Renewable and Sustainable Energy Reviews 107 (2019) 446–461

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Hydropower development in the Hindu Kush Himalayan region: Issues, policies and opportunities

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ARTICLE INFO

Keywords:
Renewable energy
Hydropower
Energy policy
Regional cooperation
Hindu Kush Himalayan region

ABSTRACT

Worldwide, the demand for energy has increased significantly in last two decades, leading to an increased use of non-renewable energy resources. The global agenda aims to reduce the carbon intensity of energy in long-term climate change mitigation strategies, and to achieve Sustainable Development Goal 7 (SDG-7) on affordable and clean energy. Use of renewable energy (RE) can contribute to reducing global greenhouse gas (GHG) emissions while providing incremental financial resources to stimulate clean development mechanisms. Hydropower continues to be the leading RE option and has the additional benefits of water storage for agriculture and other uses. Drawing on the position of four Hindu Kush Himalayan (HKH) countries – Bangladesh, India, Nepal and Pakistan – this paper investigates the current status of hydropower generation and related policies, and attempts to identify the key challenges to and opportunities for hydropower development in the region. Collectively, four HKH countries have commercially feasible hydropower potential of nearly 190 GW. However, only one-third of this potential has actually been tapped so far. Nepal and Pakistan have tapped 2% and 12%, respectively, of their hydropower potential. The current hydropower supply has not been able to fulfill the electricity demand in the region, where 26–37% of the rural population is living without access to electricity, and future demand for electricity is likely to increase sharply. There are several economic, social, technical, environmental, ecological and political challenges to hydropower production in the HKH countries. Despite these challenges, hydropower remains an important option for achieving renewable energy goals in the region. To achieve these goals, we suggest capitalizing on emerging opportunities such as large hydropower development using a 'smart approach', micro-hydropower promotion, energy trade, and regional cooperation for collective energy development programs.

1. Introduction

Energy is one of the most important strategic inputs for socio-economic development for any economy [1,2]. Worldwide, the demand for energy has risen significantly and quickly, due to an increase in population, consumption and industry, leading to greater use of non-renewable energy (non-RE) resources such as petroleum and coal. This has led to serious impacts on environmental sustainability [3], and has hindered global efforts to cope with climate change mitigation [4]. Non-RE resources contribute nearly 60% to total global greenhouse gas (GHG) emissions [4]. For achieving long-term climate change mitigation goals and overall sustainable development, it is a key objective to reduce the carbon intensity of energy [5].

The use of renewable energy (RE) can play an important role in reducing GHG emissions while providing incremental financial resources to stimulate clean development mechanisms [6], so offering a win–win solution for developing economies in particular. RE technologies can also help countries to meet the 'Sustainable Development Goal - 7' on reliable, clean and affordable energy, expand people's access to electricity and promote sustainable development [7]. In the face of climate change, environmental degradation and health issues, it is a huge challenge to provide affordable and clean energy to more than 1.2 billion people in the world living without electricity [8]. Globally, around 2.8 billion people still rely heavily on coal, wood, dung and

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https://doi.org/10.1016/j.rser.2019.03.010
Received 29 September 2018; Received in revised form 24 February 2019; Accepted 4 March 2019
1364-0321/

charcoal for heating and cooking, resulting in over 4 million premature deaths per annum due to indoor air pollution [9]. These challenges are more pronounced in South Asia, which is known as one of the most energy deprived regions globally.

Worldwide, the production of RE has shown extraordinary growth in recent decades, particularly from 1999 to 2009 [10,11]. Hydropower is the largest RE source, generating almost one-fifth of the world's electricity [12] and over 80% of the world's renewable electricity [7]. It is an economical source of energy that is not affected by fluctuating fuel prices [13]. Despite other emerging energy storage technologies, hydropower continues to be the only technology offering economically viable large-scale storage and relatively efficient energy storage options. Global hydropower installation is growing at an average annual growth rate of 3% [7]. Hydropower is subject to stringent regulations that are related not just to energy, but also to water and environment. Water, energy and climate policies have the potential to exert a significant influence on decisions about hydropower development [14].

South Asia's considerable hydropower potential is concentrated in the Hindu Kush Himalayan (HKH) region[1] (Fig. 1). This is manifested by high mountains, many glaciers and large rivers. The region is of importance as a source of ten large river basins – the Amu Darya, Indus, Ganges, Brahmaputra (Yarlungtsanpo), Irrawaddy, Salween (Nu), Mekong (Lancang), Yangtse (Jinsha), Yellow River (Huanghe) and Tarim (Dayan) [15]. These rivers provide water, ecosystem services and the basis for the livelihoods to 1.9 billion people – one-fourth of the world's population [16]. Tapping the vast hydropower resources of the countries in the region is considered to be crucial to meet the region's rapidly growing energy demand in a cost-effective and environmentally sustainable manner [17,18]. Four HKH countries (Bangladesh, India, Nepal and Pakistan) have a hydroelectric potential of 334 Gigawatt (GW). However, owing to inadequate infrastructure, technological constraints and lack of credible cooperation among the countries, only one-third of this potential has actually been tapped so far [17,19,20]. Nepal and Pakistan have tapped 1.7% and 12% of their commercially feasible hydropower potential, respectively [21,22]. This least-developed status has not been able to fulfill the per capita commercial energy consumption in these HKH countries, which is much lower than the world average [23].

Challenges continue to persist for hydropower generation in HKH countries. Wazed [24] found that conflicts about land acquisition, displacement of families, remoteness of potential areas and associated high transmission costs, environmental impacts and low investment by banks to be the key constraints hindering efforts to improve hydropower generation. Yazdanie and Rutherford [25] argued that the slow uptake of RE technologies could be attributed to factors such as lack of infrastructure and poor competition with conventional power generation. Some hydropower projects experience time and cost overruns due to geological issues and surprises [26]. Other deterrents to investment in hydropower projects include high up-front costs, and the lengthy time required for planning, acquiring permissions and construction [27]. For instance, in the next 20–25 years, Pakistan will need US$210 billion to meets its growing energy demands [28]. About 13% of country's river water flows can be stored and easily used for hydropower generation. Such development again depends on fund mobilization, which is a major political issue [29]. Local perceptions of the environmental impacts of hydropower projects also result in low local acceptability of these projects. A study [30] conducted in the state of Jammu and Kashmir (India) revealed that local communities perceived hydropower projects as a source of noise pollution; waterlogging and soil erosion; deterioration of water quality; and losses in animal, bird and plant diversity.

[1] The HKH region extends 3500 km across eight countries – Afghanistan, Bangladesh, Bhutan, China, India, Nepal, Myanmar and Pakistan – covering an area of 3,441,719 km^2, and accommodating 210.53 million people.

Despite these challenges, hydropower still remains one of the most environmentally friendly and cost-effective options for achieving RE goals in the HKH region. It may contribute to improvement in agricultural productivity through water storage and timely supply in irrigation systems [31,32]. There are significant complementarities and synergies for hydropower generation among HKH countries [33], opening the door of opportunity for regional cooperation [6]. A number of bilateral electricity exchange initiatives have been started, and still await implementation. The policy spheres are largely being managed quite separately across various governments, leading to disjointed decision making and conflicting signals [14].

Drawing on the case of four HKH countries– Bangladesh, India, Nepal and Pakistan – this paper maps the current status of hydropower generation and related legal provisions/policies, and attempts to identify and investigate the key challenges to and opportunities for hydropower development in the region. The study is based on reliable official documents and published studies on hydropower development in the selected countries.

2. Methodology

This review study was conducted as a part of a large project ‘Himalayan Adaptation, Water and Resilience (HI-AWARE)’ (2015–2018) which was one of the four consortia of the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA). The study emphasized on identifying the issues, mapping the policies and highlighting the opportunities related to hydropower development in the HKH region. It focused only on four countries – Bangladesh, India, Nepal and Pakistan, out of eight countries in the HKH region. The prioritization of countries was based on the geographical scope of the HI-AWARE initiative.

