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The role of renewable energy in achieving water, energy, and food security under climate change constraints in South Asia

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The energy demand in South Asia is increasing at a rapid rate and it is becoming harder to meet the demand due to the high cost of conventional energy sources, the unsustainability of energy use, and the high emissions caused by the energies. South Asia is blessed with a high potential for renewable energy, especially hydropower, but that has not been adequately tapped. This has highly compromised the food, water, and energy security of the people in South Asian countries. This article identifies the roles of renewable energy sources in achieving energy, water, and food security for South Asian nations and provides suggestions for enhancing the utilization of renewable resources. The article identifies the potential for the promotion of hydropower and other renewable energy sources as well as opportunities and potential challenges for multilateral energy trade for increasing the availability of energy. It also recommends possible solutions and approaches for the promotion of hydropower and other renewables in South Asia. The article infers that a nexus approach for integrated planning, policy coherence, and institutional harmonization increases the benefit by reducing transaction costs, generating additional synergies, and reducing the trade-off at different scales. These approaches enhance energy, food, and water security, and eventually improve the quality of life in the region. Improved access to renewable energy can contribute directly and indirectly to achieving Sustainable Development Goals (SDGs) in this region.

KEYWORDS

renewable energy, hydropower, water-energy-food nexus, climate change, South Asia

Introduction

South Asia is home to 1.75 billion people which is almost one-fifth global population living within an area of 5,134,641 km^2, i.e., 23% of the world's land (Rasul, 2014). Approximately half of the world's poor and slightly more than one-third of the world's undernourished people live in South Asia. Per capita energy consumption is among the lowest in the region. About 417 million people (24%) lack access to electricity and 60% of the total population depend on biomass for cooking and heating (Rasul, 2014)[1,2]. About 20% of the population lack access to safe drinking water (Rasul, 2014) and 60% of the population lack access to improved sanitation (WHO/UNICEF Joint Water Supply Sanitation Monitoring Programme, 2014). Energy demand is increasing at 7.4% per year (Hydro Status Report, 2017) due to the growing population and rapid economic transformation. The energy and water demand of India and the cereal demand of the entirety of south Asia are expected to double by 2035 (Rasul, 2014; EIA, 2018).

Meeting energy demand in South Asia from conventional energy sources is expensive and unsustainable; it contributes to higher emissions and global warming. About 80% of the commercial energy mixture in South Asia comes from fossil fuels and hydropower contributes <6% to commercial energy (Tortajada and Saklani, 2018). The use of coal in South Asia is expected to grow from 2 to 27.6% in 2030, as coal is the main indigenous energy source in Pakistan and Bangladesh (see text footnote 2). Nepal alone imported fuel of Rs 214.48 billion in 2020 which is nearly 15% of Nepal's total budget in that fiscal year.

Figure 1 depicts the trend of three different sources of irrigation over a period of half-century starting from 1950 in South Asia. The figure clearly shows the exponential growth in the use of groundwater over the fifty years, which implies that the insecurity in energy imposes a threat to water and food security globally and in South Asian nations in particular. Considering the upstream-downstream interdependency in this region, energy, water, and food challenges remain crucial. Unfortunately, no country in South Asia is energy sufficient. More than 30% of energy demand is satisfied through imports in this region. The share of imported energy to total primary energy use (excluding biomass energy) is 86.3% for Nepal, 56.7% for Bhutan, 43.3% for India, and 26.3% for Bangladesh (Tortajada and Saklani, 2018). Currently, 60% of GHG emissions come from energy in India. India's energy-related CO_2 emission was 573 MTOE in 1990 and it increased to 1,566 MTOE in 2015, a 173% point increment in the total global emissions (EIA, 2018)[3]. CO_2 emission in India is increasing at 1.8% annually compared to 1.3% global growth rates (see text footnote 3; EIA, 2018). On the other hand, higher dependency on biomass and fossil fuel contributes to higher emissions and global warming.

The South Asian region is very rich in freshwater resources since it is interconnected by the Transboundary River system of the Ganges, Brahmaputra, Meghna, and Indus. As the riparian countries in those river basin systems, there is a strong upstream-downstream linkage among Afghanistan, Pakistan, India, Bangladesh, Nepal, and Bhutan. The upstream countries provide freshwater to the downstream countries for irrigation, domestic use, flood regulation, and drought mitigation, while the downstream areas supply food and feed to the living beings in the upstream areas. Agriculture downstream depends on upstream water sources.

The upstream areas have locational advantages for multipurpose hydro-dams because of their comparatively low population density and hence lower domestic demand. The surplus can be traded to downstream countries which can be a good source of revenue for the upstream countries. Hydropower is non-consumptive water use and thus it is advantageous from an economic perspective to let each cubic meter flow through as many hydropower generation facilities as possible before it is withdrawn for consumptive use, such as agriculture. For example, a cubic meter of water flowing through the Himalayan rivers from upstream Nepal to India and then to Bangladesh can generate hydropower at different dam sites in Nepal and also add irrigation values to the farmers living downstream in India and Bangladesh on its way to the Bay of Bengal. The importance of upstream-downstream interdependence and the value of regional cooperation for optimal hydropower development and regional electricity trade of resources have not yet been fully appreciated in this region.

Hydropower is only the renewable energy in this region that is commercially viable on a large scale. It is an important source of power to resolve energy-water and food challenges (World Bank, 2014), and can also be a gateway for the economic development of the region. This region has an estimated 388 GW of hydropower potential; to date, only 16% has been tapped. Nepal, Afghanistan, and Bhutan have the lowest hydropower exploitation rate. Nepal alone has a hydropower potential of 83,000 MW, and it has only developed <2% of technically feasible hydropower capacity. Even if the energy demand of Nepal increases at a rate of 10% annually, domestic demand will reach only 3,679 MW by 2027 (Bergner, 2013), which is only 8% of the technically feasible hydropower potential and 4% of the theoretical potential. This presents an immense opportunity for the hydro-rich country such as Nepal in terms of energy trade, which will also help enhance the energy security of the South Asian region (Rahaman, 2012).

