EUROPEAN ACADEMIC RESEARCH
Vol. VI, Issue 1/ April 2018

ISSN 2286-4822
www.euacademic.org

Impact Factor: 3.4546 (UIF)
DRJI Value: 5.9 (B+)

Hydropower and Its Feasibility: Cost Benefit and Option Value Analysis

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Abstract:

With increase in world's consumption on energy usage and an alarming rate of depletion of non-renewable resources such as oil and natural gas there has been considerable shift in focus to use of alternative energy sources. In this paper we analyse the feasibility of Hydropower projects to harness energy from water resource. We have discussed various impacts of such projects and we used techniques such as cost benefit analysis and option value method to determine the optimality of execution of hydropower projects. We have used data in reference to Chilime Hydropower Project of Nepal for this analysis.

Key words: Hydropower, Energy, Cost-benefit analysis, Nepal.

1. INTRODUCTION

Production of energy using natural resources is an integral part of human civilization. Use of natural resource for electricity generation is one of the most common practices regarding use of natural resource harvest. Governments as well as private sector have many options available for investing in electricity generation infrastructure. However, achieving a cost effective, forward thinking, reliable and environmentally sustainable portfolio of generating stations is challenging for all investors. Hydropower being one of the cleanest energy generation techniques has led nations with a wealth of hydropower to naturally exploit this resource, as long as doing so provides good value for money. According to the Department of Energy (US government), U.S. produces 95,000 megawatts of hydropower per year, this is enough for 28 million households or to replace 500 million barrels of oil. Water, being one of the renewable resources, is considered a better option than harvest of energy using non-renewable resources such as oil and natural gases. But as it is common with every natural resource extraction, it does come with benefits as well as costs which are not only explicit in nature but also implicit. There are also many externalities associated with the use of renewable resource in energy production.

Water can be used as hydropower by harnessing its energy. Compared to other resources that are used to produce energy and power, water is considered renewable as well as having the least solid waste during energy production. Hydroelectricity is a form of hydropower. Hydropower harnesses the power from moving water, under the influence of gravity, transforming it into mechanical or electrical power. In the case of hydroelectricity, the mechanical power created by the moving water is used to create electricity by 'feeding' the mechanical power through a generator, which in turn produces the electricity. In hydropower system, the water is held back in the reservoir, being channelled through a gate that can be regulated according to water levels and also required output of power. As the water passes through the gate(s), it is channelled in a tunnel through the turbine. The flow of water makes the turbine turn as water passes through, spinning a generator that in turn generates electricity. The next illustration shows the simple workings of a hydroelectric dam.

The reservoirs all vary in size and proportions. Some reservoirs have a large surface area but are not deep, whilst other reservoirs have smaller surface areas but are very deep. For creation of such dams it entails huge costs. Also development of such dams has many adverse effects on the surrounding environment as well. The impacts of such reservoir dams used to harness the potential of water as a natural resource to generate electrical energy are discussed below:

1.1. Impact of Dams

As dams are built, the area in which the dam is constructed will see some very strong changes whereby the very physical character of the host location will be altered permanently as result of several key reasons. A poorly planned and built dam can result in an ecological disaster. Not only such dams would have devastating effect on environment but also have major impacts on social, cultural and economic aspects. It is vitally important to equally consider these impacts as well. The reason for this is that even though they might have their own individual effects on the host environment, they also have specific impacts when combined with each other, depending on the characteristics of the host environment. Therefore, these impacts should be seen as interrelated, despite the fact that they don't seem to be initially, there are a lot of impacts that are understood to be related after dam construction has taken place. Many of these 'interrelated' impacts are not initially contemplated during the planning stages of a dam because planners responsible in predicting all potential impacts have not considered any reason to link or foresee such impacts related or linked to each other. The various impacts caused by dams can be categorized as follows:

- Water Quality

Changed river flow pattern due to construction of reservoir dam has a huge impact on the water quality of the river. Because in the reservoir the water stays stagnant for a long period of time as a result of which green plants, and organic material will die and then undergo anaerobic decomposition creating lots of methane. These types of changes will have a big impact in the ecological system of the river. Fisheries may suffer due to such type of effect. Water quality change must be found out during EIA[1] process. This type of cost should also be included while building the dam.

