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Review article

Hydropower: A low-hanging sour-sweet energy option for India

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A R T I C L E I N F O

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A B S T R A C T

India is the world's second largest populous nation, fifth largest economy with seventh largest geographical area but experiences high energy poverty. With the lowest per capita energy consumption among world's top ten economies, India ranks at 137 out of 218 nations. Hydropower has the potential to alleviate India's energy asymmetry as well as realize its sustainable growth aspiration of a low-carbon regime. However, hydropower in India has been plagued by debates on human displacement, loss of biodiversity, increased risk of natural disasters, and socio-economic conflicts making it an unpopular energy alternative. Here, we review and address various concerns related to India's hydropower sector, examine scientific evidence, analyze energy policy imperatives, geopolitical considerations, and future directions for a sustainable hydropower policy in India in the context of ongoing climate change. Evidence indicates that besides electricity generation, hydropower infrastructure helps: (i) avert floods, (ii) mitigate the impacts of global warming, and (iii) ensure redistribution of water to arid regions and improve water security. As a part of sustainable hydropower policy, we propose that most of the ecological and social problems associated with hydropower development can be avoided to a great extent through careful planning, proper project design, responsible ownership, and public participation. As short-term measures, we propose: (i) entrepreneurs and planners follow credible and transparent pre-project investigations, (ii) mandatory implementation of environmental management plans, and (iii) better accountability and transparency of statutory bodies as well as hydropower developers. For long-term measures, we suggest: (i) create a 'National Institute of Energy & Environmental Sustainability' to oversee post-project hydropower developmental activities, (ii) streamline various bureaucratic and institutional procedures, and (ii) establish a trans-boundary water management system for seamless and coordinated implementation of hydropower development programs across upstream-downstream nations.

1. Introduction

Despite great strides in economic development in the last seventy-five years after independence, India continues to experience energy poverty, ranking at 137 out of 218 nations in electricity consumption for which data is available. Among the top ten world economies, India's per capita electricity consumption is the lowest at 1208 kW-hour per year (kWh/year) compared to 14,612 kWh/year of Canada, 12,154 kWh/year of USA, 5885 kWh/year of China and 2830 kWh/year of Brazil. The scale of India's per capita electricity consumption asymmetry is quite stark. On average, an Icelander consumes 43 times, a Norwegian 19 times, a Canadian 12 times, an American 10 times, a Chinese about 5 times and a Brazilian 2 times more electricity compared to an Indian. Despite such a

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low global rank in electricity consumption, hydropower in India is a contentious energy option. The low electricity consumption levels in India are a function of multiple causes including low generation capacity and supply. Projection models reveal that the demand-supply gap in electricity in India was around 20.5% in 2021–22 which is likely to reduce to 17.4% by 2026–27 and to 14% by 2036–37 [1]. Thus, the increasing demand for electricity to meet India's economic growth targets, the demand-supply gap will continue for some more time before it eases out considerably. Generating electricity from as many sources as India possibly can, is key to the nation's energy policy. Hydropower is an important part of this mix, but the sceptics hold dams and dam-building activities to be the root cause of ecological and socio-economic catastrophes. On the contrary, hydropower planners and developers consider that some civil society groups and non-governmental organizations (NGOs) present a lop-sided view including fearmongering about hydropower development. This debate, for instance, has engendered a public perception that most of the disasters in the Himalaya including floods, landslides and other natural hazards are associated with the dams and dam building. As such, dam-building cannot be labelled as an environmentally benign activity, but does scientific data support this perception and is the level of criticism commensurate with the evidence? Dam-building, like any other major developmental activity, transforms natural landscapes and brings about the degradation of natural resources and ecosystems besides having negative socio-economic and cultural impacts [2,3]. Given the contestations and claims surrounding hydropower [4], a critical analysis of the available evidence is warranted for making informed choices as far as hydropower development in India is concerned. Moreover, a pertinent question is: whether or to what extent can or should a nation be prepared to bear the losses caused by hydropower infrastructure. Because the hydropower development in India is largely concentrated on the Himalayan rivers (Fig. 1), the following analysis is largely focused around this region.

