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How Would Cross-Border Electricity Trade Stimulate Hydropower Development in South Asia?

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Abstract

This study examines the importance of enhancing the cross-border transmission interconnections and regional electricity trade to promote hydropower in the South Asia region and quantifies the potential of hydropower development and trade under alternative scenarios. While South Asia is endowed with large (> 350 gigawatts) hydropower potential, only around 20 percent has been exploited so far. This study shows that development of regional electricity markets through expanded cross-border transmission interconnections and regional electricity trade agreements is needed to benefit the region from the exploitation of the untapped hydropower resources. It also finds that development of hydropower in the region would increase by 2.7 times over the next two decades if the region could facilitate an unconstrained flow of electricity across the borders in South Asia. If a moderate carbon tax is added on top of that, hydropower capacity in 2040 could be more than three times as high as the current level.

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How Would Cross-Border Electricity Trade Stimulate Hydropower Development in South Asia?

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Key Words: Hydropower, South Asia, Cross-border transmission interconnection, Regional electricity trade, Power sector

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1. Introduction

The South Asia Region (SAR)[1] has for some time confronted several challenges affecting its national electricity systems. Electricity supplies have not kept pace with demand growth, leading to long daily outages as well as frequent unplanned interruptions. These conditions impose hardships on households and businesses, and discourage new business investment in the economy, as well as impeding extension of service to the many millions in the region still without access to grid-supplied electricity. They also stimulate use of often-inefficient and highly costly alternative power sources, notably diesel generators operated both on the grid and by end-users. In addition, pressures to hold electricity prices for end-users below costs, and difficulties in collecting tariffs, have put many electricity generators and distributors in serious financial stress. This further degrades service quality by undercutting incentives for maintenance and new investment in the sector.

The region, on the other hand, is endowed with a large potential of hydropower resources that can be utilized for supplying "green electricity" that would not only help reduce greenhouse gas (GHG) emissions, but also reduce air pollution through use of zero-emissions electricity to substitute for use of more polluting fuels for power generation and other purposes. The hydropower resource potential in Nepal and Bhutan is much higher than they need to meet their

[1] In this report, SAR consists of Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka. Maldives is also part of SAR, but it is not included in this paper since its location puts it outside the scope of regional electricity trade in the region.

internal electricity demand for many decades to come. Without expansion of cross-border transmission interconnection and regional cooperation for electricity trade, most of the hydropower potential in Nepal and Bhutan would remain untapped in future as well. Besides the surplus hydropower potential in Bhutan and Nepal, as well as Afghanistan, there are many other factors to justify regional electricity trade and cooperation. These include, among others, the role of hydropower to provide flexibility in power system balancing; the potential contribution of hydropower for sharing of reserve margins and reducing peak loads. In addition, large hydropower projects can have other benefits, such as irrigation and flood control, that can be shared between the neighboring counties (e.g., India and Bangladesh, Nepal and India).

At present, regional electricity trade is limited to small volumes of bilateral trade between India and its eastern and northern neighbors (Bangladesh, Bhutan and Nepal). Current capacity of cross-border transmission interconnection is small as compared to the potential hydropower capacity that can be traded. Expansion of cross-border transmission interconnection is expected to evolve over time, which will benefit Bhutan and Nepal by increasing their scope for making cost-competitive hydro investments. Similarly, development of Indian hydro capacity in the remote northeast would benefit from opportunities to export power to Bangladesh and to transmit power through Bangladesh to other parts of India. The Governments of India and Bangladesh have already agreed to build a multi-terminal transmission system from the North East of India to other parts of India passing through Bangladesh.

This paper first provides some background information on the global status of hydropower development using the data provided by the International Hydropower Association (IHA, 2017). It compares the growth of hydropower capacity with that of other power generation technologies including other renewable energy technologies over the last 17 years (2000-2016).

It also analyzes the trends of hydropower development in South Asian countries. It then qualitatively analyzes the critical role of increased cross-border interconnections and regional electricity trade to stimulate the development of hydropower in the region. The paper also presents quantitative results of a power system planning model to measure the expansion of hydropower capacities in the region over the next two decades under various scenarios.[2]

2. An Overview of Hydropower: Global and South Asia

In this section we briefly reflect the current situation of hydropower development around the globe with an additional discussion on historical trends of hydropower development in the South Asia region.

2.1 Global Overview

As of January 1, 2017, 1,242 GW of hydropower capacity had been installed around the world,[3] of which the South Asia region accounts for a small fraction, 5% (IHA, 2017). As illustrated in Figure 1, 116countries around the world have installed hydropower with capacity more than 100 MW, of which 36 countries have installed more than 5,000 MW each; 47 countries, each, have installed capacities between 1,000 MW and 5,000 MW and another 33 countries, each, have installed capacity between 100 MW and 1,000 MW. China tops the list with 331,110 MW, followed by the United States with 102,485 MW, Brazil with 98,015 MW and Canada with 79,323 MW. India, the biggest South Asian country, occupies the fifth position with almost 52,000 MW installed capacity.

[2] This study uses the same electricity planning model used in Timilsina and Toman (2016) and Timilsina and Toman (2018). However, the quantitative results presented here are additional to those presented in the previous studies.

[3] Installed capacity of small hydropower plants (< 100 MW) is not included.

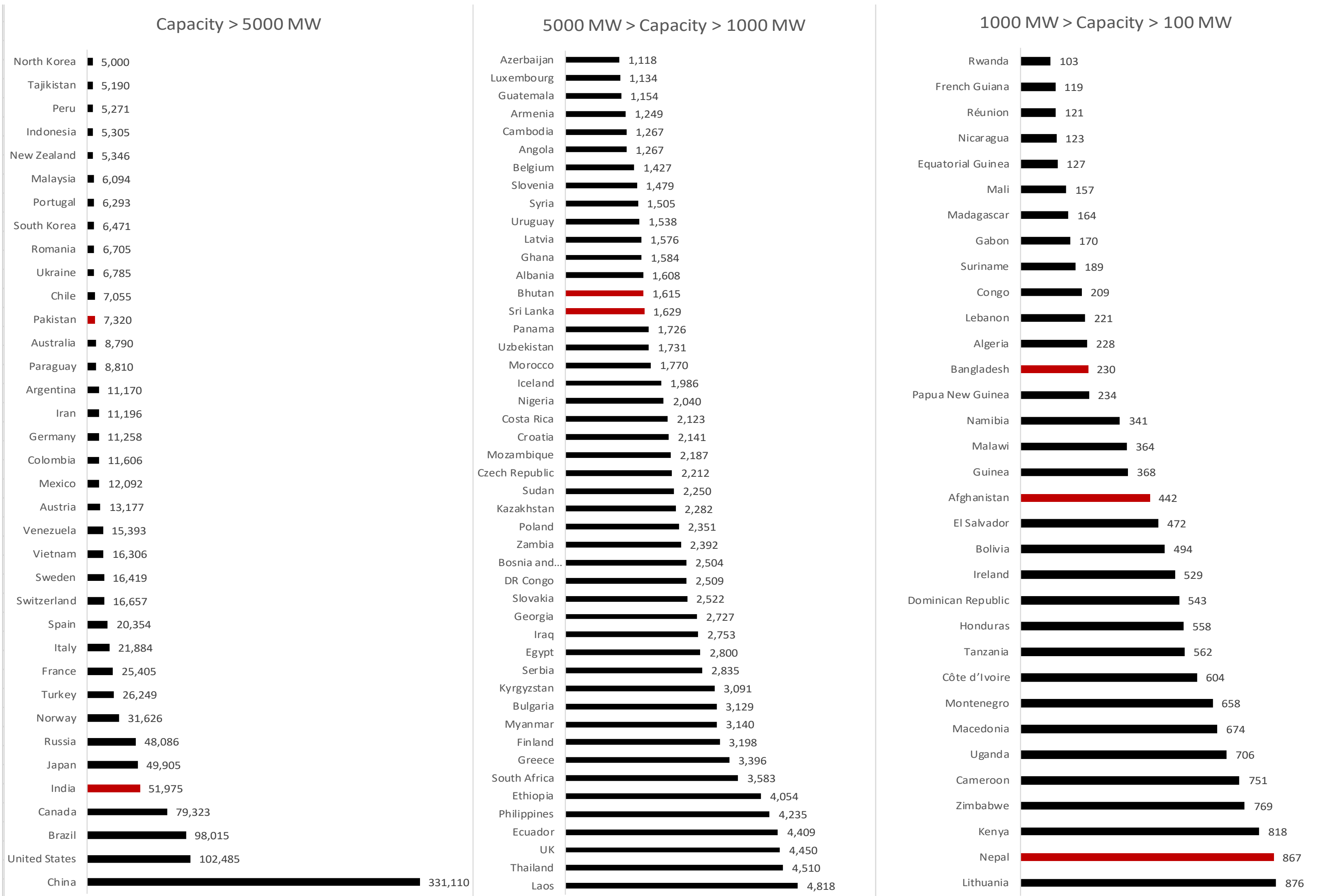


Figure 1. Installed hydropower capacity in different countries as of year 2016, MW (in descending order). Source: IHA (2017)

How does hydropower compare with other sources of electricity generation in terms of installed capacity? Figure 2 answers to this question. As of January 1, 2017, the world's total installed capacity for power generation stands at 6,665 GW, of which hydropower accounts for 19%. As expected, coal and natural gas fired electricity generation technologies have more installed capacity than that of hydropower. While coal accounts for 30% of the global installed power generation capacity, natural gas accounts for 25%. Other renewable energy, including wind, solar and biomass, accounts for 13%.