Operationalization of the energy-water-agriculture nexus would help find the solution for energy, water, and food security issues in South Asia. The nexus approach helps bring policy coherence and institutional harmonization at cross-sectors and cross-country levels. Nexus is a universal principle but issues differ with the different resource endowments. In the South Asian context, water availability and yield improvement are possible through improvement in energy access. Here, nexus

1 International Energy Agency (IEA) (2018). Available online at: http://www.iea.org/statistics/.

2 World Bank (2018). Available online at: https://data.worldbank.org/.

3 World Energy Outlook (2017). Available online at: https://www.iea.org/weo2017/.

has to be looked into from an energy perspective because energy is central to water and food security and climate change adaptations. The UN Sustainable Development Goals (SDGs) have stressed that access to modern energy is a requisite for achieving Sustainable Development Goals (UNDP, 2013) and is also considered the best adoption option for climate change. This is the current policy focus of South Asian countries. For instance, during COP 21 in Paris on Intended Nationally Determined Contributions (INDCs), India committed to reducing 33–35% of greenhouse gas emissions by 2030. This commitment is considered the game-changer of the energy mix of all of South Asia to switch to a more sustainable mode of energy which is only possible through improvement in energy trade in the region. It will help increase energy availability, change the current fossil-fuel-dominated energy mixture to clean energy, and most importantly the hydro-rich countries will generate substantial revenue through electricity exports. A World Bank study shows this region can save up to US$226 billion during 2015–2040 at the rate of US$9 billion per year by adding only 95 GW energy (only 25% of the total potential) if there is the provision of unrestricted cross-border trade (Timilsina and Toman, 2016).

This article aims to present energy, water, and food security in the South Asian context from a nexus perspective, where the untapped potential of renewable energy, particularly hydropower can play a vital role in improving the nexus. It shows the major challenges of the slow growth of renewable energy and suggests nexus-focused solutions for overall national improvement.

Challenges of energy, water, and food security in South Asia

South Asia suffers from energy security which has a direct linkage with food and water security. Climate change further exacerbates energy, water, and food security. This section describes the issue of energy security in South Asia that affects food and water security differently and how climate change further impacts the nexus.

Energy security

The major source of energy for the population of South Asia is biomass, followed by oil, gas, coal, and electricity. Approximately, 65% of the total population relies on the biomass of mostly wood, crop residues, and animal dung. This dependency on biomass is not only inefficient but also has severe health and environmental consequences. South Asia's commercial energy mix is composed of 50% coal, 29% petroleum, 13% natural gas, 5% hydroelectricity, 1% nuclear energy, and 17% renewables (see text footnote 2). But the contribution of clean energy, which mostly consists of hydropower, is very minimal; it is only 6%.

Fossil fuel is the main source of commercial energy in most South Asian nations. Fossil fuel is considered an unsustainable and unpredictable source of energy with higher emissions and, additionally, its supply is subject to price volatility. Even though India and Pakistan have the largest technically feasible hydropower source in South Asia, the electricity generation in these nations is not only predominantly based on fossil fuels but also shows an increasing trend in harvesting electricity from fossil fuels (Tortajada and Saklani, 2018) This trend has been reflected in some of the other South Asian nations as well.

By sector, in South Asia, the industrial sector is the most energy-intensive area which consumes 45% of the total energy supply, followed by domestic use (25.1%), transportation (13.5%), commercial and public services (3.7%), agriculture/forestry (2.5%), other non-specified (1.3%), and non-energy use (9.2%) (see text footnote 2). As the industrial sector is the most energy-intensive area, the impacts of economic growth, growing population, and climate change will demand more energy in the future. The expansion of industrial sectors in South Asia has elevated economic growth and livelihood, while the GHGs generated from this sector also aggravated the impacts of climate change in the region.

Figure 2 depicts the per-capita energy consumption in South Asian countries which is almost negligible in comparison to a developed country, for example, Iceland, which has the highest per-capita energy consumption. It shows there is a higher gap and energy demand in this region is expected to increase exponentially with the pace of their economic growth. For instance, energy use in India has doubled since 2000 and 80% of its demand is still fulfilled by coal [International Energy Agency (IEA), 2021]. Low per-capita energy consumption and higher dependency on biomass and fossil fuel reflect energy insecurity and energy poverty in South Asia. Per-capita energy consumption is strongly correlated with food and water security and the overall economic development of the region. Considering the growing economic growth and increasing population and climate change impacts, it is expected to shrink further in the future.

Electricity access is another important dimension of energy security. This is also very poor in South Asia. Figure 3 depicts the population access of electricity to the percentage of national population in south Asia.

Over 376 million population in the six South Asian countries are deprived of electricity. Access to the electricity grid, reliability, regularity, adequacy, and quality energy supply in South Asia is very poor. The access to electricity in rural areas is even worse in South Asian countries even though the rural areas need quality energy supply for transportation, to improve agricultural productivity, and to bring new opportunities for generating income (Practical Action Nepal: Annual Report, 2010).

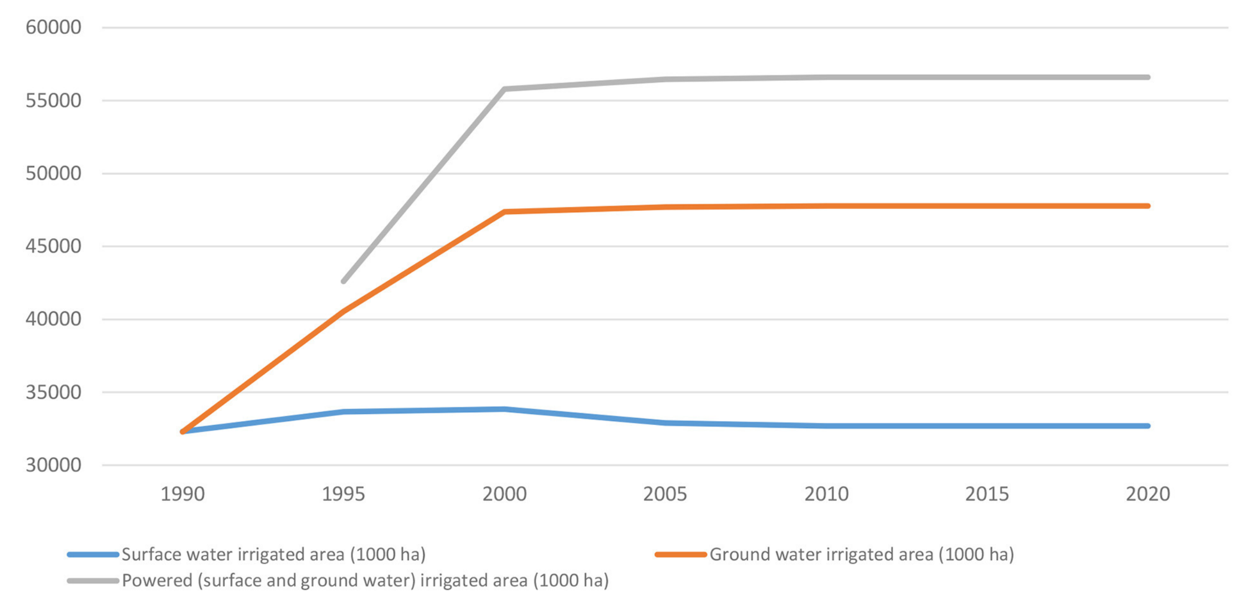

FIGURE 1
Trend of use of different sources of water for irrigation in South Asia from 1990 to 2020 (AQUASTAT, 2020).

