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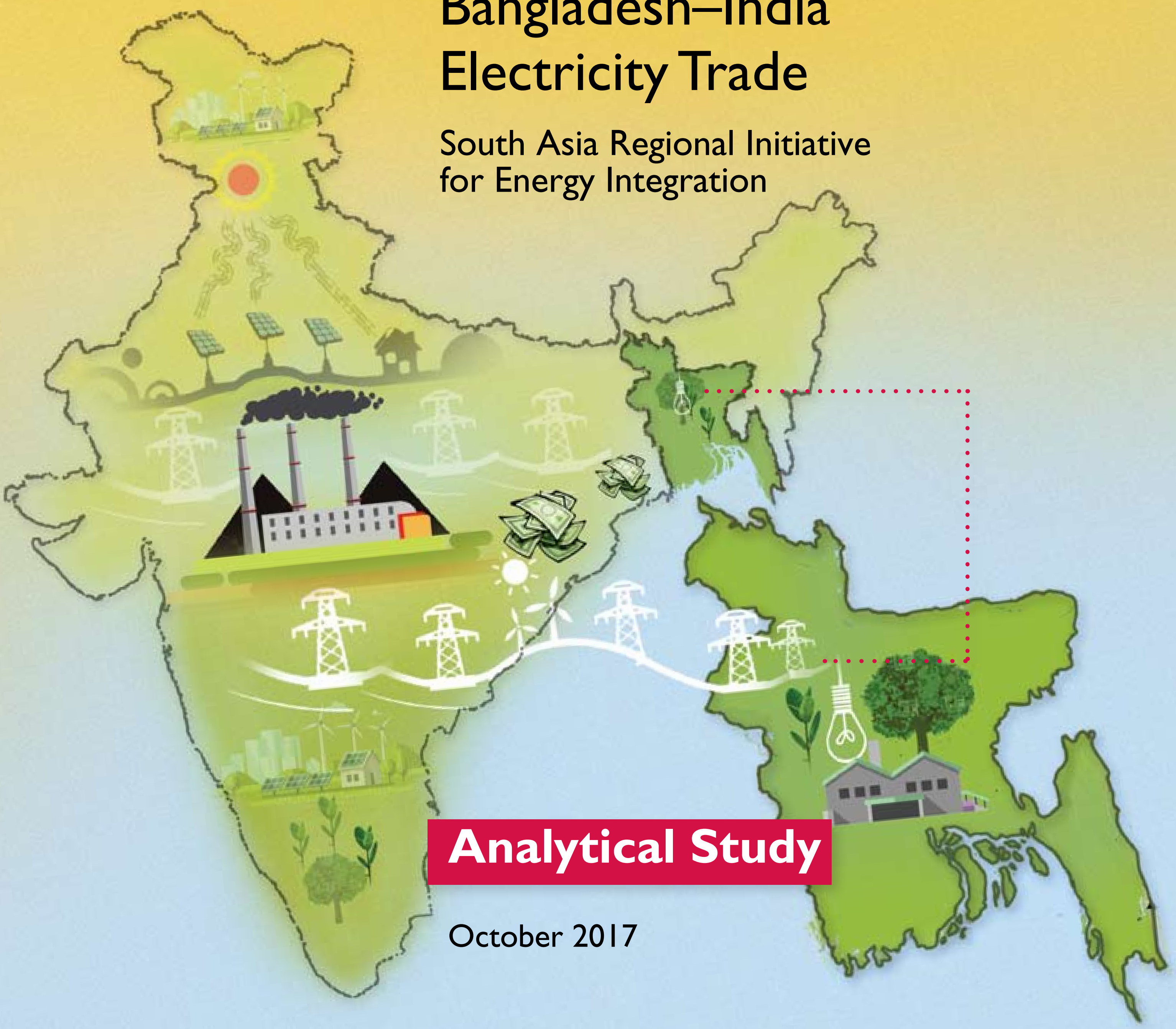
IRADe Integrated Research and Action for Development

Economic Benefits of Bangladesh–India Electricity Trade

South Asia Regional Initiative for Energy Integration



Analytical Study

October 2017

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Contents

List of Figures

List of Tables

Preface

We are pleased to present the report, 'Economic Benefits of Bangladesh–India Electricity Trade', carried out under the South Asia Regional Initiative for Energy Integration (SARI/EI) project supported by USAID. It was felt that the macroeconomic benefits of the power trade from a long-term perspective could help to bring wider consensus among power sector experts, economists, financiers, and policymakers.

Bangladesh wishes to be a developing country from its status of 'the least developed country'. Such economic progress requires energy as the country had a per capita consumption of 310 kWh in 2014, compared to India's 806 kWh and the world average of 3,128 kWh. Unfortunately, Bangladesh does not have energy resources beyond 2030 for its vast population of 163 million (2016). Thus, it needs to work out import arrangements from neighboring countries.

We held many discussions with stakeholders, focused groups, and electricity planners from India and Bangladesh. This was a painstaking and novel exercise where the power system models of the two countries were linked at an hourly level (reflecting the average demand and generation for that hour for the month) and for every month of the year to capture the impact of peak and off-peak hours of the different seasons to explore compatible trade. This exercise helped to assess the scope for trade and the resultant gain to both the countries; it gives very different insights than doing it just once, based on the annual overall demand and supply. We also linked this to the macro models of each country to capture the macroeconomic benefits, especially to Bangladesh. The results find substantial gains to the economy of Bangladesh.

We had earlier conducted a similar exercise for the India and Nepal electricity trade. The results showed substantial gains for Nepal's economy and its people.

I am grateful to USAID for supporting this path-breaking modeling exercise and extend my gratitude to our Bangladeshi, Indian, and USAID colleagues who supported our work. I take this opportunity to thank the IRADe team that worked diligently, enthusiastically, and relentlessly for many months.

Jyoti Parikh

Dr. Jyoti Parikh
Executive Director, IRADe

Foreword

Over a decade, the U.S. Agency for International Development (USAID) has been working towards regional energy cooperation in South Asia under USAID's South Asia Regional Initiative for Energy (SARI/E) program. Launched in 2000, the program covers eight countries of 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 "Assessing Macroeconomic benefits of Bangladesh-India electricity trade". This study attempts to provide concrete evidence of benefits of power trade to policy and decision makers in both the countries for building consensus to support creation and implementation of regional power trade.

The study used a state-of-the art analytical tool to quantify the power trade potential and macroeconomic benefits for both the countries for three different trade scenarios – reference scenario (imports limited by the inter-connection built by 2018 called REF), Power Sector Master Plan 2016 scenario (Bangladesh achieving 15% electricity import in its electricity supply by 2040) and TRADE-30 scenario (enhanced electricity import scenario of 30% in the total supply). Extensive consultations were conducted with key stakeholders in both the countries to review the methodology, scenarios and assumptions.

The study throws some interesting figures underlining the fact that power trade is a win-win for both the countries. While Bangladesh benefits from the cheap electricity imports from India to sustain its desired economic growth, India also gains from the export earnings. For Bangladesh, the aggregate expenditure for household consumption increased by USD 523 billon in the TRADE-30 scenario from 2011 to 2045 compared to the reference scenario. India's cumulated GDP gain is USD 636 billion at 2011-12 market exchange rate between TRADE-30 and reference scenario.

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 both the countries.

Thank you

Michael Satin
Regional Energy Director,
Clean Energy & Environment Office
USAID/India

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Foreword

As the power sector is capital intensive and over the years the complexity in power sector has increased manifold, many regions of the world are taking initiatives for power pooling in order to create robust regional power grids, increase reliability of supply, lower investment requirements, optimize the use of resources, and reduce overall electricity supply cost. However, such strong power pool is missing in South Asia region, except some bilateral trade of electricity.

For energy resource constrained Bangladesh, expansion of future power system is a serious challenge. However, the South Asian region has significant unevenly distributed energy resources (fossil fuel, hydro and renewables) across the countries. A combined hydro potential of about 350 GW in the region offers a huge scope for tapping/harnessing clean energy and addressing the problems of shortage of electricity. South Asian Electricity trade would not only increase exploitation of the available energy resources and improve energy security but also would help in providing electricity at affordable cost, increasing revenue earnings and promoting environment friendly socio-economic development by sharing energy resources, energy infrastructure and capacity reserves.

IRADE has carried out the study on "Macroeconomic benefits of Bangladesh-India electricity trade" that quantifies the trade potential and macroeconomic benefits likely to be accrued to two neighbouring countries due to electricity trade. Central Electricity Authority (CEA) has been actively engaged in exploitation of available power generation potential and planning of Cross border transmission system for South Asia Energy co-operation, not only for Bangladesh but also for the other South Asian countries such as Nepal, Bhutan, Sri Lanka and Pakistan.

Therefore, deliberation on this study was held in CEA. The report clearly indicates that export of electricity from India is an economic/cheaper option for Bangladesh and is a win-win option for both the countries. India, being surplus in generation, the export revenue earnings in the trading of electricity with Bangladesh may contribute to higher investment in the power sector and would add to the economy of the country.

I congratulate IRADe Team for carrying out such an intensive analytical work applying state-of-the-art modelling tools under SARI/EI/IRADe Project. I hope the findings of this report would be considered by Power Utilities & Electricity Regulators of both countries for promotion of regional electricity trade leading to socio-economic benefits.

(Ravindra Kumar Verma)

Message

The power sector turns into a global concern rather than a domestic issue. More and more countries of the world are taking power pooling pursuits to make more robust regional power grids to increase the reliability of supply and lower investment demands to minimize the present supply cost. On the other hand, this sort of electricity trade initiative is insignificant in South Asia, although some bilateral trade of around 2,300 MW is happening at present.

Bangladesh is a country with limited options for primary fuel. Therefore, the growth associated with a long-term energy program is really a problem, while the region it belongs to offers substantial fuel sources such as fossil fuel, hydro and renewables, though unevenly dispersed over the countries. The combined hydro potential of 350 GW in the region offers a huge scope for tapping clean energy as well as dealing with the actual persistent difficulties associated with power supply. The electrical power industry might take advantage of the actual assets, supply electricity at reduced rate to all, enhance energy security and promote environment-friendly socio-economic development by sharing energy resources, energy infrastructure, and capacity reserves. Recognizing the complexities of promoting such regional energy trade which has technical, regulatory, political and social challenges, the USAID has launched SARI/EI in 2012, which is the final phase of the SARI/E program launched in 2000. SARI/EI, with its objective of advancing regional energy integration by increasing CBET, is implemented by IRADe, a reputed think-tank/research institute located in Delhi, through a cooperative agreement with USAID.

Among a number of other activities under SARI/EI that encourages CBET in the region, IRADe has carried out this particular analytical study on the macroeconomic advantages of Bangladesh-India electrical power trade, which quantifies the actual trade potential as well as the benefits accrued between Bangladesh and India as a result of electricity trade. The research utilizes advanced as well as state-of-the-art modeling resources, depending on the optimization framework, in order to discover numerous queries upon CBET that may be appropriate with regard to policy/decision-makers/planners and acquire their quantifiable solutions. Stakeholders from both countries have been consulted and their feedback is included in the analyses. It found electricity import from India as an economic option for Bangladesh, which has two choices concerning its future electricity supply: build domestic power plants based on imported fuels (fossil fuel, gas or even nuclear energy) or/and import final product electricity from an adjoining country such as India. Electricity import brings several benefits such as reduced power supply cost, import bill, and investment for the power sector. The foreign exchange and investment saved could be diverted into other sectors where it would bring higher socio-economic improvements. By reducing dependence on imported gas, which has a more volatile market, electricity import would also help to address the energy security issue, which is a key concern for Bangladesh. CBET helps India to better use of its power plants, therefore, enhancing profitability. Export revenue earning makes Indian households gain through increased consumption, which is higher when trade is higher. Export demand and earning contribute to higher investment in the power sector as well as to the entire economy and the GDP increases.

I would like to congratulate the IRADe team for carrying out such an extensive analytical work, applying cutting edge modeling tools, under the SARI/EI/IRADe project. I hope the findings of this report will be considered by the energy utilities/electricity regulatory institutions of both countries for the promotion of electricity trading to produce the highest socio-economic returns from it.

Mohammad Hossain
Executive Director General, Power Cell
Power Division, Ministry of Power, Energy & Mineral Resources
Government of the People's Republic of Bangladesh

The Process

This study was undertaken through a consultative process that involved stakeholder consultations and workshops in Bangladesh and India. The various stakeholder consultations undertaken for this study:

October 18-20, 2016

A mission to Bangladesh to collect data, present the study to stakeholders, and discuss scenarios

- Meeting with representatives of government ministries and the channelization of contacts for data gathering for the macro model and technology model of Bangladesh.
- Presenting the study to the stakeholders and discussions on the various scenarios.

February 2, 2017

Stakeholder meeting, Hotel Sonar Gaon, Dhaka

- Meeting to present and discuss the study, its approach and scenarios, and draft outcomes to the stakeholders; validation of parameters and results by the stakeholders in Bangladesh and their suggestions to improve on the model results.

May 17, 2017

Second stakeholder meeting, Hotel Sonar Gaon, Dhaka

- Meeting to present and discuss the final results on the India-Bangladesh electricity trade and its economic impact to important stakeholders in Bangladesh and receive their feedback.

August 31, 2017

Expert group consultation meeting, CEA, New Delhi

- Presentations on the results of the India–Bangladesh hourly electricity trade model after integration with the India technology model, and the results of the Bangladesh macro model; showing the economic impact of electricity trade on the economy of both countries to Indian stakeholders; and discussions.

1. Introduction

1.1 Background

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

The countries in the South Asian region are among the poorest and the availability of reliable and adequate electricity has been one of the main bottlenecks towards achieving their economic potential. Bangladesh faces significant challenges regarding its energy resources for future power generation. The region, on the other hand, has significant energy resources such as coal, hydro, and renewables. These are, however, unevenly distributed across the countries. A combined hydro potential of 350 GW in the region offers a huge scope for tapping clean energy and addressing the chronic problems of electricity supply shortage. Electricity trade could exploit the resources, provide electricity at lower costs to all, export revenue to some, improve energy security, and promote environment-friendly socio-economic development by sharing energy resources, energy infrastructure, and capacity reserves. The current electricity trade in the region is limited to about 2,300 MW.

The South Asia Regional Initiative for Energy Integration (SARI/EI), started in 2012, is the final phase of the US Agency for International Development's (USAID's) SARI/E program, which was launched in 2000. Since its inception, SARI has helped to create an enabling environment in the region through building capacity, raising awareness, undertaking focused studies, and providing technical assistance. SARI/EI aims to further the earlier objectives of advancing regional energy integration by increasing Cross Border Electricity Trade (CBET). Integrated Research and Action for Development (IRADe) is the implementing partner of the program through a cooperative agreement with USAID. It adopts a bottom-up approach by working through the three inter-governmental taskforces with representations of each participating government to promote CBET. Under this program, IRADE has undertaken an analytical study focusing on the macroeconomic benefits from electricity trade in South Asian countries. The study on Nepal-India electricity trade is complete; the focus of this report is on India-Bangladesh electricity trade.

The socio-economic development of Bangladesh is constrained by energy supply. Its per capita electricity consumption at 251 kWh (2015) is one of the lowest in the South Asian region. 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. The small quantity of electricity import (600 MW) from India has already brought some temporary relief to deal with the acute power shortage that causes economic losses and difficulties in daily life. The lack of reliable and adequate electricity supply has been the main bottleneck in achieving the country's ambitious economic growth target.

Bangladesh faces resource challenges in the expansion of its power sector. Domestic resources for power generation are characterized by many issues. Traditionally, the country has depended on its domestic gas resources for power generation. However, an increasing demand for natural gas from other sectors limits the gas availability for power generation. The gas reserve is also declining. The development of coal reserves are hindered by complex social and environmental problems. As the country lacks petroleum reserves, it meets almost its entire oil and products needs through import. Bangladesh also lacks hydro potential. Information on renewables is limited. Despite having about 4.5 million solar home systems, awareness on the role of renewable energy in energy supply is weak. A realistic assessment on the potential of wind or solar is not available. With declining gas reserves, the socio-economic difficulties in expanding the domestic mining of coal, and an almost negligible resource of crude, Bangladesh faces a serious challenge towards securing its future energy supplies.

The choice that Bangladesh has in terms of expanding its electricity supply includes building domestic power plants based on imported fuels (coal, natural gas or nuclear fuel) or/and importing final product electricity from neighboring countries such as India. Building domestic power plants involves a massive investment in power plant construction and fuel supply infrastructure, depriving investment in other sectors, as well as regular foreign exchange outflow to pay for fuel import. The second option needs building interconnections, which may require less time and capital, but involves regular foreign exchange outflow for the payment of electricity import. Both options have different kinds of economic consequences. In addition, the almost complete dependence on import, implicitly or explicitly, for the supply of such a key product, makes energy supply security a matter of grave concern. The diversification of the power system by fuel type and supply sources improves supply security. Bangladesh needs to strategize its power supply, which would reduce the energy security threat and, at the same time, keep the power supply cost low and balance the investment and foreign exchange availability between the power sector and the rest of the economy. This raises the question: How much electricity trade is possible and desirable to ensure energy security, low power supply cost, and lead to acceptable economic consequences?

1.2 Past Studies

A detailed review on cross-border electricity trade in the South Asian region (including Bangladesh), is presented in the report on Nepal-India electricity trade.[1] The scope of the studies is limited to the power system and, therefore, estimations of costs and benefits are limited to the power sector and not to the entire economy. These studies have demonstrated that the trade brings economic benefits to the power system in terms of savings on investment and electricity supply costs.

The Power Sector Master Plan (PSMP) 2016 of Bangladesh, sponsored by the Japan International Cooperation Agency (JICA),[2] which is built upon the earlier PSMP 2010, developed five scenarios of energy mix with the share of coal and gas in the energy mix varying from 15 percent to 70 percent by 2041. The share of nuclear, PI (Power Import)/RE, and oil/hydro/others is kept fixed at 10 percent, 15 percent, and 5 percent, respectively, in the energy mix in all these scenarios.

The optimum power source composition is determined by conducting a quantitative evaluation of the economic, environmental, and energy security (3E) values of the scenarios. The scenario with the share of both gas and coal in power generation in 2041 at 35 percent has the lowest value for 3E assessment, and is, therefore, considered to be the optimum power generation mix and used for basic future power development plans.

However, none of these studies carried a socio-economic impact assessment of CBET for the nation as a whole.

[1]http://irade.org/Executive%20Summary-Economic%20Benefits%20from%20Nepal-Indai%20Electricity%20Trade-SARI-EI-IRADe-Rajiv.pdf
[2]Japan International Cooperation Agency. People's Republic of Bangladesh Survey on Power System Master Plan Draft Final Report 2016.

1.3 Current Study

This series of study introduces the macroeconomic linkages in power sector expansion planning to understand the macroeconomic impact of electricity trade as a supply option. In this context, the current study attempts to assess if electricity import from neighboring India, as one of the power supply options in Bangladesh, would bring any macroeconomic benefits. Exporter India needs to invest in power plants to build power supply capacity, depriving the other sectors of investment, and earn foreign exchange inflow from export revenue, which can be used for investment or other economic purposes. For India, the question is what would be the price and export level that brings net economic gains for the country as a whole. Applying a series of optimization models (macroeconomic and techno-economic), the study, therefore, determines the optimal level of power trade and the price of tradable electricity, acceptable to both the parties and consistent with their complete macroeconomic sustainability. The same methodology that has been applied to quantify the macroeconomic feedback and socio-economic benefits of trade between India and Nepal[3] is applied here as well.

1.3.1 Objectives

The primary objective of the study is to improve energy cooperation between the two countries by strengthening the policy and decision-makers, and other stakeholders, with the necessary information on the scope and benefits of CBET to strategize its promotion and implementation. The study attempts to produce evidence for the policy and decision-makers to build consensus between countries and within countries through informed dialogues and negotiations to support the creation and implementation of CBET.

1.3.2 Key Questions to be Answered

The study intends to strengthen the policy-makers/planners of Bangladesh with information on power supply strategies, the role of electricity import and macroeconomic implications. It also looks into the technical and economic implications (in terms of capacity, generation, various costs, and so on) to the power sector. At the same time, it also attempts to strengthen Indian counterparts with information on what would be the power sector and macroeconomic implications in India of exporting electricity to Bangladesh. The key questions explored are:

- What would be the power supply strategies (capacity, generation, technology, import/export, investment, fuel, power supply cost, and so on) in Bangladesh as well as in India with different levels of power trade?
- What are the macroeconomic implications to Bangladesh and India in terms of the growth of the GDP and investment (in the power sector and the rest of the economy) fuelled by the impact from electricity trade?

The answers to the following questions, which would be of interest to the stakeholders, are also explored here:

- What would be the optimal level of trading and price agreeable to both the buyer and the seller?
- What would be the impact on the living standard measured through per capita consumption levels?
- How would the per capita electricity use change?
- What are the consequential environmental costs and benefits?

[3]http://irade.org/Executive%20Summary-Economic%20Benefits%20from%20Nepal-Indai%20Electricity%20Trade-SARI-EI-IRADe-Rajiv.pdf

1.3.3 Scope

To our knowledge, this is the first study that attempts to assess the economy-wide impact of electricity trade. The period of the analysis is 2012–45. The scope of the study is:

- Analytical work to assess
  - Several electricity supply scenarios with electricity trade as an option.
  - The impact of CBET on power system development and the economies of both countries.

1.4 Report Structure

The report is structured in the following manner:

- Chapter 1 provides the background and rationale for the study, followed by the objectives, key questions to be addressed, and their scope.
- Chapter 2 gives a short description of the economy and electricity sector of both countries.
- Chapter 3 presents the approach and methodology.
- Chapter 4 provides the model structure and assumptions by models and by countries.
- Chapter 5 presents the results and analyses.
- Chapter 6 covers the conclusions and directions for future work.

2. Country Overview

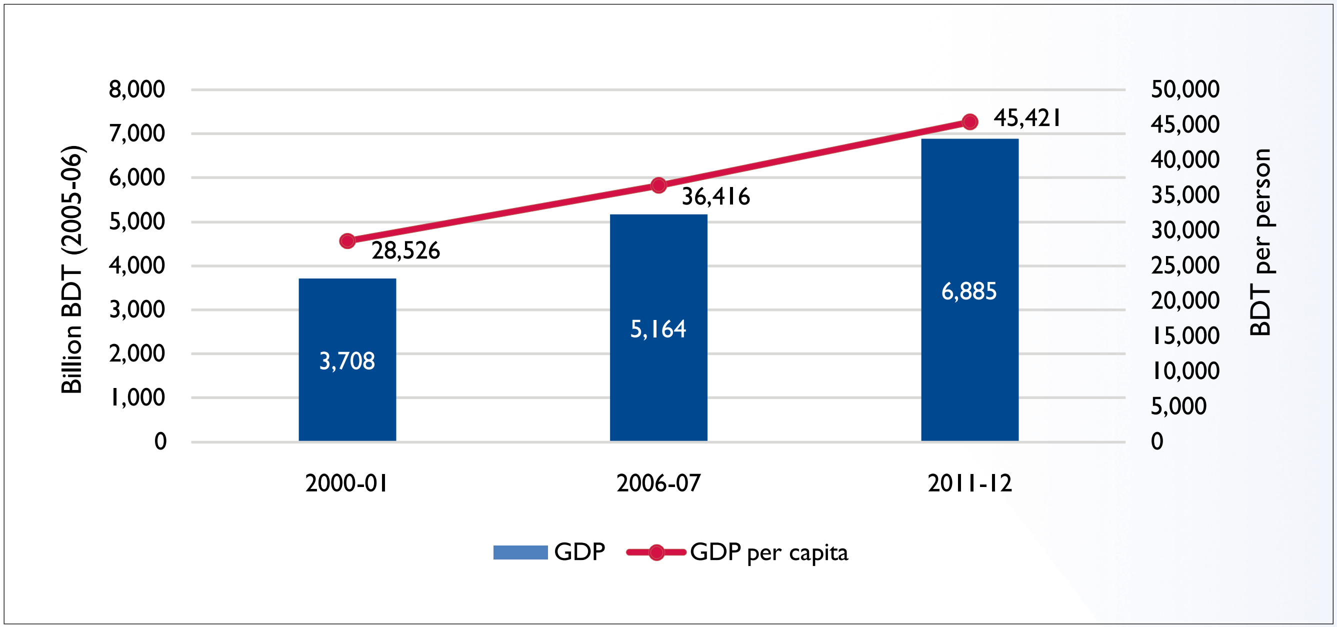
This chapter presents an overview of the economy and electricity sector for Bangladesh and India.

2.1 Bangladesh

2.1.1 Economy

Unless stated otherwise, all economic indicators of Bangladesh are at 2005–06 prices. Figure 2.1 presents the growth in GDP and per capita income. GDP (at market price) stood at 6,885 billion BDT in 2011–12, registering a compound annual growth rate (CAGR) of 5.78 percent over the period from 2001–12. The economy of Bangladesh has expanded 1.85 times in the past 11 years. The per capita income has grown from 28,526 BDT in 2000–01 to 45, 421 BDT in 2011–12.

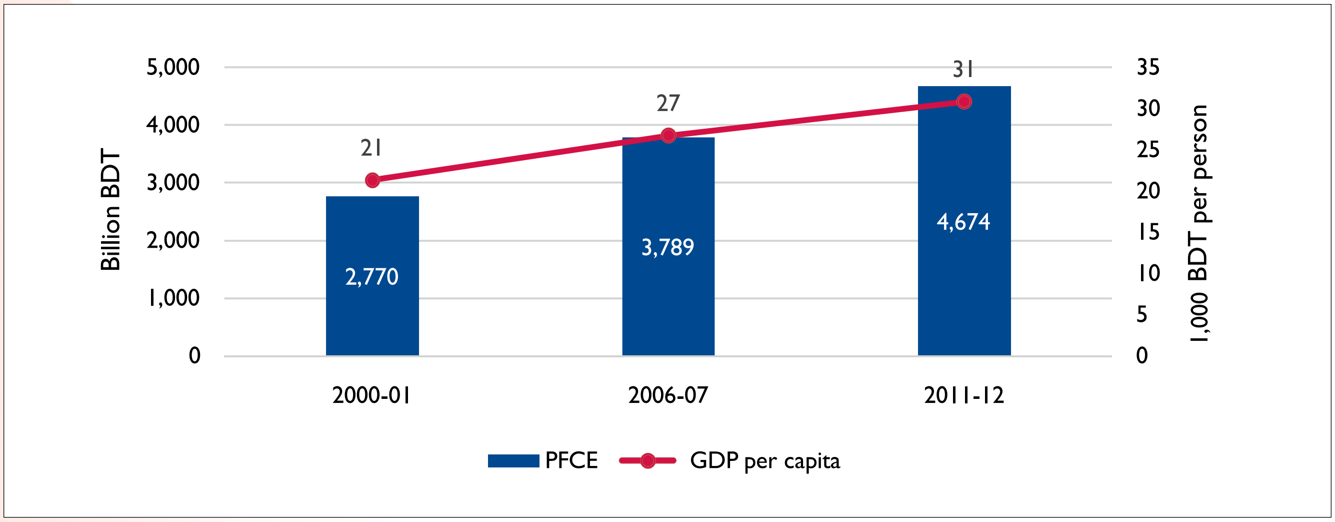
Figure 2.1 GDP and GDP Per Capita



Source: National Accounts Statistics (Bangladesh)

The private final consumption expenditure (PFCE) has increased 1.68 times in the last 11 years, from 2,770 billion BDT in 2001–02 to 4,674 billion BDT in 2011–12 (Figure 2.2). The per capita consumption as of 2012 stood at 31,000 BDT. In 2010, 31.5 percent of Bangladesh's population was below the national poverty line (Ministry of Finance, Bangladesh, 2015).

Figure 2.2 **Total and Per Capita Private Final Consumption Expenditure (PFCE)**



Source: National Accounts Statistics (Bangladesh)

Figure 2.3 presents the gross domestic savings (GDS) and gross domestic capital formation (GDCF) as a percentage of GDP at constant prices (Bangladesh NAS sources and methods, 2014). In 2000–01, the GDS of Bangladesh stood at 21 percent of the GDP; it rose to 27 percent in 2011–12. The GDCF or investment in the economy, on the other hand, formed 23 percent of the GDP in 2000–01 and rose to 30 percent in 2011–12. The net capital flow has shown growth over time (Figure 2.4), except for a downfall in 2011–12.

Figure 2.3 **Gross Domestic Savings (GDS) and Gross Domestic Capital Formation (GDCF)**

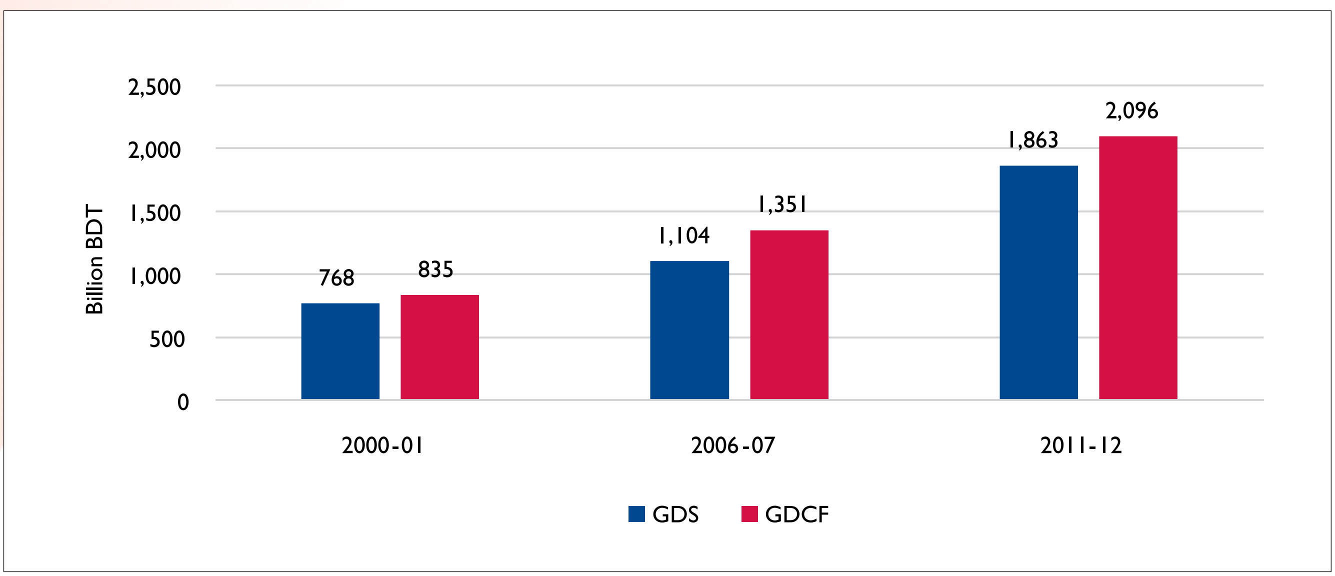
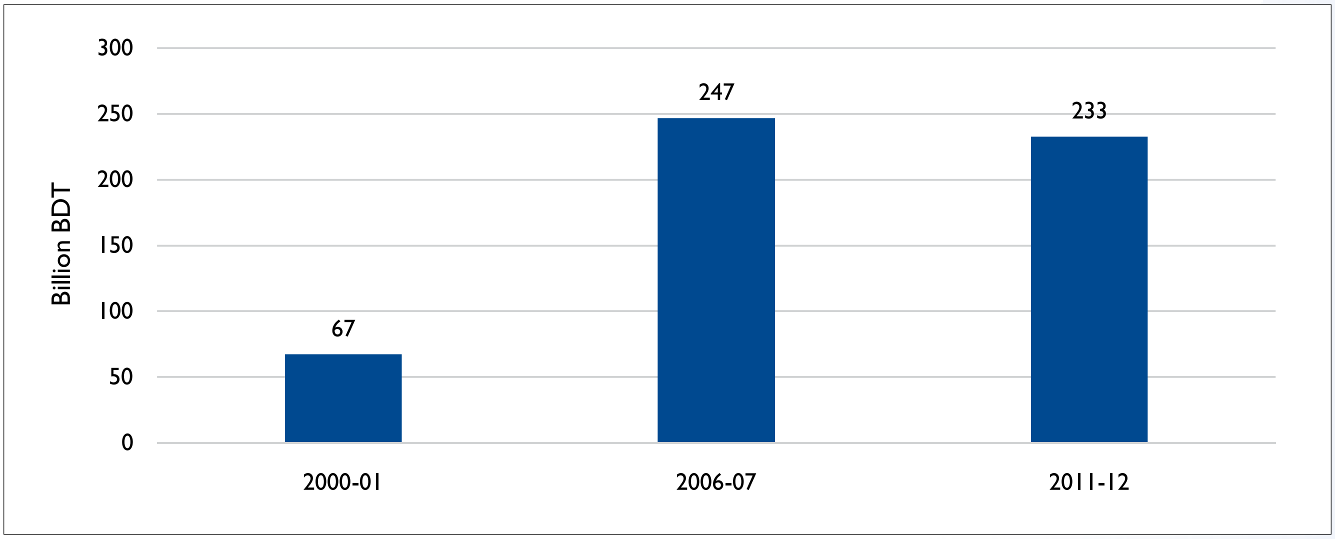
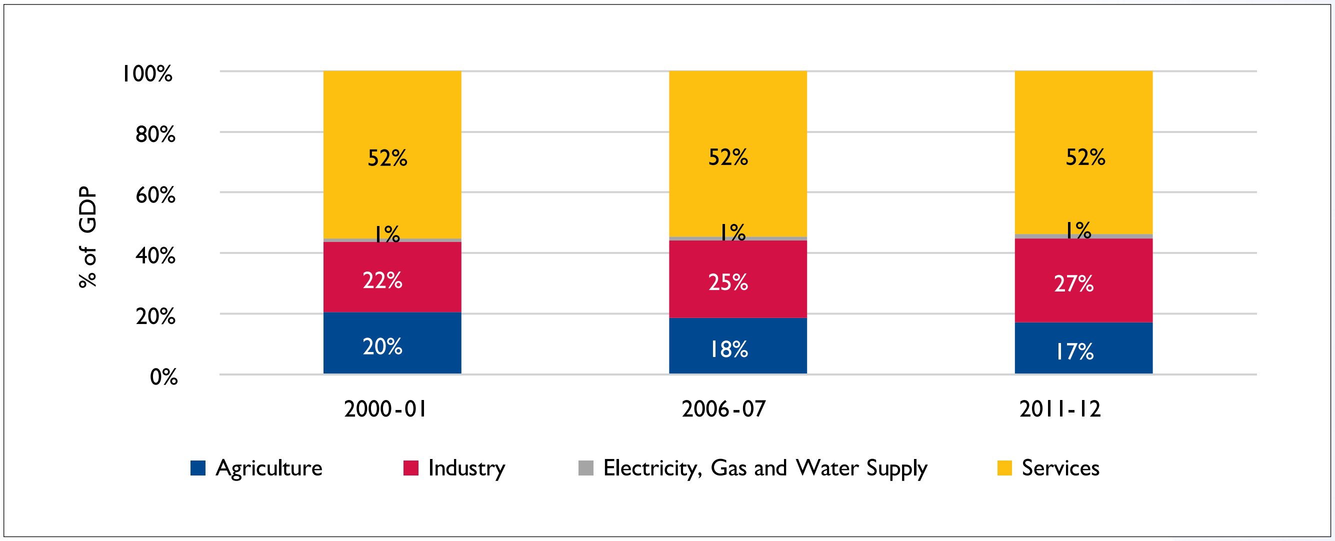


Figure 2.4 **Net Capital Inflow**



Source: Bangladesh National Accounts Statistics Sources and Methods 2014

Figure 2.5 **Sectoral Composition of the GDP**



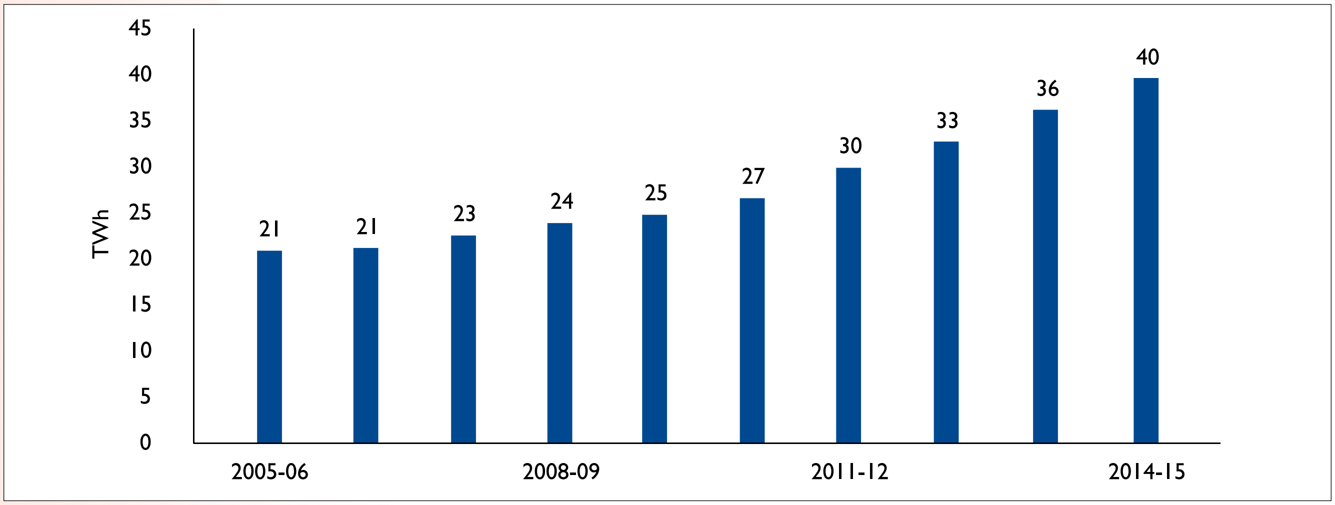
Source: National Accounts Statistics (Bangladesh)

The service sector constitutes the largest share of Bangladesh's GDP (Figure 2.5). Over the last 11 years, the share of services in the Bangladesh economy has remained constant at 52 percent. The industrial sector (excluding electricity) accounted for 27 percent of the total GDP in 2011–12, followed by the agricultural sector (17 percent). The combined electricity, gas, and water sector contributes marginally to the nation's GDP at 1 percent.