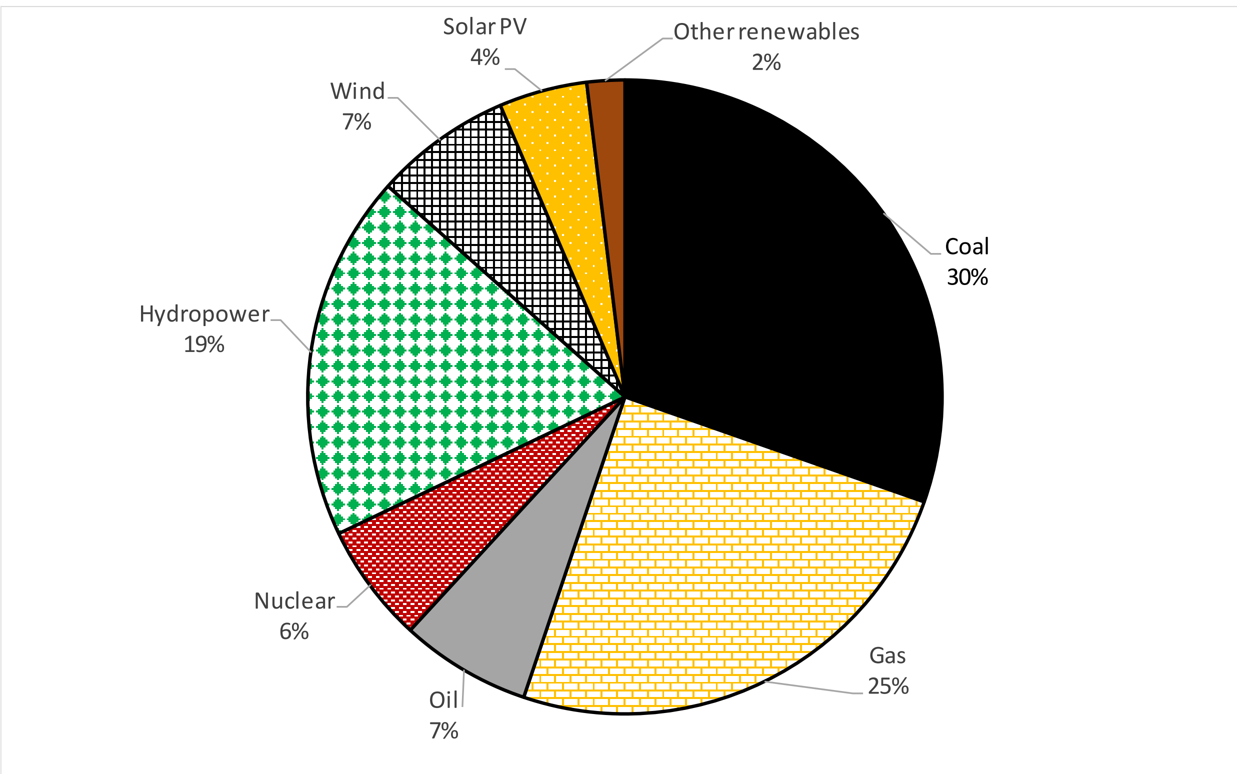


Figure 2. Electricity generation capacity mix, 2016 (%)

Source: IEA (2017b)

A comparison of power generation sources or technologies in terms of their installed capacities could be misleading for two reasons. First, different types of electricity generation capacities are not equally available to contribute to meeting the demand, or load. Some technologies, especially those where input fuel or energy can be stored (e.g., fossil fuels, nuclear, storage hydro power, biomass) are available when needed, intermittent resources such as solar, wind, and run of river hydro are not available as they vary hourly, daily and seasonally (differing plant availability factors). Second, even if a resource is available to produce electricity, it may not be used to meet the load because some other resources are more economical to produce power in a given hour (capacity utilization factor). Therefore, it would be more logical to compare different types of electricity generation sources or technologies based on the electricity they produce in a year. Based on the data maintained by the International Energy Association (IEA, 2017a), global electricity generation was 24,345 TWh in 2015, of which coal accounted for 39%, natural gas accounted for 23%, hydro accounted for 16%, nuclear accounted for 11%, and oil accounted for 4%. The remaining 7% was generated from renewable energy technologies including solar, wind, biomass, and geothermal (See Figure 3).

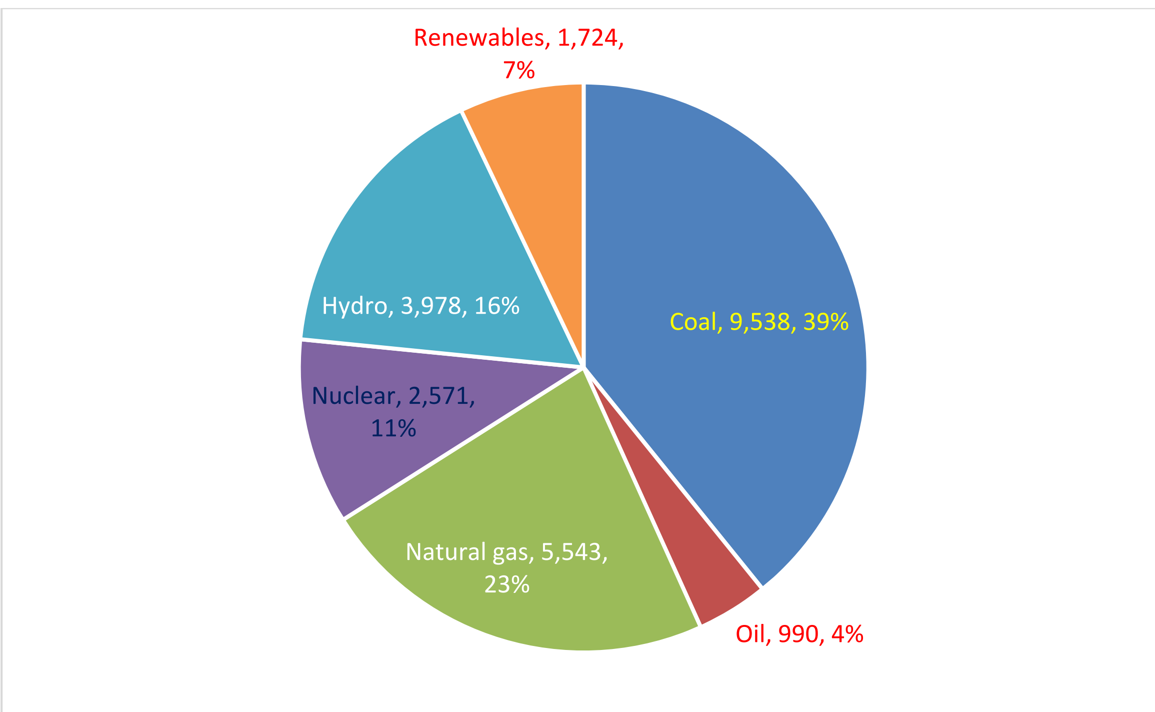
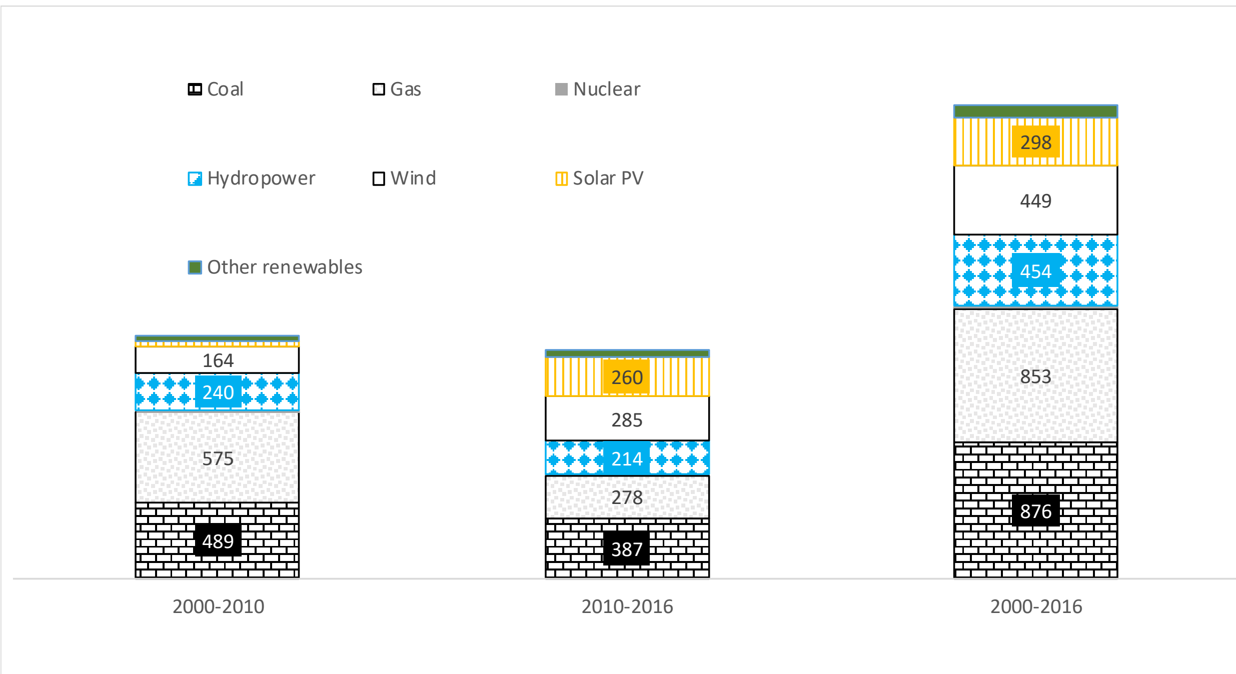


Figure 3. Global electricity generation mix in 2015 (TWh, %)

Source: IEA (2017a)

As a complement to the data on total installed capacity, Figure 4 presents electricity generation capacities added during the 2000-2016 period. During this period, a total of 454 GW of hydropower was added globally; this number is slightly higher than wind power capacity added during the same period (449 MW). Note however, that addition of wind and solar power capacities each are higher than the addition of hydropower capacity in more recent years (2010-2016) due to the rapid growth of solar and wind stimulated through government policy support and cost reduction.



Source: IEA (2017)[4]