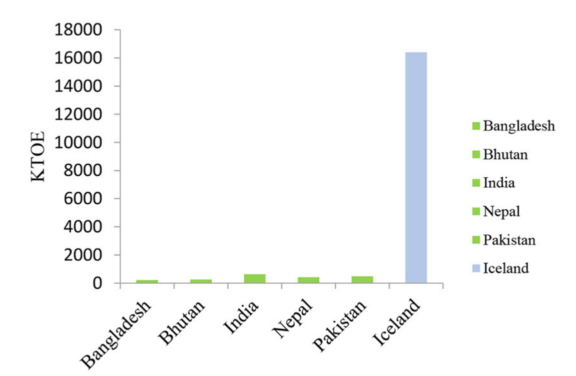

FIGURE 2
Per-capita Energy Consumption (PCEC) of SA nation compared to the nation with the world's largest PCEC (see text footnote 2).

Energy and water linkage

Energy security and water security have a two-way relationship as energy insecurity results in water insecurity and vice versa. Growing energy insecurity in this region impacts water security because energy is required to improve water availability and access.

More than half of the population that suffers from acute water scarcity lives in South Asia. Figure 4 elucidates the total percentage of drought effected area and there respective drought effected agricultural area; this is about 180 million in India and 73 million in Pakistan (Mekonnen and Hoekstra, 2016). Approximately 20% of the population lives without access to safe drinking water in South Asia (Rasul, 2014). The two largest countries of South Asia, India, and Pakistan are already water-stressed and water demand is predicted to increase by 55% by 2030 in South Asia (Rasul, 2014, 2016).

Out of 270 million ha of cultivated land in this region, 55% of the land still depends on rainwater for irrigation whereas, 45% of the land relies on an artificial irrigation system. Out of the total land with irrigation facilities, more than 55% of the land is groundwater-dependent. The production from this land contributes to 70–80% of the food demand (Rasul, 2014, 2016). Approximately 70–75% of the irrigated land in Bangladesh is fed by groundwater (Shahid, 2011) which was almost negligible during the 1960s. In India, Bangladesh, and Pakistan, groundwater is mostly used for domestic and agricultural use, which is energy-dependent. In many parts of India and Pakistan, groundwater extraction exceeding the recharge limit has resulted in its depletion. Approximately 6% of the national emission comes from groundwater withdrawal in India (Schröter, 2013). There is an estimated 26 million groundwater pumps for irrigation. Replacing only 5 million diesel pumps with electric pumps in India could save nearly 10 billion liters of diesel annually and several tons of emissions (Shah and Kishore, 2012).

Hydroelectricity generated as renewable energy has been recognized as a vital energy source in South Asia to cushion the emission generated from the industrial sectors. Since agriculture is a major source of economy in South Asia, agro-based industries such as dairy, cotton, sugar mills, fisheries, and brewery industries are growing at a faster pace, and reducing emissions by shifting from fossil fuels to renewable energy sources like hydroelectricity would help mitigation efforts to

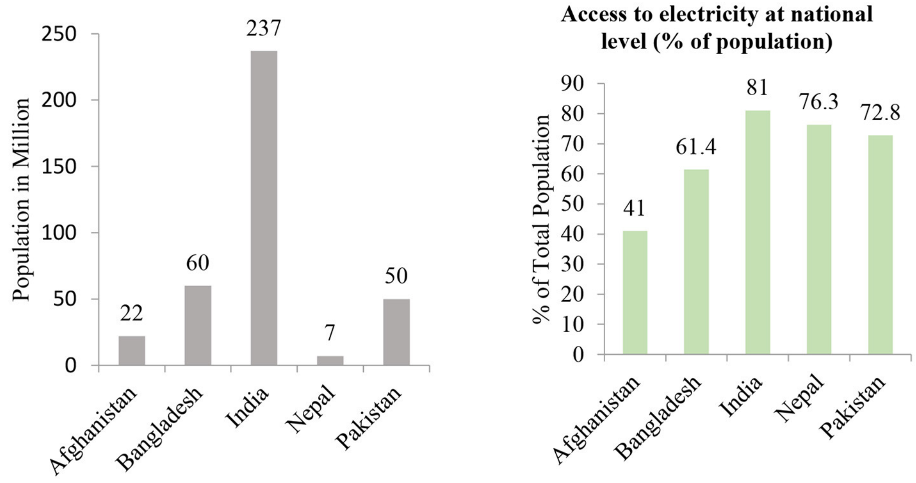

FIGURE 3
Population with electricity access.

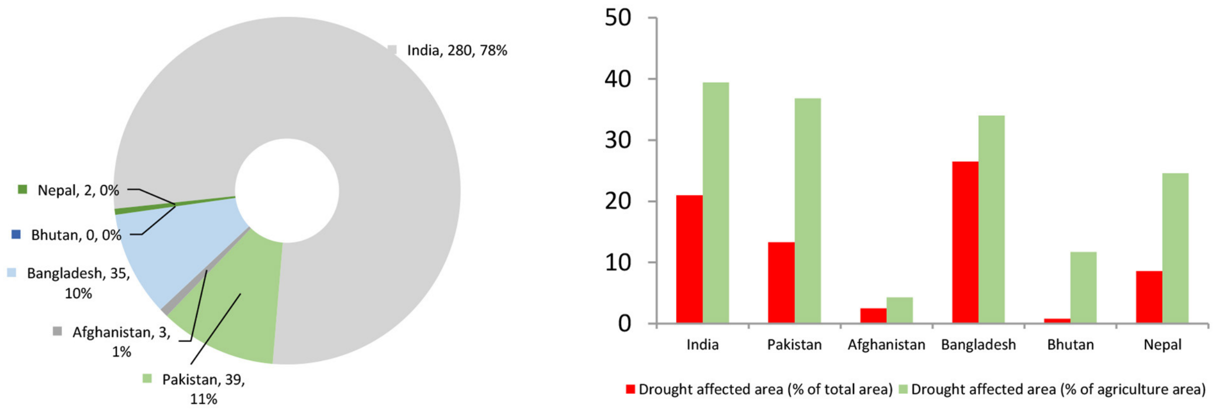

FIGURE 4
Population per million and agricultural land affected by drought.

climate change and contributes to the sustainable development in the region. Moreover, shifting to electric vehicles in the transport sector and access to cleaner energy sources in all the domestic, commercial and public sectors would help lessen the GHG emissions in South Asia. The practice of using indigenous knowledge in the region such as running water mills for small industries could be promoted as it demonstrates the nexus of water-energy and food under the changing climate.

