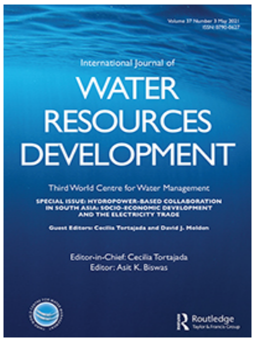

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The role of hydropower in South Asia's energy future

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ABSTRACT

With rising energy demand in Asia, the high potential for hydropower development and the need for low-carbon energy development, hydropower would seem to have a significant role in South Asia's energy future. However, the extent of hydropower development will depend on several risk factors, including the cost of alternative energy sources, the environmental sustainability of hydropower and social issues of equitable development. Using a risk-analysis framework, it is concluded that the future of hydropower will depend on how well policies and institutions manage the risks, facilitate efficient financial markets, and promote fair and friendly cross-border electricity trade.

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Sustainable hydropower; risks to hydropower; renewable energy; low-carbon energy; Hindu Kush Himalaya

Introduction

With economic development and a growing population, the demand for energy is rapidly growing in South Asia. At the same time, South Asia is threatened by climate change, and low-carbon energy development is needed to prepare for the future. As a low-carbon energy source with great development potential, hydropower would seem to have a significant role in this situation. How will that energy demand be met? What will be the role of hydropower in meeting that demand?

The answers to these questions are not obvious. Other low-carbon energy sources such as solar and wind energy are growing in importance. Hydropower construction is not easy or straightforward, especially in the Hindu Kush Himalaya. There are also questions about environmental and climate change impacts on hydropower, and conversely, the impact of hydropower development on the environment. There are questions about whether these environmental costs are significant, and if there is enough effort and planning to mitigate these negative impacts – some of which, such as flooding and sedimentation, might be exacerbated by climate change. In some political contexts, hydropower development is being questioned with respect to social equity. There are claims that hydropower development benefits cities and downstream populations more than the local people who bear the direct environmental consequences.

This paper analyses published studies on the future of hydropower, including papers developed for this special issue of the journal on 'Hydropower-Based Collaboration in

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South Asia: Socio-economic Development and Electricity Trade'. First, it examines the present energy mix in some South Asian countries, and the potential for hydropower development there. It then compares the cost of hydropower with other energy sources, especially solar energy, given the rapid decrease in the cost of solar. The study explores the financing of hydropower, and how its financial risks could be reduced. It then considers the social and environmental aspects. The key questions for the future of hydropower are as follows:

- How much of the region's hydropower potential is environmentally sustainable?
- How do you achieve social justice in hydropower development?
- Will hydropower be cost competitive compared with other sources of energy?

Finally, a risk-analysis framework is used to better understand the future of hydropower in South Asia. The argument is that the future of hydropower will depend on how financial, social, environmental and climate risks are handled. The means of addressing these risks is also described.

Current energy use and energy mix in South Asia

South Asia has not yet achieved access to electric energy for all its citizens, but this situation is changing fast. Within South Asia, the Bangladesh, Bhutan, India and Nepal (BBIN) subregion is the first to demonstrate cooperation in cross-border energy trade. At present, India imports power from Bhutan and exports it to Bangladesh and Nepal. In the future, the subregion expects to develop broader arrangements for cross-border electricity trade (CBET) based on grid interconnections, by which energy produced in Nepal and Bhutan can be sold in India and Bangladesh (Dhakal et al., 2019; Haran, 2018). Lessons from other regions that have developed grid interconnections are useful in South Asia (Vaidya et al., 2019).

Table 1 compares the countries in South Asia, except the Maldives and Sri Lanka, plus Japan and the United States. Of these countries, only Bhutan provides everyone access to electricity. Overall, electric power consumption is quite low compared with Japan or the United States.

The Hindu Kush Himalayan assessment report indicated that 80% of people in mountainous areas do not use clean energy such as biogas or electricity for cooking (Wester et al., 2019), but rather depend heavily on firewood and biomass. Certainly, to meet the

Table 1. Electricity consumption and access in South Asian countries.

Country	Access to electricity (% of the population), 2018	Electricity consumption (MWh per capita)	
		2014	2018[c]
Afghanistan	98.7	0.100[a]	n.a.
Bangladesh	85.2	0.320	0.5
Bhutan	100	2.799[b]	n.a.
India	95.2	0.805	1.0
Nepal	93.9	0.146	0.2
Pakistan	71.1	0.448	0.6
Japan	100	7.820	8.0
United States	100	12.994	13.1

Sources: World Bank (2020), except for: [a]ADB (2015); [b]NSB (2017, tab. 9.8); and [c]IEA (2020).

Sustainable Development Goals, access to more clean energy for more people will be important.

It is important to note that South Asia is not only energy poor but water stressed and food deficit, a clear indication of all the progress that is needed in comprehensive policy-making to improve resource management (Rasul et al., 2019). While the objective in the region is to provide access to electricity for domestic and industrial uses, the quality of life of the population must also be improved through better water and food security.

At present, different countries in South Asia have different energy sources for electricity. Bhutan and Nepal rely mostly on hydropower for electricity. In Bangladesh, India and Pakistan, fossil fuels are still an important energy source (Table 2). With pressure to reduce the dependency on fossil fuels because of climate change, and with more cross-border trade and cheaper renewable energy sources, the mix of energy sources is likely to change in the future.

The undeveloped hydropower potential of South Asia is striking. As of 2019, Afghanistan had developed only 1% of its hydropower potential, Nepal 3% and Bhutan 10% (Table 3). There are questions about the real potential, and whether all of it could really be developed. Looking only at the supply side, it seems that there is scope for more hydropower development. However, this will be achieved only through cooperation between the countries (Haran, 2018). Historically, a vision for the development of the region has been lacking (England & Haines, 2018; Pakhtigian et al., 2019). But in any case, hydropower is a development opportunity for millions of people living in South Asia.

Table 2. Sources of electricity generation in South Asian countries, 2017 (percentage of total electricity generation).

	Total electricity generation (GWh)	Combustible fuels (%)	Hydro (%)	Nuclear (%)	Wind (%)	Solar (%)	Other sources (%)
Afghanistan	1098	15.3	84.7	–	–	–	–
Bangladesh	73,158	98.3	1.4	–	[a]	0.2	–
Bhutan	7730	0	100	–	[a]	–	–
India	1,490,293	81.7	8.5	2.6	2.6	1.7	3.0
Nepal	4639	–	99.8	–	0.1	[a]	–
Pakistan	123,533	66.7	26	5.6	1.2	0.5	–

Notes: [a]Less than 0.05%.
Other sources: geothermal, tide, wave, marine, electricity from chemical heat, and other non-specified sources. Percentages are rounded and may not add up to 100.
Source: UN (2017).

Table 3. Potential and installed hydropower capacity in South Asian countries.

Country	Potential capacity (MW)	Installed capacity (MW) (various years)	Installed capacity as a percentage of potential capacity (%)
Afghanistan	23,000[a]	333 (2019)[b]	1
Bangladesh	1897[c]	230 (2018)[d]	12
Bhutan	23,760[e]	2334 (2019)[f,g]	10
India	148,701[h]	50,411 (2020)[i]	34
Nepal	42,915[j]	1129 (2019)[k]	3
Pakistan	59,796[l]	9900 (2019)[b]	17
Total	300,273	64,337	21

Sources: [a]MEW (2015); [b]IRENA (2020b); [c]Halder et al. (2015); [d]BPDB (2018); [e]IHA (2020); [f]NSB (2017); [g]*Economic Times* (2019). [h]CEA (2016); [i]CEA (2020); [j]WECS (2002); [k]NEA (2019); and [l]PPIB (2011).

