Comparison of hydropower options for developing countries with regard to the environmental, social and economic aspects

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Abstract

With world electricity demand increasing, exploitation of the considerable potential for hydropower generation in many developing countries is an attractive prospect. However, with increased awareness of the potential adverse effects of hydropower and the underlying need for cost-effectiveness, decisions on the scale of new developments are more difficult to make. This paper compares large, small and pico hydropower generation, focusing on the relative adverse environmental and social effects of each, and their economic performance.

A hypothetical scenario was formulated featuring three routes to hydro powered rural electrification in developing countries. Costs and population densities were based on data for Pakistan and Peru. Cost-benefit analysis (CBA) techniques were employed to compare the costs and benefits of three hydropower development options providing the same level of service to rural consumers. The results show that investment is recouped 25% more quickly where a number of very small hydro schemes are used instead of one large scheme, but the level of investment required for the single scheme is far greater. Based upon these results, the applicability of hydro projects utilising schemes of different sizes is discussed.

Introduction

Hydropower currently provides 16.3 % of the worlds electricity supply [1], and there is still considerable untapped potential in many areas of the world even though this is a relatively old technology. Continued exploitation of this resource is likely as a response to the world demand for energy. Environmental legislation such as the Kyoto Protocol is increasing pressure on all governments to generate 'clean' energy or energy from sustainable sources. Hydropower produces little CO_2, but in other respects may not be truly sustainable.
In many developing countries electricity usage is widespread in urban areas but for many rural areas, infrastructure investment is much lower, and many communities rely on batteries or nothing at all. With the current population rise in many developing countries there is even greater demand to generate more electricity, and also to distribute it to poorer people so that they do not get left behind in the race to develop. Electricity provision to rural communities results in a better quality of life for householders, but also has positive impacts on schools, hospitals, businesses and agriculture/industry.

Hydropower schemes range from the massive to the very small. The biggest schemes involve damming huge rivers, and supply large urban population centres with electricity. A dam built across a river valley creates an artificial storage reservoir and an increase in hydrostatic head (height through which water will fall). A powerhouse containing turbines and generators is built at the foot of the reservoir. The storage capacity of the dam reduces the effects of seasonal changes in river flows and allows regulation of releases through the turbines. These hydro-schemes will usually be grid connected, although smaller projects may serve localised users, particularly in rural areas.

Run-of-river systems do not rely on a reservoir. Generation capacity can vary significantly depending on seasonal river flows. These schemes often utilise existing weir technology. Run-of-river schemes can vary in size significantly but many are relatively small and so often not grid connected.

Micro and Pico systems typically utilise the high heads and small flows often found in upland regions. Their small generating capacity makes them suitable for isolated off-grid locations to provide power to small rural communities. They are typically run-of-river, although small storage tanks may be required to hold a small amount of water to ensure that, even at times of low flow, generation can be guaranteed for at least a short period every day.

Large dams on rivers are now well understood to be far from environmentally benign, and such schemes have suffered much criticism in recent years. It is generally accepted in the literature on hydropower pitfalls (i.e. Rosenberg et al [2] and Trussart et al [3]) that, the larger the hydropower scheme, the greater the adverse effects are to riverine wildlife, riverside communities and river ecology. These effects are mainly a result of water storage in the river valley and disturbed downstream flows. It should be understood that size is not the exclusive indicator of negative effects; run-of-river schemes can produce significant quantities of electricity, but with no storage they offer a very clean form of energy.

A typical classification table is shown in Table 1. The 10MW outer boundary for a 'small' project is subject to alteration in different countries or by different organisations, the value shown here is as defined in the EU.

Classification	Power Output
Large	> 100MW
Medium	10 - 100MW
Small	1 - 10MW
Mini	100kW - 1MW
Micro	5 – 100kW
Pico	< 5kW

Table 1 - Typical hydropower classification by generating capacity.

