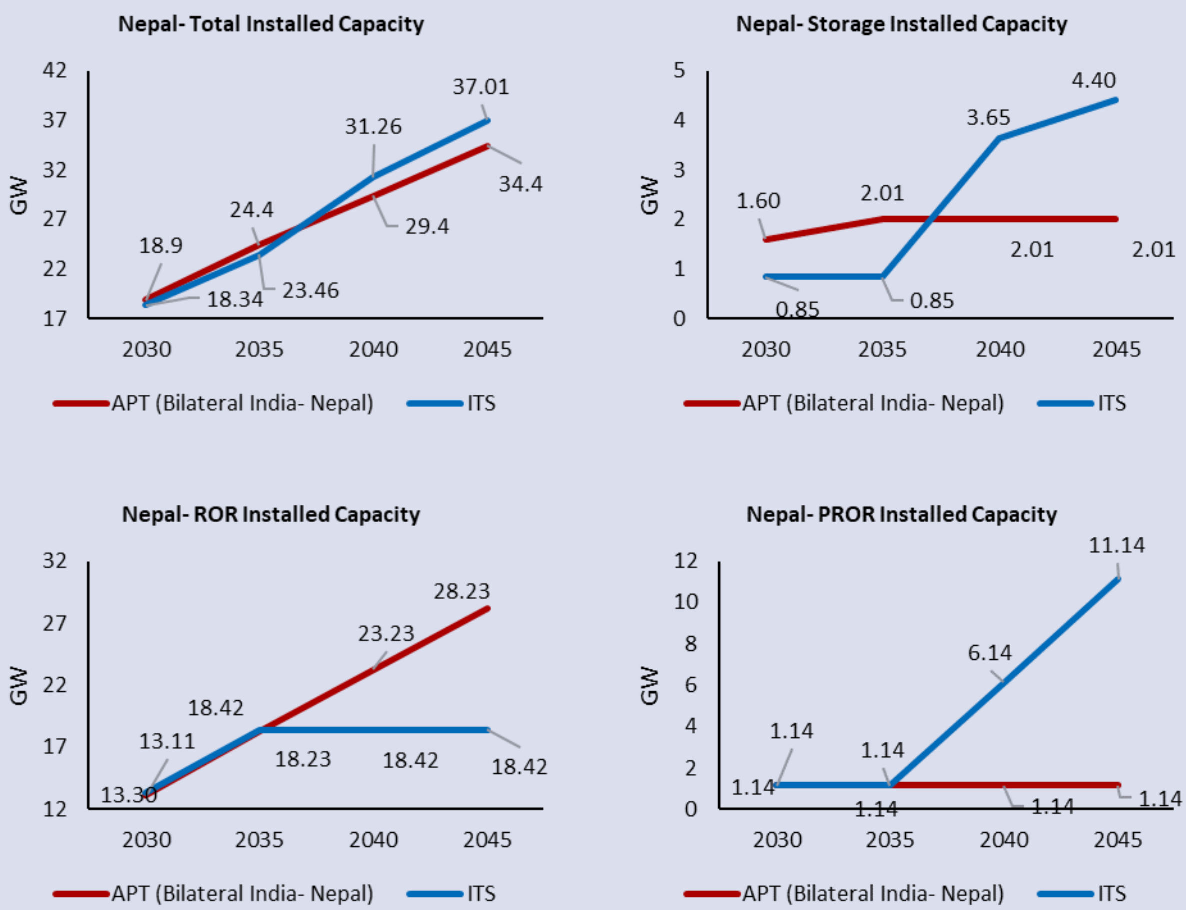


Figure Box 1 Impact of ITS on Nepal's Installed Capacity

4.5 Impact on Fuel Consumption

As highlighted in the previous section, electricity trade will reduce capacity requirements for both Bangladesh and India, and will also reduce fuel consumption in the two countries. Coal consumption by the Indian power sector is expected to decrease by 3.1 per cent and 0.9 per cent by 2030 and 2045, respectively, compared to the REF scenario. Similarly, electricity trade will also help in reducing gas consumption in the Indian power sector by 16 per cent and 27 per cent by 2030 and 2045, respectively, compared to REF scenario as shown in Figure 4.12. Apart from India, Bangladesh also benefits from electricity trade as it reduces both its coal and gas consumption. Although the coal consumption will be marginally influenced by 2030 due to committed coal capacities to be installed in Bangladesh, by 2045 electricity trade will help it reduce coal consumption by 23 per cent compared to the REF scenario. In addition to coal, electricity trade will also help in reducing gas consumption by the Bangladesh power sector. In ITS, Bangladesh power sector's gas consumption will reduce by 59 per cent by 2030 compared to REF scenario and its almost complete phase-out by 2045 as shown in Figure 4.13.