Risk-analysis framework for sustainable hydropower

This paper uses a risk-analysis framework to explore various issues related to the future of hydropower development (Figure 1). The rate of return required by investors in a hydropower project, or the cost of capital, depends on several risks specific to investments in hydropower, besides the market, currency and sovereign risks that investments in other sources of energy may also face.

These risks have to do with environmental and climate risks, such as glacial lake outburst floods (GLOF), high streamflow variability and sediment load changes. It is recognized here that hydropower faces environmental challenges, especially in the light of climate change. These risks are associated with uncertainty in future climate projections due to their coarseness and assumptions about non-climatic factors, such as population dynamics, technologies, land use, economic changes and political uncertainties (IHA, 2019; NDRI, 2017; Ray et al., 2018; Ray & Brown, 2015).

Ray et al. (2018) assessed multidimensional risks (such as climate change, natural hazards, including earthquakes, and financial risk) to investments in hydropower projects, and noted the importance of considering multiple uncertainties together. Some hazards result in cascading events. For instance, earthquakes often trigger landslides, which severely damage hydropower plants (Schwanghart et al., 2018). It is therefore essential to evaluate both the natural- and human-induced uncertainties associated with hydropower projects, as compared with other energy sources, to gain an understanding about its competitiveness.

Conversely, hydropower development also affects the environment, which is a deep concern in terms of sustainability and societal values. The social acceptability of hydropower is in question in many different settings, often related to its environmental impacts, and for hydropower to be viable these concerns need to be addressed. Social risks also

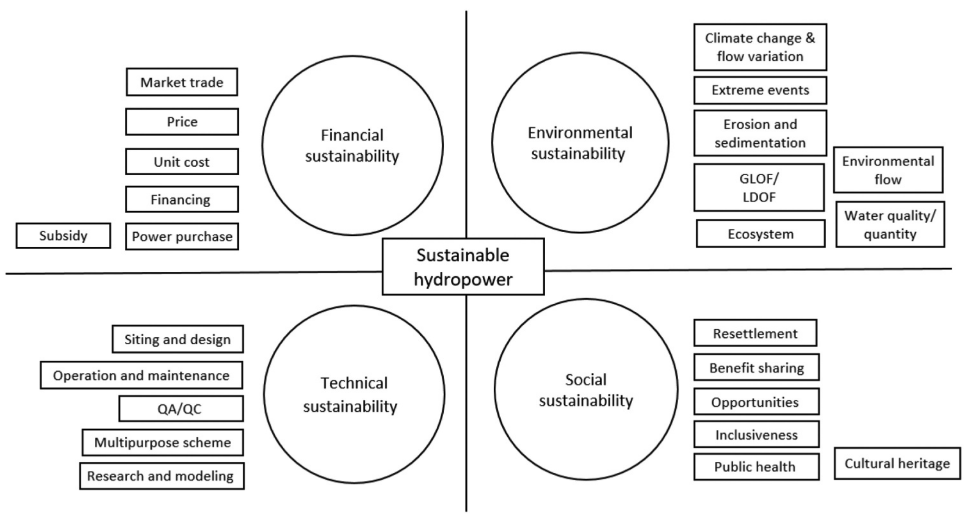

Figure 1. Framework for the risk analysis of sustainable hydropower.
Note: Governance plays an underpinning role in all the components of the framework. GLOF, glacial lake outburst floods; LDOF, landslide dam outburst floods; QA/QC, quality assurance and quality control process.
Source: Authors.

include disagreements over benefit-sharing, local as well as upstream versus downstream. Mitigating these risks can help reduce the cost of capital.

Improvements in the siting and design of power plants could also help. (However, this paper does not discuss the details of technical sustainability.) And the competitiveness of hydropower can be increased by promoting cross-border trade in electricity, which will help system efficiency because of seasonal and diurnal complementarity in production and demand. Governance plays an underpinning role in all the components of the framework.

Eventually, the risk a project faces determines the competitiveness of the electricity it generates. First, the returns required by investors in a power project depend primarily on the level of risk of the project. The higher the risk, the higher will be the rate of return required by the investors. Second, the higher the cost of capital, the higher will be the generation cost of the power plant and the price at which it can deliver a unit of electricity to the marketplace, thereby lowering its competitiveness. The various risks specific to hydropower and mitigation measures to these risks for the long-term viability of hydropower will be discussed in detail.

Environmental sustainability

While hydropower is a clean and renewable source of energy, there are environmental challenges to its long-term sustainability (Figure 1). Extreme events such as GLOFs, floods, landslides and climate-induced variation in the hydrological regime pose threats to hydropower projects (Pokharel, 2001) by shortening their useful lifetime (Ray et al., 2018) and reducing production capacity (Bhatt, 2017). Glacial hazards, for example, can threaten the safety of hydropower dams (International Hydropower Association (IHA), 2019). Stream flow variability is expected to increase with climate change, bringing too much water in the wet season and too little water in the dry season. Hence, hydroelectric projects are highly vulnerable to such hydrological variabilities (Ray et al., 2018) and to uncertainties associated with the projections from the general circulation models (GCMs). Flow variations impact the operation and energy production of hydropower projects. Erosion and sedimentation can also threaten hydropower projects by compromising dam safety and reducing reservoir storage capacity, thus limiting energy production and flood attenuation.

Many hydropower projects have already been harmed by environmental events. For instance, the 1985 GLOF in Dudh Koshi (International Centre for Integrated Mountain Development (ICIMOD), 2011), the 2015 earthquake, the 2014 Jure landslide (Bhatt, 2017) and the 2013 Uttarakhand floods (Satendra et al., 2014) damaged hydropower plants in Nepal and India. From 1982 to 2004, sediment took up more than 21 million m^3 of the reservoir storage (about 25% of capacity) of Kulekhani I in Nepal (Sangroula, 2006); of this, about 5.1 million m^3 (about 6% of capacity) were deposited during the 1993 cloudburst event (Dhital, 2003).

Future climate change is projected to increase hydropower production in some parts of the world and reduce it in other parts, ranging from −8% to 5% under the RCP8.5 emission scenario (Turner et al., 2017). Projections for the Hindu Kush Himalaya suggest higher annual and seasonal flow, with potential for greater hydropower generation (Bajracharya et al., 2018). But Shrestha et al. (2016) projected mild to moderate risk in future energy production under two baseline conditions (1963 and 2281 GWh) for the

Upper Tamakoshi Hydroelectric Project in Nepal, where energy production was projected to decrease by 0.69–13.4% when using the three GCMs under two emission scenarios of RCP4.5 and RCP8.5. Similar results were reported by Shrestha et al. (2020) for the Kulekhani Hydroelectric Project in Nepal. Therefore, the impacts of climate change have to be examined on a case-by-case basis.