2.1.2 Electricity Sector

In the past decade, the electricity demand in Bangladesh has risen from about 20.9 TWh (2005–06) to 39.6 TWh (2014–15), registering a growth rate of 7.3 percent per annum (Figure 2.6). Despite this growth, the per capita consumption remains one of the lowest in the world. The per capita electricity consumption in 2014–15 was 251 kWh.

Figure 2.6 Growth in Electricity Sales

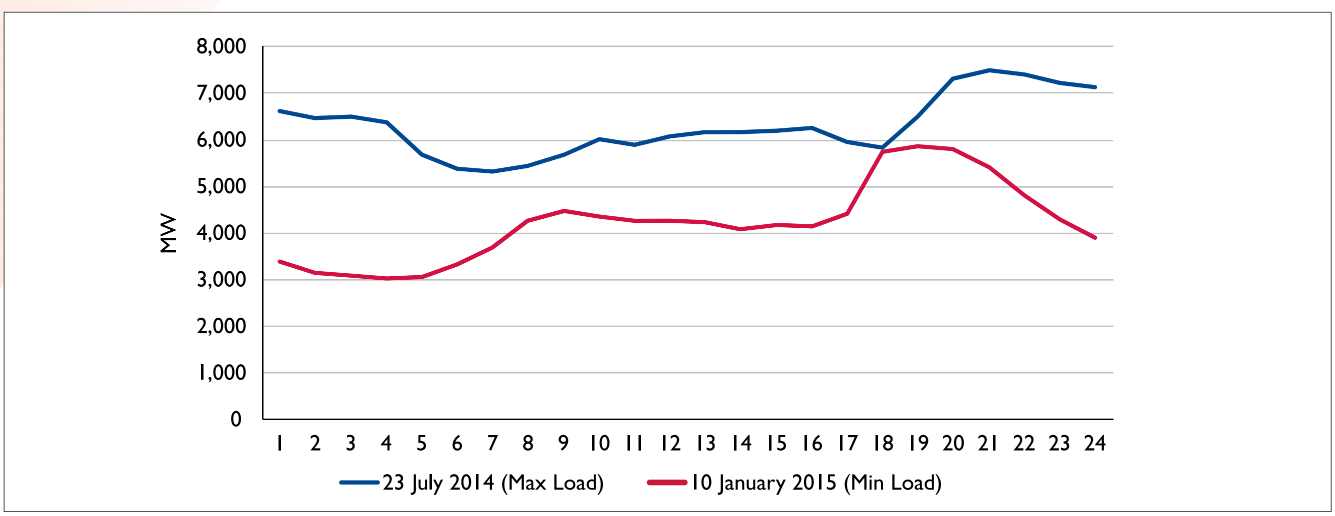


Source: BPDP Annual Report 2015–16

The domestic sector is the largest consumer of electricity in Bangladesh, accounting for more than 50 percent of the total consumption, followed by the industrial sector, accounting for 33.6 percent.

Figure 2.7 shows the daily load curve for days recording the maximum load and the minimum load recorded in a particular year (2014). The summer peak occurs between 8 pm and 9 pm. In winters, on the other hand, the peak occurs between 6 pm and 7 pm, as depicted in the figure. The annual maximum load occurred in July and the minimum system load was in January.

Figure 2.7 Daily Load Curve



Electricity Supply System

As shown in Figure 2.8, the generation capacity has increased from 5,202 MW in 2007–08 to 12,855 MW as of August 2016. The generation system is dominated by gas-based capacity powered by domestically available natural gas resources. However, in order to overcome the shortage of electricity caused by a dwindling domestic supply of fuel, the installation of high-cost oil-based plants in the form of Quick Rental Power Plants (QRPPs) has been promoted in the last five years. Apart from natural gas and oil-based plants, Bangladesh has limited hydro and coal-based capacity, which cumulatively totals to about 412 MW only. Since 2014–15, Bangladesh has also begun importing electricity from India.

The last eight years has seen electricity generation in Bangladesh grow from 24.3 TWh (2007–08) to 43.7 TWh (2014–15) (Figure 2.9). In 2007–08, natural gas was the dominating fuel for electricity generation, with a share of 86 percent. However, over the years, as domestic gas production stagnates and the demand for gas in the competing sectors grows, the share of gas in power generation declines, although gas-based generation increases in absolute quantity.

Figure 2.8 Power Generation Capacity Development by Fuel Sources

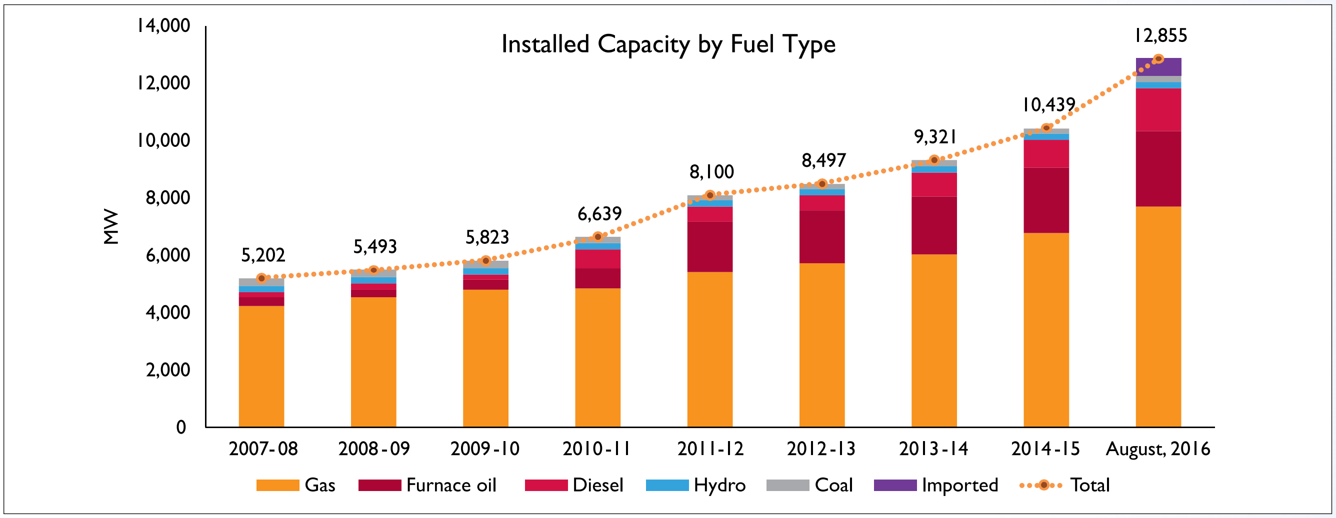
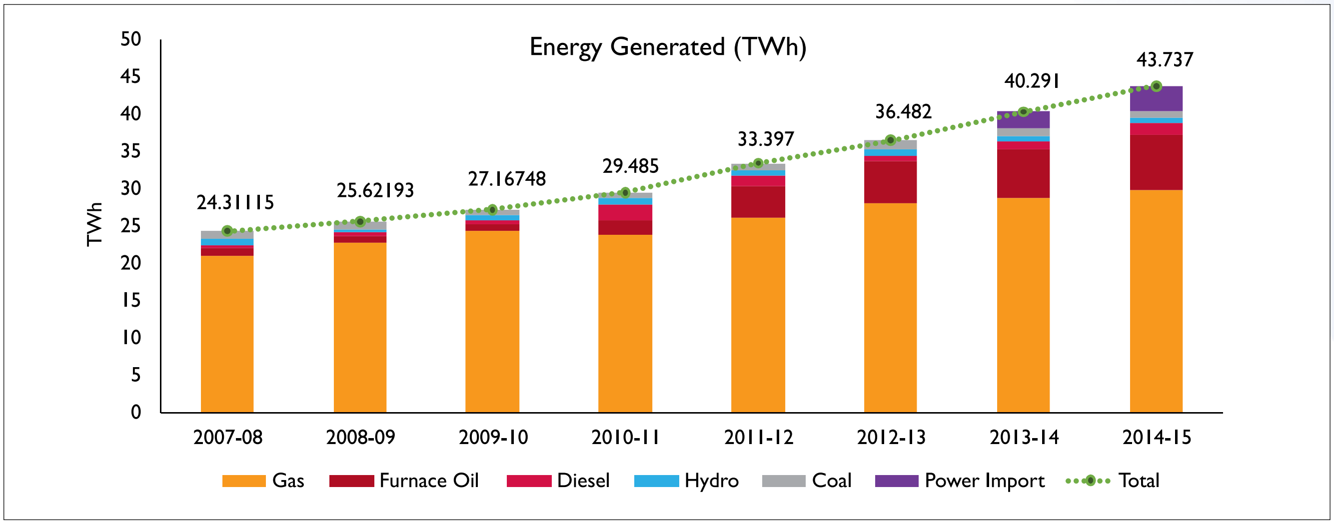


Figure 2.9 Electricity Generation



The share of gas is gradually replaced by furnace oil and diesel. Import from India starts from 2013–14. The import during that year was 2.26 TWh, which increased to 3.38 TWh in the next year.

The progress on renewable energy development is not impressive. At present, the total capacity is 202.9 MW, which is predominantly solar PV. Table 2.1 presents the current capacity by technology.

Table 2.1 Capacity (MW) by Technology Based on Renewable Energy

Technology	Off-Grid	On-Grid	Total
Solar PV	193	1	194
Wind	2	0.9	2.9
Biogas to Electricity	5	-	5
Biomass to Electricity	1		1
Total	**201**	**1.9**	**202.9**

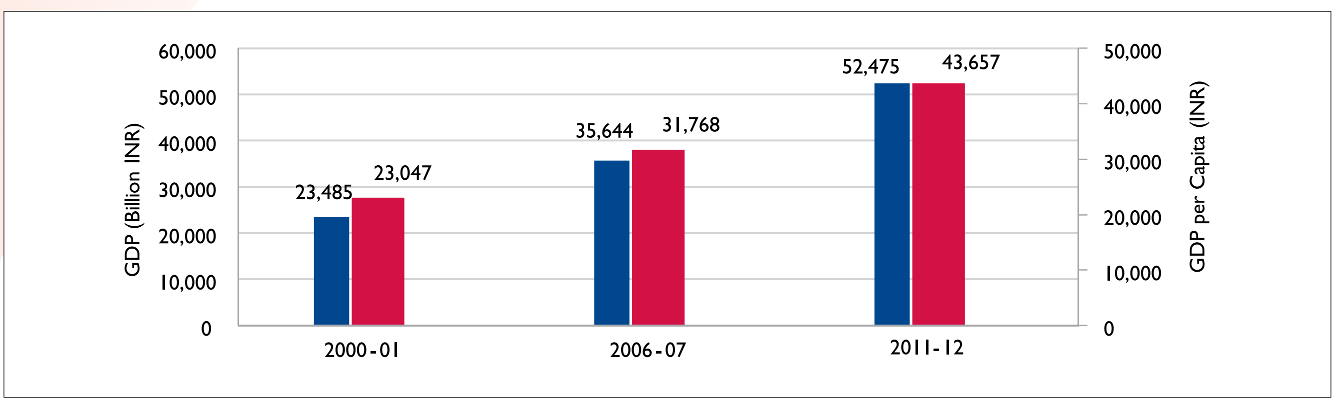
The Bangladesh Power Development Board (BPDB) provides fuel consumption only for the public power plants; the International Energy Agency (IEA) provides the annual energy balance for Bangladesh (latest data available for 2014). According to the IEA energy balance data, in 2014, the Bangladesh power sector consumed about 446 billion cubic feet (bcft) of natural gas, 1.5 million tonnes of petroleum products, and 0.4 million tonnes of coal. The national availability of natural gas was 786 billion cubic feet during the same year, therefore, the power sector accounted for about 57 percent of the total gas availability (762 bcft).

2.2 India

2.2.1 Economy

Unless stated otherwise, all economic indicators of India are at 2004–05 prices. Figure 2.10 presents the growth in the GDP and per capita income. The GDP (at factor cost) stood at INR 52,475 billion[4] in 2011–12, registering a CAGR[5] of 7.73 percent over the period 2001–11. At 2004–05 prices, the Indian economy has expanded by 2.23 times in the past 12 years. The per capita GDP (at factor cost) has nearly doubled in 12 years, from INR 23,047 to INR 43,657.

Figure 2.10 GDP and GDP Per Capita, India

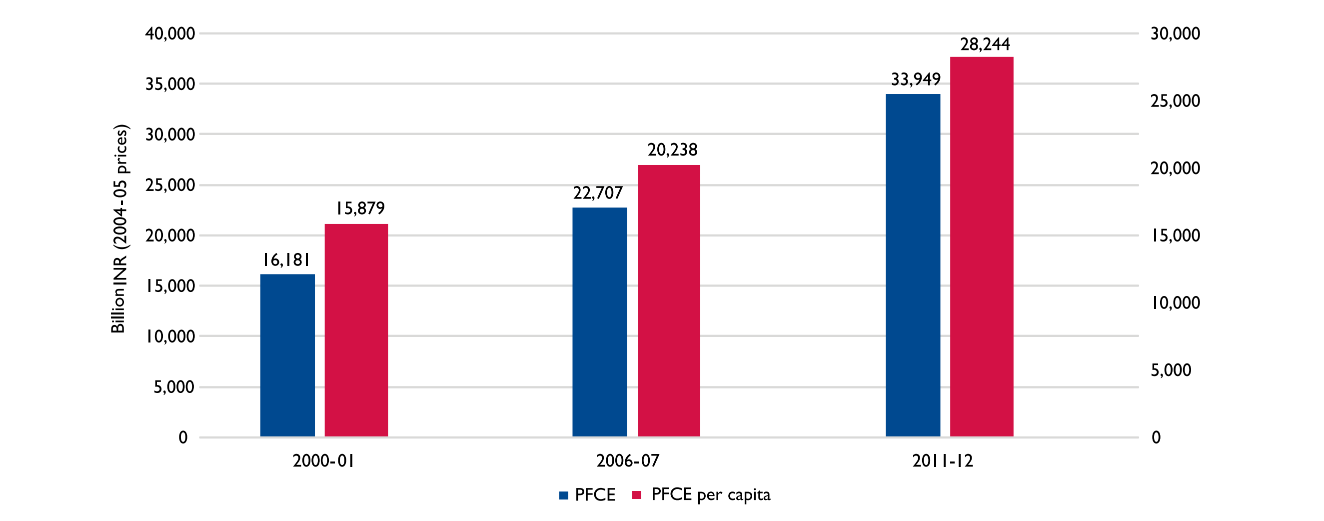


Source: RBI Handbook of Statistics on Indian Economy 2015, CSO

[4]At 2004–05 prices.
[5]Compounded annual growth rate (CAGR).

The PFCE has increased significantly, from INR 16,181 billion in 2000–01 to INR 33,949 billion in 2011–12 (Figure 2.11). The per capita consumption expenditure in the domestic market is INR 28,244 for 2011–12.

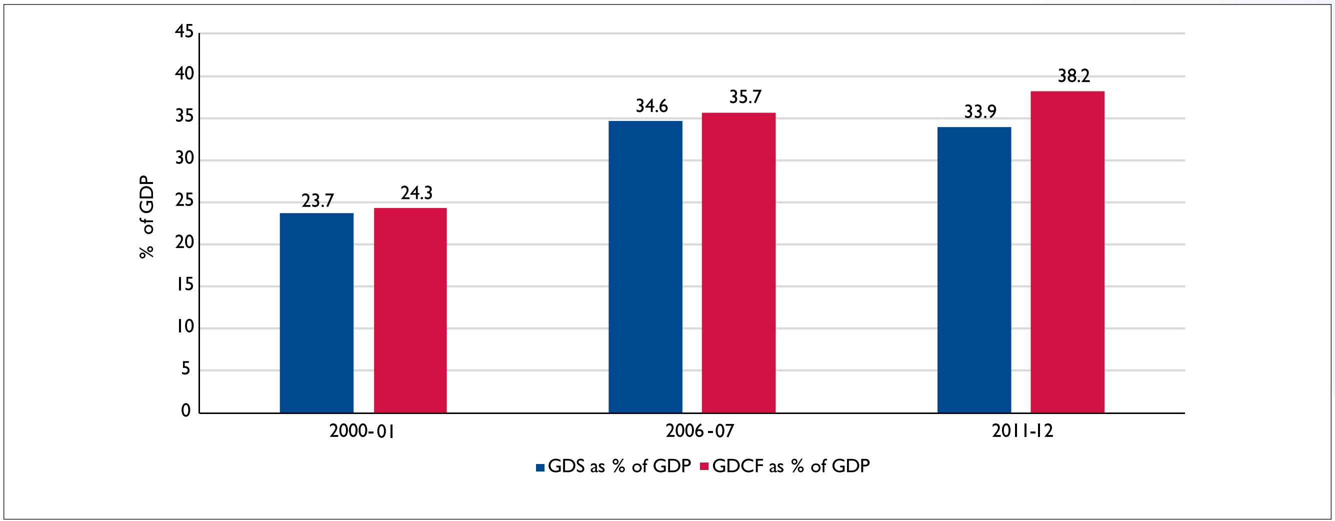
Figure 2.11 PFCE and PFCE Per Capita



According to the Tendulkar Methodology,[6] the percentages of the rural and urban poor have halved from 1993 to 2011, from 50.1 percent to 25.7 percent in the rural areas and 31.8 percent to 13.7 percent in the urban areas.

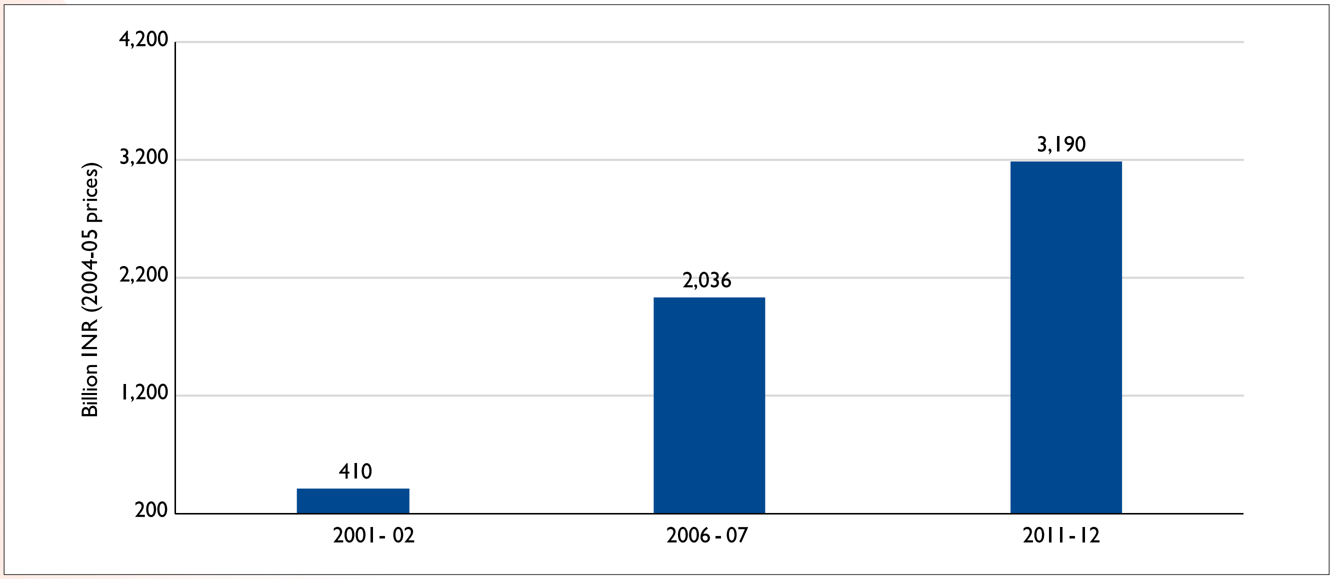
Figure 2.12 presents the GDS and Gross Domestic Capital Formation (GDCF) as percentage of the GDP. In 2000–01, the GDS was 24 percent of the GDP, which has risen to 30 percent in 2012.[7] The GDCF (or investment) was 24 percent in 2000–01 and rose to 35 percent in 2012–13. The net capital flow has increased from INR 411 billion in 2001–02 to INR 3,190 billion in 2011–12 (Figure 2.13).

Figure 2.12 GDS and GDCF



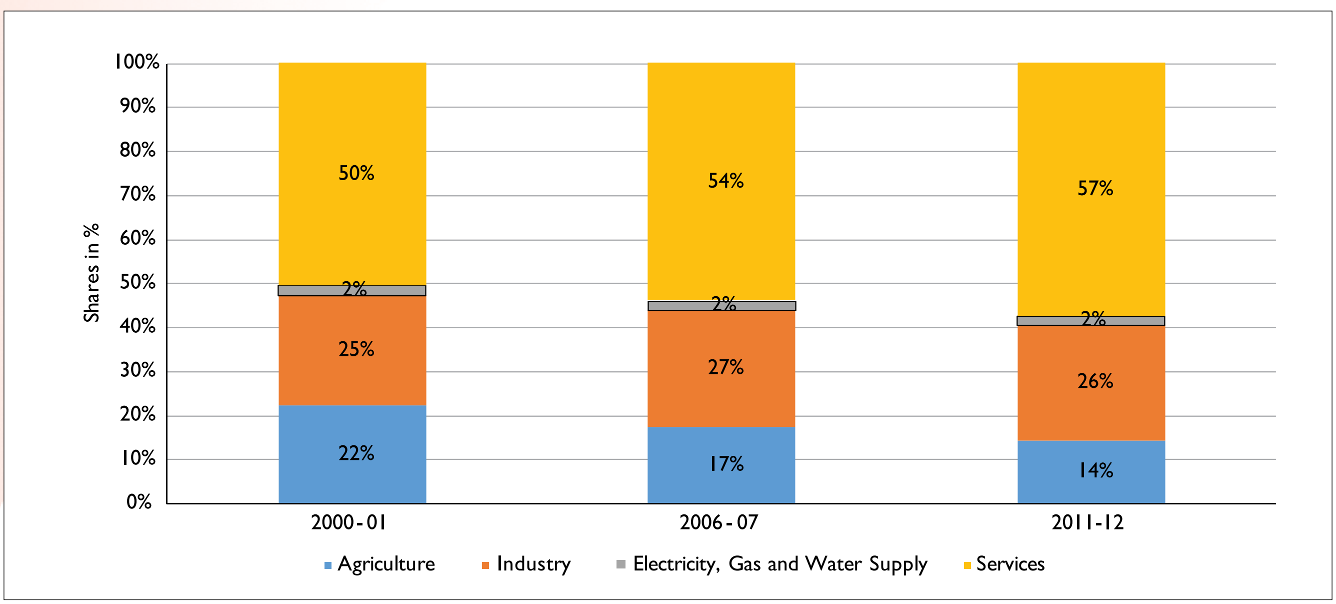
[6]Source: Planning Commission, Indian economy major sectors at a glance, 2014.
[7]Source: Planning Commission, Indian economy major sectors at a glance, 2014.

Figure 2.13 Net Capital Flow



The services sector is India's largest sector. The GDP at constant prices for this sector was INR 36 billion in 2012 (Figure 2.14). Over the last decade, the share of the services sector in the total GDP has increased from 52 percent to 55 percent. Industry (excluding the electricity sector) accounts for 26 percent of the total GDP, followed by the agriculture sector at 17 percent. The electricity sector contributes only marginally to the GDP, at 0.02 percent, which has remained almost the same over the last decade.

Figure 2.14 Sectoral Composition of the GDP



2.2.2 Electricity Sector

India has rapidly grown in installing power generation capacity. As on March 31, 2015, the installed power generation capacity (utility and non-utility) stood at 316.3 GW. Figure 2.15 presents the development in the power generation capacity by fuel sources during the period 2006–07 and 2014–15. Coal dominates with a steadily increasing share of about 60 percent. Hydropower accounts for the second largest capacity and stood at 40.5 GW in 2012–13; however, its share has fallen significantly. The renewable capacity during this period has increased four times, from 7.9 GW to 37.1 GW.

The gross electricity generation almost doubled to 1,266 TWh in 2014–15, from 623.8 TWh in 2005–06, registering a CAGR of 6.7 percent. Figure 2.16 presents the generation by fuel sources from 2006–07 to 2011–12. In terms of generation, coal dominates with a share of 68 percent in 2011–12. In 2014–15, the electricity sector consumed 527 million tonnes (MT) of coal and10.7 billion cubic meter (BCM) of natural gas. Transmission and distribution loss was very high, at 22.8 percent in 2014–15, although this has declined over time. The electricity consumption in 2014–15 was 948 TWh. Although consumption registered a growth of 8.5 percent compared to the previous year, India remains one of the lowest consumers of electricity when per capita consumption (957 kWh in 2013–14) is considered. About 78.7 percent of the population has access to electricity (2012).

Figure 2.15 Development in Installed Power Generation Capacity

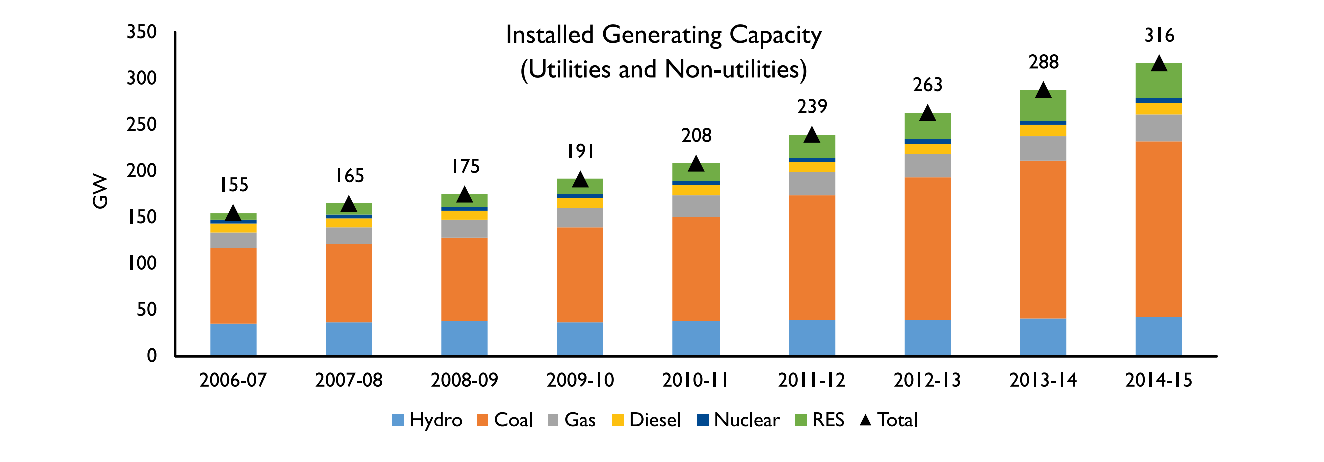
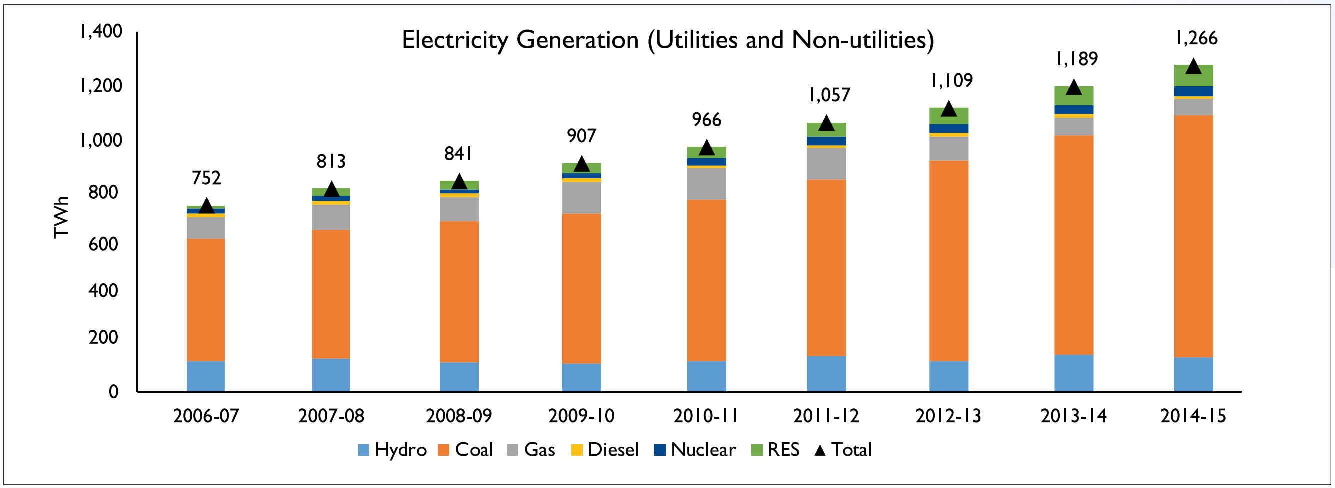


Figure 2.16 Growth in Electricity Generation



The Indian electricity system is connected with that of Bangladesh, Bhutan, and Nepal. The country is importing electricity from Bhutan since 1986, when the Chukhahydel power plant was commissioned, with Indian support. Trade is increasing as a couple of plants have already been constructed, or are under construction, with support from Indian companies. Further, exports to Nepal have grown over the years, from 638 GWh in 2010 to 1,318 GWh in 2014. On October 21, 2014, India and Nepal signed a historic Power Trade Agreement allowing the exchange of electricity, opening up new vistas of cooperation in the hydropower sector.[8] In 2013–14, India started exporting electricity to Bangladesh. The current interconnection capacity between India and Bangladesh is 600 MW.

India is endowed with a large coal reserve; as on March 31, 2015, the estimated reserves of coal and lignite were 306 BT and 43 BT,[9] respectively. Little wonder, then, that coal dominates India's energy supply, including its power generation. However, India's hydrocarbon reserve is not satisfactory and the estimated reserve stood at 763 MT of crude oil and 1,488 BCM of natural gas. The total potential for the renewable power generation in the country, as on March 31, 2015, is estimated at 896,603 MW. This includes a wind power potential of 102,772 MW (11.46 percent); a small hydropower (SHP) potential of 19,749 MW (2.20 percent); a biomass power potential of 17,538 MW (1.96 percent); 5,000 MW (0.56 percent) from bagasse-based cogeneration in sugar mills; and a solar power potential of 748,990 MW (83.54 percent).

[8] http://www.business-standard.com/article/news-ians/finally-nepal-india-sign-power-trade-agreement-114102101037_1.html

[9] GoI, 2016, Energy Statistics 2016, Central Statistics Office, Ministry of Statistics and Programme Implementation, Government of India, New Delhi.

3. Approach and Methodology

3.1 Approach

The approach includes a modeling framework and scenario analyses. While scenarios in this study are different and Bangladesh-specific, the framework remains the same as that used for the Nepal-India study report.[10] However, the methodology is reproduced here for the convenience of the reader of this report.

The assessment of the economy-wide impact of electricity trade from 2012 to 2045 needs to factor in the future development of the physical power system of the country. This involves its physical system orientation, operation, future investment plan, time-variant potential optimal acceptable electricity trade in physical quantity, and tracing its two-way linkages and implications to the rest of the economy.

A modeling system that applies two types of models is developed, a power system model and a macroeconomic model, soft-linked to each other through an iterative process. The power system model assesses the physical (energy, capacity, traded quantity) and economic implications (electricity price, investment, and trade revenue) related to the power system of the country. Generally, the demand for electricity is externally specified in such models. However, the cost of supply and earnings from trade would affect the growth of the economy and the demand for electricity. In our system, the macroeconomic model assesses this impact on the economy and the demand for electricity and the other segments of the economy through its linkage to the electricity sector. These models are solved iteratively to ensure that the power system requirement, plans and trade revenues are consistent with the growth of rest of the sectors in the economy. The models are used to develop scenarios and carry out analyses to quantify the CBET benefits.

3.2 Models

The physical power systems of each of the two countries are modeled separately, using an energy system modeling software, TIMES. The TIMES[11] model is a technology-rich, least-cost, dynamic linear programming model representing the physical orientation 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 of the 288 sub-periods of the year over the period 2012–45. 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, and so on) in the country. These two models are named IBTec for Bangladesh and IITec for India.

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

[10] http://irade.org/Executive%20Summary-Economic%20Benefits%20from%20Nepal-Indai%20Electricity%20Trade-SARI-EI-IRADe-Rajiv.pdf

[11] The Integrated MARKAL-EFOM System model, for details, visit http://iea-etsap.org/index.php/etsap-tools/model-generators/times

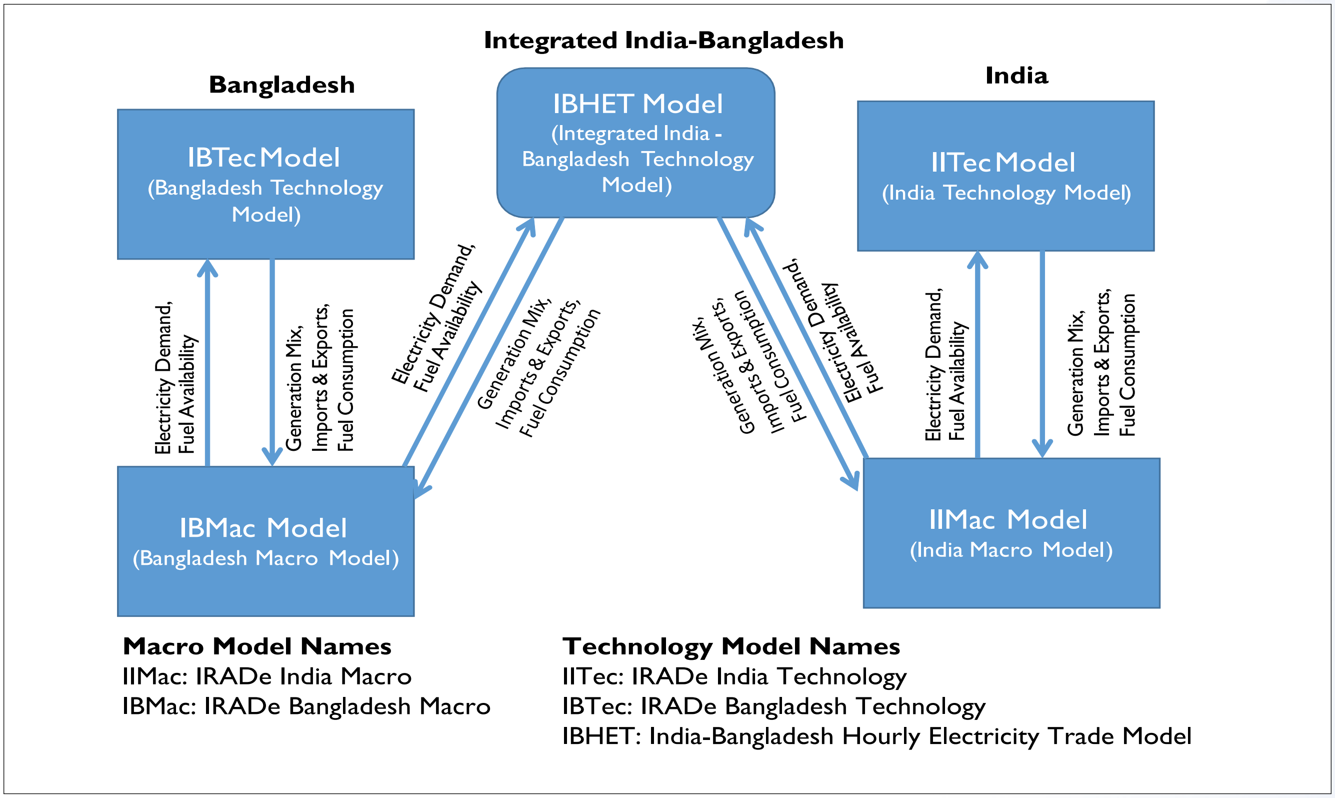
The macroeconomic model applies a Social Accounting Matrix (SAM)-based activity analysis model for India and Bangladesh separately using the latest available SAM. The model optimizes discounted values of total consumption flows in the economy, subject to a set of constraints. It solves, among other things, the demand (including electricity), production, trade, and investment requirement for all sectors in the country. To establish the link between the physical power system model and the macroeconomic model (represented in monetary value), the macroeconomic model has a detailed representation of the energy sector, especially the power sector, which includes the break-up of output by power generation technologies consistent with the power system model.