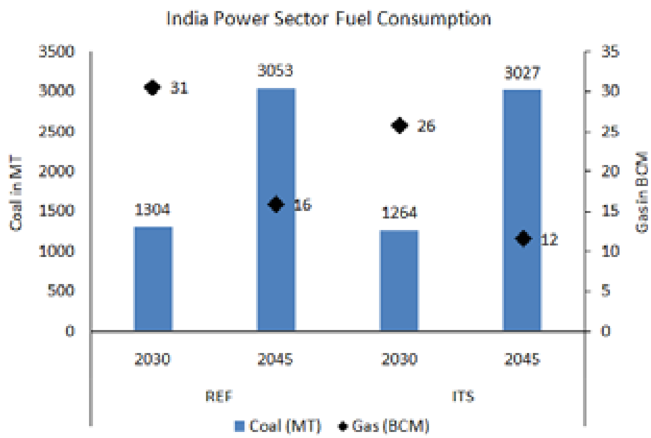


Figure 4 12 Power Sector Fuel Consumption in India

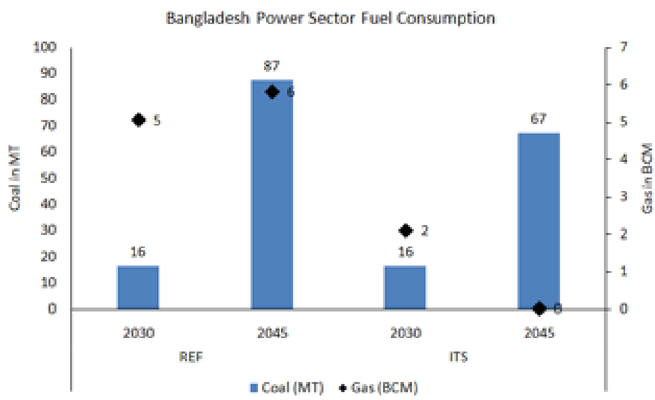


Figure 4 13 Power Sector Fuel Consumption in Bangladesh

Section Highlights:

- Under ITS, the Indian power sector coal consumption will decrease by 3.1 per cent and 0.9 per cent by 2030 and 2045, respectively, compared to the REF scenario. Similarly, gas consumption by Indian power sector will reduce by 16 per cent and 27 per cent by 2030 and 2045, respectively, compared to REF scenario
- In Bangladesh, under ITS, power sector coal consumption will only be marginally influenced by 2030; however, by 2045 electricity trade will help to reduce coal consumption by 23 per cent compared to the REF scenario. Similarly, the gas consumption will reduce by 59 per cent by 2030 compared to REF scenario and almost no gas consumption by the power sector under ITS by 2045

4.6 Impact on Power Sector CO_2 Emissions

Power sector primarily based on coal is one of the major source of global CO_2 emissions. With electricity trade, India will reduce its CO_2 emissions from the power sector by four per cent and one per cent by 2030 and 2045, respectively, compared to the REF (trade-restricted scenario from bilateral India-Bangladesh study) scenario. Similarly, Bangladesh will also reduce its CO_2 emission from the power sector by 16 per cent and 29 per cent by 2030 and 2045 compared to the REF scenario as shown in Figure 4.14. Please note that the CO_2 emission reduction is close to the electricity import restriction of 30 per cent imposed on Bangladesh model.

ITS will lead to the cumulated CO_2 emission reduction of 120 MT by 2045 for Bangladesh and India. At the same time, Nepal and Bhutan will have no CO_2 emissions from the additional installed Hydropower capacity.

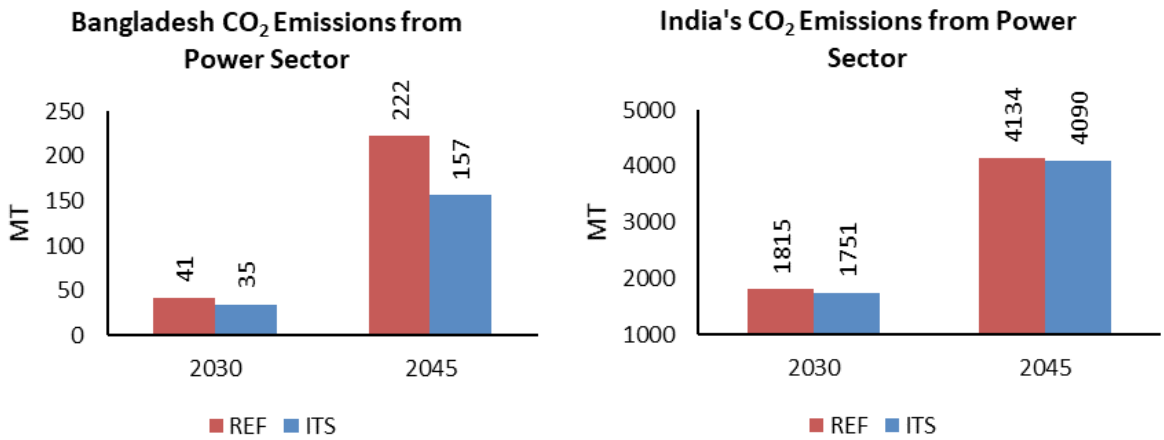


Figure 4 14 Power Sector CO_2 Emission for India and Bangladesh

Section Highlights:

- Under ITS, CO_2 emissions from Indian power sector will reduce by four per cent and one per cent by 2030 and 2045, respectively, compared to the REF scenario. For Bangladesh power sector CO_2 emission reduction will be to the tune of 16 per cent and 29 per cent by 2030 and 2045, respectively, compared to the REF scenario.

4.7 Impact on Power Sector Investments

Electricity trade is expected to reduce capital investments in the power sector of India and Bangladesh whereas it will increase in Nepal on account of new capacities to be installed. For India, the cumulated capital requirement from 2012 to 2030 under ITS will be USD 490 billion (at 2011-12 price level), which is USD 24 billion (in 2011-12 price level) less than the REF (trade-restricted scenario from bilateral India-Bangladesh study) scenario. Similarly, India's cumulated capital requirement from 2012 to 2045 under ITS will be USD 1956 billion (at 2011-12 price level), which is USD 48 billion (at 2011-12 price level) less than the REF scenario as shown in Figure 4.15.

For Bangladesh, the cumulated capital requirement from 2012 to 2030 under ITS will be USD 21 billion (at 2011-12 price level), which is 2 billion USD (at 2011-12 price level) less than the REF scenario. Further, the cumulated capital requirement from 2012 to 2045 under the ITS scenario will be USD 60 billion (at 2011-12 price level), which is USD 24 billion (at 2011-12 price level) less than the REF scenario. However, the cumulated capital cost for Nepal in 2012 to 2030 will increase to USD 34 billion (at 2011-12 price level), which was only USD 5 billion (at 2011-12 price level) in the BASE (trade-restricted scenario from bilateral India-Nepal study) scenario. Similarly, the cumulated capital cost for Nepal for 2012 to 2045 will increase to USD 70 billion (at 2011-12 price level) compared to USD 15 billion (at 2011-12 price level) in BASE scenario.

