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A planning perspective on Hydropower Development in the Indian Himalayan Region

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ABSTRACT:

The Indian Power Sector(IPS) is under gradual transition from over-reliant fossil fuel (62%) to Sustainable Energy Source(SES), primarily to achieve targets of SDGs and the Paris Agreement to base 40% of the total power generation capacity on non-fossil fuel resources by 2030. In this context, the solar power generation is on the fast-track whereas, hydropower development is lagging behind due to various reasons causing time and cost escalation, hence the sustainability of IPS in terms of flexibility and reliability in integration with other Renewable Energy Source will remain a challenge. With this concern, the focus of this study is to *(i)* analyze and prioritize the hydropower potential (HPP) in the Indian Himalayan Region, *(ii)* identify the prime constraints in the way of hydropower development and *(iii)* discuss the way-forward for sustainable planning of hydropower development whilst appropriately managing time & cost over-runs including socio-environmental concerns. The methodology involves literature review and analysis of secondary data about IPS, hydropower resources and project-specific risks prevalent in ongoing HEPs in India. The result shows that the Indian Himalayan Region has enough (73%) balance HPP in 12 different States; sustainable harnessing of which requires proper addressing of the prime constraints viz., multiple public consultations in clearance process, litigations, high investment, socio-political and contractual issues, mainly through procedural reforms by the State Governments which have constitutional right over land and water in the federal structure of India. The finding of study will be useful for planning process of entrepreneurs, investors and policy makers in the direction to achieve the target of SES beyond India's Nationally Determined Contribution.

Key words:

IHR;
Hydropower;
Indian Power Sector;
Paris agreement;
Constraints;

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1. Introduction

The Indian Himalayan Region (IHR) constitutes 67% of total Himalayan region and approximately 18% of India's total geographical area [1]. It is located between 21°57'–37°5' N and 72°40'–97°5'E and has a total geographical area of about 533,604 km^2 with 39,628,311 inhabiting population [2]. The IHR comprises fully/partially twelve States of India (Figure 1) stretching over 2500 km from Jammu and Kashmir in the northwest to Arunachal Pradesh in the northeast. IHR is significant for its high conservation value due to its rich biological diversity [3, 4], socio-cultural and aesthetic values.

Besides, IHR has rich source of water as glaciers melt in summer, heavy snowfall in winter and rainfall from southwest monsoon as well as northwest winter rains. Availability of water potential combined with topographical variation in IHR offer huge HPP. IHR accounts for approximately more than 75% of total exploitable HPP (148.7 GW) of the country as per assessment study conducted by CEA [1].

Hydropower holds special significance for the growth of Indian economy. The first prime minister of India, Pt. Jawaharlal Nehru had proudly proclaimed dams as the temples of modern India. A number of river valley

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Acronyms

IHR	Indian Himalayan Region
HPP	Hydropower Potential
HEPs	Hydroelectric Projects
IPS	Indian Power System
INDC	India’s Nationally Determined Contribution
IHR	Indian Himalayan Region
SDGs	Sustainable Development Goals
RES	Renewable energy source
SES	Sustainable Energy Source
CEA	Central Electricity Authority
HSAP	Hydropower sustainability assessment protocol

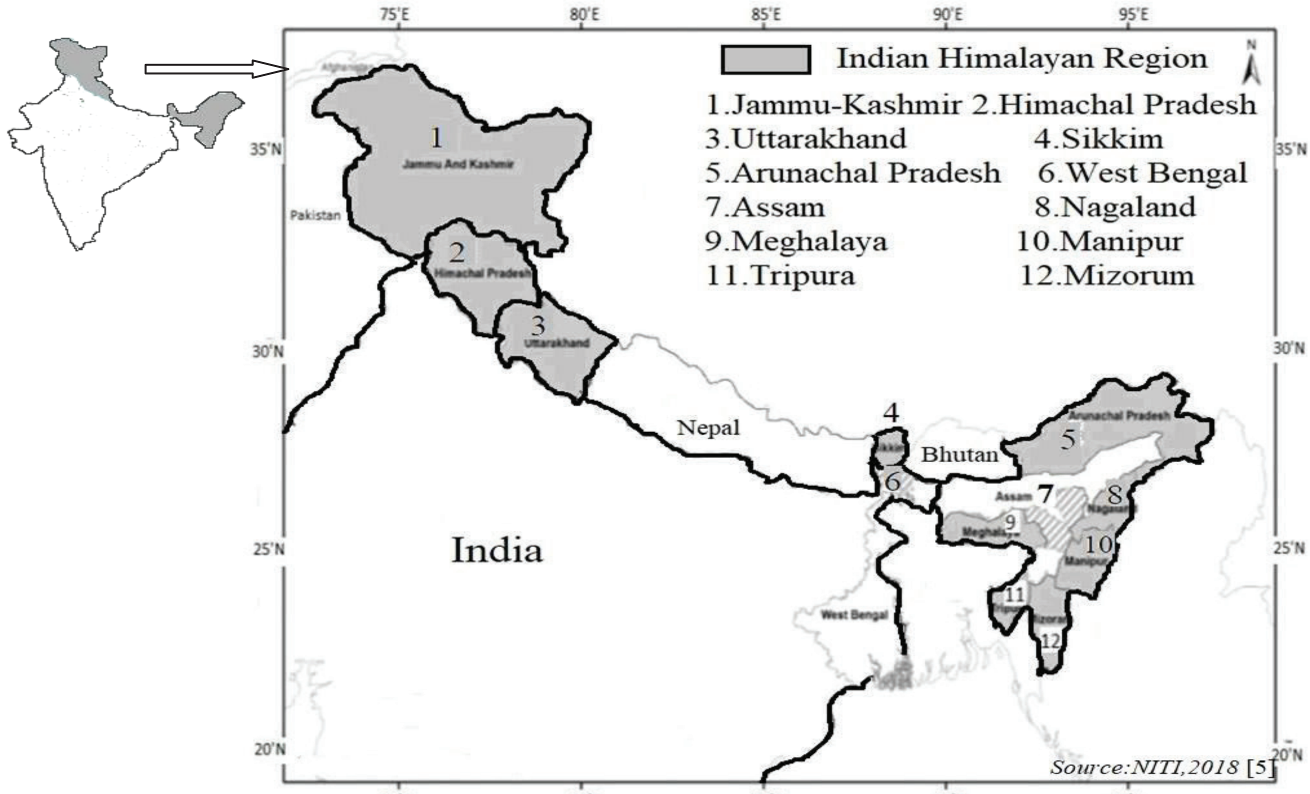

Figure 1: Location of States in IHR [5]

projects were envisaged mainly to increase the agricultural productivity and to accelerate the industrial development in the post-independence era of India. The inherent attributes of hydropower like reliability, flexibility, and variety in project scales and sizes, gives it the ability to meet large centralized urban and industrial needs as well as decentralized rural needs [6]. HEPs constructed across the country over the years bear testimony to large scale ‘local area development’ in terms of infrastructure facilities such as road, bridge for proper connectivity, job prospects in construction works, medical facilities, market and other civic facilities in the hitherto remote hilly terrain [7,8]. More importantly, in our increasingly carbon constrained world, hydropower has the uniqueness to meet the economic, social and environmental criteria of sustainable development while considering its very important role in future mitigation of scenarios of climate change.

