CROSS-BORDER POWER TRADING IN SOUTH ASIA: A TECHNO ECONOMIC RATIONALE

Priyantha Wijayatunga, D. Chattopadhyay and P. N. Fernando

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Priyantha Wijayatunga is Principal Energy Specialist, South Asia Energy Division, ADB.

D. Chattopadhayay is Consultant, South Asia Regional Power Exchange Study, ADB.

P.N. Fernando is Senior Advisor, South Asia Regional Power Exchange Study, ADB.

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Asian Development Bank
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
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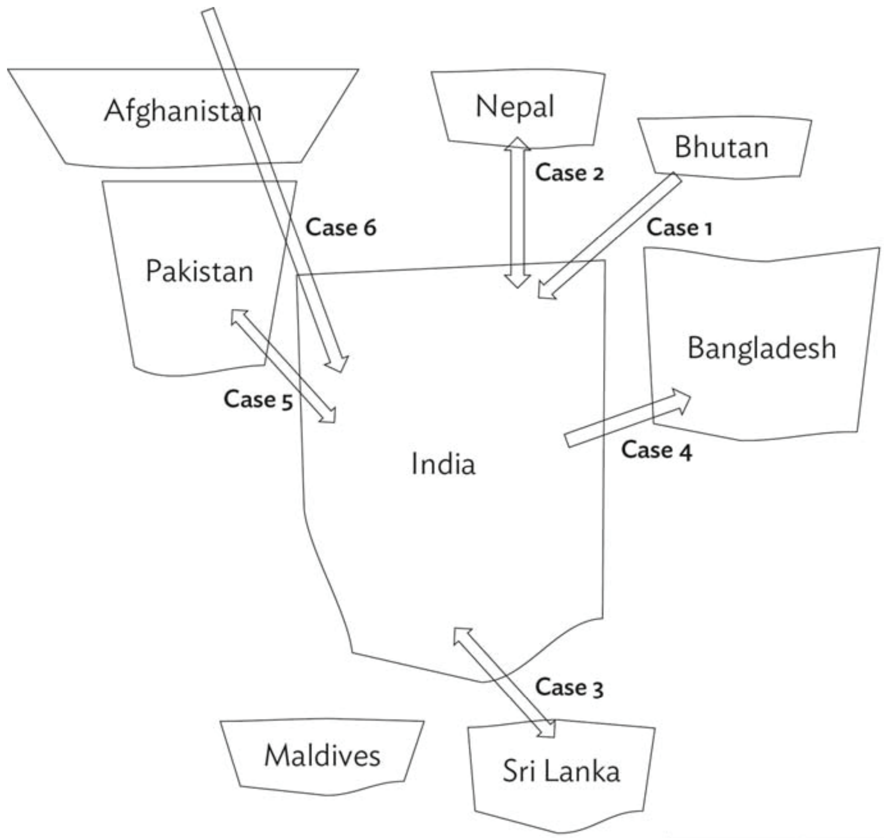
EXECUTIVE SUMMARY

The paper presents the results of a study on the economic and reliability benefits of electricity trading among the countries in South Asia encompassing the subregion containing Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka. This study complied in 2013 built on the SAARC (South Asia Association of Regional Cooperation) Regional Energy Trade Study (SRETS) conducted by Asian Development Bank (ADB). Such electricity trading would allow utilities to optimally utilise the available resources to satisfy demand across the whole subregion. Maldives was not considered in the study due to its remoteness from the rest of the South Asian landmass and hence the difficulty in providing an electricity transmission interconnection. The study also considered the possibility of South Asian region benefitting from electricity trade with Central Asian region bordering Afghanistan. It specifically examined the costs and benefits of six ongoing or planned cross-border electricity transmission interconnections at the time. These are (i) Bhutan-India additional grid reinforcement, (ii) India-Nepal 400 kilovolt transmission link under construction, (iii) India-Sri Lanka proposed high voltage direct current transmission link which includes a submarine cable component, (iv) Bangladesh-India high voltage director current transmission link which was commissioned in October 2013, (v) India-Pakistan 220 kilovolt and 400 kilovolt transmission link and (vi) India-Pakistan 400 kilovolt transmission link coupled with CASA 1000 transmission link. Each of these six transmission interconnections with capacity varying from 250 megawatts to 2100 megawatts costs between $ 140 million to $ 1000 million to construct.

The study clearly demonstrated that large scale transmission interconnection capacity would assist development of large hydropower potential in Nepal and Bhutan which can then be transferred to India resulting in a significant drop in fossil fuel use, power shortages and Carbon Dioxide (CO_2) emissions in the region. This study is a unique effort to illustrate how important these benefits can be even with minimum interventions. The study undertook modelling based on optimal load-flow analysis, transmission constrained investment and dispatch optimization with Monte Carlo simulation to incorporate uncertainties. The economic and reliability benefits of six transmission interconnections among the countries in the said subregion have been estimated for the year 2016/17, with more than one scenario for some of the interconnections. The benefits in terms of CO_2 reduction have also been quantified. It was estimated that the benefits of each of these interconnections range from $ 105 million to $ 1840 million under different scenarios. The benefit to cost ratios of the interconnections are extremely attractive and in the range from 3.7 to 102. The carbon dioxide reduction due to hydropower generation transferred from Bhutan to India alone would be about 10 million tons in 206/17 and can be as high as 40 million tons annually by 2020/21.

The paper concludes emphasising the need to construct these transmission interconnections in an orderly manner, extending the existing power exchanges in India to accommodate regional trading and strengthening legal and regulatory regimes. In this regard because the of geographical location and the sheer size of the power system with a significant appetite for large quantities of power India has to assume the role of a central hub in driving power trading the region, at least initially. A market-driven process for cross-border power trading together with a regulatory framework that enforces a strong economic discipline would maximise the benefits from the development of interconnection projects.

Keywords: economic benefits, technical feasibility, transmission interconnections, cross-border electricity trade



	Annualized Interconnection Cost ($ million)	Annual Benefit ($ million)
Case 1	18 -20	1840
Case 2 (i)	20	105
(ii)	20	215
Case 3	50	186
Case 4	25	145 -389
Case 5 (i)	6	335
(ii)	18	491
Case 6	110	1250

Costs and the Benefits of Six Interconnections

ABBREVIATIONS

AC	–	Alternating current
ADB	–	Asian Development Bank
CASA	–	Central Asia South Asia
CEA	–	Central Electricity Authority
GW	–	Gigawatt
GWh	–	Gigawatt hours
HVDC	–	High voltage direct current
HVAC	–	High voltage alternating current
IEX	–	Indian Energy Exchange
kV	–	kilovolt
MW	–	Megawatt
MWh	–	Megawatt hour
NEA	–	Nepal Electricity Authority
PXIL	–	Power Exchange India Limited
RIT-T	–	Regulatory investment test for transmission
SAARC	–	South Asian Association for Regional Cooperation
SAPP	–	Southern African Power Pool
SRETS	–	South Asia Regional Energy Trade Study
USD	–	United States Dollars
USE	–	Expected Unserved Energy