Although the power system of each country is modeled separately in the TIMES model generator, the software allows the integration of two national power system models into one. This can solve the optimal quantity of tradable electricity for each sub-period and the price along with the optimal investment on the new capacity in each system. At the same time, it minimizes the net present value of the total power system costs of both countries together. This integrated model is called IBHET (India-Bangladesh Hourly Electricity Trade).

The *IRADe System for Analysis of Power Trade and Economic Growth (I-SAPTEG)* modeling system has three power system models and two macroeconomic models: (1) **IBTec, IRADe Bangladesh Technology**; (2) **IITec, IRADe India Technology**; (3) **IBHET, India-Bangladesh Hourly Electricity Trade**; (4) **IBMac, IRADe Bangladesh Macro**; and (5) **IIMac, IRADe India Macro**. Two of the three power system models represent the power system of each country separately; the third one represents the power system of two countries in an integrated framework so that they could interact for the trading of electricity. The last two models capture the macroeconomic structure of each of the two countries separately. The modeling system, including the five models and their linkages, is depicted in Figure 3.1.

Inevitably, numerous assumptions are entered into all these models ranging from domestic energy resource availability, fuel imports, scheduled construction of power projects, available technology options and their respective technical and economic performances, to 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 both countries were consulted for these assumptions, which are listed in Chapter 4.

Figure 3.1 Modeling System (I-SAPTEG)



3.3 Scenarios

To assess the impact of electricity trade as an option for future power sector development, we developed three scenarios primarily focusing on the situation in Bangladesh, which are then simulated for both countries:

- Reference (REF)
- Power Sector Master Plan (PSMP)
- TRADE-30

The REF scenario assumes no increased interconnections between countries beyond what are currently in place (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.

As stated earlier, the Power Sector Master Plan 2016,[12] prepared by JICA and the Bangladesh Government, has become the central planning document for the expansion plan in Bangladesh. As per the recommendations of the study, the Bangladesh Power Development Board (BPDB), under the guidance

[12]http://powerdivision.portal.gov.bd/sites/default/files/files/powerdivision.portal.gov.bd/page/4f81bf4d_1180_4c53_b27c_8fa0eb11e2c1/%28E%29_FR_PSMP2016_Summary_revised.pdf

of the Ministry of Energy, has decided to adopt an energy security framework for the expansion of the power sector. The key objective of this framework is achieving energy security through diversifying the sources of power supply. Accordingly, shares of capacity based on coal, natural gas, nuclear, electricity import, liquid, hydro, and renewables are fixed at 35 percent, 35 percent, 12 percent, 16 percent, 1 percent, and 1 percent, respectively, of the total power generation capacity by 2041.

The PSMP scenario that we have developed follows the same resource mix, but instead of capacity, considers the generation while distributing the share by different sources of power supply as it makes the scenario results more stable and meaningful. Also, to accommodate the 2015–21 renewables target of SREDA, the share of liquid has been reduced. These targeted shares of 2041 will be achieved with linear increase over the period 2015–41 and will continue thereafter.

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 results of the PSMP scenario are compared with the BASE scenario to quantify the cost and benefits of energy security gain as imposed by the PSMP scenario. The TRADE-30 scenario is then compared with the PSMP scenario to demonstrate if the strategically increased electricity import could address the energy security concern through the diversification of sources at a cheaper cost than the PSMP scenario, additionally bringing some macroeconomic and environment benefits to the country. Essentially, since Bangladesh is going to have a shortage of domestically available fossil fuel resources, as would be later explained in section 4.1.2, hence its energy future is likely to be import dependent. It has to either import fossil fuels to generate electricity or import electricity itself. The PSMP and TRADE-30 scenarios are two different import-based strategies for the electricity sector in Bangladesh. The PSMP scenario represents a fossil fuel import strategy to produce power domestically and the TRADE-30 scenario represents an electricity import strategy to provide for power.

The quantification of the power trade and its economic implications on the economy are carried out through the iterative simulations of the power system technology models and the macroeconomic ones. This ensures that the levels of trade generation by different technologies and the demand for electricity, taking into account the earning from trade, are consistent. The detailed working of the iterative process is described in the box.

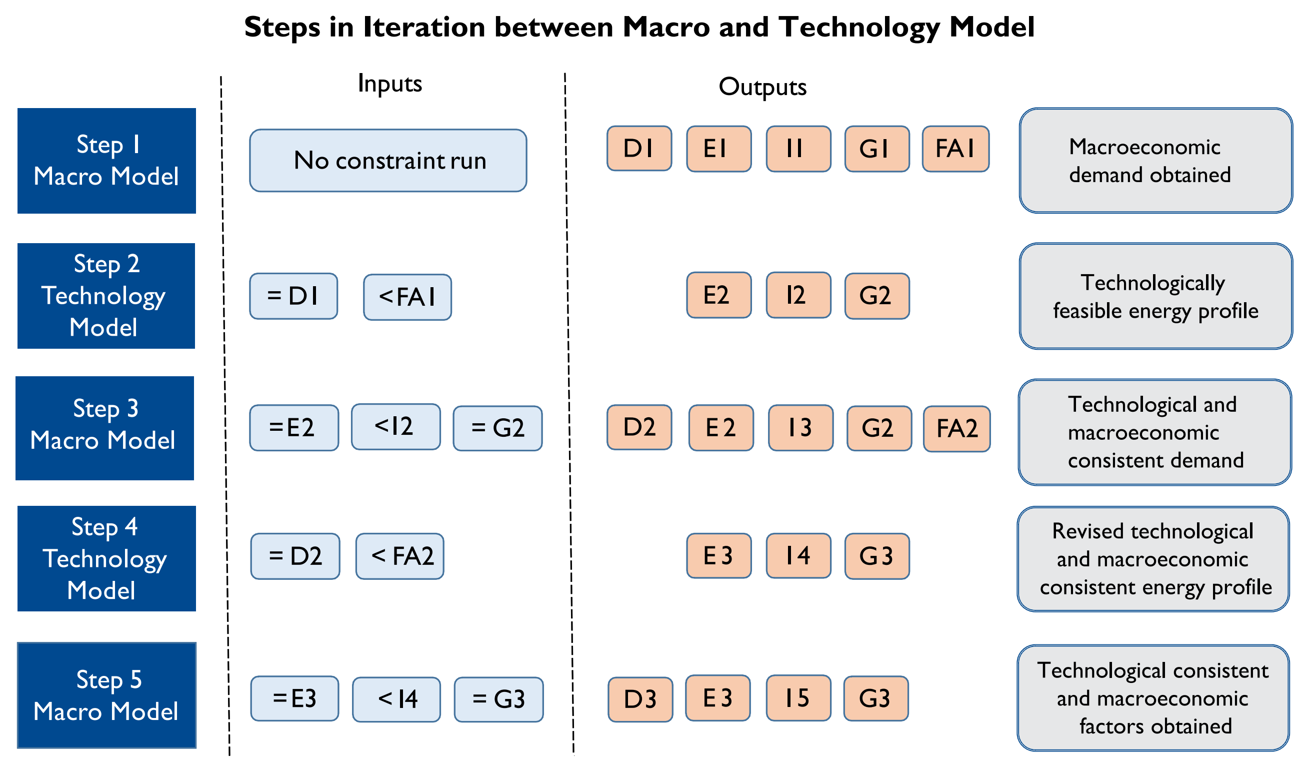
The Iterative Process

The iterative process between the power system and macroeconomic models works in the following manner (depicted in Figure 3.2):

- In the BASE scenario, the iterative process is separately executed for India and Bangladesh. The India technology model interacts with the India macroeconomic model for India and the Bangladesh technology model and Bangladesh macroeconomic model are iterated for Bangladesh. The steps in the iteration are:
  - Iteration starts with the simulation of the macroeconomic model of a country projecting the electricity demand (D), exports (E), and imports (I). E and I are within prescribed upper bounds.
  - D, E, and I are fed into the power system model of that country, which then calculates the optimal electricity supply with the technology mix, and the trade levels within the prescribed upper bounds (with limited quantities in the BASE scenario). Whereas the macroeconomic model balances the electricity demand and supply at an annual level, the power system technology model balances it at an hourly level. The technology mix is thus more realistic.
  - The optimal electricity output with the electricity generation technology mix is fed into the macroeconomic model along with the opportunity cost of the electricity trade prices. This makes the electricity sector representation in the macroeconomic model technologically consistent with the power system model. The macro model then calculates the new electricity demand with the technology-wise output of the electricity sector, consistent with the physical power system. The earnings from the electricity trade are accounted for in the macro model that affects investment availability and consequently the growth of the economy and the demand for electricity. Though the generation mix is fixed, the trade levels adjust to satisfy the change in demand. This electricity demand and balance of payment–compliant electricity trade (small in this scenario) is fed into the power system model.
  - With the changed demand, a new generation mix with technology is obtained, which is again fed into the macroeconomic model to compute income, production, consumption, trade, and investment.
  - The iteration stops when the outcomes between two successive iterations converge.

- In the TRADE-30 and PSMP scenarios, the models that participate in the iterative process include (1) IBHET (with the India and Bangladesh power systems in one framework interacting with each other for optimal trading); (2) India macroeconomic model; and (3) Bangladesh macroeconomic model. The initial process is the same:
  - The final electricity demands of the two countries from the REF scenario are fed into their respective power systems in the IBHET model framework.
  - In the integrated technology model, as the trade option is not limited, it may be the minimum cost to meet part of the demand in both countries at certain times of the year and certain times of the day through trade. Consequently, the generation and technology mix and new investment will also be affected for both countries. The model generates country-wise new results on generation, technology mix, levels, and prices of trade (import/export). It may be emphasized that these are levels of trade balancing the supply and demand in both the countries. These are fed into the respective country's macroeconomic model.
  - The macro models generate new levels of electricity demand, macroeconomically consistent (complying with the balance of payment constraint of the country) with the levels of trade.
  - The iteration process continues until convergence. While the integrated technology model produces an optimal hourly trade and electricity price, the macroeconomic model of each country produces income, production, consumption, GDP, and trade.

Figure 3.2 Iterative Process



Where
D: Demand
E: Export
I: Import
G: Generation Mix
FA: Fuel Availability

Macro Model Names
IIMac: IRADe India Macro
IBMac: IRADe Bangladesh Macro

Technology Model Names
IITec: IRADe India Technology
IBTec: IRADe Bangladesh Technology
IBHET: India-Bangladesh Hourly Electricity Trade Model

4. Modeling Structure and Assumptions

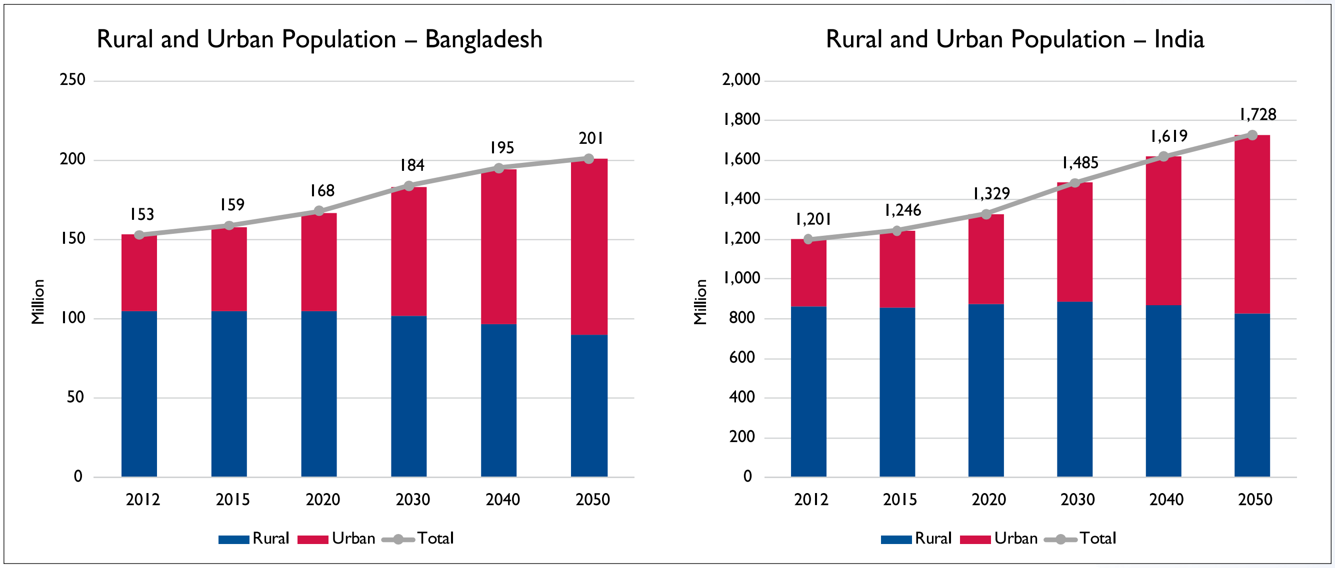
As stated in the earlier chapter, two types of models are applied: macroeconomic and power system. Some key assumptions are presented here.

4.1 Modeling Bangladesh and Indian Economies

4.1.1 Population

The UN medium variant population is used for both Bangladesh and India. Figure 4.1 depicts the rural and urban populations assumed in the models. For Bangladesh, urbanization has been assumed to grow from 33 percent in 2015 to 37 percent in 2020 and further to 44 percent, 50 percent, and 55 percent, respectively, in 2030, 2040, and 2050. Urbanization in India is assumed to grow from 31 percent in 2015 to 35 percent in 2020, and further to 40 percent, 46 percent, and 52 percent, respectively, in 2030, 2040, and 2050.

Figure 4.1 Development in Population and Urbanization*



* Population UN Medium Variant

4.1.2 Economic Assumptions

Inclusive growth policies are part of India's development model. These policies ensure access to electricity, clean cooking fuel, pucca houses, education, and health services, as well as income transfer to the poor. In keeping with the promise for sustainable energy access for all (SE4All), the households consume at least 1 kWh per day of electricity by 2015. The Government makes up the deficit from the household's normal consumption and provides it free of cost to the poor households. Additionally, the Government supplements the poor households' expenditure on energy so that they can have at least six cylinders of LPG per year. (More details are provided in Annexure 1.) The cost of implementing inclusive measures is assumed to be borne by the Government and reduces the investment available for other economic activities.

While Bangladesh lacks fossil energy resources, India possesses these resources. Reserves of these resources will grow over the years with the exploration for new resources. The growth rate assumption for natural resources is provided in Table 4.1.

Table 4.1 Resource Growth Assumptions for India

Resource	Reserves in 2007	Growth Rate in Reserves	Extraction* Ratio (Output/Reserves)
India			
Coal and Lignite (million tonnes)	153,103	1.0%	0.15
Crude Petroleum (million tonnes)	725	0.0%	0.15
Natural Gas (billion cubic meter)	1,055	1.1%	0.15
Bangladesh			
Coal and Lignite (million tonnes)	1,168	0.00	0.01
Crude Petroleum (million tonnes)	0	0.00	0.00
Natural Gas (billion cubic meter)	349	0.00	0.07

*For India the numbers are the maximum extraction rate and for Bangladesh they are the minimum extraction rate

Natural gas has been the main energy resource for Bangladesh for a considerable time now. However, gas is now a depleting resource with no new discoveries. It is expected that Bangladesh will completely exhaust its natural resources by 2030. The country has a good amount of coal resources to meet its energy needs, however, the coal resources are not completely mineable and exist in populated areas. Thus, technological and environmental concerns restrict the extractable reserves for coal. In the model, we have assumed that only 10 percent of the proven reserves of coal in Bangladesh is extractable and useable. India has a substantial amount of large hydro and renewable resources; their exploitable potential during the modeling period is presented in the next section.

The transport sector will continue to be a major energy consumer, for both Bangladesh and India, since the sector is heavily dependent on petroleum products. However, India has announced its NDCs based on announced Government policies in power, transport, and energy efficiency. The policies and interventions in the transport sector are considered as common assumptions across scenarios. The transport policies would have significant implication on energy demand, including electricity and thus need to be modeled. The modeled transport policies are presented in Table 4.2.

Table 4.2 Transport Policies Included in the Model

Transport Sector Policies	
Share of railways in total freight movement	Stipulated to increase by 1.5 percent per year, from around one-third in 2015 to almost two-third by 2050
Greater use of public and non-motorized transport	Reducing marginal budget shares for petroleum products by 0.2 percent per year, beginning 2015
Change in fuel mix in the road transportation sector	Reducing petroleum products inputs in the transport sector by 0.5 percent per year, and replacing them by increasing inputs of natural gas and electricity in the ratio 60:40, respectively, from 2015

Values of many parameters are exogenous to the model. Assumptions on exogenous parameters made in both countries are presented in Table 4.3.

Table 4.3 Assumptions on Certain Important Exogenous Parameters

Parameter	Sectors	Bangladesh	India
TFPG*	Agriculture	1% per year	1% per year
	Power	0% per year	0% per year
	Rest of the economy	1.5%	1.5%
AEEI for non-power sectors**	Coal	0.5% per year	1.5% per year
	Petroleum products	0.5% per year	1.5% per year
	Natural gas	0.5% per year	1.5% per year
	Electricity	0.5% per year	0.5% per year
AEEI for power sectors	Coal	No AEEI for coal use in power sector technologies assumed	
	Petroleum products	No AEEI for diesel use in power sector technologies assumed	
	Natural gas	No AEEI for gas use in power sector technologies assumed	
	Electricity	Reduction in auxiliary consumption and transmission and distribution losses is assumed in consistency with the Answer-Times Technology Model for India	
Reduction in energy use by the Government and households	Petroleum products	NA***	1.5% reduction in the marginal budget share of the expenditure on petroleum products by households due to the use of more efficient vehicles
	Electricity	NA	2% reduction in the marginal budget share of the expenditure on electricity by households due to the use of efficient appliances

*Total Factor Productivity Growth

**Autonomous Energy Efficiency Improvement

***Not applicable

Energy sector representation in this model replicates the policy assumptions made in the energy system model (presented in the ensuing section); for example, normal cost reduction for renewables (solar PV and wind) due to the efficient use of production factors, no investment in capacity, and no fall in costs due to factor productivity for subcritical coal are assumed from 2017. India has announced its intended nationally determined contributions (INDCs) and commitment towards low carbon growth. The Government has announced various low carbon measures through support schemes and program targets and these announced plans in power, energy efficiency, buildings, and the transport sector have been incorporated. The share of buildings complying with the Energy Conservation Building Code (ECBC) is specified to grow by 0.1 percent per annum. In transportation, higher vehicular efficiency, switch from conventional oil-based transport to gas- and electricity-based transportation, and the shift from private vehicle use to public transportation are assumed.

For Bangladesh, the 57x57 sector Social Accounting Matrix for 2011–12 (GTAP database) forms the reference for the base year data of the model. The base year of the model is 2011–12 and the 57x57 sector Social Accounting Matrix is aggregated to 9x20 sectors to capture the most appropriate representation of the energy sector and the power sector and its linkages with the country's economy. The economy is aggregated to nine commodities: agriculture, manufacturing, coal, crude oil, petroleum products, natural gas, power, transport, and other services. The power sector, which is the focus of this study, is disaggregated to 11 power generating technological sectors. The entries in the Social Accounting Matrix 2011–12 for Bangladesh from the GTAP database is in 2011–12 PPP US$. However, to maintain comparability of impacts, all monetary results are reported in 2011–12 US$ market exchange rate.

For India, the 78x78 sector Social Accounting Matrix for 2007 (Saluja et al., 2013) forms the reference for the base year data of the model. The base year of the model is the same for 2007–08. The 78x78 sector Social Accounting Matrix for 2007–08 is aggregated to 25x41 sectors for the most appropriate representation of the power and energy sector and its linkages with the overall economy. There are seven agricultural sectors, 10 industrial sectors (excluding energy sectors), and three services sectors. There are three primary energy sectors and two secondary energy sectors. The major macroeconomic assumptions are provided in Table 4.4. The entries in the Social Accounting Matrix 2007–08 for India is in INR at 2007–08 prices. However, as in the case of Bangladesh, all monetary results are reported at 2011–12 prices in the 2011–12 US$ market exchange rate.

Table 4.4 Assumptions on Important Macroeconomic Parameters

Parameter	Bangladesh	India
Maximum growth rate of per capita consumption	8%	10%
Government consumption growth rate	8%	8%
Maximum savings rate	Assumed to increase from 16% at present to 25% by 2045	40%
Discount rate	4%	4%
Post-terminal growth rate	3%	3%

In addition, some trade-related assumptions are made, which are presented in Annexures 1 and 2.

4.2 India and Bangladesh Technology Models

Certain modeling procedures and assumptions are common to both the countries. These have been described here first and then country-specific key assumptions are presented.

The existing power system (2011–12) is the starting point. A mathematical representation of the current electricity supply system is created within the TIMES modeling framework. This includes the characteristics of the various existing generating stations (vintage, techno-economic performance, and so on), transmission and distribution, energy flows, demand, load characteristics, energy resources, and import/export links. The variations in seasonal and daily load patterns as well as hydro generation and the availability of solar and wind energy sources are captured by using data for 2014–15 for India and Bangladesh, the entire year is divided into 12 seasons to capture seasonal variation (each month represents a season). The average hourly load pattern for a day in a month (or season) represents the daily load pattern for that particular season (or month). Thus, an average hourly load of over 24 hours of a day in each month represents the daily load pattern of each month in the model. We, therefore, have 288 = 24 x 12 sub-periods for each year. Figure 4.2 presents the organized form of the load curve of the 288 sub-periods for a year for India and Bangladesh, which is used in the model.

Figure 4.2 Load Curve Representation in the Model, Bangladesh

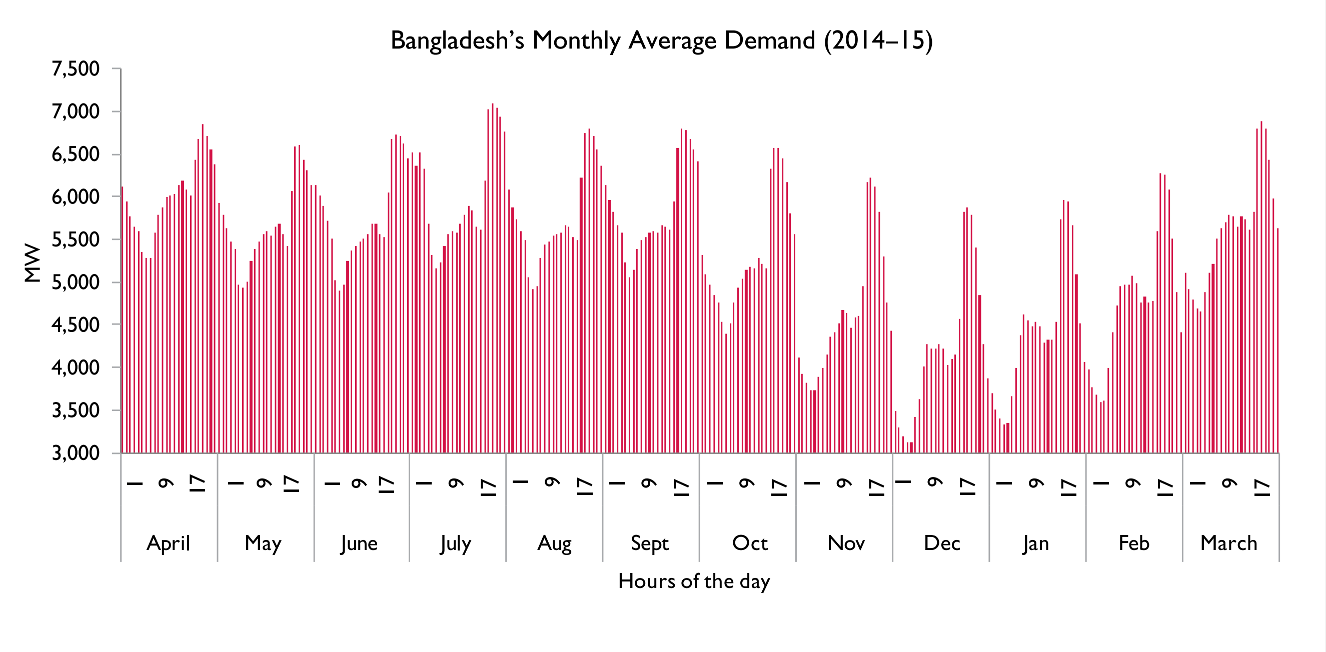
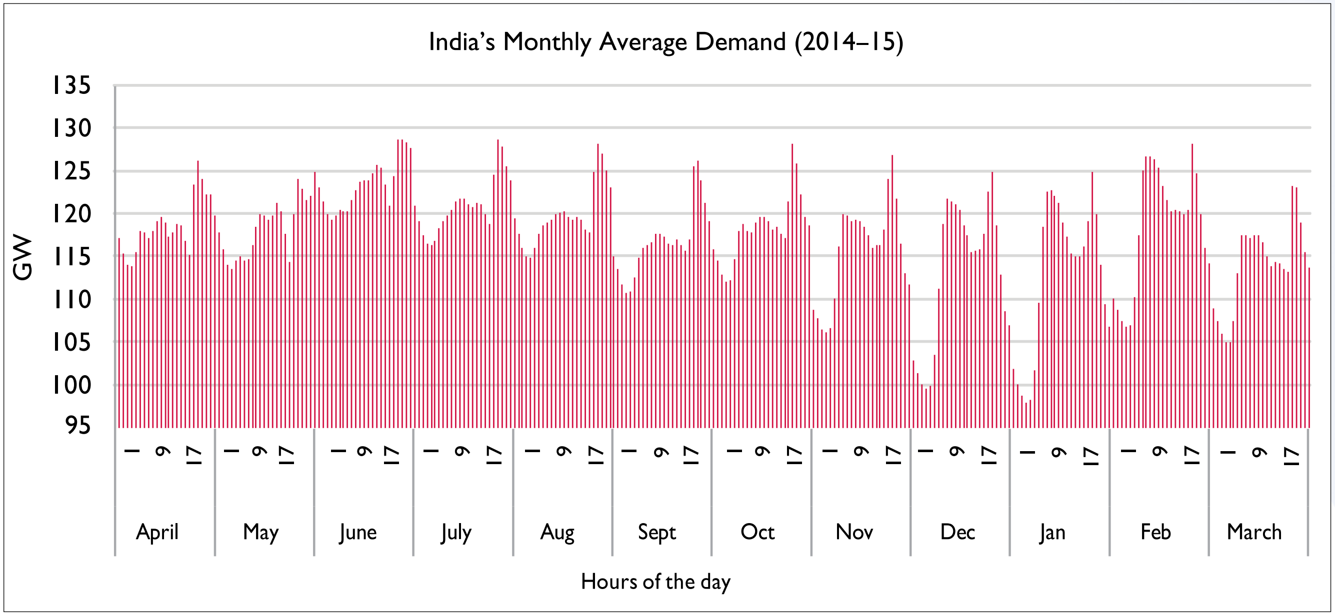


Figure 4.3 Load Curve Representation in the Model, India



All cost data are at constant 2011–12 US$ and the assumed real discount rate is 4 percent. The exchange rates for the Indian and Bangladesh currencies are INR 46.67 and TK 81.8, respectively, for US$ 1. The policies and measures that are in place as of end-2015 are included in the model. Country-specific key assumptions are described below.

4.2.1 Bangladesh

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 supercritical and ultra-supercritical 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 Tables 4.5 and 4.6. Bangladesh is expected to continue to import fuels (petroleum products) for power generation from India.

Table 4.5 Technical and Economic Assumptions for Future Power Generation Technologies

Technology Data						
Parameter/Tech	**Gas (CC)**	**Gas (OC)**	**Oil**	**Dual Fuel**	**Nuclear PP**	
Thermal Efficiency	0.57	0.38	0.35	Gas - .45 Oil - .43	0.35	
Fuel Type	Gas	Gas	Oil	Gas and Oil	Uranium	
Annual Availability Factor	<.85	<.90	<.80	<.85	<.90	
Operational Lifetime (Year)	25	20	20	25	60	
Construction Period (Year)	3	2	2	3	8	
Economic Data						
Capital Cost ($/kW)	622	838	838	622	5,000	
Fixed O&M Cost ($/kW/year)	26	26	26	26	68	

*Cost declined over time and presented in the next table

Table 4.6 **Capital Cost Assumptions for Solar and Wind Technology**

Capital Costs (US$/kW)									
Year	**2015**	**2017**	**2022**	**2027**	**2032**	**2037**	**2042**	**2047**	**2052**
Solar PV	1,447	1,282	869	622	622	622	622	622	622
Wind	1,691	1,650	1,549	1,488	1,488	1,488	1,488	1,488	1,488

Table 4.7 gives the fuel prices that are assumed to remain constant at the 2012 level for the entire study horizon.

Table 4.7 **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

	Coal (Sub) PP	Coal (SC) PP	Coal (USC) PP	Wind PP	Solar PV	Biomass	Hydro
	0.35	0.37	0.43	-	-	0.3	
	Coal	Coal	Coal	-	-	Rice husk	
	<.80	<.80	<.80	<.21	<.18	<.60	<.50
	30	30	30	25	25	20	80
		5	5	2	2	2	6
	959	968	1,306	1,690*	1,446*	1,920	1,736
	20	22	34	30	23	109	16

The T&D loss is assumed to decline from 13.5 percent in 2015 to 9 percent, 7 percent, and 6 percent, 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 9 GW, to be achieved by 2041. In addition to the 16 percent upper limit on electricity import, the PSMP scenario also assumed 9 GW as the upper limit on the interconnection capacity to be achieved by 2040 and will continue thereafter.

4.2.2 India

- A comprehensive list of technologies is considered for the future expansion of the Indian power system. This includes:
  - Various coal technologies (subcritical, supercritical, ultra-supercritical).
  - 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 4.9 to Table 4.11.

Table 4.8 Assumptions on the Technical and Economic Performance of Future Technology Options, India

	Gas Power Plant		Coal Power Plant				Diesel Thermal Plant	
Technology Data	**OC**	**CC**	**IGCC**	**SUBC**	**SUPC**	**USUPC**		
Net Efficiency (PJ output/PJ input)	37.5%	55%	46%	30%	37%	43%	25%	
Fuel Type	Gas	Gas	Coal	Coal	Coal	Coal	Diesel	
Availability Factor	90% (UP)	(55-90)%	(60-70)%	(55-70)%	(55-70)%	(55-70)%	70%	
Plant Availability Modeling Level	Annually	Annually	Annually	Annually	Annually	Annually	Annually	
Operational Lifetime (Year)	40	40	40	40	40	40	15	
Economic Data								
Capital Cost ($/kW)	482	771	2,143	1,028	1,136	1,307	1,071	
O&M Cost ($/kW/yr)	39	31	54	26	28	33	107	

Table 4.9 **Capital Costs (US$/kW) Assumptions for Solar Technologies, India**

	Storage	2017	2022	2027	2032	2037	2042	2047	2052
Solar Power Plant (PV)*	W/O 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)#	W/O 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 percent cost reduction trajectory by 2025 and a 40 percent cost reduction by 2050, which is still on the conservative side as the other scenarios in the report consider a 36 percent reduction in 2025 and a 72 percent reduction in 2050.

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

	Nuclear Power Plant		Hydro Power Plant		Solar Power Plant				Wind Power Plant		Bio Power Plant
	LWR	PHWR	Large	Small	PV with STG	PV without STG	TH with STG	TH without STG	On-Shore	Off-Shore	
	163%	18%									25%
	Enriched Uranium	Natural Uranium									Biomass
	80%	80%	39%	41%	37%	18%	37%	18%	(21-28)%	(33-37)%	50%
	Annually	Annually	Monthly	Monthly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Annually
	50	50	50	30	25	25	25	25	25	25	20
	4,500	1,778	2,036	1,393	Refer Next Table				1,286	3,857	964.2
	112	44	67	42	Refer Next Table				19	29	39

Table 4.10 O&M Cost Assumptions for Solar Technologies, India

	Storage	2017	2022	2027	2032	2037	2042	2047	2052	% of CAPEX
Solar Power Plant (PV)	W/O 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)	W/O 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 percent in 2030, linearly increasing to 50 percent in 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,[13] we have imposed the technical minimum schedule for operation as 55 percent 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 4.11.

Table 4.11 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

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

5. Results and Analyses

Bangladesh faces serious challenges in augmenting its future power supply system as domestic resources for power generation are scarce (as stated in Chapter 1). The country can either build power plants domestically, using fuels that are to be imported and/or import electricity from neighboring countries such as India. Electricity import from neighboring countries offers a quick and cheaper option as it does not require a heavy investment for building fuel and power supply infrastructure. It also does not involve the long project planning and construction period of a nuclear power plant. However, almost complete dependence on import, implicitly or explicitly, for the supply of such a key product as electricity makes energy supply security a grave concern. Bangladesh needs to strategize its power supply, which would reduce the energy security threat and, at the same time, keep the cost of power supply to the consumers and economy low. The diversification of the power system by fuel type and supply sources improves supply security. A range of supply mix, based on different combinations of fuel import and electricity import, is possible; however, each has not only different electricity supply cost implications, but investment, foreign currency, and macroeconomic implications as well.

Striking a right mix, balancing multiple conflicting aspects such as supply cost, energy security, investment and foreign currency implications, and so on, is a complex undertaking and depends on the decision-making process on how each aspect is prioritized. The study intends to strengthen the policy-makers/planners of Bangladesh with the information on power supply strategies with the role of electricity import and their macroeconomic implications. We also look into their technical and economic implications (in terms of capacity, generation, various costs, and so on) to the power sector. Three scenarios, namely, REF, PSMP, and TRADE-30, are built that consider a different mix of fuel and electricity import for the future electricity supply in Bangladesh. At the same time, we also attempt to strengthen the Indian counterparts with information on what would be the power sector and macro implications in India of exporting electricity to Bangladesh under these three scenarios. The key questions explored are:

- What would be the power supply strategies (capacity, generation, technology, import/export, investment, fuel, power supply cost, and so on) in Bangladesh as well as in India with different levels of power trade?
- What are the macroeconomic implications to Bangladesh and India in terms of the growth of the GDP and investment (in the power sector and the rest of the economy) fuelled by the impact from electricity trade?

The answers to the following questions, which would be of interest to the stakeholders, are also explored:

- What would be the optimal level of trading and price agreeable to both the buyer and the seller?
- What would be the impact on the living standard measured through per capita consumption levels?
- How would the per capita electricity use change?
- What are the consequential environmental costs and benefits?

The answers to these complex techno-economic questions are sought applying the methodology described in Chapter 3 and assumptions presented in Chapter 4. Consequently, this chapter deals with those answers through comparative analyses of the three scenarios, REF, PSMP, and TRADE-30, described in Chapter 3. An analysis for Bangladesh is reported first, followed by that for India.

5.1 Bangladesh

Trade has two kinds of impact on the economies of the trading countries: 1) Production specialization 2) Higher consumption. Bangladesh being an importer country in this case, the production specialization leads to lower power sector output and higher output of other sectors compared to a no trade scenario. At the same time, trade results in higher consumption levels of all commodities, including power by private households.

Does Bangladesh's economy benefit in terms of production specialization and higher consumer welfare from the import of electricity? To answer this, we use a macroeconomic model that covers the whole economy. Electricity trade affects the economy through four channels. The first is the **investment channel**. Here, the availability of electricity through import helps the country reduce some investments in the power sector. This provides an opportunity to re-distribute the investible resources to the other economic sectors. The second channel is the **intermediate demand channel**, where the decrease in generation leads to the lowering of the intermediate demand by the power sector of the output of other sectors of the economy. This results in an overall lowering of demand. The third is the **consumption channel**. Here, the lower investment requirement and re-distribution of investment resources into other sectors lead to higher consumption expenditure by private households, resulting in an increase in aggregate demand. The next is the **foreign exchange channel**. Competition for foreign exchange changes the structure of trade and, consequently, the economy. The first and third channels increase the GDP and consumption; the second has a negative impact on the overall GDP; and the fourth channel's impact may be in either direction.