- Sediment Transport and Erosion

Rivers carry sediment as they flow. But when dams are built the sediment is collected in the reservoir. This has an impact in the downward stream of the river. Unbalanced sedimentation load downstream can change geomorphic processes, thus creating environmental hazards.

- Downstream Hydrology and Environmental Flows

The change in river hydrology after the construction of a dam affects the people, land, biodiversity on the downstream of the river. It is always a recommendation to maintain a certain minimum value of the downstream flow.

- Rare and Endangered Flora and Fauna

Construction of dam may require deforestation. This has a severe impact on the wild flora and fauna of that region. And when it is the case that the forest, that has to be cut down contains rare and endangered flora and fauna the case become more detrimental. Dam construction poses serious danger to endangered terrestrial and aquatic species because of habitat loss, impoundment, disturbance upstream and the downstream flow patterns and the mutation due to the changed conditions of life.

[1] Environmental Impact Assessment (EIA): EIA is an assessment conducted to inform decision makers of the projects of the positive and negative effects of a project upon the environment and help in developing the associated mitigation measures against the effects.

- Passage of Fish Species

Fish breed in the rivers and they require the hydrosphere for their life time. The construction of hydropower acts as a barrier for the fish to move from either the upstream or the downstream. If rivers contain mostly the migratory fish, issue has to be addressed and a mechanism for their transfer such as fish ladders, mechanical elevators, guidance devices and translocation programs has to be constructed. Also, some other mitigation measures such as trapping and hauling, constructing trash racks, louver systems and hatcheries, ramping and monitoring must be used. But, still the adverse impact to the fisheries is possible, if not probable.

- Health issues

Health issues are important factor to determine the sustainability analysis. Human health effects due to disease, hydrologic conditions and the changed water quality are the most important considerations. The hydropower developers must make a public health plan and implement it in the precautionary phase.

- Social/Cultural Issues

Development of hydropower plants impacts in various ways how people live their lives. Generation of electricity might cause a huge boon in development of various sectors. But many people are displaced due to the development projects. Thus, these projects will have various social and cultural impacts in lives of those people. It is necessary that such development projects should have these types of costs included while determining the optimal value of feasibility of the project.

1.2. Economic Aspects of Hydropower

In the study of natural resource economics, the impact of timing and desirability of projects play an important role, which might irreversibly alter a natural environment. We are considering a hydroelectric power project for which needs the construction of a reservoir, which may cover a large area with water behind a dam, alter the hydrological processes of a free-flowing river, and be very costly to remove.

Evaluation of hydropower projects as a means to extract benefits from water which is a form of renewable natural process has many seen and unseen parts attached to it. Many of the costs regarding the case of hydropower projects are in the initial part of the project. All the mechanical, electrical and civil engineering construction has to be done at the start of the project. It looks expensive at the first glance. But, after the initial investment, it doesn't need any investment except for a nominal operational and management cost. Also, the PPA[2] is always carried out in the forehand of the project completion; hence the whole project has not any concerns from inflations and market prices. But a caution has to be taken while pricing the externality attached with it. We can use various calculation techniques to find the optimality of the project. Two commonly used techniques, cost benefit analysis and option value method in infinite time horizon, are discussed in this paper.

2. HYDROPOWER DEVELOPMENT IN NEPAL

Nepal is rich in hydro-resources, with one of the highest per capita hydropower potentials in the world. According to World Bank and Asian Development Bank, Nepal's estimated theoretical power potential is approximately 83,000 MW. However about 42,000 MW are technically and economically viable hydropower potential. Nepal's huge potential in hydropower is still untapped. Though Nepal has not yet been able to tap even five percent of its potential electricity capacity. According to IHA (2017), Nepal has 867 MW installed capacity till date which is merely two percent of potential capacity.