Despite these inherent attributes, hydropower development in India is at a slower pace in comparison to thermal source; as a result the IPS is presently over-reliant (62.7%) on fossil fuel (figure 2 & 3). However, in wake of the growing global concern regarding the impact of fossil fuel on climate change, rising energy-cost and the ratification of Paris Agreement, India has embarked on energy transmission strategy to reduce

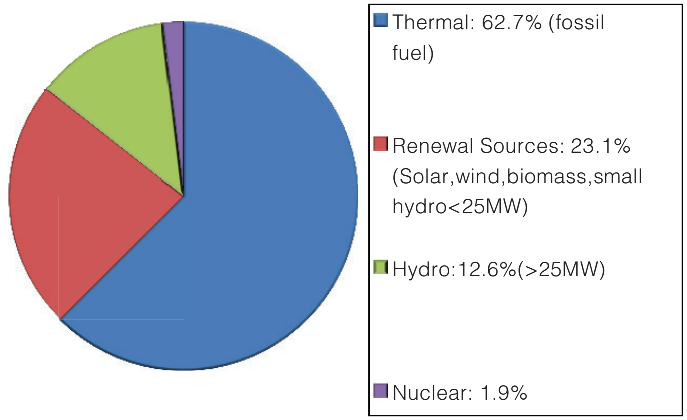

Figure 2: Energy-mix (%) in IPS (as on Dec, 2019) [9]

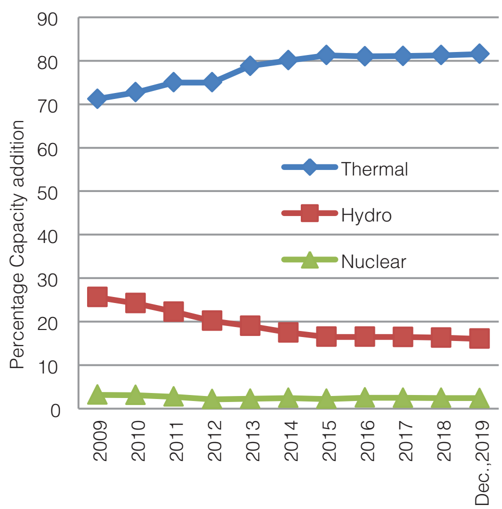

Figure 3: Trends of capacity addition as % of total hydro - thermal mix

reliance on fossil fuel, augment SES and improve energy efficiency. The Paris agreement was adopted on 12th December 2015 and India signed the Agreement on 22nd April 2016 and while agreeing to ratify the agreement, it had declared that it would treat its national laws, its development agenda, availability of means of implementation, its assessment of global commitment to combating climate change and predictable & affordable access to cleaner source of energy as the context in which the Agreement was being ratified [10,11]. Accordingly, India submitted its Nationally Determined Contribution to the UNFCCC on 2nd October, 2015, outlining the climate actions intended to be taken under the Paris agreement. India's NDC aims to base 40% of the total installed power generation capacity on non-fossil fuel resources by 2030. This includes the Government of India's ambitious target of achieving 175GW of renewable energy by the year 2022 primarily from solar power.

To achieve the emission reduction target and to ensure reliable supply of electricity, an integration of hydropower with solar and wind power could be a preferred alternative over other energy source in terms of flexibility to meet peaking requirement, reliability and bulk generation ability vis-à-vis availability of huge HPP in IHR.

Although, HEPs are categorized as complex structures and the construction phase of these projects are susceptible to various technical, socio-political, geological surprises and environmental risks; which impose restriction on the pace of hydropower development in India over the last decade or so. The track record of the construction industry to deal with these risks has not been very good [12]. Due to which, most of the HEPs are facing time and cost overruns[13]. However, the core element of 'project success' depends on its timely completion within the specific budget for the benefits of developers, investors and energy security of the country. Therefore, it is imperative to analyze the challenges in Indian Hydropower Sector and explore resolution thereof. Most of these issues could be resolved through renewed planning and procedural reforms under the purview of the constitutional framework of India. With this perspective, the present study is focused to (i) analyze and prioritize the balance exploitable hydropower potential in the territory of different States/region in IHR (ii) identify the prime constraints including time and cost-overrun in the way of hydropower generation in IHR and (iii) discuss the way-forward for appropriate planning of hydropower development whilst appropriately managing environmental concerns and time-cost escalation (iv) emphasizing the responsibility of respective State Governments in timely completion of HEPs alongwith other RES in order to accomplish INDC target, sustainability of IPS and SDGs as well.

1.1 Scope and Structure:

The outline of the article is as follows. Section 2 describes the methodology of research along with flow-chart, Section 3 presents literature review. In Section 4 we discussed the result and accordingly in Section 5 we presented the way forward for development of hydropower in a sustainable way. Finally, concluded with Section 6.

2. Methodology

As per the scope of study outlined above, comprehensive literature review has been done by referring the published reports in international and national journals to get insight about the global and Indian trend in dealing energy issues with special reference to hydropower prospects in the IHR and sustainable development perspectives. Further, as per requirement of this study, we refered secondary data from CEA reports about IPS, Indian hydropower sector and status of all HEPs under construction stage and clearance stage in India till March 2019. Based on hydro-potential data and project-specific risk prevalent in HEPs, data was analyzed in light of relevant reports and policy(ies) of Government of India (i.e Central Electricity Authority, Ministry of Power, Ministry of Environment, Forests &Climate Change) and statutory Acts/notifications linked with development of HEPs in India to arrive at result and accordingly recommendations as way forward have been drawn up.

