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Energy Security Insights

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Foreword

This issue of *Energy Security Insights* is focusing on the role of hydroelectric power in India and how the hydro option is an important element in addressing India's energy security. There is clearly much larger technical potential for hydropower than seems feasible in the short term on account of political, environmental, economic, and social constraints. Much of the adverse reaction to large hydro projects that we encounter today is the result of previous projects not having taken into account several of these factors, particularly the environmental aspects and the serious problem of displacement of people resulting from major projects. There is now clearly a growing preference all around for run-of-the-river projects which have far more acceptable impacts than large dams, particularly in sensitive areas like the Himalayas and the north-east of India.

One aspect which future projects would need to take into account would be the impacts of climate change which would affect precipitation patterns and the availability of water in catchment areas on which hydropower depends. On a regional scale, mountain snowpack, glaciers, and small icecaps play a crucial role in fresh water availability. Widespread mass losses from glaciers and reduction in snow cover over recent decades are projected to accelerate throughout the 21st century reducing water availability, hydropower potential, and changing seasonality of flows in regions supplied by melting water from major mountain ranges. India is not the only region where these trends pose challenges, but such phenomenon would also apply to Hindu Kush and the Andes.

However, changes in precipitation and temperature lead to changes in run off and water availability. Run off is projected to increase by 20 to 40 per cent by mid-century at higher latitudes and in some wet tropical areas. The recent *Special Report on Managing the Risks of Extreme Events and Disasters* brought out by the Intergovernmental Panel on Climate Change (IPCC) clearly highlights the likelihood of increase in extreme precipitation events. The frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe. Also, heavy rainfall associated with tropical cyclones is likely to increase with continued warming of the climate system. In some regions increase in heavy precipitation will occur despite projected decrease of total precipitation in those regions. For a range of emissions scenarios, the IPCC found that a 1-in-20 year annual maximum daily precipitation event is likely to become a 1-in-5 to a 1-in-15 year event by the end of the 21st century in many regions, and in most regions the higher emissions scenarios would lead to stronger projected decrease in return period.

The implications of these projected changes are very serious. In future, whenever plans have to be drawn up for designing hydropower projects these must be preceded by a careful scientific assessment of projected changes in precipitation patterns and snowmelt wherever relevant. Such an exercise requires sophisticated climate modelling using global models which are downscaled to assess likely impacts on smaller areas such as the catchment of a particular hydro project. In general, climate change impacts would exacerbate stresses that are caused by other human activities. Changes such as excessive siltation which results from large-scale deforestation in catchment areas, also need to be taken into account.

All in all while hydropower is a sustainable and clean source of energy which can certainly reduce any threats to energy security, it would need to take into account several future changes and developments, including those related to the impacts of climate change.

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Hydroelectric power development - an overview

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1. Introduction

The right to development is a basic human right and it is a proven fact that development cannot take place without energy. Access to electricity gauges development contributing to human well-being and economic growth. Developing countries like India have a great and ever-intensifying need for power and water supplies. To meet the rapidly growing demand for energy, exploitation of all available sources will be necessary, but for environmental reasons, the first priority should be the development of all the technically, economically, and environmentally feasible potential from clean, renewable energy sources such as hydropower. All forms of infrastructural development and in particular energy development have different degrees of impacts on the environment. Among these, hydropower has significant positive and few negative impacts on society and the environment, by limiting greenhouse gas emissions. Today hydro professionals are well aware of the problems to be addressed, and the expertise exists to mitigate the known impacts to achieve an acceptable balance. Hydropower is the largest source of renewable energy currently available at society's disposal.

2. Energy consumption studies:

2.1 World scenario

The Energy Information Agency (EIA), the United States Department of Energy, and the World Energy Council monitor global energy consumption on a regular basis. An EIA Report, Energy Outlook 2011, forecasts that the energy consumption, worldwide, from all sources will grow by 53% between 2008 and 2035. Net electricity generation will grow by 84% during the same period.

In the above study, the pattern of use and generation of electricity have been studied in two groups, OECD (Organization for Economic Cooperation and Development) countries, and non-OECD countries.

Total electricity generation in non-OECD countries increases by an average 3.3% per year, led by non-OECD Asia (including China and India, where the annual increase is about 4% per year) during the period 2008-2035.In contrast, net generation in OECD countries is only in the order of 1.2% during the same period.

In many parts of the world, concerns about security of energy supplies and the environmental consequences of greenhouse gas emission, has spurred Government Policies that support a projected increase in renewable energy sources. As a result, renewable energy is the world's fastest growing form of energy, and the renewable energy share of total energy use is projected to increase from 10% in 2008 to 14% in 2035. More than 82% of this increase is projected in the form of hydroelectric power and wind power. Majority of hydropower growth occurs in non-OECD countries.

The International Hydropower Association (IHA), the Implementing Agreement on Hydropower Technologies and Programmes of the International Energy Agency (IEA/Hydro), the Canadian Hydropower Association (CHA), and International Commission on Large Dams (ICOLD) are worldwide organizations that are proponents of responsible hydropower development.

The comprehensive study carried out by IEA/Hydropower Agreement has analysed virtually all social and environmental aspects of hydropower and has suggested the following procedure for developing and managing future hydropower projects:

a. Nations should develop energy policies that clearly set out rational objectives regarding the development of all power generation options including hydropower, other renewable sources, and conservation.
b. Stakeholders should establish an equitable, credible, and effective environmental assessment process that considers the interests of people and

environment within a predictable and reasonable schedule. The process should focus on achieving the highest quality of decisions in a reasonable period.

c. Project designers should apply environmental and social criteria when comparing project alternatives to eliminate unacceptable alternatives early in the planning process.
d. Project design and operation should be optimized by ensuring the proper management of environmental and social issues throughout the project operation cycle.
e. Local communities should benefit from a project, both in short term and in the long term.

Together these five recommendations constitute a sustainable approach to renewable hydropower resource development.

2.2 Indian scenario

As per Central Electricity Authority (CEA) Report dated 31-3-2012, the total hydropower capacity available in India is 148,701 MW out of which, 145,320 MW are in Projects with capacity above 25MW.

Out of the above, 34,205 MW (23.54%) is developed and 12,252 MW (8.43%) is under development. The balance 98,863 MW (68.03%) is yet to be developed.

3. Unique Characteristics of hydropower:

- Abundant availability of unutilized capacity: About 70% of economically feasible projects remain to be developed in India as well as across the world.
- Proven and well advanced technology: More than a century of experience and modern power plants providing the most energy efficient energy conversion process (more than 90%), which is an important environmental benefit.
- Fast response ability to adjust according to daily and seasonal variations in demand, thereby contributing to grid stability. Use of modern variable speed generators and turbines can ensure optimization of operation commensurate with the load demand.
- The production of peak load power from hydropower allows for the best use to be made of base load from other less flexible electricity sources, like coal, wind and solar.
- It has lowest operating cost and longest plant life, compared with other large-scale generating options. Once the initial investment is made in the necessary civil works, the plant life can be extended economically by relatively cheap maintenance and periodic replacement of electromechanical equipment (replacement of turbine runners, rewinding of generators etc.- in some cases the addition of generating units). Typically a hydropower plant in service for 40 to 50 years, can have its operating life doubled.
- The medium used (water) is renewable, is not subject to market fluctuations, and hence contributes to energy independence.
- It is the only source that is not consumed, and is available for downstream use for irrigation, drinking, and other purposes
- It is the only renewable source, which can be stored and used as per demand requirement. Pumped storage plants can reuse the same water repeatedly.
- It is the only source of power, which has many other parallel benefits in addition to generation of electricity, as explained below under the additional benefits.
- Black start capability: The ability to start generation without an outside source of power.