The future projections are also associated with uncertainties, largely due to uncertain greenhouse gas (GHG) emissions and level of climate change in the future and large variations projected from the climate models (Nepal Development Research Institute (NDRI), 2017; Ray & Brown, 2015). Hence, a robust approach is required to address the uncertainty and its potential impacts on infrastructure planning (Ray & Brown, 2015). This could be carried out either through a top-down approach, where a future projection is fed into a hydrological model to quantify the future impacts in considering potential adaptation responses, or by a bottom-up approach, which uses climate risk assessment (CRA). The CRA assesses the sensitivities of present and future hydropower systems' performances to future climate change and its impact ('stress test') and includes active stakeholders' involvement in the decision-making process (Ray & Brown, 2015).

For the sustainability of hydropower in the region, it is important to minimize environmental threats and also consider the possibility of taking advantage of some of the related changes. Recently, the International Hydropower Association (IHA) prepared guidelines on how sustainability factors should be defined and measured in the hydropower sector (IHA, 2018), along with guidelines on climate-resilient projects (IHA, 2019). This latter document suggests mitigating risk through both structural (e.g. sediment settling basin, erosion protection works) and non-structural measures (e.g. legal instruments, operating rules).

Table 4 lists some of the challenges, their impacts and possible mitigation measures. It summarizes three major challenges to and three from hydropower projects. On challenges to hydropower projects, first, on climate change and flow variability, to address flow variation due to climate change, an analysis of the availability of water resources in the short- and long-terms under different climate change scenarios should be carried out using available tools, from regression models to hydrological models, during the planning and operation phases. For the analysis of future water availability, the uncertainties associated with future projections also need to be considered. For major storage projects, flow data for up to 25 years are required to inform project design (IHA, 2018).

Second, on extreme events, the impact of geohazard-induced floods, such as GLOFs and landslide dam outburst floods (LDOF), can be minimized by estimating the potential flooding and making appropriate design adjustments. Possible adaptation measures include glacier monitoring (and designing corresponding operational changes) and changing the dam type to allow overtopping. For intense rainfall-induced floods, probable maximum flood (PMF), standard project flood (SPF), and floods with return periods up to 10,000 years should be calculated and considered along with other aspects, such as national requirements, reservoir size, hydraulic head, including potential downstream and operation risks (IHA, 2018). Considering extreme weather events, along with the reinforcement of steep slopes and early-warning systems for natural hazards, could make the project sustainable (Tang et al., 2013). Depending on the nature of the risks and their impacts, non-structural measures can be implemented where costly engineering

Table 4. Environmental challenges to and from hydropower projects.

Challenge	Impacts	Mitigation measures
Challenges to hydropower projects		
1 Climate change and flow variability	Energy production	Climate trend and projection; water availability analysis; climate risk screening; design/location considerations
2 Extreme events (rainfall-induced flood/LDOF, GLOF)	Damage to infrastructure; reduction of storage	Design based on flood estimation (probable maximum flood (PMF), standard project flood (SPF)); monitoring glaciers and the potential impact of GLOFs; design considerations; site selection; adjustments in plant operation
3 Erosion and sedimentation		
Sedimentation	Damage to plant components; reservoir capacity reduction	Sediment flushing, dredging, bypass, slope protection works, cement lining; catchment management
Bank erosion	Damage to plant components	Slope protection, bioengineering
Challenges from hydropower projects		
4 Environmental flows	Altered flow downstream; change in river morphology	Objective assessment of environmental flows; maintain environmental flows, operating rules
5 Water quality	Heavy metal contamination; turbidity; higher water temperatures	Treatment facilities; drainage collection, storage facility; flow management, bank protection
6 Ecosystem	Impact on aquatic species; harm to native flora and fauna; interference with migration	Increase minimum flow requirements for species or ecosystem of interest; fish ladders; site location

Notes: GLOF, glacial lake outburst floods; and LDOF, landslide dam outburst floods.
Sources: AECOM (2012); Bhatt (2017); Botelho et al. (2017); Chen et al. (2015); ERM (2018); IEA (2000); IHA (2018, 2019); NDRI (2017); Schellenberg et al. (2017); Tang et al. (2013); and Wang and Hu (2009).

structures are not mandatory. For instance, during likely flood periods the reservoir level can be lowered to prevent flooding and protect populations downstream, or operating rules can be changed to allow sediment to pass (NDRI, 2017). For such smart operations reliable climate and weather services and flow forecasting systems are essential.

Third, on erosion and sedimentation, sediment accumulation limits the benefits of hydropower plants. Heavy sediment load and debris may block dam spillways, damage important structural components (e.g. turbines), and reduce the storage and power generation in the medium and long terms. Sediment reduces the reservoir's storage capacity, leading to reduced lean-season energy generation (NDRI, 2017). In Nepal, on a single event on 31 July 1996, 24,400 parts per million sediment concentration passed through the turbines of Jhimruk Hydropower Plant (Water and Energy Commission Secretariat (WECS), 2011); and Kali Gandaki-A has lost about 50% of its pondage capacity in 10 years of operation. All three turbines of Kali Gandaki-A were replaced after the first few years of operation because of their wear and tear due to high sediment loads (NDRI, 2017). Therefore, sediment management must be incorporated in all phases of the project cycle (Schellenberg et al., 2017). The pattern and distribution of sediment deposition needs to be predicted and planned for so that mitigation/management measures can be designed. The measures could include sediment flushing, bypass, slope protection works or cement lining (IHA, 2018). Flushing, dredging and releasing turbidity have been successfully practiced in the Three Gorges project on the Yangtze River in China (Wang & Hu, 2009). However, remedial measures such as dredging are a very costly last resort (AECOM, 2012; NDRI, 2017).

Furthermore, riverbank erosion can be mitigated by natural bank protection using bioengineering techniques near the project area. A holistic, basin-wise approach is needed to manage erosion and sedimentation. Some of the opportunities that can be highlighted are proper land-use planning (e.g. retention of forest cover); use of new technologies; improved land-use practices, such as crop rotation, crop choice and modified ploughing techniques; and partnerships with the community to maintain the upstream environment (IHA, 2018).

Given the long-intended life of power plants, and their vulnerability to climate impacts, hydropower projects must be developed, operated and maintained to be resilient to a range of climate change scenarios (IHA, 2019). According to the IHA (2018) guidelines, climate risk screening, climate trend projections, climate stress tests, and risk-management plans and monitoring may be needed, depending on the project type. Extreme events and their associated uncertainties also need to be considered.

On top of all the challenges hydropower projects may face, they also can cause their own environmental impacts, which can compromise their sustainability. Some of the environmental issues related to hydropower are changes in land use, degraded water quality (mainly during construction), changes in river flow pattern and reduced flow, fluctuation in river flow due to the sudden release of stored water (e.g. hydropeaking), and changes in sediment transport patterns (Bhatt, 2017; Chen et al., 2015; International Energy Agency (IEA), 2000). In some cases, local ecosystems (mostly aquatic) and riparian biodiversity are affected (Botelho et al., 2017; Chen et al., 2015). The nature and extent of the impacts strongly depend on site characteristics and the type and dimensions of the plant (Bhatt, 2017; Botelho et al., 2017).

Next, the three major challenges from hydropower projects to the environment are summarized in Table 4. First, environmental flows can be maintained based on rules governing releases to limit alterations to downstream flow, along with off-river water storage (IHA, 2018). The effectiveness of such measures must be carefully monitored and promptly improved.