The cumulated capex of all three countries together reduces by USD 17 billion because of efficiency gains due to integration.

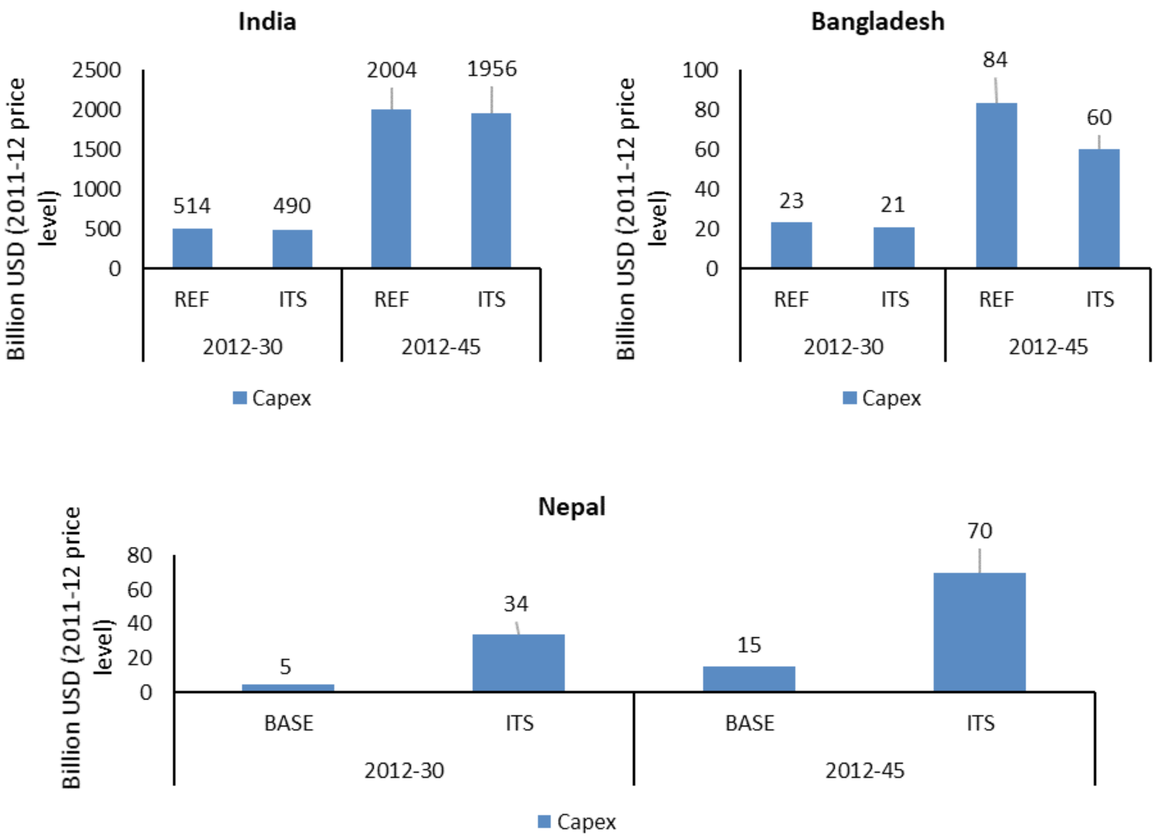


Figure 4 15 Cumulated Capital Investment in the Power Sector

Section Highlights:

- For India, under ITS the cumulated capital investment requirement of the power sector from 2012 to 2030 will be USD 490 billion (at 2011-12 price level), which is USD 24 billion (at 2011-12 price level) less than the REF scenario. Similarly, cumulated capital investment requirement from 2012 to 2045 will be USD 1956 billion (at 2011-12 price level), which is USD 48 billion (at 2011-12 price level) less than the REF scenario.
- For Bangladesh, under ITS scenario the cumulated capital requirement of the power sector from 2012 to 2030 will be USD 21 billion (at 2011-12 price level), which is two billion USD (in 2011-12 price level) less than the REF scenario. Further, from 2012 to 2045 cumulated capital requirement will be USD 60 billion (at 2011-12 price level), which is USD 24 billion (in 2011-12 price level) less than the REF scenario.
- For Nepal, the cumulated capital cost for power sector from 2012 to 2045 will increase to USD 70 billion (at 2011-12 price level) compared to USD 15 billion (at 2011-12 price level) in BASE scenario on account of higher installed capacities for power export.
- The cumulated capex of all three countries together reduces by USD 17 billion because of efficiency gains due to integration.

5 Key Messages and Way Forward

5.1 Key Messages

- **Regional Power Supply Balance:** At present both Nepal and Bangladesh face significant power shortages. However, with electricity import from India, they are able to reduce their power shortages significantly. In future also, Bangladesh power system gains through power import from India, whereas Bhutan and Nepal gain in terms of utilizing their hydro potential and selling the excess power to India. The study projects 12 per cent annual growth in India's exports to Bangladesh, and 11 per cent and 43 per cent annual growth in its imports from Bhutan and Nepal, respectively, from 2015 to 2045.
- **Higher volumes of Trade in BBIN region:** The volumes of electricity trade is higher under ITS as compared to the optimal trade scenarios of the bilateral trade models (India-Nepal and India- Bangladesh). For instance, Nepal's exports to India under ITS is 18 per cent higher than the APT scenario of bilateral India-Nepal model.
- **Impact of Electricity Trade on Indian Power System:** Since the magnitude of Indian power system is huge compared to that of Bangladesh, Bhutan and Nepal together, the impact of cross border electricity trade on Indian power system will be marginal. However, Indian power system gains marginally in terms of reduced capacity and generation requirements, reduced capital investment and fuel consumption and lower CO_2 emissions.
- **Impact of Electricity Trade on Bangladesh's Power System:** Through electricity import, Bangladesh saves investment in capacities in its own country. Moreover, due to limited domestic fossil fuel supply and availability, Bangladesh has to either import fuels for its power plants or directly import electricity from India. Further, electricity imports from India help Bangladesh to lower its fossil fuel consumption by the power sector resulting in lower CO_2 emissions.
- **Regional Gains:** Overall, BBIN region gains with electricity trade among the member countries as it leads to efficient utilization of the regional hydro potential, lower capital investments and reduced CO_2 emissions.