[2] PPA : Power Purchase Agreement is the agreement between government and private sector for the procurement of right to develop a power plant

After the establishment of the first hydropower plant (500 KW) in 1911, the second hydropower plant (640 KW) was established at Sundarijal in 1936. The development of hydropower was institutionalized after the initiation of the development planning process. The First Five-year Plan (1956-61) targeted to add 20 MW of hydropower. However, the target was unmet. During the Second Three-year Plan (1962-65), some progress was achieved. Till 1962, the Electricity Department of HMG was responsible for the generation, transmission and distribution of electricity. In 1962, Nepal Electricity Corporation (NEC) was established and was given the responsibility of transmission and distribution of the electricity. The Electricity Department was responsible for the task of electricity generation.

Until 1990, hydropower development was under the domain of government utility, Nepal Electricity Authority (NEA) only. However, with the enactment of new Hydropower Development Policy 1992, the sector was opened to the private sector also.

Despite a huge potential for hydro-electricity, Nepal has not been able to fully harness its water resource for energy generation purpose. As a result, electricity is available to only 70% of the population. Table 1 gives the current status of power plants and their capacity. Whereas table 2 presents the power plants installed capacity till 2015.

Table 1: Theoretical, Technical and Economical Hydropower Potential of Nepal

Major River Basins	Theoretical Potential in MW			Technical Potential		Economical Potential	
	Major river courses having catchments areas above 1000 km^2	Small river courses having catchments areas 300-1000 km^2	Total	Number of Project Sites	Technical Potential in MW	Number of Project Sites	Economical Potential in MW
Sapta Koshi	18750	3600	22350	53	11400	40	10860
Sapta Gandaki	17950	2700	20650	18	6660	12	5270
Karnali and Mahakali	32680	3500	36180	34	26570	9	25125
Southern River	3070	1040	4110	9	980	5	878
Country Total	72450	10840	83290	114	45610	66	42133

Source: Water and Energy Commission Secretariat, Government of Nepal.

Table 2: Power Plants Installed up to year 2015

		2011	2012	2013	2014	2015
1	Total Major Hydro (NEA)-Grid Connected	472,994	473,394	473,394	473.394	473,394
2	Total Small Hydro (NEA)-Isolated	4,536	4,536	4,536	4,536	4,536
3	Total Hydro (NEA)	477,530	477,930	477,930	477,930	477,930
4	Total Hydro (IPP)	187,581	230,589	255,647	255,647	324,446
5	Total Hydro (Nepal)	665,111	708,519	733,577	733.557	802,376
6	Total Thermal (NEA)	53,410	53,410	53,410	53,410	53,410
7	Total Solar (NEA)	100	100	100	100	100
8	Total Installed Capacity (Including Private & Others)	718,621	762,029	787,087	787,087	855,886
9	Total Installed Capacity (NEA & IPP) - Grid	713,985	757,393	782,451	782,451	851,250

Source: Water and Energy Commission Secretariat, Government of Nepal.

3. METHODOLOGY:

There are various methods that are used to find out the optimality of the projects to be carried out. As in every other natural resource harvest, production of electricity through water also entails in depth analysis and calculation of cost and benefits involved. Commonly used techniques that are used find the optimal solutions to these problems are as follows:

3.1. Cost Benefit Analysis (CBA)

Cost Benefit Analysis (CBA) is a technique commonly used by economists to evaluate potential investment options based upon the costs involved, and the benefits to be brought through realisation of the project. Although the unit of value is money, this is merely a vehicle enabling a common unit of comparison, and many non-monetary costs and benefits are evaluated during the process; one difficulty being the conversion between non-monetary and monetary valuations. Where multiple options are considered for achieving a particular goal, the role of the CBA is to calculate which option offers the greatest excess benefit over cost (Figure 2).