Second, water quality in the project site during construction can be improved by treatment facilities and a well-designed drainage-collection system; storage facilities for oil, fuel and chemicals also need to be in place. Increased turbidity during hydropeaking and aggressive river effects can be mitigated by ramping rules, flow management and bank-protection works (IHA, 2018).

Finally, on the ecosystem, to minimize the risk to aquatic species, the construction of fish ladders is important. Some impacts on flora and fauna can be mitigated by reducing noise, limiting vehicular movement and increasing awareness (Environment Resource Management (ERM), 2018).

To minimize these environmental impacts of hydropower, protective measures are required (Chen et al., 2015), along with resilient hydropower infrastructure (Bhatt, 2017). Major steps include an environmental impact assessment (EIA) for predicting and quantifying potential impacts, the identification of protective measures, and the development of a management plan for minimizing the negative impacts and maximizing the benefits (AECOM, 2012). For example, hydropower-specific EIA guidelines recently developed by the Ministry of Forests and Environment of Nepal (MoFE) (2018) provide better assessment and mitigation strategies, along with guidance on good practices. The guidelines cover assessing the environmental risk and impact, identifying opportunities and management strategies, focusing on resources, recognizing stakeholders, and informing decision-makers. Regarding climate, the guidelines mention the need to evaluate the relevant climate change impacts and recommend climate screening. A thorough EIA is crucial in making hydropower projects sustainable. The National Water Plan of Nepal mentions the need to promote research and studies on 'existing dam structure and climate change and its impact on the environment' (WECS, 2005, p. 26).

Furthermore, when appropriate, environmental risks can be reduced by developing small-scale hydropower (Ogino et al., 2019). This approach can be adapted to the local landscape and meaningfully aligned with local processes of recuperation and repair after disasters, as seen in Langtang, Nepal (Lord, 2017). But the cumulative impact of the small-scale projects that would be needed to generate the desired amount of energy must also be assessed.

Finally, on the mitigation measures to challenges to hydropower projects, first, the hydropower sector may benefit from some of the environmental changes that are now happening or are likely in the future. A comprehensive analysis of future water availability could even expand hydropower potential if design adjustments can be made accordingly. Bajracharya et al. (2018) analysed the climate change impact on river discharge and hydropower. For this they used the Soil and Water Assessment Tool (SWAT) for future changes in the hydrological regime based on two scenarios (RCP4.5 and RCP8.5) of the ensemble downscaled Coupled Model Intercomparison Project's (CMIP5) GCM outputs. The results suggest that future discharge is unlikely to decrease during the 21st century, and dry season flow might increase by 20–35% by 2090 in the Kali Gandaki basin, and run-of-river hydropower plants could greatly benefit. However, there is uncertainty in the projection of future temperature and precipitation more towards the end of the century.

Second, some approaches can be more sustainable in the long run. Multipurpose water resource development projects could be more cost-effective than hydropower-only projects. Amjath-Babu et al. (2019) analysed the sustainability of water resources development projects – hydropower, irrigation and flood control – in the Koshi basin under climate change and reported that storage dams would reduce flood losses in downstream areas by 27%. There could also be benefits for water supply, navigation, introduction of industrial units, expansion of agricultural area, and recreation and tourism revenue generation (Bhatt, 2017; Chinnasamy et al., 2015).

In addition to reservoir storage, pumped-storage hydropower (PSH) schemes could also be a viable alternative for balancing energy resources. Reduced environmental impacts and minimal environmental review, minimum aquatic interaction, no requirement for flood control and a minimum construction period (two to four years) are some of the benefits associated with closed-loop PSH systems. PSH represents 96% of the installed energy storage capacity worldwide (169 out of a total of 176 GW) (IRADe, 2020), with China alone accounting for 32 GW (IRENA, 2018). It is, however, a negative energy source; hence, the input power cost of pumping operations needs to be minimized to make such plants viable (IRADe, 2020).

Third, the integrated river basin approach, which considers the river basin as a single unit for planning, can support sustainability, as it is fundamental in considering various environmental risks along with social and financial components of the project. Projects in one part of the basin will affect those in other parts, so a holistic basin approach is necessary (Rao & Prakash, 2015). Shifting from the project to the basin approach would help foster close coordination and consensus among the wide range of stakeholders for sustainable and equitable project development at various stages. Energy production can be optimized through cascade projects (e.g. two adjacent projects on the Alaknanda River in India are likely to increase annual energy production by 230 GWh). Better collaboration in the construction of infrastructure, such as roads and transmission lines, can reduce both project and environmental costs (Haney & Plummer, 2008). The basin approach can help leave river corridors of high spiritual and environmental significance untarnished, while other river corridors are intensively used. To this end, cumulative impact assessment is a step forward because it considers the overall environmental and social impact of multiple hydropower projects in a basin, sub-basin or river corridor (International Finance Corporation (IFC), 2013). This supports selecting the optimum combination of projects and sites, or multipurpose projects, for minimizing the total impact (Haney & Plummer, 2008).

In addition, a basin perspective on hydropower development can address some of the concerns regarding environmental flows. Understanding and implementing environmental flows requires a basin perspective. From a basin perspective, it may make sense to leave part of the river system free flowing to maintain aquatic ecosystem services. Unfortunately, the basin perspective is often ignored, and piecemeal approaches dominate based on other factors, such as an ideal location for a single hydropower plant, or a consideration of who has the licence to develop hydropower.

In summary, for the sustainable development of hydropower in South Asia, mitigation measures for managing risks due to environmental challenges to hydropower are just as important as those for managing challenges from hydropower to the environment. An integrated river basin approach to planning for hydropower projects would help to enhance their benefits to hydropower projects and to the environment, for example, by optimizing energy production through cascade projects, or by leaving a part of the river free flowing for sustaining aquatic ecosystem services. Hydropower-specific EIAs and recommendations for protection measures should be complemented by the design of time-bound plans and institutional mechanisms for their implementation as well as budgetary commitments. In the context of climate change and its impact on intra- and inter-annual variability in water availability, a comprehensive analysis on how much water is going to be available in the future is necessary, and appropriate multipurpose projects need to be planned prudently.

Social sustainability

In addition to environmental challenges, there are social challenges to the sustainability of hydropower (Figure 1). A lesson learned from large-scale water infrastructure is that social justice, real and perceived, is a critical concern for hydropower development. An important issue is who benefits from hydropower development, and if there are any direct or indirect disbenefits to local communities, including differential impacts on women and men. For better design and a clear understanding of all aspects of hydropower, a participatory approach is required, engaging all stakeholders actively to design the rules of the game, right from the inception of planning and design of the project (Molden et al., 2014). The recent introduction of the concept of 'free, prior and informed consent' (FPIC) in hydropower projects is a step in this direction. For example, in the

216 MW Upper Trishuli – 1 project, a tripartite negotiation between the representatives of the local community (constituted through a self-selection process), the power company (Nepal Water and Energy Company) and the lenders, including the International Finance Corporation (IFC), resulted in a consent statement in November 2018 supported by a framework agreement on indigenous peoples' demands and a tripartite agreement for its plan implementation. The plan is expected to be executed by a fully functioning governing board (NEFIN, 2019; World Bank & ESMAP, 2020).