4. Additional benefits of hydropower:

- Hydropower plants can be planned as multi-purpose projects to include irrigation, flood control, navigation, and municipal and industrial water supply benefits.
- Hydro power plants harvest rainfall, thereby storing and supplying fresh water for drinking and irrigation. By storing and managing water, hydro projects can protect aquifers from depletion and reduce our vulnerability to costly and deadly floods. Hydro also helps to manage irregular and unevenly distributed supplies of water thereby insulating against drought situations also.
- Hydro contributes to human welfare by ensuring safe and sufficient drinking water and sanitation and enhancing the food security and self-sufficiency by making irrigation water available.
- Reservoir can also provide a stable source of water for industrial development.

- Hydro plants enhance wetlands and support healthy fisheries.
- Wildlife preserves can be created around reservoirs, which in some cases provide stable habitats for endangered or threatened species.
- Boating, skiing, camping, picnic areas and boat launch facilities are all supported by hydropower.
- Ability to meet moment-to-moment fluctuations, provide stability against voltage fluctuations thereby protecting electrical equipment and computers.
- Greenhouse gas emission (GHG) factor for hydropower projects is typically 30-60 times less than factors for fossil fuel generation. In the case of new plants to be developed, even this low emission can be avoided/ minimized by removing the biomass cover, before impounding the reservoir. A coal-fired plant will emit about 1000 times more SO2 than hydropower systems. The magnitude of the impact of particulate emissions from fossil fuel is now also being recognized, particularly in connection with respiratory disease.
- The employment and business opportunities created by the Project activities in the local areas will improve the financial status of the local community. In fact, most of the hydropower projects are located in remote and backward areas, and improve the infrastructure facilities and living standards of people living in those areas.
- The infrastructure facilities such as access roads, medical facilities, and educational institutions created during Project construction, local availability of electricity, and other activities associated with the reservoir are possible sources of sustainable economic and social development of the area adjacent to the projects.

5. Financial aspects

Though the capital cost for construction of hydropower projects are higher compared to those for fossil fuel plants, there is only negligible cost for operation, as there is no fuel required. Except the water cess to be paid to the State Government for the quantum of water used, no other payment is to be made. As there is less mechanical equipment involved, the maintenance cost also is less for hydro projects compared to fossil fuel projects. The life of hydro projects is also much longer for hydro. Because of all these advantages, the overall long-term cost of generation in hydropower projects is comparatively lesser than other sources of power.

The cost of hydropower projects is site-specific, and depends on the facilities required at different sites. The location of the project decides the transportation costs for construction materials, equipment, and power generation equipment. Project financing is generally done with debt-equity ratio of 30:70.

The approximate cost involvement for hydropower projects is indicated in the following table.

Item	Approximate cost
Overall completed cost of projects	INR 50 to 100 million per MW
Indicative cost distribution for major components in % of completed cost: • Land- about 4 to 5 % • Civil &hydro mechanical works- about 35 to 40 % • Electromechanical works- about 15 to 20% • Environmental protection works including compensatory afforestation, Catchment area treatment, Local area development etc.- about 6 to 8% • Escalation- (@ 4to6% for civil works and 4% for EM works) – overall about 10% • Interest during construction- (as per bank rate)-generally about 25 to 30%	

6. Indian policies / practice and clearances required

6.1 Policies/practice

As per the prevalent hydropower policy and practice being followed in India, the following provisions are being made in the project proposals.

- Minimum 10-year's hydrological data will be collected and analysed and the projects are designed based on 90% dependable discharge available.
- The design flood discharge is estimated based on the probable maximum precipitation provisions as per BIS Codes. Provision will be made for evacuating the design flood discharge safely to the downstream, with 10% gates non-functional.
- The site-specific earthquake parameters used in the design of dams and other important structures are evaluated by eminent Institutes like Central Water & Power Research Station (CWPRS)

and IIT Roorkee, and approved by a National Committee; hence the risk due to failure of dams under seismic action is well taken care of.

- A dam break analysis is carried out and precautionary measures are planned to avoid hardships to the downstream inhabitants and properties even in case of an unexpected failure of dam.
- The Project developers shall give minimum 12 % power generated as free power to the State, during the entire operation period.
- Additionally, 1% of power generated shall be given to the State free, during the entire operation period, the revenue obtained from which shall be utilized for the development of the project affected areas.
- 2.5 % of the overall project cost shall be utilized for Catchment Area Treatment works (CAT), to mitigate slides and erosion of the soil.
- Not less than 1% of the overall project cost shall be utilized for initial development of the project-affected areas.
- In addition, as a corporate social responsibility, the developers shall provide water supply, medical facilities, education facilities etc. for the benefit of project-affected people.
- The Rehabilitation and Resettlement facilities including various compensations required shall be provided to the Project affected people as per the prevailing policy of the State.
- The minimum ecological discharge shall be released for the benefit of downstream areas between the diversion structure and powerhouse tailrace outlet, as per the quantum decided by MOEF and State Governments.
- Wherever, the fish movement is affected due to construction of dams/barrages, the feasibility of constructing fish ladders, fish lifts etc. will be considered first. In case such structures cannot be constructed, fish hatcheries will be developed upstream of dam for creating new fish life.
- Wherever forestland is to be acquired for project development, double the area is acquired for compensatory afforestation at the project cost. The values of trees cut is compensated at project cost. In addition, the cost for planting new trees in the compensatory area is paid from project cost. Thus, in fact, there will be increase in the forestland area and not any depletion of forests due to construction of hydroelectric projects.
- Detailed Environment Impact Assessment (EIA) is done for 3 seasons and Environment Management Plan (EMP) is worked out.
- A public hearing is conducted to explain to the local public about the mitigation measures proposed and benefits to be derived from the project. The views of the local people and local administration are considered to take suitable action to mitigate their additional difficulties if any.

6.2 Statutory clearances

For setting up hydropower projects in India, various statutory clearances are to be taken from government departments.

Projects costing beyond INR 500 Crores, (INR 2500 crores for Projects included under National Electric Plan) environmental clearance shall be obtained from MOEF.

The State Governments will allot the hydropower projects in their states to various developing agencies as per the norms prevalent from time to time.

The Project developers shall prepare a Detailed Project Report (DPR) and a Checklist as per the Standard Guidelines issued by CEA and submit to CEA for obtaining the Techno Economic Clearance (TEC). The preparation of the DPR may take about 1.5 to 2 years, including collection of data.

While the DPR is under preparation, the developer can apply to MOEF for Stage I clearance, which is the Site Clearance.

After obtaining site clearance, the agency can proceed with Phase-II activities, involving Project Siting details, Environmental Impact Assessment (EIA), and Public hearing.

After completing EIA and public hearing, and obtaining NOC from the concerned local bodies, the agency can apply for Phase III (final environment clearance), along with copy of DPR.

MOEF will ensure that all environmental safeguards required are satisfied, before according Environmental Clearance to the projects.