Energy and food linkage

Energy is vital for food production, agriculture intensification, food transportation, and food price stabilization. Due to the rapid population growth, the per capita land availability in South Asia is decreasing. Per capita land availability in south Asia has dropped by almost four times within half a century (1960–2013) (see text footnote 2). By 2050, the population of South Asia is expected to reach 2.3 billion, and 65 % of this population will be urban. Accordingly, cereal demand is expected to double during the same time. On the other hand, due to urbanization and an increase in incomes, there is a significant move from starch-based diets toward more protein-based diets such as meat and dairy, which are more energy and water-intensive.

Currently, the use of energy in the agriculture sector is <5% in South Asia (Figure 5). The energy used in the agricultural sector is mostly fossil fuel-based which is used for farm mechanization, agrichemicals, and transportation. The portion of energy shared by South Asian nations in agriculture is far less

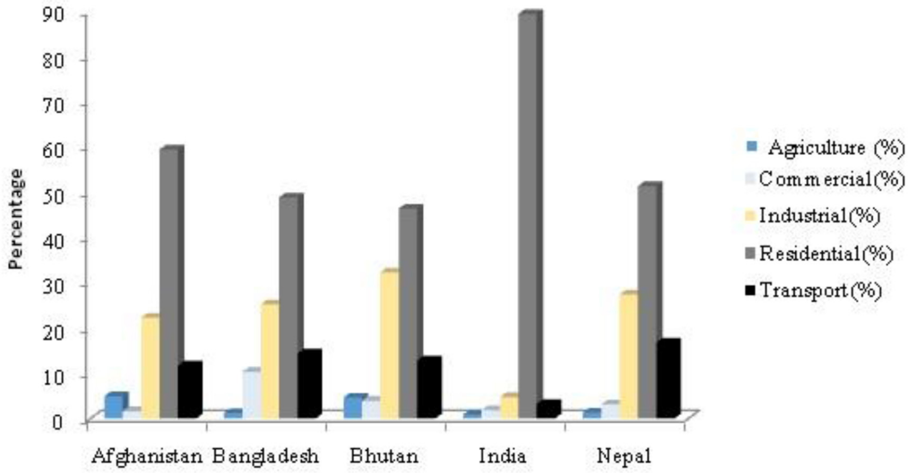

FIGURE 5
Energy consumption by different sectors in 2016.

when compared to that of developed nations. More than 55% of water in irrigated agriculture comes from groundwater in South Asia (Rasul, 2014) which requires energy. Most of the pumps in South Asia use fuel as a source of energy. In India alone, agricultural pumping accounts for 1/3rd of the total energy consumption, which mostly comes from fossil fuels (Kumar, 2005).

Similarly, the production of fertilizers and agrochemicals requires a huge amount of energy. About 40 GJ of energy is required to produce one ton of Ammonia. The use of agrochemicals in agriculture results in Methane (CH_4) and Nitrous Oxide (N_2O) emissions. Looking at the aggregate figure in agriculture, for example, the total commercial energy input to Indian agriculture has increased from 425.4 × 109 Mega Joules (MJ) in 1980–81 to 2592.8 × 109 MJ in 2006-07. The consumption of energy per hectare of the net sown area has increased from 3 to 18.5 thousand MJ during this period (Surendra et al., 2011).

Increases in oil prices impact all aspects of commercial food systems. For example, between 2007 and 2008, world oil prices dramatically increased to US$150 per barrel, which was considered a major driver for increases in food prices. This has added millions of food-insecure people in the developing world (AQUASTAT, 2020). At present, the production of biofuels in South Asia is very modest, but might increase as a result of rising energy prices. This will increase competition for land and water resources for food or fuel production in South Asia, which is struggling for both food and energy security (De Fraiture and Wichelns, 2010). The increase in biofuel production in agricultural land in South Asia may increase energy production to some extent, but directly compete with food security as per capita land availability in South Asia is already very low in comparison to the global average.

Climate change impacts on energy

Climate change and extreme events alter water availability which ultimately imposes impacts on energy generation. On the other hand, higher dependency on biomass and fossil fuel contributes to higher emissions and results in global warming and climate change. There exists a two-way relationship between climate change and energy. Water availability is highly vulnerable to climate change. Rising temperature accelerates glacial melting and increases evapotranspiration, erratic rainfall, and droughts.

The mountains of the Hindu Kush Himalayan (HKH) region, the water tower of Asia, are warming significantly faster than the global average. By 2050, the temperature in the HKH region is predicted to increase by 1–2°C on average. In mountainous and high-altitude areas, temperature increases of 4–5°C result in faster shrinkage of the snow cover and glaciers (Shrestha and Aryal, 2011). Snow and glacier contribute more than 10% of annual discharge in the Nepalese river basin (Andermann et al., 2012). Glacier meltwater accounts for 10–15% of dry season flow in the Ganges (DFID, 2008). In the Budi Gandaki basin in Nepal, for example, glacier contribution to the total measured streamflow is about 30% (Jeuland et al., 2013). The disappearance of mountain glaciers in this region will have a significant impact on water resources, energy production, agriculture, and other uses. It is estimated that there will be a 3% average reduction in hydropower supply in Nepal, 2.7% in India, and 3.5% in Bangladesh by 2050 (Turner et al., 2017) due to climate change.

Increasingly intense flood events and glacial lake outbursts can cause severe harm to power production infrastructure and can result in more frequent blackouts in regions where

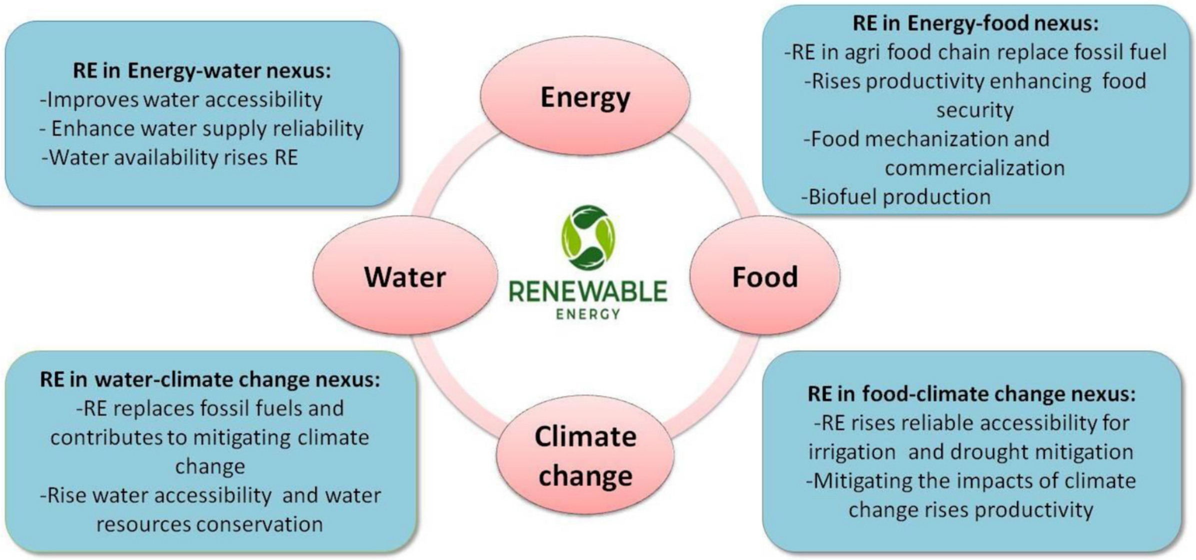

FIGURE 6
Renewable energy opportunities in the water, energy, food nexus, and climate change adaptations.