5.1.1 Impact on the Power Sector

5.1.1.1 Demand Development

With higher electricity imports from India, the domestic power demand decreases by a small amount in trade scenarios as compared to the REF scenario. However, this decrease is more due to the reduction in auxiliary consumption (intermediate demand) of electricity for domestic generation and not at the level of final household and industrial consumers.

Figure 5.1 Total Electricity Demand in the Economy of Bangladesh

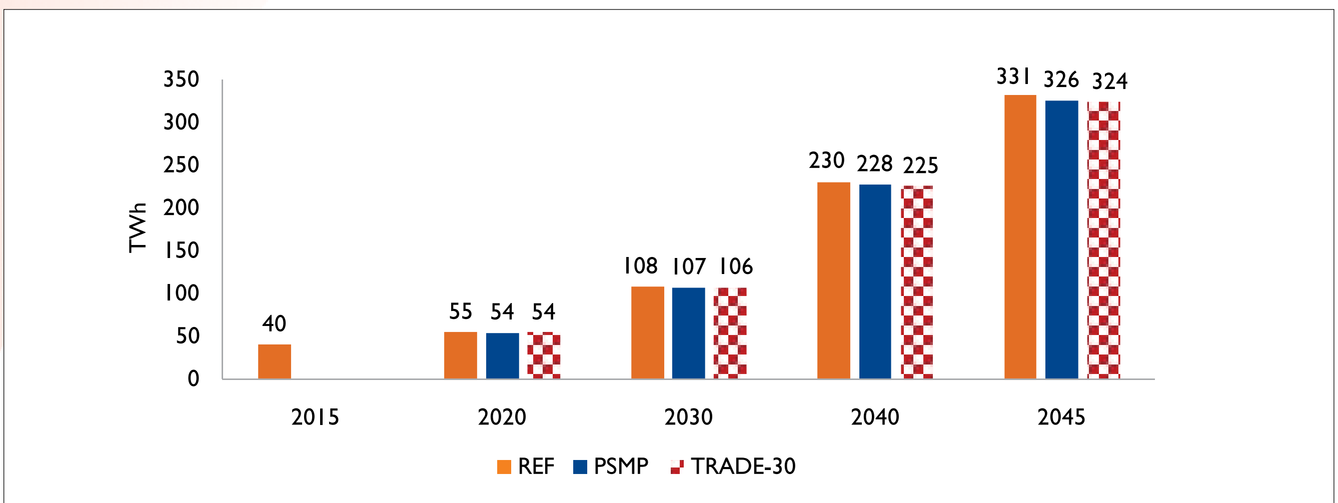
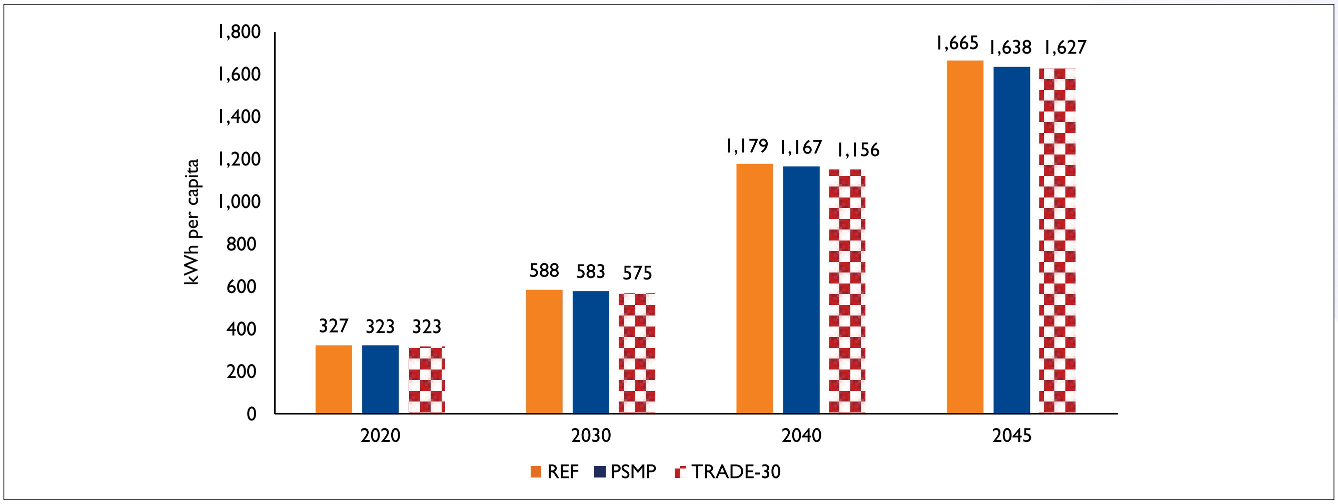


Figure 5.1 presents the electricity demand development in the three scenarios. In the REF scenario, the electricity demand in 2020 is projected as 55 TWh, which increases to 108 TWh by 2030, with an annual growth rate of 7 percent. During the same period, Bangladesh's GDP is expected to grow by 6.4 percent per annum, indicating an elasticity of 1.1. Demand growth in the next decade is even higher, at 7.8 percent per annum, with the electricity demand reaching 230 TWh in 2040. Growth slows down slightly thereafter and, by 2045, the demand is 331 TWh. The growth rate of the GDP during 2030 to 2045 is 8.2 percent and that of electricity is 7.8 percent, showing an elasticity of about 0.94. While our demand projection is in the form of energy, the demand projection in the Power Sector Master Plan 2016 (prepared by JICA and endorsed by the BPDB) is in terms of peak load demand (GW), so they are not directly comparable. However, both the studies make the projections on capacity requirement and we will compare them in the relevant section.

As can be seen in Figure 5.1, due to trade, the electricity demand decreases by around 2 percent in 2045 in the TRADE-30 scenario and by less than 1 percent in the PSMP scenario, compared to the REF scenario. As import replaces domestic electricity generation, this leads to a lower output and income and less investment in the power sector. This results in a lower GDP and hence production activities in the sectors linked to the power sector (fuel supply and equipment manufacturing). This is partly due to the multiplier impact through a lower intermediate demand from the power sector and partly due to a lower investment demand in the power sector, which results in a lower manufacturing sector output. In addition, the activities in the fuel production and supply sectors, which are required for electricity generation, decline. As these sectors shrink in terms of output and income, they cause further cascading effects and structural changes in the economy, resulting in a fall in electricity demand, although it is marginal as compared to the REF scenario.

The per capita electricity demand, calculated by dividing the total electricity demand in the economy with the total population, is an important indicator for socio-economic development, as shown in Figure 5.2. The current per capita electricity consumption of Bangladesh, at 281 kWh (2015–16), is one of the lowest in the world. In the REF scenario, it will double by 2030, reaching 588 kWh. In 2045, it will increase by a factor of six from the current consumption level. In trade scenarios, as the aggregate demand declines, so does the per capita demand, however, only by a negligible amount. Therefore, a very healthy and robust demand growth is foreseen for the Bangladesh economy across all the three scenarios.

Figure 5.2 Per Capita Electricity Demand



5.1.1.2 Electricity Supply Strategies

Capacity and Technology Mix

Figure 5.3 presents the build-up of the power generation capacity needed in Bangladesh in the three scenarios to meet the demand depicted in Figure 5.1. The REF scenario is based on building domestic power plants in Bangladesh and restricting electricity import at the present level, therefore, the requirement of domestic capacity is large. To meet its electricity demand, Bangladesh needs to have 20 GW of capacity by 2025, which has to go up to 26 GW by 2035. In the next decade, it needs to expand its capacity by almost two-and-a-half times to reach 64 GW by 2045. It should be noted that another 1.1 GW of capacity would be available through interconnection (Table 5.1).

In the PSMP scenario, electricity import is limited, however, the upper limit is much higher than the REF scenario. The impact on capacity development is visible. As import is cheaper than domestic generation, based on all sources (except coal), the upper limit on import is completely used and the remaining power need is met through domestic capacity. The domestic power generation capacity needs to be built, however, at a slower pace than the REF scenario. For example, the domestic capacity need in 2030 is 22 GW, as against 26 GW in the same year in the REF scenario. In 2045, 53 GW would be sufficient, 11 GW less than the REF scenario. However, it needs the interconnection capacity of 3 GW, 5 GW, 7 GW, and 9 GW, respectively, in 2025, 2030, 2035, and 2040 (Table 5.1). Beyond 2040, 9 GW will continue.

When comparing this with the capacity projection presented in the plan document of BPDB (Power Sector Master Plan 2016), our capacity projection in the PSMP scenario is on the lower side. For example, in the BPDB plan document, the capacity projection for 2025, 2030, 2035, and 2040 is 24.4 GW, 31.1 GW, 40.8 GW, and 53.9 GW, respectively. In our study, taking into account the interconnection capacity of 3 GW, 5 GW, 7 GW, and 9 GW, respectively, in 2025, 2030, 2035, and 2040 (Table 5.1), the capacity requirement is 22 GW, 27 GW, 32 GW, and 44 GW, respectively. The difference between the two approaches explains the low capacity projection in this study. PSMP 2016 assumes a constant electricity-GDP elasticity of 1.27 throughout the study period of 2015–41.A reflection of the structural changes of the economy on elasticity during this long time horizon is ignored. Our study uses a detailed macroeconomic framework for demand estimation that takes into account the evolution of the Bangladesh economy, both internally (GDP, GDP structure, and so on) and externally (trade, foreign investment) over the study horizon. This study uses a constant electricity elasticity of household consumption expenditure of 1.23. The electricity elasticity of GDP would depend on the level and composition of household consumption, which, in turn, would influence the structure of production in the economy. The electricity elasticity of household consumption expenditure from the GTAP SAM is 0.96. However, for the model we assume a higher elasticity of 1.23 given that after 2011–12 (base year of the SAM), Bangladesh's economy has seen an increase in the rate of growth of domestic electricity demand. Also, while the PSMP 2016 document assumes that T&D losses would be reduced up to 11.5 percent in the future, we have assumed a further reduction in T&D losses to 8 percent and 7 percent, respectively, in 2030 and 2040, which also contributes to a reduction in the capacity requirement.

Being cheaper, import is a preferred option in the TRADE-30 scenario that offers a higher import possibility. The domestic capacity build-up, therefore, further declines here than in the PSMP scenario. The upper limit of 30 percent electricity import as an option of electricity supply is completely used up, further reducing the need for building capacity at home. The domestic power generation capacity in 2020 is the same as in the PSMP scenario, at 18 GW, and no new capacity is built in this scenario up until 2025. In 2035, the total capacity is 2 GW and 8 GW, respectively, less than the PSMP and REF scenarios. The impact increases over time and, by 2045, Bangladesh needs only 37 GW domestic capacity as compared to 53 GW and 64 GW in the PSMP and REF scenarios. A considerable saving in the domestic capacity development is possible when the import from India is further enhanced from the PSMP scenario, leading to a substantial reduction in investment in the power infrastructure. This could be diverted for investment in other sectors or for consumption. The interconnection capacity is projected as 6 GW, 11 GW, 18 GW, and 25 GW, respectively, in 2025, 2035, 2040, and 2045 (Table 5.1).

Figure 5.3 Power Generation Capacity Requirement

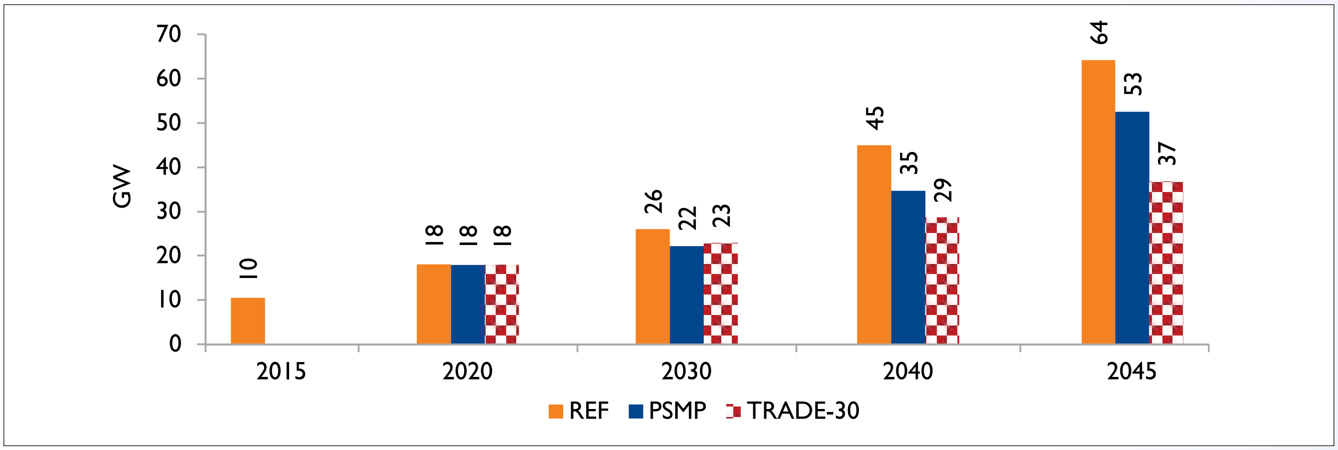


Table 5.1 Potential Interconnection Capacity (GW) by Scenario

Scenario	2025	2030	2035	2040	2045
REF	1.1	1.1	1.1	1.1	1.1
PSMP	3	5	7	9	9
TRADE-30	6	7	11	18	25

Figure 5.4 Capacity Mix by Technology, Bangladesh

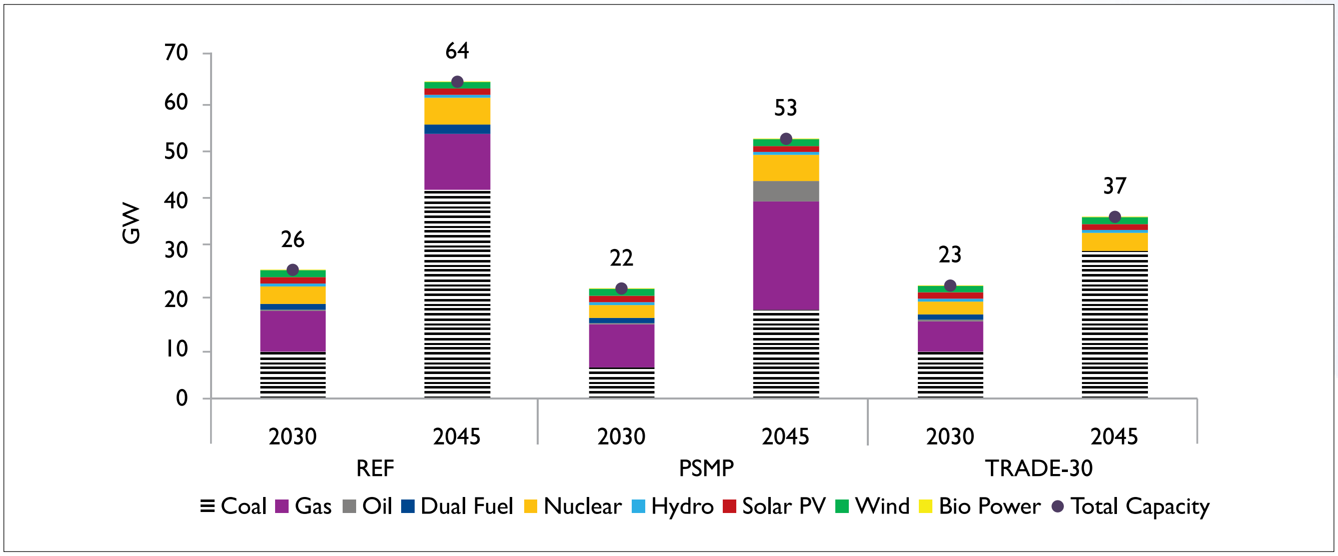


Figure 5.4 presents the capacity breakdown by technology in the three scenarios. Currently, gas-based capacity dominates the power system followed by power plants fuelled by petroleum products. This picture changes considerably and coal, being the cheapest option, is expected to dominate Bangladesh's future capacity development. By 2030, the power system becomes more diversified as a new coal-based capacity of about 9 GW and a nuclear capacity of 2.4 GW are added. Coal dominates thereafter also; however, it is restricted by the annual coal availability due to the limited domestic coal production as well as import restricted by foreign currency availability.[14] By 2045, about 42 GW of coal capacity would be part of the optimal solution. Nuclear becomes the next best option. As per current plans, two nuclear reactor units at Ruppur, totalling 2.4 GW, are expected to be installed before 2025. Nuclear capacity is expected to increase to 3.6 GW in 2030 and to 5.5 GW by 2045. Domestic gas is assumed to be used up by 2027, after which all gas-based power plants need to be operated with imported gas, which is the most expensive option due to high import price assumption. The gas-based capacity, therefore, declines from 10.6 GW in 2020 to 8.2 GW in 2030, and thereafter fluctuates between 8.4 to 11.3 GW as the operational flexibility of the gas-based power plants works in its favor.

The technology mix in the PSMP scenario is driven by the scenario definition, characterized with equal share (35 percent) of coal and gas in power supply from 2040 and onwards. The capacity based on coal and gas is 6.3 GW and 8.7 GW, respectively, in 2030. It goes up to 18 GW and 22 GW, respectively, in 2045. The nuclear capacity increases to 2.8 GW in 2035 and goes up to 3.7 GW in 2040 and 5.3 GW in 2045.

In the TRADE-30 scenario, coal, being the cheapest option, dominates the generation capacity. The nuclear capacity declines to some extent. Electricity import from India reduces the gas-based capacity, which is the most expensive power generation option because of higher gas price, despite the investment cost being lower.

Generation and Import

Figure 5.5 presents the electricity supply strategies in different scenarios, which comprises domestic generation and import from India. The REF scenario depends almost entirely on domestic generation to meet the electricity demand as import is restricted by the capacity available in 2018. In 2020, domestic generation is expected to be at 54 TWh, thereafter, it increases by more than a factor of two in each successive decade. Hence, generation in 2030, 2040, and 2045, respectively, is 113 TWh, 242 TWh, and 350 TWh, respectively. Electricity import from India was 3.8 TWh in 2015, which will increase slightly in the future in the REF scenario, as a new capacity for imports of 500 MW will be available from 2018. Thereafter, it will remain at the same level, in the range of 7-9 TWh, only contributing 2-3 percent of the total supply.

Domestic generation in the PSMP scenario declines as import is enhanced smoothly up to a modest percentage of 16 percent of the total supply by 2041. A visible impact over the REF scenario starts only after 2030. Domestic generation in 2030 and 2040 is 101 TWh and 206 TWh, respectively. This is 11 percent and 15 percent, respectively, less than the REF scenario. The import in these years is 17 TWh and 39 TWh, which is much higher than the REF scenario.

The TRADE-30 scenario allows further increase in import up to 30 percent of the total supply. Full utilization of this opportunity suggests it is economical to import rather than produce domestically to meet the electricity demand. Domestic generation declines more compared to the PSMP scenario. Import grows rapidly. In 2025, import is expected to be 25 TWh, which increases to 28 TWh in 2030, goes up further to 51 TWh, 73 TWh, and 104 TWh in 2035, 2040, and 2045, respectively (Figure 5.5).

[14]Optimal import amount of all fuels consistent with the country's balance of trade are determined by the macroeconomic model.

Figure 5.5 **Generation and Imports by Scenarios**

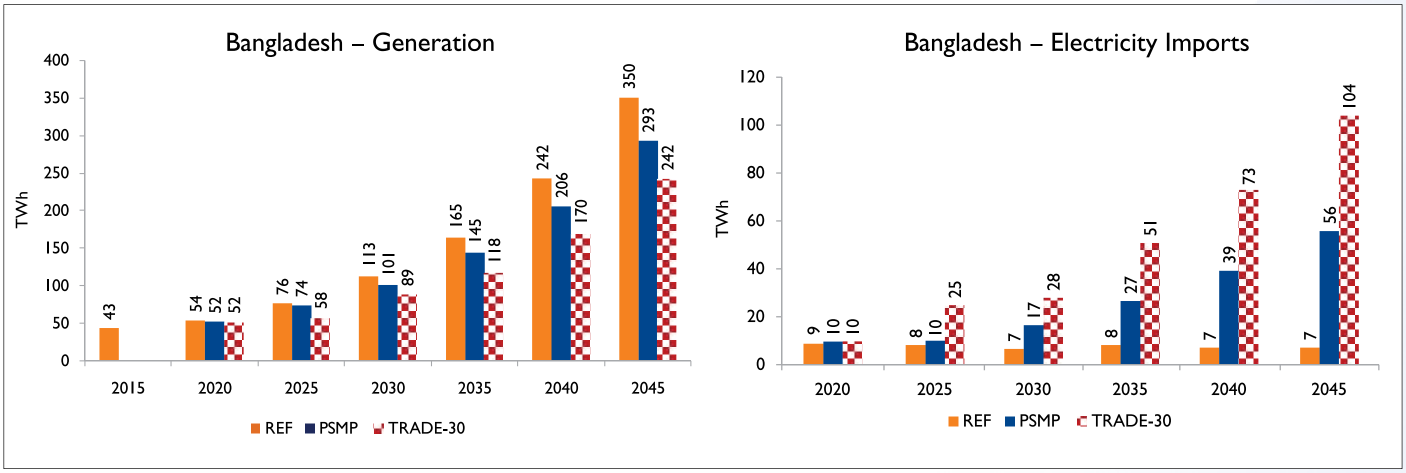


Figure 5.6 **Generation Mix by Scenarios, Bangladesh**

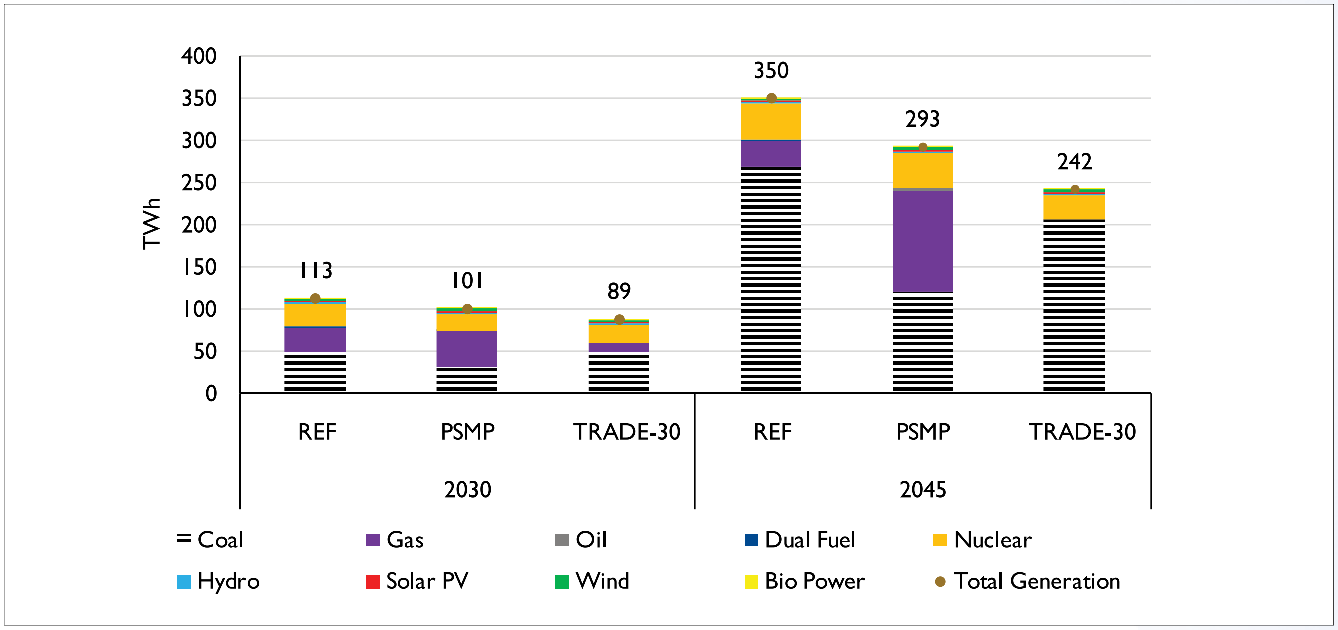


Figure 5.6 presents the generation mix by technology/fuel for 2030 and 2045 in the three scenarios. Coal is the cheapest option, so it dominates the domestic generation in both the REF and TRADE-30 scenarios even though the availability of imported coal is restricted by the country's balance of payment constraint. In the long term, as domestic gas declines and LNG is assumed to be expensive, nuclear becomes the next best economical option, followed by gas. In the PSMP scenario, the source diversification policy restricts the use of coal for power generation. Coal and gas in this scenario are used in equal proportion. Generation from renewables is negligible in all the three scenarios. Higher electricity import in the TRADE-30 scenario pushes out gas for electricity generation, which is a more expensive option leading it to be of no use by 2045.

Figure 5.7 Import Pattern by Month (2045)

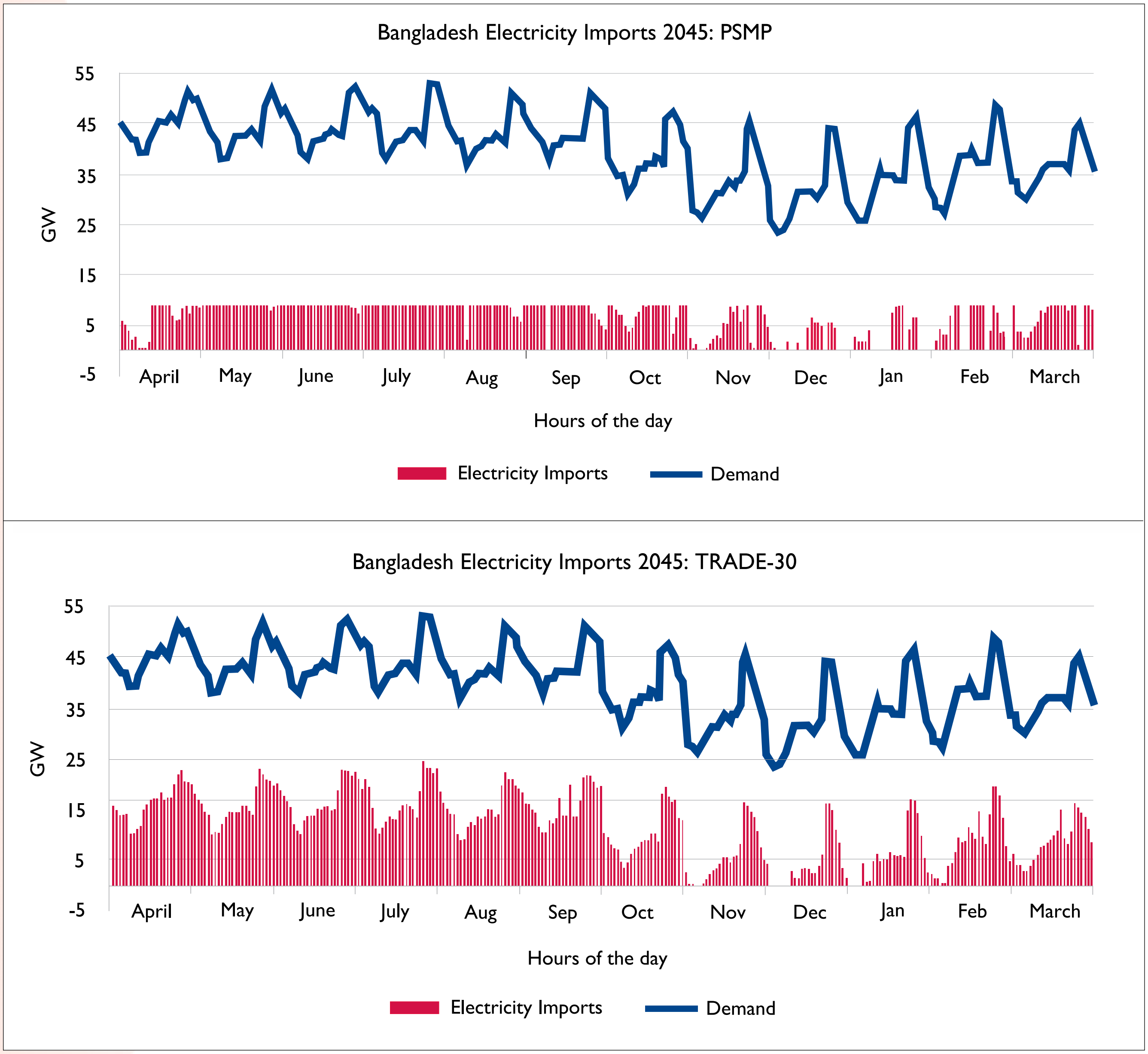
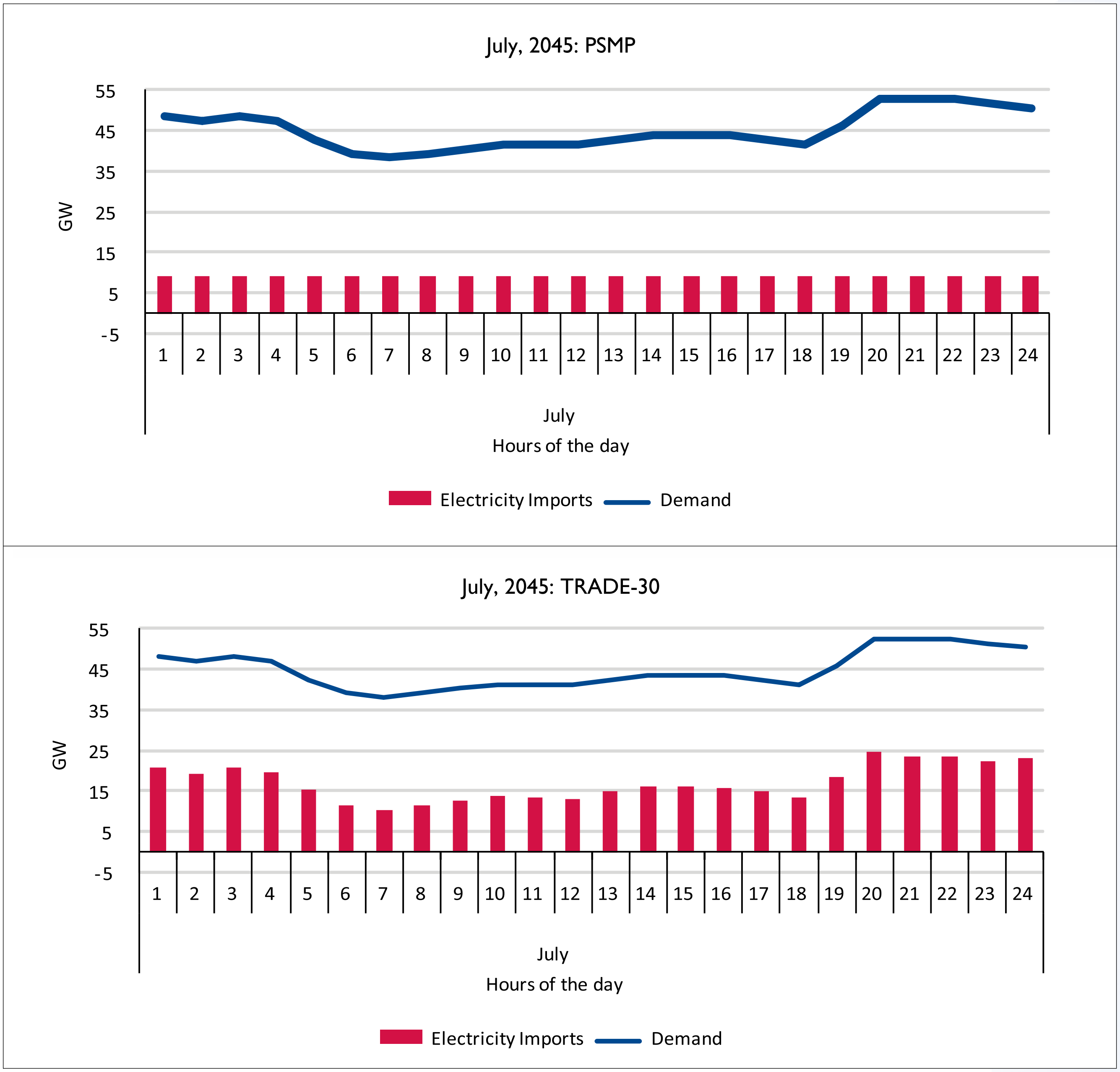


Figure 5.7 depicts the import by month for 2045. In the PSMP scenario, as the total annual import is limited, so the maximum import takes place during May-July, when the demand is high (the annual peak demand occurs in June-July). The same pattern is seen in the TRADE-30 scenario; import is saved for the peak months and it is low during the low demand period.

Figure 5.8 presents the daily import pattern in July (when the annual peak occurs). The daily peak in Bangladesh occurs in the evening between 7 and 10 pm. In the PSMP scenario, in 2045, the maximum import is limited to 9 GW. Import remains the same throughout the day at 9 GW during the peak month of July.

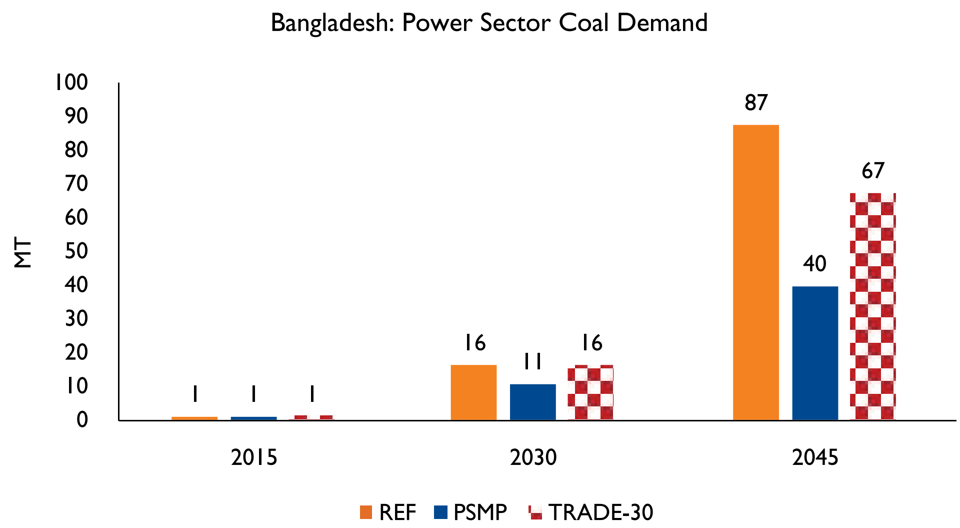
Figure 5.8 **Daily Import Pattern in July, 2045**



In the TRADE-30 scenario, in 2045, about 25 GW of capacity import is possible. Import is high during the peak hour of the day (8 to 9 pm) and the entire import capacity of 25 GW is used to meet about 40 percent of the peak load.