Once the DPR is submitted to CEA, before according TEC, CEA will take the assistance of other specialist organizations like Central Water Commission (CWC), Geological Survey of India

(GSI), Central Soil and Materials Research Station (CSMRS), MOEF etc. These bodies go through the proposed schemes in the DPR and evaluate the projects for adequacy of the provisions made to ensure safety. They will also examine and certify that the construction time of project considered is reasonable.

Before according clearance, CWC will examine the structural suitability and safety of various structures proposed and satisfy that the concepts adopted in the design of various components are in accordance with the BIS Codes and standard practices being adopted world over. They will also examine and approve the water availability and the design flood considered. CWC will also verify and certify the adequacy of Quantities for various components, to establish financial viability of schemes proposed. CWC will also examine whether any interstate or international interests are affected due to construction of the project.

GSI will examine the geological aspects and CSMRS will examine the availability and adequacy of construction materials.

The electromechanical and financial aspects including power potential and transmission facilities will be examined by CEA.

After getting clearances from CWC, GSI, CSMRS, and MOEF, the CEA will request the project developer to make a detailed presentation on the finalized project parameters, in which experts from all reviewing agencies also will be present. After detailed discussions in the presentation meeting, and after ensuring that all technical, financial, environmental, and safety aspects are satisfied, CEA will accord TEC to the Project.

After obtaining TEC, the Developer can proceed with land acquisition activities. In case of forestland diversion, additional forest clearance will be required from State Forest Dept. / MOEF, depending upon the extent of forest area. Only after forest clearance, State Forest Department can take action for physical handing over of the forestland.

After physical possession of land only the construction of project can start.

7. Way forward:

As per present the situation in India, after the allotment of the project, a substantial amount of time lapses while obtaining all statutory clearances before construction can start. Owing to this delay, the project costs escalate substantially compared to the cost envisaged at the beginning, mainly due to an increase in the cost of land, construction materials / equipment, and labour. With improvements in technology, the project construction methodology, equipment, and planning is modified and alters the project cost during such a long gap, leading to the perception that hydro projects attract cost and time overruns.

As such, it is essential that all clearances be issued in parallel and in a time bound manner, say, within a period of 1 year after the preparation of Detailed Project Reports.

Public consultation is required with participation of all stakeholders. However many times, it happens that due to lack of knowledge and misinformation provided by vested interests, local unrest is created even before public hearing is held to explain the relative merits and mitigation measures proposed. Public hearing should be made mandatory for all stakeholders. In case it is not held, the proposals should be widely publicized and circulated by way of pamphlets etc. Public hearing should be limited to mitigation measures such as water supply and protection of local properties, and not on technical merits of the projects, as these are already taken care of by competent technical bodies. The onus of consultations should be with local administration.

11. Conclusions

Hydropower has an important role to play in the future, and provides considerable benefits to an integrated electric system. It has social and environmental impacts, but expertise is also available to avoid or mitigate negative impacts. Impacts of hydro projects are well understood today and appropriate mitigation and compensation measures can ensure that any project represents a net gain for the affected populations. The remaining hydroelectric potential of the country needs to be considered in the new energy mix, taking into consideration social and environmental impacts, so that necessary mitigation and compensatory measures can be taken. Clearly, the population affected by a project should enjoy a better quality of life because of the project. Any development involves change and some degree of compromise, and it is a question of assessing benefits and impacts at an early enough stage, and in adequate detail, with full involvement of those people affected, so that the right balance can be achieved.

The hydropower industry must collaborate with interested stakeholders including regulatory bodies, global financial leaders, and competent interest groups, to develop future standards to ensure balanced and reasonable planning, construction and operation of hydropower plants.

Hydropower should be a priority in our energy security matrix, as it is a clean, reliable, and competitively priced energy source. Better technology coupled with efficient systems and processes and clearances will reduce gestation period.

India has the potential to become a major producer of hydropower and the need of the hour is to demonstrate the same by will, and vision to tap this sustainable source of energy.

Acknowledgement

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Hydropower: The Need for a More Nuanced Debate

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Introduction

At the heart of discussions on energy in India, or for that matter on any resource, are key issues relating to access to that resource, and its consequences. Most would agree that principles of equity require us to create infrastructure so that anyone who needs important resources like energy, water, food, education, and healthcare is able to physically and financially procure those resources. However, creation of such infrastructure which enables access, and thereby promotes equity, can often lead to negative consequences for the same people, or more controversially, for some others. So how do we make decisions? Should we proceed by applying a utilitarian ethical principle and allow for projects as long as the absolute value of negative consequences is far outweighed by positive outcomes[1]? Or should we view projects through a deontological lens and only allow those to proceed which cause no harm to anyone, and consequently allow sections of the population to continue without access to critical resources? Is there a middle path that is largely acceptable to most stakeholders? How do we arrive at it? This development conundrum is well illustrated by looking at the issue of hydropower.

India needs more energy, wherever it comes from

The Government of India has recognized the link between poverty alleviation and energy access, and has identified access to energy, particularly electricity, to be an essential requirement for improving human development indicators. There are 600 million Indians living with no access to electricity, a number equal to the combined populations of the United States and the United Kingdom[2]. The National Electricity Policy (February 2005) has set universal access to electricity as a goal to be accomplished by 2012. Additionally, the per capita electricity consumption in India in 2006 was 503 kilowatt-hour (kWh); for the same period, the per capita electricity consumption in low, middle, and high income countries was 309 kWh, 1651 kWh, and 9675 kWh respectively[3]. The National Electricity Policy has instituted a goal of making 1000 kWh electricity available per capita by 2012, for which it has been calculated that an additional capacity of 1,00,000 MW will have to be created [4]. Thus, as per the Government's plans, not only is more energy required to increase the number of people with access to electricity, but also to increase the amount of electricity that is available to each person.

Benefits of hydropower: Why it should be included in India's energy mix?

India's current installed power generation capacity is 1, 99,627 megawatts (MW), out of which hydropower

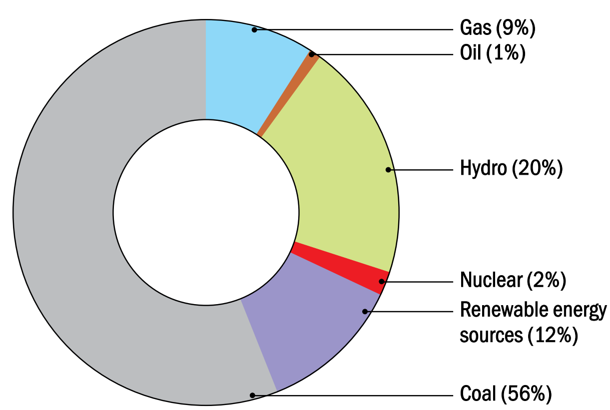

Figure 1 Installed power generating capacity in India, as on 31 March 2012
Source Central Electricity Authority, 2012

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[1] There are challenges of how to estimate positive and negative consequences, and where to draw the boundary for analysis, but even assuming that questions of methods could be resolved, the applicability of the principle is still in question.

[2] Ministry of Environment and Forests (MoEF), *India: Addressing Energy Security and Climate Change*, Ministry of Power, Bureau of Energy Efficiency, Government of India, October 2007.

[3] The Energy and Resources Institute (TERI), *TERI Energy Data Directory and Yearbook*, 2010.