power plants are constructed close to surface water resources. Flooding as a consequence of climate change and climatic variability has a plethora of negative impacts on agricultural land, and infrastructure including hydro energy production in many cases. For instance, in India, 1,282 people were killed by flooding, with millions of people affected (EM-DAT, 2021). In addition, fuel transport by road faces increased delays due to the interruption in the transportation routes by flooding.

Similarly, with the increase in temperature and drought events, the agricultural sector will require frequent irrigation, and energy demand in the agriculture sector will increase. Bandara and Cai estimated a significant reduction in crop yield in this region due to climate change. This could reduce GDP by 2–5% by 2050 (Bandara and Cai, 2014). The decrease would mainly be due to excessive heat and insufficient water interrupting crop growth in combination with extreme events, especially floods and droughts (Bandara and Cai, 2014). Droughts are severe challenges in South Asia. The major river basins of this region are categorized as having high drought severity (Chapagain, 2017). India and Pakistan reported major droughts at least once every 3 years in the past four decades, while Bangladesh and Nepal also suffer from frequent droughts. It is estimated that 5,308 people were killed; 1.3 billion people were affected. This caused total damage of USD$37.43 billion due to droughts between 1975 and 2015 in South Asia (EM-DAT, 2021).

On the other hand, the overuse of fossil fuel and biomass as a source of energy is contributing to greenhouse gas emissions and global warming. South Asia contributes about 16% of the total global emissions (Tortajada and Saklani, 2018), and 60% of South Asia's emissions come from the agriculture sector. Black carbon mostly comes from the burning of fossil fuel and biomass, and cooking fires. It is considered the main cause of the rapid increase in temperature in the mountains. An estimated, 30% of glacial retreat across HKH was caused by black carbon which might have a significant impact on water availability, energy production, and food production in this region. Due to the over-dependence on natural gas, GHG emissions have increased particularly in more industrialized countries which is further accelerating global warming. CO_2 emissions from the consumption of natural gas in India, the third-biggest greenhouse gas emitter in the world have increased from 7 MMTOE in 1980 to 101 MMTOE in 2015. Energy-related CO_2 emissions in India are almost 5% of total global emissions. Similarly, CO_2 emissions in Pakistan and Bangladesh have increased from 15 to 66 MMTOE and 2 to 52 MMTOE, respectively (EIA, 2018). The emissions are further expected to increase in the future if South Asia does not switch to renewable energy very soon.

The commitment of South Asian nations to achieve SDGs by 2030 have being compromised by the impact of climate change and extremities which is further intensified in the absence of access to reliable sources of energy. For instance, this region depends on groundwater for agricultural use and food security, and fossil fuel is mostly used for groundwater pumping which not only increases the GHG emissions but also increases the variability in production due to timely access to energy for agricultural uses and variability in energy prices. The recent Russia-Ukraine war has increased the prices of energy used in agriculture by 3 to 4 folds resulting in reduced agricultural production and dramatically increase in food prices (Jagtap et al., 2022). Therefore, an increase in the availability of renewable energy in this region will provide an opportunity to achieve SDGs, ensuring a resilient production system and healthy environment for present and future generations.

Renewable energy is central to the water-energy-food nexus and climate change adaptations

Figure 6 depicts the Renewable energy opportunities in the water, energy, food nexus, and climate change adaptations. Renewable energy, mostly hydropower can contribute to achieving energy, water, and food security in various ways and it is also considered the best adaptation option to climate change. The interdependencies among water, energy, and food are multidimensional, and their relationship often has a nexus. Energy is central to the nexus as it is required for food production (especially irrigation) and farm mechanization. Energy is needed for water supply, including the extraction, purification, and distribution of water as well as for adaptation to climate change impacts, such as droughts. But the exploitation of fossil fuel and biomass for energy is creating unsustainability in energy supply, higher energy prices, and, most importantly, GHG emissions and global warming. The energy is needed to be decoupled from fossil fuel to overcome food prices, increase access to food and maintain energy security for other uses.

The use of renewable energy increases agriculture production through farm mechanization and expansion in irrigated land, fertilizer production, food processing, and transportation and helps to switch from traditional subsistence-based agriculture to more competitive and commercial agriculture. Renewable energy could help stabilize food prices for consumers and reduce financial risks for producers and others involved in the food supply chain. Additionally, it could also strengthen the development of non-farm commercial activities, including micro-enterprises, and create opportunities for other livelihood activities (DFID, 2008). Substituting traditional biomass for cooking with renewable energy is imperative for social, health, environmental, and economic development. Additionally, traditional biomass demands more labor and time, particularly affecting women. This effect can be reduced through the introduction of renewable energy in rural areas. Switching from fossil fuel to renewable energy in agriculture is important from the perspective of decreasing the cost of agriculture production, decreasing uncertainties in power supply, reducing fossil-fuel use, and emissions. Therefore, there is a need to integrate energy, water, and food chains with renewable energy, such as hydropower development, that produces little or no greenhouse gases and does not consume water.

Potential of renewable energy development in South Asia

There is huge potential for harnessing hydropower and other renewable energy in South Asia. Harnessing hydropower potential in the region can change the current fossil-fuel-centric energy mixture, ensure a reliable supply of energy, improve energy, water, and food security, and reduce emissions. Some 400 million people in South Asia who lack electricity can get access by tapping the renewable energy potential. In addition, renewable energy helps stabilize volatile energy prices and can play an important role in energy trade and regional power pools. Considering the potential of renewable energy, governments in the region have recently emphasized renewable energy in their national policies.

During COP 21 in Paris on Intended Nationally Determined Contributions (INDCs), India has committed to reducing 33–35% of its greenhouse gas emissions by 2030. This commitment is considered a game changer to change South Asia to a more sustainable mode of energy. Now India is leading the world in terms of solar energy production. There is already some satisfactory growth in other renewable energy in Bangladesh and Pakistan as well.

