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Environmental Considerations of Small-Scale Hydroelectric Power Plants in Himachal Pradesh, India

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"When we try to pick out anything by itself, we find it hitched to everything else in the Universe."– John Muir

The need for increased energy production in India is high priority and hydroelectric power has been identified as having the greatest potential for achieving energy independence. The Indian government has continually created more streamlined methods for efficient implementation of hydroelectric facilities with an emphasis on small-scale (<25 MW) and micro (<5 MW) facilities in the more remote regions. Himachal Pradesh has effectively achieved one hundred percent electrification due to these initiatives and realized some of the most successful development in the nation with respect to rural electrification and improved infrastructure such as roads, schools, and hospitals. Hydroelectricity, and especially that produced through run of the river type systems, is generally embraced as a renewable source of energy by many established standards. Small scale run of the river facilities are also heralded for the minimal impact to the environment. However, with increased development and construction in continually industrializing areas, measureable human impacts have increased felt within the environment and ecosystems. Several studies and papers published by the Indian government, as well as the state government of Himachal Pradesh, identify these impacts as low to nonexistent. In contrast, a growing number of studies refute this claim and deserve consideration. There is a diversity of opinion on this subject. Some secondary sources indicate minimal to non-existent environmental impacts stemming from projects less than 25 MW, considered as Small Hydro Power (SHP); while other sources express significant concern. Interviews with government officials and researchers in the Indian states of Himachal Pradesh and Uttarakhand as well as in the capital city of Delhi revealed a wide range of views. This paper presents observations and argues for greater exploration of these issues through future research.

Introduction

India will become the most populated country in the world in the not too distant future. With this increase in population has come the ever present dilemma of providing energy needs to the people. At present the country falls disastrously short of providing an accepted western standard of access to affordable electricity.

In response to this shortage, village people burn propane, kerosene, wood, cow dung, hay and other materials to meet their personal energy demands. These actions tend to result in effects such as deforestation and accelerated erosion of soils. And, thus, the vicious cycle is created whereby a need is met by a solution that perpetuates the problem. Nowhere else are these issues more pronounced than in the remote regions of India where the tribal village culture is still predominant, dictating societal norms and modes of survival.

This paper attempts to enlighten the reader as to how India has tried to alleviate the challenges in satisfying energy needs while conforming to the policies of the industrialized world and the United Nations. There are implications both moral and financial at stake.

Background

Conventional fossil fuels are a known driver of economic progress and while the benefits are broadly known, the environmental impacts are many. Pollution in the form of increased carbon emissions, acidification of meteoric water, and destruction of natural landforms in the pursuit of natural resources are just a few of the known negative impacts of this energy source. The International Energy Agency (IEA) has identified hydroelectric power as an efficient and more environmentally friendly form of energy production compared to similar carbon based systems. This is primarily achieved through reducing greenhouse gas production which is non-existent during the operational stage of a hydropower facility.

India began its current thrust toward green and renewable energies in the early portion of the 1980s. Small and micro hydroelectric production began increasing along with the establishment of the Alternate Hydro Energy Centre (AHEC) in Roorkee in 1982. This establishment was founded by the Indian government on the campus of the Indian Institute of Technology (IIT) at Roorkee, with the charter to perform research and development in the area of hydropower in India. The staff and student body are responsible for development of many new technologies, methods and systems for creating energy (chiefly hydropower). The objective of IIT Roorkee is coupled with the added mission of researching the effects of hydroelectric plant implementation on the environment and Indian people.

India has one of the greatest potentials for hydroelectric power on the planet with an estimated 150,000 MW, equivalent to 84,000 MW at 60% load factor. Of this, SHP and MHP can contribute an estimated 15,000 MW-*(EIA, 2012)*. India's installed capacity of 37 Gigawatts (GW), which is 3.3% of the world's total output, comprises 11.9% of the country's total energy generation- *(International Energy Agency, 2009)*. These staggering values help to portray the massive energy potential which stands to be harnessed in Northern India. India seeks to harness the energy by combining the abundant water supply with the effects of gravity.. India's location south of the Himalayan mountain range, which has one of the planet's largest reserves of glaciers and glacial melt-water, gives it the best potential for production.