[4] National Electricity Policy, Government of India, February 2005.

[5] Central Electricity Authority, as on 31 March 2012.

constitutes 38,990 MW, or roughly 20%[5]. Shown in Figure 1 is India's installed power generating capacity on the criteria of source, till March 2012.

As can be seen from Figure 1, hydropower currently generates a significant portion of India's electricity, generating more than any other source except coal. Large hydropower systems, globally defined as anything over 10 MW, generated 16% of the world's electricity, and 90% of the world's renewable electricity in 2006[6]. There are strong reasons for power utilities to favour hydropower – it is an efficient and renewable resource of electricity, it can adapt very quickly to increasing or decreasing demands from the grid, and, if executed in certain ways, produces negligible greenhouse gas emissions for the energy produced. Hydropower can satisfy both base and peak loads. Therefore, it complements other sources of electricity well. Several countries have embraced hydropower due to its advantages. Shown in Table 1 is a list of the top ten hydropower producers and the percentage of hydropower in their domestic electricity generation. Note that Table 1 shows the 2010 data, and hence differs slightly from the 2012 data for India, quoted earlier in this article.

Table 1 Major hydropower producers (2010)*

Country	Percentage of Hydropower in Total Domestic Electricity Generation (%)	Installed Capacity (GW)
Norway	99.0	29.6
Brazil	83.9	84
Venezuela	73.4	13.8#
Canada	59.0	74.4
Sweden	48.8	16.25@
Russia	19.0	49.5
India	17.5	38
China	15.5	200
Italy	14.0	20
France	8.0	21
Rest of the world	14.3	379.6
World total	15.9	926.1

* The table presented here has been adapted from information presented in the source.

Source: "World Atlas and Industry Guide", *International Journal of Hydropower and Dams*, quoted in A Kumar, T Schei, A Ahenkorah, R Caceres Rodriguez, J-M. Devernay, M Freitas, D Hall, A Killingtveit, and Z Liu, "Hydropower", in *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*, eds, O Edenhofer, R Pichs-Madruga, Y Sokona, K Seyboth, P Matschoss, S Kadner, T Zwickel, P Eickemeier, G Hansen, S Schlomer, C von Stechow, Cambridge, UK and New York, USA: Cambridge University Press, 2011.

- This information was sourced from a presentation made by Tong Jiandong, "The Opportunities and Proposals for Small Hydro Development in Latin America and Caribbean Region".
- This information was sourced from the Swedish Hydropower Association, available at http://www.svenskvattenkraft.se/default.asp?L=EN(accessed on 14 May 2012).

In fact, the Government of India has planned for the addition of 30,000 MW of hydropower in the 12th Five Year Plan[6].

There are benefits to diversify India's energy supply mix from a geopolitical standpoint as well as to provide some protection from the uncertainty caused by climate change. In addition to the above benefits, which are perhaps accrued by diversifying with any energy source, the advantages of hydropower, in particular, are the following:

- Hydropower projects can be designed to have low life cycle greenhouse gas emissions

As India takes increasing responsibility to mitigate greenhouse gases, policy makers will look to increasingly efficient and climate-friendly forms of generating electricity to meet the country's growing demands. The life cycle emissions of hydropower projects can be significantly lower than other forms of energy, even other renewable sources. Shown in Figure 2 are life cycle greenhouse gas emissions from various sources of electricity, and it can be seen that hydropower is shown to have very low emissions per kilowatt-hour electricity generated. However, a very important factor has been excluded from this graphic, that is the emissions from land use changes in the reservoir. These emissions, caused due to the anaerobic decomposition of organic matter in the areas inundated upstream of dams that have

[6] Intergovernmental Panel on Climate Change (IPCC), "Hydroelectricity", *Fourth Assessment Report*, 4.3.3.1., Climate Change 2007.

[7] Central Electricity Authority, Hydro Development Plan for 12th Five Year Plan (2012–2017), September 2008.

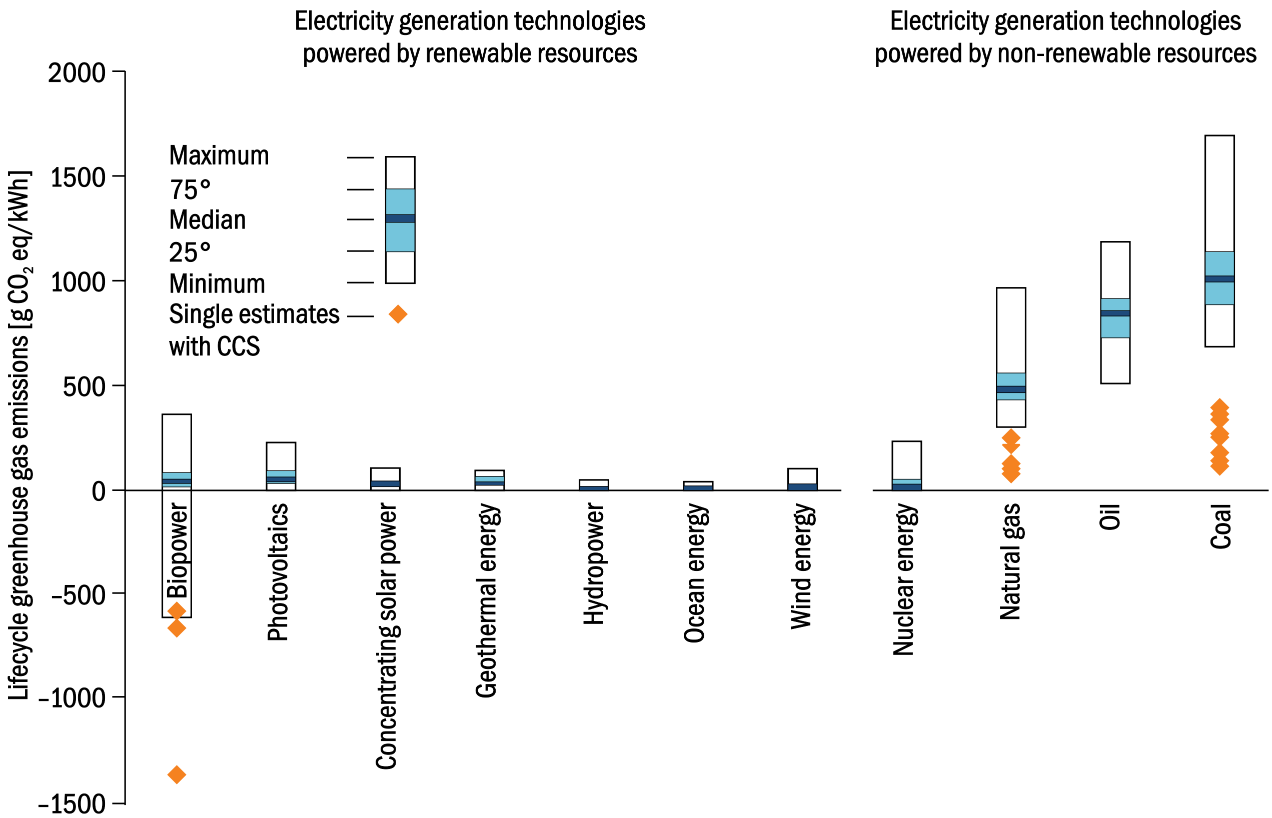

Figure 2 Estimates of life cycle greenhouse gas emissions
Source IPCC, "Summary for Policy Makers", in *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*, 2011.

reservoirs, can potentially make large contributions to the emissions of greenhouse gases in the life of the project, as indicated in Figure 3.