Investing in hydropower

Governments have many options available to them for investing in electricity generation infrastructure. Achieving a cost effective, forward thinking, reliable and environmentally sustainable portfolio of generating stations is challenging for all investors, but especially so for governments of developing countries where the spread of electricity usage can act as a catalyst for development, and so it is particularly important that new investments are made wisely. Of particular interest is the supply of electricity to the rural and/or isolated communities of developing countries, for which electricity infrastructure provision would provide real opportunities to improve quality of life and encourage economic development. Those developing nations with a wealth of hydropower potential will naturally wish to exploit this resource, as long as doing so provides good value for money.

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 1).

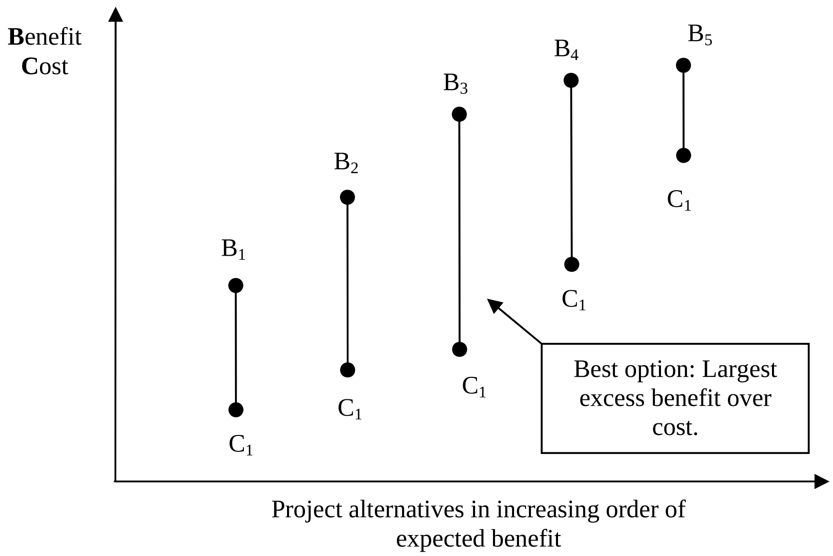


Figure 1 - Comparing project options using CBA (Adapted from Cost Benefit Analysis, E.J. Mishan [4]).

It is not always easy to apply CBA techniques; in fact CBA has suffered considerable criticism in the past. The following briefly explains the main issues and difficulties surrounding CBA (WCD, 2000) [5]:

- 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?

Although there are difficult issues to consider, and many potential pitfalls for an analyst, CBA is a widely used and respected technique. The World Commission on Dams confirmed that it ‘provides an explicit, systematic approach to evaluating a project’s net benefits’[6]. In the following section, CBA techniques are employed in order to assess the relative successes of theoretical investments in different types of hydropower.

Project Definition

Definition of the boundaries of consideration is the first step of any CBA, and it is very important for the success of this analysis that this is done in a manner which reflects reality and leads to a convincing and useful result. For this analysis there is the difficulty of dealing with a typical, yet hypothetical, situation. Assumptions have been based on real-life experience in the form of published literature and statistical information.

In a hypothetical scenario, the government of a developing country is considering tapping the hydropower resource of a particular region by building a 100MW hydropower dam on the region's main river. The intention of the government is to further the economic development of the country through increased access to electricity, particularly for the many rural inhabitants of the region who currently rely on wood and car batteries for power. They intend to connect 100,000 rural households to supplies of around 75W each and it is hoped that this action will improve the quality of life of very poor people and encourage industrial end uses of the electricity.

This scenario was addressed through economic assessment using CBA style techniques and decision making to decide the relative balance of costs and benefits for three discernible hydropower schemes utilising different scales of hydro technology:

Option A 'Single Large': A large dam on the region's main river with a considerable storage reservoir can continuously supply 100MW of electricity. In order to connect rural communities, a significant grid extension program will be required. Generating capacity in excess of that required to electrify rural communities will be used for urban centres, large industry or export.

Option B 'Several Small': There are several smaller river basins and tributaries to the region's main river which could be used for a series of small hydropower projects in the region of 5MW each. Power stations will be dispersed throughout the region but a significant new distribution network will be required.