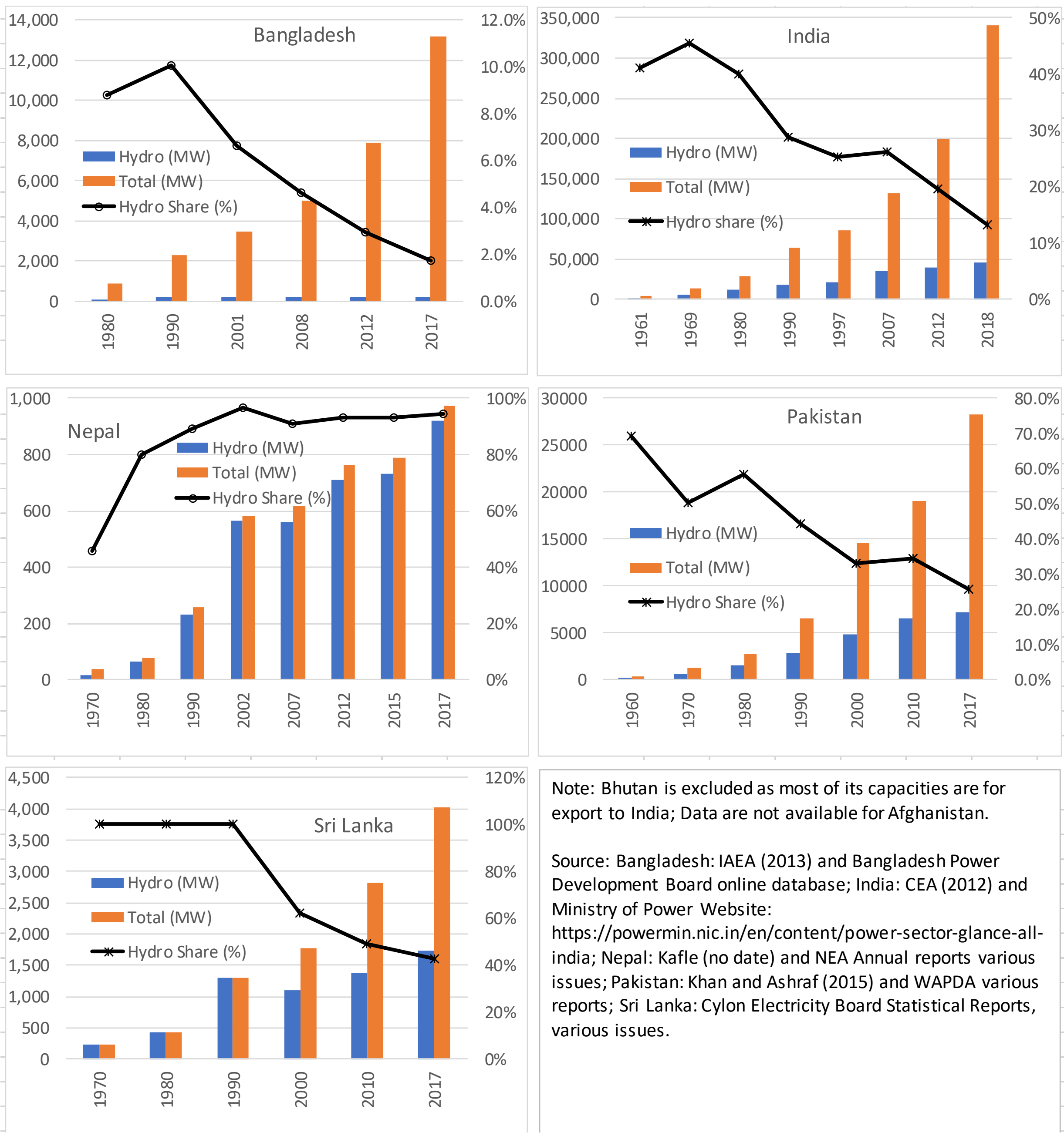
Figure 4. Addition of electricity generation capacity mix (2000-2016) (GW)

[4] This figure is based on data provided by Mr. Heymi Bahar of the International Energy Agency through personal communication.

2.2 Hydropower Development Trend and Resource Potential in South Asia

In this sub-section we discuss first the trend of hydropower capacity development vis a vis the growth of total capacity to generate electricity in South Asian countries, followed by hydropower resource potential in the region. Figure 5 shows the growth of hydropower development in South Asian countries. In early years, 1960s, 1970s, hydropower has relatively higher contribution to total electricity demand in South Asian countries. For example, the share of hydropower in total electricity generation capacity in 1980 was 30% in India. Today it has dropped to 13% because electricity demand increased rapidly and growth of hydropower could not catch the growth of total electricity demand and required generation. In Pakistan, hydropower contributed more than 60% of the total electricity demand in 1980, it has dropped to a half by 2017. In Sri Lanka, hydropower was the main electricity generation source to meet its demand by 1990; its share has dropped to 40% over the last 25 years. In Nepal, hydropower is the primary source of electricity generation since 1990. The same is true for Bhutan (not shown in Figure 5). Like in other parts of the world, the growth of hydropower in South Asia was slow in the 1980s and 1990s for various reasons such as increased environmental concerns, social (e.g., resettlement) issues, long lead time for construction, lack of project finance, etc. The climate change debate has brought hydropower to the forefront again (Ahlers et al. 2015).

South Asia could benefit from the reemergence of hydropower development because of its huge yet to be exploited potential. Figure 6(a) and (b) indicate those potentials. As illustrated in Figure 6(a), South Asia processes a large potential for hydropower, almost 350 GW. Of the total potential less than 20% has been exploited so far. This means the region has a huge potential of untapped hydropower resource that offers a great opportunity for clean and green power production.



Note: Bhutan is excluded as most of its capacities are for export to India; Data are not available for Afghanistan.

Source: Bangladesh: IAEA (2013) and Bangladesh Power Development Board online database; India: CEA (2012) and Ministry of Power Website: https://powermin.nic.in/en/content/power-sector-glance-all-india; Nepal: Kafle (no date) and NEA Annual reports various issues; Pakistan: Khan and Ashraf (2015) and WAPDA various reports; Sri Lanka: Cylon Electricity Board Statistical Reports, various issues.

Figure 5: Historical growth of hydropower vis a vis total electricity generation capacity

India alone has a potential of almost 150,000 MW hydropower of which only one-third has been exploited so far. Almost a half of the potential yet to be exploited is located in the Northeastern state of Arunachal Pradesh which is estimated to have more than 50,000 MW. Less than 7% of the potential of this state has been exploited currently. Other states with large hydropower potential (> 18,000 MW) are Himachal Pradesh and Uttarakhand. While more than 60% of the potential in Himachal Pradesh has been already developed, only 30% has been exploited in Uttarakhand.

In Pakistan, hydropower potential is estimated to be around 60,000 MW, of which only around 8,000 MW has been developed so far. Nepal offers 83,000 MW of hydropower potential, of which less than 1,000 MW has been exploited so far. Afghanistan and Bhutan each offers more than 20,000 MW potential. While about 10,000 MW is being developed in Bhutan to export to India, hydropower potential in Afghanistan has not been exploited yet except for a few power plants with total installed capacity of around 450 MW (out of 23,000 MW potential).

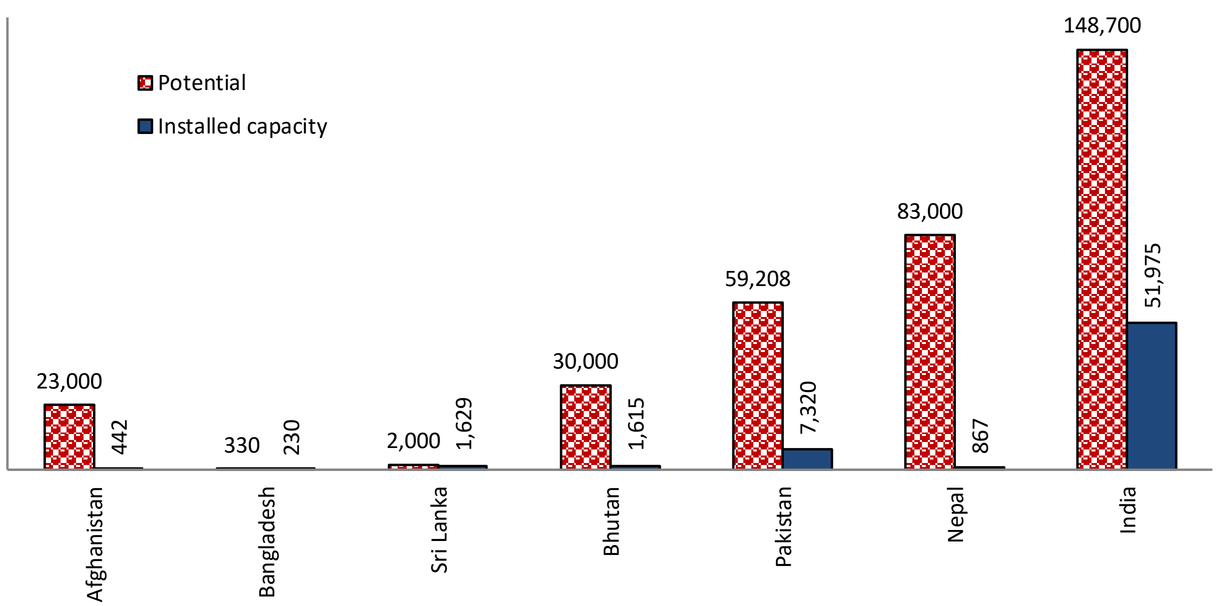


Figure 6 (a): Hydropower Potential in South Asia (MW)

Source: Installed capacity: IHA (2017); Hydro Power Potential: MEWA (2017) for Afghanistan, CEA (2018) for India, WAPDA (2011) for Pakistan, CEB (2017) for Sri Lanka and SAARC (2010) for the rest of the countries

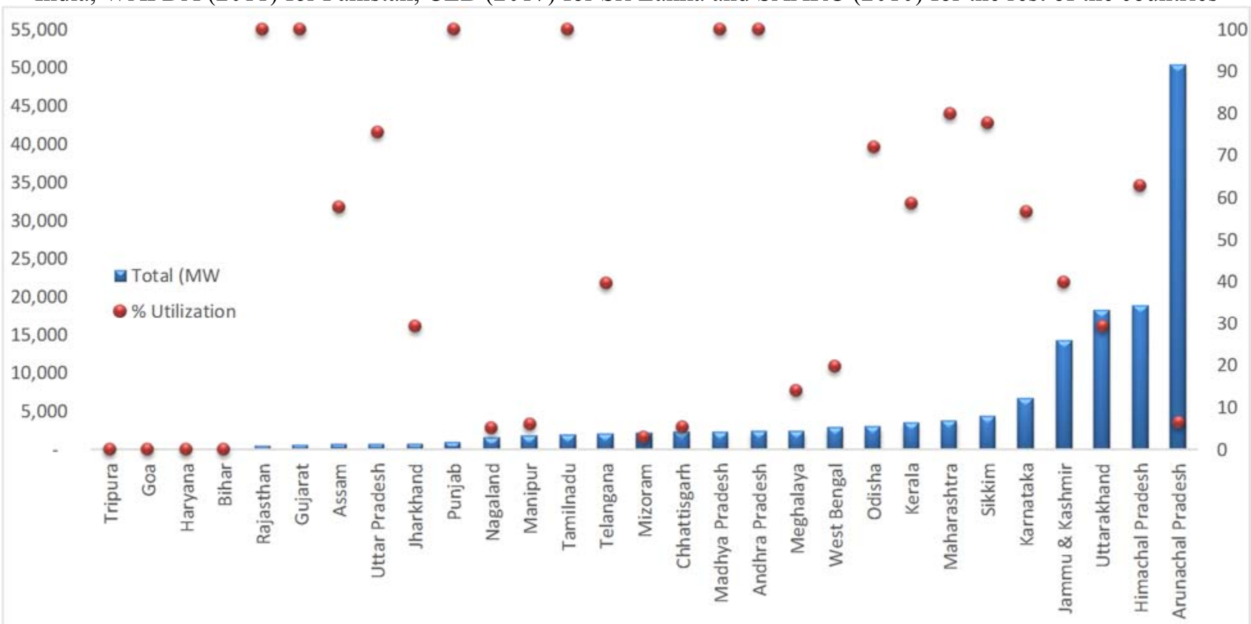


Figure 6 (b): State-wise Hydropower Potential (MW) and Current rate of utilization in India (%)

Source: CEA (2018).