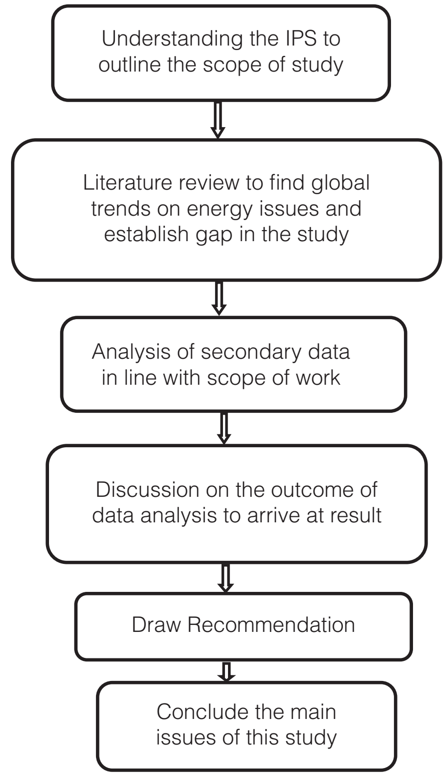

Figure 4: Flow Chart of Study

Also, for this study, different reports like World Bank, IEA reports (India-2020), sustainability protocol of IHA, media reports and google search engine have been referred. The flow chart of methodology depicting systematic steps is shown in Figure 4, which is based on the pattern adopted by Ebhota W.S [14].

3. Literature Review

Based on the review of the previous studies, we correlate here three important energy aspects viz., energy transition strategy from fossil to SES, advantage of hydropower over other RES and relevance of hydropower in Indian context to find the latest trends and gap in research in context to the objectives framed in this study.

3.1 Transition from fossil fuel to SES

Østergaard and Sperling [15] presented an overview of the of global energy trends focusing on energy costs, energy use and carbon dioxide emissions. They highlighted that the rising energy costs, anthropogenic climate change, and fossil fuel depletion calls for a concerted effort within energy planning to ensure a sustainable energy future.

Narula [16] defines Sustainable Energy Security (SES) as "provisioning of uninterrupted energy services in an affordable, equitable, efficient and environmentally benign manner. With this concept, he undertook a comparative assessment of SES of various energy sources for the residential sector in India and by development of SE index he concluded that the energy sources which are relatively more secure and sustainable for rural and urban India.

Waenn et al. [17] put forward the hypothesis, that it is required moving from the national level to the regional level when addressing energy system scenario design and energy system analyses with the goal of achieving sustainable energy systems.

Drummond and Marsden Davidson [19], Holling [20], and Roseland [21] deliberated that the energy sector reforms being undertaken need to satisfy the requirements of sustainable development, which according to them is to balances economic, social, and environmental interests of economies [18].

Ferreiraa et al. [22] state that sustainable development challenges call for a multidisciplinary approach to energy decision making and require an effective bridge-building between political, technical, economic and social aspects. Moreover, by bringing to the debate different disciplines and authors with different backgrounds we expect to create synergies and merge social, economic, environmental and technical knowledge to support policies towards a sustainable energy transition.

Abdallah et al. [18] examined whether energy reforms being taken in developing countries conforms to the concept of sustainable development. They described that the energy sector reforms with an emphasis on electricity growth have been taking place extensively worldwide and in developed north, reforms are motivated chiefly by classical economics' standpoint of efficiency and market considerations; this models of reforms in the North have in turn been replicated in developing countries. Taking a case study of Kenya and neighboring countries, they examined whether the models used are suitable on sustainable development perspective for the mostly rural and socioeconomically disadvantaged economies in the South and observed that importance being placed by Kenya on rural electrification and renewable energy is noteworthy. Nonetheless, the Kenyan energy policies and strategies that are shaping electricity reforms are heavily skewed towards the economic aspect of sustainability.

Ebhota [14] deliberated that Power infrastructural development in emerging economies attracts international investments, supports and aids because of the dominant role access to electricity plays in the socioeconomic development of a country or region. Taking note of growing threat of climate change, Rigot Sand Demaria [23] highlighted that the accounting standards as followed by financial intermediaries (banks and insurers) in the energy market do not differentiate between low and carbon intensive investment and do not take into account climate risks beforehand, hence is a critical issue for the development of a sustainable economy. He emphasized the need for reform in order to foster long-term and then low-carbon capital spending in Europe.

The outcome of several studies has corroborated the benefits of RES over fossil fuel. The study conducted by Owusu & Asumadu-Sarkodi [24] brought to light the opportunities associated with renewable energy sources; energy security, energy access, social and economic development and climate change mitigation and reduction of environmental and health impacts. The study further examined how a shift from fossil fuel-based energy sources to renewable energy sources would help reduce climate change and its impact.

In India, Panwar et al. [25] described the role of renewable energy sources in environmental protection as Renewable energy technologies provide an excellent opportunity for mitigation of greenhouse gas emission and reducing global warming through substituting conventional energy sources. He tried to find out the scope of renewable energy gadgets to meet out energy needs and mitigation potential of greenhouse gases mainly carbon dioxide.

As regard to renewable energy scenario in India, Kumar and Majid [26] presented the significant achievements, prospects, projections, generation of electricity, as well as challenges and investment and employment opportunities due to the development of renewable energy in India. He deliberated that the strong government support and the increasingly opportune economic situation have pushed India to be one of the top leaders in the world's most attractive renewable energy markets. The government has designed policies, programs, and a liberal environment to attract foreign investments to ramp up the country in the renewable energy market at a rapid rate. However, in this study, challenges for in RES in general have been deliberated; but the sector specific concerns have not been discussed.

Kumar et al. [27] analyzed the low impact renewable energy technologies, energy planning tools and renewable policy framework for promotion of renewable in India.

Bhattacharya [28] deliberated that a number of renewable energy technologies (RETs) are now well established in India and number of factors are likely to boost the future prospects of renewable energy in the country; these include global pressure and voluntary targets for greenhouse gas emission reduction, a possible future oil crisis, intensification of rural electrification program, and import of hydropower from neighboring countries.

The IEA in a recent report [29] mentioned that India's per capita emissions today are 1.6 t of CO_2, well below the global average of 4.4 t, while its share of global total CO_2 emissions is some 6.4%. However, Government of India is implementing reforms towards a secure, affordable and sustainable energy system to power a robust economic growth. In this direction, country has launched a number of important energy policy programmes along the four priority pillars: energy access at affordable prices, improved energy security and independence, greater sustainability, and energy efficiency.

3.2 Relevance of Hydropower over other RES

Each renewable source of electricity has its own limitations. However, among RES, hydropower technology has additional advantages as deliberated in substantial literatures.

Lund et al.[30] in their study mentioned that the renewable energy is not a viable option unless electricity can be stored and Electrical Energy Storage Systems (ESS) are one of the most suitable solutions to increase the flexibility and resilience of the electrical system.

Kaunda et al. [31] and Ahmad and Farooq [32] reviewed the world energy scenario and described how hydropower fits in as the solution to the global sustainable energy challenge. Issues of hydropower resource availability, technology, environment and climate change have been also discussed. They urged that a sustainable hydropower project is possible, but needs proper planning and careful system design to manage the challenges. Well-planned HEPs can contribute to supply sustainable energy and therefore an up-to-date knowledge is necessary for energy planners, investors, and other stakeholders to make informed decisions concerning HEPs. However, policy and constraints have not been covered in the study.