Most hydroelectrically-produced power in India is fed into the national grid which supplies larger cities downstream, such as New Delhi and Chandigarh. Unreliability and inadequate production coupled with aging and sometimes dilapidated transmission infrastructure lead to periodic power outages and frequent rolling blackouts in these urban areas. Remote locations of sub-Himalayan villages and difficult topography can lead to similar interruptions in these regions.

Classification schemes and limits of Mega vs. Small vs. Micro scale power production vary across the globe. In India, Small hydropower (SHP) is limited to production of less than 25 Megawatts (MW) of electricity while Micro hydropower (MHP) is limited to producing less than 5 MW. Hydropower production can be roughly grouped into two different types of operations, Impoundment and Diversionary. Impoundment implies that somewhere within the system there will be storage of water at elevation (ponding, damming or pumped storage) for release at a prescribed time for energy production. Diversionary systems imply there is no storage of water and energy production is dependent upon water flow at a given point (the production facility). Such facilities are commonly termed Run of the River (RoR) type schemes. Universally, larger scale facilities employ impoundment technology while small scale production can utilize either. MHP is almost entirely diversionary in design. An important note is that some systems may employ both types of technology within the same operation (e.g. diversion to an impoundment location).

Large scale impoundment type hydroelectric facilities have many known detractors such as submergence of land leading to deforestation and dislocation of inhabitants. A loss of biodiversity in the form of aquatic life and biota can also be expected in such scenarios. Many examples of this can be seen in countries such as China, Brazil as well as India. One example of large scale impoundment is the Three Gorges Dam along the Yangtze River in China. Although producing up to 22,500 MW of electricity, there have been several notable effects such as landslides and massive deforestation.

However, SHP doesn't typically involve water storage and is generally observed to be a benign, renewable energy source.

Furthermore, diversion type schemes are especially noted for the negligible impact on the surrounding environment. In a report published by the AHEC in 2007, it was stated that the effects of SHP in India are little to non-existent and any impacts are temporary in nature -*(Sharma, 2007)*. While this may indeed be true, there has yet to be a longitudinal study several years in duration which could empirically substantiate such a claim.

Method

The primary method employed to understand the situation was to compile several journal articles relevant to the topic of hydroelectric production prior to departure for field investigations in India. Current events in the region were also closely monitored in the media (e.g. international newsfeeds, websites, and social media) before and after the field excursion. Interviews were conducted with several state officials and researchers within Indian government who are responsible for implementation of energy production projects. These visits took place in the capital city of Delhi and in the Indian states of Uttarakhand and Himachal Pradesh.

The initial field visit was completed at the IIT's Alternative Hydro Electric Center (AHEC) in Roorkee in the state of Uttarakhand. At this campus, a tour of the learning facilities and the training modules for educating future production facility personnel was led by a graduate student and faculty member of the AHEC. A presentation on the AHEC's objectives and research activities was received as well. Insights and details were provided about preliminary procedures and future SHP facilities completed prior to construction.

In Delhi, the Director of the Ministry of New and Renewable Energy provided numerous insights into the larger dilemmas public officials face during investigation of potential projects and licensing. A project developer was also briefly interviewed on his personal experiences while developing a project in the state of Jammu and Kashmir. Together, the director and developer provided a glimpse into one of several such meetings that must take place before construction begins.

In Shimla, the capital city of Himachal Pradesh, the Himachal Pradesh State Electricity Regulatory Commission was visited; however, information was not readily accessible. Also in Shimla, library materials were accessed and literary research was performed performed on the campus of the Indian Institute of Advanced Study.

In the city of Chamba, the Deputy Commissioner was interviewed and provided several of his concerns relative to the topic of SHP in the region. He provided information on the proper avenues developers must take in this region to obtain licensing as well as the concerns the Deputy Commissioners office must observe regarding residents and impacts when issuing permits. Also in Chamba, the Ministry of Environments and Forests (MoEF) was visited at the main office location in downtown Chamba and the Chief Conservation Officer was interviewed. The objectives of this department were outlined as were the many types and instances of improper procedures that occur during construction (e.g. illegal dumping of waste material or muck disposal and improper forest reporting procedures). Additionally, three SHP facilities were visited in the Chamba region during operational periods. Facility tours were taken at Churchind II, and two unnamed sites, one of which in the planning stages.