5.2 Way Forward

This study is one of its kind on the BBIN region that focusses on the technical analysis of the possibility of electricity trade among the BBIN countries along with the identification of the associated benefits of power trade. It is evident from the study that power trade benefits all BBIN countries, and already some level of bilateral trade between India-Nepal, India-Bhutan and India-Bangladesh is taking place. However, this needs to increase through political and technical association among the BBIN partners for a prosperous BBIN region. Integrating electricity trade will further boost the regional security as the sources of imports and customers for exports increase.

Bibliography

Asafu Adjaye, John, 'The relationship between energy consumption, energy prices and economic growth: time series evidence from Asian developing countries', *Energy Economics* 22, 615-625, 2000.

Bazilian Morgan, Hobbs Benjamin F., Will Blyth, Iain MacGill and Mark Howells, 'Interactions between energy security and climate change: A focus on developing countries', *Energy Policy* 39, 3750-3756, 2011.

Bergel, C. Haurie, A. and Loulou, R., 'Modeling Long Range Energy/Technology Choices: The MARKAL Approach, Report', *GERAD*, Montreal, 1987.

Brooke, A., Kendrick, D. and A. Meerhaus. 'GAMS – A User's Guide', *The Scientific Press*, Redwood City, California, USA, 1998.

Fishbone L.G. and Abilock, H, 'MARKAL, A linear programming model for energy systems analysis: technical description of the BNL version', *Energy Research* 5, 353-357, 1981.

Government of India: 'Households Consumption Expenditure of Various Goods and Services in India', National Sample Survey, 66th Round, Ministry of Statistics and Programme Implementation, Government of India. *NSS Report* No: 541(66/1.0/3), 2009-10.

Hawdon David and Pearson Peter, 'Input-output simulations of energy, environment, economy interactions in the UK', *Energy Economics*, Vol. 17, No. 1, 73-86, Elsevier Science Ltd. Printed in Great Britain, 1995.

Jewell Jessica, Cherp Aleh, Riahi Keywan, 'Energy security under de-carbonization scenarios: An assessment framework and evaluation under different technology and policy choices', *Energy Policy* 65, 743-760, 2014.

Lee Chien-Chiang, 'Energy consumption and GDP in developing countries: A cointegrated panel analysis', *Energy Economics* 27, 415- 427, 2005.

Loulou R., Shukla P.R. and Kanudia A., 'Energy and Environment Strategies for a Sustainable Future: Analysis with the Indian MARKAL Model', *Allied*, New Delhi, 1997.

Luken Michael, Edenhofer Ottmar, Knopf Brigitte, Leimbach Marian, Luderer Gunnar, Bauer Nico, 'The role of technological availability for the distributive impacts of climate change mitigation policy', *Energy Policy* 39, 6030-6039, 2011.

MoEF (2009), 'India's GHG Emissions Profile: Results of Five Climate Modelling Studies', *Climate Modelling Forum, supported by Ministry of Environment and Forests, Government of India, New Delhi, India*, <http://www.moef.nic.in/downloads/home/GHG-report.pdf>, September, 2013.

MoEF, (2010), 'India: Greenhouse Gas Emissions', *Ministry of Environment and Forests, Government of India, New Delhi,* 2007.

MoEF, (2015), 'India's Intended Nationally Determined contribution: Working Toward Climate Justice', *Ministry of Environment and Forests, Government of India, New Delhi* http://www.moef.gov.in/sites/default/files/press-releases/INDIA%20INDC%20TO%20UNFCCC.pdf

Tarancon Moran Miguel Angel and Gonzalez Pablo del Río, 'A combined input-output and sensitivity analysis approach to analyze sector linkages and CO2 emissions', Energy Economics 29, 578-597, 2007.

Murthy N.S., Panda Manoj, Parikh Jyoti, 'Economic development, poverty reduction and carbon emissions in India', Energy Economics 19, 327-354, 1997.

Nag Barnali and Parikh Jyoti, 'Carbon emission coefficient of power consumption in India: baseline determination from the demand side', *Energy Policy,* 33(6), 777-786, 2005.

Parikh J. and Ghosh P., 'Energy Technology Alternatives for India till 2030', *International Journal of Energy Sector Management*, 3(3), 233-250, 2009.

Parikh K.S., Binswanger-Mkhize H.P., Ghosh P., D'Souza A., 'Double Digit Inclusive Growth: Not Without Robust Agricultural Growth, Background Paper to Centennial Group,' *India 2039: Transforming Agriculture,* Washington DC, 2011.

Parikh K.S., Ghosh Probal, D'Souza, Alwin and Binswanger-Mkhize, Hans, 'Estimating a Consumer Demand System for Long Term Projections with Emphasis on Agricultural Goods for India', Discussion Paper, *Integrated Research and Action for Development (IRADe)*, New Delhi, 2014.

Parikh K.S., Karandikar V., Rana. A., and P. Dani, 'Projecting India's Energy Requirements for Policy Formulation', *Energy - The International Journal* 34(8): 928-941, 2009.

Parikh Kirit S., Parikh Jyoti and Ghosh Probal, 'Indian perspectives on global energy scenarios till 2050', *IRADe-PR, 26, 2010.*

Parikh Kirit S., Parikh Jyoti, Ghosh Probal and Khedkar Gayatri, 'Maps India study on Poverty and low carbon strategy', *IRADe-PR*, 35, 2012.