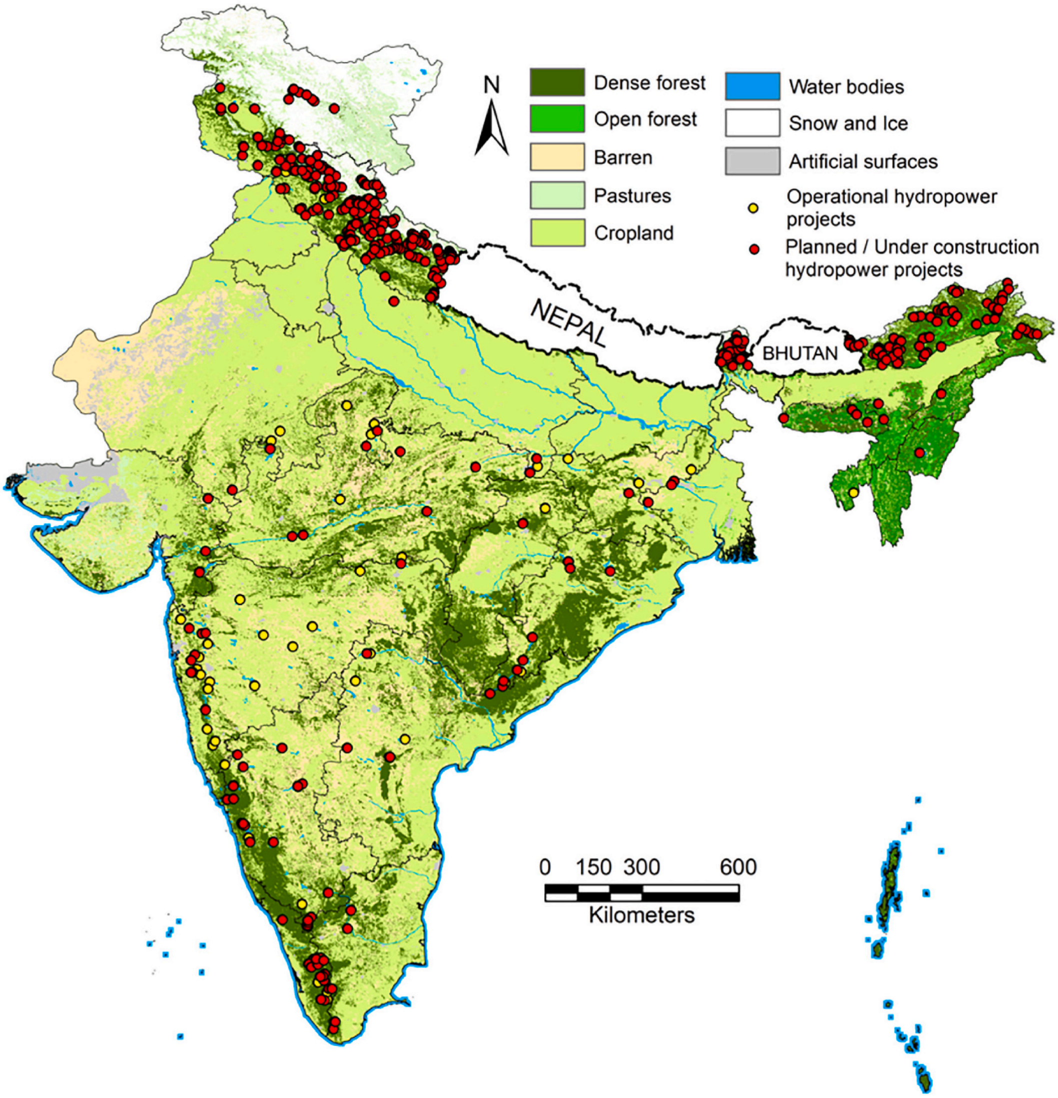

Fig. 1. Distribution of hydropower projects across India. Although, the hydropower infrastructure is spread across different states and regions, a larger number is located/proposed in the Himalayan mountains which is the main reason for the controversy surrounding hydro-projects and dams.

2. The context

The story of hydropower development and its contribution to the energy mix in India is a mixed bag. While the absolute numbers have witnessed significant growth, the share of hydropower contribution to India's energy basket has seen a progressive decline. At the time of independence, hydropower contributed nearly 40% of total energy generation capacity in India which steadily continued as such till the 1980s but fell sharply to about 25% in the first decade of 2000s and to about 12% at current levels. However, in absolute terms, the growth of hydropower has progressively gone up from a mere 500 MW in 1947 to nearly 47,000 MW as of 2022. India's