I. INTRODUCTION

1. Exploiting the large renewable energy potential in South Asia and the vast hydropower resources in Nepal and Bhutan in particular is critical in the efforts of the electricity industry to supply the fast expanding demand in the region at the lowest cost, with minimum impact on energy security and environmental emissions. Even though there are numerous large hydropower sites in Nepal in the close proximity to major load centers in India, efforts to develop these resources have been minimal. In the case of Bhutan a few of such sites have been developed with a large potential yet to be exploited. Electricity supply industry in Bangladesh, India and Pakistan dominated by fossil fuels such as coal, gas and petroleum has been increasing its contribution to generation capacity to meet the exponentially increasing demand and hence the environmental emissions. As a result, with increasing cost of fossil fuels, particularly petroleum, many of the countries will be exposed to rising cost of electricity and a significant risk of power outages due to their inability to cope up with the demand increase. At the same time many of these countries struggle to increase access to electricity for its remote and poor population groups where approximately about 300 million people are yet to be connected to the grid [Chattopadhyay and Fernando 2011]. In this regard, the development of hydropower potential and related transmission strengthening for power evacuation including cross-border interconnections becomes a major focus in the sustainable development agenda of these countries. Further, diversity in natural resources and the electricity demand patterns both time-of-day as well as across different seasons in these countries open up opportunities for greater use of cheaper and cleaner resources aided by related transmission system strengthening including cross-border links [SAARC 2010]. However, none of the previous studies have attempted to quantify the indicative economic and other benefits of such trade against the cost of construction of related cross-border transmission links.

2. Sharing of large quantities of renewable energy requires strong interconnections between respective regions (or countries) and hence they tend to be at high transmission voltages. Such Integration has received increasing attention in recent times [Porrua et al 2009, Fox Prenner et al 2009]. One such example is the Green Power Express study concerning connecting 20 GW of wind resource based generation into the grid in the Midwest region of the United States [Fox Prenner et al 2009]. This study showed that these interconnections would reduce 6,600 million BTU of fossil fuel use in the thermal power plants with a corresponding reduction of 370 million tons of Carbon Dioxide by the year 2030. However the costs involved with the corresponding transmission lines which include 756 kilovolt, 5000 kilometer long high voltage lined is estimated to be around USD 10 billion. When compared to this cost, the interconnections to exploit the hydropower potential in Nepal and Bhutan would cost only a fraction due to their proximity to major load centers in Northern Indian region. However the benefits of such interconnections have been hardly quantified systematically and the development has so far being largely on an ad hoc basis.

3. The study presented in the paper is a pioneering attempt to derive the benefits of the key ongoing and planned transmission interconnections projects in South Asia as well as those connecting South Asia and Central Asia, for cross-border power trading. The main contribution of this study is to determine the estimates of economic and reliability benefits of these cross-border interconnections with elaborate power system load flow and optimization studies covering not only the economic feasibility but also their technical feasibility.

A. South Asian Power Grid

4. Figure 1 shows the countries in the South Asian Association for Regional Cooperation (SAARC) with a summary of the power sector which provides the basis for power trading in the short to medium term among them as well as with the Central Asia. Table 1 provides a snapshot of the electricity generation and supply in the SAARC region. With a strongly interconnected power system in the India-Bangladesh-Bhutan-Nepal subregion, the large hydropower potential in Bhutan (estimated to be 11 GW by 2020) and Nepal (economic potential is estimated to be 42 GW) can be developed and transmitted to load centers to meet the exponentially increasing electricity demand in Bangladesh and India.

5. There are large capacity interconnections already existing between Bhutan and India. The annual power transfer between India and Bhutan has grown considerably over the recent years and it stood around 6,000 GWh in 2011/12. However the construction of the first large capacity interconnection (1000MW) between India and Nepal has only just started. Therefore the power transfer between India and Nepal is currently limited to about 400GWh which is also in the form of power imports to Nepal from India, particularly during the dry season.

Table 1: Electricity Supply and Demand in SAARC Countries (2013/14)

	Installed Generation Capacity (MW)	Peak Demand (MW)	Generation (GWh)	Demand (GWh)
Afghanistan[a]	620	700	880	3890
Bangladesh	9821	9268	42195	36233
Bhutan[a]	1510	282	6750	1640
India	237742	129815	957734	802567
Maldives	141	N/A	290	270
Nepal	787	1200	3558	3448
Pakistan[a]	22860	23953	92860	76860
Sri Lanka	3362	2164	11962	10632