Gopalkrishna [33] urged that India has the capacity to play a lead role in energy security and stability of grid by harnessing all the 3/4th of exploitable hydro energy in the region, including Himalayas in collaboration with its neighboring countries like Bhutan and Nepal. This can make South Asia's energy position quite enviable.

World Bank [8] in its report about hydropower project in India corroborated that hydropower has brought power, roads and much-needed development to Himachal Pradesh, especially to remote mountain communities.

Singh & Dash [7] in a case study of a Parbati-III hydropower project located in western himalayan state in India and observed that hydropower is a tool of local area development in the remote himalayan valley by provisioning of infrastructure(Road, bridges), health, education facilities and livelihood prospects besides supplying reliable green power to national grid.

As regard to the prospects of small hydro power (SHP<25MW) in India, Mishra et. al 2015[34] analyzed the barriers in the growth of SHP which must be overcome to accelerate the growth of the sector and should target a capacity addition rate of nearly 600 MW/year to harness full SHP potential even by 2050. As per sensitivity analysis they suggested that cost of generation is sensitive to capital cost, interest rate, and capacity factor, but less sensitive to life time and O&M cost.

In a study conducted by Hussain et al. in 2019 [35] analyzed the hydropower development prospects in four Hindu Kush Himalayan countries – Bangladesh, India, Nepal and Pakistan. They asserted that despite several challenges, hydropower continues to be the leading Renewable Energy option in view of global agenda aims to reduce the carbon intensity of energy in long-term climate change mitigation strategies, and to achieve Sustainable Development Goal-7 (SDG-7) on affordable and clean energy. To achieve these goals, they suggested capitalizing on emerging opportunities such as large hydropower development using a 'smart approach', micro-hydropower promotion, energy trade, and regional cooperation for collective energy development programs. However, author has not covered the enhanced prospects of hydropower generation in India due to outcome of policy declaration stating 'measures to promote Hydropower sector' by Government of India in March 2019. Also, mechanism of appraisal of environmental issues in light of further capacity addition of hydropower has not been covered in the study.

Laha et al. [36] explores the possibility of a zero import-dependent Indian electricity system in 2030 by developing a model of the electricity system, exploiting the optimal mix of RES namely solar PV (photovoltaic), wind, river hydro and biomass. However, in the study, constraints in IPS especially hydropower sector in India has not been correlated.

3.3 Relevance of Hydropower in Indian Context

Hydropower, besides reliable RES, the following points highlights its significance to meet the long-term goal of the India and best suited for the power market as well as sustainability of IPS.

- In the energy-mix of IPS, the percentage of hydropower (small & large) has come down from 45% in 1970 to 16 % in 2019 and presently IPS is over-reliant on fossil fuel (62.7%) as thermal source of electricity. Dominance of coal in India's energy-mix is highly problematic for the country [37] and lower percentage of hydropower may affect the stability of grid.
- Even at this stage, the country faces lack of sustainable power sources capable of meeting peaking deficits [38] and with quick response characteristics.
- As regard to demand, IEA [29] reports that based on current policies, India's energy demand could double by 2040, with electricity demand potentially tripling as a result of increased appliance ownership and cooling needs.
- In India, the energy sector is a large water user. As India's energy demand continues to grow, the government should ensure that energy planning takes into account the water–energy nexus, as well as future space cooling needs [29].
- Unlike, thermal and solar power, the hydropower technology does not consume water. Rather, it is technically designed for flood moderation, water storage and regulated water supply for agriculture and domestic use besides electricity. Moreover, hydropower contributes significantly to climate change mitigation, and could play an important role in climate change adaptation regarding the availability of water resources [6].
- HEPs are generally located in very remote Himalayan terrain; the activities carried through this developmental process promotes socio-economic development of the IHR [7,8] and thus partnering in achieving SDGs for the developing country like India.
- Hydropower offers significant potential for carbon emissions reductions [6, 39] and dealing with the global warming issue as a substitution for a fossil fuel power source [40]. It can contribute significantly in achieving the targets of INDC.

4. Result and Discussion

4. 1 Hydropower potential in the IHR

India ranks fifth in the world in terms of availability of HPP [33]. Total HPP of 145.32 GW (>25MW) capacity has been identified by CEA. Out of which, as of Nov, 2019, about 27.95% HPP is under operation stage, 7.45% is under the construction stage and remaining 64.60% of total potential is yet to be taken up for construction as depicted at Figure 5 and table-1 [41]. The contribution of electricity generated from hydropower and other sources in the existing total power scenario of India have been illustrated at Figure 2 &3, which shows that India is presently drawing 62.7% of electricity from thermal source, 23.2% from renewable sources(comprising of mainly Solar, wind, Biomass small hydro <25MW), 12.6 % hydropower (>25MW) followed by nuclear source(2%). It can be seen that the exiting 12.6% contribution of hydroelectricity in Indian power-mix has been achieved in the country till the November, 2019 and therefore, the remaining 64.60% (93.8GW) of total HPP (>25MW) is still available that can be harnessed in order to reduce the existing dependence on the primary source of electricity i.e thermal from fossil fuel (62.7%). On analysis of the availability of remaining 64.65% HPP in different region in India, it is found that the North-Eastern region of India contains maximum un-harnessed hydropower potential of about 93% (54.3 GW) followed by the northern region (53.05%) and the Eastern region (42.8%) located in IHR as depicted at Figure-5 & Table-1. The scenario is in sharp contrast to the southern and the western regions of the country where more than 65% of the potential has already been harnessed. Besides clean power, State Governments of these regions get revenue equivalent to 12% of total annual power generated from the hydropower developers in India, so it is perennial source of income for the State.

The regional availability of total HPP in India has been discussed above. In each region there are different