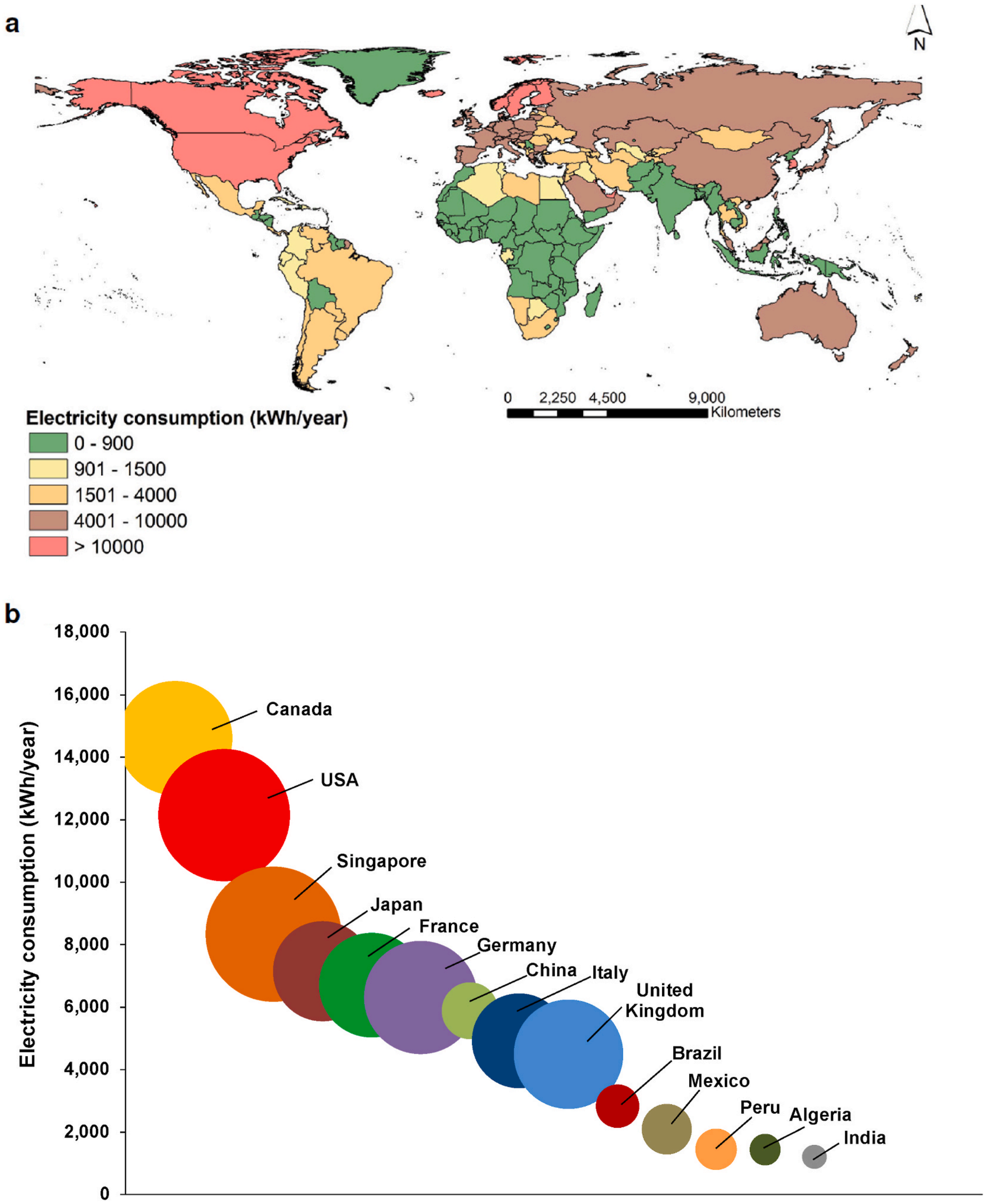

Fig. 2. Ranking of nations based on electricity consumption (kWh/year) and GDP per capita (US$) a. World map showing the nation-wise electricity consumption (kWh/year). b. Ranking of some the selected countries in different continents, based on electricity consumption and GDP per capita. The values on Y-axis represent electricity consumption, while X-axis represents the various countries. Bubble size reflects the relative values of GDP per capita of each country with bigger size representing higher GDP per capita. Note the USA ranks at 10, China at 47 and India at 137 globally in terms of electricity consumption per capita. (Data sourced from World Bank [47,48]).

region-wise hydropower potential has been estimated at around 150,000 MW of which only 38% has been tapped [5]. Though the share of hydropower in India's current energy profile is historically at its lowest, the overall share of renewable energy at present is around 40% [5]. Notably, between 2000 and 2019, India's growth in gross hydropower generation and capacity among the top ten countries was the third highest after China and Brazil [6]. This policy thrust reflects India's commitment to the global push toward a low greenhouse gas (GHG) emission regime. The Prime Minister's 50,000 MW hydropower initiative, envisaged way back in 2004, was the first major concerted effort to prioritise renewable energy in India. Equally, the galloping demand for electricity in India around 1380 billion kilowatt-hour (kWh) in 2020, which is likely to increase by nearly one and a half times in the next decade is yet another reason for the federal government to explore as many electricity generation options as possible. The conservative estimates suggest that India is looking at the electricity energy demand of nearly 4000 billion kWh by 2030–31. Analysis of the rising electricity consumption in India indicates that the peak demand will double by the year 2036–37 translating into an electricity demand of nearly 400 GW (GW) [7]. The current electricity peak demand deficit in India is around 8657 MW [5]. The plan of making India a USD 30 trillion economy by 2050 is likely to drive electricity demand and demand deficit even higher if serious efforts are not made to plug this deficit from as many sources as are technically, economically and environmentally sustainable.

Most critics of hydropower development in India would realize that India's per capita electricity consumption is pitifully low at around 1208 kWh/year compared to nations such as Canada, USA, China, Brazil, Mexico, Peru, Algeria, etc. (Fig. 2). Even though, in the last decade, India has improved its rank by 15 places from 152 to 137 as far as per capita electricity consumption is concerned, it must be of utmost concern to the planners and public policy experts that around 6 million households in India still lack access to electricity [8] and those have access face perennial and long power outages. Recent estimates indicate that electricity shortages and supply disruptions in India reduce industrial revenues and producer surplus by 5–10% on average and negatively impact national productivity [9].