Parikh Kirit S., Parikh Jyoti, Ghosh Probal, Khedkar Gayatri, 'Low-Carbon Development Pathways for a Sustainable India', IRADe-PR, 41, a collaborative partnership between WWF India, CEE, LAYA, CASA, Bread for the world and Welthungerhilfe, 2014.

Parikh Kirit S. and Ghosh Probal, 'Economy wide Model for Low Carbon Strategy', *IRADe-PR-42-2014*, prepared for the Planning Commission, 'Final report of the expert group on Low Carbon Strategy for Inclusive Growth', Planning Commission, Government of India, 2014.

Paul Shyamal and Bhattacharya Rabindra N., 'Causality between energy consumption and economic growth in India: a note on conflicting results', *Energy Economics* 26, 977-983, 2004.

Pradhan, Saluja and Sharma, 'Institute of Economic Growth', Working Paper, 325, 2013.

Rana Ashish and Shukla P.R., 'Macroeconomic Models for Long-term Energy and Emissions in India', OPSEARCH (*Special Issue on Energy and Environment Modelling*), Vol. 38, No. 1, February 2001.

Selim Raihan and Bazlul Haque Khondker (2011), "A Social Accounting Matrix for Bangladesh for 2007: Methodology and Results"

Shukla P.R. and Rana A., 'Energy Economy Model Applications for India: Long-term GHG Trends and Mitigation Costs' *Climate Change Economics and Policy: Indian Perspectives, Resources for Future*, 2000. (Forthcoming)

Stone, R., 'Linear Expenditure System and Demand Analysis, An Application to the Pattern of British Demand', The Economic Journal, Vol. LXIV, 1954.

Swamy G., Binswanger H.P., 'Flexible Consumer Demand Systems and Linear Estimation: Food in India', *American Journal of Agricultural Economics,* 65(4), November: 675-684, 1983.

Urban F.; Benders R.M.J., Moll H.C., 'Modelling energy systems for developing countries', Energy Policy 35, 3473-3482, 2007.

van Vliet Oscar, Volker Krey, David McCollum, Shonali Pachauri, Yu Nagai, Shilpa Rao and Keywan Riahi, 'Synergies in the Asian energy system: Climate change, energy security, energy access and air pollution', *Energy Economics* 34, S470–S480, 2012.

Weyant J. and J. Parikh, 'India, Sustainable Development and the Global Common', ICFAI Publication (Edited Book), 2004.

Annexure A: Common Modelling Assumptions

Certain modelling procedures and assumptions are common to all countries. The following annexures describe these procedures and assumptions followed by country-specific key assumptions.

The existing power system (2011–12) is the starting point. A mathematical representation of the current electricity supply system was created within the TIMES modelling framework. This included characteristics of the various existing generating stations (vintage, techno-economic performance, etc.), transmission and distribution, energy flows, demand, load characteristics, energy resources and import/export links. Variations in seasonal and daily load patterns as well as hydro generation and availability of solar and wind energy sources were captured by introducing semi-chronological load and supply curves. Based on the analyses of 8,760 hourly load data for the year 2014–15 for India and Bangladesh, and hourly load curve of four peak days in the year 2011–12 for Nepal, the demand curve for the country was modelled. To capture seasonal variation, the entire year is divided into 12 seasons (meaning each month represents a season). Average hourly load pattern for a day in a month (or season) represents the daily load pattern for that particular season (or month). Thus, average hourly load over 24 hours of a day in each month represents daily load pattern of each month in the model. Thus, we have 288 = 24 x 12 sub-periods for each year. Figure 4.1 in Chapter 4 presents the organised form of the 288 sub-periods' load curve for a year for Bangladesh, India and Nepal used in the model.

All cost data are at constant 2011–12 US dollar rate and the assumed real discount rate is four per cent. Exchange rates for Bangladeshi, Indian and Nepalese currencies are respectively BDT 74.02, INR 46.67 and NPR 74.02 for 1 USD. Country-specific key assumptions are described below.

Annexure B: Assumptions for IRADe Nepal Technology Model (INTec Model)

Taken from report "Economic Benefits of Nepal-India Electricity Trade" published by IRADe.

The Nepal power system is relatively simple. Potential technologies for the future expansion of Nepal power system are hydro (run of the river [ROR], pondage for a day, and storage), solar PV and thermal plants based on oil products. Table A.2 presents the technical and economic data related to these technologies. Nepal's total hydropower potential is taken as 42 GW. IPP hydro projects having PPAs signed with NEA and expected to be installed between 2017 and 2022 are included in the study. The study has also included hydro capacity addition as per Japan International Cooperation Agency's (JICA) national master plan[19] accepted by NEA, and planned for export-oriented projects. In addition, from 2022 and onwards, upper limit of five GW per period is imposed separately on new capacity addition based on storage and ROR and pondage together. Potential of grid connected solar PV is assumed as 2,100 MW.

A. 2 Assumptions on Technical and Economic Performance of Future Technology Options (Nepal)

Technology data	**PROR**	**ROR**	**STG**	**PV-W/O STG**
Availability factor	70%*	71%*	42%**	17.7%***
Operational life time (Year)	50	50	50	25
Economic data				
Capital cost ($/kW)◻	2,233	1,916	3,395	Table A.3
O&M cost ($/kW/yr)•	55.8	47.9	84.8	Table A.3

[19] NEA, 2014, Nation-wide Master Plan study on Storage type Hydroelectric power development in Nepal, Final report, Japan International Cooperation Agency, February 2014.