Benefit-sharing

In many South Asian contexts, communities and civil society have expressed loudly and clearly their concerns about the environmental and social impacts of hydropower. These include the notion that local people are not receiving the benefits of hydropower, but have to bear the social and environmental costs, including land degradation, water quality issues and changes in their cultural landscape. To make hydropower more politically feasible, such concerns need to be heard, and open communication is essential. There is also concern that EIAs are not performed rigorously. Resettlement will almost always be a contentious topic. One measure to mitigate these social concerns is benefit-sharing, where the local people receive a fair share of the benefits of hydropower development.

Local scale

At a local scale, a common concern of local communities is that hydropower development largely benefits people living downstream of the project site, while the local community faces most of the social and environmental costs (Molden et al., 2014).

Project proponents can make systematic efforts to sustainably benefit local communities affected by hydropower investments. A World Bank guidebook states that 'benefit sharing is a promising approach for implementing hydropower projects sustainably, and is emerging as a supplement to the requirements of compensation and mitigation' (World Bank, 2012, p. v).

The International Centre for Integrated Mountain Development (ICIMOD) has conducted local benefit-sharing studies of hydropower projects in India (Arunachal Pradesh, Himachal Pradesh and Sikkim), Nepal and Pakistan (Upper Indus). The Nepal study has already been published (P. Shrestha et al., 2016). It identifies three major characteristics of local benefit-sharing. First, the 'royalty' mechanism in the laws of Nepal serves as a basic legal framework for local benefit-sharing. In this mechanism, the government transfers 12% of the royalties generated by the hydropower plant to the district where the plant is located (Karky & Joshi, 2009). Second, the practice of setting aside a certain portion of equity securities for local people is a unique practice in Nepal. The report claims that 'to the best of our knowledge, none of the other countries in the region have similar instruments for allowing local people to participate in hydropower programmes as equity investors' (P. Shrestha et al. 2016, p. 43).

In spite of the best efforts of the hydropower company and the government to make provisions for local benefit-sharing, some communities in the project area may lose out, especially the midstream communities. Suhardiman and Karki (2019) present an interesting analysis of the planned Upper Karnali Hydropower Project. The local benefit-sharing plan included provisions for revenue-sharing in the form of royalties, equity share offers, rural electrification, and industrial and employment benefits. But there was no provision for livelihood improvements for midstream communities, or rather compensation for harm to their livelihoods. This was not considered because of power plays between the three parties: upstream communities; downstream and midstream communities; and the power company (Suhardiman & Karki, 2019).

National scale

Between countries, a sense of equity in benefit-sharing is often a major concern; the country producing the power may feel that it is getting an unfair deal from the country consuming it. To provide an environment conducive to a free flow of electric power, when the economies of the two countries are very different in size, an analysis of the macroeconomic impact of a project on each country may not give a true picture; the impact on the economy of the country with a large economy will obviously be small. It might be necessary to conduct a microeconomic analysis of the distribution of net economic benefits of the project to the two countries.

In South Asia, such a study has been conducted on power exports from Bhutan to India from its Chukha hydropower project (Dhakal & Jenkins, 2013). The project was built with an Indian investment of US$404 million, 60% as a grant and 40% as a loan at 5% interest. As of 2008, Bhutan had received US$636 million in cumulative revenues since the commencement of the project. The Bhutanese people also benefitted in terms of better access to electricity. India benefitted by importing electricity more cheaply than it could have been produced in India. The import price was renegotiated in 2005 at INR2/kWh of electricity, equivalent to US$0.051/kWh at the prevailing exchange rate in 2008. When all the benefits and costs were accounted for, the distribution of net economic benefits to Bhutan and India was 48–52% (Dhakal & Jenkins, 2013).

Basin scale

At a basin scale, to facilitate the development of multipurpose water infrastructure projects, institutional arrangements have to be made for benefit-sharing – and sometimes cost-sharing – between upstream and downstream communities affected by the projects (Molden et al., 2014). ICIMOD estimated the benefits of proposed water infrastructure projects in the Koshi River basin for hydropower generation, farm production and flood-damage reduction. Simulation runs show that 'the Bihar plains downstream in India receive by far most of the water compared with the Nepalese mountains, mid hills and plains, and are hence the largest beneficiaries' (Amjath-Babu et al., 2019, p. 499). In the baseline scenario, the estimated annual benefits in 2010 US$ of US$2.3 billion were much higher than the estimated annual costs of US$0.68 billion for the 11 hydropower projects, at an initial investment of US$12.5 billion. Hydropower (11 projects in the Nepal part of the basin, of which four are of a storage type) contributed 61% and 57%, respectively, of the total benefits in the baseline and future climate – RCP (Representative Concentration Pathway) 4.5 – scenarios (Table 5).

These results are consistent with those of the World Bank's study in the much larger Ganges basin, of which the Koshi is a sub-basin (Wu et al., 2013). It found that hydropower (23 projects in Nepal, including three large storage types) contributed 56%, 67%, 67% and 95% to the total economic benefits in the Ganges basin, under a combination of assumptions about the value of water for irrigation (US$0.01–0.10/$m^3$) and the value of low flows

Table 5. Estimated economic benefits of water infrastructure projects in the transboundary Koshi River basin.[a]

	Benefits in the baseline scenario		Benefits in the future climate scenario	
	US$ billions per year	%	US$ billions per year	%
Hydropower generation	1.39	61	1.39	57.3
Additional crop production	0.82	36	0.95	39
Flood control	0.07	3	0.09	3.7
Total	2.28	100	2.43	100

Note: [a]Benefits are estimated in 2010 US$.
Source: Amjath-Babu et al. (2019).

to Bangladesh (US$0.01-0.10/m^3). These results are not very different, especially the first three, to those of the ICIMOD study, which found 57% and 61% for its two scenarios under a slightly different set of assumptions (e.g. the value of hydropower as US$0.06/kWh compared with US$0.10/kWh in the World Bank study). The last one, a 95% contribution of hydropower, appears unrealistic because it assumes low values for both low flows (0.01) and water for irrigation (0.01).

Social risks often cause long delays in the execution of hydropower projects and uncertainties during their operations. To mitigate such risks, it is necessary to develop policies and institutional mechanisms for benefit-sharing at all scales – local, national and basin – that reflect equity and social justice for the local people, between the countries, and between upstream and downstream communities in the basin.

Mixing grid and off-grid systems to provide universal access to electricity

In addition to local benefit-sharing, access to electricity in rural areas (for lighting as well as for motive power) is an issue of concern in the region. While some countries (Bhutan and India) have been reasonably successful with a centralized grid extension mode of delivery, others, including some states in India (Uttar Pradesh, for example), have made efforts to maintain a balance between centralized grid extensions and off-grid systems, including mini-grids and standalone solar systems. Energy experts in the region and beyond have concluded that universal access to a reliable supply of electricity will be possible only with the support of off-grid systems (Bhattacharya & Palit, 2016; Martin, 2015; Palit & Bandyopadhyay, 2016).