The research was carried out in two phases. In the first phase (2016–2017), a detailed situation analysis was carried out and four country specific research reports were produced (one from each country). Situation analysis was guided by below specific objectives.

- Assessing the state of energy resources and access to energy by country population.
- Taking stock of the hydropower resource potential and identifying the gap between commercially feasible potential and the installed capacity.
- Identifying and critically examining the key issues related to hydropower development.
- Carrying out a critical assessment of legal provisions/policies governing the renewable energy in general and hydropower in particular.
- Identifying the key opportunities for hydropower development in the region and suggest the possible way forward and scope for regional cooperation.

Situation analysis mainly relied on an extensive review of existing literature (published journal articles, reports, and policy documents), and descriptive statistical analysis (e.g. percentages and trend analysis). To search out the published journal articles and reports from Google Search and ScienceDirect database, mainly the key words of ‘renewable energy’ and 'hydropower’ were used in combination with country names and other key words presented the specific objectives. Policy documents were either physically procured from the respective ministries and institutions, or were downloaded from official websites using the full names of the documents. Collated policy documents were thoroughly reviewed and information were put in more structured manner to draw some meaningful conclusions. For statistical analysis and graphical presentation, raw data were mainly procured from the reports and databases of Alternative Energy Promotion Center (AEPC), International Energy Agency (IEA), International Hydropower Association (IHA), Power Grid Company of Bangladesh Limited (PGCB),

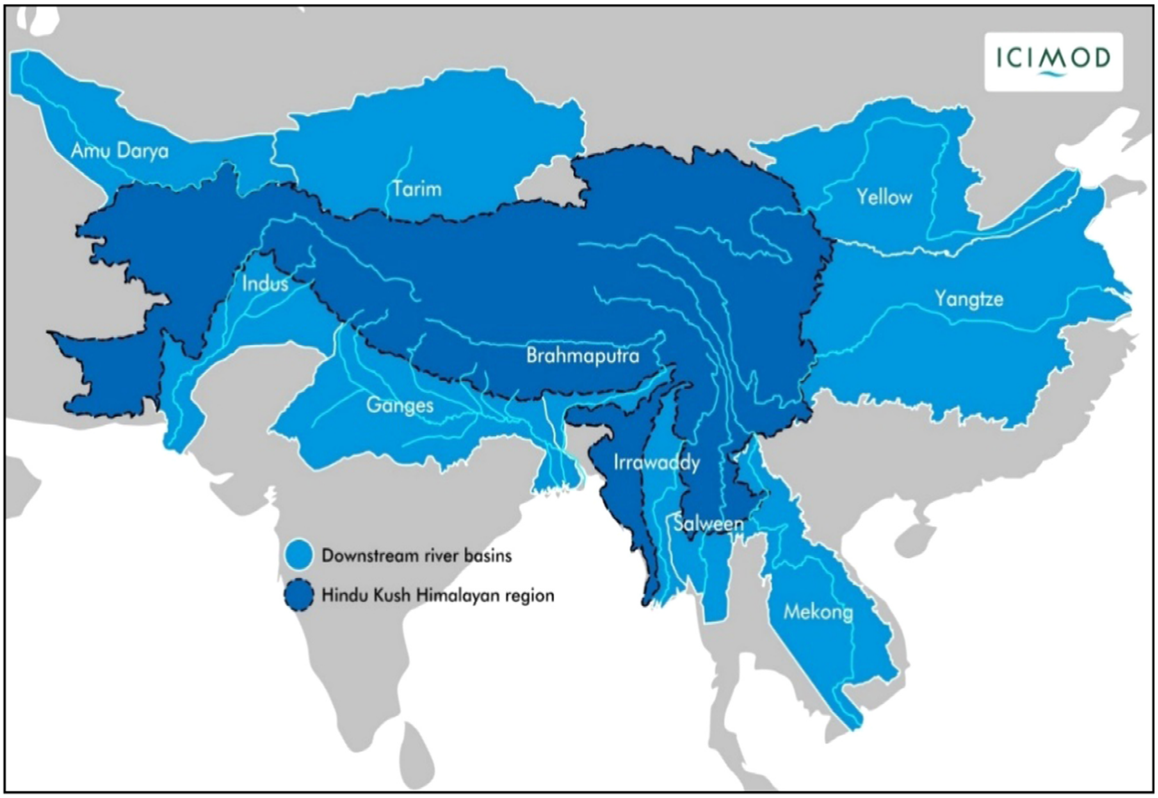

Fig. 1. The Hindu Kush Himalayan region.

National Electric Power Regulatory Authority (NEPRA) of Pakistan, Central Electricity Authority (CEA) of India, Ministry of New and Renewable Energy (MNRE) in India and South Asian Association for Regional Cooperation (SAARC).

In the second phase (2018), a synthesis report was prepared based on all four country specific reports, and the synthesis document was ultimately transformed into this journal article.

3. Energy resources and electricity access in the HKH

3.1. Primary energy supply

In the HKH region, about 80% of the rural population still depends on traditional energy resources such as biomass [34]. Statistics of energy data from Bangladesh, India, Pakistan and Nepal also show that biofuels and waste contribute substantially to total primary energy supply (TPES) in these countries (Fig. 2a–d). Biofuels and waste account for around one-quarter of primary energy supply in India and Bangladesh. In Pakistan, one-third of the TPES is contributed by this source. Nepal depends predominantly on biofuels and waste, which constitute 82% of TPES (Fig. 2c).

Among other resources of TPES, natural gas contributes 56% in Bangladesh, and coal contributes 45% in India (Fig. 2a and b). Crude oil and oil products also contribute one-quarter to TPES in India. Pakistan depends heavily on natural gas, crude oil and oil products for more than half of its TPES (Fig. 2d). In all four countries, nuclear, geothermal and solar either have no contribution or have a very tiny share. Most importantly, hydropower contributes a very small share to their TPES. In Bangladesh, hydropower contributes the least (0.1%) (Fig. 2a), and in Pakistan it contributes the most (3.1%) (Fig. 2d). In India and Nepal, it contributes 1.4% and 2.6%, respectively, to TPES (Fig. 2b and c). This clearly implies that scope exists to improve the energy mix of almost all countries by tapping into the hydro-energy resources of the region.

In Bangladesh, India and Pakistan, electricity is produced predominantly from non-renewable resources. For instance, electricity generated by fossil fuels contributes 98%, 69% and 68% to total electricity generated respectively in Bangladesh, India and Pakistan [36]. The share of hydroelectric resources in total electricity production has declined in Bangladesh, India and Pakistan (Fig. 3). In India, the share of hydroelectric resources decreased from 42% in 1971 to 10% in 2014. Likewise, in Pakistan, the share decreased from 49% in 1971 to 30% in 2014. In Bangladesh, it decreased from 17% to 1% during the same period. This indicates that, in the face of increasing demand for electricity, these countries did not adequately harness the potential of water resources for hydropower generation. However, in Nepal, the share of hydroelectric resources in total electricity production increased from 78% in 1971 to 100% in 2014 (Fig. 3).

3.2. Access to electricity

South Asia, being one of the world's least electrified regions, encounters grave challenges in accessing modern forms of electricity. The problem is accentuated by increasing urbanization, and by growth in agriculture, rural development and population, resulting in a dramatic increase in demand for electricity in both rural and urban areas. In the recent past, the HKH region has shown a significant improvement in agricultural development and economic indicators such as gross domestic product (GDP) growth rate and reduction in unemployment rates. In India, Bangladesh and Pakistan, GDP growth rate is more than 5%, and India shows the highest rate at 7.6% [38]. If the economic development goals are to be met, energy demand in the region is also expected to grow at an annual rate of 5% [39].