3. Why Is Cross-border Electricity Trade Needed to Develop Hydropower in South Asia?

Cross-border electricity trade is essential for hydropower development in the South Asia for the following reasons: (i) opportunity to utilize surplus hydropower resources in Afghanistan, Bhutan and Nepal; (ii) need for hydropower in India and Bangladesh to improve hydro-thermal system balancing and peak load supply; (iii) need for clean energy in India, Bangladesh and Pakistan to meet their climate change and other environmental targets; (iv) excellent opportunity for better utilizing existing capacities due to difference in monthly/daily/hourly load curves across the electricity grids; (v) peak load management; and (vi) strong economic incentives for all countries. These factors are elaborated in the sub-sections below.

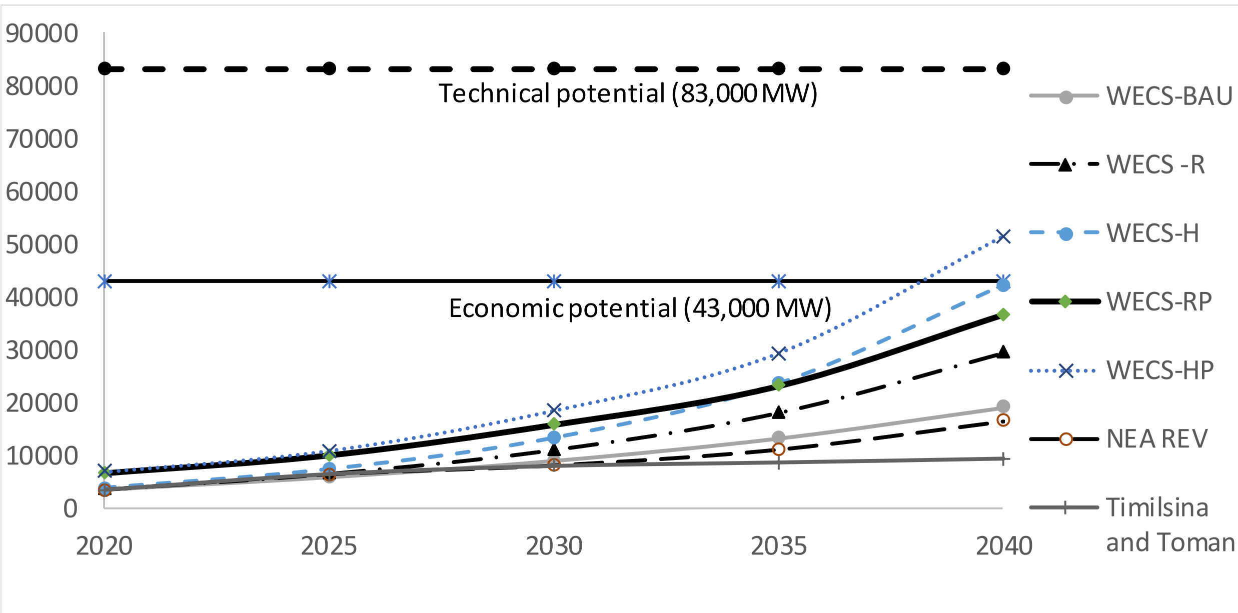
3.1 Surplus Hydropower Potential in Afghanistan, Bhutan and Nepal

One of the key barriers to develop hydropower in South Asia, particularly Afghanistan and Nepal, is the lack of access to neighboring markets. These countries' domestic demands in the next several decades are likely to be much smaller than the hydropower potential they have. Since these countries may not be able to absorb the available hydropower potential domestically, export markets and transmission access to the export market are needed. Therefore, regional or sub-regional electricity trade is necessary to exploit the surplus hydropower potential in these three countries.

Figures 7(a), (b) and (c) show that technical and economic potentials of hydropower in these countries are higher than domestic loads projected for several decades to come. Several load forecasts and associated generation capacity needs are available for Nepal. These projections include WECS (2017), NEA (2016) and Timilsina and Toman (2016). WECS (2017) considers five scenarios. WECS's Business as Usual (BAU) scenario that assumes the continuation of the status quo with 4.5% average annual GDP growth over the next two decades estimates that Nepal would need 3,384 MW, 5,787MW, 8,937 MW, 13,242 MW and 19,151 MW in years 2020, 2025, 2030, 2035 and 2040, respectively. If the average annual GDP growth increases to 7.2%, the corresponding capacity requirements would be, respectively, 7%, 14%, 24%, 37% and 54% higher than the BAU projections. If Nepal achieves high economic growth (9.2% on average annually) due to the change in state administrative structure and political stability that has been achieved after decades of political uncertainties, generation capacities required in 2020, 2025, 2030, 2035 and 2040 would be respectively, 3,794MW, 7,366MW, 13,296MW, 23,588MW and 42,228MW. If targeted policies are implemented to substitute, by 2020, 75% of the water heating in urban households, 100% of the cooking in urban households and 7% of the cooking in rural households and 100% electrification, and electrifying 18% of the total passenger kilometers by 2025, capacity requirements (under the 7.2% GDP growth scenario) will be 6,621MW, 9,987MW, 15,731MW, 23,049MW and 36,489MW.

Figure 7. Hydropower potential vs. capacity required to meet domestic demand in Nepal, Bhutan and Afghanistan (MW)[5]

7 (a) Nepal



Note and source: 'WECS-BAU' refers to electricity capacity requirement forecast made by the Water and Energy Commission Secretariat WECS of Nepal to meet domestic demand under the Business as Usual scenario. 'WECS-R' and 'WECS-H' refer to the capacity requirement forecasts made by WECS under the reference economic growth (7.2%) and high economic growth (9.2%) scenarios, respectively. 'WECS-RP' and 'WECS-HP' refer to capacity requirement forecasts made by WECS with government's policy interventions for substitution of cooking, heating and transportation fuels with electricity under the reference and high economic growth scenarios. All these forecasts are from WECS (2017). 'NEA' refers to capacity requirement forecasts based on electricity load forecasts made by the Nepal Electricity Authority (NEA) in 2015 (NEA, 2016). 'Timilsina and Toman' refers to load projections used in Timilsina and Toman (2016) study.

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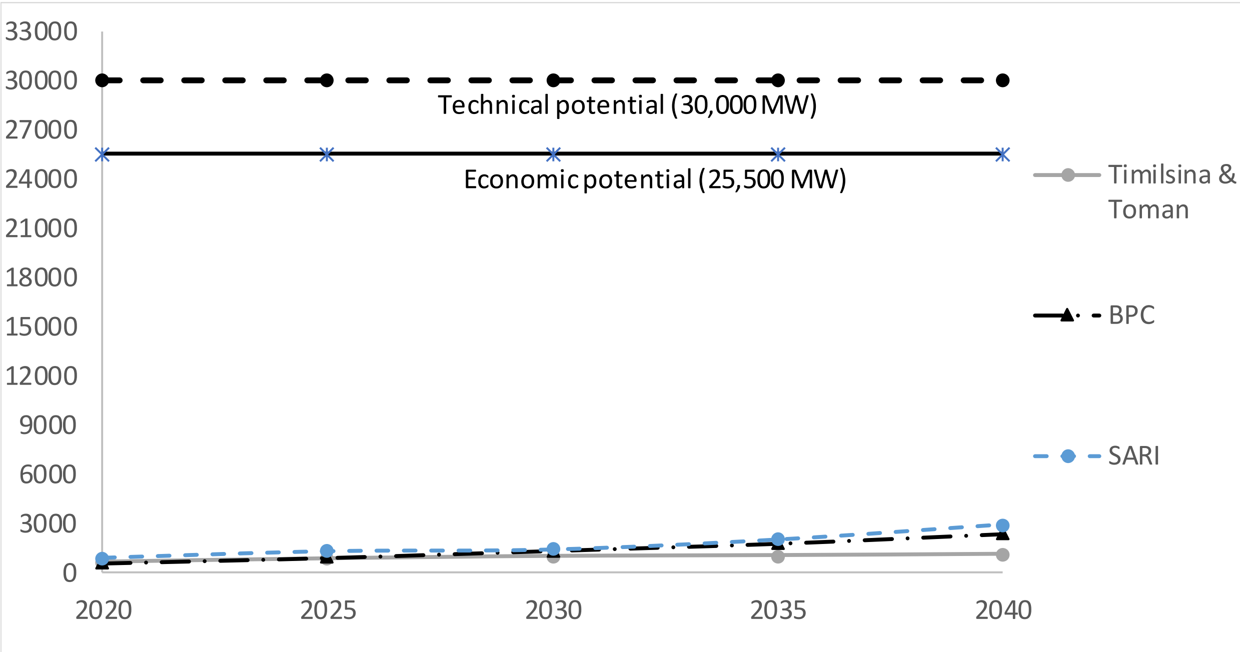
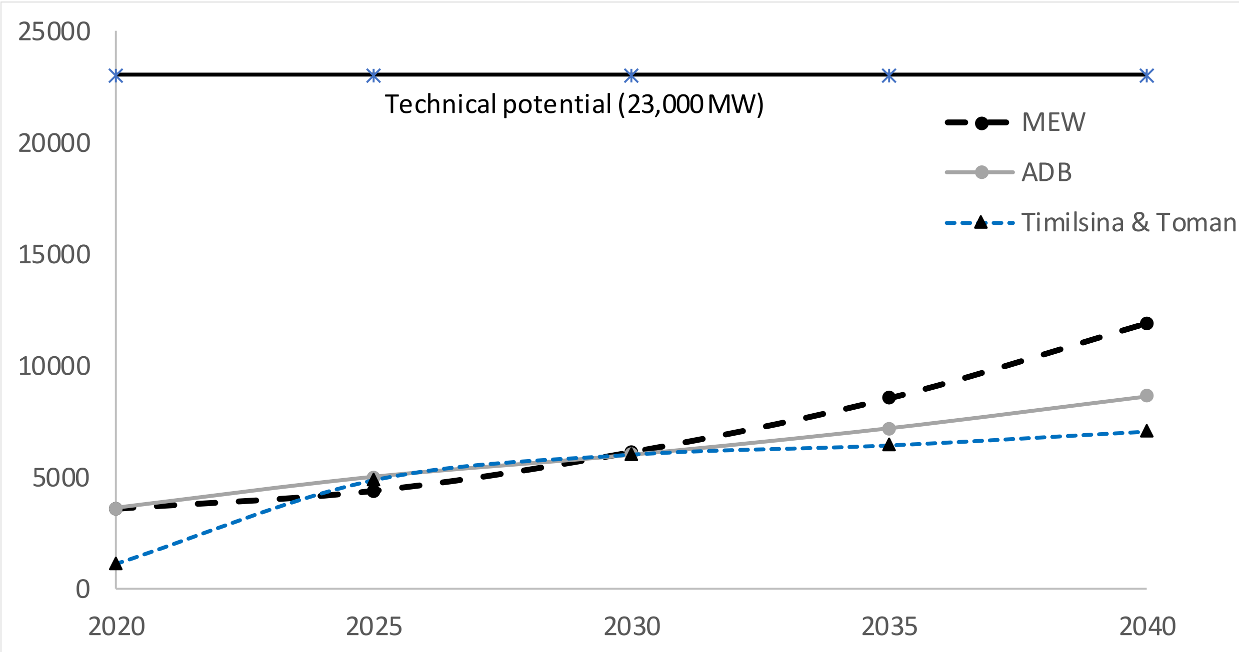
[5] The generation requirement forecasts presented here, especially for Afghanistan and Bhutan are not the precise ones, very simplistic assumptions are made to extrapolate the load forecasts where needed and to calculate required capacity from the load forecasts. They should be used as indicative numbers and should not be interpreted as 'World Bank' electricity forecasts for the corresponding countries.