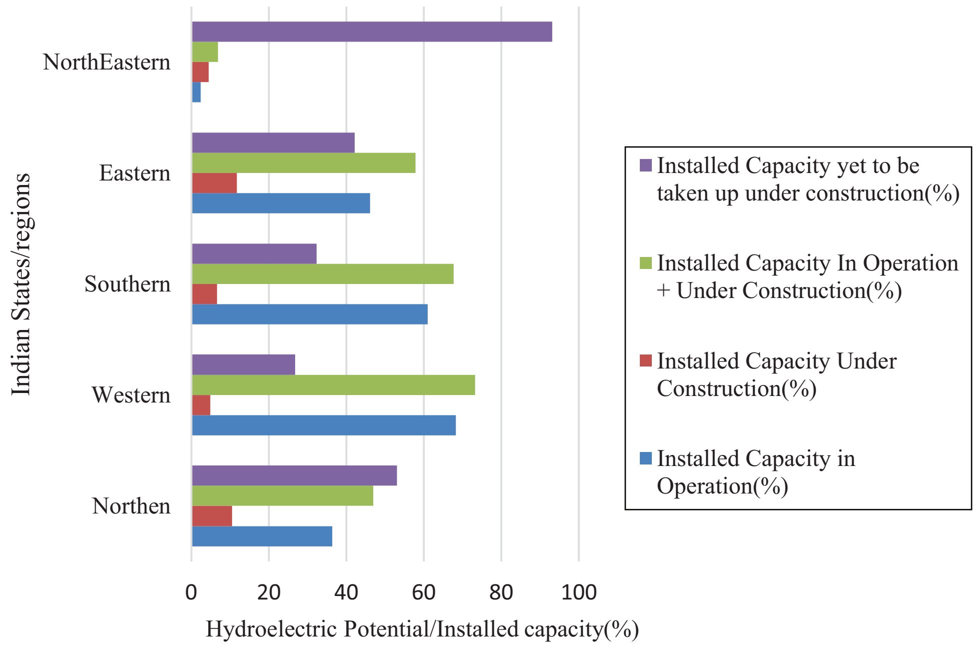

Figure 5: Comparative aspects of harnessing of HPP in Indian region

Table 1: Status of Hydro-electric potential development (as on 30th November 2019,CEA)[41]

Indian Region/ State	Identified Capacity(Hydropower Potential)		Capacity in Operation		Capacity Under Construction		Capacity in Operation + Under Construction		Capacity yet to be taken up under construction	
	Total (MW)	Above 25 MW	(MW)	%	(MW)	(%)	(MW)	(%)	(MW)	%
Northern	53395	52263	190233	36.4	5516.5	10.56	24539.8	46.95	27723.2	53.05
Western	8928	8131	5552	68.3	400	4.92	5952	73.2	2179	26.8
Southern	16458	15890	9688.9	61.0	1060	6.67	10748.9	67.65	5141.1	32.35
Eastern	10949	10680	4922.5	46.1	1253	11.73	6175.5	57.82	4504.6	42.18
North-Eastern	58971	58356	1427	2.5	2600	4.46	4027	6.9	54329	93.1
All India	148701	145320	40613.6	28.0	10829.5	7.45	51443.1	35.4	93876.9	64.6

States, out of which 12 Indian States located in IHR (Figure-1, Table-1) contains 78% (113.4GW) of total hydropower potential (>25MW) identified in the country. Out of total potential available in IHR, 26.55% has already been harnessed and remaining 73.4 % (83.3 GW) is yet to be harnessed in these location/States. A comparison between 'total hydropower potential identified initially through reassessment study and HPP remain balance presently after hydropower generation' in IHR has been depicted in figure 6 & 7.

It reveals that Arunachal Pradesh state has maximum balance unharnessed HPP of 46.9 GW (93.78%) out of total potential identified in assessment study by CEA. Similarly, Uttarakhand has about 12.7 GW un-harnessed hydropower potential (71%) followed by J&K of 6.2 GW (54%), Himachal Pradesh 6.8GW (37%) and Sikkim 0.9GW (22.2%) out of total potential identified initially. The remaining states like Nagaland, Manipur Meghalaya etc. have very minimal HPP in terms of installed capacity (MW), but on analysis of data in terms of percentage, the balance potential comes out more than 85%, which is confusing. This is because of the least difference between 'HPP identified initially and potential (MW) remain balance after the development of hydropower i.e these areas/States have low installed capacity (Hydropower Potential) and that has also not

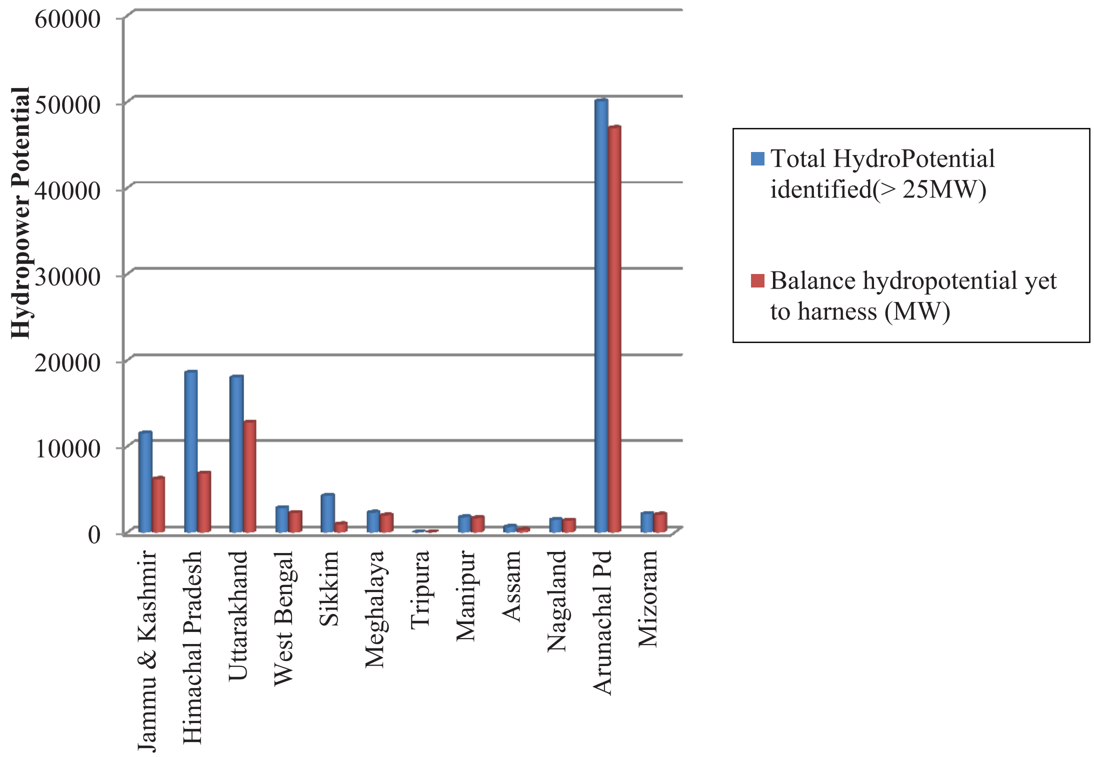

Figure 6: Comparison of HPP balance out of total potential identified in each State of IHR

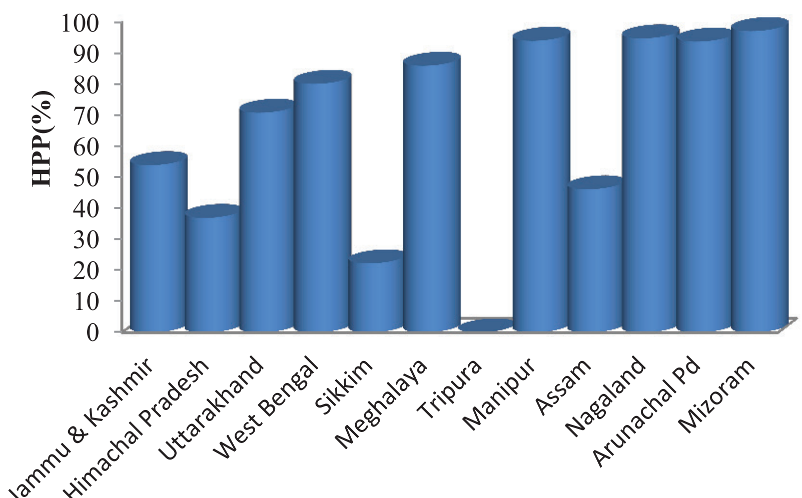

Figure 7: Balance HPP (%) in States of IHR

been developed. Therefore, for planning purpose, these areas may be construed as not so significant source of hydropower.