In Bangladesh, India, Nepal and Pakistan, 20%, 43%, 15% and 53% of the population, respectively, had access to electricity in 2000 [40]. However, by 2016, the electrification rate had substantially increased in these four countries compared to 2000. In 2016, 75%, 82%, 77% and 74% of the population in Bangladesh, India, Nepal and Pakistan,

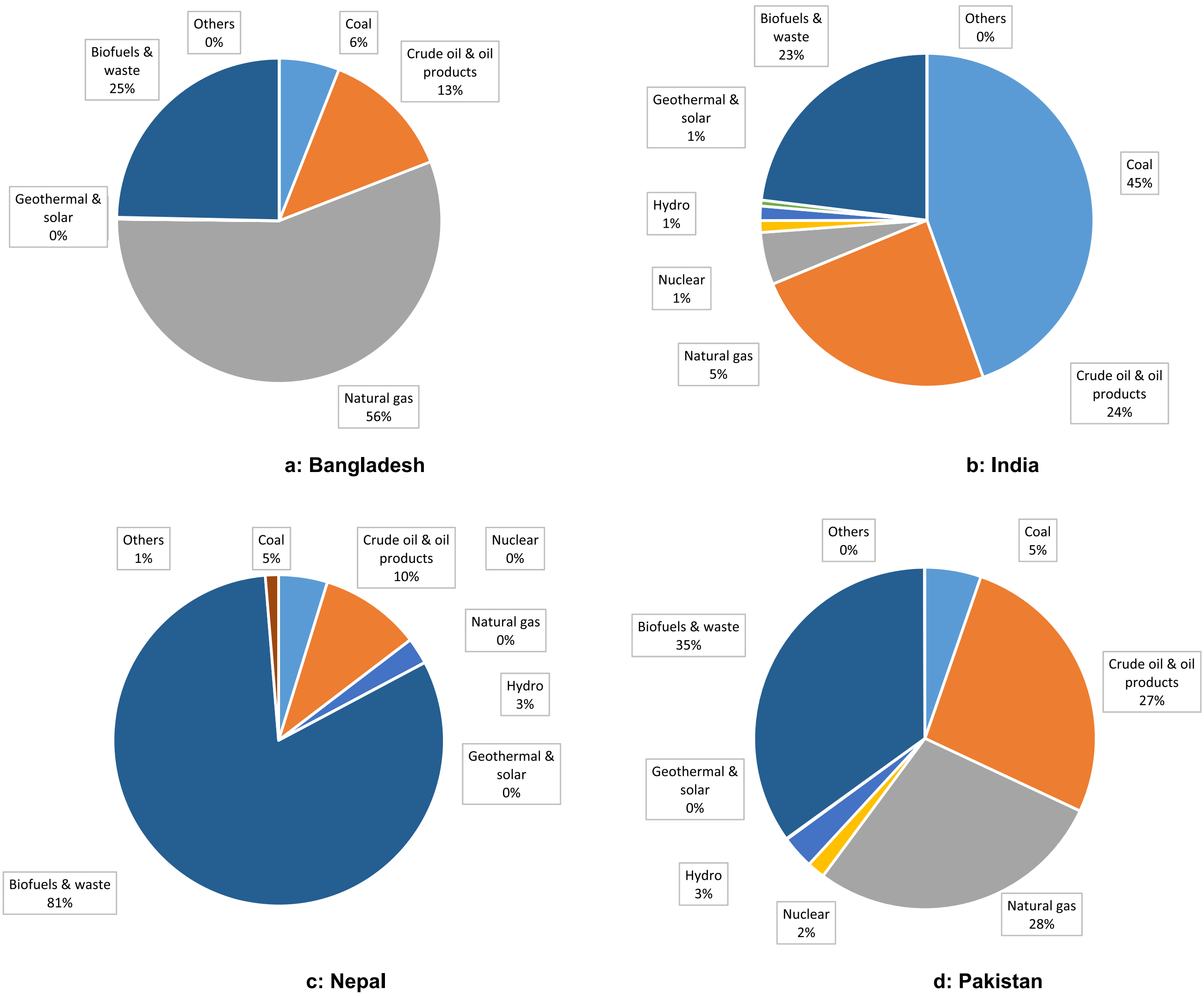

Fig. 2. Percentage shares of different resources in total primary energy supply. (a) Bangladesh; (b) India; (c) Nepal; and (d) Pakistan.
Source: International Energy Agency (IEA) [35].

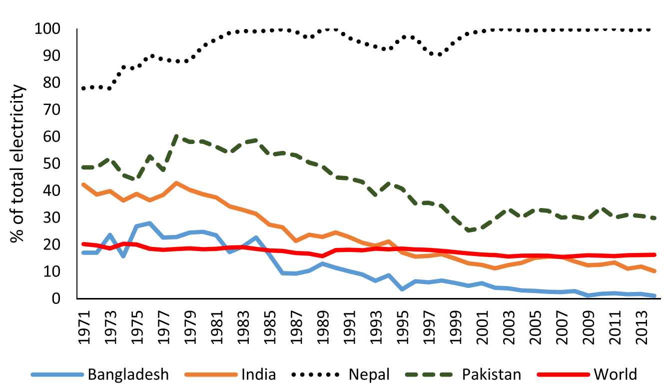

Fig. 3. Electricity production from hydroelectric resources.
Source: IEA [37].

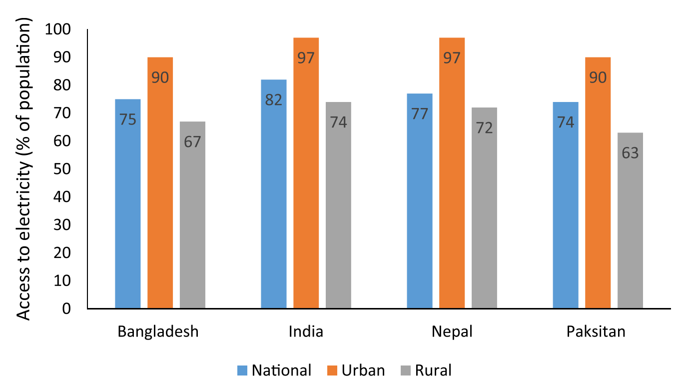

Fig. 4. Populations with access to electricity in Hindu Kush Himalayan countries. Note: All data are for 2016.
Source: IEA [40].

respectively, had access to electricity (Fig. 4). Despite this progress in national electrification rate in HKH countries, 26–37% of the rural population lives without electricity access (Fig. 4). This implies that demand for electricity will continue to rise in future to improve the electrification rate in rural areas and ensure stable supply in urban areas.

At present, all four countries are facing an electricity deficit (Table 1). The electricity deficit in Pakistan and Nepal, particularly, is very high and impacts almost all development sectors. These two countries have to increase their installed electricity capacity and production, not only to fill the current deficit, but also to meet the growing future demand.

Table 1
Potential for hydropower development.
Source: PGCB [41][a]; CEA [42][b]; Malla [43][c]; NEPRA-Pakistan [44][d]; SAARC [20]*; Bergner [21]**; IHA [22]***

Country	Hydropower capacity (MW)			% Commercially feasible capacity harnessed	% Electricity deficit
	Gross*	Commercially feasible**	Installed***		
Bangladesh	775	755	230	30	11[a]
India	150,000	84,044	51,975	62	03[b]
Nepal	83,000	43,000	867	02	31[c]
Pakistan	100,000	59,000	7320	12	24[d]
Total	333,775	186,799	60,392	32	

Note: Megawatt = MW; 1000 Megawatt = 1 Gigawatt (GW)
[a] Average deficit in 2017 during peak hours from March to July.
[b] Deficit during peak hours of December 2017.
[c] Deficit during peak hours of dry season in 2017.
[d] Deficit in 2015 during National Transmission and Dispatch Company's peak hours from June to August.

4. Hydropower potential and installed capacity

The HKH region has hydropower potential, but this electricity generation potential is unevenly distributed across countries and seasons [18,37]. Three countries (Pakistan, India and Nepal) have hydroelectricity potential of 333,000 MW (Table 1). Of this, nearly 60% is commercially feasible. However, only one-third of commercially feasible potential has actually been harnessed so far. Pakistan and Nepal have harnessed only tiny proportions of their commercially feasible hydropower potential, at 12% and 2%, respectively (Table 1). Among all four countries, India has done remarkably well with installed capacity by harnessing about 62% of feasible potential (Table 1). All four countries have techno-economically feasible non-diminishing hydro potential of about 186,799 MW [17]. If hydropower is developed sensibly, it can result in multiple benefits as a source of clean electricity, and also as a strategic approach of water management for irrigation, industry, flood control, and domestic uses [17].