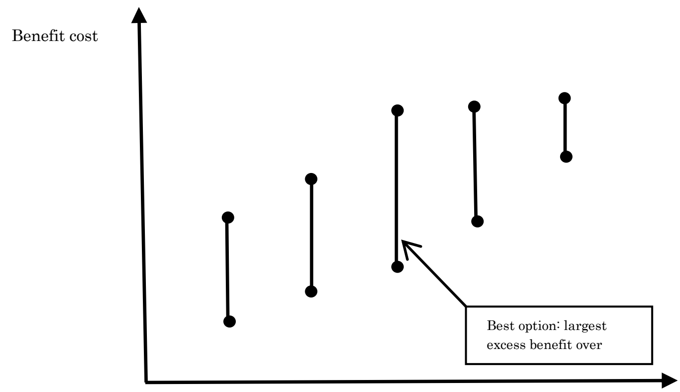

Figure 1: Project alternatives in increasing order of expected benefit

To evaluate the desirability of an investment project we use the cost benefit analysis. In the process of cost benefit analysis of project, we are concerned with the optimal timing of the project or when the investment for the project should occur, the cost and the benefits generated from the project.

The net benefits over the horizon t= 0, 1, 2… T, can be calculated by

$$N = \sum_{t=0}^{T} \rho^t N_t \qquad \ldots\ldots\ldots (1)$$

Where $\rho = \frac{1}{1+\delta}$ is discount factor, $\delta>0$ is the discount rate, and net benefit is $N_t = B_t - C_t$ at period t. B_t and C_t are the benefits and costs respectively in a particular period dependent on resource used. In cost benefit analysis of project, the construction of project leads to the flow of benefits over a period of future time horizon and costs includes the construction costs, operation and maintenance costs and at the end the of the project the decommissioning costs.

The positive present value of the net benefits shows that the project in consideration provides positive net benefits to the society over the opportunity cost of the resources needed to implement the project. It is important to note, as Conrad argues "… there has been no consideration of who pays the costs and who receives the benefits. The issue of who pays the costs and who receives the benefits may be hotly debated or deliberately obfuscated within the political process in which public projects are proposed, designed, and funded. In the real world, projects with a positive present value for net benefits have been rejected because they were seen as inequitable (unfair) in their distribution of costs and benefits. Projects of questionable net present value have been approved because they are viewed as an acceptable way of helping a deserving segment of society." (Conrad, 2003, p.146)

Another way to evaluate the project is to calculate cost-benefit ratio by using the formula given below:

$$B/C = \frac{\sum_{t=0}^{T} \rho^t B_t}{\sum_{t=0}^{T} \rho^t C_t} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

This is the ratio of the present value of benefits to the present value of costs. If the ratio is greater than 1, then the project is provides the positive benefits to the society.

Next criterion for evaluation of the project is the Internal Rate of Return (IRR). IRR is the rate r which when used as a discount rate would reduce the present value of net benefits to 0. Internal rate of return must satisfies the following equation:

$$\sum_{t=0}^{T} \frac{N_t}{(1+r)^t} = 0 \quad \ldots\ldots\ldots\ldots (3)$$

But as many non-monetary items should also be included in cost and benefit analysis of the project, it is not easy to apply

CBA techniques. The following briefly explains the main issues and difficulties surrounding CBA (WCD, 2000)[3]:

- Economic valuation of project externalities i.e. environmental and social impacts has, in the past, been ignored; and when it is carried out, there are limitations to its usefulness.
- Valuation of impacts over time: there is a variety of perspectives on how this should be tackled.
- Difficulty in accounting for risk and uncertainty i.e. energy demand may not live up to forecasts.
- Macroeconomic effects: accounting for changes in, and impacts on, the wider marketplace.
- Equity and distribution issues: i.e. who is receiving the benefits and who is paying the costs?