Small Hydro

As previously noted, hydropower can take two primary forms, Impoundment and Diversion. RoR schemes utilize a diversion weir placed at a strategic location, typically along an existing stream route, and water flow is diverted to a desired location (the powerhouse). This system is known to have far fewer environmental impacts on the ecosystem while providing such benefits such as high-efficiency electricity production with no carbon emissions.

Facilities such as the one seen in Figure 1 are typically small in building footprint (>3000m^2) and adequate for projects producing less than 25 MW of production. (Refer to Figure 2 for a simplified diagram of the typical components of a hydroelectric facility). Larger facilities can produce more energy but need storage space located on larger streams providing adequate water flow. This requirement is not always feasible in more remote regions.

Figure 1. typical small scale hydroelectric production facility located in Chattrarri, Himachal Pradesh, India. Note visible penstock left of the building, and the discharge, not visible in the picture, at the bottom near the stream.

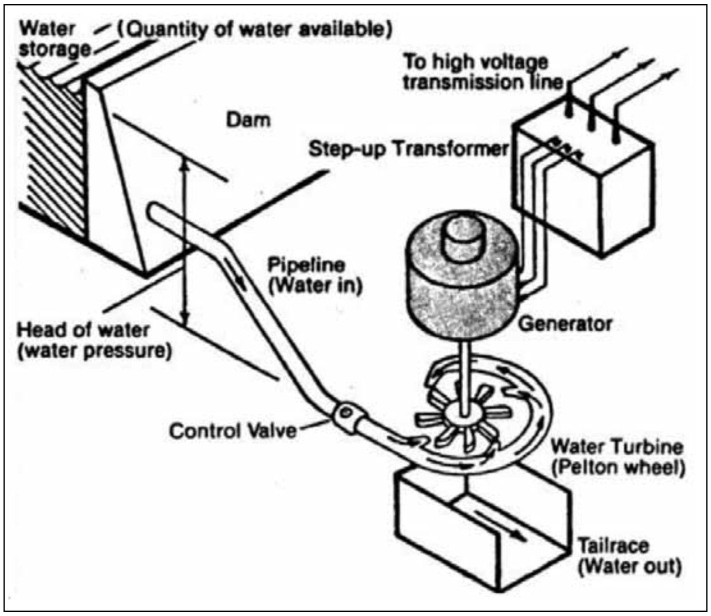

Figure 2. a simplified diagram of a hydroelectric production system.

Construction costs rise as a result of the difficult nature of the terrain in this region. Such advantages make SHP a more attractive option over construction of larger hydro sites which typically require greater infrastructure investments (e.g. damming and reservoirs).

Small-scale hydro has flourished not only on the Indian subcontinent but in many other parts of the world. Norway, for example, has utilized small scale (1-10 MW) production for decades and now has 480 such facilities in the country along with 291 Mini (100kW-1 MW) and 211 Micro (<100kW) *(Glette, 2013).*

There is scant literature published on studies of the effects of SHP in particular studies conducted in India and the Himalayan Range. Bakken et al. (2012) examined the accumulated effects of 27 small-scale facilities (in Norway small-scale is <10 MW as compared to India which classifies small-scale at <25 MW) versus the effects of three large-scale facilities. The results indicated the accumulated effects of several small-scale facilities were slightly more than those of the few larger facilities and the benefits of the larger facilities were greater than the combined benefits of several small-scale facilities.

In India, however, long term studies of small-scale hydro and the aggregate effects of several facilities which are located within the same catchment area have not been conducted in this region. In addition, within the nation of India, and the state of Himachal Pradesh in particular, there is a major thrust for development of several such run of the river type schemes; many are already in the construction phase and are located along the same river routes within the same catchment area (Rao 2011a). Although the adverse environmental impacts of an individual SHP may not be significant, the aggregate impact of several projects in the same vicinity could be of a magnitude to cause significant damage to the environment *(AHEC, 2011).*

In similar research, the Water Resources Institute at Oregon State University has studied the effects of SHP in both China and India. Their work has identified possible negative impacts as well, particularly with respect to damming procedures and water diversion. Although, in many cases the studies are preliminary or need further sampling to make confident assertions, these introductory findings are a basis for further examination. The issues stemming from the accumulated effects of such environmental impacts such as stream diversion, increased sediment load due to construction, and immediate loss of stability due to deforestation and accelerated fracturing of bedrock are topics that merit continued study.