5. Issues related to hydropower development

Despite the region's tremendous hydropower potential, tapping this resource has encountered several economic, social, technical, institutional, political, environmental, ecological, physical and geological issues that continue to hinder development. Some factors, which are common and applicable to both storage and run-of-river hydro projects, are discussed below (Sections 5.1 and 5.2). In addition, some key broader challenges are also discussed (in Section 5.3) which constrain the hydropower development in the HKH region.

5.1. Economic, social, technical, institutional and political issues

In the HKH region, most large hydropower projects are located in remote areas with limited accessibility, exacerbating the economics of project development. The developers have to bear the high costs of transporting the heavy machinery and equipment required to these remote areas (Table 2). Moreover, lengthy transmission lines passing through the mountainous terrain need to be installed to evacuate power to the main grids, resulting in increased project costs. Problems are compounded by issues related to mobilizing private capital, asset–liability mismatch and lack of awareness in the banking communities about such projects. High interest rates combined with short loan tenures further complicate the problem [24]. Quite often, some projects experience time and cost overruns due to geological issues and surprises. Other deterrents for investment in hydropower projects entail high up-front costs and lengthy time required for planning, permitting and construction [27].

Even in the case of small scale hydropower projects, the local communities are facing the lack of funds for sustainable operations and maintenance of plants. Moreover, a lack of trained technicians and engineers is also resulting in poor maintenance of plants (Table 2). A study from Nepal [45] revealed that some technical constraints related to design of micro-hydro turbines are also resulting in lower production efficiency which is 60–70% the efficiency of other designs. These rely on cross flow, not really designed for electricity generation but adapted from milling. Studies [45,46] also identified some social issues such as community disagreement, inequality, and a lack of good relationships between upstream and downstream villages. These issues are influencing the operations and maintenance of both small and large scale projects. In Nepal, some political issues such as Maoist insurgency also induced severe impacts on the construction, operations of small scale hydropower projects [45–47].

Evidence from the HKH region (Table 2) shows that local communities living in areas adjoining hydropower projects are the most vulnerable to the impacts of these projects. A host of issues revolves around the acquisition of land for project development, including displacement of local people, disturbances caused to their communities and disruptions to their livelihoods. All these lead to strong resistance to such projects, further hindering hydropower development in the region. In some cases (for instance in Himachal Pradesh, India), common pool resources such as forests and pastures are also affected, resulting in direct impacts on local people's livelihoods (Table 2). Generating alternative livelihoods has been challenging because of the limited skill sets of locally displaced youth. This is primarily because the youth lacks experience and technical knowledge with them [48]. In Himachal Pradesh, and Jammu and Kashmir states of India, the local people also raised issues about cracks in their houses and shops due to the blasting activities carried out to cut rocks near the inhabited areas (Table 2). The incidence of waterborne diseases such as malaria also increases in adjoining areas, as reported by Bose et al. [49] from the Indian Himalaya.

5.2. Environmental, ecological, physical and geological issues

Overall, hydropower is cleaner option of energy than non-RE resources. However, in project areas and some adjacent locations, hydropower developments may have some environmental, ecological and geological impacts (Table 2). The HKH region is very rich in globally significant biodiversity, and large hydropower development projects may disturb or destroy the habitats of several terrestrial plant and animal species. Studies in the HKH [31,50,51] found that deforestation can occur, leading not only to diversity loss in forest ecosystems, but also affecting the communities depending on forests for their livelihoods. Pandit and Grumbine [50] predicted that deforestation due to dam building in the Indian Himalaya is likely to result in extinction of 7 vertebrate taxa and 22 angiosperm and by 2025. Disturbance due to dam building is also likely to reduce tree density by 42%, tree species

Table 2
Issues related to hydropower development in the Hindu Kush Himalayan (HKH) region.

Economic, social, technical, institutional and political issues	Environmental, ecological, physical and geological issues	Area and country	Scale of hydropower project	Investigating studies
● Cracks in houses due to blasting activities ● Affected livelihoods of forest-dependent people	● Dust clouds (air pollution) due to blasting activities	Himachal Pradesh, India	Large and medium	Sharma and Rana [51]
● Increased incidence of waterborne diseases such as malaria ● Dismantled familial socioeconomic and cultural bases created over generations ● Loss of access to common property	● Sudden drop in floods in downstream areas, affecting soil fertility and decline in crop production	Indian Himalaya	Large	Bose et al. [49]
● Low load factor ● Long payback period ● Long distance from consumption center ● High cost of development ● Inadequate technology	● Variability in river flow ● High sedimentation	HKH region in India, Nepal and Pakistan	Small	Vaidya [54]
-	● Change in water temperature ● Demolition of natural vegetation	Himachal Pradesh, India	Medium	Lata et al. [55]
● Larger area requirements for big projects ● Cracks in houses due to blasting activities ● Health problem caused by air pollution ● Displacement of people affecting their economic, cultural, religious and archaeological aspects ● Longer distance from the load center ● Affected ecotourism ● Affected commercial activities and local industry ● High resettlement and rehabilitation cost to people	● Air and noise pollution ● Affected water quality ● Affected local animals, birds and aquatic life ● Affected forest land ● Increased soil erosion	Jammu and Kashmir state, India	Large	Sharma and Thakur [30]
● Lack of political will ● Law and order situation ● Problems in land acquisition process	-	Khyber Pakhtunkhwa, Pakistan	Large	Batool and Abbas [53]
● High manpower, material, machinery and transportation cost ● Difficulty in arranging finance from banks ● High rate of compensation ● Affected communities conflicting with developer on various social issues ● Damage to property (houses/fields/orchards) due to project operations ● Affected religious sites ● High cost of new roads ● High cost of extension of transmission lines to remote areas for grid connectivity	● Difficulty in maintaining economic efficiency due to higher variation in stream discharge across seasons ● Continuous monitoring of mandatory 15% environmental flow for sustainability of aquatic life, water demand downstream for irrigation and drinking ● Increased air and noise pollution from construction of access roads, dumping waste, drilling, blasting etc. ● Depletion/diversion of natural water sources ● Increased soil erosion ● Geological risks and surprises in fragile mountain zones, e.g. unstable strata, caving in of tunnels, frequent landslides and land subsidence ● Seismic risks	Himachal Pradesh, India	Small	Kumar and Katoch [52]
-	● Destruction of plant and animal habitats ● Drying up of natural springs due to blasting for tunnel construction ● Obstacles to fish migration	Himachal Pradesh, India	Large and medium	Erlewein [56]
● Opposition from local people ● Resistance from NGOs ● Bureaucratic approach from governments ● Lack of skilled labor ● Management problems and corruption ● Prolonged payback period	-	Himachal Pradesh, Uttarakhand, and Jammu and Kashmir states, India	Small	Khan [48]
–	● Deforestation ● Loss to biodiversity	Entire Indian Himalaya	Large, medium and small	Pandit and Grumbine [50]
● Constraints to land acquisition ● Displacement of local people ● Remoteness of potential areas ● Long distance load centers	–	Bangladesh	Small	Wazed [24]

(*continued on next page*)

Table 2 (*continued*)

Economic, social, technical, institutional and political issues	Environmental, ecological, physical and geological issues	Area and country	Scale of hydropower project	Investigating studies
• Low lending by banks • Lack of financial resources for sustainable operations and maintenance of hydropower plants • Less efficient design of turbines • Lack of trained technicians and engineers for maintenance of plants • Underutilised potential of electricity for economic productivity • Lack of interest from banks in micro hydro projects • Insurgency and political unrest	• Difficult to access the project site in rainy weather • Inadequate connectivity of project sites to roads	Selective districts of Nepal	Small/micro	Sovacool et al. [45]
• Inadequate financing and foreign investment • Lack of funds for sustainable operations of small projects • Inadequate institutional capacity • Non-availability of technical experts in remote sites for repair and maintenance of pants • Lack of trust and cooperation between upstream and downstream communities • Insurgency and political unrest	• Problems of sedimentation • Mismatch between the time of water availability and the time of water requirement. • Remoteness of project sites	Nepal	Small and medium	Sovacool et al. [46]

NGO, non-governmental organization; Hyphen (-) means that the study did not report any thing on the particular aspect.
Note: In above table, micro-hydro and small plants are considered as 'small' scale projects.

richness by 35%, and tree basal cover by 30% in dense forests. These projects may also disturb the habitats of aquatic species such as fish.