Option C 'Micro & Pico': Fast flowing streams pass close to or through many of the target communities, which lend themselves to Micro or Pico hydro schemes. Only village distribution networks are required or short transmission lines to distribute Micro-hydro power to several small villages.

The options have been chosen so that the most difficult to quantify benefit, economic growth due to electrification, will be the same for each as the same number of households are to be electrified. The level of service may be slightly different (i.e. Pico may not be able to generate electricity all of the time) but this discrepancy can be accounted for through the final analysis. Estimation of the benefits obtained through rural electrification has been attempted, for example, in the Philippines by the World Bank [7], but there is a large margin of error in measuring economic and social benefits.

75W is taken as the average figure per household, which represents a typical supply for a rural household, being enough for a single standard bulb (or several compact fluorescent lamps) and a radio. Actual usage during the day would vary from 0-75 W.

Identification of Gainers and Losers

Identification of the populations of gainers and losers is an important step in a CBA because it sets boundaries and focuses attention on specific groups. It is also identifies who loses and who gains from a particular course of action, which is important if the focus is on poverty reduction. For instance, if the impact of an action provides a benefit for group A, but a cost of equal but opposite value for group B the resultant cost/benefit is zero. However, if group B are poor and group A are wealthy then this course of action is less justifiable in social and political terms.

All potential groups of losers and gainers are now listed:

1) The rural populations targeted for new permanent electricity supplies: These people typically have limited or no access to electricity, many will be users of rechargeable car batteries and dry cell batteries for lighting, radio and possibly television. Cooking will be done over stoves fuelled by locally collected wood or any other suitable materials available locally. These people will typically work the land and/or fish to feed themselves and possibly to trade.
2) Rural populations negatively affected by development: Those displaced by the creation of reservoirs who may suffer loss of livelihood, cultural identity, social support network etc.
3) Urban householders: Residing in the region's most densely populated towns and cities, these people have some or total access to electricity. Their lifestyles and increasing wealth lead them to purchase gradually more consumer electrical goods.
4) Industry: Major users of electricity, industrial companies are drawn to developing countries by cheap labour, raw materials and emerging markets.
5) The government: In this scenario, they are the hydropower investors – and they have a vested interest in the economic prosperity of the region and the standard of living of its inhabitants.
6) The world at large: People with an interest in the sustainability of the planet.

Identification of Project Impacts

This stage identifies all possible impacts of the three project options. It is also necessary at this stage to identify which of these impacts are economically relevant.

- Potentially all the negative environmental and ecological effects associated with large dams such as greenhouse gas emissions, obstruction to fish migration, reduced delivery of sediment to the sea, loss of diverse ecosystems etc. as discussed in ….
- Negative sociological effects of large dam installations described in …, such as population displacement and resettlement.
- Reliable supply of electricity to rural communities.
- Alteration of rural landscapes due to power lines.
- For the 'Single Large' option, electricity will be generated in excess of that required for the identified rural population. This will result in more electricity being available for urban households and/or industry – and the impact could manifest itself as cheaper electricity, or a more stable supply for these users. If the excess is exported then this will help with the investor's balance of payments.
- For the 'Micro & Pico' option, employment opportunities for inhabitants of rural communities in the construction and operation of multiple localised generating stations.

Costs and Benefits

Conversion of this list of possible impacts into a set of costs or benefits requires some initial decision making. The detrimental effects of hydro schemes will differ in their severity from country to country and from project to project. A good example of this is the difference in GHG emissions recorded from reservoirs in tropical and in boreal regions. Ideally, this comparison is intended to estimate costs and benefits for a *general* case. For items that are difficult to evaluate, this analysis attempts to find innovative routes to achieving realistic estimates.

The following costs and their respective time scales have been identified to include in the analysis, alongside a list of benefits.