Issues

There are many impacts on the environment resulting from the construction of a hydroelectric power plant. Any effect resulting from human activity is termed an "anthropogenic effect," and construction can create many of these effects. These anthropogenic effects have been highlighted by several people interviewed in the state of Himachal as the true source of pollution and negative environmental impacts. The following section will describe three such major impacts associated with facility construction in remote regions of India, deforestation, muck creation, and bedrock fracturing.

Deforestation is the removal of stands of trees for the purpose of construction, fuel, or some other motive. Currently most deforestation in this area occurs for the procurement of building materials not directly used in the construction of hydroelectric facilities. Although wood is used in home construction, the primary building material for power plants of this region is brick and concrete. So where is the deforestation resulting from hydro really taking place? The answer is in road construction. Road construction for the transit of commercial vehicles involved in the construction of hydro facilities and the associated infrastructure construction that comes with development.

Clearly not every tree can be replaced or conserved. While the construction of a production facility may not result in massive deforestation, the associated road construction does create a significant amount of deforestation. This does not seem to be accounted for in most Project Development Reports produced. The Ministry of Environment and Forests is aware of this problem and has vowed to address it in the soon to be published "Revised Interim Report, Comprehensive CAT Plan for the Ravi River Basin" (2014).

Muck disposal is another serious problem associated with SHP. Muck is the term for any by-product from the construction activities, such as waste rock material generated during tunnel excavation to soil and/or excess building materials. There are numerous examples of disposed muck contaminating and polluting river systems. Unfortunately, the impact may not always be observed at the construction site but further downstream where the suspended load of sediment is deposited. These locations can be far removed from the construction site making it difficult to identify the source of pollution.

There are many guidelines and policies in place to govern the proper disposal of construction debris. However, few, if any, of these are followed to the letter of the law. An official of the Indian Forest Ministry displayed footage of one such instance. In his opinion, the most notable environmental impact is not created by the power plant itself, but is created during the construction and use of the roads upon which materials and personnel are using. This is where the distinction between a human impact and an environmental impact becomes a gray area. While it may be true that humans have caused the effect, the impact is sustained by the environment.

Bedrock fracturing occurs as part of the construction phase during tunnel blasting. Some of the facilities in Himachal Pradesh do not require much tunneling at all and this effect is mitigated extensively. However there are several other such facilities (figures are unobtainable at this time) which do require extensive tunneling and, as a result, extensive blasting of bedrock. The composition of the study area in Chandigarh and much of Himachal Pradesh is that of highly deformed, steeply dipping, metamorphosed mudstone. The region has also been heavily deformed due to tectonics resulting in the steeply dipping beds. This can be seen in Figure 3, with the author for a scale of the inclination of the bedrock.

Generally, the effects of blasting are observed by villagers in the form of cracks and fractures in homes. These instances are handled on a case by case basis and are usually remedied with compensation.. A connection of damage to the underlying bedrock has been weakly addressed. There are alternatives to this practice as in the case of open channel diversion and trench construction. This relatively non-intrusive method is generally abandoned for tunnel construction which provides a safer transport system of water resulting in a more secure system.

Another impact worth noting, but generally overlooked, is the loss of biodiversity due to stream diversion. This is almost unavoidable in nearly all small projects. The national requirement is that a developer must provide at least 15% of original stream flow to an existing water body to maintain the aquatic and

Figure 3. Steep inclined layers of bedrock (primarily metamorphosed mudstones) are displayed in the sub-Himalayans regions were typical SHP facilities are proposed. The author is provided for scale and orientation of the topography.

floral life. This guideline is weakly enforced and there appears to be no repercussion in the event a developer violates this requirement. In the case of small hydro plants, these facilities are not required to file an Environmental Management policy. For this reason, the aggregate effect of several projects' impacts may not be realized, or even observed, until irreversible damages with respect to aquatic and biotic life have taken place.