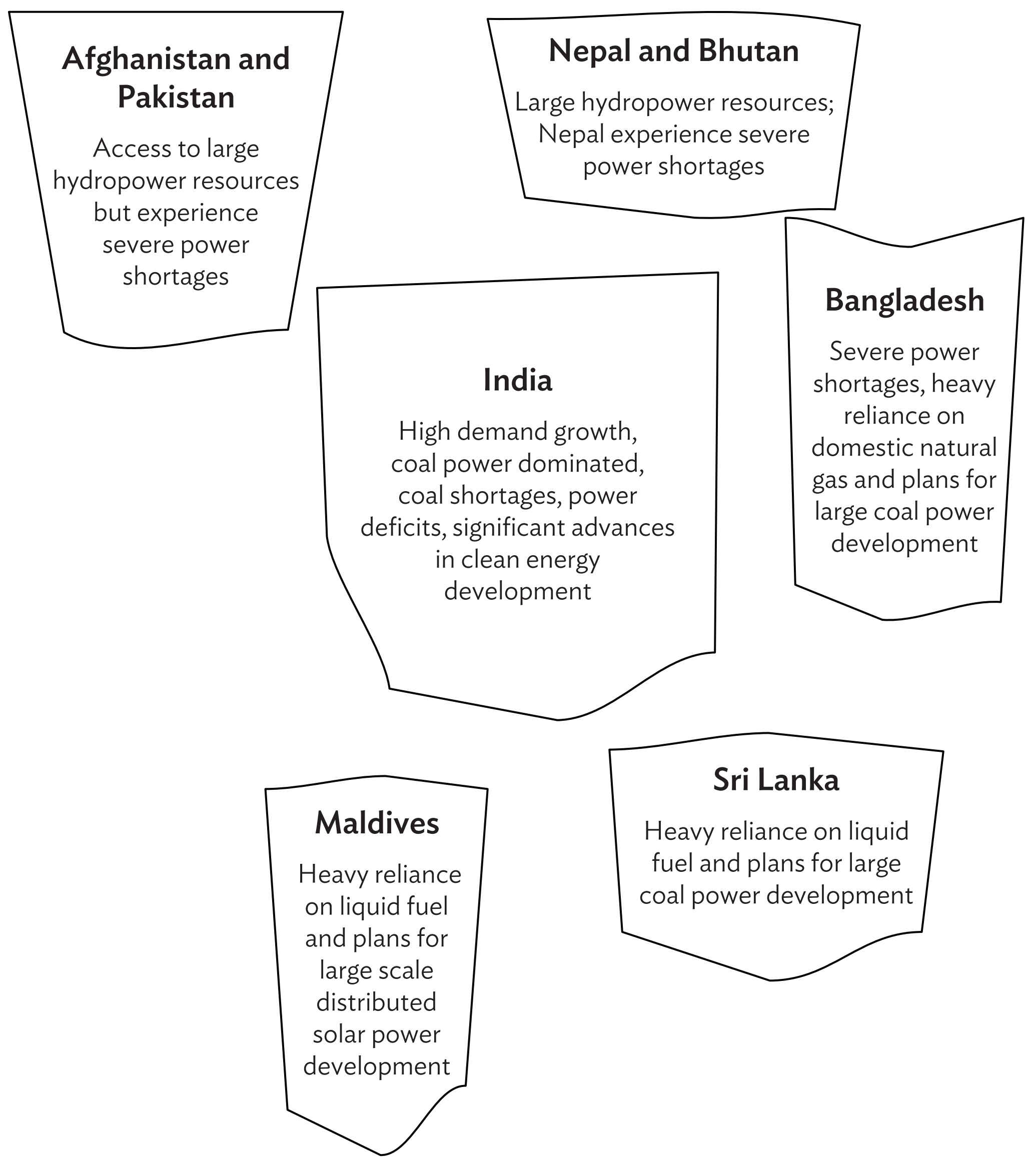
[a] Data in the year 2011/12

Source: Annual reports from respective ministries, departments and utilities

6. The first interconnection between India-Bangladesh of 500MW capacity was constructed with Asian Development Bank (ADB) assistance and was commissioned in October 2013. Interconnection between India-Sri Lanka is being seriously studied with the blessing of the two governments. However, because of the difficulties in long submarine cable link requirement it would not be prudent to consider any power interconnections between Maldives with the rest of SAARC region. Additional high capacity lines and grid reinforcement projects are in various stages of development. However, these developments have come about in a sporadic fashion. There have been little orchestrated efforts to develop an interconnected South Asian grid that offers significant economic, reliability and environmental benefits to all participating countries [Rahman and Wijayatunga, et al, 2012].

7. A development which enables the environment towards a regional power market is the introduction of power exchanges in India such as the Indian Energy Exchange (IEX) and Power Exchange India Limited (PXIL). Such power exchanges would provide space for a market place allowing the transactions to be based on demand and supply between buyers and sellers. Extension of these exchanges to encompass the interconnected South Asia region would present a good market place for the producers and buyers in neighboring countries to sell and buy power anywhere in the region. Such exchanges would naturally improve investor confidence in the power sector in the region.

Figure 1: Major Drivers of Power Trading in South Asia



B. An overview of the literature

8. Some of the recent studies such as the SAARC Regional Energy Trade Study (SRETS) [SAARC 2010] funded by the Asian Development Bank and the Vision 2020 [Obaidullah 2010] have identified the many opportunities for power trading in the South Asia region and the needs relating to the development of related infrastructure. In the case of SRETS, it has gone beyond the power sector to include trading in other energy subsectors such as gas and petroleum [Rahman and Wijayatunga, et al 2012] and how the SAARC Member States can reap related benefits from them. This includes the opportunities for potential for electricity trading among SAARC Member States with a regional power exchange which can be an extended form of the existing Indian power exchanges. SRETS has also dealt with the legal and regulatory aspects of the Member States and emphasized the need to address some of them immediately and others in the medium and longer term. In a similar manner the *Vision 2020* has underlined the importance of carrying out feasibility studies for the high capacity transmission interconnections between India and its neighboring countries, Bangladesh, Bhutan, Nepal, and Sri Lanka if the renewable energy development benefits to be shared optimally for the benefit of the whole region.

9. When developing these transmission infrastructures it is important that the necessary regulatory regimes at the country, subregional and regional level, are in place to ensure optimal investment. Such regimes which are now focused mostly on economic regulation is critical considering that the pricing of transmission services needs to reflect the allocation of optimal investment costs which would be finally passed on to the electricity consumers. For instance, the energy regulator in Australia has introduced regulatory investment test for transmission (RIT-T) where cost benefit analysis of any new transmission investment is a requirement [Australian Energy Regulator 2009]. Madrigal and Stoft [Madrigal and Stoft 2011] and Hasan et al [Hasan and Saha et al. 2013] have extensively discussed the need for new regulatory regimes governing the transmission investments and services for integration of renewable energy in different subregions and regions, among others, in Brazil, Egypt, Europe, Mexico and the United States. Similarly, such analysis of regulatory requirements, though not unique, is undoubtedly a prerequisite when discussing the challenges to power trading in South Asia.

10. As discussed in SRETS there is a need to harmonize regulatory frameworks across South Asia for smooth operations of cross-border trading. South Asia can learn from such harmonised regulatory regimes found in Southern African Power Pool (SAPP) where the trade has grown continuously since its formation. Also, the lessons from the Greater Mekong region where the Lao People's Democratic Republic has become a major exporter of hydropower to Thailand (expected to grow to 10GW by 2017) would be useful for South Asia [ESMAP 2010].

C. Economic Context for South Asian Power Trading in the Near Term

11. The energy sector in the SAARC region has a considerable diversity in generation sources, generation patterns, demand patterns in all time frames (daily, monthly and annually) and access to energy sources outside South Asia. In addition, all the countries experience exponentially growing demand coupled with power shortages in majority of the countries. This diversity naturally helps to make a case for economically feasible power trading among SAARC member states and between the SAARC region and neighbouring regions.

12. For instance Bangladesh and Nepal has significant peak and energy shortages at present and they could have benefited immensely if all the power systems were connected and operated through a

regional power exchange where surplus power from other countries can be traded. Such operation through a power exchange helps the development of the Nepal hydropower sector in the long term since transactions under such operation will be equitable and transparent based on the power exchange operational rules. This will take away one of the major concerns of Nepal where there is doubt on equitable treatment of power traded when the trade occurs based on bilateral agreements. The present annual power exchange between Bhutan and India which is mostly based on large hydropower transfer from Bhutan to India is a good example for possibilities between Nepal and India. In 2011/12, the annual net power transfer from Bhutan to India was 6000 million units (GWh). This is likely to grow significantly in the future with large scale development of its hydro resources. The National Transmission Master Plan of Bhutan [Central Electricity Authority 2011] has assumed 11000MW of power transfer by 2020 and identified required grid reinforcement projects.

13. Further, India has large power needs with its rapidly increasing demand with its fast growing economy and increasing rural electrification. Its demand is expected to grow from 933 billion units in 2011 to 1390 billion units by 2016. This requires new generation capacity additions amounting to about 100,000MW. While more than half of India's present electricity supply is based on thermal power plants mainly using coal it is also going through a significant shortfall of coal supplies. Such short falls can grow to about 42,000 MW of coal-based generation capacity facing the shortage by 2016/17. The economic cost of such shortages emanating from available generation capacity shortages can be extremely high.

14. In the case of Sri Lanka, in the future it is likely to face peak-load generation shortages while its base-load generation will be in excess. At same time Bangladesh will also experience both peak and base-load generation shortage in future. Therefore any interconnection with India will be able to ease this situation in Bangladesh and Sri Lanka with long term access to Indian power market.