In pre-para, it is derived that IHR still holds 73.4% of its total hydropower Potential (HPP) which is equivalent to 83.3 GW potential located in 12 states of IHR. For planning perspective, we considered 83.3 GW as 100% balance HPP in IHR and to find which is the most potent States among IHR, the balance HPP in each State is compared with total potential of IHR. The result is

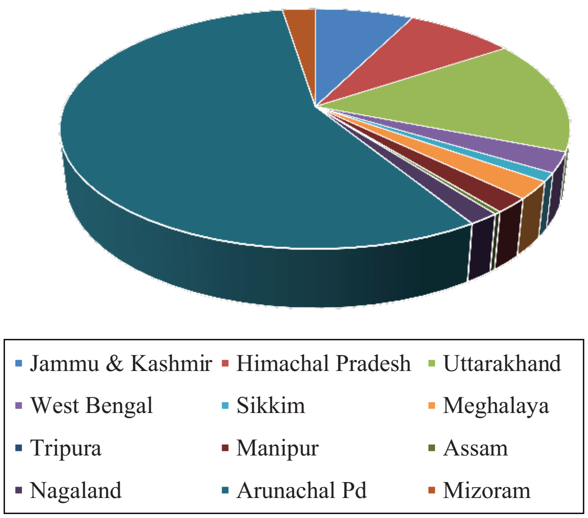

Figure 8: HPP share (%) among IHR States

shown in Figure-8 in terms of percentage. Finally, it is found that among 12 states in IHR, Arunachal Pradesh state is the most potent source of hydropower by holding 53% share of total HPP (in terms of installed capacity) available in IHR, followed by Uttarakhand (15%), Himachal Pradesh (8%), J&K (7.4%) and remaining states contain less than 3% share of total hydropower potential available in IHR. It is expected that this finding shall be quite useful for the policy makers and planners in the country for devising procedural reforms to ensure ease of business in hydropower generation in IHR.

4.2 Prime Constraints in the way of Hydropower

Data analysis shows, India has abundant HPP. However, the pace of its development has been very slow in the last few decades. Despite various advantages of hydropower over conventional sources of energy and RES, the hydro power sector has been saddled with many bottlenecks [42,43] impacting the gestation periods and cost. The prime constraints are discussed below:

4.2.1 Enabling Infrastructure

Mostly, HEPs are located in the remote and inaccessible himalayan terrain which poses challenges to the developers. Implementations of these projects require development of associated infrastructure such as roads and bridges for accessibility of sites and power evacuation system. In most of the HEPs, the expenditure incurred on development of such associated infrastructure exerts financial load on per unit cost of power generation, which ultimately affects project's viability and sustainability in comparison to power available from solar and wind energy. This aspect has been taken in to consideration by the Government of India in March 2019 by declaring measures to promote hydropower sector, which entails inter alia, provision for budgetary support to HEPs for enabling infrastructure like road/ bridges @ 15 M INR/MW for project up to 200MW and 10 M INR/MW for above 200MW [44]. These measures shall be economical for capacity addition through new HEPs, but not applicable for the ongoing HEPs.

4.2.2 Technical challenges

HEPs are site specific and every hydro power project is different from others. Techno-economic viability of HEPs depends primarily on the topography, geology, hydrology and accessibility of the project site, etc. These aspects are duly investigated during survey and planning stage of project. Even then, geological surprises during construction stage cannot be ruled out as has been seen in many projects located in IHR [45]. This 'unpredictable geology' is more pronounced in the young fold Himalayas where most of the Indian HPP resides. Such technical challenges add to construction risks and attendant cost to resolve them. The time required for resolution of geological surprises also causes impact on construction schedule as envisaged during planning of project. Therefore, it is imperative for planner or project proponent to keep a cushion of emergency fund and time for managing such surprises efficiently.

4.2.3 Statutory Clearances

There are standard procedures for statutory clearances and concurrence of HEPs under India's Electricity Act, 2003, Environment (Protection) Act, 1986, Forest (Conservation) Act, 1980 and other Acts. However, the progress of many projects has been affected because of environment and forest issues [46]. Among other reasons, such delay is primarily attributed to the localized socio-political concern which causes hindrance in clearance processes like public hearing, gram-sabha meetings, public consultation under SIA process etc. In a case study [47] it is observed that some projects have been stalled on the demands of the non-government organizations and those people who are completely not concerned and not affected by the project. On account of such actions, the States get reluctant to sign power-purchase agreements with developers and financers causing uncertainties and discouragement in further development and funding of HEPs.

On data analysis of pending HEPs (Table 2) it is observed that the viability of these projects on

Table 2: HEPs techno-economically concurred by CEA but yet to be taken up for construction [48] (as on 31st March, 2019)

Reason for Delay	Installed Capacity (MW)	Estimated Cost (billion INR)	Projects location in IHR (%)
A) Pending for Clearance i) Environment Clearance (EC) accorded but forest clearance (FC)awaited	13813	1210	89
ii) Both EC and FC awaited	6266	521	100
iii) EC &FC Sub-Judice in Courts	3345	236	100
Sub-total	23424	1967	96 (Average)
B) Pending due to other reasons like approval for invest of fund and contractual issue	1846	147	83
C) Developers denied for implementation of projects	1190	122	100
Total	26460	2235	

techno-economically fronts have already been concurred by CEA at a total estimated cost of 2235.25B INR for total 26.4 GW installed capacity, however the construction of these projects have not been started due to pending statutory clearances, court and other matters. About 88% (23.4 GW) of total projects are pending for clearance, in which clearances of 14% projects (3.3GW) are sub-judiced in hon'ble courts. The location of more than 96% projects are in IHR mainly in Arunachal Pradesh, Uttarakhand, J&K, and Sikkim, which are among 12 States identified strategically rich in HPP. In the north-eastern region of India, even after approval of the statutory clearances; projects are embroiled in litigations for years which cause delay in implementation of projects. Such litigation issues are attributed to the concerns raised by the certain localized groups on the pretext of environmental concern or land acquisition or other socio-political aspects of HEPs. In some cases, the court has rejected their plea after long investigation of facts and figures. To curb such situation, from the perspective of both developers and regulatory agencies, it is imperative to take procedural reforms to ensure that the concerns raised by certain groups of people do not act as deterrents to the development of projects.