3. What are India's options?

The per capita energy consumption data above does not inspire confidence in the energy policy of arguably the largest democracy in the world. The glaring asymmetries in the quantity and quality of electric supply to Indian households and businesses needs to be addressed. A more pertinent question is: where will electricity come from and are there more sound options for India? Thermal power is constrained by the supply of coal, its quality, price fluctuations and pollution related problems. There is a justifiable need to reduce overdependence on non-renewable energy sources such as coal, lignite, gas and diesel which comprise nearly 58% of India's electricity generation sources [5]. Notably, the GHG emissions from these energy sources in India are estimated to be 2310 metric tonnes of CO_2, the third largest emissions globally [10]. However, on per-capita basis, India ranks 110th globally with annual emissions of merely 1.74 tons of CO_2 [10]. Nuclear power is wrought with serious environmental and human health hazard risks and concerns. The stiff opposition to the Kudankulam Nuclear Power Plant in India's southern state of Tamil Nadu from different quarters is an indication that the nuclear option may be losing steam. Equally, there are global concerns and general agreement on reducing nuclear energy option notwithstanding the fact that it appears to be one of the least polluting energy sources besides hydropower and wind (Fig. 3). Solar power, one of the highly promising renewable energy candidates has received a significant push in India at the highest level. International Solar Alliance, spearheaded by the Indian Prime Minister with 109 signatory countries, is an indicator of India's push for solar energy [11]. There are however worries in terms of generation costs as well as capacious land requirements for solar option. An estimate by the Institute for Energy Economics and Financial Analysis suggested that solar power infrastructure would require about 50,000–75,000 km^2 of land which translates into 1.7–2.5% of India's geographic area or 2.2–3.3% of non-forested land area [12]. Similarly, the large-scale development of wind energy is plagued by land-related issues, high capital costs, lack of official regulatory

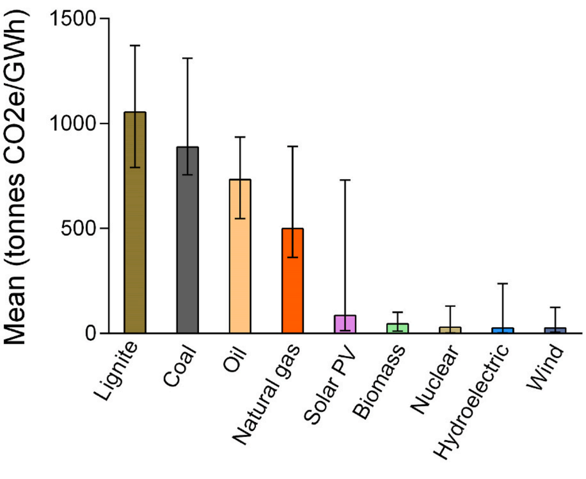

Fig. 3. Relative greenhouse gas emissions (CO_2e/GWh) as average emission intensity by electricity generation source. The bars represent the minimum and maximum (range) of emissions associated with each source (Source: World Nuclear Association [49]).

and policy frameworks and uncertain nature of wind power [13]. These constraints may have forced India to downgrade its target of 500 GW plan of renewable energy by 2030 to the new proposal of meeting the 50% target from non-fossil fuel sources [14,15].

Given the limitations of a low-carbon world order and the vast human population of India, hydropower seems to be a plausible choice of power generation to meet multifarious demands albeit with a number of environmental downsides [2]. For instance, dams significantly alter the river continuum and aquatic ecosystem dynamics which undermine terrestrial and aquatic biodiversity including fish species richness and migration patterns [16,17]. There are other negative ecological impacts of dams which are not yet fully understood. In particular, dams impacting river flow patterns may result in biological invasions [18] which are known to seriously endanger hydropower infrastructure such as choking of slow-moving streams by the monster diatom species like *Didymosphenia geminata* as reported in New Zealand [19]. However, studies in India so far have not revealed any signs of *Didymosphenia geminata* choking our regulated rivers [18].