5.1.1.3 Fuel Demand in the Power Sector

Figure 5.9 Fuel Demand in the Power Sector



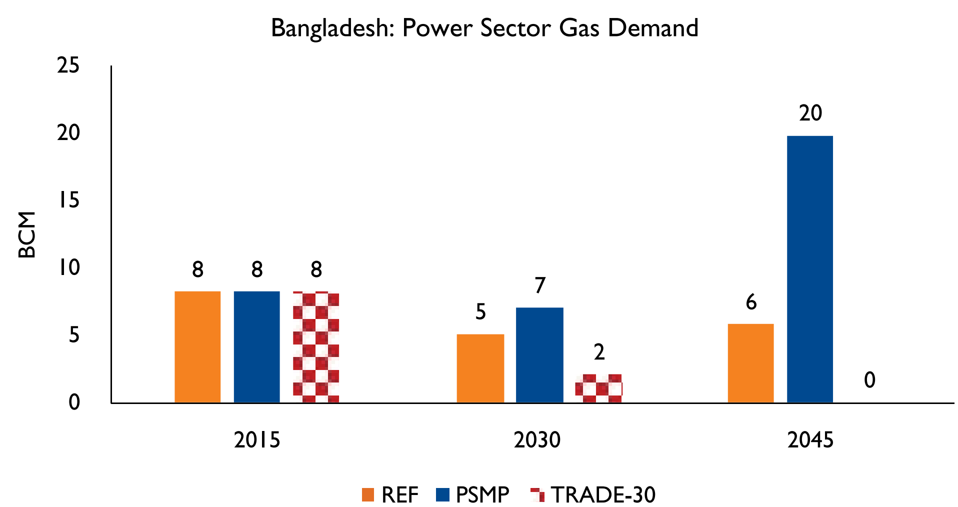


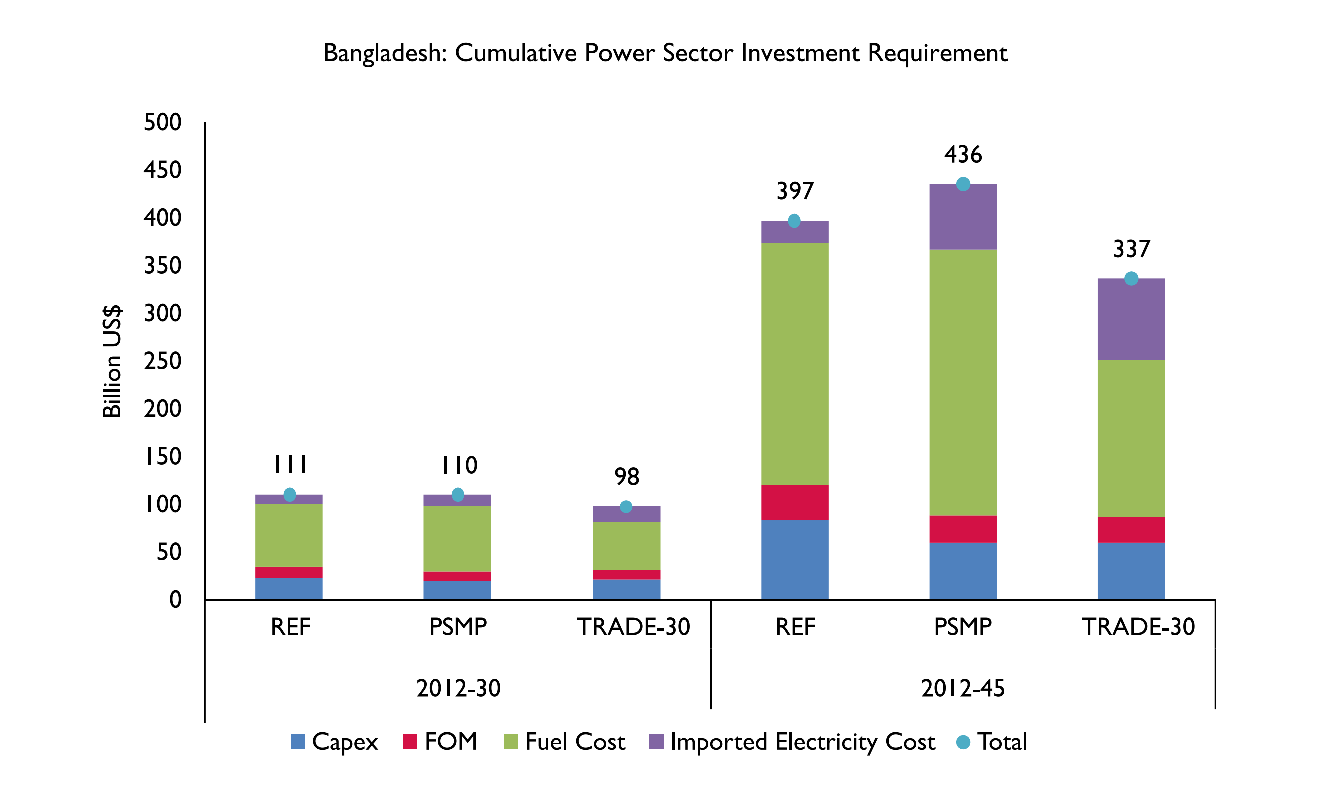
Figure 5.9 presents the fuel demand (coal and gas being the main fuels) for power generation in all scenarios for 2030 and 2045. The REF scenario is based on creating domestic power plant and electricity import limited to the current level. Therefore, fuel requirement in this scenario is high and mostly needs to be imported. In 2030, the total demand for coal and gas is 16 million tonnes and 5 billion cubic meter, respectively, and Bangladesh needs to import 13 million tonnes of coal and 1 billion cubic meter of gas, as domestic gas would be still available. By 2045, domestic gas gets completely used up, coal and gas import goes up to 85 MT and 6 BCM. A large volume of foreign currency is needed to pay the fuel import bill for the power sector.

The PSMP scenario depends on modest electricity import. This is also a fuel diversification scenario, with an equal share (35 percent) of coal and gas in power supply. Therefore, coal demand is lower than the

REF scenario, while gas demand is higher. The import demand for coal is 8 MT and 37 MT, respectively, in 2030 and 2045. The gas demand is 7 BCM in 2030, however, as domestic gas is available, only 3 BCM of gas needs to be imported. By 2045, as by scenario definition, 35 percent of the supply needs to come from gas. The gas demand goes up to 20 BCM and the entire amount needs to be imported as the country is expected to run out of domestic gas. The fuel import bill would be substantial as gas is more expensive than coal. The demand for coal in 2045 is less than half of the REF scenario. Also, in this scenario, the electricity import bill may be significant (as reported later), compared to the REF scenario.

In the TRADE-30 scenario, as electricity import replaces gas-based generation, gas demand is much lower than the other two scenarios in 2030 and, in 2045, there is no demand for gas. Electricity import also replaces coal to some extent; therefore, the demand for coal is also lower than in the REF scenario. The import of fuels (coal and gas) declines, but electricity imports increase substantially. Figure 5.10 presents the power system costs in the three scenarios, where costs include capital investment, fixed O&M, fuel cost (imported), and electricity import costs, cumulated over the period 2012–30 and 2012–45. Looking into the cost over 2012–45, clearly the PSMP scenario, which is devised as an energy security strategy, is the most expensive among all the scenarios. The cost of energy security is an additional cost over the REF scenario, in the order of US$ 36.6 billion (3 trillion BDT). By enhancing electricity import from India in combination with using coal for domestic power generation and minimizing the use of expensive gas, Bangladesh can get energy security at a significantly lower cost, US$ 97.7 billion (8 trillion BDT), from the PSMP scenario, as demonstrated in the TRADE-30 scenario. Electricity import, therefore, brings significant economic gain as well as energy security benefit through supply source diversification.

Figure 5.10 Power System Costs in the Scenarios



The REF scenario, which depends on the domestic power generation capacity for power supply, needs larger investment in building power generating capacity than the other two scenarios as those scenarios depend on higher electricity import. Fuel cost dominates the power system cost in all the scenarios, however, it is the largest in the PSMP scenario as it depends on expensive gas import.

5.1.2 Socio-economic Impact

As is evident from the discussion on the technological impact on the power sector, the two scenarios, PSMP and TRADE-30, differ considerably in terms of technological choices for power generation mix and installed capacity requirements. Though both strategies consider electricity trade, they represent two different strategies for the future growth of Bangladesh's power sector. The PSMP scenario aims at diversifying the fuel sources for power generation, thereby securing future power generations from the uncertainty associated with fossil fuel resources at the expense of making non-optimal choices and increasing costs of power generation. The TRADE-30 scenario, on the other hand, also tries to secure power availability for the Bangladesh economy at more competitive costs. The two strategies are bound to have differing impacts on the economy through the power sector. In the following section, we try to examine the impacts of the two strategies or scenarios on the Bangladesh economy. As shown earlier, the electricity demand in the Bangladesh economy is not really impacted due to trade, though the required generation is significantly reduced. The economic model for Bangladesh maximizes the discounted sum of private consumption streams over a period of 35 years. Thus, the choice of alternative strategies of the PSMP and TRADE-30 scenarios, compared to the REF scenario, is bound to impact the model's choice of optimal household consumptions. We start by first analyzing the impact of the consumption of electricity by domestic households. Figure 5.11 shows the increase in absolute and per capita household consumption of electricity. The values of the absolute levels in the REF scenario are provided in Annexure 3.

Figure 5.11 Increase in Absolute and Per Capita Household Electricity Demand Compared to the REF Scenario

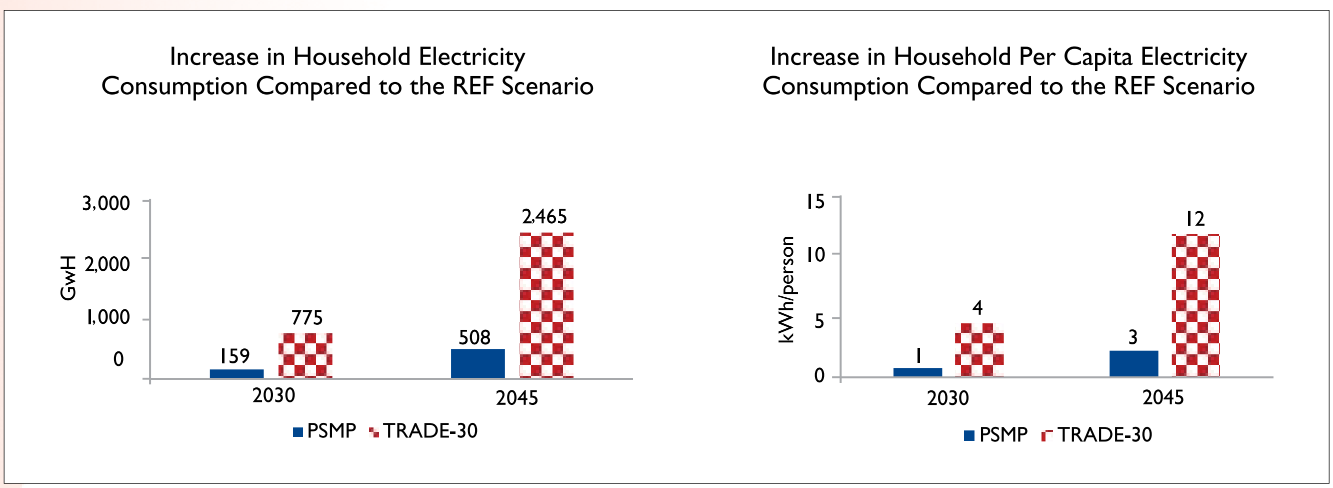


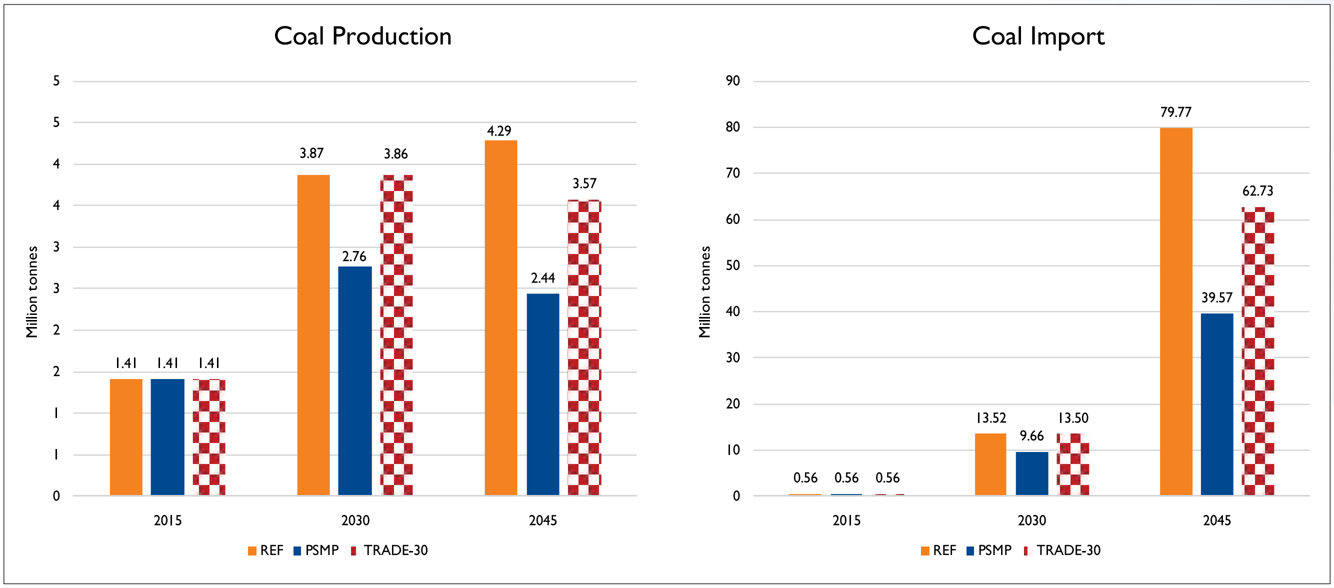
Figure 5.11 shows that, compared to the REF scenario, both the PSMP and TRADE-30 scenarios increase household electricity consumption; however, the increase in household electricity consumption, both in absolute and per capita terms, is nearly four times in the TRADE-30 scenario, as compared to the PSMP scenario. Thus, even though the aggregate electricity demand does not get much impacted in the PSMP and TRADE-30 scenarios, compared to the REF scenario, the households' share in that aggregate demand increases much more in the TRADE-30 scenario. This is because in the TRADE-30 scenario,

due to the higher imports availability, the domestic generation and domestic generation capacity requirement is reduced, compared to what would have been required in the REF and PSMP scenarios. This results in lower domestic output of power and, through power sector production linkages to other sectors, a reduction in the economic output of the other sectors as well (sectors whose output is an intermediate input into the power sector production process). The negative multiplier impact on the economy due to the power sector output reduction is, however, countered by an increase in the output of the non-energy sector due to the re-allocation of investment resources. This is shown in subsequent discussions. On the whole, the lower power sector output translates to a slightly lower GDP. This reduces the intermediate demand for power from industrial, agricultural, and commercial sources, leaving surplus power that can be re-distributed to the household sector, as reflected in Figure 5.11. A more detailed analysis on the demand and supply situation of each sector, including the power sector, is provided in Annexure 3. Having detailed the impact of the two alternative scenarios on the demand and supply of electricity, the following sections present the impact on the non-power energy sector and the non-energy sector.

5.1.3 Economic Impact on the Energy Sector

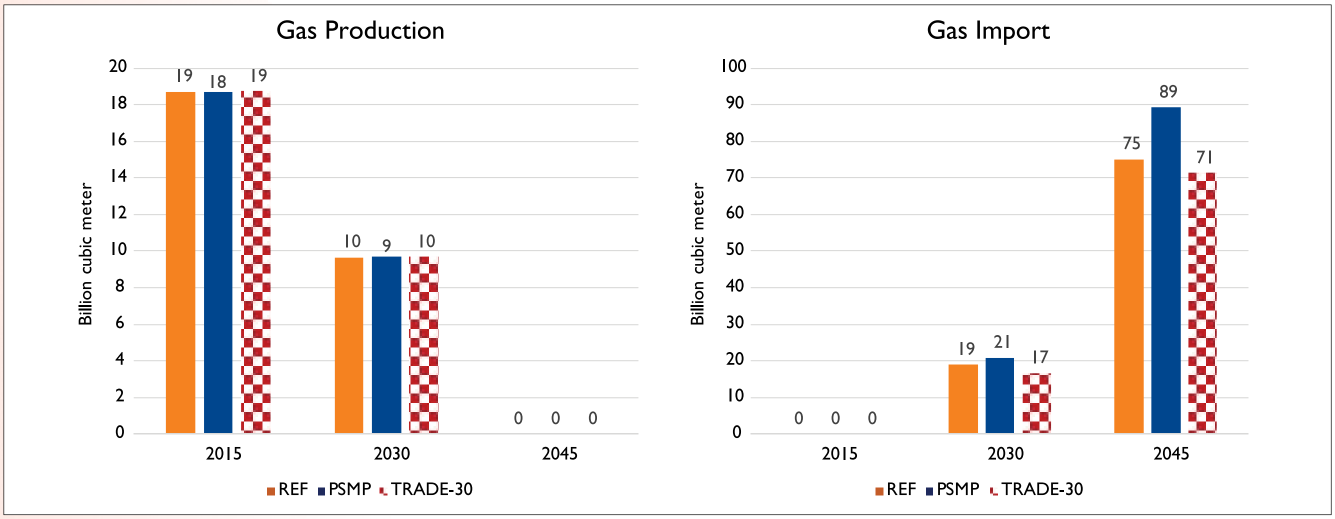
Domestic coal production is at a very nominal level in 2015 (1.4 million tonnes), increases to 3.87 MT in 2030 and to 4.29 MT in 2045 in the REF scenario (Figure 5.12). The economic model projections show that there would be a manifold increase in the import of coal, from 0.5 MT in 2015 to 14 MT in 2030 and to 80 MT in 2045 in the REF scenario (Figure 5.12). Almost the entire coal import would be used for power generation. Electricity trade in the TRADE-30 scenario reduces the demand for coal in the Bangladesh economy as well as the domestic production and import. Imports of coal decrease by 17 MT in the TRADE-30 scenario. The PSMP scenario almost halves the coal imports in 2045 to 40 MT. Production in 2045 decreases by 0.72 MT in the TRADE-30 scenario and by 1.85 MT in the PSMP scenario. However, the coal consumption in the power sector decreases by 20 MT in the TRADE-30 scenario and by 40 MT in the PSMP scenario in 2045 (Figure 5.9), which is higher than the economy-wide decrease. This implies that some amount of the coal resources saved in the power sector is redirected to other sectors of the economy. Overall, both the TRADE-30 and PSMP scenarios reduce the dependence of the Bangladesh economy on coal that needs to be imported.

Figure 5.12 Coal Production and Import



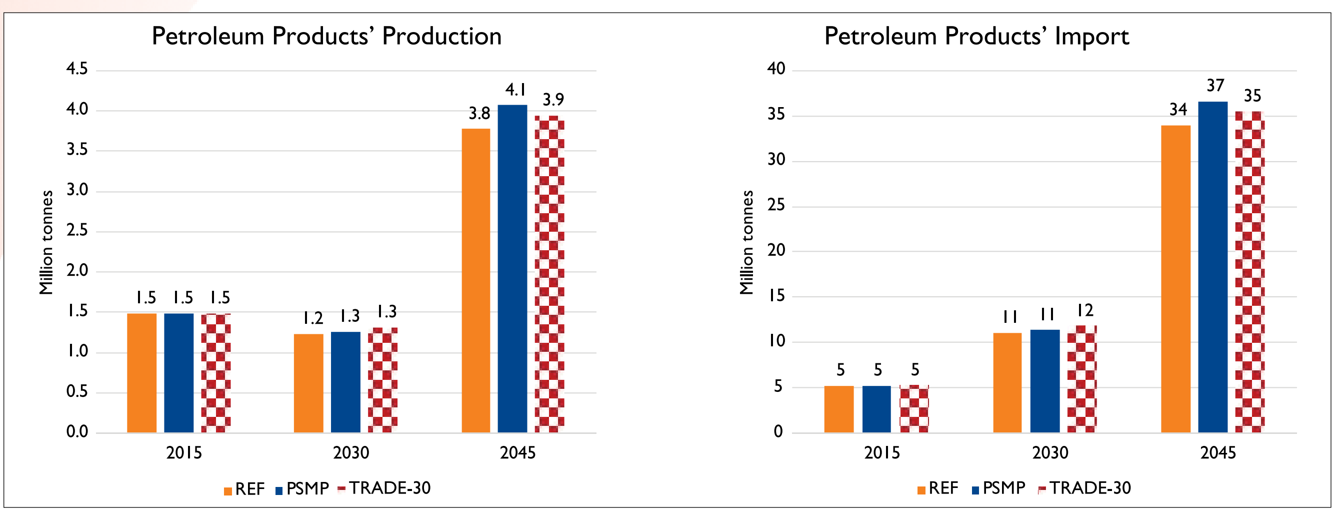
Gas is a depleting resource for Bangladesh. Gas production decreases over time and is invariant across the scenarios. Future import increases across the scenarios. The TRADE-30 scenario helps to restrict the growth in gas imports in 2030 from 19 BCM in the REF scenario to 17 BCM and, in 2045, from 75 BCM in the REF scenario to 71 BCM (Figure 5.13). However, the PSMP scenario, which focuses on the diversification of the fuel source portfolio, results in an increase in gas imports, from 21 BCM in 2030 to 89 BCM in 2045. The volatile gas market, with an expected high growth in global demand due to climate awareness, may pose a risk because of this increased dependence in the PSMP scenario.

Figure 5.13 Gas Production and Import



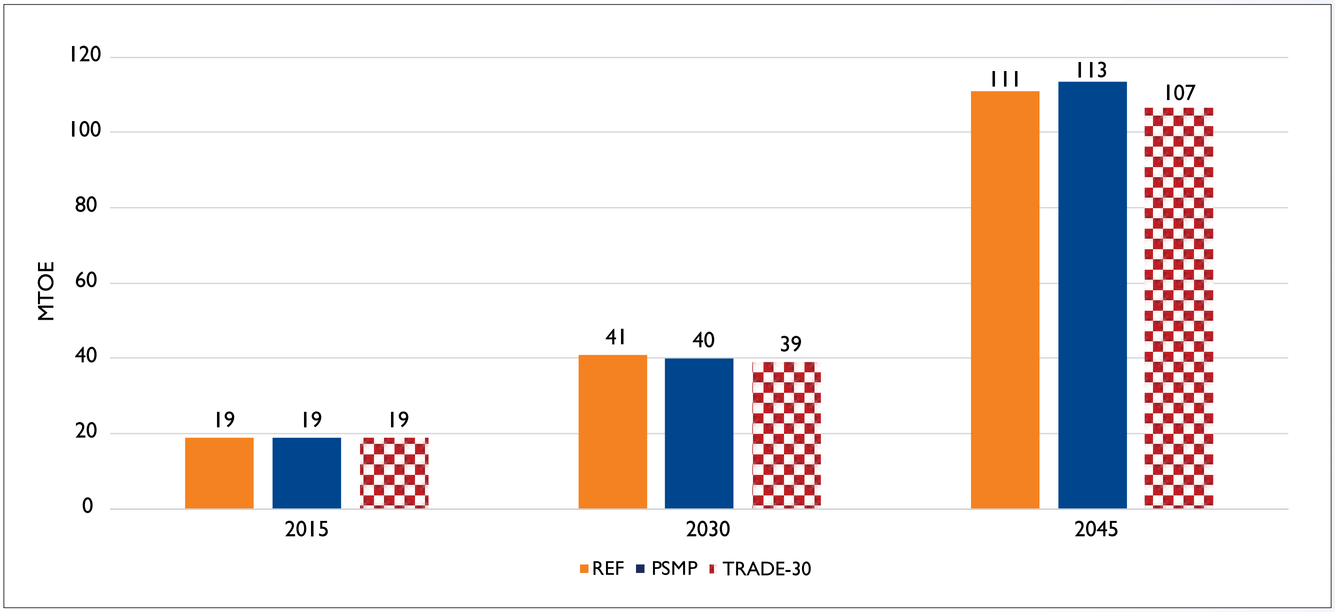
Bangladesh has no oil resources. It imports crude to refine as petroleum products and also imports petroleum products. Currently, power generation depends significantly on oil products; however, the official policy has been to eliminate oil use for future power generation. However, since the transport sector would continue to be heavily dependent on petroleum products, oil demand continues to remain high for Bangladesh's further electricity trade (TRADE-30) and fuel diversification strategy (PSMP). This may cause some amount of restructuring of the economy of the country, increasing the import of petroleum products in 2045 (Figure 5.14).

Figure 5.14 Production and Import of Petroleum Products



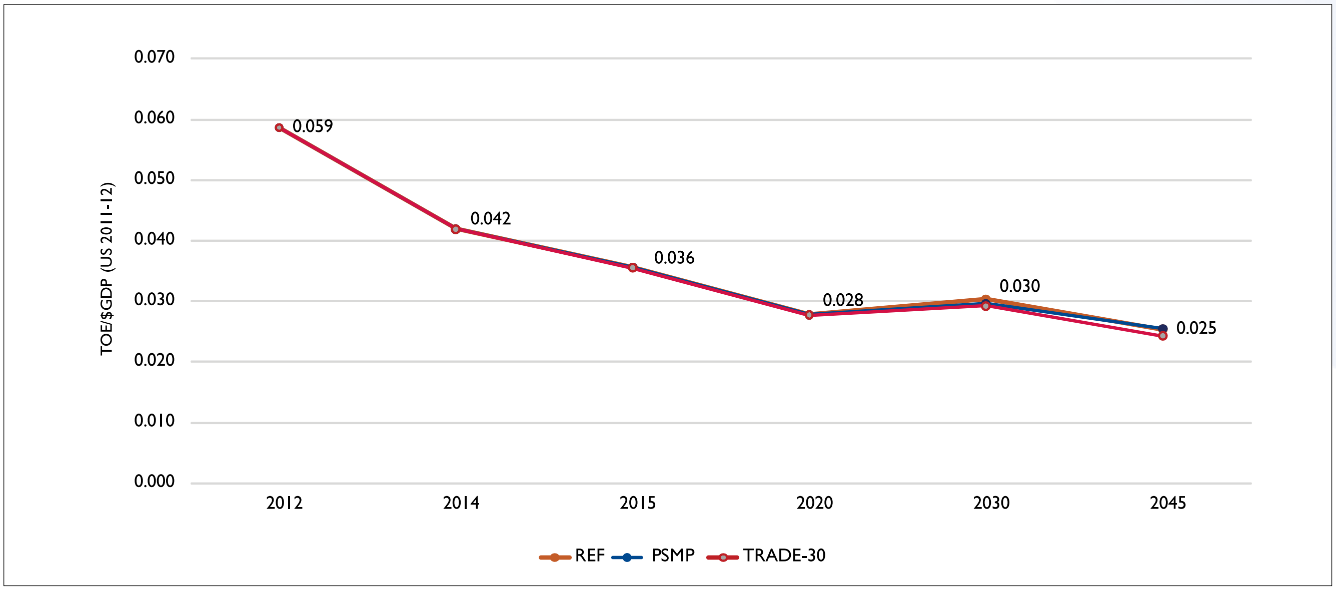
Despite the significant changes in the electricity, coal, and gas sectors, the primary energy demand for the Bangladesh economy is only marginally impacted. In the REF scenario, the primary energy mix is projected to increase from 19 MTOE in 2015 to 41 MTOE in 2030 and further to 111 MTOE in 2045; an over fivefold growth in primary energy demand over 30 years. The impact on primary energy demand is shown in Figure 5.15.

Figure 5.15 **Primary Energy Demand**



Our model forecast shows that primary-energy-GDP intensity (Figure 5.16) decreases by 25 percent, which is more than the target reduction of 20 percent by 2030 from the 2013–14 levels set by the Bangladesh Government. Over the period 2012–45, intensity falls by 40 percent. However, there is no visible change in energy intensity across the scenarios (Figure 5.16).

Figure 5.16 **Development in Energy-GDP Intensity**



5.1.4 Macroeconomic Impact

The future of Bangladesh's power and energy scenarios is dependent on import. The choice is to import electricity or coal and gas. Higher imports would have macro consequences through the balance of payment constraint. The total import bill for the economy changes very little across the scenarios as the export levels are fixed through upper bounds and financial flow from abroad depends on the level of the GDP, which also hardly changes (Figure 5.17). The total import bill of the economy declines marginally in the TRADE-30 scenario over the REF scenario. However, the impacts on energy import expenditures are noticeable (Figure 5.18).

As stated earlier, Bangladesh's energy future lies in import. This is reflected in the increase in its energy imports under the three scenarios over time (Figure 5.18). The share of energy in the total import bill in the REF scenario increases from 34 percent in 2020 to 41 percent in 2030 and further to 45 percent in 2045. The PSMP scenario increases the total energy import bill significantly, by 8 percent and 16 percent, respectively, in 2030 and 2045, over the REF scenario. However, higher electricity import in the TRADE-30 scenario brings down the fuel import bill and, subsequently, the total import bill over the PSMP scenario. The latter, therefore, increases energy import dependence in monetary terms.

Figure 5.17 Import Bill by the Economic Sector

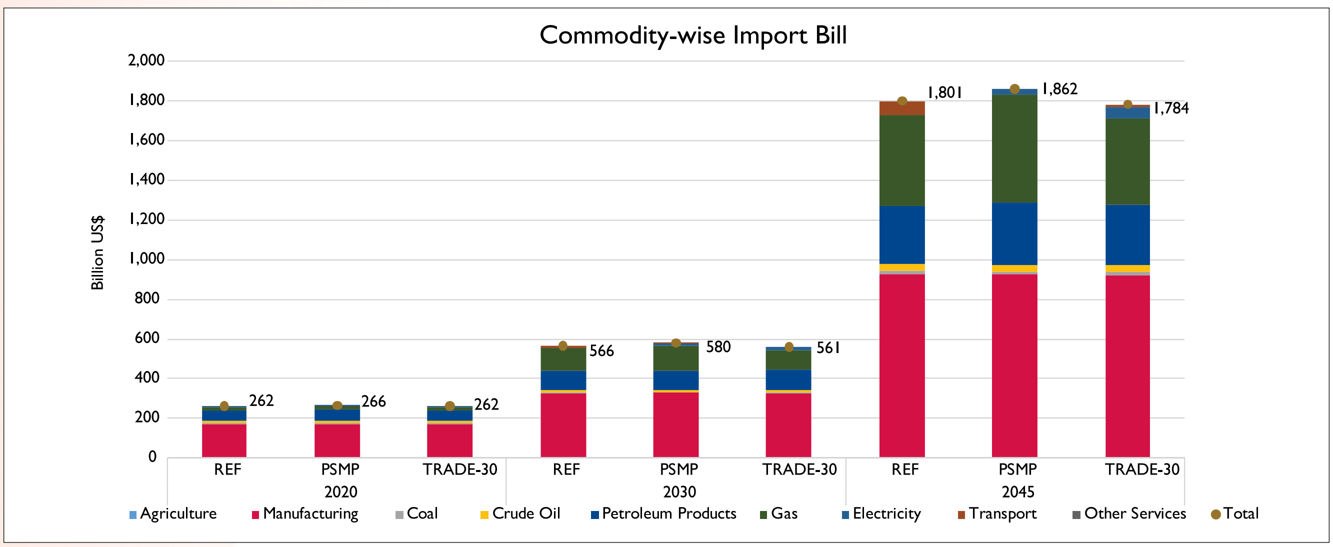
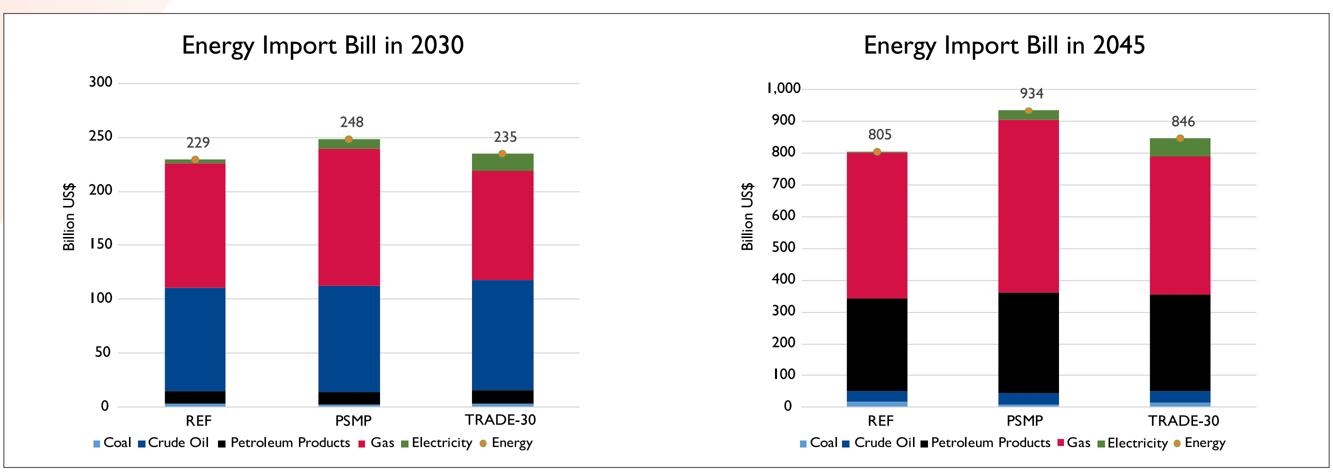


Figure 5.18 Import Bill by Energy Commodity



The increase in the energy import bill in the TRADE-30 scenario for 2030 and 2045 is mainly due to higher electricity imports and higher crude oil, petroleum product imports, though the imports of gas and coal (in 2045) decrease in this scenario due to the power generation forgone using these two products. This is shown in Table 5.1. The cost of coal import decreases for all years across both the scenarios. The decrease is higher in the PSMP scenario. Crude oil, petroleum products, and electricity imports increase in both the scenarios. This increase is higher in the TRADE-30 scenario. However, gas imports reduce in the TRADE-30 scenario but increase in the PSMP scenario. ***In the PSMP scenario that tries to ensure energy security via the diversification of power generation resources, the energy import bill actually increases due to higher electricity and gas imports, as compared to the REF and TRADE-30 scenarios***. The higher energy imports may imply a higher demand itself or a lower domestic production to meet the same demand. Thus, the TRADE-30 and the PSMP scenarios have implications for domestic production, capital stock build-up and, hence, investment.

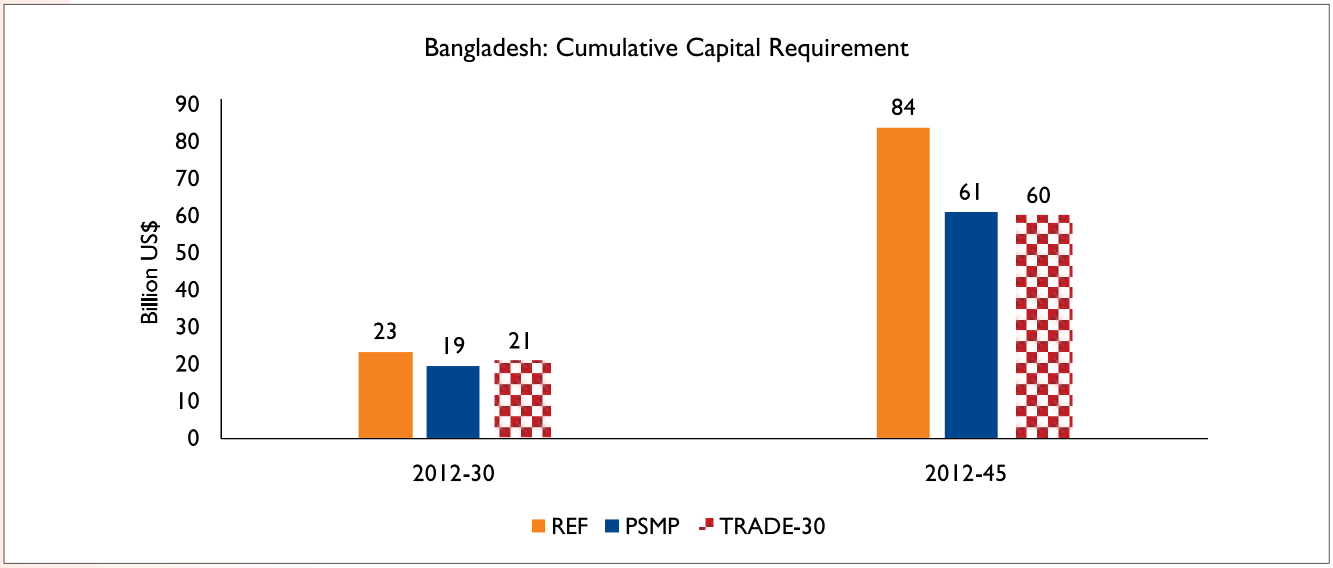
Table 5.2 Increase in Energy and Non-energy Import Bill Compared to the REF Scenario in US$ Million (2011–12)

	2020		2030		2045	
	PSMP	TRADE-30	PSMP	TRADE-30	PSMP	TRADE-30
Coal	-182	28	-873	-4	-9,120	-3,866
Crude Oil	0	0	269	791	2,643	1,515
Petroleum Products	1,183	587	2,181	6,287	22,709	13,037
Gas	1,844	-1,543	11,907	-13,550	85,852	-23,412
Electricity	699	806	5,566	11,819	26,914	53,840
Energy	3,544	-122	19,050	5,343	128,998	41,115
Non-energy	350	227	-5,205	-10,089	-68,498	-58,793

5.1.4.1 Structural Change

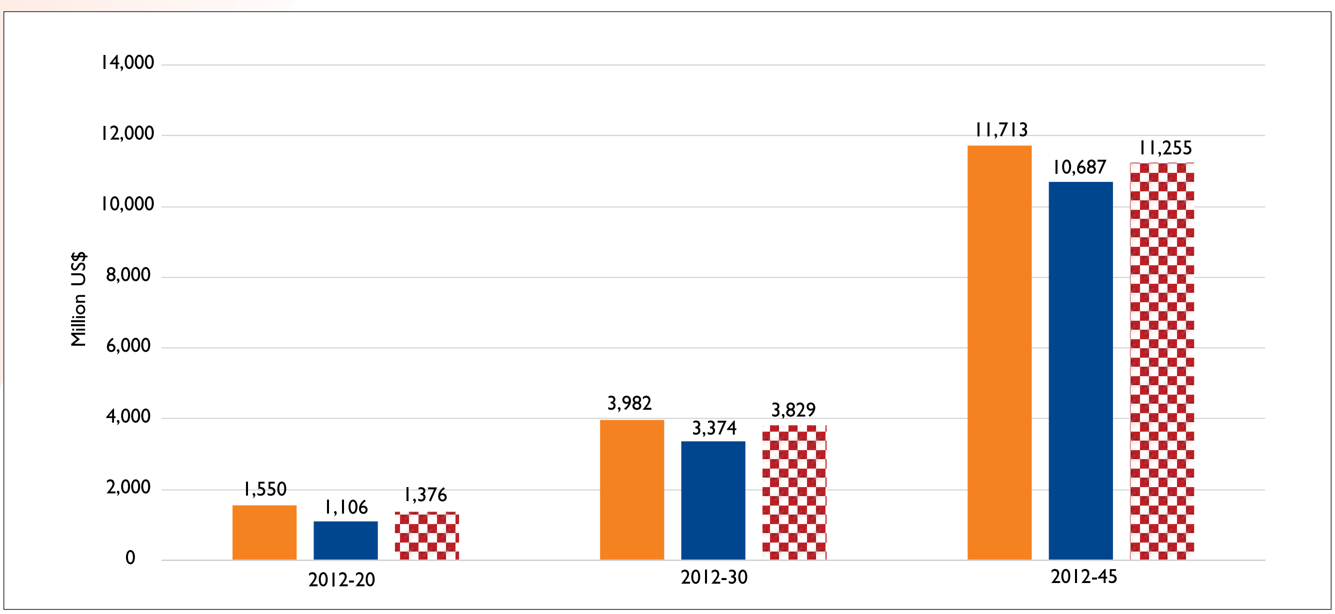
Figure 5.19 presents the cumulative investment potential in the power sector, considering only CAPEX, during 2012–30 and 2012–45, in the three scenarios. The REF scenario requires the highest amount of investment, US$ 23 billion (2 trillion BDT) of investment over 2012–30, or US$ 1.3 trillion (105 billion BDT) every year. The investment requirement during the same period declines by 17 percent in the PSMP scenario and by 11 percent in the TRADE-30 scenario. The TRADE-30 scenario needs slightly more capital because it depends on coal plants, which are more expensive, whereas the PSMP scenario, as defined, relies more on gas plants, which need less capital to build.