Shown in Figure 3 are the ranges of emissions that are seen from hydropower projects across the world. As can be seen, the life cycle emissions of hydropower projects can vary greatly, depending on the type of project, whether run-of-river type or reservoir based. But it is important to note that the impacts of both cases, even including the reservoir decomposition emissions, have the potential to be very low as compared to more traditional and renewable forms of electricity generation. The majority of projects emit less than 40 grams of CO_2 -equivalent per kilowatt-hour (g CO_2-eq/kWh) of electricity generated over the lifecycle of the project, although some projects have shown values as high as 150 g CO_2-eq/kWh. The median value for coal based electricity generation plants is 1000 g CO_2-eq/kWh. Thus, hydropower can be considered to be a cleaner form of energy than coal, by just evaluating the greenhouse gas emissions record. If we include into consideration the adverse health impacts from particulate matter emitted from coal power plants, the balance shifts more in favour of hydropower.

It is not surprising therefore, that hydropower projects are one of the largest contributors to the Clean Development Mechanisms (CDM) and Joint Implementation Mechanisms (JI). Around 562 out of the 2,062 projects registered for CDM credits were hydropower projects, and it is estimated that the registered projects will help avoid more than 50 million-tonnes of CO_2 emissions per year by 2012.

Thereby, the question that arises is whether it is possible to learn from the low emission intensity hydropower projects, and apply that learning while planning and executing new projects.

- *Hydropower projects can be designed to provide cheap electricity, thereby creating possibilities for wider access*

Hydropower remains one of the most cost effective forms of generating electricity. This is illustrated in Figure 4. As India strives to increase access to

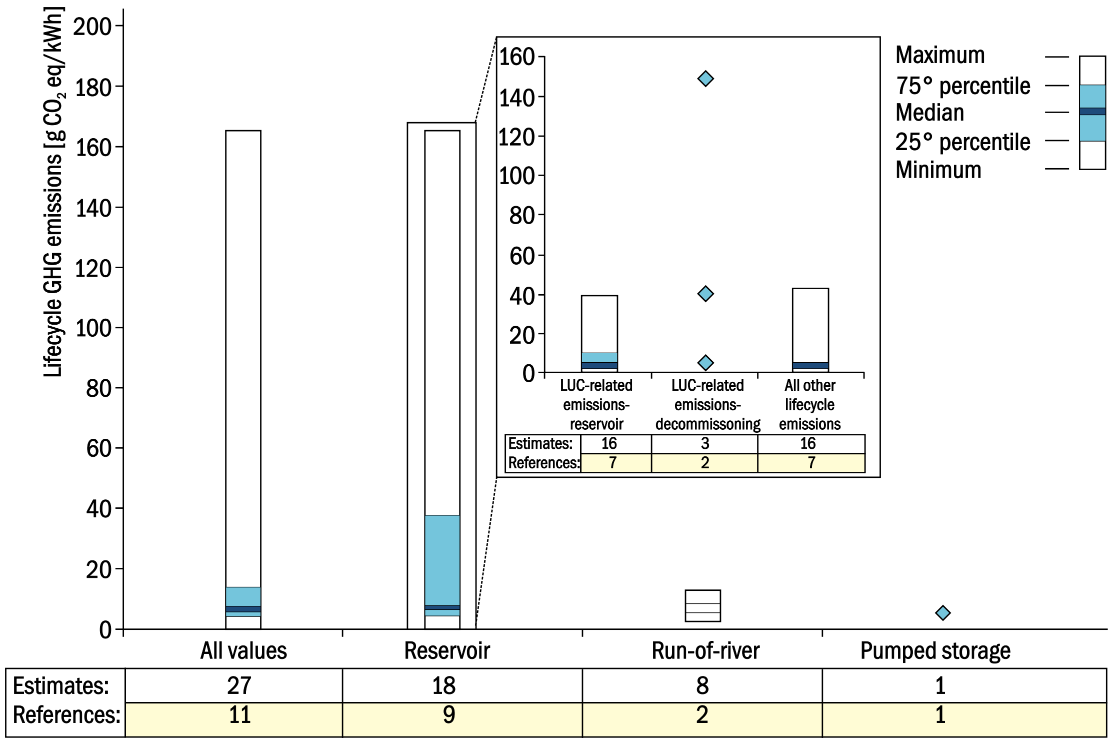

Figure 3 Lifecycle greenhouse gas emissions for hydropower technologies
Source A Kumar, T Schei, A Ahenkorah, R Caceres Rodriguez, J-M Devernay, M Freitas, D Hall, A Killingtveit, Z Liu, "Hydropower", in *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*.

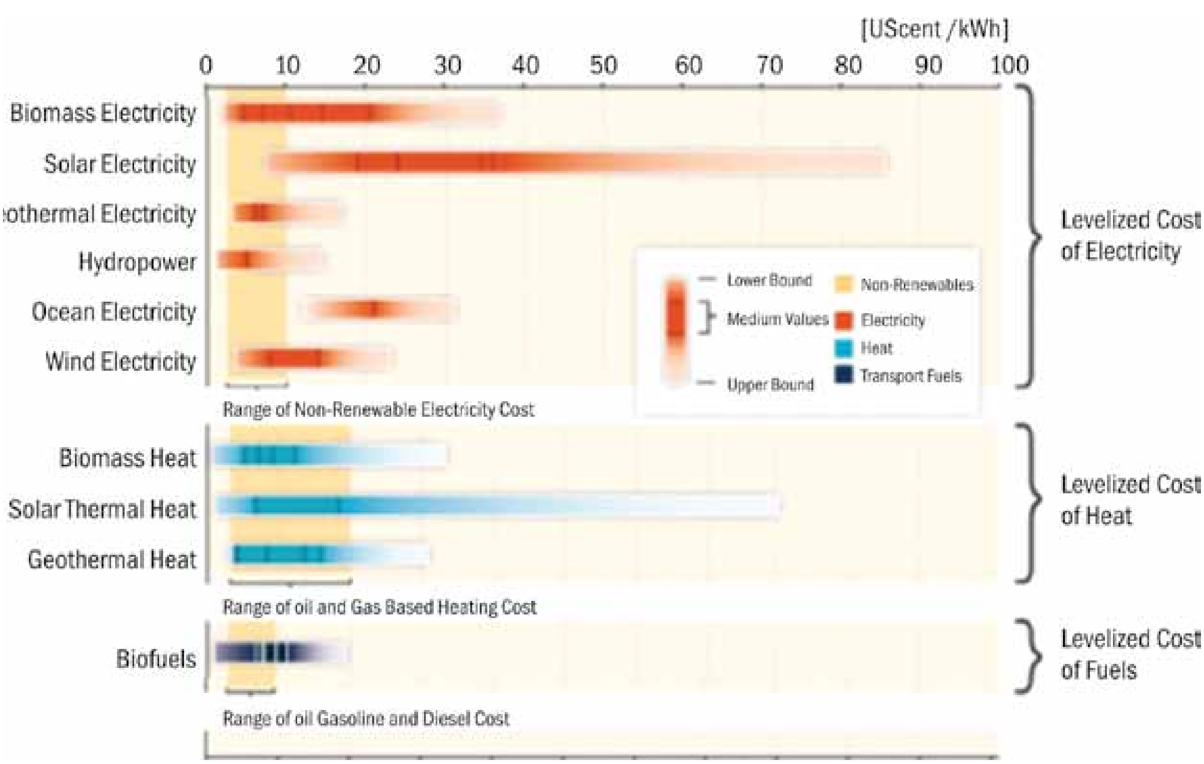

Figure 4 Costs of electricity generated from various sources
Source IPCC, 2011: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1075 pp

electricity, it will also aim to achieve its goals in a cost effective manner.