Limited exploitation of hydropower potential is also partly due to problems associated with the geological features of the region. The HKH region is in a seismic zone, so it is imperative to take earthquake resilience into account during construction, to avoid adverse future impacts on populations. In a study from Himachal Pradesh, India, Kumar and Katoch [52] identified seismic risk as one of the most important factors to be considered during the construction of hydropower projects.

In Jammu and Kashmir, India, local people have reported that during the construction phase of projects, dust clouds add to air pollution, resulting in respiratory health problems for them (Table 2; [30]). Hydropower projects also result in changes to water quality and temperature, soil erosion and degradation of land quality (e.g. waterlogging). Sometimes, across seasons, it also becomes difficult to maintain minimum stream discharge to sustain the environment and ecosystems in the downstream areas. Large hydropower projects in upstream areas reduce the frequency and magnitude of floods downstream, and benefit downstream communities; but these changes may also negatively affect downstream soil fertility and crop productivity in the long run (Table 2). In Pakistan, a recent study [53] found that the country's limited hydropower development can be attributed to factors such as inadequate investigation of projects, environmental apprehension, relocation and rehabilitation issues, land procurement problems, regulatory issues, long administrative procedures and – in some cases – interprovincial political issues.

5.3. Broader challenges to hydropower development

In addition to key issues presented in Table 2, there are some broader issues which have been affecting the hydropower development in the HKH region. The biggest challenge is that large scale projects involve high initial capital costs due to rugged topography [57]. In Pakistan, for instance, estimated construction cost of the Diamer-Bhasha Dam is around USD 14 billion, and the government is facing challenges in acquiring funds [58]. Similarly in Nepal, the estimated construction cost of West Seti dam of 750 MW is USD1.2 billion. Recently, some concerns are shown that this project might be financially unfeasible due to very high resettlement and rehabilitation costs because of difficult topography. Now, the government is thinking to reduce the power generation capacity to 600 MW for the same construction cost [59].

Policies of the HKH countries are also directly and indirectly affecting hydropower development. The governments are providing subsidy to import the fossil fuels that has favored the increased use of imported fossil-fuels. In Bangladesh, India and Pakistan, fossil- fuel subsidies were 0.6–0.7% of GDP in 2017 [60]. Particularly, in India, subsidies led to an increase in 'net coal import' nearly by 8 times in 2016 compared to 2000 [61]. Moreover, in the past, the governments in the HKH countries mainly followed sectoral approaches to construct dams with single purpose. These dams ignored the emerging interconnection of sectors such as irrigation (for agriculture and food, security), energy and disaster risk reduction, and paid inadequate attention to regional benefits such as navigation, transboundary river management and regional cooperation. Policies did not realize the importance of multipurpose dams (MPD) which address the interlinkages of sectors [62–66]. MPDs are more cost effective and efficient, and generate long term benefits across sectors [66].

Political factor within countries also severely impacted the hydropower development in the past. For example, the Maoist insurgency in Nepal lasted eleven years and ended only in 2006 damaged the powerhouses, small and medium dams, and transmission lines. The insurgency also resulted in a decline in the supply of finacial and technical resources from the international community to keep the existing grid working [45,47]. Internal political factors of countries may also affect the cooperation across countries. For example, the 'Power Trade Agreement' between Nepal and India in 1996 is yet to be approved by the Nepalese parliament. The frequent change in the government in Nepal, is affecting policy continuity and thereby, affecting the bilateral cooperation. Unstable political situation also leads to uncertainty in the business environment [67].

In the region, most of the rivers with higher hydropower potential are transboundary. The model of single purpose infrastructures is problematic in the transboundary river basins, and pays no attention to the mutual benefits for countries [62,65]. Without the mechanism of mutual benefits, it is difficult to strengthen the cooperation among countries. For example, India and Pakistan have dispute over water which also affects their diplomatic relations and overall cooperation at regional level [68].

Climate change induced extreme events are considered as one of the major challenges to water and hydropower infrastructure. The melting of glaciers in the HKH region has resulted in the formation of rapidly enlarging glacial lakes (GLs). Since the 1990s, there has been an increase in both area and number of GLs [69]. In Nepal and Pakistan, respectively 21 [70] and 52 GLs present a potentially dangerous risk [71]. These glacial lakes are potential threat to hydropower and irrigation infrastructure in the HKH region. In addition, increased incidence of erratic precipitations are resulting in high variability in the water availability in the region, affecting the hydropower projects in the region [65].

Some broader social challenges within countries such as community disagreement, income inequality, and divisions based on caste, ethnicity and religion are also significantly affecting the hydropower development in the HKH region [45,72].

6. Current policies and strategies on hydropower

While the physical hydro resources of the HKH region do not follow any administrative boundary, political boundaries in the form of countries shape the management and utilization of hydro-resources through pronouncement of various policies and strategies declared from time to time by countries of the region. The four countries considered in this study have various policies and strategies on energy, and have started to pay attention to RE resources, including hydropower. It is interesting to examine the specific policies framed to promote hydro-energy development and to assess how far these policies are effective in driving the sector.

In Bangladesh, energy consumption has grown significantly in last two decades [73], with a rise in economic growth [74]. This increasing trend is likely to continue in coming years as development efforts and economic growth accelerate [73]. Thus, energy supply must be improved to sustain the growth momentum of the country. In the past, poor pricing policies and similar bottlenecks resulted in inadequate investment of private sector in energy related projects [73]. The situation requires long-term sustainable plan to cope with the energy crisis and improve the energy supply to support development in the country [75]. The government has been trying to mitigate these challenges by undertaking plans and programs to ensure the supply of affordable and reliable electricity (Table 3) for all citizens by 2021 [74]. The government has paid attention to RE resources in respect of long-term sustainability (Table 3). The commercially feasible hydropower potential in Bangladesh is limited to 755 MW. The Renewable Energy Policy 2008 includes a provision to tap 70% of this unharnessed, but commercially feasible, potential (Table 1).

India has made substantial progress in its energy sector in general, and in RE in particular – including hydropower resources. Present-day policies (Table 3) are not immediate formulations; rather, they have undergone constant transformations from time to time. Factors promoting RE in India have changed, depending on the exigencies and requirements of the country from time to time. In the early 1970s 'energy security' was the motivation for energy policy making in the country, whereas the policy thrust during the early 1990s was to liberalize the sector and attract private investment. More recently, energy policy making is largely dominated by emerging concerns related to climate change and access to energy. Institutional arrangement of hydropower development is based on constitutional provision of energy as a 'concurrent item'. At the federal level, both the Ministry of Power (MoP) and the Ministry of New and Renewable Energy (MNRE) are responsible for the development of hydropower. MoP is entrusted with looking into projects of more than 25 MW capacity. MNRE is responsible for developing projects of up to 25 MW capacity (largely known as micro, mini and small hydel projects). The Ministry of Environment, Forests and Climate Change (MoEFCC) contributes to hydropower development in an indirect fashion by its involvement in the environmental impact assessment of projects and providing the necessary clearance processes. In addition to the ministries, central-level entities such as the Central Electricity Authority (CEA) is involved in the technical planning and appraisal of hydro projects. Provincial-level institutions are also created to promote hydropower (Table 3). Over the years, several policies and guidelines have been declared from time to time to promote hydro-energy resources (Table 3). Apart from national policy, state-level policies (e.g. in Uttarakhand and Sikkim) are also in place to promote hydropower development.