Figure 5.19 Power Sector Investment, Bangladesh



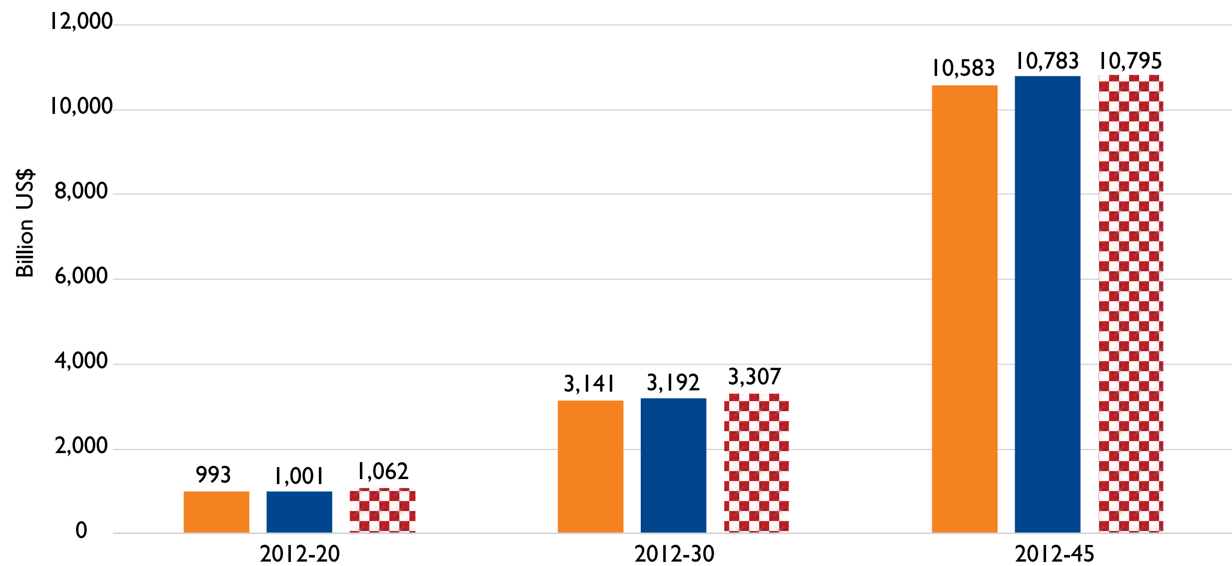
As electricity import reduces the fuel needs for power generation, there is less expansion in the fuel sectors used for power generation, both in domestic fuel production as well as developing import infrastructure, for example, for LNG. The investment in the non-power energy sector in the TRADE-30 and PSMP scenarios is hence lower than in the REF scenario (Figure 5.20). However, some amount of investment would be diverted to the sectors dealing with petroleum products, for example, refining activity or fuel import infrastructure. This makes investment in the non-power energy sector in the TRADE-30 scenario higher than the PSMP scenario. On the whole, the total investment in the two trade scenarios remains lower than the REF scenario, which could be diverted to the non-energy sectors (agriculture, manufacturing, and so on).

Figure 5.20 Cumulated Investment in the Non-power Energy Sector



The reduced investment in the energy sector (power and non-power) is re-distributed to the non-energy economic sectors (agriculture, manufacturing, transport, and other services). This is evident in Figure 5.21, which shows higher cumulative investment in the TRADE-30 and PSMP scenarios as compared to the REF scenario.

Figure 5.21 Cumulated Investment in the Non-energy Sector



Thus, electricity trade with India results in a re-distribution of investible resources to the non-energy sectors of the Bangladesh economy (Figure 5.22). The bars for each scenario in this figure represent absolute deviations of cumulated investments from their corresponding value for each sector in the REF scenario or, in other words, increments over the REF scenario. Investments reduce in the power sector and the non-power energy sector, and they increase in the non-energy sector. The decrease in power sector investments is amply compensated in the non-energy sector in the PSMP scenario, implying a net increase in investment in the economy. However, in the TRADE-30 scenario, the decrease in investment in the power sector results in a less than corresponding increase in investments in non-energy, resulting in lower net aggregate investment requirements in the economy and higher resources available to support imports and consumption. The re-distribution of investment resources should result in a production gain in the non-energy sector, indicating trade-induced production specialization.

Figure 5.22 **Sectoral Changes in Investment**

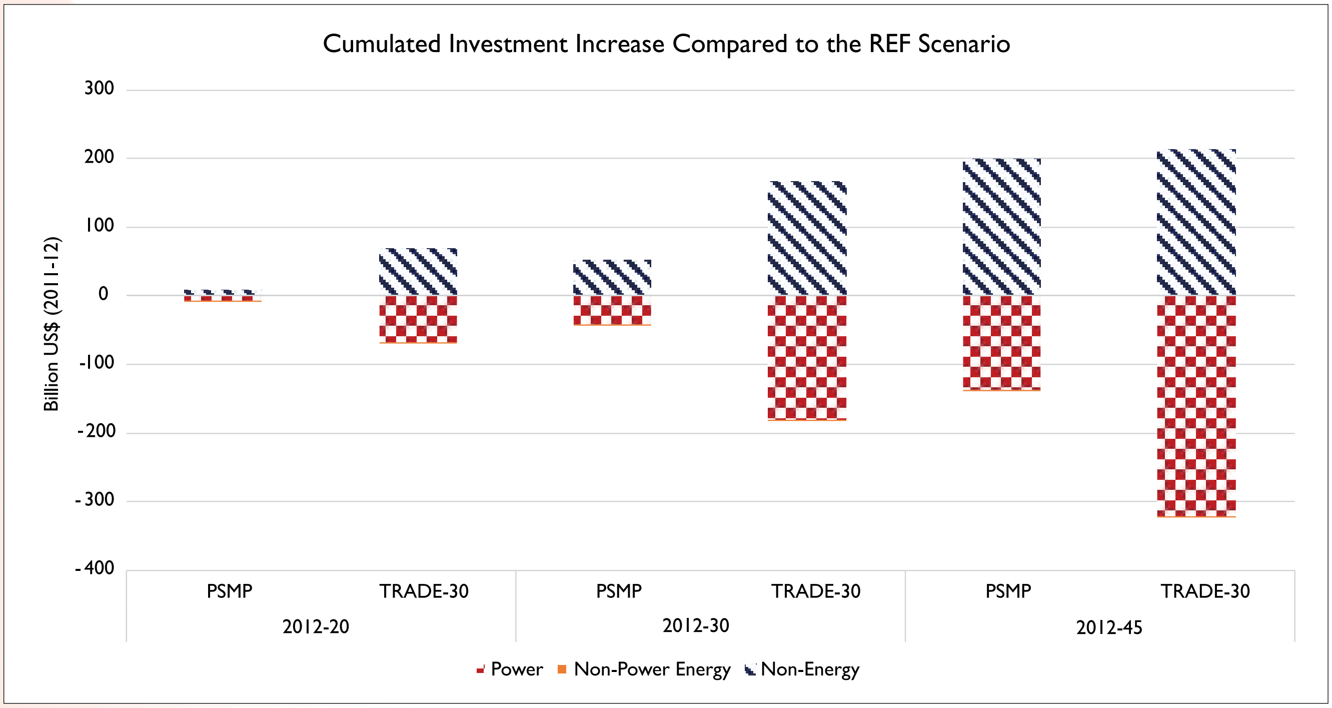
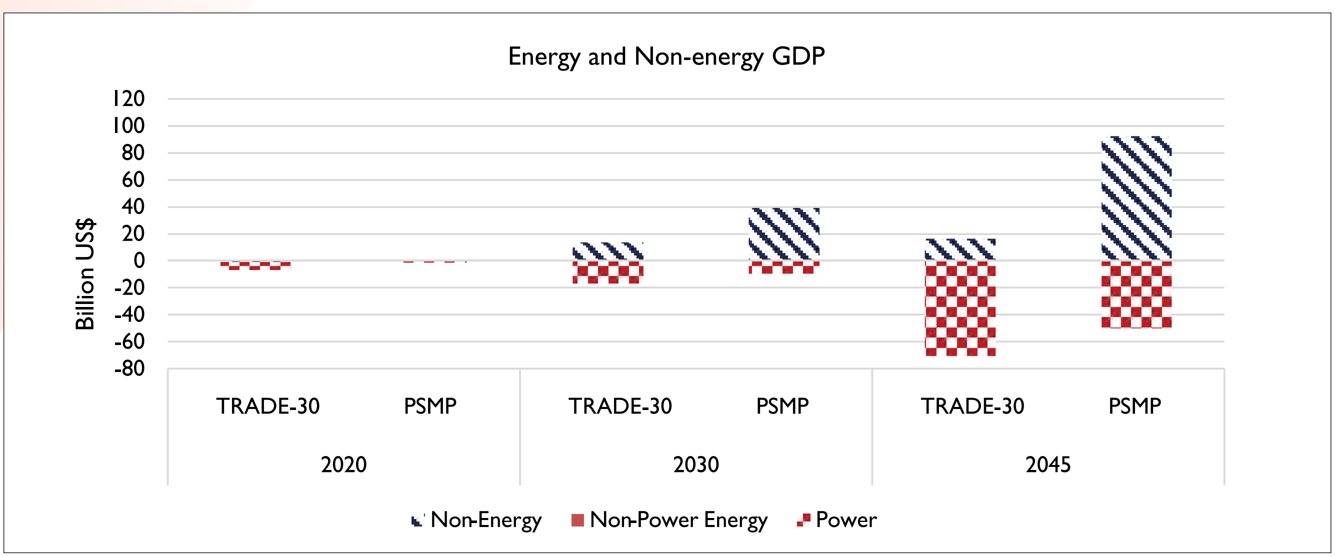


Figure 5.23 shows the impact on the GDP of the energy and non-energy sectors in the TRADE-30 and PSMP scenarios, as compared to the REF scenario. The value for each sector is reported as absolute deviations from the REF scenario. As expected, the GDP from power decreases in both the TRADE-30 and PSMP scenarios; the decrease is more in the TRADE-30 scenario. The non-energy sector GDP gains in both the scenarios; however, the gain is more in the PSMP scenario. The impact on the demand and supply of the non-energy sectors and power leading to the structural changes is presented in more detail in Annexure 3.

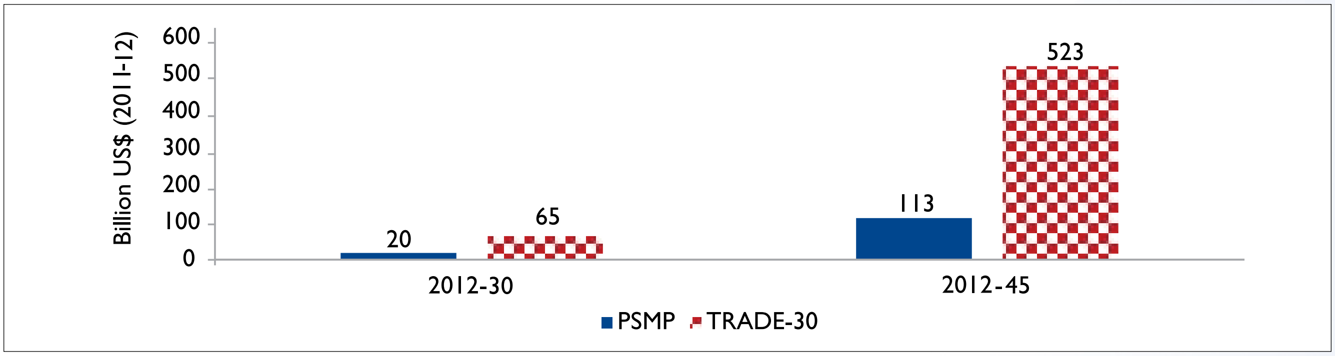
Figure 5.23 **Impact on the Sectoral GDP in the Trade Scenarios**



The net decrease in the power sector GDP outweighs the increase in the non-energy sector GDP, resulting in a lower GDP in the TRADE-30 scenario, as compared to the REF scenario. In the PSMP scenario, however, the increase in the non-energy GDP outweighs the decrease in the power sector GDP, resulting in a higher GDP in the PSMP scenario in comparison to the REF scenario. In terms of the GDP, the PSMP scenario seems to be a more beneficial scenario for Bangladesh.

5.1.4.2 Impact on Welfare

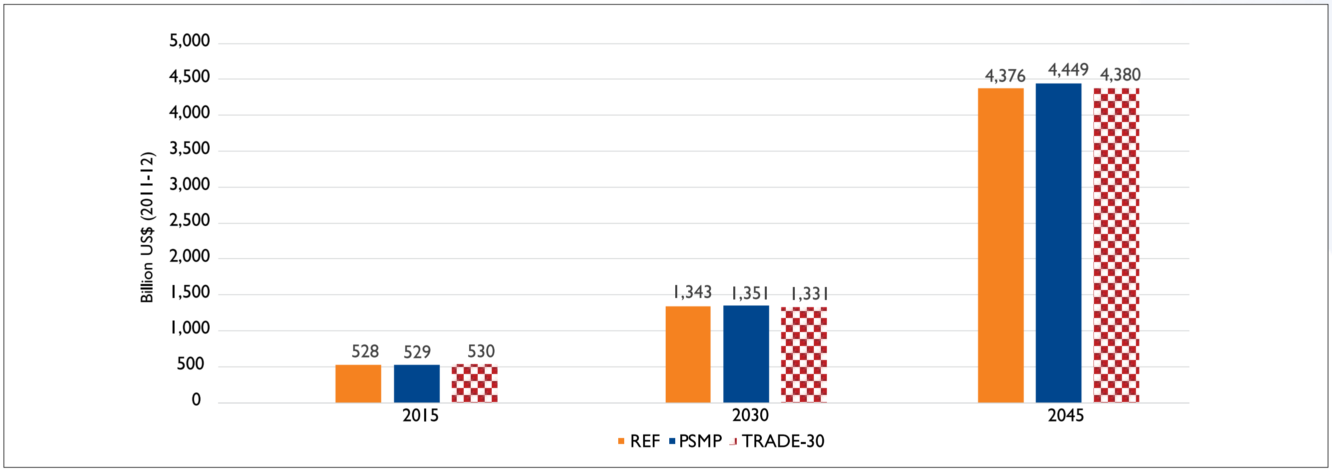
Figure 5.24 **Impact on Household Aggregate Consumption in the Trade Scenarios**



However, if we consider the impact on the household aggregate consumption (which is a measure of economic welfare) shown in Figure 5.24, the increase in the total aggregate household consumption for all commodities is much more in the TRADE-30 scenario than in the PSMP scenario. The gain in cumulated consumption from 2012–45 is US$ 523 in 2011–12 prices and market exchange rate (Figure 5.24). This is higher than the corresponding cumulated consumption gain in 2012–45 for India (Figure 5.37) of US$ 401 in 2011–12 prices and market exchange rate. **Thus, to sum up the macroeconomic impacts of the two scenarios, the PSMP scenario provides a higher GDP with lower welfare (household consumption) at the cost of higher investments while the TRADE-30 scenario provides a lower GDP with higher welfare (consumption) at a lower investment cost to the economy**.

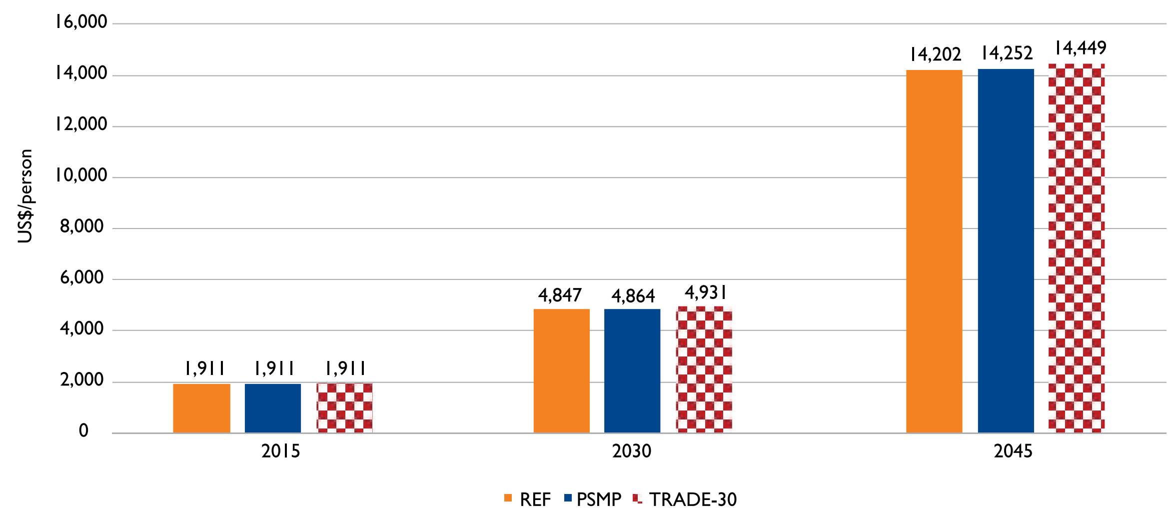
The impact on the aggregated GDP and per capita household consumption is shown in Figures 5.25 and 5.26.

Figure 5.25 **GDP Development by Scenarios**



The GDP is marginally lower in the TRADE-30 scenario and higher in the PSMP scenario. The TRADE-30 scenario, however, shows higher per capita consumption, compared to both the REF and PSMP scenarios. This implies that electricity trade would be a more welfare-enhancing option than a fuel portfolio diversification strategy.

Figure 5.26 Per Capita Consumption in the Scenarios



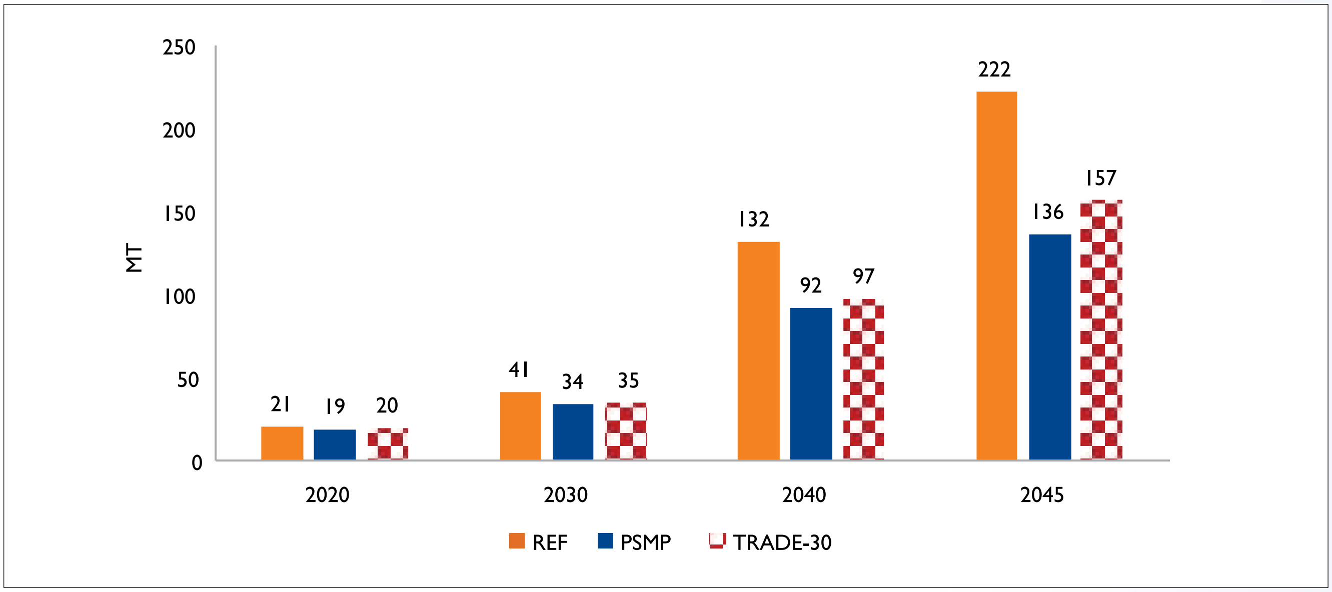
5.1.5 Impact on the Environment

CO_2 Emissions

As far as climate goes, Bangladesh is a highly vulnerable country whose emissions are less than 0.35 percent of the global emissions. Electricity production is a dominant contributor of the energy-related CO_2 emissions in the country. Figure 5.27 presents the CO_2 emissions from the power sector for all the scenarios. In the REF scenario, it will increase substantially in the future, as power generation, currently dominated by gas, would become increasingly dependent on coal for power supply, along with a manifold increase in power generation. However, the use of nuclear for power generation helps to limit the growth to some extent. Emissions in 2030 are 41 MT, which go up by more than a factor of five in 2045, reaching 222 MT.

The presence of nuclear, modest electricity import combined with a higher share of gas in generation reduce the growth of CO_2 emissions in the PSMP scenario when compared to the REF scenario. Emissions in 2030 and 2045 are 17 percent and 38 percent, respectively, lower than the REF scenario.

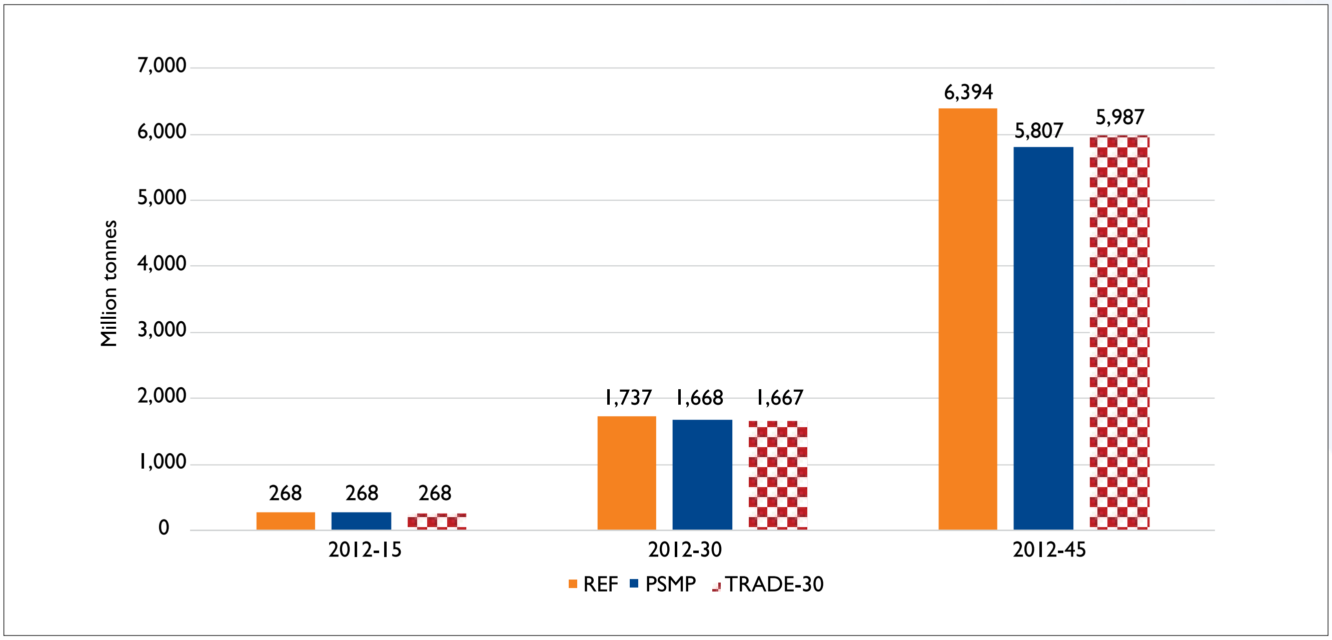
Figure 5.27 Annual CO_2 Emissions from Power Generation, Bangladesh



In the TRADE-30 scenario, although emissions are higher than in the PSMP scenario, due to a higher presence of coal, they are substantially lower than the REF scenario. Higher electricity import contributes to less CO_2 emissions compared to the REF scenario.

The changes in fossil fuel use, reduction in power generation requirement, and a structural change in the economy reduce the cumulated CO_2 emissions from Bangladesh. The cumulated emissions in 2012–45 reduces from 6.3 GT in the REF scenario to 6 GT (6.4 percent reduction) in the TRADE-30 scenario and furthur to 5.8 GT (9 percent reduction) in the PSMP scenario (Figure 5.28).

Figure 5.28 Cumulated CO_2 Emissions from the Energy Sector



5.2 India

As India's power system is more than 30 times larger (316 GW) than that of Bangladesh (10 GW), the electricity trade between the two countries would also be a case of a large country (India) and a small country (Bangladesh) trade. In such a case, if imports or exports increase by a small country, it does not have significant impact on the large country's economy. The power sector accounts for a very small share of the Indian economy, two percent, which will decline further in the future. Hence, the economic impact on India is not expected to be substantial, though some economic and technological benefits do accrue.

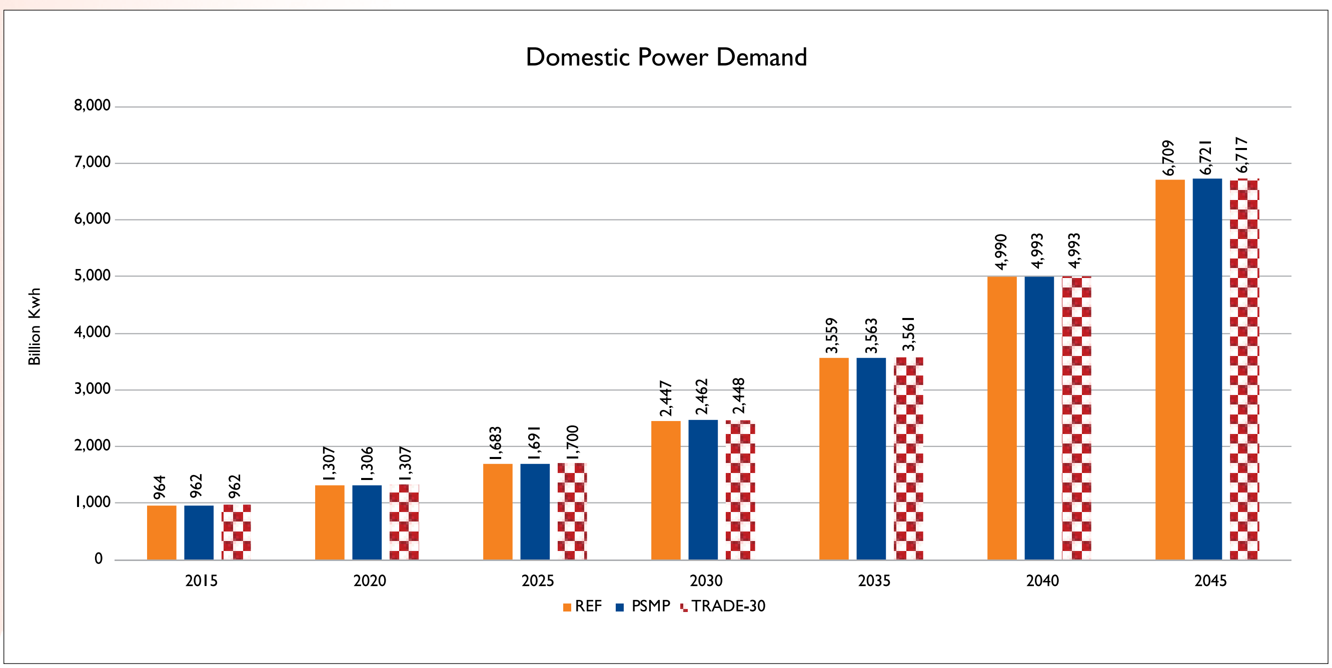
With trade, the exporting country gains through production specialization and welfare increase. The exporting country increases its production of the exported commodity and hence has a GDP gain. This enables higher investment and greater consumption gain due to higher income generation through exports.

5.2.1 Impact on the Power Sector

5.2.1.1 Electricity Demand

Electricity trade with Bangladesh has an impact of increased generation through rise in the utilization (PLFs) of the power plants in India. This increases the profitability of the power sector. However, as shown in Figure 5.29, there is not a significant impact on the power demand in India. The domestic power demand increases to 2,447 TWh in 2030 and further to 6,709 TWh in 2045.

Figure 5.29 Electricity Demand Development in India



5.2.1.2 Export to Bangladesh

Figure 5.30 Export Development in the Scenarios

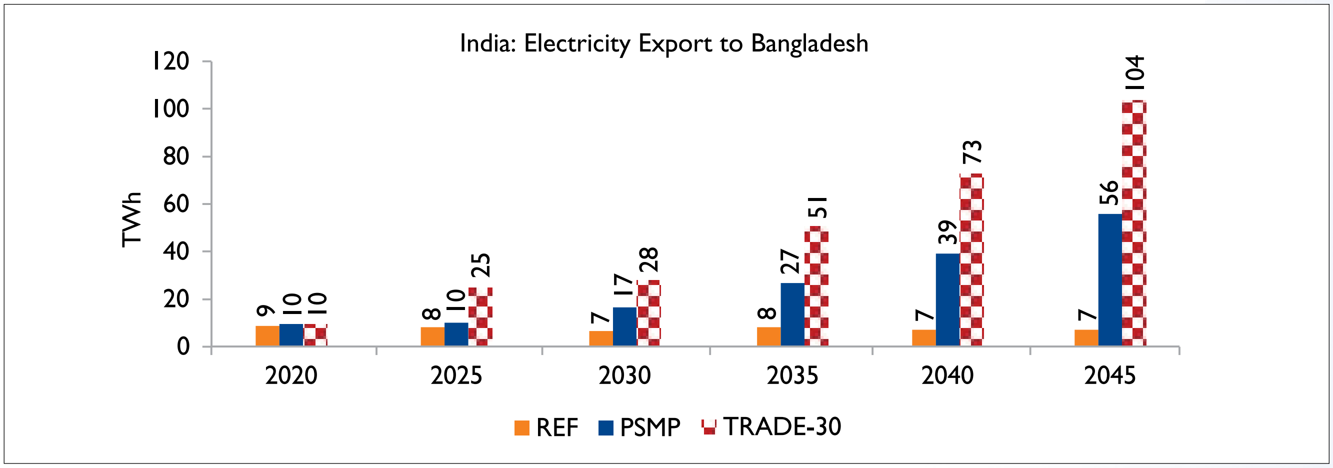


Figure 5.30 presents India's export to Bangladesh in three scenarios. The volume of exports when compared with the domestic demand of India is insignificant in the REF scenario; it is very small in two trade scenarios in all the years and is in the percent range between 1-1.5 percent for the TRADE-30 scenario that allows higher import of electricity in Bangladesh.

5.2.1.3 Supply Strategies

Capacity and Technology Mix

Figure 5.31 Capacity Requirement in India

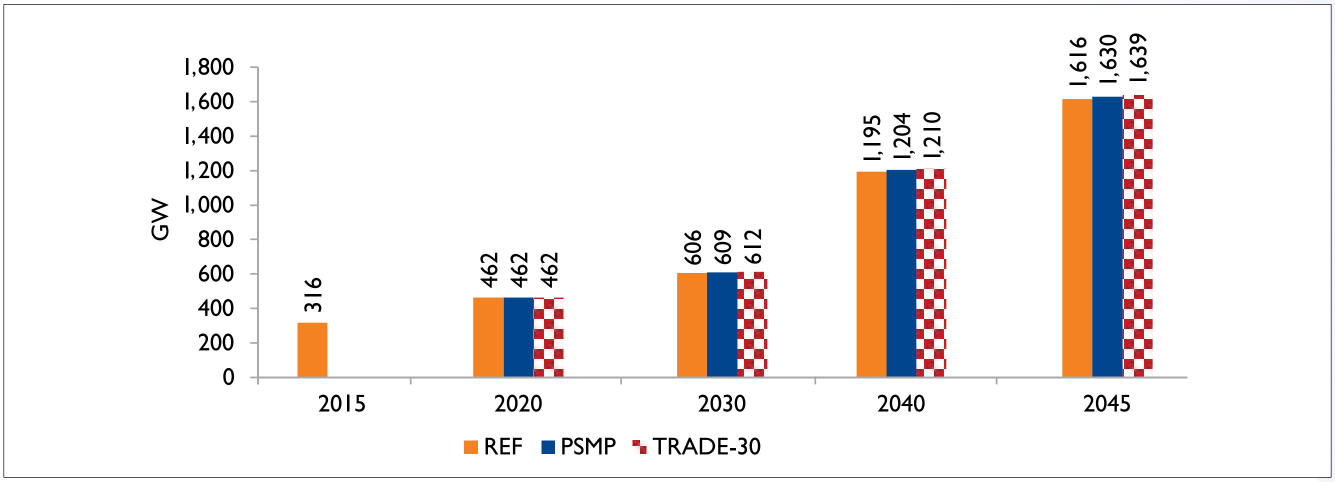


Figure 5.31 presents the capacity development in India. In the REF scenario, where electricity export from India to Bangladesh is kept at 1.1 GW, India's power generation capacity needs to meet its electricity demand of 513 GW in 2025. Capacity requirement further grows to 896 GW and 1,616 GW in 2035 and 2045, respectively. Though the capacity projected for 2045 may sound big, China has an almost similar capacity today.

In the PSMP scenario, by 2025, India can meet the electricity import needs of Bangladesh without adding extra capacity, as compared to the REF scenario. By enhancing the utilization of the capacity, Bangladesh's needs could be met. In 2030, the PSMP scenario requires 3 GW additional capacity to export electricity to Bangladesh, whereas the TRADE-30 scenario needs 6 GW additional capacity. In either case, this is a 0.5 percent increase. In 2035, the PSMP scenario needs 11 GW additional capacity, while the TRADE-30 scenario needs only 1 GW additional capacity by choosing a different technology mix (more coal power plants that offer higher capacity factor and less solar PV). Beyond that, only 1-1.5 percent additional capacity, as compared to the REF scenario, is required for both the scenarios.