Environmental Monitoring

It is the resounding opinion of Indian academia, notably the Indian Institute of Technology, Roorkee, that the nation need not implement nor integrate monitoring systems of the aforementioned small and micro hydroelectric power production facilities. The current environmental monitoring system in India is Environmental Information Systems (ENVIS). The main objective of this system is to record data measurements in the atmosphere, in water quality domains and compile these recordings into a central repository. This data would be available to staff of the Indian ministries. This data is not readily available to outside nations and cannot be utilized in any fashion to the general public, such as for climatological modeling for instance.

IndoFlux is a monitoring system devised and modelled after FluxNet, the environmental monitoring system used by several developed nations such as the United States. The objective of IndoFlux is the same as described above with the added benefit of data being readily accessible to outside parties. FLUXNET is a global collection of >300 micrometeorological terrestrial-flux research sites that monitor fluxes of CO_2, water vapour, and energy-*(Sundereshwar, et al. 2007).* It is not only conceivable but also possible that such monitoring equipment could be installed at small and micro hydroelectric sites, likely at an added cost to the developer.

The added benefit of integrating this data into the global system is readily apparent. With the sites linked into the monitoring system it would be possible to identify problems or negative impacts observed at the sites. Continued data gathering can provide the basis for longitudinal studies.

There are other steps which the nation has taken to observe changes occurring in the topography. The National Geomorphological and Lineament Mapping (NGLM) project on 1:50,000 scale using satellite data followed by limited ground validation was conceived by NNRMS Standing Committee on Geology and Mineral Resources (NNRMS SC-G) in 2004 who recommended the Geological Survey of India (GSI) and Indian Space Research Organisation (ISRO) to take up the project jointly-*(Geological Survey of India, 2013)*.

Although the purpose of this project is to map the observed landforms present on the continent and the associated geomorphic changes, the potential is present through this system to also monitor changes to fluvial landforms and streams both large and small. The benefits of this system are also readily apparent with application to the possible impacts of production facilities and increased urbanization in remote areas.

Connectivity within India for Monitoring

During the interview with the Chief Conservation Officer in Chamba, it was stated that the reluctance to establish a nationwide monitoring network within India stems from the lack of connectivity in many areas of the remote regions. He identified this as the most important hurdle to establishing a network of shared data and information about environmental conditions. This proves to be a major stumbling block in the establishment and subsequent sharing of data within the country.

Although the IndoFlux system would relieve some of the problems associated with this issue, it would not solve all of them. Another issue associated with this idea was the lack of experienced operators at small hydro facilities. While interviewing the Chief Conservation Officer in Chamba at the MoEF offices on the state of the environment in India, he informed that there is a Revised Interim Report which is a comprehensive Catchment Area Treatment Plan (CAT Plan) for the Ravi River Basin, expected to be completed in early 2014. In this document, the state of Himachal Pradesh will address several of the concerns raised both locally and nationally about the increased development in the area. This document should provide insights into the current state of the environment as well as the state's plan to continue monitoring environmental concerns such as reforestation and water quality.

Inconsistencies within the framework of reforestation

As part of the Environmental Impact Assessment (EIA) associated with all major energy construction projects >25 MW as well as small and micro projects less than 5 MW, an inventory of forested lands is created and assessed. This standard phase of the environmental clearance portion of all Development Project Reports (DPR) determines the amount of monies which a developer must apportion to the Himachal Pradesh Ministry of Environment and Forests (MoEF) for reforestation. In theory, this money is then used by the department to replenish and replant trees in lieu of those taken down for construction purposes. This is a novel idea and in theory will replace the wooded footprint which is destroyed.

The unfortunate reality is most of these funds are depleted through administrative costs and never actually replace tree stands, especially larger primary growth. There is also the component of corruption within this system in which the value of a tree, which is assessed based on size and age, is understated; thereby decreasing the amount of funds a developer is responsible to pay and consequently the amount of funds the state MoEF realizes. It is also very possible that the authorities involved in these practices are unaware of the harm caused to the state by these illicit actions.