4. The hydropower option

The potential power generation projections of India's Ministry of Power (MoP) indicate adequate but unutilised water availability for non-consumptive use such as hydropower generation. India presently has an installed capacity of only around 47,000 MW from hydropower plants which contribute about 12% of India's power generation against a potential of about 150,000 MW (38%) of the total installed generation of ~4,00,000 MW [5]. In addition to adequate water resource availability, hydropower scores high at being a green energy option. For example, hydropower generates 50-, 40- and 25-times lesser GHGs than coal, oil and natural gas, respectively (Fig. 3). Even solar photovoltaics (PVs) seem to generate twice more GHGs than hydropower (Fig. 3). Moreover, hydropower is increasingly becoming economically more viable in terms of cost of generation per MW witnessing an appreciable 47% reduction from about USD 200,000 per MW in 2013 to about USD 100,000 per MW [20]. Current estimates suggest that hydropower generation is reasonably environmentally cost-competitive. The illustrative total environmental costs for hydropower are estimated at 0.04 pence per kilowatt-hour (P/kWh) as compared to 0.48 P/kWh for nuclear, 5.40 P/kWh for coal and 6.05 P/kWh for oil [21]. Moreover, general public appears to favour hydropower as an energy generation option. A survey carried out by Ipsos-MORI in 2011 reported that hydropower had the support of 76% of respondents as opposed to 37% and 36% for coal and nuclear, respectively [22] (Fig. 4). Seen together, hydropower is likely to witness less opposition, and this may be an opportune time and environment for hydropower sector in India. Incidentally, the growth of electricity generation from renewable resources in India has appreciably gone up since 2015 from a mere 6.5% to nearly 30% annual growth in 2018 [23]. In absolute terms, the last two decades have witnessed nearly four-times growth in power generation from renewables including hydropower, from ~54,000 MW in 2002 to 200,000 MW at current levels [5].

4.1. Hydropower, geopolitics and cooperation

The recent UNICEF report on water security indicates that two-third of the world population (about 4 billion people) faces severe water scarcity, and by 2025 half of the world's population is projected to face water stress, while 700 million people would be displaced due to water scarcity by 2030 [24]. Yet another study predicts alarming consequences of asymmetry between inter-basin electricity distribution in China arising from hydroelectric transmission between water-abundant and water-stressed areas. The study indicates that 10% of China's population (134 million) lives in areas with lower water scarcity (southern China) but is dependent on electricity generated from areas of high-water scarcity [25]. The authors point out that the proposed inter-regional electricity transmission from the hydropower projects in China is accompanied by a trade-off wherein 20% population will benefit from the proposed inter-basin electricity transmission at the cost of 12% higher number of water-stressed population [25]. In the African continent, the Grand Ethiopian Renaissance Dam (GERD), under construction for a decade now, has given rise to a hydro-electric project crisis that looms large over the Nile basin. The downstream nations like Sudan and Egypt are aggrieved that the GERD

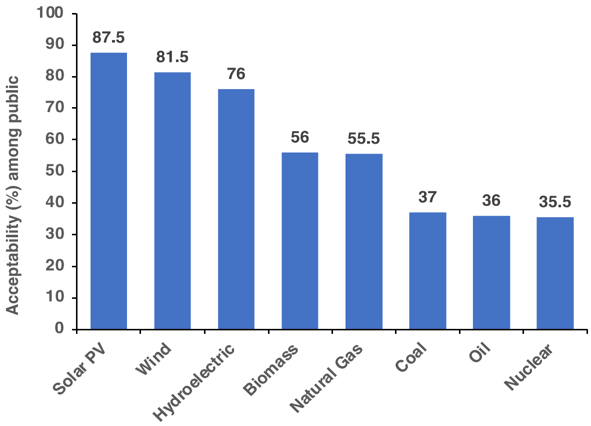

Fig. 4. Public support for various energy sources expressed as acceptability or favourability for different energy sources (Modified after Corner et al. [22]).

project will spell doom for the agrarian economy of these nations. The water-resource development conflict between Ethiopia and the downstream nations is believed to be the result of mistrust on one hand and a 'resource' bargain chip with Ethiopia by the latter on the other [26]. On the contrary, studies show minimal impact on the water supply to Egypt by the construction and filling of the GERD dam, and in fact accruing benefits to Sudan and Ethiopia, two nations struggling with serious socio-economic issues [27]. This and other empirical studies indicate that the geopolitical conflicts arising from transboundary natural resource sharing can be circumvented through cooperation and agreements. Moreover, hydroelectric projects and dams will have increasing relevance globally in the backdrop of climate change. Dams could prove useful in mitigating downsides of climate change, namely prevent flooding due to abnormal precipitation events and augment water availability across time and space [28,29].

While agreements are crucial instruments in trans-boundary sharing of water resources, post-agreement conflicts can arise due to newly evolved situations. Resource partitioning agreements get impacted in view of withdrawal by the upstream nations and increase in demand of downstream nations [30] or sometimes due to natural catastrophes or upheavals. However, numerous examples of largely successful multilateral agreements confirm and are reassuring of the benefits of cooperation and trust among nations. The Hinterrhein Kraftwerke in the Hinterrhein River (Switzerland, Italy), Iron Gates complex in the Danube (Serbia and Romania), Itaipú and Yacyreta Dams in the Parana River (Brazil, Paraguay), Kariba and the Lesotho Highland Dams (Lesotho and South Africa), Tuyamuyunsk Dam (Uzbekistan and Turkmenistan), the Doosti Dam (Iran–Turkmenistan Friendship Dam) are some of the notable models illustrating successful implementation of hydroelectric projects based on bi/multilateral cooperation.