Similarly, the National Renewable Energy Policy (NREP) of Pakistan has indicated that 2% of the annual development budget will be allocated every year for the development of renewable energy (Solangi et al., 2011). The National Renewable Energy Policy of Bangladesh (2008) has determined that it will make a 10% increase in the share of renewable energy by 2020 of its target (Biswas et al., 2011). Afghanistan has identified in its national plan that electricity exporting is a key strategy for economic development. Nepal and Bhutan policy documents prominently consider hydropower exports as an important source of income for their economies and a major driver of their economic growth. The Energy Policy of Nepal (2006) has envisaged contributing to rural poverty reduction and environmental conservation by ensuring access to clean, reliable, and appropriate energy in rural areas. The Rural Energy Policy of Nepal (2006) of Nepal declared that the government would provide a subsidy amounting to 40% of the total costs of the renewable plants for the private sector/community or households depending upon the type of renewable energy. The government of Nepal has declared that it will generate 20MW of electricity by wind energy in the Three-Year Interim Plan of Nepal (Surendra et al., 2011).

Potentiality of hydropower and other renewables

Hydro power

Hydropower has the most potential but radially exploited clean source of energy in South Asia. Tapping its potential can be the gateway for achieving energy, water, and food security and economic development of the region. The Himalayan topography, good rainfall, and abundance of glacier-fed perennial river basins provide an opportunity for generating an enormous amount of hydropower. The potentiality for the generation of hydroelectricity is higher than other renewables like wind and solar energy considering the economic feasibility, and topographical and meteorological factors on a longer basis.

The total hydropower potential of the six south Asian countries is more than 388 GW. Only 62 GW (16%) is exploited currently. The highest potential exists in India, Pakistan, Nepal, Bhutan, and Afghanistan. Bangladesh holds very little potential. The exploitation rate is very negligible in comparison to the potential. For example, OECD has exploited up to 70% of its hydropower potential and other developing countries have exploited 23% (World Bank, 2009). The hydro potential of South Asian countries is minimally exploited especially in Afghanistan, Nepal, and Bhutan where the exploitation rate is below 6% of the commercially feasible potential supply. The total electricity supply from hydro-source is about 100% in Bhutan, 92% in Nepal, 33% in Pakistan, and 17% in India (see text footnote 2).

At the river basin scale, Brahmaputra holds a total of 200 GW of hydropower potential. This is the greatest in the world but the least exploited (only 10 GW). The Ganga's theoretical hydropower potential is estimated to be about 83,000 MW in Nepal, 21,000 MW in Bhutan, and almost 59,000 MW in northeast India of which half or more is considered to be feasible for harvesting (Rasul, 2015). The Ganges and its tributaries also have huge potential for hydropower development and trade. A recent study conducted by the World Bank suggests that about 25,000 MW of electricity could be generated in the Ganges basin through upstream storage of water in 23 dams and that this could provide benefits worth USD 5 billion per year with little trade-off. The collective potential of hydropower in the Indus River system is about 60 GW, but only 6,720 MW (11%) have been utilized (Rasul, 2015).

Others renewables

Given that South Asia is a tropical region and its weather, both solar and wind could be equally potential sources of renewable energy after hydropower. Currently, the government of India is paying higher attention to solar power and has initiated the Solar Mission as one of the major initiatives for renewable energy. The solar power installed capacity in India has increased from only 3.7 MW in 2005 to about 4,060 MW in 2015, with more than 100% annual growth over the decade. India has a target to generate 100 GW of solar energy by 2022. Similarly, wind energy potential in India accounts for 102 GW; currently, only 21% is installed. India currently stands as the 5th largest wind power producer in the world. India has a target to install 60 GW of wind power by 2022. Pakistan carries a huge potential for both wind and solar energy. Approximately, 6,840–8,280 MJ/m^2 of solar energy can be generated annually and three provinces – namely Balochistan, Sindh, and Punjab have the most potential for solar energy in Pakistan (Solangi et al., 2011). Similarly, Pakistan has 20 GW of economically viable wind power potential (Sheikh, 2009). In Nepal, about 25% of the population is getting access to electricity through renewable sources, such as solar and wind. The annual average solar potential varies from 3.5 to 7.0 kWh/m^2/day and the estimated number of days of sunshine in Nepal is 300 days per year (Mainali and Silveira, 2013). Afghanistan has an annual average solar potential that varies from 4 to 6.5 kWh/m^2/day spread over 300 days of sunshine per year (Mainali and Silveira, 2013). Solar energy is largely untapped in both countries. The current status and potentiality of solar and wind energy in South Asian nations are shown in Table 1.

Opportunities for regional electricity trade

Electricity trade in the South Asian region will increase energy availability, change the current fossil-fuel-dominated energy mixture to clean energy, and, most importantly, the hydro-rich countries will generate substantial revenue through electricity exports. No country in South Asia is energy secure. South Asian countries have different resource endowments, demand trends, and development needs. The feasible hydropower potential of Nepal, Bhutan, and Afghanistan are significantly higher than the domestic demand. India and Pakistan also have higher hydropower potential but their domestic demand is also higher. Bangladesh does not have more hydropower potential and mostly depends on fossil fuels. These complementary opportunities provide an ideal situation for power trade in this region and trade flows from surplus zones to scarce zones. Energy resource surplus countries could benefit from energy exports to the countries with more demand for power. The geographical proximity of hydropower plants from Bhutan and Nepal to the major demand centers in Northern India, and Bangladesh would allow sub-regional interconnections. Theoretically, electricity generated in Nepal could be transmitted to Bangladesh, Bhutan, India, and Pakistan (Pokharel, 2001) through regional electricity trade. Currently, regional energy trade in South Asia constitutes $<5\%$ of total trade within the region. Bhutan is in the process of developing

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TABLE 1 Renewable energy and its potential in South Asia (Brown, 2009; Sheikh, 2009; Baruah, 2017; Hydro Status Report, 2017).

Indicators	Afghanistan	Bangladesh	Bhutan	India	Nepal	Pakistan
Theoretical hydropower potential	23,000	–	30,000	184,700	80,000	100,000
Commercially feasible Hydropower potential (MW)	23,000	755	24,000	84,004	43,000	59,000
Hydropower Installed (MW)	442	230	1,615	51,756	867	7,320
Current utilization (%) (of the technical feasible)	1.9	30.4	6.7	61.61	2.01	12.4
Wind potential (MW)	66,000	20,000	760	102,778	448	131,800
Wind Installed (MW)	0.375	1.9	0.6	22,465	–	20,000
Solar Potential (kWh/m^2/day)	6.5	5	4	5	4	5.3
Installed solar photovoltaic (MW)	11	368	–	4,060	–	1,600

export-oriented hydro- projects with success, whereas Nepal has not achieved much success yet. As per the draft NEP (Dec 2016) of India, Nepal would have an export potential of 13.2 GW by 2015 and 24.9 GW by 2035; excluding the 3 major projects of Karnali, Chisapani, and Pancheshwar.