But despite criticism, CBA is still used widely for the project analysis. The WCD (2000) confirmed that it 'provides an explicit, systematic approach to evaluating a project's net benefits'.

3.2. Option Value: An Infinite Horizon value Model

One of the approaches of dealing with the harvest of natural resource is option value approach where we can consider infinite horizon value model. The cost benefit approach that we discussed earlier has its limitations. Even though it includes environmental damage and forgone amenity benefits which a project might induce or cause it is not able to include the damage that extend beyond projects horizon. Conrad (2003), argues "...Uncertainty and the fact that a project may be economically costly or ecologically impossible to reverse are two aspects that are not easily introduced into the traditional cost-benefit approach…" In this approach we will compare the

[3] WCD: World Commission on Dams is an independent commission which undertook the task of developing a framework for decision making regarding the development of dams.

option values of continuing the project or abandoning the project in different time periods. Here the option value is the discounted expected net value of behaving optimally in the future.

The first question is to figure out what is the option value of protecting the environment at time t = 0 with infinite time horizon: the amenity provided by the forest, wild flora and fauna and the value of fisheries that would otherwise be forgone if we build the hydropower project.

We start with the following assumption:

- Suppose we continue with the project, then we would benefit from the electricity generated by the hydropower and we suppose here that the benefit thus generated will be continued over infinite time horizon. We denote such net benefit by D_1.
- However if we do not continue with the building of dam at time t then there are two possible states in the period (t+1), and it will be optimal to build the project if state 1 (s=1) occurs. We suppose that the probability of state 1 (s=1) to be constant and is denoted by π. State 1 refers to the situation where $T_1 > A_1$. Here, T_1 and A_1 are the stationary optimal net benefits. T represents the revenue, from start of the project, besides selling electricity (e.g. for construction of dam, forest has to be cut down and timber from the forest can be used for sale) and A represents the value of amenity. State 2 refers to a situation where $A_2 > T_2$.
- The expected value of entering the next period with the environment unharmed is
    - $[\pi T_1 + (1 - \pi) A_2]$

The net present value of building the dam today is given by:

$$D = T_0 + \frac{D_1}{\delta} \qquad \dots\dots\dots\dots (4)$$

Where δ is the discount rate and is assumed to be constant.

Similarly the net present value of not building the hydropower today or the value of amenities received from the environment when hydropower project is not launched is given by:

$$P = A_0 + \frac{[\pi T_1 + (1-\pi)A_2]}{\delta + \pi} + \frac{\pi D_1}{\delta(\delta + \pi)} \quad \dots\dots\dots\dots (5)$$

The point of indifference where D = P is given by

$$T_0 + \frac{D_1}{\delta} - A_0 = \frac{\pi T_1 + (1-\pi)A_2}{\delta + \pi} + \frac{\pi D_1}{\delta(\delta + \pi)} \quad \dots\dots\dots\dots (6)$$

In this above equation where D = P, LHS side represents present value of building the reservoir dam for harvesting water to produce energy, less the forgone amenity benefits at time t = 0 whereas in the RHS side we have the option value of amenities provided by the environment by not building the reservoir dam at time t = 0, for the infinite time horizon.

4. DATA AND RESULTS

For this we have taken reference to the cost and revenue of Chilime Hydropower project of Nepal. Chilime Hydropower project is a 22.1 MW project. We have ignored the increasing scale of return that is usually associated with bigger projects. Similarly, the geographical and other factors such as interest rate, credit availability and political dynamics are also assumed to be constant. Assuming all of the aforementioned factors to be constant we have scaled up the cost and revenue of Chilime Hydropower project as if it was a project of 100 MW. Amenity value used is taken in an ad hoc basis but a careful sensitivity is taken for its value by referring to various simulation exercise conducted in Conrad (2003). All the calculations are denominated in dollar ($) value.