7 (b) Bhutan



Note and source: 'BPC' refers to the capacity requirement provided, through personal communication, by Mr. Gem Tshering, Managing Director and Mr. Gorab Dorji, General Manager, R&D, Bhutan Power Corporation (BPC). This forecast provides data up to 2030. Data for 2040 was extrapolated using the same annual average load growth for 2025-2030 period and assuming the same capacity to load ratio as in year 2030. 'SARI' refers to the forecast available in SARI/EI (2016). We assumed the same capacity factor for power generation for meeting domestic and export demands. 'Timilsina and Toman' refers to capacity requirement corresponding to load projections used in Timilsina and Toman (2016) study. The 'Timilsina & Toman' projection applies the same ratio of domestic firm power capacity requirement to load used by 'BPC' forecast to calculate domestic capacity requirement.

7 (c) Afghanistan



Note and source: 'MEW' refers to the capacity requirement calculated based on load forecast provided in MEW (2017). This forecast goes until 2023, we used the same annual average growth rate of load for 2020-2023 for the rest of the period. 'ADB' refers to capacity requirement based on reference case load forecasts available in ADB (2013). The available load forecast goes up to year 2032. We extrapolated to 2040 using the same growth rate for 2025-2032. Required capacity to load in both forecasts is assumed to be 2 based on installed capacity to peak load ratio in India at present. The 'Timilsina & Toman' refers to capacity requirement used in Timilsina and Toman (2016) study.

The WECS load forecasts for Nepal, especially the high economic growth and policy intervention scenarios are highly optimistic. The capacity requirement forecasts based on load forecasts made by the state electricity authority, Nepal Electricity Authority (NEA) are very close to WECS's BAU forecasts.[6] The capacity projections used in Timilsina and Toman (2016) are on the lower side as they are based on NEA's earlier (i.e., 2010) load forecasts that were available when the study was carried out.

[6] Capacity requirements are estimated based on the load forecasts assuming the same peak load to capacity requirements ratios as used in Timilsina and Toman (2016).

A large surplus of hydropower potential is apparent in Nepal in most scenarios for meeting domestic demand, except WECS' very optimistic scenarios (high growth, policy intervention scenarios). Even if the gap is small, cross-border transmission interconnections and regional/sub-regional electricity trade would be needed to exploit Nepal's hydropower resource. This is because, it is neither necessary nor economical to meet the entire domestic load with domestic resources because cross-border electricity trade provides more flexibility to meet the demand through inframarginal trade, sharing of reserve margins and better utilization of hydropower capacities. These issues will be discussed later in this section.

Projections of capacity requirement for meeting domestic load in Bhutan by 2040 vary from 1,100 MW to 2,900 MW. As noted in footnote 6, these estimations are crude ones, still they could be useful to indicate the size of the capacity requirement needed for domestic demand. Even if we take the higher estimate of 2,900 MW, Bhutan would have more than 22,000 economic potential and more than 27,000 technical potential to export. Note also that for a system like Bhutan which has been fully integrated with India's large electricity system, it may not be appropriate to build electricity generation capacity to only meet its own load. The transmission interconnection provides flexibility to meet its peak load importing from India even if its installed capacities are not available to meet the peak load in certain circumstances. Meaning that the upper range of the estimated required capacity presented in Figure 7(b) could be too high.

Considering the historical and current situation in Afghanistan, long term forecasts of electricity load and generation capacity are highly uncertain. Therefore, not that many projections are available for Afghanistan. Some rough estimates based on available information show that Afghanistan might need 7,000 MW to 12,000 MW to meet its domestic demand. Even if we consider the higher estimate, the country will have large room, about 11,000 MW hydropower resources, to export.

3.2 Need for Hydropower for System Balance

Since electricity is a non-storable commodity and its demand varies across hours, days and months, required installed capacity should be higher than the maximum demand or peak load plus reserve margins. Due to these hourly changing load patterns, the capability of quickly increasing or decreasing (or ramping up or down) of power generation along with the load is an essential characteristic of a power supply system. However, many technologies (e.g., steam turbine technologies), cannot be switched off and on so frequently for technical reasons. Hydropower, particularly, storage type, is very useful in such a situation. Therefore, power systems with predominantly steam turbine technologies, such the Indian power system, need enough storage hydropower capacity for load balancing as well as meeting peak load. In India, with 60% of the total installed capacity based on coal, a higher share of hydropower is needed to provide flexibility to the system.[7] However, at present, hydropower supplies only 13% of the total capacity installed. In the 1960s, half of the total electricity in India was supplied through hydropower. Considering the important role of hydropower to provide more flexibility to the power system, the Government of India (GOI) periodically introduces promotional policies for hydropower. These policies include differential pricing, introduced in the 2006 National Tariff Policy for peak and off-peak power, which provides extra incentives to storage hydro that is mainly used for meeting peak load, and the 2008 mega project policy that provides additional incentives, such as a 10-year tax holiday,

[7] Government of India, Ministry of Power Website. https://powermin.nic.in/en/content/power-sector-glance-all-india

exemptions of duty on import of equipment for power projects with capacity greater than 500 MW (PWC, 2014).[8]

The role of hydropower in balancing the power system in India has increased significantly due to the rapid expansion of intermittent renewable resources (solar and wind). At present, intermittent renewable resources account for almost 20% of the total installed capacity. Having a larger share of intermittent resources would mean that a power system would need more flexible or quick ramping technologies, such as storage hydro, to ensure the system balance. This situation further demands hydropower power capacity, particularly storage type in India. Since, solar power is likely to face more interruptions during the monsoon season, enhanced cross-border transmission interconnection would help India to access hydropower generation from Nepal and Bhutan, where hydropower generation from run of the river capacities would be much higher in the monsoon season as compared to the drier season. Like India, Bangladesh and Pakistan would also benefit if the share of hydropower in their capacity mix is increased. Thus, the critical role that hydropower plays in power system balancing will increase the demand for hydropower in South Asia, particularly from countries where surplus potential exists.

3.3. Hydropower for Climate Change Mitigation

South Asia makes an important contribution to global greenhouse gas (GHG) emissions. The region accounts for about 7% of global greenhouse gas (GHG) emissions from fossil fuel

[8] In Bangladesh and Pakistan, demand for hydropower to provide flexibility in their power systems may not be as critical as in India because hydropower supplies sufficient share for balancing the system in Pakistan, and both systems have enough gas fired generation capacities which can provide flexibility to the systems due to its quick ramping up-down characteristics. Therefore, we have not discussed here the importance of hydropower for system flexibility in Bangladesh and Pakistan. In future, however, as the size of their systems increases, importance of hydropower to improve their system flexibility also increases.

combustion, and the power sector accounts about half of the region's total fossil fuel-based CO_2 emissions (IEA, 2015). Most South Asian countries have set targets to reduce their GHG emissions under the Paris Agreement through their nationally determined contributions (NDCs) pledges. India has set a target of reducing its emissions intensity of GDP by 33% to 35% by 2030 from the 2005 level (UNFCCC, 2015). Pakistan intends to reduce up to 20% of its 2030 projected GHG emissions if international financial supports are provided.[9] Bangladesh intends unconditionally to reduce GHG emissions by 5% from its BAU level by 2030 in the power, transport and industry sectors. The reduction in each of these sectors will be increased to 15% if international supports (e.g., grants, technology development and transfer, and capacity building) are provided.[10]

Since the power sector is an important contributor to GHG emissions in Bangladesh, India and Pakistan, expanding the clean energy sources, including hydropower for power generation, would be the main strategy to meet their NDCs. Timilsina and Toman (2018) estimate that regional electricity trade that stimulates hydropower development and trade in the region would help reduce power sector emissions by 43%, 9% and 3% in, respectively Bangladesh, India and Pakistan in 2030 from the baseline. For the South Asia region as a whole, the corresponding reduction would be 11%. If a carbon tax is added on top of the regional electricity trading provision, hydropower and other renewable energy resources would further substitute fossil fuels thereby reducing power sector emissions in 2030 by 55%, 16%, 26% and 20% from the baseline in Bangladesh, India, Pakistan and South Asia, respectively. These results suggest the importance of hydropower to mitigate climate change in South Asia.

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[9] Pakistan's Intended Nationally Determined Contribution (Pak-INDC).
http://www4.unfccc.int/ndcregistry/PublishedDocuments/Pakistan%20First/Pak-INDC.pdf

[10] http://www4.unfccc.int/ndcregistry/PublishedDocuments/Bangladesh%20First/INDC_2015_of_Bangladesh.pdf

3.4 Advantage of Hydropower When Load Profiles across Countries Are Different

Different countries have monthly or seasonal load profiles with different shapes. Figure 8 shows a comparison of the monthly load curves of Bangladesh, India and Pakistan. The figure illustrates that demand for electricity is higher during June to October in Bangladesh, May to September in Pakistan and August to October in India. For months between April to July, India's load curve shows declining electricity demand. During these months electricity demand is increasing in Bangladesh and remains at a high level in Pakistan. This implies that India could supply electricity to Bangladesh and Pakistan during these months.

Although the latest monthly load curve is not available for Nepal and therefore could not be included in Figure 8, monthly load profiles in earlier years show that electricity load is higher during the winter months (November to February) as compared to summer months (June -August). During the summer months, not only electricity demand remains lower, but also electricity production is higher because of the monsoon. This means that Nepal can export maximum amount of hydropower to the potential export markets (India, Bangladesh, Pakistan) when their demand is high. This type of monthly or seasonal variation in electricity demand across the countries provides an excellent opportunity for electricity trade, thereby facilitating the better utilization of existing capacities. The improved capacity utilization strengthens the financial conditions of electricity suppliers and provides incentives to investors.

These countries do not exhibit significant difference in hourly load profiles, as each of them has evening peak during the same hours (5 PM to 8 PM). They might have difference in daily load profiles, however, necessary data are not available to compare daily load profiles.