Although centralized grid extensions as a mode of delivery may result in electricity services at a lower financial cost per customer per year compared with off-grid systems such as mini-grids, the reliability of the former mode is often poorer, thereby resulting in a higher total cost per customer per year, when both the financial cost and the non-served energy costs are accounted for (Ellman, 2015). For example, in South Asia, the World Bank Enterprise Surveys found the percentage of firms citing unreliability of power supply as a major constraint to growth ranging from six in Bhutan (survey year, 2009) to 78 in Bangladesh (2007). The percentages were 32% in India (2006), 66% in Afghanistan (2007), 74% in Pakistan (2007) and 76% in Nepal (2009) (Singh et al., 2018).

The adoption of mini-grids nationally may, however, be feasible only if arrangements are made for them to eventually be connected to the centralized grid and feed surplus electricity to the grid, or draw electricity from it, as and when necessary (Bhattacharya et al., 2019; Comello et al., 2017). Research on these issues is in progress. The harmonious mix of grid extensions and off-grid systems is a strategic issue that might affect the development strategy of the nation as a whole.

In the Hindu Kush Himalaya Assessment study, mixing on- and off-grid systems was a major component of the road to a prosperous Hindu Kush Himalaya region. In the 'Scenarios and Pathways' chapter of the study, two broad pathways towards 2050 were presented (Roy et al., 2019). The first pathway envisages a world of large-scale, centralized electric power projects, funded by domestic and international agencies, to serve a market across the region, facilitated by CBET. The second pathway envisages small-scale, decentralized, generation systems using hydro and other sources, especially solar, serving communities through local mini-grids, and funded by domestic public and private investments, with strong support from the central government and donor agencies, especially through climate finance initiatives. Pakhtigian et al. (2019) also discuss similar development pathways in the context of the Karnali and Mahakali basins of western Nepal.

The countries in South Asia have chosen a mix of pathways discussed by Roy et al. (2019) and Pakhtigian et al. (2019), with differences in emphasis. As discussed, Bhutan and India have pursued centralized grid extensions. However, some states in India with low access to electricity at the household level, such as Bihar and Uttar Pradesh, are pursuing mini-grids. Nepal's approach so far has been a balanced one. Recently, the government of Nepal commissioned a study in order to analyse the options of central grid extensions with or without mini-grids connected to it. For the 753 rural and town municipalities in the country, the study proposed 221 hydropower plants, 481 solar photovoltaic (PV) plants and 50 biomass plants (193 MW, 481 MW peak and 20 MW installed capacities, respectively). Only one wind power plant (0.2 MW capacity) was proposed (Government of Nepal, 2018, p. 18). The study also conducted an economic analysis for two scenarios of grid extensions with or without distributed generation for two of the seven provinces in the country. It recommended a grid extension with a distributed generation at 137 plant sites at municipalities in Province No. 1 and 136 in Province No. 2. If and when this plan is implemented, it will be an interesting example of mixing on- and off-grid systems.

Access to a reliable supply of affordable electricity is a benefit local people expect from hydropower projects. To serve the needs of local communities, a balance has to be maintained between on- and off-grid modes of delivery and between hydro and other renewable sources, especially solar.

Financial sustainability

Finally, on financial sustainability (Figure 1), this section discusses how long hydropower will continue to be cost-competitive in global energy markets and what the implications will be for South Asia. What role the state and the markets can play to make hydropower cost-competitive is also discussed. In addition, the section discusses the complementarity of hydropower with variable renewable energy (VRE) sources as a reliable source of energy storage.

How long will hydropower continue to be cost-competitive in global markets?

The International Energy Agency's (IEA) World Energy Outlook 2018 predicts that the greater competitiveness of solar PV will push its global installed capacity past hydropower by around 2030, and past coal before 2040. It also states that the new solar PV is well placed to outcompete new coal almost everywhere (IEA, 2018). *The Economist* recently reported that in the context of utilities in the United States, 'the "levelised" cost of electricity is now lower for wind or solar power than it is for coal' (*The Economist*, 2019).

Three studies that have specifically looked at the cost-competitiveness of different technologies are the IRENA (2019) study, the World Bank study (Timilsina et al., 2012) and the Intergovernmental Panel on Climate Change's (IPCC) *Special Report on Renewable Energy Sources and Climate Mitigation* (Arvizu et al., 2011). The metric used to compare cost per unit of power is the levelized cost, which is the ratio of the present value of capital and operating costs (over the power plant's lifetime) to that of the units of electricity generated.

Hydropower, at the global average, is still cheap compared with other sources of energy, especially solar. But the trend shows it might change in the long term. According to the IRENA study, in 2018 the levelized cost of electricity (LCOE) from solar PV was only 1.81 times that from hydropower (Table 6). A World Bank study found that the minimum and maximum values of LCOE (in 2008 US$/MWh) of solar PV were, respectively, 6.62 and 7.12 times that of hydropower (Timilsina et al., 2012). The IPCC report also found a similar figure, with the levelized cost of solar PV (assumptions: utility-scale one-axis project, US$4050/kW investment cost, 25 years lifetime, 10% discount rate, and 21.8% capacity factor) at about six times that of hydropower (assumptions: US$2000/kW investment cost, 60 years plant lifetime, 10% discount rate and 44% capacity factor) (Arvizu et al., 2011; Kumar et al., 2011). In addition, the World Bank study also estimated the LCOE of coal-fired power plants: the minimum and maximum values were, respectively, 1.5 and 0.9 times that of hydropower. And the minimum and maximum LCOE values of solar PV plants were, respectively, 4.5 and 8.2 that of coal-fired power plants (Timilsina et al., 2012).

While the LCOE is a useful metric to compare the market competitiveness of hydropower now and in the future, a clear picture of the appropriate generation mix for a national grid or a cluster of national grids interconnected by cross-border transmission lines can be obtained only after analysing the system as a whole (IEA, 2018; Rose et al., 2016). From a system optimization perspective, the picture of hydropower's market competitiveness in South Asia may be different from that implied by the levelized cost of its electricity. Sterl et al. (2020) provide an example of a system-level perspective in which a model is developed to determine the optimum amount of solar and wind power generation whose variability can be compensated for by a set of hydropower plants with reservoirs. It has simulated the model with data from West Africa. The study recommends a hydro–solar–wind mix of 51%–32%–17% for the West African regional power pool.

Table 6. Levelized cost of electricity (LCOE) by generation technology, 2018.

Technology	Global weighted average cost of electricity (US$/kWh)	Range in the cost of electricity (5th and 95th percentiles, US$/kWh)
Bioenergy	0.062	0.048–0.243
Geothermal	0.072	0.060–0.143
Hydro	0.047	0.030–0.136
Solar photovoltaic	0.085	0.058–0.219
Concentrating solar power	0.185	0.109–0.272
Offshore wind	0.127	0.102–0.198
Onshore wind	0.056	0.044–0.100

Source: IRENA (2019).

Furthermore, in the context of energy transition currently going on in South Asia, when VRE resources, such as solar and wind, are integrated into the power system, the flexibility of the power system needs to be increased in order to meet the load demand reliably (IRENA, 2019). Hydropower is a potential source of energy that can provide this flexibility because more than three-fourths of the potential hydropower capacity in the region remains unexploited (Table 3). Moreover, Bhutan and Nepal have plans to expand their hydropower capacity greatly in the near future. Not all the plants will have large reservoir storage capacity, but often the run-of-the-river plants in these countries do have a substantial diurnal pondage storage capacity.