4.1. Cost-Benefit Analysis

The net benefits over the horizon t= 0, 1, 2… T can be calculated by

$$N = \sum_{t=0}^{T} \rho^t N_t \quad \dots\dots\dots\dots (7)$$

We have plotted the time path of net benefits in the figure below: (refer Table 1)

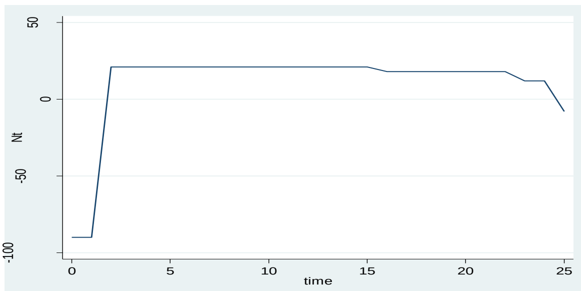

Figure 2: The Time Path of Net Benefits

In the first two periods benefits is 0 but there is construction cost of $ 90 million. From period 3 to period 15 net benefits is 21 million whereas the maintenance costs is $6 million in each time period. Similarly, from period t= 16 to 22, the net benefits is $18 million and the costs is $7 million, and so on. At t= 25 is the period of decommissioning of the project and in this period the net benefits is -$8 million that is at t=25 the decommissioned cost is $8 million.

Now for cost benefit analysis we have use the discount rate δ=0.07 per period. The discount here represents the opportunity cost of the resources use in the construction and maintenance of the project. The present value of net benefits is calculated using the above formula and presented in the table below. The sum of the present value of net benefits over the period is $36.110 million. As the present value of the net benefits is positive the project that we have taken for analysis provides the positive net benefit to the society.

Table 3: Costs, Benefits, Net Benefits, Discounted Net Benefits etc.

T	B_t	C_t	N_t	Discounted B_t	Discounted C_t	Discounted N_t	N_t for IRR
0	0	90	-90	0	90	-90	-90
1	0	90	-90	0	84.11214953	-84.11214953	-82.3138958
2	27	6	21	23.58284566	5.24063237	18.34221329	17.5663119
3	27	6	21	22.04004268	4.897787261	17.14225541	16.06612853
4	27	6	21	20.59817073	4.577371272	16.02079945	14.69406255
5	27	6	21	19.25062685	4.277917077	14.97270977	13.4391726
6	27	6	21	17.99124004	3.998053343	13.9931867	12.2914517
7	27	6	21	16.81424303	3.736498451	13.07774458	11.2417475
8	27	6	21	15.71424582	3.492054627	12.2221912	10.28168925
9	27	6	21	14.68621105	3.263602456	11.42260859	9.403621088
10	27	6	21	13.72543089	3.050095753	10.67533513	8.600540962
11	27	6	21	12.8275055	2.850556778	9.976948724	7.866044809
12	27	6	21	11.9883229	2.664071755	9.324251144	7.194275477
13	27	6	21	11.20404009	2.489786687	8.714253406	6.579876023
14	27	6	21	10.47106551	2.326903446	8.144162061	6.017946995
15	27	6	21	9.78604253	2.174676118	7.611366412	5.504007355
16	25	7	18	8.468364945	2.371142185	6.09722276	4.314821791
17	25	7	18	7.914359762	2.216020733	5.698339028	3.946331015
18	25	7	18	7.396597908	2.071047414	5.325550494	3.609309779
19	25	7	18	6.912708325	1.935558331	4.977149994	3.301070546
20	25	7	18	6.46047507	1.80893302	4.651542051	3.0191553
21	25	7	18	6.037827169	1.690591607	4.347235561	2.761315942
22	25	7	18	5.642829129	1.579992156	4.062836973	2.525496365
23	20	8	12	4.218937667	1.687575067	2.5313626	1.539877368
24	20	8	12	3.942932399	1.57717296	2.365759439	1.408370058
25	0	8	-8	0	1.47399342	-1.47399342	-0.85872908
Total				277.6750657	241.5641838	36.11088183	0.00