4.2. River regulation and regional geopolitics

There are geopolitical concerns related to river water sharing and dam building vis-à-vis India's neighbors that cannot be undermined. Even as China and India pursue an assertive hydropower policy, China enjoys a significant geographic advantage in the form of the headwaters of Indus (Sind) and Brahmaputra and its technical experience of large-scale engineering operations in high-altitude regions. Moreover, China's polity allows for a far more forceful hydropower policy than India due to lack of visible public resistance. Occasional reports, however, suggest that in 2005 Chinese government faced 50,000 public protests over water-related issues [31]. India, on the other hand, has to carefully balance vocal opposition from different corners including political opponents and civil society groups. According to World Commission on Dams [32], China has constructed over 45,000 dams within its borders and is engaged, technically and financially, in building over 300 dams overseas. The large dams in China, which are more than 15 m in height, number around 20,000 while smaller ones are estimated to be around 800,000 [31]. That said, India may not necessarily follow the Chinese route to aggressive hydropower development, but there are numerous genuine reasons for India to develop hydropower where it can.

In the context of regional geopolitics, there are consequences of widespread dam building in the Himalaya [2]. For example, combined land use changes for agriculture expansion, urbanization and hydropower development are likely to result in loss of about 32% total forest cover in the Indian Himalaya by 2100 and the loss of dense forests will result in the extinction of 23.6% of their species [2,3]. However, scientific investigations show that dam building contributes a smaller fraction to forest cover loss and species extinctions; the main causes are land use changes to accommodate mounting demographic pressures, growth of human settlements resulting in the spread of agriculture and urbanization [33]. Species extinction projections show that haphazard dam building in the Indian Himalaya is likely to result in the extinction of 18 species (16 plants and 2 vertebrates) as opposed to the extinction of 1779 species (1505 plants and 274 vertebrates) likely driven by deforestation activities due to other land use pressures [2]. The consequences besides species extinctions include ecosystem loss and degradation, human resettlement issues, etc. [3]. A case in point is the massive ecological and human strife in this region resulting from China's Three Gorges Dam, which is not fully known yet [34,35]. China is engaged in yet another colossal 60 GW hydro-project on the Yarlung Tsangpo section of the Brahmaputra River, close to the great bend of Brahmaputra, before it enters the Indian territory [36]. The large-scale dam-building in Tibet by China is a worry for India on several counts, ranging from downstream depletion in water flow, ecological impacts thereof on the aquatic ecology, damages to riparian ecosystems and undermining water requirements of downstream communities in Brahmaputra and Indus basins in east and west, respectively. As such, China surpasses other nations in dam building, therefore, Indian response to this ground reality has to be both democratic and robust. The upstream dams are likely to alter numerous riparian habitats in the Assam Valley and cause species' as well as evolutionary adaptation extinctions in numerous wetlands that comprise some of India's best known protected areas such as Kaziranaga National Park and Namdapha National Park and Tiger Reserve [2,37].

5. The middle path

Public perception shaped by the ongoing debate in India, condemning dams for the disasters such as flash floods, etc. in the Himalayan region may not be rational. To blame natural hydrological catastrophes in the region on dam building and hydropower projects does not stand scientific scrutiny. There is little connection between the natural disasters generated upstream and dams, mostly located downstream, except when the engineering structures destabilise the area or fail under extraordinary circumstances. The debate has attracted reactions from the power developers claiming numerous benefits from dams including for instance the regulation services of dams like Tehri in averting a much greater crisis downstream in the disaster that struck in June 2013 [38]. Looking at it dispassionately, the flood protection service of Himalayan dams may well be worth more public debate.

There is an increasing understanding of the co-benefits of hydroelectric dams in terms of flood control and climate change adaptation [39]. Globally, ignoring flow regulation services by dams will put millions of people at flood risk in the downstream areas. This is particularly relevant in the case of the Himalayan rivers in India which drain into the vast Indo-Gangetic plains and discharge significantly more water during monsoon season. So, a more nuanced approach may be followed in the context of unique Himalayan topography and the Indian summer monsoon. The geophysical realities point to imperative of a sustainable flow regulation of rivers in the upstream regions to avoid massive losses to life and property because of floods year after year. Besides electricity generation and water storage for irrigation and drinking water, the role and purpose of dams in flood control perhaps needs more recognition today more than ever. Two important aspects that need careful considerations in today's circumstances of climate change are: (i) changed hydrographic flow patterns resulting from higher precipitation and likely more extreme rainfall events, and (ii) extra water requirements for irrigation for agriculture due to higher temperatures. India's vast agrarian economy is closely tied to its water resources and is prone to the vagaries of climate. Recent studies show that a spate of farmers' suicides in India is linked to failing crops under the impact of climate change [40]. Consequently, India needs to prepare for extreme weather events, floods and droughts, and dams in the Himalaya may be an important part of the solution in that direction.