15. Similarly a large volume of hydropower resources which are in excess compared to the electricity demand in the Central Asia region can be transferred to the power starved South Asia through Afghanistan. There are two key projects which are being pursued in this regard. CASA 1000 project involves transferring over 3-6 terawatt hours of hydroelectricity during the summer from Kyrgyz Republic and Tajikistan to South Asia. A complementary TUTAP (Turkmenistan-Uzbekistan-Tajikistan-Afghanistan-Pakistan) interconnection project designed to meet Afghanistan's power need for the entire year will enable Afghanistan to be an export hub for Pakistan for domestic hydropower as well as exports from Turkmenistan, Uzbekistan, Tajikistan and the Kyrgyz Republic.

D. Lessons from Power Interconnections in South Asia

16. The first national grid to national grid electricity interconnection in South Asia constructed is between Bangladesh and India and it was commissioned in October 2013. This project was financed by ADB. The main driver for the interconnection was the large power deficit in Bangladesh and the political commitment of the two governments to proceed with power trading. Possible technical difficulties in system control with the small Bangladesh power system being connected to the vast Indian power system was overcome with the connection confined to a back-to-back high voltage direct current system permitting both countries to retain independent control over the power systems. The interconnection allowed Bangladesh to access the power market in India for a capacity of 250MW through a commercial agreement while the remaining 250MW is supplied through a set of Government of India owned power plants. ADB facilitated this first ever commercial power purchase agreement between Bangladesh and India. Based on the success of the first interconnection, additional interconnections in the Eastern and Northern parts of Bangladesh with the Indian system

are being designed. Power imports from the market which accompanies all the complex market rules and settlement systems under the regulatory environment in India shows the need to develop relevant capacity in the partner trading countries like Bangladesh and to harmonize the regulatory environments to ensure minimum disputes arising from these transactions.

17. The renewed interest and the corresponding initiatives in India-Nepal electricity trade subsequent to the signing of the power trade agreement in 2014 with the blessings of the political leaders in the two countries also confirm the need to have political commitment to further cross-border trading. At the same time, the dialogue at the working level among technocrats and agreements on legal, regulatory and technical, aspects is a necessary condition to achieve the final outcome. Such dialogue can even provide the basis for engagement among political leaders finally leading to political commitment. Both in the case of Bangladesh and in Nepal working committees have been set up at the joint secretary level to deal with policy and operational issues on a regular basis. Such an arrangement can always provide advice, guidance and comfort to the utilities in planning and implementation of cross-border projects.

E. Risks

18. The risks associated with the cross-border power trading in South Asia are no different to those in any region consisting of developing countries. These encompass political, commercial and technical risks. There is a significant level of political risk in some of the countries in South Asia particularly in the context of cross-border power trading which could lead to uncertainties in policy, legal and regulatory regimes. Naturally these uncertainties also filter down to commercial risks in the form of exchange rates, taxes and duties, repatriation of earnings and transaction costs.

19. Many of the issues associated with political risks and to a certain extent, commercial and technical risks, in cross-border power trading are mitigated through bilateral agreements between the governments such those already signed between Bhutan and India, Bangladesh and India, and India and Nepal. Further, the SAARC Framework Agreement for Energy Cooperation (Electricity) signed by the member states in November 2014 includes principles based on which most of these risks can be addressed.

20. All the countries in South Asia follow similar, if not the same, technical standards in power system planning and operation which find their roots in the British technical standards. Therefore technical risks can be minimized and this can be relatively easily achieved through harmonization of standards and codes related to cross-border trading. In the case of the Bangladesh India cross-border interconnection, power flows are through a HVDC back to back link that permits each country's system operator to independently manage their grid. The practice of joint technical studies on interconnections also reduces information asymmetry and as noticed in the case of Bangladesh-India and India-Nepal Power Trading Agreements, working group mechanisms have been established to address technical issues so that the respective risks can be avoided or at least minimized.

21. Many of the commercial risks can be mitigated through appropriate provisions in the legal agreements for power purchase and the use of the transmission network services supported with by necessary payment security structures, commercial risk guarantees and specified dispute resolution mechanisms.

II. SCOPE OF STUDY

22. This paper presents the outcome of a modelling study that was undertaken to assess the economic benefits of six major near-term interconnection projects in the South Asia region. The empirical findings of this study provide quantitative estimate of benefits for the interconnectors for the first time and can have major implications for policy development in the South Asian energy sector. The study also advances the idea of probabilistic simulation of interconnection benefits. Monte Carlo simulation embedded in an investment planning and dispatch optimization shows that interconnection benefits can vary widely depending on the demand-supply balance and other parameters. It is therefore prudent to look at the probability distribution of benefits to understand the value-at-risk associated with these projects rather than a set of deterministic estimates, which seems to be the norm internationally [Parikh and Chattopadhyay 1996].

23. Table 2 lists the projects that form the basis for economic assessment. Since there is limited planning data that at best covers the next 5 years, the output of the analysis is limited to the year 2016/17 assuming that all these interconnectors will be in place by that time.

Table 2: Interconnection Projects Selected for Case Studies

Case study	Description	Capacity (MW)	Total estimated cost (USD million)
India-Bhutan grid reinforcement	Hydropower evacuation to India	2,100	140-160
Nepal-India 400 kV link	Hydropower evacuation to India	500	186
India-Sri Lanka HVDC link	HVDC including under-sea cable	500-1000	650
India-Bangladesh HVDC link	HVDC line	500	192-250
India-Pakistan 220/400 kV Link	Short 220/400 kV AC links	250-500	50-150
CASA 1000 and India-Pakistan 400 kV link	Portfolio of transmission projects	1,000	1,000

AC = alternating current; CASA = Central Asia – South Asia; HVDC = high voltage direct current; kV = kilovolt

III. METHODOLOGY

A. Modelling

24. The detailed modelling study assessed economic, reliability and environmental benefits. There are two main analytical components underlying the economic analysis:

(i) An alternating current (AC) load flow analysis undertaken considers the power flows in India with its neighbouring countries including Sri Lanka, Nepal, Bhutan and Bangladesh represented as external nodes. A load flow study was used to develop an equivalent network for the Indian power system; and

(ii) NATGRID, an investment planning and optimisation model is used to simulate the optimal operation of the combined South Asian interconnected system for 2016/17 system [Parikh and Chattopadhyay 1996].