Costs	*Cost time scale*
Plant construction (i)	8-10 years (large/ small); 10-12 years (micro/ pico)
Transmission	As above.
Distribution	Towards the end of plant construction period.
Pre-inundation clearing (ii)	Immediately before flooding.
Operation & maintenance	Once plant is completed.
Resettlement (iii)	Before flooding
Loss of agricultural land	As long as river is dammed.
Damage to ecosystems	Infinite and irreversible
Other environmental or sociological effects	Mainly long-term

Benefits
Income from sale of electricity. (iv)
Time savings for household chores.
Improved productivity for home businesses.
Less expensive/more use of lighting/radio.
Reduced deforestation.
Cheaper/reliable electricity for industry/urban consumers.
Contribution to economic growth.
Additional-purpose benefits of reservoirs i.e. irrigation, flood control, fisheries.

Thus is not an exhaustive list of costs and benefits in terms of detail, as certain types of effects have been grouped together under single headings to aid handling. Additional notes explaining the above are included below.

i. The construction cost has been spread over a 8-10 year period for dam projects, but for Micro & Pico, the duration is assumed to be longer (10-12 years) to account for the difficulty in planning and implementation over a widely dispersed population.
ii. The cost has been included of clearing the pre-flood countryside of organic material in order to prevent the emission of greenhouse gases from any reservoirs introduced. The more quickly it can be completed the more effective it is, so the cost will be concentrated in a single year. This is rarely carried out in practice but is included so that GHG emissions are comparable for the different options.
iii. Resettlement: The total cost of removing people from any areas to be flooded and resettling them such that they are not disadvantaged socially or financially. This must begin as soon as possible and completed before flooding.
iv. The revenue collected will continue for as long as electricity is generated by the facilities but may be affected in the future by fluctuations in energy prices and dam siltation or other efficiency losses.

The above list includes the development benefits to rural populations that are inherent in the structure of each of the three options and so will apply to all and in equal measure. On this basis they can be excluded from the economic analysis but consideration of their effects will be included in the final discussion. The convenience of not needing to value certain benefits because they are the same for all options is not uncommon in CBA, and is sometimes described as Least-Cost Analysis.

Scheme sizes and transmission lines

Using information from Harvey [8] and the World Bank [9] typical village sizes were determined, and the total rural households divided up. Table 2 shows the resultant breakdown of rural communities forming the foundation of the model:

Village Type	Households per village	No. Villages	Capacity per scheme (MW)	Schemes per village	Households served	Supply MW	Type	No. Schemes
Small	67	350	0.005	1	23450	1.75	Pico	350
Medium	134	175	0.005	2	23450	1.75	Pico	350
		225	0.05	0.2	30150	2.30	Micro	45
Large	335	69	0.05	0.5	22950	1.70	Micro	35
Totals		819			100000	7.5		780

Table 2 - Breakdown of rural populations based upon 75W household supplies and the specific needs of the micro & pico option.

The table illustrates that 100,000 households each with 75W supplies entails a total demand of 7.5MW, which is the same for all options. The types of plant for the 'several small' option were chosen according to ratio of typical schemes. The resulting quantity for each type of hydro scheme is shown in

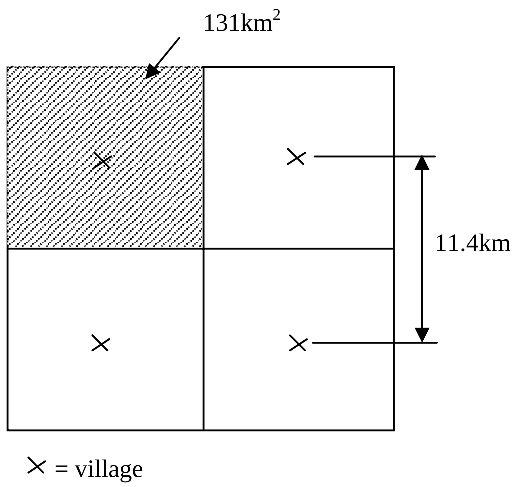
Table 3 and takes into account the result derived for option C in the previous figure.