A judicious balance between hydropower development and ecological conservation is needed [41,42]. A trade-off between dams and conserving fragile Himalayan ecology is a reasonable response. Such a balance has been suggested in various scientific studies and does not need more elaboration here except that dam building needs to be prioritized based on geological vulnerability, ecological fragility, and cultural sensitivity of various Himalayan sites [33,37]. 'No dams' in the Himalaya is a non-starter and the Indian state would not like to lend itself to be cornered into such a discourse on anyone's insistence – national or international. Besides, opposing every dam makes the entire resistance look frivolous, obstructionist and irresponsible. Sustainable hydropower development would need sacrifices from all sides.

6. Policy implications

To ensure universal access to basic amenities such as electricity, India needs to generate and supply power which is economically and environmentally sustainable. Hydropower satisfies most of these conditions notwithstanding some unavoidable, but its manageable flip side. However, before a strategy of response to fair and unfair criticism unfolds, there is a need to examine some lacunae within the power development sector. Addressing these shortcomings would help assuage or mitigate the negative narrative surrounding hydropower in India. The recommendations enunciated here are based on our experience of over two and a half decades of working on EIAs of more than 50 hydropower developmental projects. Moreover, based on the available literature, we recommend the following short-term and long-term measures that can be adopted by the hydropower developers which will help reduce the existing constraints on hydropower development.

6.1. Short-term measures

6.1.1. Accountability of power developers

To counter public hostility towards hydropower, power development agencies (PDAs) need to adopt good practices from pre-project or pre-feasibility studies to the execution of a project. The pre-feasibility reports (PFRs) and the detailed project reports (DPRs) need to be more independent and rigorous documents, based on sound scientific and technical data and robust analysis. Developers may like to avoid cutting corners either on the site investigations or on the reportage of data. It makes economic and logistical sense to better know your difficulties *a priori* than to hide them and be surprised later, and to suffer criticism as well as time and cost overruns. Likewise, Environment Impact Assessment Statements (EIAs) and Environmental Management Plans (EMPs) submitted by the PDA must not only instil confidence in the statutory environmental appraisal committees (EAC) of the federal government but also in the public at large. It calls for detailed site investigations suggested in the terms of reference (ToR) at the time of scoping. The investigations must be carried out by credible independent agencies and not by lesser-known entities who cannot later engage with critics opposing a hydro-power project. PDAs, at times, engage not-so-well-known institutions to save a minuscule of funds and are likely to insist on sidestepping the mandatory time requirement of data collection for EIA. PDAs often impose their views in EIA reports that cannot be backed by scientific investigations. It becomes embarrassing for the experts as well as project developers when evidence contrary to the enforced view is put forth by the challenging side/s. Equally, the PDAs must undertake to follow, in letter and spirit, the pledges and promises made in the EMPs and make efforts to support various management plans and activities through payments of the budgeted amounts. There is a huge gap between what is promised during the process of environmental clearance and what is finally executed. PDAs are better served by involving local stakeholders, credible experts and institutions in various projects of the social sector, biodiversity conservation, environmental management, and risk mitigation. In practice, PDAs often transfer their responsibility to the local forest and other government agencies, which results in disenchantment and disengagement among local communities who turn against the development projects. As a policy, the majority of the EMP works should be entrusted to local NGOs, civil society groups, women's self-help groups, etc.

6.1.2. Accountability of statutory authorities

The statutory authorities such as EAC of the federal government must follow a transparent method to accord clearance to hydropower projects once a PDA satisfies the mandatory requirements of the ToR. The concerns of PDAs about frequent shifting of goal posts need careful attention and consideration by the EAC and the relevant Ministry of Environment and Forests (MoEF). Correspondingly, sanctions including withdrawal of clearance, may be imposed on the PDA if it fails to comply with the guidelines, terms of project clearance and/or the provisions made in the EMP documents. The relevant Ministry may consider having only one statutory body for appraisal and clearance instead of multiple ones (environment, forests, wildlife, etc.) for awarding clearance to hydro-projects. This will reduce duplication of effort and wastage of time and resources. As far as possible, the EAC must comprise members who are independent with relevant domain knowledge.

6.2. Long-term measures

Energy security is a critical contemporary public issue amid concerns of uncertainty and sovereign risks related to oil supplies and their fluctuating prices, problems associated with the import and use of coal and its capricious supply and market behaviour. For hydropower to become an energy source of choice, India's Ministry of Power must actively consider linking it with India's energy security. These steps, being re-iterated here, include a desirable policy shift of switching from the old-fashioned approach of *'least-cost'* generating option to the *'least-price volatile'* option [43]. This policy shift focusses on developing power plants that have a constant supply of electricity with minimum market price fluctuations instead of developing power plants with least power generation and capital investment costs [43]. This can, in turn, offer more opportunity to and develop interest in hydropower sector among investors and power developers, and also avoid perception of risk. The federal government may like to ensure a system of '*feed-in tariff*' by providing higher rates than the market to the renewable energy producer and '*compulsory renewable energy purchase*' ensuring mandatory renewable power purchase by the consumers and grid companies [43–45]. These steps will assuage the negative sentiment among hydropower developers for investing in a relatively non-competitive business option. Equally, important is the introduction of an *environmental damage cost* on other energy sources with significantly higher pollution loads and higher carbon footprint to provide a level playing field and ensure price parity with a slightly costlier hydropower energy option. Finally, the federal government may consider introducing a '*green-certificate-trading*' market mechanism. Under this mechanism, private and state-owned businesses and corporations need to purchase certificates that represent the environmental value of renewable energy from energy developers on monetary basis. The funds generated can be solely used to cross-subsidize and incentivise hydropower development.