4.2.4 Land Acquisition

Land is a limited asset in any society and mostly inherited in the successive generation, thus people attach a lot of economic and emotional significance to it. Resistance against relentless land acquisition has drawn public attention in last two decades and it is far more organized and powerful than what it was in the past [49]. It tends to create an anti-development and undemocratic sentiment among the people. There are several cases where disputes in land acquisition were an important cause for plan delays and cost over-runs [43, 50]. In the recent past, local movements against land acquisition in West Bengal (India) for the Tata Nano project and another in Odisha state for Vedanta projects and POSCO and many such problems faced across the country with respect to the processes under the colonial land acquisition Act-1894 necessitated the reforms in land acquisition process. Subsequently, the Government of India notified the new Land Acquisition Act named as 'Right to fair compensation, transparency in land acquisition, Rehabilitation and Resettlement (RFCTLARR) Act', 2013, which came into effect from January, 2014 after replacing erstwhile Land Acquisition Act-1894. The new Act attempts to address the social inequities in the existing framework of land acquisition by provisioning of fair compensation of land, consent of landowners, R&R scheme and many others provisions addressing the concerns of landowners. However, there are certain lengthy procedures in land acquisition like SIA study, updating of land records, formulation of R&R scheme, multiple public consultations, etc. which need to be addressed timely to fasten the land acquisition process. As per the constitutional framework of India, 'land' is under the purview of state Government and acquisition process of land is being done by the concerned State Government for the developers. Therefore, timely completion of land acquisition process solely depends upon the political-will of Government as well as hydropower policy of State. It has been observed that State like Sikkim and other states

Table 3: Major reasons for cost and time overruns of HEPs being implemented through three Sectors/Agencies (factors depicted as percentage of total observed instances)

Sectors/ Agencies executing HEPs	Reasons								
	Geology	Civil/ Mech. Works	Statutory Clearances	Law & order	Contractual issues	Land Acquisition/ R&R	Natural Calamities	Litigation /Arbitation	Other issues (poor approach Road/fund constraint)
Central government	17.5	5	11.3	11.3	11.3	2.5	20	12.5	7.5
State Government	11	3.7	7.4	11	14.8	18.4	7.4	7.4	18.5
Private	20.5	5.8	11.5	5.8	2.9	8.8	11.7	5.8	26.4

in the country where land acquisition process for HEPs have been delayed due to SIA aspect, legal issues and non-updation of land records. Also, in north-eastern States of India, particularly Arunachal Pradesh where land revenue records are not aligned with the existing pattern in the rest of the country, the process of land acquisition is complicated thus likely to be delayed.

4.2.5 Time and Cost overrun

Electricity infrastructure is prone to cost overrun issues almost independently of technology or location [51]. The economic impact of a construction cost overrun is the possible loss of the economic justification for the project as the cost overrun can be critical to policies for pricing electricity on the basis of economic costs, because such overrun would lead to under-pricing. Also, the financial impact of a cost overrun is the strain on the power utility and on national financing capacity in terms of foreign borrowings and domestic credit [51,52]. Thus, project proponents, investors and energy analysts need to rethink and re-evaluate the present status of time and cost overrun of projects and factors responsible for time and cost overruns.

In Indian hydropower sector, case studies of total 35 nos. of HEPs with total 11.9 GW under construction stage till march 2019 [48] reveals that these projects are lagging behind their fixed schedule of commissioning. The data analysis of their cost estimate shows that total cost overruns amounting to 477.13 B INR has been occurred and time overrun is surging from 9 months to 240 months till March 2019. In certain project like Subansiri Lower HEP (2GW) under construction in India, the surge in cost overrun has been estimated as 132.11B INR, which is the highest among the stalled hydel projects as has been reported in national print media [43,53]. The reasons behind time and cost overrun are of varying degrees of issues specific to individual project. However, the factors plaguing the hydro sector in the country under the present circumstances have been analyzed and reflected in the Table-3.

In the above assessment, factors have been categorized based on the analysis of project specific reasons identified in the different HEPs referred in the relevant reports [46,48] across the country. The aforementioned issues acting as impediments in the process of smooth implementation of projects in the country are common to hydropower projects being implemented through all three sectors namely, Centre Government, State Governments and Private agencies. Mostly, reasons like delay in statutory clearances, law and order problem as well as contractual issues are equally responsible for delay in harnessing of HEPs. When combined, these issues account for more than 33% of total observed instances holding back HEPs in the country.

4.2.6 Long gestation and high investment

Hydropower demands high investment and long gestation in comparison to other RES, thus contributes slow capacity addition. In purview of the Paris Agreement, India has to achieve ambitious target of electricity generation from renewable source to comply with the INDC target. In this concern, the priority of hydropower generation is lagging behind solar power in the last few years. It is fact that hydro and solar power technologies are two time-tested forms of renewable energy and both have pros and cons [54]. However, hydropower holds strong advantages over solar and wind power, particularly flexibility to meet peak load and promoting local area development in the vicinity of project area located in remote

Himalayan terrain. [7]. In spite of the drawback of long gestation and high investment, hydropower is required for the timely synergy with solar and wind power to ensure sustainability of IPS. Off late, looking into the advantage of hydropower vis-à-vis constraints of high investment, the Government of India notified institutional measures to promote hydropower sector by introducing tariff rationalization measures and hydropower purchase obligations besides budgetary support [44] in order to make hydropower compatible with other RES.

4.2.7 Environmental concern and sustainability aspects

Although hydropower is a reliable RES however, the environmental and social impacts associated with it need to be addressed thoroughly while planning for capacity addition of hydropower. In India, Ministry of Environment, Forest & Climate Change is apex body of Government of India in the environmental matter. To deal with such challenges, the mechanism of Cumulative Impact Study (CIA) and Carrying Capacity Study (CCS) of various river basins study are in place. The CCS gives idea about optimal number of power projects in a basin, whereas CIA study of a basin reflects the cumulative impact of commissioned and up-coming hydro-power projects in the basin taking into account of environmental flow, bio-diversity, muck disposal sites, R & R issues etc. [55]. Based on the appraisal of project specific environment impact assessment and CIA report of river basin, statutory clearance of a project is accorded by the Government stipulating therewith conditions for compliance of environ-social safeguard measures. Subsequently, the performance audit on 'Environmental Clearance and Post Clearance Monitoring' is done to examine the process of grant of Environmental Clearance with respect to timeline and transparency and its compliance with the prescribed process. The social impacts of hydropower mainly due to land acquisition aspects are adequately addressed in the newly promulgated land acquisition act i.e RFCTLARR Act, 2013. On sustainability aspects, the HSAP developed by IHA is a global framework for assessing the sustainability of HEPs. The protocol defines good and bad practice at each stage of life cycle of a HEP across twenty four environmental, social, technical and economic topics. In India, sustainability assessment of Teesta-V hydropower station in Sikkim has been conducted during 2019, which is the best learning experience for other ongoing and proposed HEPs.