A study done by the World Bank shows this region can save up to US$226 billion during 2015–2040 at the rate of US$9 billion per year by adding only 95 GW energy (only 25% of the total potential) if there is a provision for unrestricted cross-border trade (Timilsina and Toman, 2016). This provision would reduce regional power sector carbon dioxide emissions by 8%, mainly through the substitution of coal-based generation with hydro-based generation. It has been estimated that regional electricity would bring an 8-fold increase in electricity supply and bring electricity access to the entire continent with multiple additional benefits for water management and regional integration.

There are successful electricity trades outside the region which can be a good lesson for South Asia. Examples of successful regional/sub-regional electricity trade include the Gulf Coast Countries (GCC), the Greater Mekong Sub-region (GMS), the Nile Basin Initiative (NBI), Nordpool, the Southern African Power Pool (SAPP), South East Europe (SEE), the European Network of Transmission System Operators for Electricity (ENTSO-E), and Central American Electrical Interconnection System (SIEPAC).

Challenges to renewable energy development in South Asia

Hydropower development in South Asia started long ago. India started hydropower production 150 years ago from Darjeeling, whereas Nepal started it in 1911 with a 500 kW Pharping hydropower plant. Despite the head start, renewable energy development in South Asia did not accelerate regardless of its potential. To date, in South Asia, only 16% of the total hydro potential has been tapped into and hydropower contributes 6% of the total energy mix (see text footnote 2).

This section describes the major limitation to the development of hydro and other renewable energy in South Asia.

Policy barriers

Despite the fact that renewable energy is critical for development, the renewable energy sector has not received significant attention in the policy arena. Governments in most South Asian countries are directly and indirectly providing subsidies to import fossil fuels and that has favored the increased use of imported fossil fuels.

In Bangladesh, fossil fuel subsidies have exceeded 3% of the GDP for many years (see text footnote 2). The significant increase in the use of fossil fuels in India is influenced by the subsidy for fossil fuels. High levels of regulation and trade barriers in electricity trade and low incentives for private sector participation are the other policy challenges inhibiting hydropower growth in South Asia. Water policies and institutions in the transboundary basin scales and regional scales in South Asia are fragmented and have led to poor coordination for hydropower development, water resources planning, and management. Moreover, the generated hydroelectricity in South Asia has faced challenges in cross-border trade with its limited transmission lines (Timilsina and Toman, 2016). For instance, policy barriers have been one of the major challenges in the trade of hydroelectricity between Nepal and India which imposes conflict on bilateral and multilateral agreements. The strategic multilateral agreements between the South Asian countries are equally important rather than the bilateral agreements of most of the nations with India. Thus, it requires the periodic amendment of policies and laws favoring the cross-border hydroelectricity trade including the establishment of the regional/sub-regional grids and institutional arrangements in the region.

Limited infrastructures

Hydro-power sector infrastructure includes hydro dams and transmission at the national, sub-regional, and regional levels. The infrastructure development in this region is severely challenged particularly in mountainous countries like Nepal, Bhutan, Afghanistan, and the northern part of India. Infrastructure development in this region is severely challenged by rugged terrain, and higher risks of natural disasters, such as Glacial Lake Outburst Floods (GLOFs) and sedimentation. These countries have limited technical capabilities for infrastructure development.

The biggest challenge of renewable energy is that it involves high initial capital costs and a long payback period. The cost of dam construction is very high in mountainous countries like Nepal. For example, Exim Company of China constructed the West Seti Dam in Nepal with 750 MW capacity for 1.6 billion USD. Similarly, a hydro project of 2,600 MW was constructed in Nigeria by the same company for USD 1 billion during the same period (McDonald et al., 2009). The resource required for hydropower infrastructure development in South Asia is very high. In India alone, the Planning Commission estimates that $500 billion is required for the next 5 years to meet the energy needs of a growing population and rapid urbanization through renewable energy (World Bank, 2009).

The South Asian nation has barely developed basic infrastructures like transportation in the hilly areas. Most of the potential hydrogenation sites are located in remote areas and, therefore, the lack of basic infrastructure development increases the cost of the entire project. Furthermore, the lack of basic infrastructures such as transmission lines and regional power grids has been a major challenge for the cross-border electricity trade. Direct foreign investment or national investment in the development and expansion of such infrastructures would help in cross-border trade in South Asia.

Suggested solutions for promoting hydropower and other renewables in South Asia

The promotion of broader regional and sub-regional cooperation goes beyond the current bilateral arrangement. A nexus approach for policy coherence and institutional harmonization, collaborative investment in infrastructure, and private sector participation are the key areas for promoting renewable energy and hydropower in South Asia. Research and information sharing are equally important to examine the interventions in the South Asian context.

Regional cooperation should go beyond the current bilateral arrangement of energy trade

Energy can be the entry point for regional and sub-regional cooperation in South Asia. A strong bilateral trade is the entry point for establishing a regional power pool and regional electricity trade (Singh et al., 2015). Such regional and sub-regional cooperation help to increase mutual benefit through stimulating emerging opportunities in renewable energy, particularly in the hydropower sector to achieve water, energy, and food security, and climate change adaptation at transboundary and regional scales. The bilateral and sub-regional arrangements that exist today are sector-specific and cannot fully utilize those opportunities. The lack of timely cooperation in this region may result in many non-cooperative and unilateral efforts and can result in negative externalities to the neighboring countries and future potential conflicts on water. For example, unilateral hydropower development and water diversion plans in the Ganges and Brahmaputra Rivers basins by India may bring environmental disasters and conflicts in the decades to come with Bangladesh being affected the most negatively (Rahaman, 2012). The South Asia region is losing USD$10 billion dollars annually due to the lack of proper water resource development (see text footnote 2) and hydropower development. So, for mutual benefit and co-development, broader regional cooperation is important in this region, keeping the energy at the center.

Nexus approach for integrated planning, policy coherence, and institutional harmonization

The nexus approach helps to address energy, water, and food security and climate change adaptation at regional scales for which integrated planning, policy coherence, and institutional harmonization play a crucial role. Realizing the energy challenges of South Asia, each south Asian country has developed its own plan to meet the energy demand. Undermining the cross-sectorial and cross-country impacts, such divergent, fragmented, and independent sectoral approaches are more risky, expensive, and unsustainable, and can also create serious problems at national and transboundary scales. Therefore, the planning and implementation of hydropower should be integrated with nexus components, such as water and food security and climate change.