** We have taken monthly availability based on monthly averages of past 4 years. If, PLF of the individual upcoming plant was available then the same was used, otherwise average PLF is used.*

*** Based on "Nationwide Master Plan Study on Storage-type Hydroelectric Power Development in Nepal" February 2014 considering annual generation from Nalsyau Gad, Andhi Khola, Chera-1, Madi, Naumure, Sun Koshi-3 and Lower Badigad hydro plants (storage based)*

**** For assessment of solar availability in Nepal, we have used the PV Watts Calculator developed by National Renewable Energy Laboratory (NREL) of the U.S. Department of*

(•) Capital Cost calculated as average of various project costs from Final Report Summary "Nationwide Master Plan Study on Storage-type Hydroelectric Power Development in Nepal" February 2014

(•) O&M Cost calculated as 2.5% of the average capital cost for hydropower plants

A. 3 Solar PV Without Storage Cost Assumption

Capital cost ($/kW)•	1,714	1,174	1,071	984	904	830	762	700	643
O&M cost ($/kW/yr)•	25.7	17.6	16.1	14.8	13.6	12.4	11.4	10.5	9.6

Nepal is expected to continue to import fuels (petroleum products) for power generation from India. Table A.4 gives the fuel prices that are assumed to remain constant at 2012 level for the entire study horizon.

A. 4 Assumptions on Fuel Price (Nepal)

Furnace oil	Import	Rs/Ltr	2012	89	Nepal Economic Survey
Diesel	Import	Rs/Ltr	2102	84.6	Nepal Economic Survey

The above technological assumptions were common to all three selected scenarios, i.e., the BASE, APT and DCA. However, Table A.5 gives the key assumptions on the Nepal model that differentiate the three scenarios, other than trade assumptions.

A. 5 Key Scenario Assumptions (Nepal)

Under-construction plants*	Capacity commissioning assumed as per plans		
Export-oriented plants**	No capacity commissioning assumed	Capacity commissioned as per plans	Capacity commissioned with delay of 5 years as per plans
Planned and candidate hydro projects***	Capacity addition as per plans introduced as upper bounds; however, technology model chooses when and how much capacity addition is made.		Capacity addition as per plans introduced with a delay of five years as upper limit; however, technology model chooses when and how much capacity addition is made.
IPP's plants having PPA with NEA	Capacity addition as per plans introduced as upper bounds; however, technology model chooses when and how much capacity addition is made.		Capacity addition as per plans introduced with a delay of five years as upper limit; however, technology model chooses when and how much capacity addition is made.
Export and import quantum	Maximum limit based on 2011–12 exports/ imports	No limits on export/ imports quantum; model chooses the optimal trade.	No limits on export/ import quantum; model chooses the optimal trade.

**As per the Nation-wide Master Plan study on storage type hydroelectric power development in Nepal, Final report, Japan International Cooperation Agency, February 2014*

***Commissioning year information as received from Investment Board Nepal*

****As per the Nation-wide Master Plan study on storage type hydroelectric power development in Nepal, Final report, Japan International Cooperation Agency, February 2014*

Annexure C: Assumptions for IRADe India Technology Model (IITec Model)

Taken from report "Economic Benefits of Bangladesh-India Electricity Trade" published by IRADe.

A comprehensive list of technologies is considered for the future expansion of the Indian power system. This includes:

- Various coal technologies (sub-critical, super-critical, ultra-super-critical)
- Open cycle and combined cycle gas turbine using natural gas
- Solar technologies such as solar PV and solar thermal, with and without storage
- Wind onshore and off-shore
- Large and small hydropower
- Biomass-based power
- Nuclear light and heavy water reactors

Assumptions used in the model on the technical, economic, and environmental performances of these technologies are presented in Table A.6 to Table A.8.

A. 6 Assumptions on the Technical and Economic Performance of the Future Technology Options, India

	Gas Power Plant		Coal Power Plant				Diesel Thermal	Nuclear Power Plant		Hydro Power Plant		Solar Power Plant				Wind Power Plant		Bio Power Plant
Technology Data	OC	CC	IGCC	SUBC	SUPC	USUPC		LWR	PHWR	Large	Small	PV-With STG	PV-W/O STG	TH-With STG	TH-W/O STG	ON-SHORE	OFF-SHORE	
Net Efficiency (P) Output/PJ input)	37.5%	55%	46%	30%	37%	43%	25%	163%	18%									25%
Fuel Type	Gas	Gas	Coal	Coal	Coal	Coal	Diesel	Enriched Uranium	Natural Uranium									Biomass
Availability Factor	90%(UP)	(55-90)%	(60-70)%	(55-70)%	(55-70)%	(55-70)%	70%	80%	80%	39%	41%	37%	18%	37%	18%	(21-28)%	(33-37)%	50%
Plant Availability Modelling Level	Annually	Annually	Annually	Annually	Annually	Annually	Annually	Annually	Annually	Monthly	Monthly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Annually
Operational Life Time (Year)	40	40	40	40	40	40	15	50	50	50	30	25	25	25	25	25	25	20
Economic Data																		
Capital Cost ($/kW)	482	771	2143	1028	1136	1307	1071	4500	1778	2036	1393	Refer Next Table				1286	3857	9642
O&M Cost ($/kW/yr)	39	31	54	26	28	33	107	112	44	67	42	Refer Next Table				19	29	39

A. 7 Capital Costs (US$/kW) Assumptions for Solar Technologies, India

Solar Power Plant (PV)*	WO-STG	1,173.6	1,071.3	983.9	903.6	829.9	762.1	699.9	642.8
	With STG	3,526.1	3,223.7	2,959.2	2,716.3	2,493.3	2,288.7	2,100.8	1,928.4
Solar Thermal Plant (CSP)#	WO- STG	2,314.1	2,036.4	1,873.5	1,761.1	1,708.3	1,674.1	1,640.6	1,538.6
	With STG	3,373.4	2,968.6	2,731.1	2,594.6	2,464.9	2,366.3	2,295.3	2,111.7

(*) The Solar PV cost reduction is undertaken on the CERC benchmark cost for financial year 2015–16, which is 6,010.4 US$/kW (CERC Benchmark Cost 2015). The reduction is undertaken as per the report, 'Current and Future Cost of Photovoltaics', of the Fraunhofer-Institute for Solar Energy Systems, Germany. From the report, we have considered a 20 per cent cost reduction trajectory by 2025 and a 40 per cent cost reduction by 2050, which is still on the conservative side as the other scenarios in the report consider a 36 per cent reduction in 2025 and a 72 per cent reduction in 2050.