<table>
<tr><th colspan="2">Option</th><th>A</th><th>B</th><th colspan="2">C</th></tr>
<tr><td colspan="2">Demand MW</td><td>7.5</td><td>7.5</td><td>4</td><td>3.5</td></tr>
<tr><td>Installation type:</td><td>MW</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Med/Large dam #</td><td>100</td><td>1</td><td></td><td></td><td></td></tr>
<tr><td>Small dam #</td><td>5</td><td></td><td>3</td><td></td><td></td></tr>
<tr><td>Small run-of-river #</td><td>5</td><td></td><td>1</td><td></td><td></td></tr>
<tr><td>Micro hydro ror #</td><td>0.05</td><td></td><td></td><td>80</td><td></td></tr>
<tr><td>Pico hydro ror #</td><td>0.005</td><td></td><td></td><td></td><td>700</td></tr>
<tr><td colspan="2" rowspan="2">Total Power generated MW</td><td rowspan="2">100</td><td rowspan="2">20</td><td>4</td><td>3.5</td></tr>
<tr><td colspan="2">7.5</td></tr>
<tr><td colspan="2">Surplus power (MW)</td><td>92.5</td><td>12.5</td><td>0</td><td>0</td></tr>
</table>

Table 3 - Breakdown of plant requirements to satisfy demand.

Information on the proportions of electricity used by different sectors in LEDC's (Less Economically Developed Countries) was obtained from Geofile Online. For the 'several small schemes' option (B), excess power was made available for large industries relatively close to the dams, so that additional transmission was not required.

In order to calculate the likely total length of transmission infrastructure required, it was necessary to consider population density, and the distribution of villages within the region. Peru and Pakistan were selected as transmission case studies as they have similar hydropower development potential but very different population densities. From Bongaarts [10] the average number of people per household was taken as 5.2. This was used together with the population density information to calculate the typical distances between villages and households in the two countries, as shown in Figure 2.



E.g. For Peru:
Village size = 134 households
Typical household size = 5.2 persons
Rural population density = 5.3/km^2

Proportioned area = $\frac{134 \times 5.2}{5.3} = 131 km^2$

Assume population grouped in central village.

Distance between villages $= \sqrt{131} = 11.4 km$

Figure 2 - Example of village spacing model.

As three different village sizes are used in the model, there are three different grids for each country. A summary of this information is provided in Table 4.

	Peru			**Pakistan**		
Rural population density (persons/km^2)	5.3			123		
Village type	Large	Medium	Small	Large	Medium	Small
Average distance between villages (km)	18.1	11.5	8.1	3.8	2.4	1.7

Table 4 - Details of village spacing model.

The transmission line lengths were calculated depending on the different hydro options, with layouts as shown in Figures 3 and 4. Option C (Micro & pico) only requires transmission line when a micro hydro installation supplies several medium or large villages in close proximity. To account for these instances, 5km (Peru) and 2km (Pakistan) is added for each village connection to a centralised Micro site. A summary of transmission lengths is given in Table 5. Distribution costs were added only for options A and B because for Micro and Pico systems, the cost of installing distribution networks tends to be included in the overall scheme cost, which has been used in the analysis.

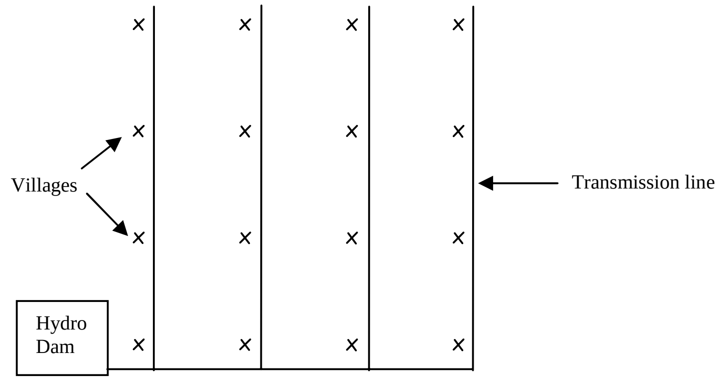


Figure 3 - Transmission model for 'single large hydro' option (A).