When the flexibility of a power system, enhanced by hydropower in the generation mix, is insufficient to integrate large amounts of variable renewables, 'energy storage' solutions for providing grid flexibility may be necessary. Here again, hydropower has a role to play in the form of pumped-storage hydropower (PSH) technology, that used most widely for providing grid flexibility through energy storage. In the region, India already has several facilities that provide a significant level of pumped-storage capacity. Such schemes can provide ancillary services, including load shifting, fast and flexible ramping, frequency regulation and black-start capability (IRENA, 2020a). However, it may be difficult at times to find suitable land to site PSH facilities.

Lithium-ion battery storage is its nearest competitor. While the PSH technology is appropriate for long duration storage of greater than 20 hours, for shorter durations of 4–6 hours, lithium-ion batteries are also available (Mallapragada et al., 2020). The levelized cost of a PSH system, with a 40-year lifetime, has been estimated as US$186/MWh compared with US$285/MWh for a lithium-ion battery system (Giovinetto & Eller, 2019, cited in IRENA, 2020a). In 2017, PSH accounted for 96% of global energy storage power capacity (IRENA, 2017), but its share may decline over time as the price of lithium-ion battery packs continues to fall. Nevertheless, PSH is likely to remain the most economic technology in South Asia for storing large volumes of energy over long durations.

Presently, India is the only country in South Asia with a significant level of installed PSH capacity (4786 MW in nine schemes, out of 96,524 MW potential capacity in 63 sites) (Government of India, 2018). While it has not yet reached a stage where it needs a large energy storage to balance its grid, PSH technology will be a good option for the country in the future. To make it viable, considerations should be given to factors that would make it technically and economically feasible.

On technical feasibility, it has been assessed that India can integrate in its grid 175 GW of renewable energy, including 100 MW of solar and 60 MW of wind power, by 2022, with minimal challenges (Government of India & USAID, 2017). However, strategic oversizing with renewables in the future may require additional energy storage capacity.

On economic feasibility, since PSH technology is a negative energy source, assuming 80% round-trip efficiency of energy output to input (IRENA, 2017), the ratio of incremental (marginal) benefit to cost has to be higher than 1.25. The marginal benefit will be determined by the price at which electricity could be sold during peak hours. And the marginal cost will be determined by the price during off-peak pumping hours, assuming the electricity is marketable during those hours (Government of India, 2018). In addition, the capital cost (estimated at between US$2000 and US$4000/kW) will be important (IEA & IRENA, 2015).

Short-term market clearing prices in India's power-exchange markets may help with price discovery. It should be noted, however, that in the future both supply and demand may change resulting in a very different market clearing price.

Policy-makers in India have made recommendations to negotiate higher prices for peaking power in long-term power-purchase agreements: 'Hydropower shall be considered for compensation for balancing the grid by implementing differential tariff for peak and off-peak power. Pumped storage plants should be encouraged to operate in pump mode by providing incentive for its operation' (Government of India, 2018, p. 7.17).

Hydropower is still cheap compared with other sources of energy, but it is quickly losing ground to variable renewables. Its strength, however, lies in its complementarity with VRE sources for providing flexibility to power systems. In addition, when the flexibility is insufficient for integrating large amounts of variable renewables, PSH continues to be the one most widely used among the energy-storage technologies.

What role can state and markets play to make hydropower cost-competitive?

The state and markets may be able to help improve the competitiveness of hydropower. The state has an important role (along with the developer) in managing the environmental risks. The developer has an important role in managing the social risks. The capital market has a role in making the maturity period of loans to the projects closer to their life span, eventually reducing the unit cost of production. And CBET and cooperation could increase power system efficiency and flexibility, especially when variable renewables need to be integrated with the grid.

The role of capital markets

The sources of financing for hydropower projects can be public or private, foreign or domestic. Typically, the debt-to-equity mix is about 70:30. Since debt is a big part of the capital structure in capital-intensive projects such as hydropower, the capital market can play a role in reducing the loan payments and thus the cost of generation by matching the maturity period of loans to the life span of the project. Such a longer maturity period loan may be available from life insurance companies and pension funds, since their liabilities tend to have longer maturity periods, and they can thus hold assets of longer maturity periods as well. In addition, national infrastructure development banks, backed by the full faith and credit of the government, could issue bonds. Lately, international financial institutions have also taken initiatives towards issuing local currency bonds. In the near future, hydropower projects may also qualify for funds raised by issuing 'green bonds'.

In India, the need for the capital market to issue debt with longer maturity was highlighted by the government's Standing Committee on Energy in its report *Hydropower – A Sustainable, Clean and Green Alternative* (Government of India, 2016). It noted that banks and financial institutions typically provide loans with a maturity of 12 years. The committee recommended that in future the average life span of hydropower projects be treated as 30–40 years, instead of 12 years, when estimating the tariff per unit of electricity. It also recommended that long-term bonds with sovereign guarantees be floated and that these bonds be tax free. In his concluding statement to the committee, the finance secretary said:

> One of the demands which have been raised on the financing side of hydro projects is the requirement of long-term financing for them, with the loan spread over the entire life-cycle, say 50 years instead of 12 years. [...] They have been demanding infrastructure bonds to finance these projects. We can look at long term infrastructure bonds. (p. 31)

Stakeholders in the financial sector in South Asia (central banks, governments and private sector) should, therefore, collaborate to develop financial instruments, promote capital markets and build institutions suitable for raising investments in clean energy. Efforts should also be made for hydropower to qualify for funds through green bonds.

The role of cross-border electricity trade (CBET)

South Asia could benefit from seasonal complementarity in load-demand profiles and power-supply capacity between Bhutan and Nepal, on one side, and Bangladesh and India, on the other. CBET may also help improve the capacity utilization of power plants during off-peak hours of the day. Such seasonal, diurnal and geographical complementarities may be further enhanced by India's rapid expansion of the power supply from variable renewables, especially solar PV.

By 2050, electricity demand may exceed generation by about 2500 TWh in Pakistan, 2000 TWh in India, 300 TWh in Bangladesh and 110 TWh in Afghanistan. But generation may exceed demand by about 130 TWh in Bhutan and 120 TWh in Nepal (Shukla & Sharma, 2017). This might provide an opportunity for hydropower-based CBET between Bhutan and Nepal (as net exporters) and Bangladesh and India (as net importers).

Several system optimization studies on CBET in South Asia have been carried out at the World Bank (Timilsina, 2018; Timilsina & Toman, 2016) and at the Integrated Research and Action for Development (IRADe) under the South Asian Regional Initiative on Energy Integration (SARI/EI, 2017). These studies have provided evidence for a strong potential for hydropower-based CBET in the region.

First, Timilsina (2018) developed a system optimization model to analyse how much of the hydropower potential of South Asia could be developed if the region is fully connected and a free flow of electricity takes place, the regional trade scenario. In its baseline scenario, the potential is to be developed to meet domestic demand and only the currently existing and agreed-on electricity trade. All major sources of electricity are included in the analysis. Under the baseline scenario, the hydropower capacity that will be developed by 2040 is projected as 170 GW: 99 GW in India, 38 GW in Pakistan, 15 GW in Bhutan, 9 GW in Nepal, 6 GW in Afghanistan, 2 GW in Sri Lanka and 0.4 GW in Bangladesh.