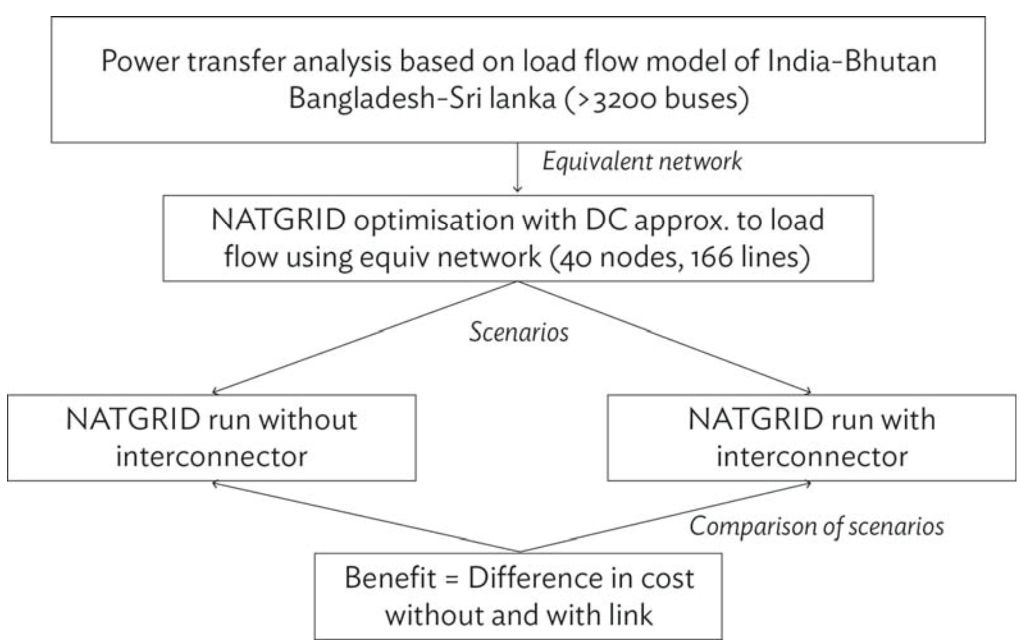
25. The economic, reliability, and environmental benefits for each interconnection project is assessed by comparing demand-supply scenarios with and without the incumbent project. The overview of the simulation is given in Figure 2.

26. The transmission asset would ultimately deliver economic benefits in one or more of three major forms, namely:

(i) Reliability benefit: Avoided expected unserved energy (USE) cost to the extent the new transmission asset lowers peak and energy curtailment in the importing region. These values vary from country to country depending on the structure of the economy [Wijayatunga and Jayalath 2004, Wijayatunga and Jayalath 2009, Tata Energy Research Institute 2001].
(ii) Operating cost benefits: Avoided cost of expensive fuel and operation and maintenance (O&M) costs that the flows on the new line may displace in the importing region; and
(iii) Capacity benefits: Any avoided cost of new generation capacity that the line renders unnecessary that may include capacity needed to produce energy in the importing region or reserve capacity needed in one or more regions.

27. Monte Carlo simulation used to model uncertainties considered random variation in capital and fuel operating costs, along with other uncertain parameters such as demand and generation availability. There is precedence in using Monte Carlo Simulation in similar areas such as production costing and pricing of transmission services, to accommodate uncertainties in electricity demand, generation and fuel costs [Wijayatunga et al. 1991, Wijayatunga et al. 1993, Wijayatunga and Cory 2003]. In this study, a total of 500 samples were used in the analysis that provided a reasonable approximation of the distribution of outcomes. A linear program based dispatch optimization was carried out for each of the samples to obtain one point estimate of system costs and later the average of all samples was used in the final analysis as an indication of the costs and the benefits involved.

Figure 2: Simulation Overview



B. Case Studies

28. Six case studies have been developed around the six proposed (or under construction at the time of the study) interconnection projects focusing on benefits delivered by these projects in 2016/17. The first case study primarily focuses on export of surplus hydro from Bhutan to India that would be facilitated by a proposed grid reinforcement project. The second, India-Nepal case study examines the role of a proposed 400 kV interconnector under two different scenarios, (i) continuation of the present state of deficit power in Nepal, and (ii) a scenario where Nepal develops its planned hydro on time to reach a surplus state by 2016. The third case study explores whether the expensive India-Sri Lanka submarine high voltage direct current (HVDC) transmission project is likely to yield sufficient benefits. The Bangladesh-India link which forms the fourth case study, focuses on the HVDC transmission line that has been recently commissioned (the link was under construction at the time of the study). The last two case studies cover power transfer between India-Pakistan including wider interconnection with Central Asia via the Central Asia-South Asia (CASA) 1000 project [SNC Lavalin 2001, CASA 2015].

29. The input data for the study including load flow datasets has been obtained from Central Electricity Authority (CEA, India) and publicly available information from utilities in the region. Due to serious limitations in data, especially those relating to transmission network beyond 2016/17 the study was restricted to determining the benefits for a single year of 2016/17. In the study the avoided USE costs are calculated using a cost of unserved energy estimate of $ 500 per MWh determined for India [Tata Energy Research Institute 2001].

30. For the purposes of comparison of costs and benefits of each of the transmission link, the cost is annualized at a discount rate of 12% (the threshold discount rate used by ADB) over a 50 year life time for the transmission investment.

IV. RESULTS

31. The results of the six case studies are given in Table 3 which includes the assumptions and annualized cost of each of the transmission links, their benefits and the cost benefits ratios. The assumptions are confined to the realisation of the planned generation capacity additions in each of the countries considered in the study, by 2016/17.

Table 3: Results of the Six Case Studies

Case study	Key assumption	Total and annualized cost of transmission[a] USD million	Annual joint benefit in 2016/17 (USD million)	Benefit-to-cost ratio
India-Bhutan grid reinforcement	Three major hydro projects totaling 3,066 MW will be developed in Bhutan	Total cost USD 140-160 million. Annualized cost USD 18-20 million pa.	Up to USD 1,840 million pa including USD 336 million in opex benefit and USD 1,504 million in unserved energy reduction benefit	92-102
Nepal-India 400 kV link	Two scenarios: (a) Nepal builds all planned projects (2000 MW) to reach **surplus state**; and (b) 650 MW of planned capacity addition is delayed i.e., **deficit state**	Total cost USD 186 million including internal transmission upgrade costs Annualized cost USD 20 million pa	Surplus state benefit of USD 105 million pa(71 million in unserved energy reduction and 34 million in opex benefits) Deficit state benefit of USD 215 million (173 million in unserved energy reduction and 42 million in opex benefits)	(a)Surplus state: 5.2; and (b) Deficit state: 10.7

Case study	Key assumption	Total and annualized cost of transmission[a] USD million	Annual joint benefit in 2016/17 (USD million)	Benefit-to-cost ratio
India-Sri Lanka HVDC link	630 MW of new coal and 400 MW of new hydro added	Total cost USD 339 million (2006 estimate) Annualized cost USD 50 million pa (2010 estimate)	USD 186 million pa comprising 96 million in unserved energy reduction, and 90 million in fuel/capacity benefits.	3.7
India-Bangladesh HVDC link	Three scenarios around demand growth in Bangladesh that range between 9,000 MW to 12,000 MW in 2016/17.	Total cost range between USD 192 million to USD 250 million. Annualized cost of USD 25 million pa assumed for cost/benefit analysis.	Annual benefits range between USD 145 million to USD 389 million, depending upon demand-supply assumptions.	5.8-15.6
India-Pakistan 220/400 kV Link	Two scenarios: (a) Short term 250 MW transfer at 220 kV (b) Medium/long term 400 kV transfer of 500 MW	Total cost of option (a) max USD 50 million for 220 kV option (45 km); and (b) Maximum USD 150 million for 400 kV option (similar to Bangladesh line). Annualized cost of (a) USD 6 million for 220 kV (b) USD 18 million for 400 kV	Annual benefit for 220 kV transfer is USD 335 million including USD 122 million in fuel cost savings. Higher transfer via 400 kV increases benefits to USD 491 million including USD 163 million in fuel cost savings.	Option (a): 55.8; Option (b): 27.2
CASA 1000 and India-Pakistan 400 kV link	Limited hydro (460 MW) development in Afghanistan. Surplus hydro from Kyrgyz Rep. and Tajikstan can be exported to South Asia.	Cost of CASA project is USD 893 million and that for India-Pakistan link max USD 195 million Annualized cost of two projects USD 110 million.	Annual combined benefit of two projects is USD 1,250 million for Base Case including USD 906 in USE cost reduction and USD 306 million in fuel cost savings.	11.4
Total		Annualized cost $ 229-243 million	Annual benefit $ 3861-4127 million	