The negative impacts of hydropower: why do they happen and can we mitigate them?

Hydropower projects vary greatly in terms of their environmental and social impacts. For example, the 500 MW Pehuenche Project in Chile flooded 400 hectares of land with minimal damage to forest and wildlife, and no water quality impacts. On the other hand, the 30 MW Brokopondo Project in Suriname flooded 160,000 hectares of tropical rainforest and caused serious water quality impacts[8]. Shown in Table 2 are a few projects from around the globe and a few quantitative indicators for measuring their benefits and impacts. As can be seen from the table, the impacts are quite varied.

Projects that include reservoirs typically have more serious impacts, and they mostly accrue from the conversion of a river ecosystem to a lake. Associated impacts include loss of terrestrial habitat, loss of terrestrial wildlife, involuntary displacement of project affected persons (PAPs), water quality impacts due to reduced oxygenation, loss of cultural property, and a change in the hydrological pattern of the basin. Unfortunately, although many of these impacts can be avoided or minimized by implementing mitigation options, more often than not, the mitigation occurs only on paper and is not implemented for real. Or, the assessment of impacts is so simplistic that it fails to capture the value of ecosystem and livelihood services received by the PAPs in their current ecosystem, and therefore, does not fully compensate them for their loss. The construction of large dams has led to the displacement of 40-80 million people worldwide, which include 16-38 million in India alone[9]. Undercounting of the displaced and discrimination against subsets of displaced, such as the disenfranchised, or those without title to their land, are seen too often.

A study by the World Bank in Latin America found that the single most important factor that determines the adverse impacts of a dam is the selection of site. In general, dams on upper tributaries are environmentally more benign than dams on large main stems of rivers[10]. Additionally, a smaller surface area of reservoirs leads to fewer damages. Significant work has been carried out to understand and devise mechanisms to minimize the environmental and social damage caused by dams. It is possible, and in fact it should be mandatory for those lessons to be applied diligently to any new projects being contemplated. Not only are the adverse impacts widely varied, but the World Commission on Dams found a high variability in the delivery of promised benefits. Can we harness the positive impacts of dams, and minimize the adverse impacts to mutually acceptable levels? It seems like a worthwhile endeavour to try. The following may be considered to be good rules of thumb for planning of hydropower projects:

- Rework existing infrastructure instead of creating new. Only one-fourth of the world's 45,000 dams currently generate electricity. Retrofitting existing infrastructure is far more benign than building an entirely new dam, and should be implemented where technically possible.
- Enforce performance monitoring of existing and newly planned large dams. This article calls for a nuanced debate of costs and benefits including a full assessment of direct and indirect costs and benefits, with a boundary for analysis jointly decided by all project partners. However, an assessment on paper is of little use if the costs and benefits in reality vary largely from those planned for. A large onus must be placed on the monitoring of projects to ensure that the planned benefits are received, and that no more than the planned costs are borne.
- Engage with all local stakeholders from the very beginning, and make joint decisions. Ensure that the benefits of the project reach the local stakeholders, otherwise there is no incentive for cooperation. National and local vested interests should not be allowed to influence the decisions of the group.

[8] George Ledec and Juan David Quintero, *Good and Bad Dams: Environmental Criteria for Site Selection of Hydroelectric Projects*, World Bank, November 2003.
[9] World Commission on Dams, *Dams and Development: A New Framework for Decision Making*, December 2001.
[10] Ledec and Quintero, *Good and Bad Dams*.

- Select run-of-river projects wherever possible, or select sites for reservoirs that are smaller in surface area relative to power generation.

Conclusion

Some large dams are relatively benign, while others have created drastic and irreparable damage to the ecosystems in which they are situated. Some deliver all their designed benefits, while others fall woefully short. How do we replicate the success stories, avoid the failures that have haunted us in the past, and harness the potential benefits of hydropower? How do we decide whether to build a dam for electricity, or to choose another source of energy such as coal, natural gas, solar, wind, or biomass? We should probably decide by fully weighing all costs and benefits of each option in a public forum, and selecting the most benign and acceptable one. In some cases, it may emerge that hydropower is the best option, and sometimes it may turn out to cause unacceptable losses.

Perhaps no other single issue related to equity captures the imagination of the public quite like large dams. Dams illustrate the complex nature of development decisions by visibly throwing up several issues such as the struggle between the preservation of natural landscape and the need for generation of electricity, the needs of local and national beneficiaries and affected persons, and the difficulties in resolution of inter-sectoral and inter-state disputes. Therefore, dams serve as great examples to illustrate the importance of a nuanced debate including a full assessment of direct and indirect costs and benefits. The pros and cons of hydropower should be viewed in a larger context of India’s energy security and energy access issues. As far as the other development issues are concerned, the answer to the question “to build or not to build (large dams)” is not written in black and white. Hydropower will certainly play an important role in helping India achieve its goals of eradicating energy poverty and achieving energy security. However, there are several factors that need to be mitigated before hydropower projects can be welcomed in many areas. A thorough understanding, analysis, communication, and acceptance of the benefits and losses by the public are required before decisions on hydropower projects are made.

Harnessing Hydro-power Potential in a Sustainable Manner

Need to Address Social and Environmental Impacts

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Introduction

India is blessed with an immense amount of hydroelectric potential, and ranks fifth in the world in terms of exploitable hydropower potential. As per an assessment made by the Central Electricity Authority (CEA), India is endowed with an economically exploitable hydropower potential to the tune of 1,48,700 MW of installed capacity (National Hydro Power Corporation Ltd.) With such significant potential, hydropower remains one of the critical options towards achieving the objective of diversification of energy sources and addressing energy/peak shortages in the country. The ability of hydropower plants to respond quickly to demand fluctuations makes them the ideal source of electricity to cope with demand peaks and help stabilize system frequency. Cheap and inflation-free power from hydropower plants for the Indian industry can lead to sustainable economic development in the country. This is even more critical since India lacks adequate resources of hydrocarbons and is a net importer of hydrocarbons to meet its energy requirement. Hydropower is a well-established technology that uses water without depleting it. While hydropower plays an important role in energy and development strategies, such natural resource projects are inherently challenging. The environmental and social impacts of hydropower projects are significant but they can be mitigated. Harnessing unexploited resources of hydro-power in a sustainable way can help in meeting growing energy needs of the country and enhancing energy security.