(#) For Solar Thermal Plants, the cost reduction trajectory is as per the IESS 2047 V2.0 model of the NITI Ayog.

A. 8 O&M Cost Assumptions for Solar Technologies, India

Solar Power Plant (PV)	WO-STG	17.6	16.1	14.8	13.6	12.4	11.4	10.5	9.6	1.5%
	With STG	88.2	80.6	74.0	67.9	62.3	57.2	52.5	48.2	2.5%
Solar Thermal Plant (CSP)	WO- STG	28.9	25.5	23.4	22.0	21.4	20.9	20.5	19.2	1.3%
	With STG	42.2	37.1	34.1	32.4	30.8	29.6	28.7	26.4	1.3%

- The current (January 2017) policy and measures that are in place have been included. The renewable capacity of 175 GW will be achieved by 2022. As indicated in India's INDC, the non-fossil capacity share would be 40 per cent in 2030, linearly increasing to 50 per cent by 2050. Until 2022, the capacity addition of large hydro, nuclear, and coal is according to the Draft National Electricity Plan published in December 2016. The potentials for large hydro and wind onshore are taken as 145 GW and 302 GW, respectively. Additionally, the potentials for solar PV and solar thermal are taken as 749 GW and 229 GW, respectively.
- Keeping in mind the regulatory guideline on the technical minimum scheduling for the operation of power plants,[20] we have imposed the technical minimum schedule for operation as 55 per cent for coal power plants. In addition, an increase in the station heat rate and an increase in auxiliary consumption with decreasing unit loading have also been incorporated, according to the CERC regulations. The cost of secondary oil consumption concerning hot/warm/cold types of plant start up/shut down has also been incorporated in the model.
- The price of fuels used for power generation is assumed to be constant at the 2012 level for the entire study horizon and is presented in Table A.9.

A. 9 Fuel Price Assumptions

Fuel	Fuel Source	Unit	Year	Price in Model	Calorific Value	Data Source
Natural Gas	Dom	INR/ SCM	2012	8.387	10,000 Kcal/ SCM	GAIL
	Imp	US$/ MMBTU	2012	10	10,000 Kcal/ SCM	GAIL
Coal	Dom	INR/tonne	2012	1,317.35	3,541 Kcal/kg	Coal Directory, MOC
	Imp	INR/tonne	2012	5,119	5,500 Kcal/kg	Coal Directory, MOC
Natural Uranium	Dom	INR Cr/tonne	2012	0.78		IESS
	Imp	INR Cr/tonne	2012	0.78		IESS
Enriched Uranium Cost	Dom/Imp	INR Cr/tonne	2012	14.486		IESS
Biomass	Dom	INR/kg	2012	2.4	3,751 Kcal/kg	IRADe Analysis

[20] Central Electricity Regulatory Commission (Indian Electricity Grid Code) (Fourth Amendment) Regulations, 2016

Annexure D: Assumptions for IRADe Bangladesh Technology Model (IBTec Model)

A menu of power generation technology fuelled by domestic and imported sources is assumed for the future expansion of the Bangladesh power system. This includes super-critical and ultra-super-critical coal power plants, combined cycle and open cycle gas power plants, nuclear, wind, solar PV, biomass, and so on. Apart from the ongoing expansion of the Barapukuria power plant, all future coal power plants will be based on imported coal. SREDA's plan for an additional 2,700 MW of grid-connected RE capacity, to be installed by 2021, is included. Several power plants that are at various stages of construction or planning, as well as two nuclear reactors with a capacity of 1,200 MW each and are expected to be online during 2024 and 2025, are also included in the model. Technical and costs assumptions made on these technologies are shown in Table A.10 and Table A.11. Bangladesh is expected to continue to import fuels (petroleum products) for power generation from India.

A. 10 Technical and Economic Assumptions for Future Power Generation Technologies

Technology Data												
Parameter/Tech	**Gas (CC)**	**Gas (OC)**	**Oil**	**Dual Fuel**	**Nuclear PP**	**Coal (Sub) PP**	**Coal (SC) PP**	**Coal (USC) PP**	**Wind PP**	**Solar PV**	**Biomass**	**Hydro**
Thermal Efficiency	0.57	0.38	0.35	Gas - .45 Oil - .43	0.35	0.35	0.37	0.43	--	-	0.3	Bangladesh Economic Survey
Fuel Type	Gas	Gas	Oil	Gas and Oil	Uranium	Coal	Coal	Coal	--	-	Rice husk	
Annual Availabity Factor	<.85	<.90	<.80	<.85	<.90	<.80	<.80	<.80	<.21	<.18	<.60	<.50
Operational Life Time (Year)	25	20	20	25	60	30	30	30	25	25	20	80
Construction Period (Year)	3	2	2	3	8		5	5	2	2	2	6
Economy Data												
Capital Cost ($/kW)	622	838	838	622	5000	959	968	1306	1690*	1446*	1920	1736
Fixed O&M Cost ($/kW/yr)	26	26	26	26	68	20	22	34	30	23	109	16
*Cost declined over time and presented in the next Table												

A. 11 Capital Cost Assumptions for Solar and Wind Technology

Year	2015	2017	2022	2027	2302	2037	2042	2047	2052
Solar PV	1447	1282	869	622	622	622	622	622	622
Wind	1691	1650	1549	1488	1488	1488	1488	1488	1488

Table A.12 gives the fuel prices that are assumed to remain constant at the 2012 level for the entire study horizon.