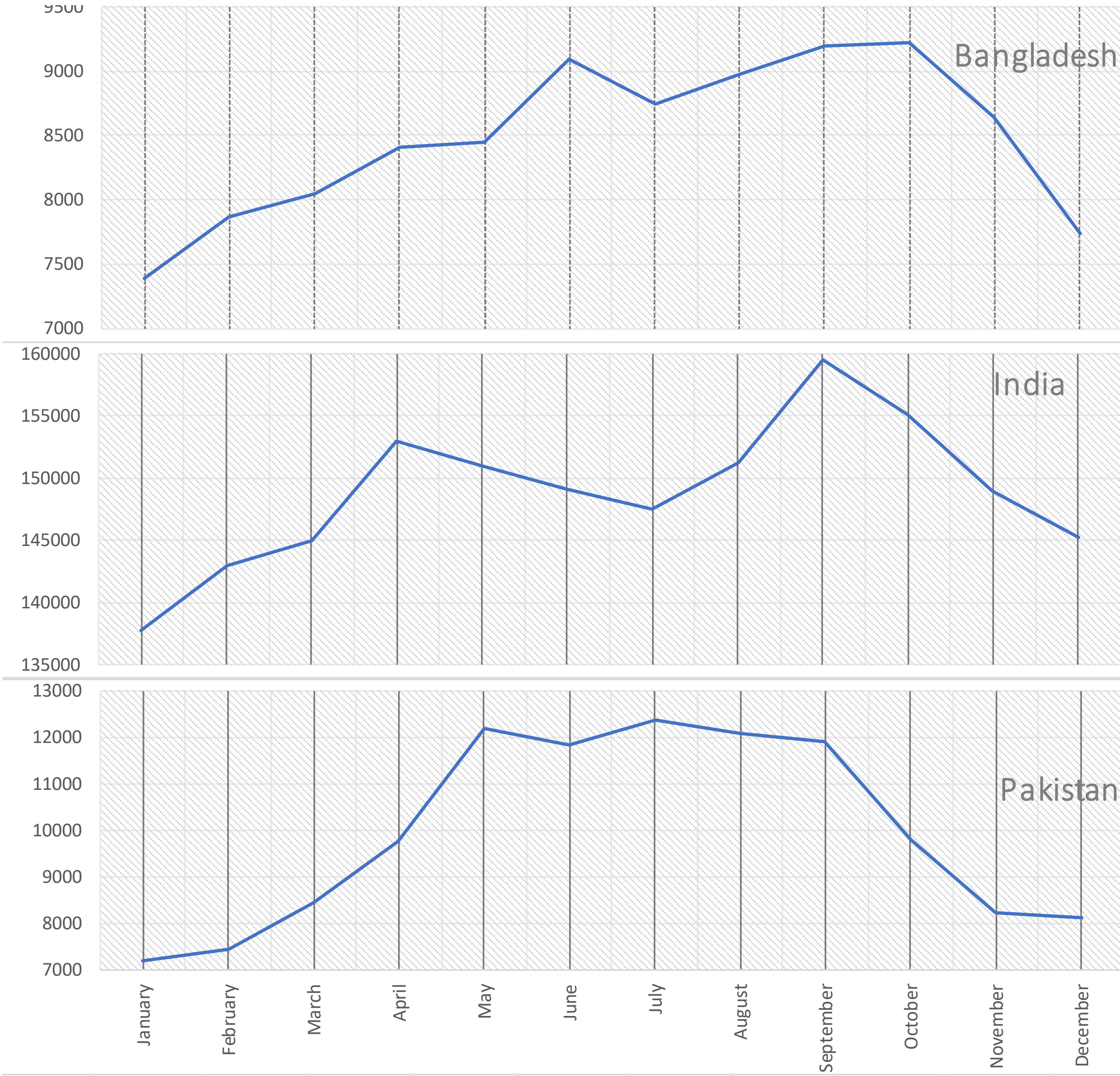

Figure 8. Monthly Load Curves of Bangladesh, India and Pakistan

Note and source: *India data are for 2016; Pakistan data are for October 2016 to September 2017. Bangladesh data refers to maximum load of 15th day of each month in 2017. Data for Pakistan are for generation instead of load, it, however, does not affect our analysis as we are interested on the shape of the curve instead of actual values, and shapes of generation and load curves are similar in Pakistan as its international electricity trade is negligible.*
Source: *CEA (2016, 2017) for India, BPDP website (http://www.bpdb.gov.bd/bpdb) for Bangladesh and online data base 'https://www.ceicdata.com/en/indicator/pakistan/electricity' for Pakistan.*

3.5 Role of Hydropower for Peak Load Management

One salient feature of connecting a hydropower dominant power system with a thermal power dominant power system is that it significantly helps manage peak loads in both systems, especially in the smaller system. The interconnection would significantly reduce the ratio of installed capacity to peak load in hydropower dominant power systems, such as Afghanistan, Bhutan and Nepal. In the absence of cross-border interconnection, total installed capacity to meet peak load in Nepal, for example, would be much higher not only because of low capacity factors of hydropower plants but also 'peaky' characteristics of some end-uses, such as lighting and cooking. Figure 9 illustrates the hourly load curve of Nepal for a typical day. The shape of the load curve is unlikely to vary much across days although the magnitude or height of the curve in each hour could be different. The curve shows that electricity demand around an hour in the evening (6 PM) is more than twice as high as off-peak hours (1-3 PM). This high peak demand is caused by lighting load. If electric cooking is promoted in Nepal, evening peak is likely to increase significantly as evening cooking hours also fall during the existing peak hours (6-7 PM). The load forecasts made by WECS (2017) under the policy intervention scenarios assume complete electrification of urban cooking. If that is the case, one can wonder how much extra capacity would be needed to meet the peak load. WECS (2017) shows that in the reference scenario (7.2% per year GDP growth), required installed capacity would double if water heating and urban cooking are electrified as compared to the situation not doing so. A very high and short peak load may not be a good indicator for a power system, especially when such a system is an isolated system (not connected with other grids). This type of peak load implies the requirement of large capacity which will not be utilized other times.

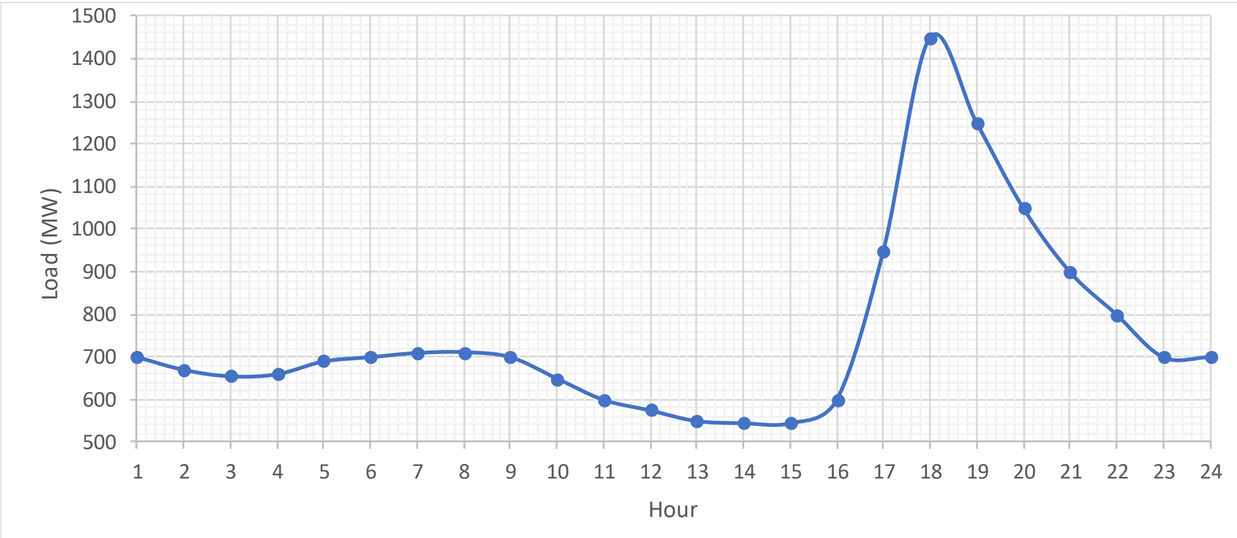

Figure 9. Hourly electricity load curve (MW)

Note: The curve is for a typical day in October in 2016.
Source. NEA (2017)

This type of sharp peaky load may not favor the economics of addition of expensive hydropower capacities into the system. In other words, an assumption of absorbing more and more hydropower internally by encouraging cooking may not be a sustainable policy for Nepal. If electric cooking is to be promoted, Nepal's power system needs to be further interconnected to a bigger system, like that of India. The better interconnection with the bigger system brings two benefits. First, addition of hydropower would not be needed to meet the peaky loads in Nepal because imported power from India could help meet those loads.[11] Second, even if hydropower capacities are added in Nepal to meet these loads, their economics would improve because the added hydropower plants would be running at all times as long as they are available to export electricity to India. Thus, cross-border interconnection would be further important and beneficial

[11] This benefit, however, may not be realized at present because India also has evening peaking.

when Nepal's own peak load increases further. This feature of cross-border electricity trading is often neglected while estimating capacity requirements to meet domestic demand in Nepal with an argument that Nepal's hydropower potential might be needed to meet its own demand in the long-run.

3.6 Reduction of Power Supply Costs Due to Hydropower in South Asia

Due to the five factors discussed above (exploitation of surplus resources, system flexibility, climate change mitigation, trade opportunity due to different load profiles and managing the 'peaky' loads) there would be a huge economic benefit of developing and trading hydropower in South Asia. The benefits do not occur only to hydropower exporting countries, but also to hydropower importing countries (e.g., India, Pakistan and Bangladesh) because imports of hydropower reduce their total electricity supply costs. Timilsina and Toman (2016) and Timilsina and Toman (2018) find that the South Asia region could save almost US$100 billion (2015 constant price) over the next 20 years (2020-2040) through unconstrained trading of electricity across the borders. While the benefits are the results of trading of electricity irrespective of its generation source, a closer look of these studies reveals that most of this savings is coming from hydropower development and trading.

4. How Much of Hydropower Potential Could Be Developed Due to Regional Electricity Trade?

This section presents projections of hydropower development and trade based on power system capacity expansion and a cross-border transmission interconnection optimization model. The details of the model including assumptions, data, scenarios and results are available in Timilsina and Toman (2016) and Timilsina and Toman (2018). The optimization model is first run for each South Asian country (i.e., Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan and

Sri Lanka) and the optimal mix of electricity generation capacity and electricity output from each type of capacity in each year for the 2015-2040 period is produced for each country ('Baseline' scenario[12]). In the next step, the model is run as if the entire South Asia is fully interconnected and there occurs free flow of electricity across the borders as driven by economics of power system expansion ('Regional Electricity Trade' or 'REG TRADE' scenario). Finally, a carbon tax with a rate of US\$10/tCO_2 during the 2020-2025 period, US\$25/tCO_2 during the 2025-2030 period and US\$ US\$30/tCO2 during the 2030-2040 period, is introduced on top of the full transmission interconnections across the borders in South Asia ('Regional Electricity Trade and Carbon Tax' or 'REG TRADE & CT' scenario).