[a] Annualized cost includes capital cost of transmission projects calculated using a Weighted Average Cost of Capital of 7.5% and life of 30 years, and operation an

V. DISCUSSION

A. Case Study 1: Bhutan-India Power Transmission Reinforcement

32. A grid reinforcement project identified the detailed augmentation that needs to be carried out to evacuate power from Puntsanchhu power plant and other hydro projects in Bhutan. In modeling, random variation in some of the critical parameters which reasonably capture the variation in economic hydropower utilization in Bhutan has been taken into consideration. The grid reinforcement would facilitate generation to expand totaling an additional hydropower output of 15,193 GWh from Bhutan. On average the benefit from avoided operating cost is calculated around USD 350 million per year that includes USD 320 million in saved fuel and coal costs and USD 30 million in ancillary services costs. Even before considering significant benefit in terms of reduction of unserved energy costs, these benefits alone are well above the estimated total cost of USD 140-160 million cost of the entire grid reinforcement project. The reduction in unserved energy cost translates into USD 1.5 billion per year.

33. In addition there would also be environmental benefits such as Carbon Dioxide (CO_2) reduction associated with hydro generation from Bhutan displacing a mix of coal and oil or gas based generation in India. The additional hydropower generation due to transmission investment will lead to an estimated reduction of 15 million tonnes of CO_2 per year. Further, In 2009/10, an estimated 2,000 MW (14,500 GWh of coal-based generation) was stranded due to lack of sufficient coal supply from Coal India Limited. Therefore, large scale hydropower import from Bhutan with associated grid reinforcement structure could be pivotal to minimize the risk of a severe electricity shortage in India.

B. Case Study 2: India – Nepal 400 kV Cross-Border Interconnection

34. Nepal presently has very significant levels of unserved energy throughout the day. There is however about 500 MW new hydro capacity under construction including the Upper Tamakoshi (456 MW) hydro project. There is also an additional 1,422 MW of planned and proposed projects that include the Budhi Gandaki (600 MW) hydro project among others. The total capacity by 2016/17 may therefore exceed 2,500 MW in comparison to projected peak demand of 1,640 MW. However, given the delay in some of the hydro project development in Nepal, one has to consider the possibility of at least part of this capacity falling behind the schedule. This presents two radically different usage of the 400 kV Dhalkebar (Nepal)-Muzaffarpur (India) interconnector that is currently under construction. The link may be able to solve the ongoing power shortage problem in Nepal in the event that sufficient generation capacity development does not eventuate over the next 5 years. On the other hand, the link could be useful in exporting several hundred MW of surplus power that Nepal may have at its disposal if some of the large projects such as Upper Tamakoshi and Budhi Gandak are fully operational in 2016/17. In either scenario, an interconnected Nepal-India system is likely to deliver some benefit although the genesis, magnitude and allocation of such benefits may differ significantly.

Scenario 1: All planned capacity addition achieves to reach surplus state

35. If Nepal attains surplus power, barring demand and generation availability risks, there is little chance of shortage of energy. USE without the interconnector for Nepal is only 0.3% (or 21 GWh), although the interconnector still renders the Nepalese system more reliable to bring it further down to 0.1% (or 7 GWh) which has some value. The source of the value of the link would however be a high level of export from Nepal across the link to reduce unserved energy and fuel costs in India. The average transfer across the link during peak hours would be 830 MW that would help to reduce reliance on expensive gas/oil based generation in India and also reduce USE in India to some extent.

36. The benefit of the link averages at USD 105 million for 2016/17. It comprises on average USD 71 million of USE reduction benefits. This represents on average 127 GWh reduction in USE with the Indian system reaping most of the benefit (approximately, 113 GWh or 88% of the total). Also it consists of fuel cost savings of USD 29 million for approximately 2,600 GWh of transfer that takes place over the link on average for the year across all samples. Although the dispatch change caused by the transfer is far greater in volume, the average value of such displacement is an order of magnitude lower than the cost of unserved energy. Hence, the benefits associated with fuel cost savings are lower than the unserved energy benefits.

37. The investment in the 400 kV line has been estimated at USD 63 million with an equivalent annualized transmission cost is expected to be around USD 8 million per annum. The average transmission charge given the high volume of transfer (~2600 GWh of export per annum) is likely to be significantly low around USD 3 per MWh, or 0.3 cents per kWh. Therefore, the annual fuel cost savings at USD 29 million per annum alone is 3.6 times the annualized cost of the link. The total benefit to cost

ratio is much higher at 13:1, making a compelling case for the interconnector. Bulk of the benefit in this scenario accrues to India both in terms of USE reduction and fuel cost savings.

Scenario 2: Nepal continues to be in a deficit state

38. If it is consider a case where about 650 MW, or one-third, of the planned capacity does not get implemented by 2016/17, leaving the capacity to be just about the same level as the peak demand. Naturally, given the uncertainties around demand, generation availability, and transmission status, a stand-alone Nepalese system would face a risk of frequent power shortages.

39. The impact of capacity deficit is reflected in a significant increase in USE in Nepal absent the interconnector. Average USE accounts for 324 GWh, or over 4% of total energy requirements in Nepal. Although this is far less than the current level, it is a significant level of USE that can largely be eliminated through imports. The interconnector would undoubtedly be of great value to ensure most of the USE is eliminated to bring its level down to about 7 GWh that model simulations show is feasible.

40. The total import into Nepal on average is 2,356 GWh in 2016/17 that amounts to 31% of its energy requirement. It contrasts sharply with the previous scenario where surplus hydro energy of about 2,600 GWh is exported out of Nepal. In this scenario, the unserved energy and fuel cost benefits represent 99% of the total benefit. Total benefit of the interconnector, on average, increases to USD 215 million with fuel cost savings at USD 42 million and USE reduction benefit substantially higher at USD 173.

41. In summary, the interconnector is highly beneficial in both states although the benefits are far higher in the latter scenario. In both cases, the annualized cost of the transmission is only a small fraction of the benefits making a very strong economic case for the link.