Figure 5.32 Development in Capacity Mix, India

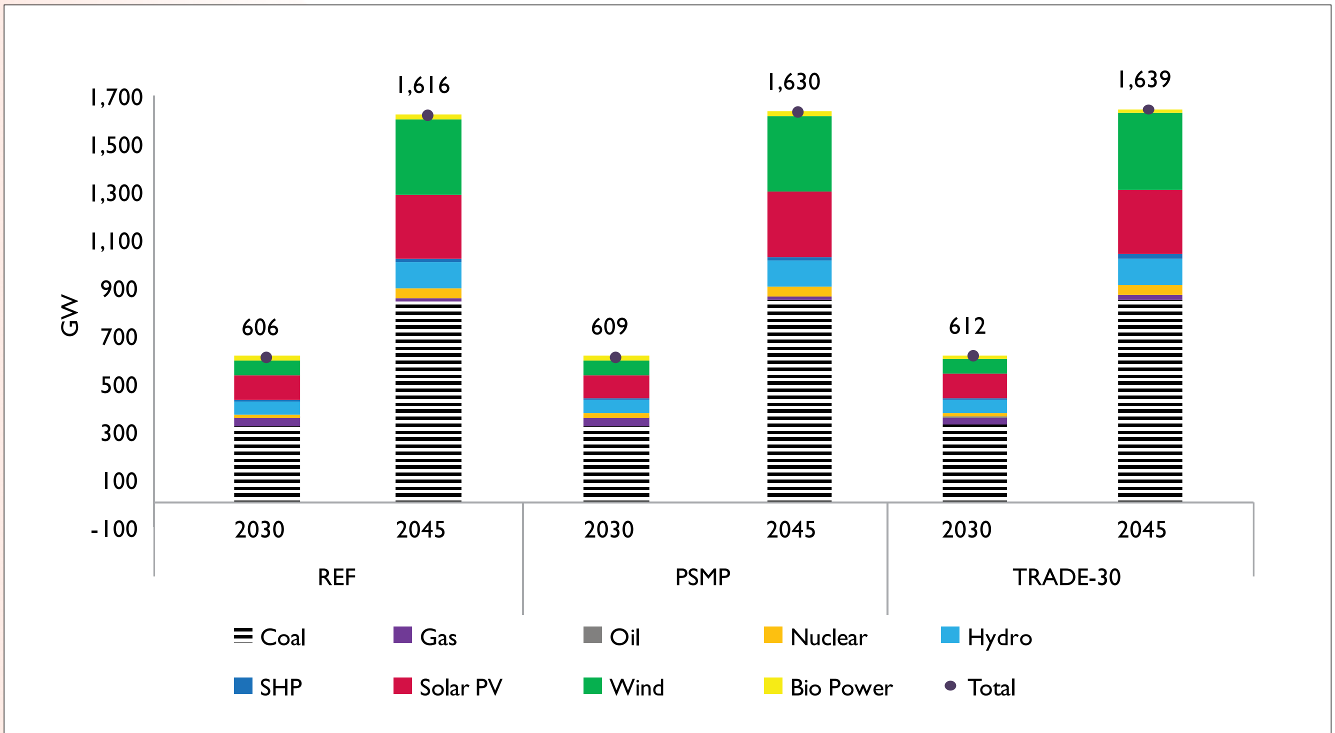


Figure 5.32 presents the capacity development by technology. India's current power system is heavily loaded with coal power plants. However, due to India's green power policies, which include 175 GW of new renewables by 2022 and a share of non-fossil fuel in total capacity as 40 percent in 2030 and onwards, the dominance of coal in the power system declines. Yet, coal would have an almost 50 percent share in the total capacity. The green policy will drive a large penetration of solar PV and wind capacity.

An additional capacity need in the PSMP and TRADE-30 scenarios is also supplied by coal right up to 2030 and, as the cost of solar PV and wind falls, they start contributing to the additional capacity requirement.

Generation and Export

Figure 5.33 **Electricity Generation, India**

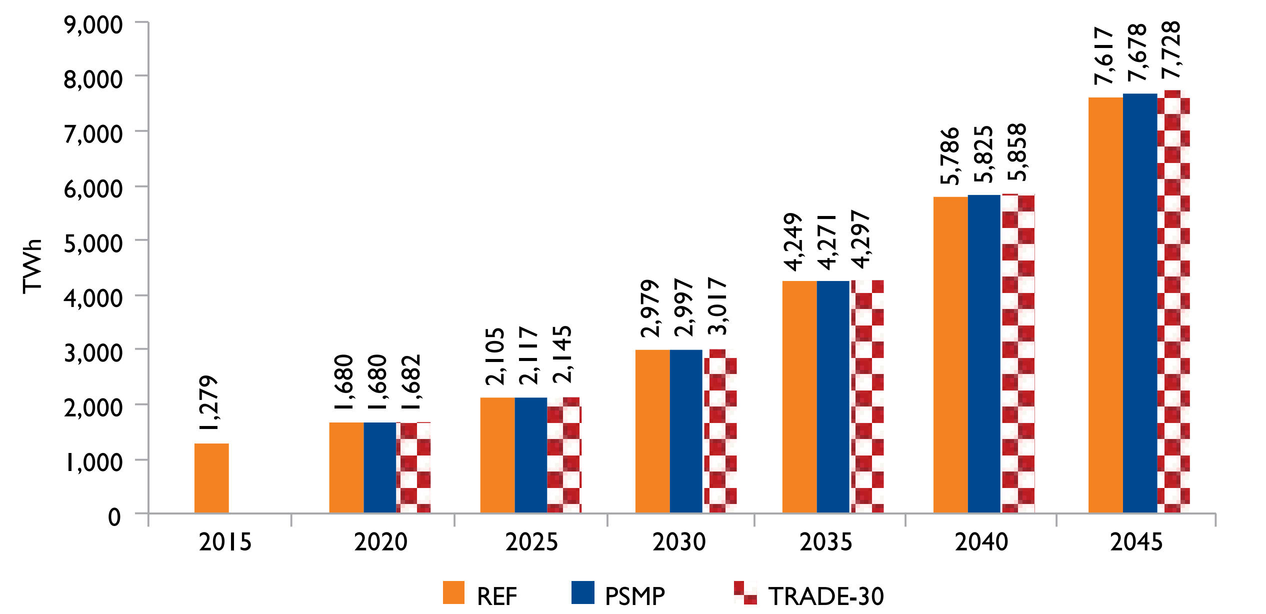
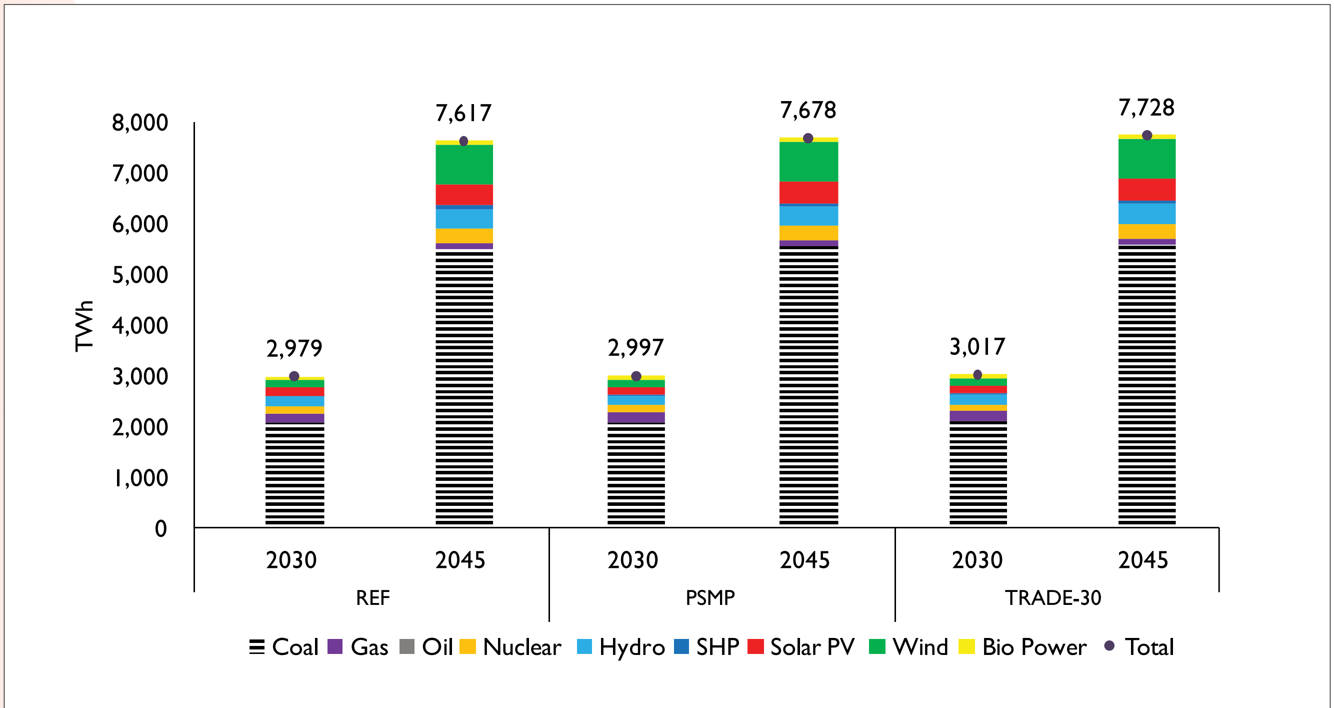


Figure 5.33 presents electricity generation in India across scenarios. India's current generation is 1,279 TWh (2015). In the REF scenario, that allows only a small quantity of electricity export; generation increases by almost two-and-a-half times by 2030, to 2,979 TWh. This further goes up to 7,617 TWh in 2045.

As India's electricity exports increase in the PSMP scenario from 2025, the generation is higher than the REF scenario. However, as import in Bangladesh is constrained, less than 1 percent additional generation is needed over the REF scenario to meet the country's import requirement.

In the TRADE-30 scenario, which allows higher export than the PSMP scenario, an additional generation need increases marginally, in the range of 1-2 percent, as compared to the REF scenario.

Figure 5.34 **Electricity Generation Mix by Technology, India**



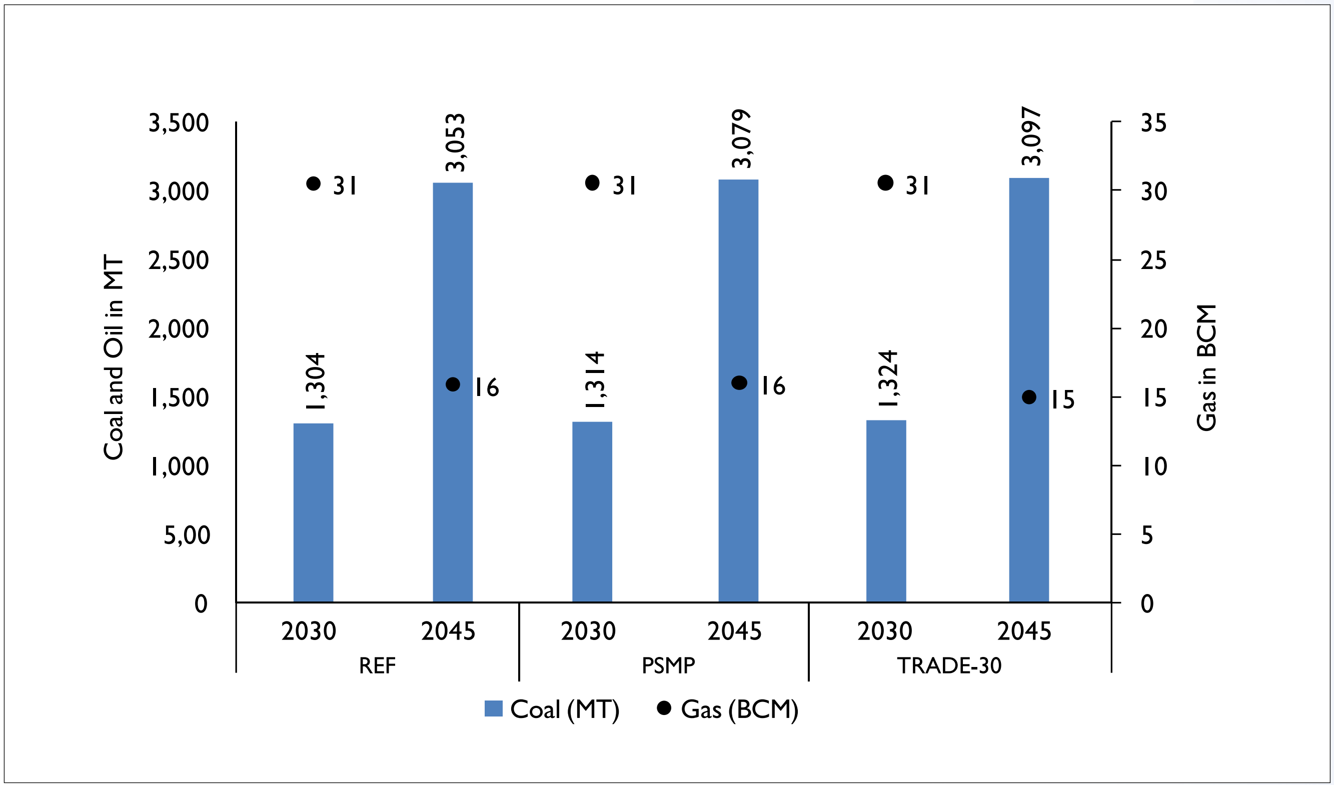
Although the green policy reduces the share of coal in the total capacity, its generation will still be dominated with a share in the total generation reaching about 72 percent by 2045 in all three scenarios (Figure 5.34). The next pre-dominant share goes to wind, with its share increasing to about 10 percent by 2045. Solar PV, nuclear, and hydro contribute almost similar amounts, while gas fills up the remaining gap.

The PSMP scenario needs additional generation that will be exported to Bangladesh. Coal, being the cheapest option up to 2035, supplies the entire additional requirement. However, beyond that, solar PV also contributes to the export demand.

Similar to the PSMP scenario, in the TRADE-30 scenario, coal power plants meet the entire export demand till 2035. However, in 2040, wind meets almost 50 percent of the export demand; in 2045, it is again coal power plants that meet the entire export demand.

5.2.1.4 Fuel Demand in the Power Sector

Figure 5.35 Fuel Demand in the Power Sector, India



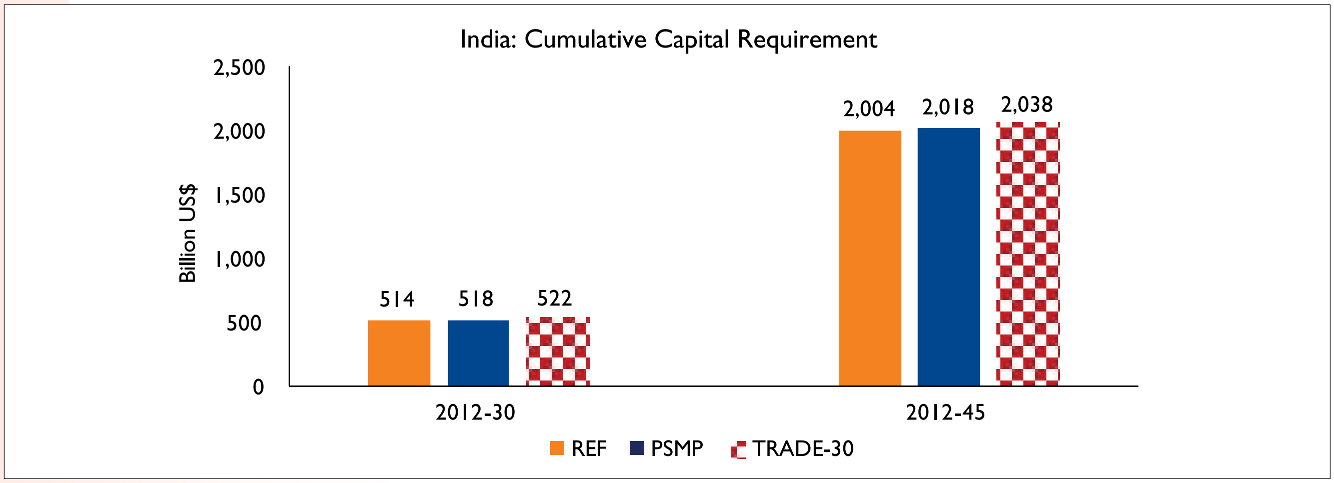
India is largely dependent on coal for power generation and needs huge amounts to fuel its coal power plants. Coal requirement in the power sector is estimated as 811 million tonnes (MT) in 2020, which will go up to 1 billion tonne (BT) in 2025 (Figure 5.35). Coal requirement in 2040 is 2.4 BT, which is expected to be 3 BT in 2045. The power sector needs 31 BCM of gas in 2030, which declines gradually over the next 15 years and, by 2045, the power sector needs 16 BCM gas.

5.2.2 Macroeconomic Impact

5.2.2.1 GDP Growth, Consumption, and Investment

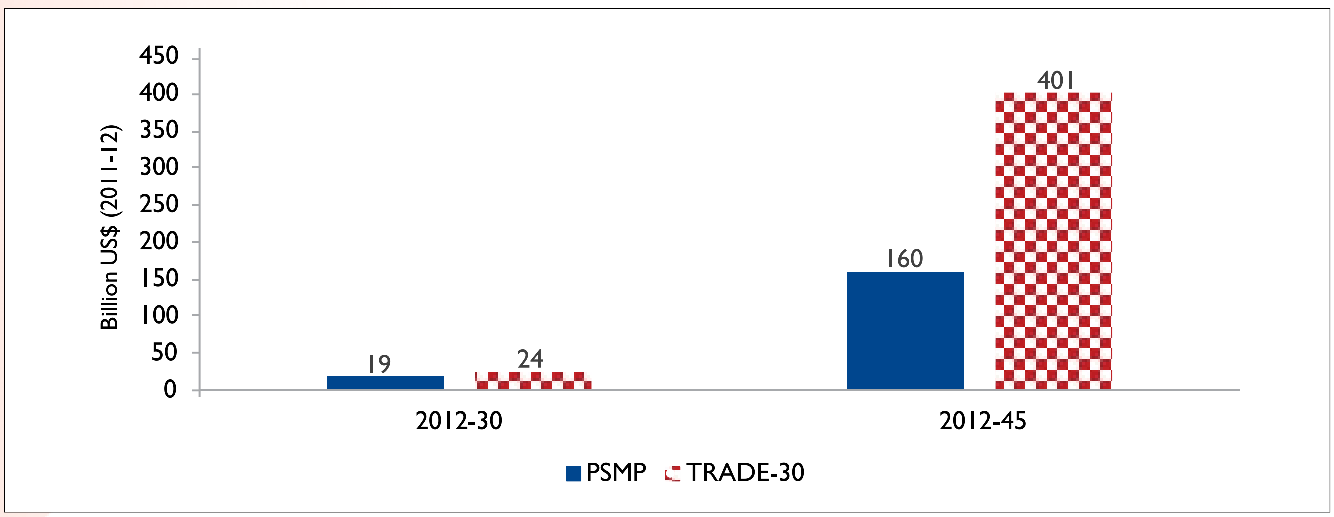
In the REF scenario, the Indian power sector needs 514 billion US$ (INR 24 trillion) of investment (CAPEX) on generation capacity development over the period 2012–30 (Figure 5.36), almost US$ 28 billion (INR 1.3 trillion) annually. In the other two scenarios that need additional capacity to export electricity to Bangladesh, the additional investment requirement during this period (2012–30) is US$ 4 billion (INR 170 billion), which is, in percentage terms, higher by only 0.7 percent. In the TRADE-30 scenario, this is higher by 1.5 percent (US$ 7 billion or INR 350 billion) compared to the REF scenario. If we consider the longer period of 2012–45, the total investment requirement on power generation capacity development is US$ 2,004 billion (INR 93.5 trillion). The additional investment requirement in the other two export-oriented scenarios is less than one percent higher than the REF scenario.

Figure 5.36 **Cumulated Investment in the Indian Power Sector**



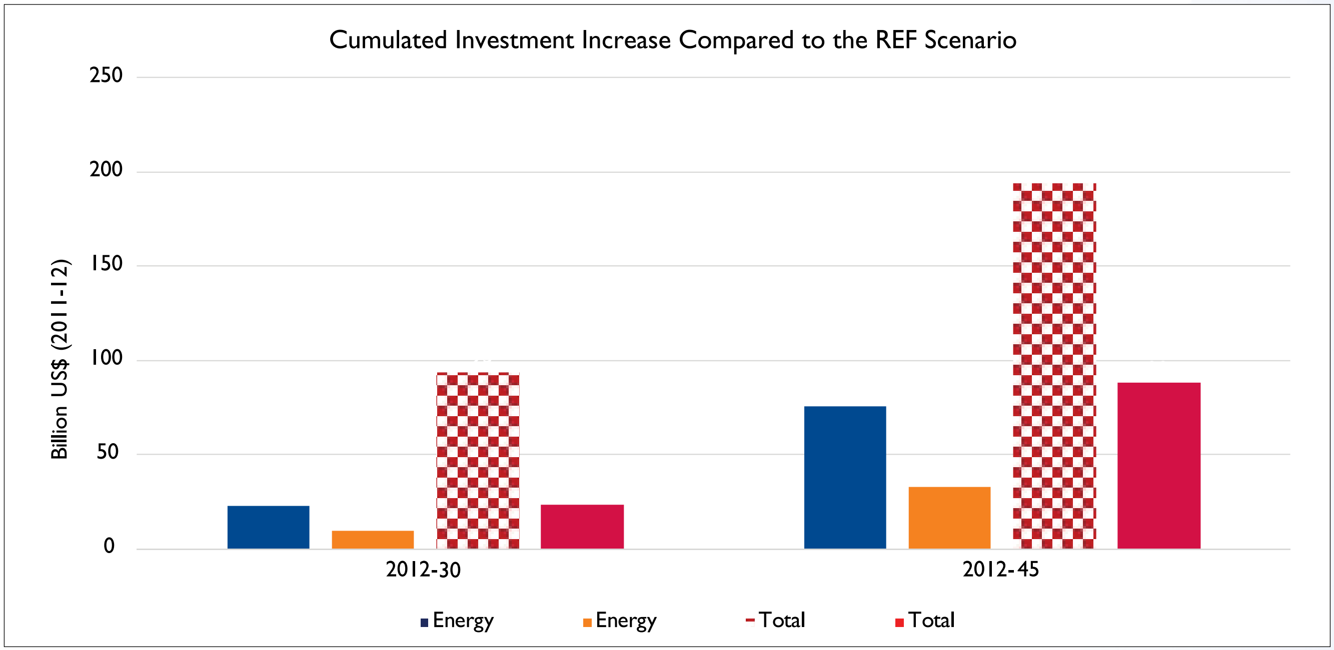
The export of power to Bangladesh results in export revenue earning for India's economy and an increase in consumption and investment for the economy. Figure 5.37 shows the increase (computed as absolute deviation from the REF scenario) in cumulated consumption for the TRADE-30 scenario and the PSMP scenario compared to the REF scenario. Consumption gain for India is much higher in the TRADE-30 scenario compared to the PSMP scenario, because the export quantum is also higher in the TRADE-30 scenario. The gain in consumption over the period 2015–45, which is US$ 401 billion (2011–12), is still only 0.4 percent of the total cumulated consumption.

Figure 5.37 **Impact on Cumulated Consumption**



The increase in power generation required to meet the additional export demand from Bangladesh results not only in an increase in power sector investment, but also in the entire energy sector and the economy. The impact on the energy sector, cumulated investments, and aggregated cumulated investments, for the TRADE-30 and PSMP scenarios, is shown in Figure 5.38, in terms of the increase over the REF scenario. The energy investments increase is higher in the TRADE-30 scenario compared to the PSMP scenario. As the power sector output increases to meet the additional export demand, it also creates additional intermediate demands for the other sectors of the economy, resulting in higher production for other sectors as well. Therefore, the total aggregate investment increases much more than the increase in the energy sector investment.

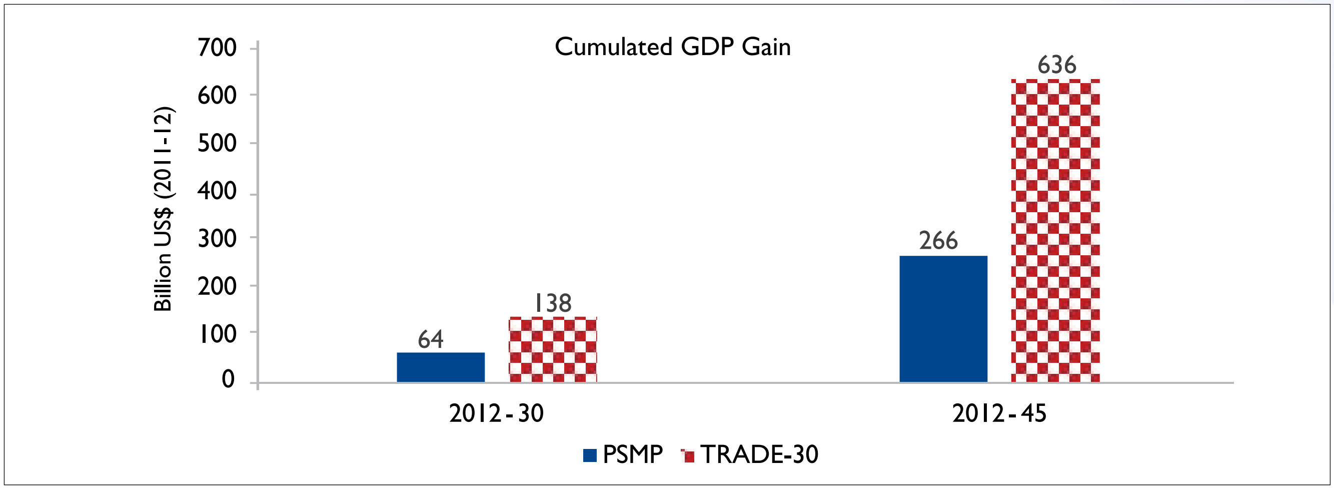
Figure 5.38 **Impact on Cumulated Energy Sector Investment and Total Investment**



The increased power sector output and the outputs of the other sectors are due to the multiplier effect result in the additional GDP creation. Figure 5.39 shows the increase in cumulated GDP for the TRADE-30 and PSMP scenarios, as compared to the REF scenario.

The cumulated GDP gain is much higher in the TRADE-30 scenario than in the PSMP scenario, as the export volume is also higher in the TRADE-30 scenario. The increase in cumulated GDP in the TRADE-30 scenario is, however, only 0.3 percent of the cumulated GDP in the REF scenario. In any case, electricity trade with Bangladesh provides a positive gain for the Indian economy.

Figure 5.39 **Impact on the Cumulated GDP**

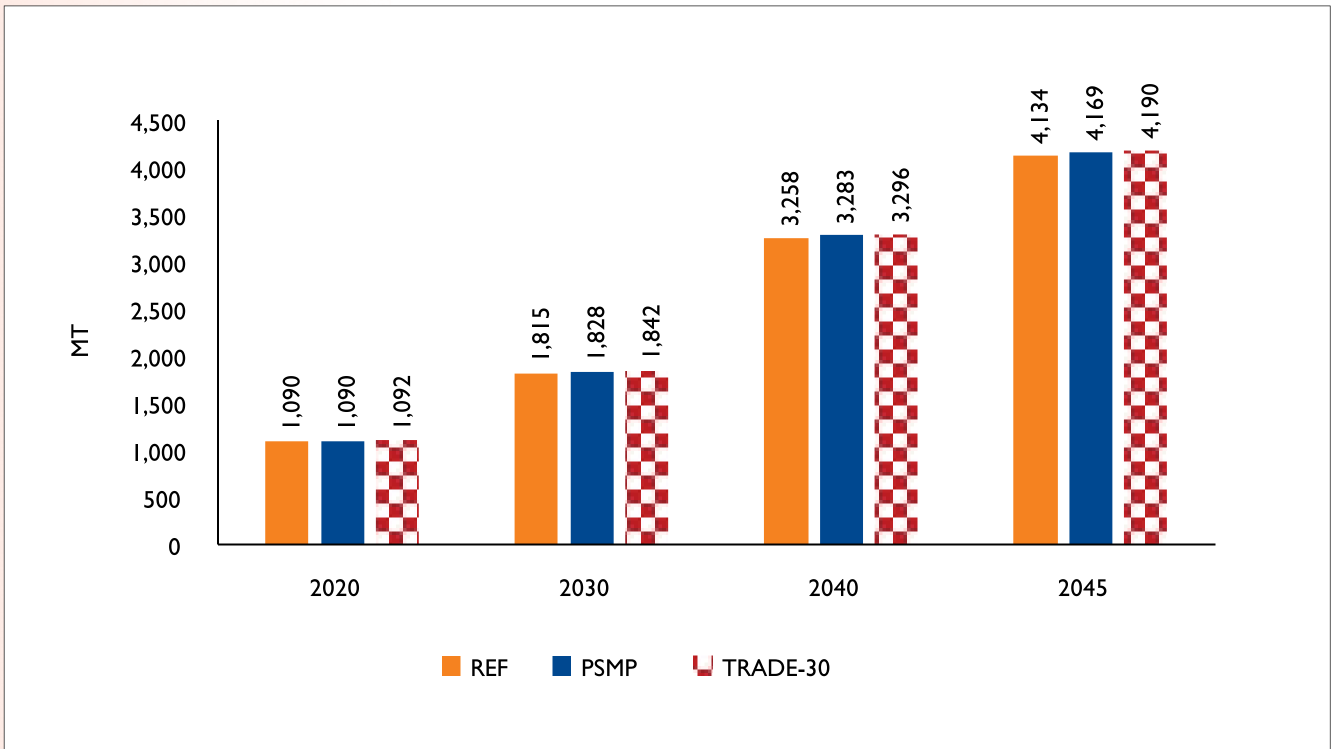


5.2.3 Impact on the Environment

The Indian power sector continues to be a large emitter of CO_2. In 2020, emissions are projected as 1 BT, which will go up to 1.8 BT in 2030 and 4.1 BT in 2045 (Figure 5.40). However, due to the efficiency improvement in the existing coal power plants as well as the introduction of clean coal technology, such as supercritical technology for new power plants, the emissions per unit of electricity generation from coal power plants declines from 0.94 kg/kWh in 2020 to 0.75 kg/kWh in 2045. This is an almost 20 percent decline. On the whole, better technologies and green polices decarbonize the Indian power system over time, as CO_2 emissions per kWh of electricity decline from 0.65 kg/kWh to 0.54 kg/kWh, which is about a 17 percent fall.

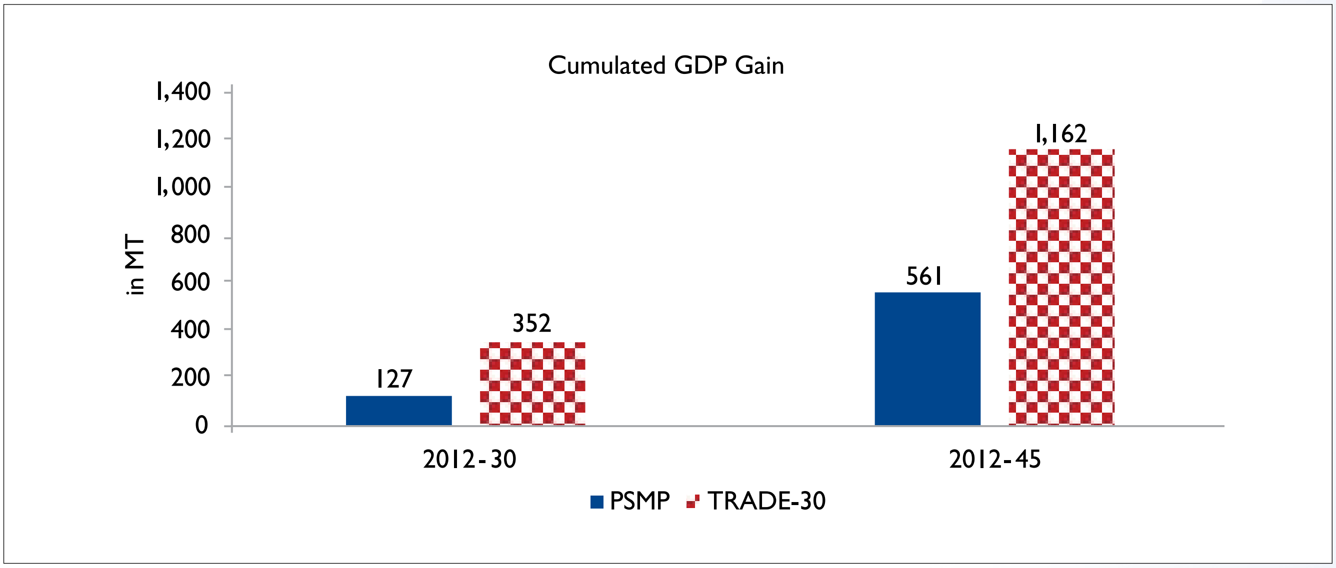
As coal power plants supply the additional electricity needed for export in the PSMP and TRADE-30 scenarios, coal demand is higher than the REF scenario; so are the CO_2 emissions, though marginally only, not even 1 percent.

Figure 5.40 **Annual CO_2 Emissions from the Indian Power Sector**



As electricity export activity spirals up the activities in other sectors of the economy, CO_2 emissions from the entire economy in the various trade scenarios increase (Figure 5.41). As expected, the increase is higher in the TRADE-30 scenario. However, as a percentage of the total emissions in the REF scenario, this is very small.

Figure 5.41 Impact on Total CO_2 Emissions



5.3 Key Highlights of the Analyses

Bangladesh

- Constrained with domestic energy resources for future power generation, the only choice for Bangladesh is to import fuels for electricity generation, or electricity or a combination of both.
- The demand for electricity is projected to increase from the current consumption of 45.3 TWh (2015/16) to 108 TWh in 2030 and then 331 TWh in 2045; that supports the GDP growth rate of 8.2 percent per annum.
- Per capita electricity demand, a key indicator for development, is projected to increase by a factor of 6, from 281 kWh (2015/16) to 1,665 kWh in 2045, in the REF scenario.
- Trade scenarios to affect electricity demand only marginally.
- Electricity import from India is an economical option for Bangladesh as it is cheaper than all the other options, including generation from coal.
- The trade scenarios need less domestic power generation capacity and hence less investment not only in power generation capacity but also in fuel infrastructure development, which could be diverted to the non-energy sector (agriculture, manufacturing) or for consumption.
- Electricity consumption as well as the aggregate consumption of households increase in the TRADE-30 scenario, leading to welfare gain. The gain can be more if a larger import of electricity is permitted (see box).

Impact of Electricity Import without Restriction

We have developed a scenario (not presented here) where the limit on electricity import has been removed.

It shows much larger welfare gain where the cumulated consumption over 2012–2045 is US$ 824 billion (in 2011–12 prices and market exchange rate) compared to US$ 523 billion in the TRADE-30 scenario. The per capita electricity consumption in 2045 is 20 KWh/person more than the REF scenario, as compared to 12 KWh/person in the TRADE-30 scenario.

Electricity imports in 2045 constitute 90 percent of the total electricity supply. Such dependence on imports may not be considered acceptable, particularly from one source. However, if the grids of India, Bangladesh, Nepal, and Bhutan were linked together, the sources of import would be diversified.

- While the PSMP scenario limits the import (interconnection) capacity to 5 GW in 2030 and 9 GW in 2040 and beyond, the TRADE-30 scenario offers a potential import capacity of 7 GW in 2030, 18 GW in 2040, and 25 GW in 2045.
- The PSMP scenario, which is devised to ensure energy security through diversifying sources of power generation, would cost significantly higher than the other two scenarios.
- The TRADE-30 scenario (Enhanced Trade) reduces the power supply cost significantly and, at the same time, improves energy security, though the diversification of supply sources is less than in the PSMP scenario.
- The energy import bill in the PSMP scenario is larger than in the other two scenarios, implying that the PSMP scenario enhances the import dependence of the country in monetary terms.
- Both the TRADE-30 and PSMP scenarios reduce investment requirement, as compared to the REF scenario.
- The PSMP scenario has a lower investment (CAPEX) requirement than the TRADE-30 scenario, but a higher import bill. Thus, the question for Bangladesh is how much reliance on foreign exchange is worth the diversification of energy supply sources.
- Bangladesh households make gains in electricity consumption and the overall consumption when electricity trade is enhanced in the TRADE-30 scenario.
- Enhanced electricity trade reduces fuel import for power generation, in particular that of gas, which has a more volatile market, thus enhancing energy security. It also reduces the fuel import bill where the released foreign currency could be used for activities with higher socio-economic benefits.
- Bangladesh significantly reduces CO_2 emissions by adopting the enhanced electricity import option.
- The PSMP scenario provides a higher GDP with lower welfare (household consumption) at the cost of a higher economy of total investments.
- The TRADE-30 scenario provides a lower GDP with higher welfare (consumption) at the cost of a lower economy of total investments.