A review of central-level policies in India reveals some interesting facets of its hydro-energy policy focus. Policies that evolved in the domain of energy, such as the Electricity Act 2003, National Electricity Policy 2005, Tariff policy 2006, Rural Electrification Policy 2006 and Hydro Power Policy 2008 have provisions to develop RE in general, with specific provisions to promote the hydro-energy sector (Table 3). Policies that evolved as part of the larger climate policy, such as the National Environmental Policy 2006 and National Action Plan on Climate Change 2008, lay emphasis on the promotion of RE (including hydropower) both as an adaptation and mitigation strategy for climate change. The most recent declaration in the promotion of hydro-energy is targeted to attract inflow of private capital into the sector, by increasing the loan and depreciation period; this will further encourage development of hydropower through private sector participation.

In Nepal, energy policy formulation and regulation is a relatively centralized process, administered by the Ministry of Energy. Realizing the huge potential for hydropower, first hydropower development Policy was announced in the year 1992 (Table 3). Since then, the policy has been successful in attracting the private sector to hydropower development. However, many aspects, such as emerging international markets and their impact, the possibility of exporting hydropower, foreign investment and commitment to environmental protection are still unaddressed. It appears that the formulation of the Hydropower Policy 2001 was built on the lacunae of the earlier policy, incorporating all new criteria to make it more comprehensive and inclusive (and it remains relevant at the date of writing). Setting high goals for rural electrification, expanding grid-based electricity and developing hydropower as an exportable commodity, the policy also emphasized generating electricity at low cost by using the country's water resources. Learning lessons from previous policies, Nepal formulated Renewable Energy policies 2006 and 2009, Renewable Energy Subsidy Delivery Mechanism 2010 and Renewable Energy Subsidy Policy 2013 (Table 2). Subsidy mechanism and policy were designed with key objective of expanding the power sector in sustainable and environmental-friendly manner. Subsidy provision has promoted community participation, and tax-free incentives have helped micro-hydro technologies to develop into exemplars. However, there is still some room for improvement in the management of off-grid rural electrification from micro-hydropower.

In Pakistan, achieving energy security has been a concern for government as the country has been searching for a sustainable, reliable and affordable energy supply [28]. In the next 20–25 years Pakistan will need US$210 billion to meet its growing energy demands [28]. About 13% of country's river water flows can be stored and easily used

Table 3
Policies and strategies related to renewable energy.

Country	Policy and strategy	General focus	Focus on renewable energy including hydropower
Bangladesh	Private Sector Power Generation Policy of Bangladesh 1996 [77]	● Attract private investment in power sector and encourage private sector power generation	-
	National Energy Policy 1996 [78]	● Meet energy demand for economic growth ● Develop indigenous energy sources ● Promote sustainable utility operations ● Encourage private and public participation in energy sector, and establish a regional market for energy ● Achieve the target of 100% electrification by 2020 ● Ensure affordable and reliable energy supply	● Develop environmentally friendly RE sources
	Private Sector Infrastructure Guidelines 2004 [79]	● Establish procedures to identify PIPs ● Set guidelines for private sector investors and government for procurement and implementation of PIPs ● Set procedure to monitor and expedite PIPs implementation	-
	Policy Guidelines for Power Purchase from Captive Power Plant 2007 [80]	● Reduce gap between energy supply and demand by using surplus capacity of CPPs and allow to purchase electricity from CPPs	-
	Remote Area Power Supply System Guidelines 2007 [81]	● Provide an area (either on-grid or off-grid) to private investors for developing an electricity generation and distribution system	-
	Policy Guidelines for Small Power Plants 1998 (revised 2008) [82]	● Accelerate establishment of SPPs ($\leq$ 10 MW) by private sector for their own electricity needs. SPPs greater than 10 MW need special permission from government	-
	Renewable Energy Policy of Bangladesh 2008 [83]	-	● Achieve 5% share of RE in total generation by 2015 and 10% by 2020 ● Facilitate public and private sector investment in RE ● Increase RE contributions to electricity, and substitute RE for indigenous non-RE sources ● Promote and facilitate RE use at every level ● Establish SEDA to act as a focal point for sustainable energy development and promotion ● Create market opportunities and start-up business models for sustainable energy technologies
	Policy Guidelines for Commercial Independent Power Producer 2008 (amended 2010) [84]	● Encourage private sector participation, efficient use of natural gas, competition, and development and revival of power plants	-
	Guidelines for the Implementation of Solar Power Development Program 2013 [85]	-	● Improve solar technology, and attract donor organizations and private investors
	Action Plan for Energy Efficiency and Conservation 2013 [86]	● Set a cohesive framework for energy efficiency and saving activities	-
	Perspective Plan Vision 2021 [87]	● Meet the projected demand for power of 20,000 MW by 2021	-
India	Electricity Act 2003 [88]	● Promoted competition, safeguarded consumer's interest and opened opportunities for IPPs	● Emphasis on promoting generation of RE ● Promote RE as part of CC mitigation solutions
	National Electricity Policy 2005 [89]	● Realize three aspects (generation, transmission and distribution) of electricity development ● Reiterate the issues raised by Electricity Act	● Realize RE as an option to enhance power generation
	Tariff Policy 2006 and Amendment 2016 [90]	● Supply electricity at competitive rates and guarantee financial sustainability in power sector ● Improve benefits under Clean Development Mechanism for projects with lower GHG emissions	● Encourage competitive bidding and promote RE
	Rural Electrification Policy 2006 [91]	● Improve rural electrification	● Promote RE-based electricity generation ● Set up institutional mechanisms to get better services and technical support for systems based on RE sources
	Hydro Power Policy 2008 [92]	-	● Increase participation of private sectors in HP development ● Safeguard and compensate HP project-affected families ● Follow environmental norms while developing HP projects ● Promote HP as an action towards mitigating climate change

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Table 3 (*continued*)

Country	Policy and strategy	General focus	Focus on renewable energy including hydropower
Nepal	Hydropower Development Policy 1992 [93]	-	● Meet electricity demand of population, particularly from rural areas, through hydropower development ● Improve hydropower to meet the energy requirements for industrial development ● Attract national and foreign private sector investment for hydropower development
	Hydropower Development Policy 2001 [94]	-	● Generate hydropower at low cost, and recognize it as essential input for national and regional economic development ● Ensure reliable electricity supply at reasonable price ● Consider HP as an exportable commodity ● Work to achieve bilateral and regional cooperation for water resource development
	National Water Resource Strategy 2002 [95]	-	● Develop cost-effective HP in a sustainable manner
	Community Electricity Distribution Bye-laws 2003 [96]	Promote public participation Encourage community management Promote technical and managerial capability of rural community Attract private investment in rural electrification	-
	Renewable Energy Policy 2006 [97]	-	● Reduce dependency on traditional energy and conserve environment by increasing access to RETs ● Increase employment and productivity through RETs ● Increase living standard of rural population by integrating RETs with social and economic activities
	Renewable Energy Subsidy Policy 2009 [98]	-	● Maximize service delivery efficiently in RE use in rural areas; provide opportunity for low-income rural households to use RETs ● Improve rural electrification ● Ensure appropriate use of donors' grants, and so attract more donors to RET sector ● Support development and extension of RET market by attracting private sector entrepreneurs
	Renewable Energy Subsidy Delivery Mechanism 2010 [99]	-	● Make necessary arrangement to channel all funds through RE fund; establish subsidy criteria and delivery mechanisms
	Renewable Energy Subsidy Policy 2013 [100]	-	● Increase access of low-income households to RETs by reducing initial costs ● Maximize service delivery efficiently for RE use in rural areas; provide opportunity to low-income rural households to use RETs ● Support productive use of energy by creating rural employment opportunities for rural people, particularly vulnerable groups ● Encourage rural households to use RE services, so contributing to better health and education conditions of people
Pakistan	National Power Policy 1995 [101]	-	● Formulate policy framework and package of incentives for private sector hydropower generation projects ● Promote hydropower development ● Identify potential hydropower sites ● Involve private sector in hydropower development ● Consider water user rights in hydropower development

(*continued on next page*)

Table 3 (*continued*)