Impacts

Hydropower provides one of the strongest examples of the close link between water and energy. Due to its link with large dam projects, which are often environmentally and socially harmful, hydropower has been the focus of heated debate. The main negative impacts of dams include displacement of local populations and degradation of ecosystems, adverse down-stream effects on rivers, as well as the threats to livelihoods of large numbers of people. Of late, large hydro projects have been presented by some as instruments of emission of greenhouse gases more than remedies of climate change, since large dams convey a public image of environmental and social degradation. The IPCC recognized in its 2006 guidelines on greenhouse gas inventories that reservoirs are a source of emissions, especially methane (CH_4). In awareness of these negative impacts, it is necessary to understand how hydropower development can be made both technically and economically attractive as well as socially and environmentally friendly. The following environmental and social impacts are expected during the project implementation of hydropower plants.

Environmental

- Land use, topography, soil erosion/sedimentation
- Impact on water resources and quality — hydrology, hydro-geology, and surface and ground-water quality
- Ambient air quality deterioration
- Impact on ecology — forests, terrestrial wildlife, aquatic ecology, and fisheries
- Health and sanitation impacts

Socio-economic

- Issues of land acquisition, compensation, resettlement, rehabilitation, and livelihood
- Impacts on agriculture
- Impacts on culture and tourism
- Community health, safety, and security

- Impacts due to potential natural hazards like flood, cloudburst, forest fire, earthquake, landslides, and avalanches

Social Aspects

Both the positive and the negative social aspects of hydropower give rise to issues that need to be addressed. On the positive side, a hydropower facility generates a lot of revenue from a natural resource, a river. Inevitably questions arise about the sharing of these revenues among local communities, government, and investors. On the negative side, those hydropower projects that include a dam and reservoir sometimes require the involuntary displacement of people from the area to be inundated. Poor, vulnerable groups such as rural populations, subsistence farmers, indigenous communities, and ethnic minorities often bear a disproportionate share of the negative impacts, while the main beneficiaries are urban dwellers, commercial farmers, and industries. The most common social risks facing populations mainly involves loss of arable land, unemployment, resettlement and rehabilitation (R&R), and decrease in health levels. Compensation usually only occurs once as a cash payment or in the form of an asset such as housing and/or land. Lands provided for resettlement are often resource-depleted and in environmentally degraded areas. The focus of resettlement programmes is on physical relocation, rather than economic and social development.

The provisions of the National Rehabilitation and Resettlement Policy (NRRP), 2007, provide for the basic minimum requirements, and all projects leading to involuntary displacement of people must address rehabilitation and resettlement issues comprehensively. State governments and Public Sector Undertakings are at liberty to put in place greater benefit levels than those prescribed in the NRRP, 2007. This policy essentially addresses the need to provide relief to the rural poor and support the rehabilitation efforts of the poorer section of project-affected families, small and marginal farmers, scheduled castes/scheduled tribes, and women who have been displaced. It also provides a canvas for an effective dialogue between the affected families and the administration for R&R.

Measures to mitigate the impacts of hydropower development on displaced people include long-term development support designed to provide a long-term opportunity for the displaced communities to move out of poverty and benefit wider development opportunities. In addition to the basic objectives of R&R policy, certain provisions need to be taken care of by the stakeholders for the effective implementation of R&R.

- To provide adequate compensation to affected tribal communities for curtailment of traditional rights and privileges of land use and collection of forest produce
- To improve standard of living of affected families
- To create a harmonious relationship between the requiring body and the affected families
- Priority to affected families in jobs during project development as well as other work, based on their skills
- Community-development initiatives in consultation with the affected families
- Learning from communities of their dependence level on fishing activities for subsistence and livelihood, the specific nature of their fishing rights, and the ongoing practices of buying and selling fishing rights — compensation needs to be provided for infringing (if in case there is any) on such rights

Increased stakeholder participation at all levels should be an integral part of the development and operation of hydro-power schemes. Sharing of project benefits which involve benefits due to power generation, dam function, improvement in infrastructure, and development of regional industries with resettlers, has, in fact, many advantages and help in reducing the resistance to the dam construction. Sharing also makes the project more equitable morally, as the beneficiaries are not gaining at the cost of displaced people.

A post construction Environment Impact Assessment study for Chamera 1 Hydropower station of NHPC Limited (formerly National Hydroelectric Power Corporation) was commissioned to assess the overall status of socio-economic environment. This study shows that if hydropower projects are handled carefully, they need not pose any serious threat to the environment. The following development indicators show that the project has proved to be a boon to the area.

Development Indicators	Pre-Project (1981 level)	Post Project (1991 level)	Change
Increase in population	311,147	392,286	26%
Increase in literacy	64,495	105,692	64%
Increase of potable water availability	886 villages	1,095 villages	24%
Irrigated area	4079 ha	5,669 ha	39%
Fish production	64 MT	286 MT	347%
Factories	48 Nos.	130 Nos.	171%

Source: Indian National Hydropower Association (2005)

Impact of Flash floods

In the face of accelerated global warming, the glaciers in the Himalayas are retreating at a rapid pace leading to rapid accumulation of water in mountain-top lakes. These glacial lakes which form behind moraine or ice 'dams' can breach suddenly, leading to floods known as Glacial Lakes Outburst Flood (GLOF). Once breached, millions of cubic metres of water and debris are discharged causing catastrophic flooding up to hundreds of kilometers downstream with serious damage to life, livelihoods, property, forest, farms as well as socio-economic and infrastructure assets.

To mitigate the adverse effects caused by flash floods, there is a need for a disaster management policy to be mainstreamed in the state's development programmes and policies so that all departments are prepared for calamities and can play an appropriate part in risk reduction, relief, and rehabilitation.

Heath Impacts

The World Health Organization (WHO) has reported that the reservoirs created behind dams are often breeding grounds for water-borne illnesses, such as schistosomiasis, malaria, and cholera, and other potentially toxic bacteria. Other health impacts include the release of toxins by cyanobacteria due to rapid eutrophication in new dams and the bioaccumulation of mercury in fish, which is released from soil by bacteria decomposing organic matter in the reservoir. Elevated mercury levels in fish downstream of dam projects have also been documented, posing long-term health risks linked to fish consumption.

Environmental Impacts

The range of adverse environmental and related social impacts that can result from hydropower projects is remarkably diverse. While some impacts occur only during construction, the most important impacts usually are due to the long-term existence and operation of the reservoirs. Generally, plants with smaller dams are considered less environmentally damaging than those with larger dams. Also, run-of-river (ROR) hydropower plants are generally less damaging than reservoir power plants, because it is not necessary to flood large areas upstream of the project for storage. Yet, in some cases ROR impacts can also be severe due to river diversion over long stretches.

Reservoir Inundation

Dams have major impacts on the physical, chemical, and geo-morphological properties of a river. Environmental impacts of dams have largely been negative. The construction of diversion structures during operation phase will result in disturbance of the existing flow pattern and water quality due to escape of suspended solids from construction activities. Some of the bio physical issues having an impact on environment are as follows.

Sedimentation: Large dams with reservoirs significantly alter the timing, amount, and pattern of river flow. This changes erosion patterns and the quantity and type of sediments transported by the river. The trapping of sediments behind the dam is a major problem. It is estimated that 0.5 to 1 per cent of reservoir storage capacity is lost due to sedimentation. The engineering problem with sedimentation is that less power is generated as the reservoir's capacity shrinks. To check soil erosion, extensive Catchment Area Treatment measures have been adopted by NHPC at various projects.