India

- Electricity trade with Bangladesh causes some beneficial impacts although these are not highly visible because of the size of India's power system and its economy.
- Additional capacity/investment needs or revenue earned through export of electricity are marginal.
- The domestic electricity demand for the whole economy is projected as 2,447 TWh and 6,709 TWh, in 2030 and 2045, respectively. Export to Bangladesh is estimated to be 17 TWh and 56 TWh, in the PSMP scenario in 2030 and 2045, respectively. In the TRADE-30 scenario, the figures are 28 TWh and 104 TWh, respectively, which are very small compared to the domestic demand.
- The power generation capacity needs are projected as 606 GW and 1,616 GW, for the years 2030 and 2045, respectively. The additional capacity need is not more than 1-1.5 percent to cater to exports in both scenarios.
- Over the period 2012–45, a total investment requirement on capacity development for power generation is US$ 2004 billion (INR 93.5 trillion), US$ 60 billion (INR 2.8 trillion) per annum on an average. Additional investment requirement in the two export scenarios is less than 1 percent higher than in the REF scenario.
- Export revenue earning makes Indian households gain in the form of increased consumption, which is higher when trade is higher.
- Export demand and earning contribute to higher investment in the power sector as well as to the entire economy and the GDP increases in the higher trade scenario.
- Despite the green policy, generation will be heavily dependent on coal and the Indian power sector will remain a large emitter of CO_2. However, due to clean coal technologies together with renewables, the carbon intensity (kg/kWh) of the system will decline.

6. Summary, Conclusions, and Future Steps

This study examined the potential of electricity trade between India and Bangladesh in a 30 years' perspective, using a system of models that evaluated the following:

- The technical feasibility by balancing power demand and supply on an hourly basis over 30 years simultaneously for each country and the countries together.
- Economic viability of the trade accounting for the need for investment and imports and the consequences of power sector development on the competition for investment and foreign exchange on the other sectors of the economy, the growth rate of the economy and the consequent demand for power, that is, consistency of demand, growth and the power sector.
- Electricity trade takes place when the opportunity cost of export for generating electricity in that particular hour is less than the opportunity cost of import for generating power, that is, trade is economically profitable to both sides.

Bangladesh is short of energy resources for power generation. With the gas resource declining, difficulties in coal exploitation and no other resources in significant amount, the country is limited with the choice of import power or fuel for power generation. In such a situation, the Government of Bangladesh aims to ensure energy needs for economic growth and improve energy security by diversifying sources of fuel supply and restricting import dependence on a single fuel or source.

India, with a much larger power system, is power surplus. It aims to improve its political ties with its neighbor with better economic cooperation. India and Bangladesh have identified infrastructure, such as power and transport, as potential areas. This also gives India an opportunity to exploit its large hydro potential in the Northeast, which could be evacuated through Bangladesh. While energy has witnessed new highs in bilateral cooperation, there are rich prospects for joint ventures among Bangladesh, Bhutan, India, and Nepal (BBIN).

With this background, the study has examined three scenarios with a various mix of fuel and electricity import as supply options for Bangladesh:

- The REF scenario assumes no increased interconnections between countries beyond what are currently in place (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 PSMP scenario is based on the consideration of energy security framework of the Bangladesh Government, targeting energy security through the diversification of energy sources for power generation and import. Accordingly, shares of capacity based on coal, natural gas, nuclear, liquid fuels, hydro, and renewables are fixed along with electricity import at 35 percent, 35 percent, 12 percent, 1 percent, 1 percent, and16 percent, respectively, of the total power supply by 2041.
- The TRADE-30 scenario further increases the electricity trade, by assuming 30 percent of import in total electricity supply in Bangladesh.

An analysis of these scenarios shows that the trade constrained REF scenario gives a large coal-based power system with coal imports supplementing domestic coal production, which is very small in any case. The PSMP scenario, which diversifies supply to multiple sources such as coal, gas, nuclear, and imports that are restricted to 16 percent of the domestic demand, gives more expensive electricity supply, a lower GDP and low per household consumption compared to the REF scenario. This reflects the cost of energy security through diversification. The TRADE-30 scenario, which permits electricity import up to 30 percent, gives higher households consumption and cheaper electricity than the PSMP scenario and a higher GDP than the REF scenario.

The study found that the cost of electricity supply is cheapest in the TRADE-30 scenario and most expensive in the PSMP scenario, defined as the so-called energy security scenario. PSMP does not reduce dependence on imports. The total cost of importing fuels and electricity in the PSMP scenario is larger than the cost of importing electricity in the TRADE-30 scenario. Increasing the import of electricity reduces the energy import bill and Bangladesh also gains economic benefit. It is unlikely that the increase of electricity import by a few percentage points would threaten the country's energy security. As the alternative is a higher dependence on imported gas for power generation (as defined in the PSMP scenario), which has been significantly volatile in the Asian market, Bangladesh, being a small consumer, would, perhaps, find it easier to manage the bilateral relationship with relatively more certainty than depending on the unpredictable gas market.

As India's economy is large now and will be larger over time, the export revenue from electricity is a very small percentage of the total GDP. However, it is large in absolute quantity and the country will gain in terms of GDP, investment, higher industrial activities, and household income.

The study establishes the benefit of higher trade in terms of energy security to Bangladesh and in terms of economic gain to both Bangladesh and India. Higher economic integration brings political stability, which is a very important advantage although its economic benefit is difficult to measure. For India, this is particularly important in the context of both the 'Make in India' initiative as well as 'India's Act East Policy'. As the second fastest-growing economy in the world in 2016, with more than 7 percent growth, Bangladesh has a firm footing in the global apparel markets and is now a role model for the developing world in poverty reduction, achieving success in health and education, fighting climate change, among others. Electricity import from India could give Bangladesh the much-needed reliable electricity and at the same time allow redistribution of the investment where its social gain is larger.

India has already been assisting its neighbors in the subcontinent to improve their power situation. The India-Bangladesh transmission line is providing safe and reliable interconnection of the power grids to supply 600 MW of power to Bangladesh. Another 500 MW is under construction with the support from the Asian Development Bank. The benefit of electricity import has already been acknowledged by the Bangladesh authorities and the 1,320 MW Maitree Thermal Power Project, a joint venture of the National Thermal Power Corporation and Bangladesh Power Development Board, is under development.

Connectivity, be it electricity or transport, offers a game-changing opportunity for India and Bangladesh. This is pivotal to India's connectivity with its Northeast region and with the ASEAN countries. It would help to exploit the large hydro potential that India has in its Northeast region. Equal emphasis on physical and institutional connectivity between India and Bangladesh will facilitate the exploration of more opportunities through trade and investment. Trade is a win-win option for both the countries. On a broader canvas, there is tremendous potential held out by the initiative on sub-regional cooperation among the BBIN nations. This envisages transit facilitation of power through India as some of these countries have large unexploited hydro potential that is waiting to be tapped by the market.[15] The Ministry of Power of the Government of India has come up with the guidelines on cross-border electricity trade.[16]

[15]http://www.thehindubusinessline.com/opinion/sheikh-hasina-visit-and-india-bangladesh-trade/article9616091.ece

[16]http://powermin.nic.in/sites/default/files/webform/notices/Guidelines%20for%20Cross%20Boarder%20Trade.pdf

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Annexure 1

1. Assumptions for Bangladesh's Economic Model

General Assumptions
The following are some of the key assumptions valid for all the selected scenarios:

Macroeconomic Assumptions
For Bangladesh, 57x57 sector Social Accounting Matrix for 2011–12 (GTAP database) forms the reference for the base year data of the model. The base year of the model is 2011–12 and the 57x57 sector Social Accounting Matrix is aggregated to 9x20 sectors to capture the most appropriate representation of the energy sector and the power sector as well as its linkages with the Bangladesh economy. The sectoral disaggregation of the Social Accounting Matrix for 2011–12 into nine commodities and 20 production sectors is provided in Table 1. The power sector, which is the focus of this study, is disaggregated to 11 power generating technological sectors.

Table 1 Sectoral Classifications

Commodity Name	Production Activity Name
Agriculture	Agriculture
Manufacturing	Manufacturing
Coal	Coal
Crude Oil	Crude Oil
Petroleum Products	Petroleum Products
Gas	Gas
Transport	Transport
Other Services	Other Services
Electricity	Gas Open Cycle
	Gas Combined Cycle
	Hydro
	Subcritical Coal
	Supercritical Coal
	Ultra-supercritical Coal
	Diesel
	Solar
	Biomass
	Nuclear
	Dual Fuel

The household consumption demand for commodities is modeled using expenditure elasticities. The estimated elasticities for each commodity are taken from the Social Accounting Matrix for 2011–12 from the GTAP database and is listed in Table 2.

Table 2 **Expenditure Elasticities of Commodity-wise Consumptions**

Sr. No.	Commodity Name	Elasticity
1	Agriculture	0.81
2	Manufacturing	0.80
3	Coal	0.00
4	Crude Oil	1.06
5	Petroleum Products	1.06
6	Gas	0.96
7	Electricity	1.23
8	Transport	1.06
9	Other Services	1.41

The representation of the power sector in the Bangladesh economic model is consistent with the Answer-Times model for Bangladesh. The same electricity generating sectors are assumed in the economic model as the technologies in the Answer-Times model. The costs for the power generation sectors in the economic model are computed, based on the technology-specific CAPEX that is assumed in the Answer-Times model. The input-output structure for the power-generating sector is computed, using the technology-wise OPEX and fuel cost coefficients from the Answer-Times model. The power generation sector-wise auxiliary consumption and T&D losses assumed for 2011–12 are provided in Table 3.

Table 3 **Power Sector Technological Assumptions**

Power Generation Technology	Auxiliary Consumption	T&D Losses	Generation and Technological Potential
Gas Open Cycle	0.01	15%	Levels assumed from the Answer-Times Technology Model for Bangladesh
Gas Combined Cycle	0.025		
Hydro	0.00		
Subcritical Coal	0.08		
Supercritical Coal	0.08		
Ultra-supercritical Coal	0.08		
Diesel	0.045		
Solar	0.00		
Biomass	0.00		
Nuclear	0.08		
Dual Fuel	0.014		

The other major macroeconomic assumptions are provided in the following tables.

Table 4 Macroeconomic Assumptions

Parameter	Assumption
Maximum growth rate of per capita consumption	8%
Government consumption growth rate	8%
Marginal savings rate	Assumed to increase from 16% at present to 25% by 2045
Discount rate	4%
Post-terminal growth rate	3%

Table 5 Trade Exports and Imports Assumptions

Sr. No.	Commodity	#Export Upper Bound	#Import Upper Bound	#Import Lower Bound
1	Agriculture	20	30	0
2	Manufacturing	40	30	0
3	Coal	0	60	0
4	Crude Oil	2	100	70
5	Petroleum Products	10	90	10
6	Gas	0.6	10	0
7	Electricity*	NA	NA	NA
8	Transport	15	10	0
9	Other Services	40	30	0

** Import and export of electricity specification is explained in the methodology section.*

 # Import bounds are specified as a percentage of total availability (production+import) and export bounds are specified as a percentage of total output.

2. Assumptions for India's Economic Model

General Assumptions

The following are some of the key assumptions valid for all the selected scenarios:

a) Inclusive Growth Policies (common to all scenarios)

All scenarios consider inclusive growth policies that are developmental in nature and differ only in the nature of low carbon policies. These policies ensure access to electricity, clean cooking fuel, pucca house, education, and health services, as well as income transfer to the poor. The specification of inclusion policies is described here.

- **Income transfer:** To substantially reduce poverty, an income transfer is given, beginning with an amount of INR 1,000 per person, per year, at 2007–08 prices; increasing to INR 2,000 by the end of the Twelfth Five Year Plan and to INR 3,000 thereafter. The coverage of rural and urban population is gradually increased over the Twelfth Plan period to reach the levels mentioned in the National Food Security Act 2013, that is, the bottom 70 percent of the rural and bottom 50 percent of the urban population.

- **Housing:** The objective is to provide every person with a pucca house by 2030. This is accomplished by stepping up the Pradhan Mantri Awaas Yojana and Rajiv Awaas Yojana and is reflected in the scenario by increased Government demand for construction from 2015 to 2025 when an additional 0.7 million houses for the poor are built.
- **Electricity:** Keeping up its promise for sustainable energy access for all (SE4All), all the households consume at least 1 kWh per day of electricity by 2015. The Government makes up the deficit from the household's normative consumption and provides it free of cost to the poor households.
- **Cooking gas:** The poor households' expenditure on energy is supplemented by the Government, so that they can have at least six cylinders of LPG per year.
- **Education and health:** The Government expenditure on education and health is increased to 7.3 percent of the GDP in 2015 and stays at that level thereafter.

The cost of implementing inclusive measures is assumed to be borne by the Government and reduces the investment available for other economic activities.

The 78x78 sector Social Accounting Matrix for 2007 (Pradhan, Saluja, and Sharma, 2013) forms the reference for the base year data of the model. The base year of the model is 2007–08 and the sectors from the 78x78 sector Social Accounting Matrix for 2007–08 is aggregated to 25x41 sectors for the most appropriate representation of the energy sector and its linkages with the overall economy. There are seven agricultural sectors, 10 industrial sectors (excluding energy sectors), and three services sectors. There are three primary energy sectors and two secondary energy sectors as shown in the tables. The other major macroeconomic assumptions are provided in the tables.

Table 6 **Sectoral Classifications**

Commodity Name	Production Activity Name
Non-energy Sectors	
Agriculture	
Food Grains	Food Grains
Sugarcane	Sugarcane
Oil Seeds	Oil Seeds
Other Crops	Other Crops
Animal Husbandry	Animal Husbandry
Forestry	Forestry
Fishing	Fishing
Industry	
Mining and Quarrying	Mining and Quarrying
Agro-processing	Agro-processing
Textiles	Textiles
Fertilizer	Fertilizer
Cement	Cement
Non-metallic Minerals	Non-metallic Minerals
Steel	Steel
Manufacturing	Manufacturing
Construction	Construction
Water Supply and Gas	Water Supply and Gas
Services	
Railway Transport Services	Railway Transport Services
Other Transport	Other Transport
Other Services	Other Services
	Other Services with ECBC
Energy Sectors	
Primary Energy Sectors	
Coal and Lignite	Coal and Lignite
Crude Petroleum	Crude Petroleum
Natural Gas	Natural Gas
Secondary Energy Sectors	
Petroleum Products	Petroleum Products
Electricity	
	Subcritical Coal
	Gas Combined Cycle
	Hydropower
	Supercritical Coal
	Onshore Wind
	Solar Photovoltaic without Storage
	Solar Thermal without Storage
	Biomass
	Nuclear
	Diesel
	Solar Photovoltaic with Storage
	Solar Thermal with Storage
	Offshore Wind
	Ultra-supercritical Coal
	Integrated Gasification Combined Cycle Coal
	Gas Open Cycle

Table 7 Power Sector Technological Assumptions

Power Generation Technology	Auxiliary Consumption	T&D Losses	Generation and Technological Potential
Subcritical Coal	0.06	27%	Levels assumed from the Answer-Times Technology Model for Bangladesh
Gas Combined Cycle	0.06		
Hydropower	0.01		
Supercritical Coal	0.06		
Onshore Wind	0.00		
Solar Photovoltaic without Storage	0.00		
Solar Thermal without Storage	0.00		
Biomass	0.00		
Nuclear	0.05		
Diesel	0.05		
Solar Photovoltaic with Storage	0.00		
Solar Thermal with Storage	0.00		
Offshore Wind	0.00		
Ultra-supercritical Coal	0.06		
Integrated Gasification Combined Cycle Coal	0.06		
Gas Open Cycle	0.06		

The representation of the power sector in the Bangladesh economic model is made consistent with the Answer-Times model for Bangladesh. The same electricity-generating sectors are assumed in the economic model as the technologies assumed in the Answer-Times model. The costs for power generation sectors in the economic model are computed, based on the technology-specific CAPEX assumed in the Answer-Times model. The Input-Output structure for the power-generating sector is computed using the technology-wise OPEX and fuel cost coefficients from the Answer-Times model. The power generation sector-wise auxiliary consumption and T&D losses assumed for 2011–12 are provided in Table 2.

Table 8 Macroeconomic Assumptions

Parameter	Assumption
Maximum growth rate of per capita consumption	10%
Government consumption growth rate	8%
Maximum savings rate	40%
Discount rate	4%
Post-terminal growth rate	3%

Table 9 **Trade, Exports, and Imports Assumptions**

Sl. No.	Commodity	Export Upper Bound	Import Upper Bound	Import Lower Bound
1	Food Grains	10	10	0
2	Sugarcane	10	10	0
3	Oil Seeds	10	10	0
4	Other Crops	10	10	0
5	Animal Husbandry	10	10	0
6	Forestry	10	10	0
7	Fishing	10	6	0
8	Coal and Lignite	1	30	20
9	Crude Petroleum	2	98	80
10	Mining and Quarrying	99	45	0
11	Agro-processing	10	20	1
12	Textiles	50	30	0
13	Petroleum Products	20	20	5
14	Fertilizer	20	33	20
15	Cement	10	0.6	0.3
16	Non-metallic Minerals	10	10	1
17	Steel	20	10	1
18	Manufacturing	40	30	1.5
19	Construction	0	0	0
20	Electricity*	NA	NA	NA
21	Water Supply and Gas	0	0	0
22	Railway Transport Services	30	0	0
23	Other Transport	30	20	3
24	Other Services	20	10	6
25	Natural Gas	0	80	20

** Import and export of electricity specification is explained in the methodology section.*

 # Import bounds are specified as percentage of total availability (production+imports) and export bounds are specified as percentage of total output.

Annexure 2: Economic Model Structure

The Social Accounting Matrix (SAM) is used to represent the whole economy. The consumption side of the economy (final demand) is represented in the SAM as the sum of private consumption demand, Government consumption demand, investment demand, intermediate consumption demand from the production sectors and export demand. The model considers each of these and projects them into the future in a consistent manner. The private household demand is modeled by using an estimated demand system. The Governments' consumption expenditure is exogenously projected. The investment demand and sectoral investment is endogenously determined by the model, based on its optimising strategy. The intermediate demand is computed using the input-output coefficients from the SAM of 2007–08. The exports and imports are computed endogenously such that they satisfy the economic relations of balance of payment and investment-savings relationships.

Overall, the model's projections for commodity demand and production is sectorally consistent and it satisfies all macroeconomic relationships. This feature helps the model to assess the energy economy linkages in a more accurate manner and hence provides a more accurate assessment of the environmental GHG emissions due to activities in the economy.

The following equations are introduced in the model as constraints.

1. Consumer Demand Structure

India

The private household consumption demand is modeled by using a separate Linear Expenditure System (LES) for each of the 10 expenditure classes for rural and urban areas. The mathematical expression for the household demand equation for each commodity is given in equation 1a:

$$C_{iht} = c_{iho} + \beta_{ih}(E_{ht} - \sum_i c_{iho}) \quad \text{.........................} \quad (1a)$$

Where,

C_{iht} = per capita consumption of the ith commodity by the hth household group in tth time period

c_{ih0} = minimum per capita consumption of the ith commodity by the hth household

β_{ih} = share of ith commodity in total per capita consumption of the hth household

E_{ht} = Total per capita consumption expenditure of the hth household

The model has an endogenous income distribution, separately for rural and urban areas, to incorporate the change in the number of people in different classes over the period of time (2005–50). As incomes rise, per capita consumption increases, which results in people moving from lower expenditure classes to higher classes. Such changes would impact the demand structure of the economy. The LES and endogenous income distribution together provide a dynamically changing commodity-wise non-linear demand structure of the economy.

Bangladesh

Unlike India, household consumer demand for commodities are specified using expenditure elasticities. The estimated elasticities are obtained from the Social Accounting Matrix for 2011–12 from the GTAP database and is reported in Table 2 in Annexure 1.

$$C_{it} = \eta_i \cdot c_i \cdot POP_t \cdot E_t + \{\prod_{t=1}^{T}[1+\lambda_t]\} \cdot (1-\eta_i) \cdot c_i \cdot POP_0 \cdot \bar{E}_{i0} \quad \text{(1b)}$$

Where,

η_i is expenditure elasticity of commodity as reported in Table 2

C_i is the share of ith commodity in total consumption in the base period

λ_t is the rate of growth of population at time point t

E_t is the per capita total expenditure at time t

POP_t is the total population at time t

2. General Model Description

The model ensures equilibrium between demand and supply in the optimal path for each commodity.

Demand and supply equilibrium equation

$$C_{it} + G_{it} + I_{it} + IO_{it} + E_{it} \leq Y_{it} + M_{it} \quad \text{... (2)}$$

Private consumption demand + Government consumption demand + investment demand + intermediate input demand + export demand = domestic production + imports

Government consumption ($G_{i,t}$) is exogenous and specified to grow at a rate of seven per cent. (The Government's tax collections and revenue are not modeled explicitly but accounted for implicitly.)

Intermediate demand ($IO_{i,t}$) is determined endogenously by the input–output coefficients. Total private consumption ($C_{i,t}$) is obtained from the LES demand function and endogenous income distribution. Exports ($E_{i,t}$) and imports ($M_{i,t}$) are determined endogenously from trade-side equations of balance of payments and other constraints.

Domestic availability of commodities is assumed to come from domestic output ($Y_{i,t}$) and imports ($M_{i,t}$). Domestic production is constrained by capacity constraint, that is, the maximum output that can be produced at the given capital stock.

Capacity constraint

$$(X_{j,t} - X_{j,t-1}) \leq (K_{j,t} - K_{j,t-1}) / ICOR_j \quad \text{.....................} (3)$$

(Incremental output is related to incremental capital)

Where,

$X_{j,t}$ = domestic output of the jth sector at time t

$K_{j,t}$ = capital of the jth sector at time t and

$ICOR_j$ = incremental capital output ratio of the jth sector, which is exogenously specified in the model

Capital stock in sector j depends upon the rate of depreciation and investment and is modelled using the following relation.

Capital stock equation

$$K_{j,t} = DEL(J) * K_{j,t-1} + I_{j,t} \quad \text{................................} (4)$$

Where *DEL (J)* is the rate of depreciation in sector j, which is exogenous, and $I_{j,t}$ is the investment in sector j.

Aggregate investment demand is assumed to depend on aggregate domestic investible resources (domestic savings determined by the marginal savings rate) and foreign investments available. Investment goods, which reflect the structure of capital goods in the sectors, are identified separately and are allocated to different sectors as fixed proportions ($P_{i,j}$) of the total investment ($I_{i,j}$) in each sector.

Investment equations

$$\sum_i Z_{it} \leq Z_o + S * (VA_t - VA_0) + (FT_t - FT_0) \quad \text{.............} (5)$$

$$\sum (P_{i,j} * I_{j,t}) \leq Z_{i,t} \quad \text{...} (6)$$

$$FT_t = (a - b * t) * VA_t \quad \text{.......................................} (7)$$

Where,

$Z_{i,t}$ = investment demand of commodity i at time t

VA_t = value added at time t

FT_t = foreign investment at time t

S = exogenously specified maximum marginal savings ratio

Z_0= investment in the base year (2004–05)

$P_{i,j}$ and a and b are pre-specified constants

Trade is endogenous to the model. Foreign capital inflow (*FT*) is a changing proportion of value added.

Though exports and imports are endogenous to the model, upper and lower limits are exogenously specified on the growth rate of export and import. The model has a balance of payment constraint for exports and imports so that they grow in a realistic manner.

Balance of payment equations

$$\sum_i (M_{i,t} * MTT_i) = \sum_i E_{i,t} + FT_t \quad \text{..............} \quad (8)$$

$$M_{i,t} \geq (1 + MGRU_i) * M_{i,t-1} \quad \text{............................} \quad (9)$$

$$M_{i,t} \leq (1 + MGRL_i) * M_{i,t-1} \quad \text{.............................} \quad (10)$$

$$E_{i,t} \leq (1 + EXGRU_i) * E_{i,t-1} \quad \text{....................... ......} \quad (11)$$

Where,

MTT_i = trade and transport margins for commodity i

$MGRU_i$ and $MGRL_i$ = upper and lower bounds for imports growth rates of commodity i

$EXGRU_i$ = upper bound for exports growth rate of commodity i

Equations (7) to (11) form the complete specifications of the trade-side of the model.

Equations (1) to (11) form a set of constraints, based on economic criteria, for the model solution to be meaningful.

Annexure 3: Sectoral Impact of Electricity Trade in Bangladesh and Reference Run Values of Macro Variables

Sectoral Effects of Trade

The sectoral impacts of the two scenarios representing the two power sector growth strategies are analyzed by comparing their impact on the level of the demand and supply components of each commodity sector. The economic model computes the commodity market equilibrium of demand and supply for each commodity sector. In this process, it computes the various macro sources of demand and supply for each commodity. In the analysis presented in the tables, the following nomenclature is used. All values are in monetary terms at 2011–12 US$. Y denotes the output of the commodity, M stands for the import of the commodity and together they combine to provide the aggregate supply. CONS denotes the household consumption demand, IODD represents the intermediate consumption demand, G is the Government consumption demand, Z stands for the investment demand for the commodity (this is non-zero only for investment commodities), and E represents the export demand for the commodity. Together, they constitute the aggregated demand. The significance of the source of demand and supply can be understood if it is considered for the electricity sector.

Table 1 shows the economic impact of two trade scenarios on the electricity sector, both on the supply and demand side. Y corresponds to the output of electricity in the technological model while M corresponds to the volume of imports; CONS compares to the demand for electricity from the residential sector and IODD compares to the demand for electricity from the agricultural, industrial, and commercial sectors. Electricity is not an investment commodity and hence its demand for investment purposes is always zero. E corresponds to the exports of electricity. Electricity trade with India reduces the generation in Bangladesh and the required domestic installed capacity compared to the REF scenario. The import share is higher in the TRADE-30 scenario, hence the decrease in generation is also higher in the TRADE-30 scenario than in the PSMP scenario, as compared to levels in the REF scenario. This is reflected in Table 1. The impact for each scenario is reported in terms of the absolute difference of level in each scenario, in monetary value, with the levels in the REF scenario (scenario value–REF value).

Table 10 Impact of Trade and Energy Security on Electricity Demand and Supply

Increase Compared to REF (Scenario REF) for Electricity Sector in US$ Million (2011–12)						
Sources	**2020**		**2030**		**2045**	
	TRADE-30	PSMP	TRADE-30	PSMP	TRADE-30	PSMP
Supply						
Y (Output)	-1,096	-1,062	-16,066	-7,794	-70,390	-37,484
M (Imports)	949	822	13,904	6,548	63,341	31,664
Demand						
CONS (Household Consumption)	-10	0	504	104	1,604	331
IODD (Intermediate Demand)	-137	-237	-2,669	-1,353	-8,653	-6,150
G (Government Consumption)	0	0	0	0	0	0
Z (Investment)	0	0	0	0	0	0
E (Export)	0	0	0	0	0	0

Output from the domestic electricity sector declines in both the trade scenarios compared to the REF scenario (Table 10). As more electricity is imported in the TRADE-30 scenario than in the PSMP scenario, compared to the REF scenario, domestic generation is even lower than PSMP. Therefore, the value of output is even lower than in the PSMP scenario. Compared to the REF scenario, the decline in the value of the electricity sector's output is larger in the TRADE-30 scenario than in the PSMP scenario. As electricity import quantity is almost double in the TRADE-30 scenario than the PSMP scenario, so is the value of import. The level of consumption per person is viewed as a central measure of an economy's productive success. As can be seen from Table 10, the household consumption of electricity increases in both the TRADE-30 and PSMP scenarios, compared to the REF scenario. However, the increase is substantially more in the TRADE-30 scenario than in the PSMP scenario. Owing to a lower output in the electricity sector in the TRADE-30 and PSMP scenarios, economic activity in the other sectors also reduces by the multiplier impact of sectoral linkages through production relations. The reduced economic activity results in a lower intermediate demand for electricity, that is, a lower demand for power in the production processes of the industrial, commercial sectors. As productive activity declines, the intermediate demand decreases in both the TRADE-30 and PSMP scenarios compared to the REF scenario. However, the decrease is much more in the TRADE-30 scenario compared to the PSMP scenario. As reduction in the electricity sector output is more in the TRADE-30 scenario than in the PSMP scenario, the decline in intermediate demand is higher in the TRADE-30 scenario than in the PSMP scenario. However, the total availability (Y+M) does not decline in both these scenarios. This implies that there is surplus electricity available for household consumption and since the decline in electricity intermediate demand is higher in the TRADE-30 scenario, the redirected increase in electricity consumption by households increases much more in the TRADE-30 scenario.

The reduction in investment requirement in the power sector due to reduced generation needs and lower installed capacity requirements and the reduced economic demand for other sectors due to the multiplier impact from the power sector, has implications for the other sectors of the economy. The impact of the two scenarios, on the demand and supply of each of the other sectors, is shown in Table 11. The results are presented for each variable as absolute deviation from the levels in the REF scenario, that is, scenario value – REF value. This is similar to the results presented for the electricity sector in Table1.

Two impacts appear consistent across all time points and for all non-energy sectors. First, that private household consumption increase is much higher for the TRADE-30 scenario than the PSMP scenario and second, the intermediate demand either decreases in the TRADE-30 scenario compared to the REF scenario, or increases less than the PSMP scenario for all non-energy sectors. The output of all the sectors decreases in the TRADE-30 scenario and increases in the PSMP scenario; the transport sector is the only exception where the output increases and import is substituted. Import of transport activities decreases much more in the TRADE-30 scenario than in the PSMP scenario. This is due to the increased domestic production and import of petroleum products on which the transport sector is so critically dependent. The transport sector demand also increases on count of household, intermediate demand and export demand. Household consumption increase in the TRADE-30 scenario is higher in the PSMP scenario, compared to levels in the REF scenario, for all commodity sectors. However, the gain in household consumption is at the expense of intermediate demand and exports for agriculture and other services while the gain in consumption for the manufacturing sector is at the expense of intermediate demand and investment. Manufacturing forms the major component of investment. The TRADE-30 scenario results in a decrease in investment and consequently reduces the demand for manufacturing goods for investment purposes. The PSMP scenario results in an increase in output, imports and all components of demand.

Table 11 Sector-wise Impact on Demand and Supply (US$ Million, 2011–12)

	Agriculture					
	2020		2030		2045	
	TRADE-30	PSMP	TRADE-30	PSMP	TRADE-30	PSMP
Y	77	237	-4,082	5,399	-29,599	40,444
M	0	0	0	0	0	0
CONS	-50	0	2,342	481	7,427	1,523
IODD	110	187	-982	1,520	-4,527	6,167
G	0	0	0	0	0	0
Z	0	0	0	0	0	0
E	13	47	-5,165	3,224	-30,839	31,076
	Transport					
	2020		2030		2045	
	TRADE-30	PSMP	TRADE-30	PSMP	TRADE-30	PSMP
Y	2,736	3,194	26,733	7,961	62,807	77,817
M	0	0	-9,247	-6,655	-53,389	-66,047
CONS	-50	0	2,419	494	7,677	1,577
IODD	134	174	227	808	1,744	5,967
G	0	0	0	0	0	0
Z	0	0	0	0	0	0
E	2,653	3,020	14,840	0	0	4,229

Reference Run

Tables 12 and 13 provide the values for some of the major macro variables for the reference run since impacts have been presented in the report in terms of deviation from their values in the reference run.

	Manufacturing					
	2020		2030		2045	
	TRADE-30	PSMP	TRADE-30	PSMP	TRADE-30	PSMP
	494	758	-822	3,849	-5,910	1,841
	210	324	-351	1,650	-2,532	788
	-100	0	4,767	979	15,114	3,104
	357	538	-3,043	2,633	-832	13,356
	0	0	0	0	0	0
	474	588	-2,940	2,101	-23,058	-13,727
	0	0	0	0	0	0
	Other Services					
	2020		2030		2045	
	TRADE-30	PSMP	TRADE-30	PSMP	TRADE-30	PSMP
	588	1,009	-25,453	7,614	36,665	48,953
	0	0	0	0	0	0
	-110	0	5,242	1,076	16,634	3,418
	461	605	-1,874	3,488	5,409	25,981
	0	0	0	0	0	0
	0	0	-7	3	-43	-27
	234	401	-28,818	3,043	14,666	19,580

Table 12 GDP and Consumption Values

	Bangladesh				India	
	Household Electricity Consumption					
Year	GDP	Per Capita Consumption	Total	Per Capita	GDP	Per Capita Consumption
	Billion US$ 2011–12	$/Person	(Gwh)	kWh/Person	US$ Billion 2011–12	$/Person
2015	528	1,911	12,592	79	21,867	7,206
2020	731	2,653	19,505	116	30,356	8,817
2025	966	3,438	27,357	155	43,693	11,561
2030	1,343	4,847	41,352	225	63,817	16,766
2035	1,962	6,889	61,986	326	96,097	25,754
2040	3,037	9,859	92,368	474	146,197	39,894
2045	4,376	14,202	137,058	689	221,388	62,009

Table 13 Cumulated Values of Macroeconomic Variables

Bangladesh					
Year	GDP	Consumption	Investment	Electricity Investment	Cumulated CO_2 Emissions
	(US$ Billion 2011–12)	(US$ Billion 2011–12)	(US$ Billion 2011–12)	(US$ Billion 2011–12)	(MT)
2012–15	1,568	1,097	372	30	268
2012–20	4,603	3,015	1,066	72	621
2012–25	8,721	5,697	2,033	169	1,100
2012–30	14,235	9,537	3,388	251	1,737
2012–35	22,075	15,174	5,418	372	2,667
2012–40	34,008	23,460	7,942	522	4,163
2012–45	51,672	35,637	11,278	733	6,394
India					
Year	GDP	Consumption Gain	Investment	Energy Investment	CO_2 Emissions
	(US$ Billion 2011–12)	(US$ Billion 2011–12)	(US$ Billion 2011–12)	(US$ Billion 2011–12)	(MT)
2012–15	6,704	2,810	2,323	166	6,350
2012–20	18,095	7,328	6,587	517	16,360
2012–25	34,212	13,397	12,845	996	29,521
2012–30	56,716	22,310	21,084	1,434	45,690
2012–35	91,591	36,555	33,389	2,233	70,227
2012–40	144,628	59,497	50,511	3,205	104,737
2012–45	225,268	96,444	74,650	4,962	151,597

Abbreviations

ADB	Asian Development Bank
AEEI	Autonomous Energy Efficiency Improvement
APT	Accelerated Power Trade
BCM	Billion Cubic Meter
BDT	Bangladeshi taka
BkWh	Billion Kilowatt Hour
BT	Billion Tonne
CAGR	Compound Annual Growth Rate
CBET	Cross Border Electricity Trade
CC	Combine Cycle
CEA	Central Electricity Authority
DCA	Delayed Capacity Addition
EFOM	Energy Flow Optimization Model
ExOP	Export Oriented Plants
FDI	Foreign Direct Investment
GAIL	Gas Authority of India Limited
GDCF	Gross Domestic Capital Formation
GDP	Gross Domestic Product
GDS	Gross Domestic Savings
GMS	Greater Mekong Sub-region
GOI	Government of India
GW	Gigawatt
GWh	Gigawatt Hour
HDI	Human Development Index
IBMac	IRADe Bangladesh Macro
IBTec	IRADe Bangladesh Technology
IESS	India Energy Security Scenarios 2047
IGCC	Integrated Gasification Combined Cycle
IIMac	IRADe India Macro
IITec	IRADe India Technology
INDC	Intended Nationally Determined Contributions
INHET	India-Bangladesh Hourly Electricity Trade Model
INR	Indian Rupee
IODD	Intermediate Consumption Demand
IPP	Independent Power Producer
IRADe	Integrated Research for Action and Development
kWh	Kilowatt Hour
LPG	Liquefied Petroleum Gas
LWR	Light Water Reactor
MARKAL	MARKet Allocation
MkWh	Million Kilowatt Hour
MMBTU	Million British Thermal Units
MOC	Ministry of Coal
MT	Million Tonnes
NREL	National Renewable Energy Laboratory
O&M	Operation and Maintenance
OC	Open Cycle
PFCE	Private Final Consumption Expenditure
PHWR	Pressurized Heavy-Water Reactor
PLF	Plant Load Factor
PROR	Pondage Run of River
PSA	Power Sale Agreement
PTC	Power Trading Corporation of India
PV	Photovoltaic
PV-STG	Photovoltaic with Storage
RBI	Reserve Bank of India
ROR	Run of River
SAM	Social Accounting Matrix
SARI/EI	South Asia Regional Initiative for Energy Integration
SE4All	Sustainable Energy Access for All
SUBC	Subcritical
SUPC	Supercritical
T&D	Transmission and Distribution
TFPG	Total Factor Productivity Growth
TH	Thermal
TH-STG	Thermal Storage
TIMES	The Integrated MARKAL-EFOM System
TWh	Terawatt Hour
USAID	United States Agency for International Development
US$	United States Dollar
USPC	Ultra-supercritical
WB	World Bank

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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, the Maldives, Nepal, Pakistan, and Sri Lanka). 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, promotes transmission interconnections, and works toward establishing a regional market exchange for electricity.

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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