Country	Policy and strategy	General focus	Focus on renewable energy including hydropower
	National Power Policy 1998 [102]	● Encourage private independent power projects ● Ensure low levels of tariff through competitive international bidding	● Revealed specific guideline for technical, financial and economic standards for HP development
	National Power Policy 2002 [103]	● Provide power at least cost and reduce shortfalls	● Encourage use of local resources (e.g. water) for power generation; consider environmental aspects
	Alternative and Renewable Energy Policy 2006 [104]	● Improve energy security; reduce dependence on single source for maximum economic benefits ● Invite investment from private investors	● Realize importance of RE ● Ensure social equity and equal distribution of electricity ● Reduce work load on women (who collect biomass) through improved RE supply ● Gradually substitute for conventional power through clean RE alternatives
	Alternative and Renewable Energy Policy 2011 [105]	-	● Encourage development and growth of alternative energy resources in joint collaboration with federal and provincial governments ● Reduce energy crisis by using alternative energy resources (AER) ● Facilitate private investors in AER ● Assist capacity building of different institutions involved in AER ● Facilitate manufacturing of country's AER technologies and technical skills ● Enhance and improve impact of alternative and RE in least-developed and poor areas
	National Power Policy 2013–2018 [106]	● Focus on socioeconomic crisis in face of energy deficit ● Emphasize integrated efforts to overcome energy crisis efficiently and effectively ● Strengthen collaborations of federal and provincial governments for energy development ● Reduce debasement, pilferage and financial losses in energy sector	-
	Power Generation Policy 2015 [107]	● Encourage investors to use country's local resources to generate power ● Ensure win–win for all stakeholders ● Distribute electricity at least cost ● Encourage projects under public–private partnership	● Ensure mainstreaming of environmental aspects ● Encourage HP development by private sectors ● Encourage 'run of the river' projects
	Khyber Pakhtunkhwa (KPK) Hydel Power Policy 2016 [108]	● Provide affordable electricity to population and industries ● Attract private sector investment ● Ensure welfare and development of all stakeholders	● Produce clean/green energy based on indigenous resources ● Ensure and encourage participation of investors in implementation and development of hydel power projects ● Ensure transparent development of hydropower projects
	Pakistan Vision 2025 [109]	● Eliminate current electricity supply–demand gap by 2018; cater to growing future demand by adding 25,000 MW by 2025 ● Introduce institutional reform and strengthen regulatory frameworks to improve transparency and efficiency	● Tap the huge potential for alternative energy ● Ensure uninterrupted access to affordable and clean energy for entire population ● Complete two major hydel projects: Diamer-Bhasha and Dasu dams

CC, climate change; CPP, captive power plant; GHG, greenhouse gas; HP, hydropower; IPP, independent power producer; PIP, private infrastructure project; RAPSS, remote area power supply system; RE, renewable energy; RET, RE technologies; SEDA, Sustainable Energy Development Agency; SPP, small power plants.
Hyphen (-) means that the policy does not have particular aspects.

for hydel power generation. Actions to tap hydropower potential depend on fund mobilization, which is a major political issue in Pakistan [29]; at the same time, it is imperative for sustainable economic growth, as envisaged in Vision 2025 [76]. The Ministry of Water and Power (MoWP) plays a vital role in implementing all energy-related policies. The country's first inventory of hydropower potential was created in the 1980s after the establishment of Mangle and Tarbela reservoir. Later, in the 1990s, detailed investigations were conducted to identify potential sites for hydropower generation in the Indus basin, River Jhelum and River Kabul. Overall, most energy policies have mainly focused on hydropower development (Table 3) owing to the country's high potential for this source of energy (Table 1). Sustainable economic growth, as envisaged in Vision 2025, means that developing indigenous energy resources (like hydro and alternative energy) is imperative [76]. To this end, the government is committed to adding 25,000 MW power (mainly hydropower) to national capacity by 2025 to ensure uninterrupted, affordable and clean energy for all (Table 3).

7. Opportunities to capitalize on existing potential

Despite various issues related to hydropower development in the HKH region (Table 3), it still has many advantages over conventional non-RE resources in terms of environmental aspects, production cost and supplementary benefits such as water storage for irrigation and drinking purposes. It also has advantages over some RE resources such as wind and solar in terms of production cost [17]. The regional countries can make efforts to mitigate the negative impacts of hydropower development by paying due attention to local communities and socioeconomics, and to environmental aspects. This section presents some opportunities to tap potential hydropower in the region.

7.1. Large hydropower projects with a smart approach and minimal negative impacts

It is important to undertake a robust study of comparative analyses of available alternative options to choose the most appropriate option. This analysis can involve the comparison of alternatives based on multidimensional criteria taking into account the technical, economic, environmental and social dimensions. The selection of the most appropriate alternative based on multidimensional criteria is referred to as 'smart approach' in this study. For instance, if the project which addresses the protection of aquatic life in its design, it will be a better option in terms of environment and ecosystems. Passage of migrating fish should be ensured through construction of facilities to allow upstream fish passages and sufficient flows within and below the reservoirs [110,111]. It is also important to allow the mandatory 15–20% environmental water flow for sustainability of aquatic life, and downstream water demand for irrigation and drinking [52]. Water quality and oxygen concentrations in reservoirs and tail-waters may be increased by installing improved aerating turbine runners, and making aeration weirs in the tailrace below the dam [112]. To reduce the possible negative impacts of dams, planning and designing phase can engage all stakeholders including potentially project-affected communities in a consultation process (indicator of social dimension). This participatory process is likely to minimize opposing outcomes with regard to compensation, resettlement and rehabilitation plans [110].

7.2. Promoting micro-hydropower

Among the range of RE technologies, micro-hydropower plants (MHPs) of up to 100 kW [113] providing a renewable, sustainable and clean source of energy to poor rural households, have been one of the most promising and commonly adopted decentralized (off-grid) technologies [114]. MHPs have far fewer negative/adverse social, environmental and economic impacts on local communities, and they are suitable technological and developmental interventions in the HKH regions [114].

India, Nepal and Pakistan have rich experience in micro-hydropower projects, and especially in relation to community involvement in the planning, construction and operation of such plants [115–117]. India has also extensively promoted its small hydro program under MNRE. The estimated potential of these projects in India is close to 20,000 MW in 6774 sites largely located in the mountainous region of Himachal Pradesh, Uttarakhand, Jammu and Kashmir, and Arunachal Pradesh as run-off projects. Plains regions such as Maharashtra, Chhattisgarh, Karnataka and Kerala also have a reasonable number of small hydro projects. These projects are largely developed by private investors with support from the Government of India. By 2016, about 1075 sites had been exploited, with a cumulative capacity of about 5325 MW. About 250 projects, with cumulative capacity of about 800 MW, are at various stages of implementation [118].

In the remote mountain valleys of Chitral and Gilgit-Baltistan in northern Pakistan, Aga Khan Rural Support Program introduced MHPs (150 kW or less) in 1990 as a community-led development initiative. By 2005, 240 such plants with a cumulative capacity of around 10,000 kW were built by the communities [119]. Promoting the use of indigenous resources and RE can reduce the country's reliance on any single source, particularly imported fossil fuels, and improve Pakistan's energy mix [120].

Similarly, beginning in the early 1960s, micro-hydro development has made a great contribution to rural electrification in Nepal [124]. Off-grid electrification through micro-hydro has grown at a rapid pace in rural Nepal (Fig. 5). With the potential of developing more than 50 MW of hydroelectric power from MHP schemes [113,125], Nepal has successfully generated around 38 MW (Fig. 5) of electricity from mini- and micro-hydro plant development [126].

7.3. Regional electricity trade: a win–win management option

Electricity shortage in the region itself opens up the possibility for regional electricity trade. Countries with potential for hydropower generation can obtain large benefits by connecting their hydropower stations to transboundary power grids and trading electricity with other nations. The power transmission infrastructure is limited in South Asia. Only India has cross-country interconnections with other countries such as Bangladesh and Nepal, placing that country in a unique position as key in promoting electricity trade in South Asia [20].