As regard to GHG emission from hydropower, research is still underway in this field. The previous study reveals that the GHGs are emitted from reservoir which depends on the characteristics and location of the HEPs. High emissions were related most strongly to low area-to-electricity ratios, large reservoir surface areas and high air temperature. Therefore, each hydropower project should be carefully analyzed for its GHG emissions [56]. In India, study of GHG emission from reservoirs of Tehri hydropower [57] and Koteshwar hydropower in Uttarakhand [58] have been studied through GRAT model. The CO2 emissions from Tehri reservoir were lower than the other tropical hydropower systems in the world, partly due to the higher depth and lower allochthonous organic carbon input from the reservoir catchment [59]. In an another study [60], it is concluded that even though a lot of efforts have undergone in determining the GHG emissions from reservoir however, due to various uncertainties like lack of standardized measurement tools and techniques, till date the determination has been little difficult and full picture of GHG emission at worldwide is still unknown [60]. In such scenario, it is obvious that careful removal of vegetation and other easily degradable organic matter from the inundated area of a reservoir, treatment of Catchment area are fundamental in minimizing GHG emissions from it [56].

Other RES are also associated with GHG. The outcome of 41 studies shows that both the wind and solar systems are directly tied to and responsible for GHG emissions when viewed in a holistic manner; including initial materials extraction, manufacturing, use and disposal/decommissioning. They are thus not completely emissions free technologies [61]. Therefore, for the planning and development perspectives, the GHGs emission cannot be a sole factor for prioritizing the RES.

5. The Way forward

Addressing the procedural gaps and constraints prevalent in the energy system would go a long way in furthering the spirit of the Paris agreement and India's commitment towards NDC and sustainability of IPS, particularly through capacity addition of hydropower. The following recommendations may be a step forward in this direction.

- Based on the lesson learnt from the past experiences in hydropower development, project developers should formulate efficient ways and means, sharing of technical know-how among other developers to deal with geological surprise, technical/construction issues and contractual matter to avoid arbitration cases. Also, the awareness and monitoring of compliance of environment and social norms and other stipulations pertaining to HEPs be looked into.

- At each project level, extensive awareness drive (about project's features, compensation and benefits aspects) should be done among local people by the developers and district administration together. Also, a mechanism of grievance-redressal should be established to address the aspiration of stakeholders to avoid legal intricacy at later stage.
- Both the Governments at Centre and State level should work collaboratively to achieve capacity addition targets through alignment of policy and institutional framework. In this context, procedural reform is required to streamline the clearance process by addressing the issue of 'multiple public hearings' in three aspects viz., environment clearance, forest clearance and land acquisition.
- The result of this study (figure 8) indicates that out of 12 States in IHR, 04 States are rich in HPP. Therefore, to facilitate the hydropower development in these 04 States, a 'Nodal Officer' may be nominated by the respective State Governments for ensuring coordination among State Government Departments, project proponents and central government for re-dressal of various issues pertaining to effective implementation of HEPs.
- The State Government should bring land acquisition process on the digital platform in line with diversion of forestland in India. The online processing of land acquisition proposal would bring transparency and accountability for delay, if any.
- Hydropower is capital intensive. The concerned State Government could help in managing the financial viability of the project by way of relaxation in realization of its share of 12% free power in staggered manner, relaxation in levy of cess/taxes, excise duty, local area development fund(LADF) wherever applicable; in the first few years of commissioning of project.
- The construction of HEPs is challenging task in himalayan terrain, for which, the developers should adopt an effective human resource management policy to sustain the professional performance of its internal stakeholders (i.e employee) and aspiration of external stakeholders (i.e local people, Gram-panchayats, administration, etc.).

6. Conclusions

India, one of the emerging economies in the world has clearly embarked on the path of energy transition from over-reliant fossil fuel to SES for the sustainability of IPS and energy security of the country. Hydropower has very important role in this direction by virtue of its inherent flexibility to meet peak load and balance out variability in the solar and wind power in the synergic state. Moreover, hydropower promotes the development of the remote himalayan villages through infrastructure support (access road,bridge), flood moderation, water supply and many more. Further, in pursuance to the Paris agreement, India is committed to achieve its ambitious target to base 40% of the total power generation capacity on non-fossil fuel resources by 2030. In this concern, the solar and wind power generation are on the fast-track whereas, hydropower development is still growing at a slower pace due to various constraints. Hence, a skewed power development scenario is a challenge for the sustainability of IPS.

To meet such challenges, the finding of our study indicates that there are substantial opportunities to strengthen the IPS through capacity addition of hydropower and reducing reliance on fossil fuel. The 12 States of IHR accounts for a staggering 65% of the total estimated HPP of the country. The development of hydropower requires addressing of the prime constraints i.e delay in statutory clearance, litigation, geological issues, time and cost escalation etc. Also, the specific procedural issues like multiple public hearings in clearances and land acquisition process of a project needs to be streamlined. Further, certain initiatives like digitization of land acquisition proposal, nomination of nodal officer, grievance-redressal mechanism etc. as recommended in this study would be a way forward in sustainable planning and development of hydropower in India through the proactive approach of the State Governments as the 'land' and 'water' two vitals for hydropower development are under their purview in the constitutional framework of India. Given the rich cultural and biological diversity vis-a-vis fragility of IHR, the practice of CIA & CC study during appraisal of projects and post-clearance monitoring of projects duly address the environmental impacts of HEPs. The promulgation of RFCTLARR Act-2013 adequately addresses the social aspects in comparison to the previous land acquisition Act, 1894. Moreover, the HSAP, a global framework for assessing the sustainability of HEPs, is applied in India to ensure sustainable implementation of HEPs.

While acknowledging the capital intensive nature of hydropower, the recent hydro-policy framework contemplated by the Government of India is definitely a welcome step in promotion of hydropower. However, given the existing federal structure of government functioning in India, a coordinated and active participation of the respective State Governments will have a significant effect on overall development of hydropower as well as sustainability of IPS.

As future research opportunities, a simulation study to optimize the further capacity addition of hydropower taking different parameters viz., projected short and long term demand of electricity, environmental carrying capacity and investment aspects in to account may explore the better planning perspective of IPS.

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