C. Case Study 3: India-Sri Lanka Submarine Link

42. The average net transfer is approximately 1,200 GWh, but the top 50 samples (or 10% of total samples) show a net transfer level exceeding 2,000 GWh. The results suggest that the link may account for 7%–15% of Sri Lankan annual energy requirement – mostly during peak. It also facilitates transfer of surplus off-peak energy to India, but the net transfer is expected to reflect a significant volume of import over the link into Sri Lanka.

43. These flows have major impacts on Sri Lankan generation dispatch and unserved energy. The expected unserved energy reduces from 280 GWh without the link (or 1.7% of total energy requirement for Sri Lanka in 2016/17) down to 107 GWh (or 0.65% of total energy) with the link. This marks a significant improvement in system reliability both in terms of reducing the overall probability of outage and the duration, impacting frequency and level of load unserved. Also, diesel generation would reduce quite considerably. While the addition of new coal and hydro in Sri Lanka would reduce reliance on extensive peaking support using diesel even absent the link, the link further reduces dispatch from these generators.

44. The impact on the Indian system is also significant in terms of reducing the need for base-load capacity in 2016/17 through transfer of excess hydro generation from Sri Lanka during off-peak hours. Since longer term impacts have not been modelled, it is not possible to assess how long the capacity requirement will be delayed. Nevertheless, the off-peak transfer on average is 328 MW. Even for a single year, the deferral cost of capacity of this magnitude can be quite significant. There is also

savings in fuel costs during off-peak hours. If the coal shortage in India continues and even worsens over the years as is predicted to be the case, this savings can in fact be very significant. Even ignoring such opportunity costs of limited coal, the fuel cost savings on the Indian side is also significant because of the high fuel cost of some of the plants (USD 120 per MWh). However the fuel cost saving is not as high as that for Sri Lanka. In the event that the Indian peak demand exceeds the projected base demand, and the Sri Lankan demand does not rise as fast, there is also the prospect of the link reducing part of the unserved energy cost.

45. The benefits in 2016/17 average at USD 186 million for the year. If we assume the annualized cost of the link in the range of USD 50 million, the benefits on average are 3-4 times as high making a very robust business case for the link. If both countries stay on a high growth path and for unforeseen reasons part of the generation does not eventuate, the link could be extremely beneficial. On the other hand, the bottom tail of the probability distribution is relatively flat. The lowest quartile of the distribution still has an average of USD 90 million per annum, which is well in excess of the annualized cost of the link (of USD 50 million). In other words, even if the utilisation of the link drops and/or the value of transfer along the link is not high, the link should still deliver sufficient system cost reduction well in excess of the annualized cost of the link.

D. Case Study 4: Bangladesh-India HVDC Link

46. There are two broad demand-supply scenarios that may emerge in Bangladesh depending on the relative growth of supply and demand. Based on these three "Cases" have been constructed for the analysis;

Surplus state (Case 1)

47. Case 1 reflects the most likely scenario or base-case demand projection with the peak demand in 2016/17 closer to the low end of the demand around 9,000 MW and the supply capacity in excess of this demand to leave little unserved energy in the system. Bangladesh may reach a state of surplus power to export power to India over the HVDC interconnector.

Tighter demand-supply balance (Case 2 and Case 3)

48. On the other hand, if the demand growth is stronger, peak demand may be around 11,000 MW by 2016 (Case 2), or even higher in excess of 12,000 MW (Case 3). The HVDC interconnector may be more heavily used to import power in this scenario.

Annual benefits vary widely across the three cases. Case 1 yields an average net annual benefit of USD 145 million resulting primarily from export of less expensive base-load gas based power generation from Bangladesh to India. Case 2 benefits are much higher at USD 234 million due to the interconnector largely importing power to meet peak demand in Bangladesh. Case 3 also sees the interconnector being used to import power to eliminate part of the unserved energy that would otherwise result. It therefore renders the interconnector to have the highest net benefit at USD 389 million.

49. The benefit of the link clearly exceeds the cost of the link for all three cases. On average the benefit-to-cost ratio of the link is in the range of 5.8 to 15.5. It is a very healthy ratio that would render the link to be attractive by any standard followed in other countries. If Bangladesh were to find itself in a state of tight demand-supply condition, the benefits are high enough to recover the entire investment in a single year in both in Case 2 and Case 3.

E. Case Study 5: India – Pakistan 220/400 kV

50. Pakistan's peak-energy shortage is likely to continue in the short to medium term till at least 2020. Apart from a shortage of capacity, high cost of fossil fuel fired power generation in Pakistan is also an issue that could justify interconnection projects. This is particularly true because many of the thermal plants in Pakistan are old and inefficient. Interconnection option for Pakistan has two levels.

- 250 MW with India: Short-term trading opportunities with India with a 220 kV AC interconnection through construction of a short 45 km line – rated up to 500 MW, although on average the import is likely to be well below that level; and
- 500 MW with India: Medium to long term opportunity of trading 500 MW (or more) using 400 kV high voltage alternating current (HVAC) or HVDC line.

Short term 250 MW power transfer: India-Pakistan

51. The transfer over 220 kV lines with transfer limited to 250 MW over 2016/17 amounts to 1,873 GWh of transfer, i.e., a very high utilization of 86%, reflecting the significant import potential of the line. The fuel cost savings amounts to USD 122 million for this level of transfer. The reduction in unserved energy benefits in Pakistan however is much more significant because it reduces 385 GWh of unserved energy that adds more than USD 200 million to the benefits. The expected benefit of the 250 MW link is USD 335 million for 2016/17.

52. Even after allowing for a significant allowance for other costs including significant costs that may be incurred in upgrading the internal transmission systems on both sides, the interconnection costs should not exceed USD 50 million. Therefore, benefits of the 250 MW transfer for a single year would be 6-7 times higher than the costs. It shows the tremendous potential for the link not only to reduce unserved energy but also to reduce consumption of expensive and limited fuel in Pakistan. The fuel cost savings alone for a single year in this case would justify the total interconnection investment.

Medium Term 500 MW power transfer: India-Pakistan

53. Total benefit for a 500 MW transfer rises to USD 491 million for this scenario and the level of transfer rises to 3,129 GWh. The total benefit comprises of fuel cost savings of USD 163 million, USE reduction related savings of USD 302 million and Capacity deferral related savings of USD 26 million. It is observed that although the power transfer capacity is doubled, total benefits or any of the components do not increase proportionately. This is because the marginal benefit of transmission capacity reduces – as more capacity becomes available.

F. Case Study 6: CASA 1000 (including India)

54. CASA 1000 is a major power transmission project to interconnect Tajikistan and Kyrgyz Republic to Afghanistan and Pakistan to transfer large hydroelectric surplus of 3-6 terawatt hours annually from Kyrgyz Republic and Tajikistan to South Asia. This includes 477km of 500kV AC transmission line from Kyrgyz Republic to Tajikistan, 750km high voltage DC transmission line from Tajikistan to Afghanistan to Pakistan and required converter stations in Tajikistan (1300MW capacity AC/DC), Afghanistan (300MW DC/AC) and Pakistan(1000MW DC/AC). The project is expected to be ready by 2016/17 according to the timeline prepared by SNC Lavalin in 2011/12 [SNC Lavalin 2011]. Afghanistan at present faces severe power shortage and a dilapidated power system that is at an early stage of redevelopment. However, it also has significant hydropower potential which according to one

estimate can be as high as 25,000 MW. There is a great deal of uncertainty on future (hydro) generation development in Afghanistan. Given the low level of demand, however, the majority of the opinions seem to point to a state of surplus emerging over the next 5 years [Rahman 2009].