6.2.1. Institutions

Before doubts are raised on the sustainability of hydropower, the state as well as the PDAs need to ensure that they are fully ecologically and socially responsible pre- and post-project construction. The role of MoEF cannot end with appraising EIAs and providing clearances or rejecting projects. Actual work of monitoring and mitigation of risks must begin once clearances have been awarded. Experience has shown that post clearance, mandatory environmental and social management plans are not followed by PDAs, which creates opportunities for the opposition to large developmental projects. Considering the national need to generate power and conserve the environment, an institution, namely 'National Institute of Energy & Environmental Sustainability' (NIEES) may be established as a joint venture between MoP & MoEF within an academic institution of repute. The institute shall be responsible for: (i) assuming leadership role in formulating sustainable energy policy; (ii) environmental and energy advocacy; (iii) offering research backup, guidance to energy developers; (iv) carrying out case studies on pre- and post-post project environmental conditions to dispel fears and unwanted criticism; (v) act as a sounding board and forum for public and private energy developers and assume the role of a mediator between governments and public at large; (vi) collaborating with education and research institutions and individuals such as Universities and IITs, with proven capabilities in the environment-energy field; and (vii) carry out the task of monitoring and supervision.

6.2.2. Institutional mechanisms

An institutional mechanism needs to be evolved that will serve as an effective and efficient advisor, regulator and watchdog over various activities of the relevant Ministries and the PDAs. The sole criterion of effective monitoring should be robust scientific investigations, data and analysis that meets international standards and shall be sufficiently autonomous in carrying out its activities. There are understandable constraints of different ministries to be watchdogs and regulators. It would be prudent to create an institutional mechanism by way of providing funds and authority to independent research institutions in different regions of India with relevant expertise to carry out this important task of monitoring and regulation. There is also a need to establish a trans-national water cooperation mechanisms and instruments. Major nations in and around the Indian sub-continent, namely Tibetan Autonomous Region (China), India, Nepal, Bhutan, Pakistan and Bangladesh depend on the trans-boundary river systems (Indus, Ganga, and Brahmaputra) for meeting their domestic water, agriculture, fisheries, and industrial needs. An estimated 700 million people in the sub-continent are sustained by water flows from these rivers; these rivers (Indus and Brahmaputra) rely on the flows from their headwater region in the Tibetan region. Consequently, any hydropower development in Tibet is likely to have serious and far ranging geo-political implications in the downstream nations. For example, the widespread dam construction in Brahmaputra basin by China and India is likely to affect 40 million small farmers in the downstream Bangladesh negatively impacting vast agriculture areas [46]. Therefore, instituting a trans-boundary and trans-national water cooperation mechanism on the lines of Mekong River Commission would be helpful in managing and conserving the water resources of the region.

7. Conclusions

Clearly, there is an environmental cost to hydropower development. But in the bigger scheme of things, dam building would contribute to relatively lesser environmental damage as compared to other on-going activities such as mounting demographic pressures, expanding agriculture and urbanization, rampant and unplanned infrastructure development, etc. A trade-off between widespread dam-building and conserving fragile ecology is a reasonable undertaking. We recommend that dam-building may be prioritized based on the triumvirate of geological vulnerability, ecological fragility and cultural sensitivity of various sites. To ensure universal access to electricity, India needs to generate more power from sources that are both economical and environmentally sustainable.

Hydropower to a great extent satisfies these conditions except for some unavoidable flip side. That said, overdoing dam-building, especially in the Himalaya, will produce an environmental and social backlash including enormous loss of life and property. Many argue that the 'environmentalism' is an entrenched religion, therefore, for a dialogue to begin is difficult. However, we may realize that 'development' is equally, if not more, a proselytizing doctrine that leaves little scope for a contrarian discourse. These hard positions need to be reconciled which justifies the need of an independent robust institution and institutional mechanism suggested here.

Author contribution statement

Maharaj K. Pandit: Conceptualization, Investigation, Writing – original draft, review & editing, Validation, Supervision. **Kumar Manish:** Software, Formal Analysis, Writing – review & editing, Visualization. **Govind Singh:** Review & editing. **Abhiroop Chowdhury:** Review & editing.

Data availability statement

No data was used for the research described in the article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. MKP declares that he was an Independent Director on the Board of Directors of a public sector undertaking, namely Tehri Hydro Development Corporation.

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