4.2. Cost Benefit Ratio

Using another way to evaluate the project is to calculate cost-benefit ratio by using the formula given below:

$$B/C = \frac{\sum_{t=0}^{T} \rho^t B_t}{\sum_{t=0}^{T} \rho^t C_t} \qquad \dots\dots\dots\dots (8)$$

This is the ratio of the present value of benefits to the present value of costs.In our project we have considered discount rate δ= 0.07, and calculated the cost benefit ratio. In this case we have

$$B/C = \frac{277.6750657}{241.5641838} = 1.149488 \qquad \dots\dots\dots\dots (9)$$

This shows that project in consideration provides positive benefits to the society as B/C > 1.

4.3. IRR Calculation

Initially we have assigned r= 0.07 which is equal to the value of δ. But now we have use the above equation to calculate the value of r, which is r= 0.09. The present value of net benefit was positive at δ=0.07, now it seems logical that a higher rate, r > δ is required to drive the present value of net benefits equal to 0. Therefore as r > δ in our calculation it is justified for construction of the project in the current period. The IRR can be considered as an average rate of return for a project assuming that the time horizon and the underlying values of B_t and C_t cannot be changed.

4.4. Option Value: An Infinite Horizon value Model

Here T_0 = $4 million is net revenue from the sale of timber that results because forest has to cut down if reservoir dam is to be built. When we execute the project it would yield the average net benefits of D_1 = $10 million per period for infinite time horizon. This net benefit results from the sale of electricity produced by the hydropower station. A_0 = $2 million, is the current amenity value. T_1 = $6 million is the net revenue that results besides selling of electricity in state 1. A_2 = $2.5 million is the amenity value in state 2.

Table 2: Simulation of Data using option value approach (infinite horizon)

T_0	4	4	4
D_1	10	10	10
δ	0.07	0.07	0.07
A_0	2	2	2
π	0.5	0.75	0.5
T_1	6	6	6
A_2	2.5	2.5	2.5
D	146.857	146.857	146.857
P	134.769	138.912	140.764
Option Value	132.769	136.912	138.764

At δ=0.07 and π = 0.5, the calculated value of D=146.857, P=134.769 and option value is 132.769, that is 98.51% of the value of P. As we know that if the D=P, then we would be indifferent between execution of project and do not run the project. If we increase the value of π to 0.75 or 0.95 the value of P increases even though the value of D remains same, D is greater than P. Hence we observe that the net present value of decision to run the project is greater than not running the project (i.e. preservation of water, forest, flora and fauna, fisheries). Therefore it is beneficial to execute the project.

5. CONCLUSION

Hydropower is one of the extensively used techniques to produce electricity. Because it involves investment mostly only in the initial period of the project and is one of the cleanest way to produce energy, it is championed by many governments and agencies around the world. However as in the case of every natural resource harness, hydropower harness too suffers from some drawback. One of the major setbacks of using water to produce electricity is that we should build a reservoir dam which may impact the host environment permanently. Therefore, it is important to take these into account while starting the projects. In this paper we have used two approaches to find out optimality of the project. Traditional cost benefit analysis, however, suffers from a drawback that it does not include effect of damages done to the environment beyond the project horizon. But in real world, hydropower projects do alter the host environment even beyond project time horizon. Therefore, option-based approach is more suited in case of hydropower projects where the project has irreversible effect on the environment. In our paper we used data with reference to scale up costs and revenue of Chilime Hydropower project of Nepal. We computed under both the approach and found that in both the case project of building hydropower project should be initiated. This result was not surprising though. This is because in most recent development projects EIA is done before starting the project and cost of environmental externality is internalized. Because building of dams usually does not require much cut down of the forest, and water is a renewable resource, amenity value lost is low. Therefore, our calculations showed that building hydropower reservoir dams to harness water potential is beneficial.

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