A.12 Assumptions on Fuel Price (Bangladesh)

Fuel	Fuel Source	Unit	Year	Price	Data Source
Furnace oil	Import	INR/liter	2012	89	Bangladesh Economic Survey
Diesel	Import	INR/liter	2102	84.6	Bangladesh Economic Survey

The T&D loss is assumed to decline from 13.5 percent in 2015 to nine per cent, seven per cent, and six per cent, respectively, in 2030, 2040, and 2050. The Power Sector Master Plan (2016) of Bangladesh has assessed the potential interconnection capacity between India and Bangladesh as nine GW, to be achieved by 2041. In addition to the 16 per cent upper limit on electricity import, the PSMP scenario also assumed nine GW as the upper limit on the interconnection capacity to be achieved by 2040 and will continue thereafter.

Annexure E: Comparison table for Restricted Trade, Bilateral Trade and Multilateral Trade

A 13. Comparison table for Restricted Trade, Bilateral Trade and Multilateral Trade

Year	**2030**			**2045**		
Scenario	**REF/BASE#**	**Change over REF/BASE**		**REF/BASE#**	**Change over REF/BASE**	
		Bilateral trade scenario (APT/TRADE30)*	**Multilateral Trade Scenario (ITS)**		**Bilateral trade scenario (APT/TRADE30)***	**Multilateral Trade Scenario (ITS)**
Total Electricity Imports (GWh)						
Bangladesh	6513	21351	21383	7151	96719	96720
Bhutan	NA	NA	NA	NA	NA	NA
India	4	64572	169626	4	114738	254059
Nepal	746	-746	-746	746	-746	-182
Total Electricity Exports (GWh)						
Bangladesh	0	0	345	0	0	0
Bhutan	NA	NA	96807	NA	NA	118383
India	7259	20604	20637	7897	95973	96538
Nepal	4	64572	72474	4	114738	135676

Year	**2030**			**2045**		
Scenario	**REF/BASE#**	**Change over REF/BASE**		**REF/BASE#**	**Change over REF/BASE**	
		Bilateral trade scenario (APT/TRADE30)*	**Multilateral Trade Scenario (ITS)**		**Bilateral trade scenario (APT/TRADE30)***	**Multilateral Trade Scenario (ITS)**
Electricity Generation (TWh)						
Bangladesh	113	-24	-25	350	-108	-108
India	2979	38	-149	7617	110	-158
Nepal	14	92	88	42	160	158
Power Generation Capacity (GW)						
Bangladesh	26	-3	-3	64	-27	-27
India	606	6	-25	1616	24	-37
Nepal	3	16	16	9	26	28
Power Sector CO2 Emissions (MT)						
Bangladesh	41	-6	-6	222	-65	-65
India	1815	27	-64	4134	57	-44
Year	Cumulated 2012-2030			Cumulated 2012-2045		
Scenario	REF/BASE#	Change over REF/BASE		REF/BASE#	Change over REF/BASE	
		Bilateral trade scenario (APT/TRADE30)*	Multilateral Trade Scenario (ITS)		Bilateral trade scenario (APT/TRADE30)*	Multilateral Trade Scenario (ITS)
Power Sector Capital Requirement [Billion USD (2011-12 price level)]						
Bangladesh	23	-3	-3	84	-24	-24
India	514	7	-24	2004	34	-48
Nepal	5	30	29	15	50	54

 # The BASE scenario is taken from 'Economic Benefits from Nepal-India Electricity Trade' study. The BASE scenario assumes no increased interconnections across India and Nepal beyond what are currently in place (CBET as in 2011–12) or are already committed to be built. In this scenario, each country independently makes its own capacity investments to satisfy its projected demand profile.

The REF scenario is taken from 'Economic Benefits of Bangladesh-India Electricity Trade' study. The REF scenario assumes no increased interconnections between India and Bangladesh beyond what are currently in place in year 2015 (600 MW) and are under construction (500 MW). In this scenario, each country independently makes its own capacity investments to satisfy its projected demand profile.

** The TRADE-30 scenario is taken from 'Economic Benefits of Bangladesh-India Electricity Trade' study. The TRADE-30 scenario allows electricity import up to 30 percent of the total electricity supply by 2040. While the supply of electricity from coal in this scenario is capped, other sources are free so that the import option will substitute the sources for power generation on least-cost basis.*

The APT scenario is taken from 'Economic Benefits from Nepal-India Electricity Trade' study. The Accelerated Power Trade (APT) scenario allows the model to utilize full potential of electricity trade between India and Nepal.

About SARI/EI

Over the past decade, USAID's South Asia Regional Initiative/Energy (SARI/E) has been advocating energy cooperation in South Asia via regional energy integration and cross-border electricity trade in eight South Asian countries (Afghanistan, Bangladesh, Bhutan, India, Pakistan, Nepal, Sri Lanka and the Maldives). This fourth and the final phase, titled South Asia Regional Initiative for Energy Integration (SARI/EI), was launched in 2012 and is implemented in partnership with Integrated Research and Action for Development (IRADe) through a cooperative agreement with USAID. SARI/EI addresses policy, legal and regulatory issues related to cross-border electricity trade in the region, promote transmission interconnections and works toward establishing a regional market exchange for electricity.

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About IRADe

IRADe is a fully autonomous advanced research institute, which aims to conduct research and policy analysis and connect various stakeholders including government, non-governmental organizations (NGOs), corporations, and academic and financial institutions. Its research covers many areas such as energy and power systems, urban development, climate change and environment, poverty alleviation and gender, food security and agriculture, as well as the policies that affect these areas.

For more information on the South Asia Regional Initiative for Energy Integration (SARI/EI) program, please visit the project website:

www.sari-energy.org