Under the regional trade scenario, Timilsina projects that 72 GW of hydropower capacity in addition to that from the baseline scenario will be developed by 2040. The analysis suggests that 52 GW will come from Nepal, 11 GW from India, 9 GW from Bhutan and 2 GW from Afghanistan, and none from Bangladesh and Sri Lanka. The capacity of Pakistan will, however, decline by 2 GW from that of 38 GW in the baseline scenario.

Second, SARI/EI (2017) has developed a system optimization model to analyse India–Nepal electricity trade. It also covers all major sources of electricity generation. It also takes into consideration India's plans to develop 175 GW of variable renewables, including 100 GW of solar (which might have substantial effects by 2040, even if its execution is delayed past 2022). In its baseline scenario, it has projected 6 GW of hydropower

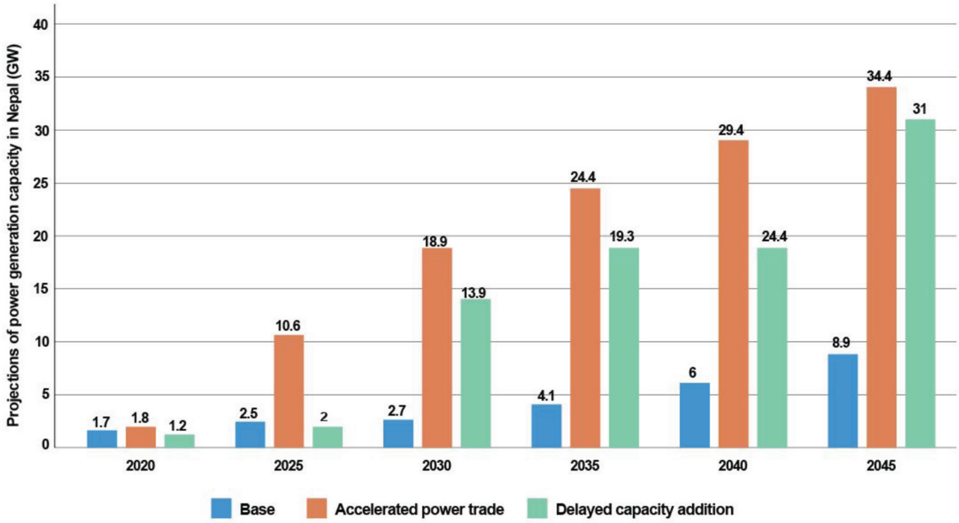

Figure 2. Projections of power generation capacity (GW) in Nepal.
Source: SARI/EI (2017).

generation capacity for Nepal in 2040. In this scenario, no new cross-border interconnections are expected beyond the existing and the committed ones.

Under the accelerated power trade (APT) scenario, in which the full potential of electricity trade would be harnessed, the study projects hydropower-generation capacity in Nepal at 29 GW. To make provision for delays in project implementation under the APT scenario, it also projects capacity under a delayed capacity addition scenario under which the capacity declines by 5 GW from that of the APT scenario (Figure 2).

On emissions reduction as a result of CBET, over the 2015–40 period, Timilsina and Toman (2016) have estimated 4.429 billion tonnes of reduction from the baseline scenario under a full regional trading scenario. (The baseline scenario is similar to that discussed by Timilsina (2018).) About two-thirds of the reduction, 2.949 billion tonnes, is expected in India, which is a 6.5% reduction from the baseline. Emissions reduction of 1.170 billion tonnes is expected in Bangladesh, which is a 33% reduction from the baseline, and 0.322 billion tonnes in Pakistan, a reduction of 7%. Very small reductions are expected in Afghanistan, Bhutan and Nepal.

The projections of system-optimization studies look attractive for hydropower-based CBET in South Asia. To benefit from these opportunities, there is a need to create an enabling environment through appropriate policies (e.g. third-party transmission access), institutions (e.g. regional coordination centre) and infrastructure (e.g. cross-border transmission interconnections). Its governments should reform policies, develop institutions and build infrastructure to accelerate the process.

Conclusions

Although the South Asian countries have made remarkable progress in recent times in providing access to electricity to their populations, per capita consumption of electricity is still low, and the reliability of delivery is poor. In the future, as they move further towards industrialization, the demand for electricity is likely to grow rapidly. The challenge is going to be providing more electricity on the ground without adding more carbon emissions to the atmosphere. To this end, hydropower will have a significant role because it is renewable, a clean alternative to fossil fuels and a reliable source of energy storage. In addition, most of South Asia's hydropower resources are yet to be harnessed. The issue of hydropower in South Asia remains a divisive issue, with many people advocating for the rapid development of vast amounts of hydropower, and others arguing against hydropower with deep concerns about its social and environmental costs. There is no doubt that hydropower will certainly have a significant role in South Asia's energy future, but how much, how quickly and how effectively it contributes will depend on several factors.

This paper examines hydropower from many angles using a risk-analysis framework: environmental and social sustainability, alternative and complementary energy sources, and cost competitiveness. It can be concluded that a middle path for hydropower is warranted, and that is not only the one where hydropower takes a significant role in South Asia's energy future, but also the one where options are carefully considered, a mix of approaches are employed, and environmental and social concerns are addressed. Such a path makes long-term economic sense.

In the short term, hydropower is still cheap compared with other sources of energy, but in the long term it might change, and hydropower may lose its cost advantage. Technological change and the cost of other renewables such as solar, wind and biomass may determine the future of hydropower as a dominant source of renewable energy in South Asia by undermining its market competitiveness. The World Energy Outlook 2018 says that the global installed capacity of solar PV could exceed that of hydropower by around 2030, and that of coal before 2040. Hydropower is likely to remain competitive if it is developed sustainably because of its complementarity with solar energy as a reliable source of energy storage. To this end, national policies and politics within and among the countries in South Asia will be important. The competitiveness of hydropower will depend on how well one mitigates the environmental and social risks, and uses policies and institutions to facilitate efficient financial markets and fair and friendly CBET.

On the environmental side, the future of hydropower may depend on how various risks are managed. Its future will be more sustainable if several measures are taken. First, in all hydropower projects, hydropower-specific EIAs should identify potential impacts, along with prevention measures and a development plan for long-term sustainability. Second, opportunities to derive benefits from environmental changes, including climate change, in multipurpose projects need to be carefully analysed and incorporated in planning. Finally, an integrated river basin approach, with the basin as the planning unit, should be used in planning hydropower projects to ensure maximum benefits and minimum environmental impacts, while mitigating risk, wherever possible, through both structural and non-structural measures.

On the social side, policies and institutions for benefit-sharing that reflect social justice need to be developed, and universal access to a reliable supply of electricity should be promoted by maintaining a balance between on- and off-grid modes of delivery.

On the financial side, policies and institutions need to be developed in capital markets to promote long-term debt instruments matching the life span of hydropower plants. And

CBET needs to be promoted to achieve system efficiency and take advantage of geographical, seasonal and diurnal complementarities in demand and supply.

If appropriate measures are taken by the government, civil society and the private sector to manage risks, where each stakeholder manages the type of risk – environmental, social or financial – it can handle best, hydropower will continue to play a significant role in South Asia's energy future, although it may be less dominant as a source of renewable energy.

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