GHG emission from dams: Freshwater reservoirs can emit substantial amounts of the GHG, CH_4 and CO_2, as organic matter submerged in a reservoir decays under anaerobic and aerobic conditions, respectively. To assess the impact of GHG, a frequently applied yardstick in international discussions is the wer density ratio (watts/m^2). Data from NHPC projects have revealed that there will be much less GHG emission when compared to thermal power of same capacity (Indian National Hydropower Association, 2012).

Geological risks: Creation of dams and storage reservoirs can induce seismic activity due to added forces of the dam along inactive faults which seem to free much stronger orogenic tensions. The Tehri dam project spurred concerns about the environmental consequences of locating a large dam in the fragile ecosystem of the Himalayan foothills. Another important concern is about dam's geological stability as it is located in the Central Himalayan Seismic Gap, a major geologic fault zone lying at the interface of tectonic plates of the Indian subcontinent and Eurasia.

Hydrology, Hydro-geology and Water Quality

- Long-term change in the hydrological regime brought about by flow modification due to diversion of water and installation of structures resulting in reduced flows downstream.
- Contamination of surface water flows due to desiltation and thermal stratification resulting in the potential decrease of dissolved oxygen. There is a possibility for anoxic conditions and cold temperatures to develop in deep waters in the reservoir and the risk of such water being discharged into the river.
- Various risks to water quality could arise from sources of pollution during construction such as spillage of fuels, lubricants, and other toxic materials at the construction site; discharge of silt laden run-off from sites; and the inadequate treatment and disposal of waste and wastewater from worker facilities.

Ecology

The development of hydropower plants result in loss of forests due to diversion of forestland for reservoir, buildings, roads, and other ancillary facilities. Excavation of tunnels and other construction activities may affect local wildlife.

Loss of terrestrial habitat: As mentioned earlier, the large-scale flooding destroys a large area of habitat for animals and destroys an equally large number of plants. Some reservoirs permanently flood extensive natural habitats, with local or even global extinction of animal and plant species. Very large hydropower reservoirs in the tropics are especially likely to cause species extinctions.

Fish and other aquatic life: Hydro-power projects often have major effects on fish and other aquatic life. The dam blocks up-river fish migrations and affects downstream passage, many river-adapted fish and other aquatic species cannot survive in artificial lakes, changes in downstream flow patterns adversely affect many species, and water quality deterioration in (or downstream of) reservoirs kills fish and damages aquatic habitats. Measures taken to mitigate this can be done by construction of fish ladder in order to facilitate upstream and downstream migration of fishes for breeding and feeding purposes; for example, fish ladder constructed on the Uri-1 barrage. A fish farm has also been developed to conserve fishes at Chamera HE project, where a fish ladder was not found to be infeasible for movement of fish due to the height of the dam.

Some of the effective mitigation measures are described below:

Institutional Framework

The Government of India regulates environmental management system in India. The ministries/statutory bodies responsible for ensuring environmental compliance by project proponents include:

- The Ministry of Environment and Forests (MoEF)
- Central Pollution Control Board (CPCB)
- State Pollution Control Boards (SPCBs)
- Ministry/Department of Environment in the states

Policies/Acts/Notifications

- Environment Protection Act, 1986
- The Forest Conservation Act, 1980
- Water (Prevention and Control of Pollution) Act, 1974
- The Air (Prevention and Control of Pollution) Act, 1981

Environmental impacts of hydropower development and possible mitigation measures

Environmental Impacts	Mitigation Measures
Reservoir impoundment	Successful measures for the development of fish communities and fisheries in reservoirs include: • creation of spawning and rearing habitats; • clearing trees prior to impoundment along navigation corridors and at fishing sites; • providing navigation maps and charts; • recovering floating debris; • introducing fish farming technologies; and • developing facilities for fish harvesting, processing, and marketing. Prevention of reservoir sedimentation done by: • protecting adequately banks and natural vegetation in the catchment area; • extracting coarse material from the riverbed; • dredging sediment deposits; • using gated structures to flush sediment under flow conditions comparable to natural conditions; • using a conveyance system equipped with an adequate sediment excluder; • using sediment trapping devices; and • using bypass facilities to divert floodwaters.
Ecology	Protection of land areas and wetlands that have an equivalent or better ecological value than the land lost; • conservation of valuable land bordering the reservoir for ecological purposes and erosion prevention; • creation of ecological reserves with rigorous and effective protective measures; • enhancement of reservoir islands for conservation purposes; • partial clearing of timber zones before flooding; and • selective wood cutting for herbivorous mammals;
Water quality	Selecting the proper site and controlling upstream pollution; • using selective or multi-level water intakes; • reducing water residence time in reservoirs, especially in tropical or subtropical regions; • ensuring proper spillway design or adding structures to favour degassing; and • adding re-oxygenation devices.
Hydrological flows	Establishment of an ecological minimum flow; • banks restoration techniques; • controlled floods in critical periods; • protection of coastal habitats; and • construction of weirs to prevent salt intrusion.
Health issues	The health benefits due to improved water supply, economic improvements, and flood control should be recognized. Proper reservoir management can be highly effective in eliminating mosquito-borne illnesses such as malaria.

- National Policy on Hydro Power Development (1998)

Under the Environmental Impact Assessment (EIA) Notification of September 14, 2006, all projects listed in Schedule-1 of the notification require prior environmental clearance. The objective of the notification is to formulate a transparent, decentralized, and efficient regulatory mechanism to:

- Incorporate necessary environmental safeguards at planning stage;
- Involve stakeholders in the public consultation process; and
- Identify developmental projects based on impact potential instead of the investment criteria

Conclusion

The growing power demand in India warrants the need of increase in power generation which can be fulfilled by development of reliable energy sources. Hydropower is eco-friendly and reliable in meeting peak load demand. In order to meet the continuous demand for power, the sustainability of hydropower projects which are under planning/execution/ operation is extremely important. Sustainable hydropower implies not only ensuring continuous power supply but also contributing to sustainable development in respect of social and environmental development. A hydropower project when established as a multipurpose project provides additional benefits in terms of irrigation, flood control, navigation, drinking water supply, promotion of tourism, etc.

Thorough sustainability assessments should ensure that detrimental social and environmental impacts are avoided, mitigated or compensated. Since environmental and social impacts of hydropower projects differ from region to region, depending on the project size, the topographical, environmental and social circumstances of the project site, measures to mitigate negative impacts and to optimize positive outcomes must be project specific. All the plans and polices in the hydropower sector should be geared towards contributing to achieving economic self-reliance and overall socio-economic development of the country. The sustainable development strategies incorporating the social and environment concerns of hydro-power development will lead to successful implementation of hydropower projects. Therefore, managing social and environmental aspects is a fundamental component of social responsibility, sound business practice and careful natural resource management.

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Centre for Research on Energy Security

Centre for Research on Energy Security (CeRES) was set up on 31 May 2005. The objective of the Centre is to conduct research and provide analysis, information, and direction on issues related to energy security in India. It aims to track global energy demands, supply, prices, and technological research/breakthroughs—both in the present and for the future—and analyse their implications for global as well as India's energy security, and in relation to the energy needs of the poor. Its mission is also to engage in international, regional, and national dialogues on energy security issues, form strategic partnerships with various countries, and take initiatives that would be in India's and the region's long-term energy interest. *Energy Security Insights* is a quarterly bulletin of CeRES that seeks to establish a multistakeholder dialogue on these issues.

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