The detailed results of the REG TRADE scenario are available in Timilsina and Toman (2016) and the detailed results of the REG TRADE & CT scenario are available in Timilsina and Toman (2018). We focus here on highlighting how hydropower development and trade would occur under those cases. The hydropower specific results presented here are additional to those available in Timilsina and Toman (2016, 2018). We also want to emphasize that while the findings reported here are for regional power trade across South Asia, Timilsina and Toman (2016, 2018) also investigated sub-regional power trade, in particular for the eastern sub-region (Bangladesh, Bhutan, India, and Nepal, abbreviated hereafter as BBIN). The findings are very similar, as discussed further below. This is reassuring since power trade among BBIN is more plausible in practice over the near to medium term than trade across the whole region.

[12] The baseline scenario includes existing and agreed but not yet started bilateral electricity trade specially between India and its northern and eastern neighboring countries (Bangladesh, Bhutan and Nepal). It also includes all power plants under construction or committed for construction through securing the necessary financing.

Figure 10 presents expansion of hydropower in South Asia under the baseline, REG TRADE and REG TRADE & CT scenarios by 2040. If electricity capacity expansion in South Asia follows the least cost planning approach,[13] the region will see 170.2 GW of installed hydropower capacity by 2040 in the baseline. Note that about 15 GW of already agreed bilateral electricity trade between India and Bhutan; about 1 GW of bilateral trade between India and Nepal and 0.5 GW bilateral trade between India and Bangladesh are part of the baseline. The baseline also includes the Central Asia and South Asia (CASA) transmission interconnection that brings 1,000 MW of hydropower from Tajikistan to Afghanistan and Pakistan. The hydropower capacity to be installed by 2040 in South Asia would be almost three times as high as the current capacity of 64 GW.

Under the REG TRADE scenario which assumes there are no cross-border transmission constraints and there does not exist any other barriers to cross border electricity trade, and capacity expansion and electricity generation follow the economic order, the South Asia region will see expansion of 72 GW of hydropower capacity as compared to the baseline scenario. Of the total addition, 52 GW would come from Nepal, 11 GW from India, 9 GW from Bhutan and 2 GW from Afghanistan. This result clearly shows that exploitation of most of hydropower potential in Nepal[14]

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[13] A least cost electricity capacity expansion planning approach identifies the optimal mix of electricity generation capacity for a given time horizon (here 2015-2040) stratifying set of constraints including technological, environmental and policy constraints. The mix of capacity and their merit order dispatching ensures that the capacity expansion plan supplies electricity at the minimum system cost. Please see Timilsina and Toman (2017) for more discussions.

[14] The export capacity demand in Nepal exceeds the economic potential of Nepal's hydropower resources, 43 GW. One could argue how could it be feasible to exploit the potential beyond its economic potential. We argue that the economic potential of Nepal's hydropower resources was estimated decades ago when electricity prices were very low and construction costs were very high due to lack of infrastructure development to access potential hydropower sites. Everything has changed since then and will continue to change by 2040 (the time horizon considered in this

and remaining hydropower resources in Bhutan[15] depends on regional electricity trade in South Asia. One would argue that the higher capacity available for trade in Nepal could be the result of lower capacity requirement projected by this study for meeting Nepal's domestic demand by 2040.[16] Even if WECS's (2017) reference case, that assumes 7.2% average annual GDP growth rate through 2040, is considered, Nepal would need 29 MW for its domestic demand. This means, the firm capacity available in Nepal for trade would be 32GW instead of 52GW. Note however that due to other flexibilities that the regional trade can bring, such as inframarginal trade possibilities, reserve sharing, peak load management discussed in the earlier section, the actual potential available in Nepal for trade by 2040 would be higher than 32 GW.

modeling exercise). Considering the availability of new technologies, increasing access infrastructure to potential hydropower sites and so on, the economic potential today would be much different as compared to that estimated two decades ago. Therefore, we did not stick with the available economic potential estimate. New studies are needed to assess the technical as well as economic potential of hydropower in Nepal and other South Asian countries to have a better measure of this resource's contribution to regional electricity supply.

[15] Note that half of the total technical potential of hydropower resources will be exploited under the existing bilateral electricity trade agreements between India and Bhutan (or in the baseline).

[16] Based on the 2010 electricity load forecast available when the model was run, the capacity requirement to meet Nepal's domestic demand was estimated to be 9 GW. This is certainly at the lower side, more recent study (WECS, 2017) shows that Nepal's domestic requirement would be 19 GW under the business as usual case (5% annual average GDP growth) and 29 GW under reference GDP growth scenario (7.2% annual average GDP growth).

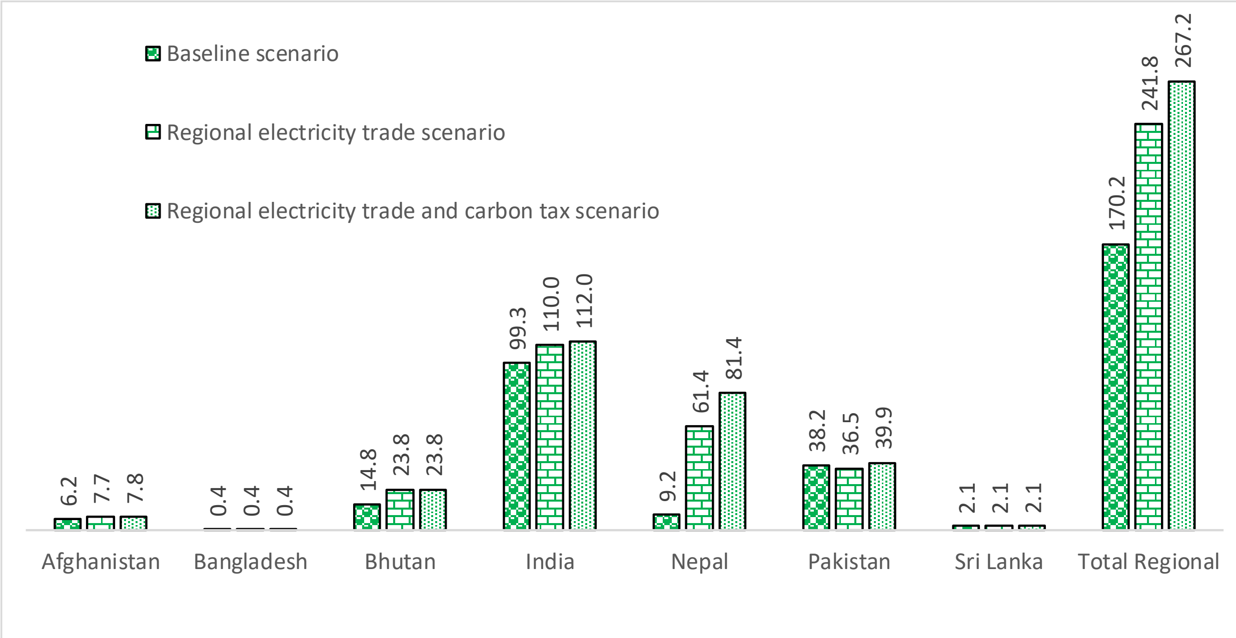

Figure 10. Exploitation of hydropower resources in South Asia under various scenarios in 2040 (GW)

If a carbon tax is considered to reduce power sector CO_2 emissions in South Asia along with the regional electricity trade (i.e., REG TRADE & CT scenario), the economics of power system expansion in the region changes significantly. Coal and gas would become more expensive as compared to hydro, and more hydropower plants would be economically attractive. This would result in a further expansion of hydropower capacities especially in Nepal. Another 20 GW hydropower on top of the capacity to be exploited under the REG TRADE scenario would be demanded from Nepal. Under this scenario, it would be basically the hydropower from Nepal to replace fossil fuels in other countries as the carbon tax does not add more hydropower in other countries except a total addition of 5 GW in India and Pakistan on top of the REG TRADE scenario. Almost the entire technical potential of 83 GW would be needed from Nepal under this scenario (10 GW for meeting the domestic demand or baseline scenario, 52 GW for meeting the export demand under the regional trade or REG TRADE scenario and 20 GW additional export demand due to the carbon tax under the REG TRADE & CT scenario). Even if Nepal's internal demand is as high as 29 GW as projected under the WECS's reference scenario, Nepal would still have a potential of exporting 53 GW.

Would these scenarios be realistic? If we look at the history of power sector development, especially the limited amount of cross-border electricity trade in South Asia to date, these scenarios may seem not to be plausible. However, if policy makers in the region realize the importance of untapped hydropower potential from economic, environmental, and climate change mitigation perspectives, and they move forward to enhance cross-border cooperation for cross-border electricity trade, then large-scale development of hydropower seems reasonable.

We also want to stress here that our analysis only indicates the maximum potential of hydropower that could be developed under a situation of full cooperation without any geopolitical or institutional hurdles among the South Asian countries. It does not mean Nepal's entire hydropower potential will be exploited by 2040. It only provides a picture of what might be possible if electricity trade and electricity system development in the region are expanded based on economic merits of competing resources. Obviously, there are a number of challenges to realizing such an outcome in practice.

However, one important finding of the study is that most of the hydropower development in the South Asia region due to regional electricity trade and carbon tax occurs in the eastern sub-region (BBIN). Although realizing electricity trade covering the entire South Asia clearly is challenging, the obstacles to realizing the benefits of developing available hydropower resources across BBIN seem much more manageable. Indeed, BBIN sub-regional level cooperation and trade is receiving more attention over the last few years (Lama, 2016).

Figure 11 presents hydroelectricity trade, particularly net exports from countries with surplus hydropower potential (e.g., Nepal, Bhutan and Afghanistan) to countries with higher demand (India, Pakistan and Bangladesh). Bhutan is estimated to export 1,160 TWh of hydropower to India in the baseline. Similarly, Afghanistan exports to Pakistan 238 TWh in the baseline. The regional electricity trade and carbon tax substantially expand hydropower trade in the region. Nepal is estimated to export 3,608 TWh of hydroelectricity to India during 2015-2040 under the regional trade scenario. Nepal's electricity export to India increases to 4,155 TWh when carbon tax is added on top of the regional electricity trade. Bhutan exports 1,702 TWh to India under the regional trade scenario, some of it would be diverted to Bangladesh due to cost advantage when carbon tax is introduced, thereby causing Bhutan's export to India under the REG-TRADE & CT scenario to be slightly lower than that in the REG-TRADE scenario.