The understating of tree stands and the level of growth-for-value assessment is only one form of possible corruption at this level. Other similar schemes were noted by developers that bribery does occur between themselves and paid ministry officials. Rao (2011b) in his article *"Role of Street Level Bureaucracy in India"* notes extensively the many challenges and forms of bribery that take place during the course of licensing and permitting of project development. Although no names were provided, it is clear that some developers utilize the influence and position of paid government officials for the purpose of reducing the amount of funds needed to pay or to expedite licensing paperwork. This type of corruption and bribery could prove to be severely harmful if not rectified and monitored at some level.

Reforestation is perhaps the most important factor in preserving the Himalayan ecosystem and the accompanying fauna. Slopes devoid of vegetative cover are more prone to landslides and soil slumping-*(Negi, 1998)*. The Himalayan range is characterized by extreme slopes and in the lesser range much of the surface geology is that of loosely consolidated shale and clay. These lithologies are extremely prone to potential natural disasters such as mass wasting in the form of landslides. An added component to the complication of this scenario is the very active fault zones which bind much of the Himalayan region. The lesser Himalayas have experienced numerous devastating earthquakes in recent history, namely in 1803 and 1905 in the Delhi and Kangra regions, respectively-*(Bilham, et al., 2001).*

Although forestation will do nothing to prevent ensuing damage due to an earthquake of these magnitudes, they will mitigate the after-effects of mass wasting associated with non-vegetative ground cover. The likelihood of an earthquake occurring in the future within this region, Himachal Pradesh in particular reinforces the idea that remotely located monitoring devices should be implemented wherever possible. Construction sites and production facilities are well-positioned remote locations. They are adequately suited to host remote seismologic devices which could provide insightful data when forecasting devastating events.

Current Events in the Region

There have been several recent events and rulings in the region to support the prior claim of insufficient research and data collection regarding the accumulated or aggregate effect, of multiple locations located on the same river or tributary river system. One specific example is a Supreme Court ruling in Delhi which has postponed all construction on hydroelectric projects in the state of Uttarakhand indefinitely.

Another recent article on this topic was published by Kelly Kibler and Dr. Desiree Tullos from Oregon State Universities Water Resources Program. In this study, which was conducted in nearby China where information is very difficult to obtain for academic purposes, the Nu River basin was examined. The results found were that the biophysical effect of several small scale facilities (in China >50 MW is small-scale) can outweigh those of large facilities when compared to the amount of electricity produced. The authors of this study concluded that further investigation is necessary to fully understand how several small facilities affect a larger singular basin.

Conclusion

Although at present the negative environmental impacts associated with small and micro hydroelectric production facilities have been measured to be low to insignificant in recent studies, it is necessary for not only Himachal Pradesh and the nation of India as well as those of other nations employing this technology, to continue to observe what little changes there are. In the author's opinion, it would be a beneficial idea to integrate remotely collected data into a globally accessible network such as IndoFlux. Although seemingly cumbersome and likely another burden placed upon developers of facilities which would result in commissioning delays, the benefits of the readily accessible data would over-ride these detractions.

In regard to the inconsistencies of reforestation through funds provided by project developers, there must be a higher level of integrity instilled within the respective parties. Whether this is done through education on the effects of deforestation or the heavy hand of penalty in the face of offense, something should be done to rectify this problem. Continued corruption and inadequate reforestation may not have initial impacts under certain circumstances, however, the possible loss of life and property to natural hazards such as landslides are immeasurable. In both scenarios continued monitoring through satellite imagery and station specific devices are just samples of the methods to track the issues.

As John Muir wrote in the opening quote from *My First Summer in the Sierra,* "When we try to pick out anything by itself, we find it hitched to everything else in the Universe." The topic of environmental impact monitoring, regardless of scale and type, will continue to persist in India as well as the rest of the world for years to come. How the country addresses their present issues and pushes forward with progress will indeed be a topic to cover from the research perspective and the historical implications those actions may have. For this reason I suggest continued research and continued funding regarding the topic of SHP and the associated environmental impacts not just in India, but around the globe.

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