55. With a Base Case using SNC Lavalin assumptions of limited hydropower capacity in Afghanistan the combined economic benefit of CASA 1000 project and the India-Pakistan link has been estimated. The total benefit of CASA 1000 and India-Pakistan (500 MW) interconnection is estimated to be USD 1.25 billion. It consists of USD 906 million of benefit in USE reduction, USD 305 million of fuel cost savings and USD 44 million in capacity deferral costs.

56. Vast majority of the benefits once again come from USE reduction as seen to be the case for most of the other interconnectors. This is to be expected given the capacity deficit in Pakistan in particular. Other benefits also add to USD 349 million for 2016/17. Since the annualized cost of the two projects together is likely to be well below USD 200 million, these benefits are expected to cover for all costs and leave a comfortable return on investment.

G. Regulations for Unserved Energy Reduction Benefits

57. However, there are some important national regulatory issues that need to be addressed for these significant benefits to be recognized [Chattopadhyay and Fernando 2011]. If USE benefits are not considered as part of overall benefits, the benefits would be confined largely to fuel (or "dispatch") related cost savings. Then the break-even utilisation level for a high cost link to recover a decent return on the investment would be very high. Similarly, about two-third of the benefit of the integrated CASA 1000 and India-Pakistan project rests on the ability to reduce unserved energy in Pakistan and other countries. Given the high investment in excess of USD 1 billion needed in this context, ignoring the USE benefits would diminish the strength of the economic argument. However, it is recognised that the extent to which USE benefits are factored in and at what cost is a policy decision in the hands of the countries concerned. Further, there needs to be a common economic regulatory framework across the countries to explicitly define the benefits of transmission including unserved energy reduction costs.

H. Emission Reduction Impact

58. Apart from fuel, reliability or unserved energy and capital cost deferral benefits that are very significant cross-border power trading also holds the key to another important benefit. Such trading will also help to contain the emissions of greenhouse gas and other pollutants in the South Asian power sector. Majority of the additional generation that can be economically exploited is in the form of large-scale hydropower projects in Bhutan, Nepal and Afghanistan, with a long term large hydropower potential. In the short to medium term, hydropower generation, primarily from Bhutan, can displace about 10,000 GWh of thermal generation in India by 2016/17 and 40,000 GWh of thermal generation in India by 2020/21.

59. The estimates suggest every GWh of coal-based generation in India releases close to 1,000 tonnes of CO_2 [Central Electricity Authority 2011]. The old and inefficient stock of coal plants have an average emission intensity of 1,350 tonne of CO_2 per GWh. Peaking gas or liquid petroleum based power generation has a lower emission intensity of 600 tonne CO_2/GWh that would also be substituted to contain CO_2 emissions quite significantly. Therefore, the reduction in carbon emissions over the medium term (by 2020/21) is close to 40 million tonnes annually. Even at USD 10 per tonne of CO_2, short term (2016/17) benefits are USD 100 million per annum and that in the medium term can be

a very significant USD 400 million per annum. These benefits are additional to the fuel cost benefits that add up to about USD 800 million in 2016/17 for all interconnectors.

60. India is the biggest beneficiary with a significant reduction in peaking gas/liquid power generation as well as reduction from its inefficient and expensive coal-fired power generation. The collective fuel cost savings (from all interconnection cases) in India from coal-based generation alone is close to USD 300 million through displacement of 10,000 GWh of coal-based generation. There are 22 coal plants where generation drops on average by 10%. The overall emissions reduction in India from a reduction in coal-based generation is over 13 million tonne of CO_2 per annum. The longer term savings through 40,000 GWh of hydro electricity from Bhutan alone would be 3-4 times as high.

VI. CONCLUSIONS AND POLICY IMPLICATIONS

61. The study presented in the paper was built on the recommendations of the SAARC Regional Energy Trade Study (SRETS) and it was focused on examining the economic and other benefits of the six priority interconnections within the South Asia Region.

62. The paper quantified the enormous benefits of a South Asian interconnected power system, particularly in the context of exploiting the significant hydropower potential that exists in Nepal and Bhutan which clearly justifies the interconnections of these two countries with India. The extended analysis demonstrated the power trading prospects from Central Asian countries to Afghanistan, Pakistan and India, with the possibility for the SAARC region to benefit from surplus hydropower in Tajikstan, Kyrgyz Republic, and potentially Afghanistan, in the future. The benefits of trading would be accrued by all parties involved through the formation of a more reliable interconnected power system and access to clean and economic electricity generation to support economic growth.

63. Study findings which led to a total benefit of over $ 4 billion accrued annually for the whole region from the six interconnections against a cost less than one tenth of that amount, make a compelling case for the near term interconnection projects all of which have large benefit-cost ratios, to be fast-tracked to ensure necessary measures are in place to realise the benefits of trading. The relative size of the Indian power system, its high growth rate of demand and location relative to other countries, suggest that India has to assume the role of a central hub in driving cross-border power trading to a greater height at least at the initial stage.

64. The successful development of power exchanges in India as laid a strong platform for cross-border power trading to be operationalized. As past experience indicates, economic power exchange would not eventuate without a policy formation and addressing the compatibility issues in legal and regulatory frameworks in all the concerned systems. If left to bilateral trading, it is possible the status quo of a limited trading regime will continue leaving the vast economic, reliability and environmental benefits only partially realised.

65. In line with international best practice, a regulatory cost-benefit determination mechanism needs to be implemented to formally recognise the economic benefits for cross-border interconnectors in the South Asian region and develop a methodology to allocate costs and benefits for each of the countries or subregions. In this regard, considering that the reliability benefits are significantly contributed by the value of unserved energy (USE), the countries need to take a policy decision on the value and the use USE in their power system planning processes. Further, it is important to note that a graduated approach to regional market development can address the

differences in market reform by initiating participation of an identified nodal agency, leading to greater participation as institutional experience accumulates in future.

66. It is concluded that a market-driven process for cross-border power trading together with a regulatory framework across the region that enforces a strong economic discipline would maximise the benefits from the development of interconnection projects among South Asian countries considered in an orderly manner.

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Cross-Border Power Trading in South Asia
A Techno Economic Rationale

Diversity in primary energy sources in South Asian countries and their electricity demand patterns both time-of-day as well as across different seasons open up opportunities for greater use of cheaper and cleaner resources for electricity generation reducing fossil fuel use in the region. Such sharing of resources through electricity trading requires electricity transmission system strengthening including planning and development of cross-border transmission lines. The paper presents the economic and reliability benefits of electricity trading among the South Asian countries with case studies involving six cross-border transmission lines.

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