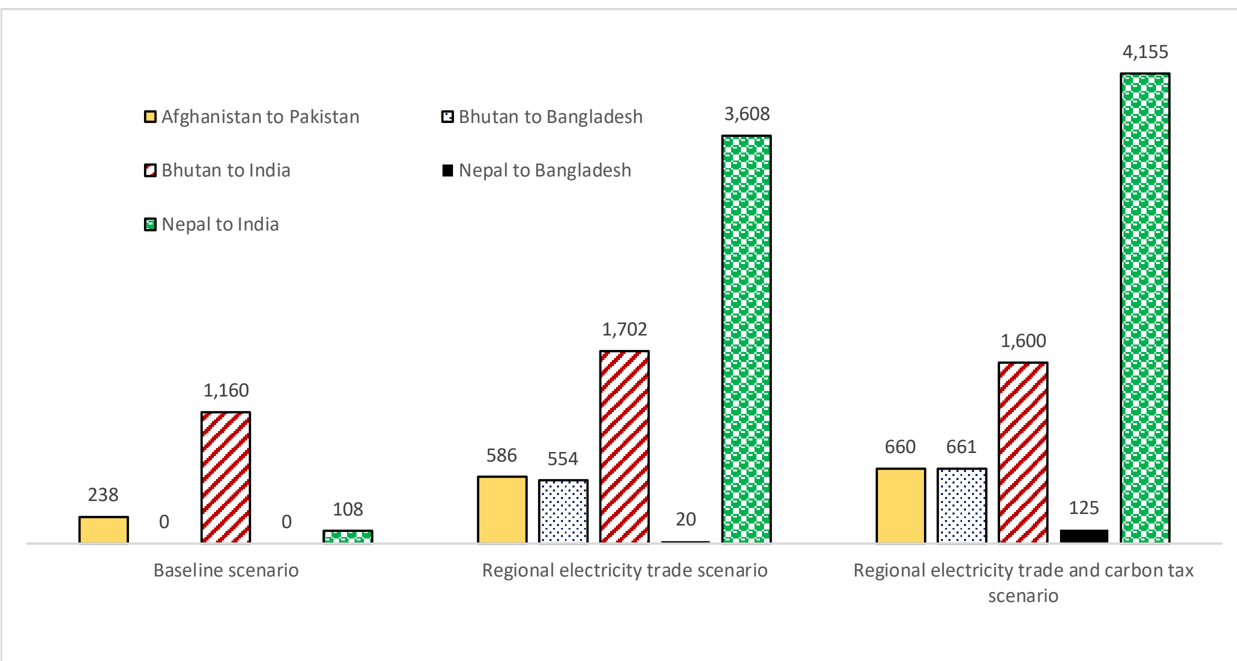

Figure 11: Cumulative hydroelectricity trade (net exports) during the 2015-2040 period in South Asia (TWh)

The monetary value of this electricity trade, especially for Nepal and Bhutan would be huge as compared to their economic output or GDP. At present Nepal is importing electricity from different parts of India with price ranging from Indian Rs. 3.98 to 6.45 per unit or kWh[17] (US$ 0.06 to 0.10), with a simple average price of US$0.08/kWh. If Nepal exports 3,608 TWh (or billion kWh) under the regional electricity trade scenario during the 2020-2040 period, it generates US$289 billion over that 20-year period at the 2018 price. This amounts to 10 times as much as Nepal's GDP in 2017. This estimate simply indicates how big would be the size of electricity export revenues for Nepal if regional electricity trade creates markets for Nepal's hydropower resources. Similar benefits would occur to Bhutan and Afghanistan although the magnitudes of their electricity export revenues would be smaller as compared to Nepal's. India will benefit in the similar way as its power supply costs reduce due to import of cheaper hydropower from neighboring countries.

5. Conclusions

South Asia is endowed with a huge potential of hydropower generation (> 350 GW) of which more than 80% is yet to be exploited. One of the primary reasons behind the limited exploitation of hydropower potential in the region is limited provisions to trade electricity across the borders. Among several possible factors, this study identifies six that are critical to promote hydropower development in South Asia through the expansion of regional electricity cooperation and trade. First, Afghanistan, Bhutan and Nepal would have surplus hydropower potentials even under highly optimistic scenarios on the growth of their domestic demand. Access to markets (i.e.,

[17] The Himalayan Times, March 29, 2018. https://thehimalayantimes.com/business/nepal-electricity-authority-renews-power-purchase-agreement-with-ntpc-vidyut-vyapar-nigam-for-15-months/

India, Bangladesh and Pakistan) is essential for the exploitation of this surplus capacity. Second, due to slow growth of domestic hydropower as compared to the growth of total generation capacity in India, hydropower from neighboring countries, especially from Bhutan and Nepal, is needed to provide flexibility in India's large power system. With the rapid increase of generation capacity based on intermittent resources (i.e., solar and wind), need for hydropower in India has increased further to balance the power system. The difference in monthly or seasonal load profiles across the countries provides an excellent opportunity to maximize utilization of hydropower plants, sharing the reserve margins and thereby lowering electricity supply costs. The regional electricity trade would help countries with peaky loads (e.g., Nepal, due to peak coincidence of lighting and evening cooking) to either avoid expansion of capacity to meet the peak load or improve the capacity utilization of the plants to be built to meet the peaky load in the absence of cross-border trade facility. Hydropower is one of reliable and economic options to reduce GHG emissions and thereby help Bangladesh, India and Pakistan to meet their climate change mitigation targets. Considering these factors, expansion of hydropower in the region through expansion of cross-border electricity trade would benefit each country in the region.

This study also shows that an unconstrained cross-border electricity trade provision would cause hydropower capacity to expand by 2.7 times over the next two decades. If a moderate carbon tax imposed to the power sector on top of the regional trading facility, current hydropower capacity will increase by more than threefold by 2040. The development of hydropower would cause large economic and environmental benefits to the region. The region will save almost a 100 billion dollars from its electricity supply costs over the next two decades through the substitution of fossil fuels with hydropower. Hydropower development stimulated through unconstrained regional electricity trade would help meet climate change mitigation targets of Bangladesh and India under the Paris Agreement.

The findings of the study should be interpreted with care. The estimations of the size of hydropower development and corresponding economic and environmental benefits over the next two decades under various scenarios merely indicate the potential. Considering the history of geopolitics in the region, the volume of cross-border electricity trade estimated here may not be realized within the next two decades. However, the study indicates, if political leadership shows strong will and strengthens the regional cooperation and electricity trade, hydropower could significantly contribute to economic development in South Asia.

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References

Ahlers, R., J. Budds, D. Joshi, V. Merme and M. Zwarteveen (2015). Framing hydropower as green energy: assessing drivers, risks and tensions in the Eastern Himalayas. Earth System Dynamics, Vol. 6, pp. 195–204.

Asian Development Bank (ADB), 2013. Islamic Republic of Afghanistan: Power Sector Master Plan: Technical Assistance Consultant's Report, # 43497, ADB, Manila.

Central Electricity Authority (CEA), 2018. Monthly Hydropower Review Report, March 2018. http://www.cea.nic.in/reports/monthly/hydro/2018/hydro_potential_region-03.pdf (Downloaded April 28, 2018).

Central Electricity Authority (CEA), 2017. The Load Generation Balance Report 2017-18, CEA, New Delhi.

Central Electricity Authority (CEA), 2016. The Load Generation Balance Report 2016-17, CEA, New Delhi.

Ceylon Electricity Board (CEB), 2017. Long Term Generation Expansion Plan 2018-2037, Draft Report, CEB, Colombo. http://www.pucsl.gov.lk/english/wp-content/uploads/2017/05/LTGEP_2018-2037.pdf

International Energy Agency (IEA), 2015. CO_2 Emissions from Fossil Fuel Combustion. 2015 Edition. IEA, Paris.

International Energy Agency (IEA), 2017a. Electricity Information 2017 Edition. IEA, Paris.

International Energy Agency (IEA), 2017b. Renewables 2017: Analysis and Forecasts to 2022. IEA, Paris.

International Hydropower Association (IHA), 2017. Hydropower Status Report 2017. IHA, London.

Lama, M. (2016). BBIN Initiatives: Options for Cross-Border Power Exchange. ORF Issue Brief, No. 137, April 2016. Observer Research Foundation (ORF), New Delhi, India.

Ministry of Energy and Water, Afghanistan (MEWA) (2017). Energy Sector Development Plans, Government of Afghanistan, Kabul. https://www.ekonomi.gov.tr/portal/content/conn/UCM/uuid/dDocName:EK-236901;jsessionid=P719f__iFOsLE0aXq5A_u_3qDWBBrhpp9Ee6T6pEGSORQQjrfJnH!-1930188290 (Downloaded on April 20, 2018).

Ministry of Planning, Development and Reform (MPDR), Pakistan. Annual Plan 2017-2018. Islamabad. http://www.pc.gov.pk/ (Downloaded on April 25, 2018).

Ministry of Power, India (MOP), 2018. Ministry of Power's Website. www. http://powermin.nic.in/

Nepal Electricity Authority (NEA). 2016. A Year in Review-Fiscal Year 2015/16. NEA, Kathmandu, Nepal.

Nepal Electricity Authority (NEA). 2017. A Year in Review-Fiscal Year 2016/17. NEA, Kathmandu, Nepal.

PricewaterhouseCoopers (PWC), (2014). Hydropower in India: Key enablers for a better tomorrow. https://www.pwc.in/assets/pdfs/publications/2014/hydropower-in-india-key-enablers-for-better-tomorrow.pdf

South Asia Regional Initiative for Energy Integration (SARI/EI) (2016). Impact of Cross-Border Electricity Trade on Bhutan (Country Series), Working Paper. SARI/EI, New Delhi. http://www.irade.org/Bhutan%20Working%20Paper.pdf (Downloaded on April 3, 2018).

SAARC Secretariat. (2010). Regional Hydropower Plants: Legal Opportunities in Bhutan and Nepal, SAARC Secretariat, Kathmandu.

Timilsina, G.R. and M. Toman (2016). Potential Gains from Expanding Regional Electricity Trade in South Asia. Energy Economics. Vol. 60, pp. 6-14.

Timilsina, G.R. and M. Toman (2018). Carbon Pricing and Cross-Border Electricity Trading for Climate Change Mitigation in South Asia. Economics of Energy & Environmental Policy, Vol. 7, No. 2, pp. 1-14.

United Nations Framework Convention on Climate Change (UNFCCC) (2015). India's Intended Nationally Determined Contribution: Working Towards Climate Justice. http://www4.unfccc.int/submissions/INDC/Published%20Documents/India/1/INDIA%20INDC%20TO%20UNFCCC.pdf (Downloaded on March 20, 2018).

Water and Energy Commission Secretariat (WECS), Nepal, 2017. Electricity Demand Forecast Report (2015-2040). WECS, Kathmandu. Nepal.

Water and Power Development Authority (WAPDA), Pakistan, 2011. Hydropower Potential in Pakistan, WAPDA, Islamabad.