The nexus approach helps to increase the benefit by reducing transaction costs, generating additional synergies, and reducing the trade-off at different scales. The nexus approach treats the issues holistically and establishes linkages across boundaries. It cannot be applied to the status-quo policy and institutional landscape. Policy coherence and institutional harmonization are key factors for operationalizing the nexus approach at different scales to achieve energy, water, and food security in South Asia. For policy coherence and institutional harmonization, the public sector can play a vital role in coordinating, setting incentives, and being the regulatory mechanism to make policy more coherent across institutions and sectors. There might be conflicting policies like subsidies for energy use in agriculture that deplete the groundwater. For harmonizing policies and institutions, there is a need to revise policies that are developed focusing on a single sector. These policies should be upgraded or removed if they are found to be counterproductive to water, energy, and food security.

There is a two-way relationship between climate change and three nexus components. The nexus should therefore be linked with issues of climate and its variability. Accordingly, the energy, water, and food policies have to be aligned to build climate resiliency. It is a time to move from sectorial to cross-sectoral adaptation and from local to the regional level to find a sustainable and holistic solution. Therefore, it calls for a strong intervention in the hydro-power sector to positively enhance the food-water-energy nexus. There is now a growing realization of the need to address energy security from a regional perspective. The role of regional and sub-regional institutions such as the South Asian Association for Regional Cooperation (SAARC), Bangladesh, Bhutan, India, Nepal (BBIN), and South Asia Regional Initiative/Energy's (SARI/E) are increasingly important and needs strengthening to bring policy coherence at sub-regional and regional level in South Asia.

Collaborative investment on multi-purpose projects and the role of private sectors

Collaborative investments in hydro-infrastructure and encouraging private sector participation in infrastructure development can aid the infrastructure challenges in this region. There is a need for substantial improvements in water infrastructure to meet food, water, and energy security. The cost of water infrastructure is excessively high with high risks and uncertainties and a long payback period. Water infrastructure also requires a high level of technology. It is very hard to channel large investments, especially for the hydro-rich upstream countries, such as Bhutan, Nepal, and Afghanistan. There is a need for collaborative investment in multi-purpose hydro projects to exploit the hydro potential of this region. India and Pakistan are relatively strong in technology for infrastructure development and this strength can be exploited through regional cooperation for infrastructure development in this region. Multi-objective collaborative water infrastructures are the implication of the nexus approach on the ground and a cost-minimizing approach. Multilateral organizations such as the World Bank have been actively engaged to foster regional cooperation for infrastructure development in this region (Bandyopadhyay, 1995). Collaboration on water infrastructures fosters regional trade and economic integration where water infrastructure acts as the entry point for the sub-regional and regional cooperation in this region (Whittington, 2004).

Normally, the private sectors are generally unwilling to invest in water infrastructure development in South Asia because of the large investment, long payback periods, risks, and government policies. For example, the private sector investment in hydro-power infrastructures in Nepal is around 20% (Shah and Kishore, 2012). Power companies are licensed only to develop power projects (Baruah, 2017) and irrigation projects from the same water source go to two different companies.

There are good examples that the Chinese Export–Import Bank and state-owned enterprises, and private firms are now involved in at least 93 major hydro projects in the world (McDonald et al., 2009). There are several potential private sectors at the regional and global scales. The private sector increases resource efficiencies through the sustainable use of resources. National and regional governments bring conducive policies and regulations to bring the private sector to the main frontier of hydropower development and other renewable energy.

Research

Empirical evidence shows that 1 dollar on expenditure in research in the water sector brings benefits of more than 100 dollars (Kattelmann, 1987) as it helps to minimize the risks of project failure and helps to create a conducive environment for the implementation. The research helps to generate more comprehensive nexus knowledge. Better knowledge improves the understanding of risks and provides a more solid basis for nexus decisions. The optimum utilization of water resources for energy, water, food security, and climate change adaptations in South Asia requires more detailed research at the transboundary and regional levels to understand the risks and develop reliable scenarios. Another goal of the research is to elaborate consistent scenarios of possible socioeconomic development and climate change impacts with the purpose of identifying future development opportunities as well as understanding the implications of different nexus-focused policies in the South Asian context. There are several threats imposed on the hydro sector from climate change, natural hazards, seismicity, and socio-economic and political drivers. There is a need for rigorous study before the implementation of such a big project.

The bio-physical challenges of integrated water resource development in this region are sedimentation control, natural hazards, and climate change. The melting of glaciers in the Himalayas because of climate change has resulted in the formation of large and rapidly swelling glacial lakes. Estimates suggest that ∼2,300 glaciers in Nepal's Himalayan region contain growing glacial lakes which are potentially dangerous to the water infrastructure. These lakes can damage agricultural fields, lives and livelihoods, and critical infrastructure, including hydropower. Glacial lake outburst is a potential threat to integrated water infrastructures, including hydropower.

Another research gap is in sedimentation. The Ganga is one of the most sediment-laden rivers in the world. The Ganges and the Brahmaputra carry over a billion tons of silt to the Ganges–Brahmaputra–Meghna (GBM) delta every year (Jeuland et al., 2013). The sedimentation issue is largely underestimated and less studied in this region (Kattelmann, 1987). Socio-economic and bio-physical factors should be clearly understood before the implementation of big hydro projects in South Asia and ICIMOD being a research organization can support the generated knowledge which will be helpful for hydropower development to achieve energy, water, and food security in South Asia.

Conclusion

The lack of utilization of the full potential of renewable energy by the nations in this region has highly compromised the food, water, and energy security of the people. Moreover, the impact of climate change is expected to further exacerbate the food, water, and energy insecurity in this region. This article identifies the roles of renewable energy sources in achieving energy, water, and food security for nations in the South Asian region and provides suggestions for further development in the utilization of renewable resources. The potential for the development of hydropower and other renewable energy and opportunities for multilateral energy trade to increase the availability of energy are identified along with potential challenges. This article suggests possible solutions for the promotion of hydropower and other renewables in South Asia through different approaches. The nexus approach for integrated planning, policy coherence, and institutional harmonization is one of the approaches that this article focuses on. This helps to increase the benefit by reducing transaction costs, generating additional synergies, and reducing the trade-off at different scales. These approaches will help mitigate several challenges faced in the process of improving energy, food, and water security. A secured supply of food, water, and energy improves the quality of life in the region and improves economic and infrastructural development processes in the region. The use of renewable energy at its full potential is considered one of the effective adaptation measures to climate change and attaining SDGs in South Asia.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Author contributions

NN prepared concept note, methodology, analysis, and writing. PC prepared concept notes, writeup and editing. YR collected primary and secondary data, analysis, interpretation, and write-up. BG worked in data collection, analysis, visualization, and write up. RB worked in data visualization, write-up, editing, and proofreading. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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