Numerous statements of cooperation and several bilateral agreements have been implemented in the energy sector between India and regional member countries. The existing agreements need to be further strengthened and operationalized. Currently, power exchange between India and Nepal is taking place at 21 interconnections through different transmission lines (e.g. 11 kV and 33 kV), but these are not adequate to accommodate the transfer of surplus summer power from Nepal to India. The Government of Nepal has established the country's first large-capacity interconnection between India and Nepal [22]. India intends to use its recent domestic experience in regional grid interconnections to expand to cross-border grid interconnections.

In 2010, Bangladesh and India signed a memorandum of understanding (MOU) to initiate cross-border electricity trade. This led to development of a 400 kV, 30-km double-circuit high-voltage direct current (HVDC) line from Bheramara (Bangladesh) to Baharampur (India) and a 500 MW 400/230 kV back-to-back HVDC substation at Bheramara with an initial capacity of 500 MW, which can be later expanded to 1000 MW [127].

There is opportunity for hydropower trade between India and Pakistan. Given the severe power shortages in Pakistan, and the open access power transmission possibilities in India, there is now renewed interest in pursuing mutually beneficial cross-border power transfer between the two countries [39].

Trade in the energy sector can help countries to strengthen national energy security, move smoothly to a RE regime, optimize electricity costs and minimize adverse impacts from energy price volatility. It is likely to induce positive impacts of power trade in South Asia with respect to industrial production, finance, revenue, GDP, foreign exchange gains and progress in rural electrification. Electricity trade in the region may result in optimal use of regional natural resources and reliable power supply.

7.4. Strengthening regional cooperation on hydropower development

In the HKH region, uneven spatial distribution of natural resources has created a need for regional cooperation in the energy sector, particularly hydropower [128]. The SDGs (particularly SDG-7 on clean and affordable energy) need intergovernmental cooperation at the regional level to increase economic opportunities.

Recognizing the importance of electricity in promoting economic growth and quality of life in the region, a number of export-oriented bilateral agreements have been implemented in the energy sector. However, to ensure optimal use of the available water resource for maximized benefit, it is now important to move action from bilateral to regional multilateral collaboration. Indeed, no matter how much technical potential exists, it is of little use unless cooperation and an effective mechanism are developed [25]. This involves a wide range of actions, including establishing a cross-border infrastructure, and promoting regional forums to share both knowledge and the experience that is widely available within the region [129]. Using infrastructure such as high-voltage transmission lines, countries with abundant hydropower resources can use their reservoirs as 'batteries', to balance the variable power generation in neighboring countries [14].

Tapping the hydro resources of the region also means it is imperative to harmonize country-level policies, regulations and legal institutions with each other to smoothen the process of creating a common platform.

A few initiatives have been taken at regional level. The formal process of energy cooperation at the level of the South Asian Association for Regional Cooperation (SAARC) was initiated in 2000. This process included most HKH countries. The South Asia Regional Initiative for Energy Integration is one of the initiatives designed to move South Asian countries towards increased regional energy security [130]. The program aims to address policy, legal and regulatory issues related to energy in the region. It has been supporting regional efforts and bilateral energy development programs through large-scale infrastructure investment, technical assistance, feasibility studies and advisory services [39]. However, concrete regional efforts are still required to implement such initiatives and allow them to be successful.

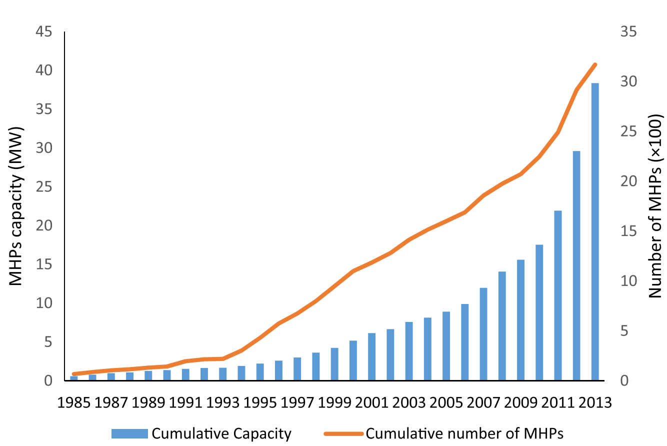

Fig. 5. Cumulative micro-hydro growth in Nepal. MHP = micro-hydropower plants.
Source: AEPC [121–123].

8. Conclusions

Hydropower continues to be the leading RE option, and it has the additional benefits of water storage for agriculture and other uses. Globally, hydropower produces almost 16% of electricity and over 80% of renewable electricity. South Asia's considerable hydropower potential is concentrated in the HKH region. Four HKH countries – Bangladesh, India, Nepal and Pakistan – have hydropower potential of 334 GW, of which nearly 190 GW is commercially feasible. However, only one-third of this potential has actually been tapped so far. Nepal and Pakistan have tapped 2% and 12%, respectively, of their commercially feasible hydropower potential. In the region, where 26–37% of the rural population is already living without access to electricity. Future electricity demand is likely to increase sharply because of fast economic growth, rising populations, rapid urbanization and agricultural development in the region.

There are several economic, social, technical, political, physical, environmental and ecological challenges to hydropower generation in the HKH countries. Some broader issues such as political instability, a lack of funds and climate change, are also adding to the challenges of hydropower development. Despite these challenges, hydropower remains the cost-effective option for achieving RE goals and, if managed well, should have relatively limited impact on the environment. The energy-related policies and strategies of HKH countries have emphasized RE resources, and particularly hydropower production. In this enabling policy environment, the countries need to realize the untapped potential of hydropower production, not only to fulfill the growing demand for electricity, but also to meet SDG-7 on clean and affordable energy. To achieve this goal, we suggest that the following opportunities should be capitalized on:

- Large, 'smart' hydropower projects may be developed, taking into account the economic, environmental and social concerns of local and downstream communities, in addition to national economic benefits. Technical provisions in smart projects can minimize the impacts on aquatic life and terrestrial ecosystems.
- MHP production may also be promoted, as it has very limited adverse social and environmental impacts on local communities. Several studies have found that MHP is a very suitable and successful technological and developmental intervention in the HKH regions of Pakistan, Nepal and India.
- Electricity shortages and growing demand in the region itself open up the possibility for regional electricity trade. Countries with potential for hydropower generation could gain large benefits by connecting their hydropower stations to transboundary power grids and trading electricity with other nations. Trade in the energy sector will help countries to strengthen their national energy security, move smoothly to RE regimes, optimize the cost of electricity and minimize adverse impacts from energy price volatility. It might have positive impacts on industrial production, GDP, foreign exchange gains and progress in rural electrification in the participating countries.
- Recognizing the importance of electricity in promoting economic growth in the region, there is need to operationalize the bilateral and regional cooperation agreements on energy security. This involves a wide range of actions including establishing cross-border infrastructure and promoting regional forums for sharing knowledge and experience widely available within the region [39]. In this regard, the formal process of energy cooperation at SAARC level may be followed, to address policy, legal and regulatory issues, and to support energy development programs through large-scale infrastructure investment and technical assistance. Moreover, regional platforms such as the International Center for Integrated Mountain Development (ICIMOD) may also be used for sharing knowledge and experiences.

Acknowledgments

Authors would like to thank the handling editor and two anonymous reviewers for their highly valuable input. They would also like to thank Elaine Monaghan for her editorial input. This work was carried out by the Himalayan Adaptation, Water and Resilience (HI-AWARE) consortium under the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) with financial support from the UK Government's Department for International Development (DFID), London, UK, and the International Development Research Centre (IDRC), Ottawa, Canada.

This work was also partially supported by core funds of ICIMOD contributed by the governments of Afghanistan, Australia, Austria, Bangladesh, Bhutan, China, India, Myanmar, Nepal, Norway, Pakistan, Sweden and Switzerland.

The views expressed in this work are those of the authors and do not necessarily represent those of DFID, IDRC or its Board of Governors; nor are they necessarily attributable to the authors' affiliated organizations.

Declaration of interest

None.

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