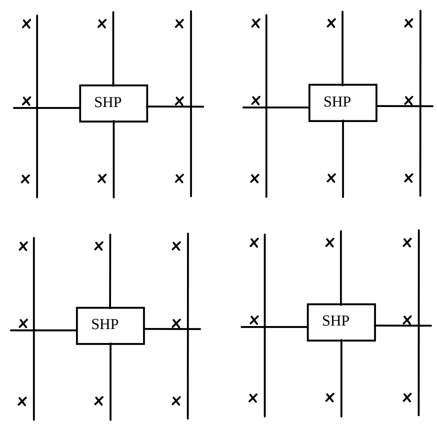


Figure 4 - Transmission model for 'several small hydros' option (B).

		A	B	C	
Peru				Micro	Pico
Medium voltage	km	9204	9932	0	0
Low voltage	km	0	0	1470	0
Pakistan					
Medium voltage	km	1910	2220	0	0
Low voltage	km	0	0	588	0

Table 5 - Grid requirements for the three options.

Construction costs of 150 hydropower projects were collated and compared on a cost per kW basis. The graph (Figure 5) shows hydro plant costs in millions of US dollars against plant capacity in MW. Both are plotted on logarithmic scales and this results in a linear distribution. The 'best-fit' line representing the average or general case was used to estimate the cost of hydro plant.

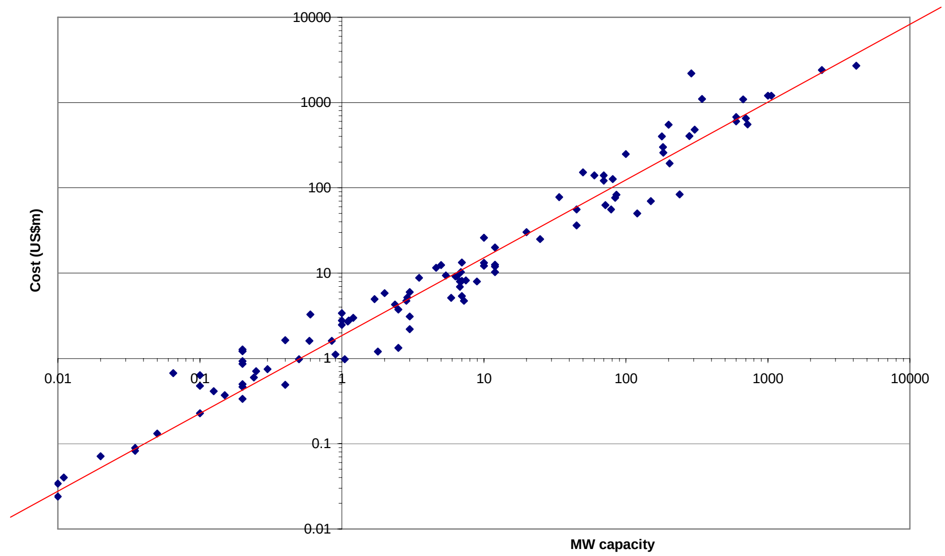


Figure 5 – Relationship between plant cost and capacity.

Reading from the graph, typical costs of hydro plants and the cumulative cost of all hydro plants to supply option A, B and C are as shown in Table 6. In the absence of other information, the distribution of the cost over time was taken to be linear for all options.

<table>
<tr><th></th><th>A</th><th>B</th><th colspan="2">C</th></tr>
<tr><td>Single plant cost (US$)</td><td>145000000</td><td>8500000</td><td>150000</td><td>17500</td></tr>
<tr><td>Quantity of plant</td><td>1</td><td>4</td><td>80</td><td>700</td></tr>
<tr><td rowspan="2">Total plant cost (US$)</td><td rowspan="2">145,000,000</td><td rowspan="2">34,000,000</td><td>12,000,000</td><td>12,250,000</td></tr>
<tr><td colspan="2">24,250,000</td></tr>
<tr><td>Construction duration (yrs)</td><td>8</td><td>8</td><td colspan="2">12</td></tr>
</table>

Table 6 - Cost of hydro generating plant.

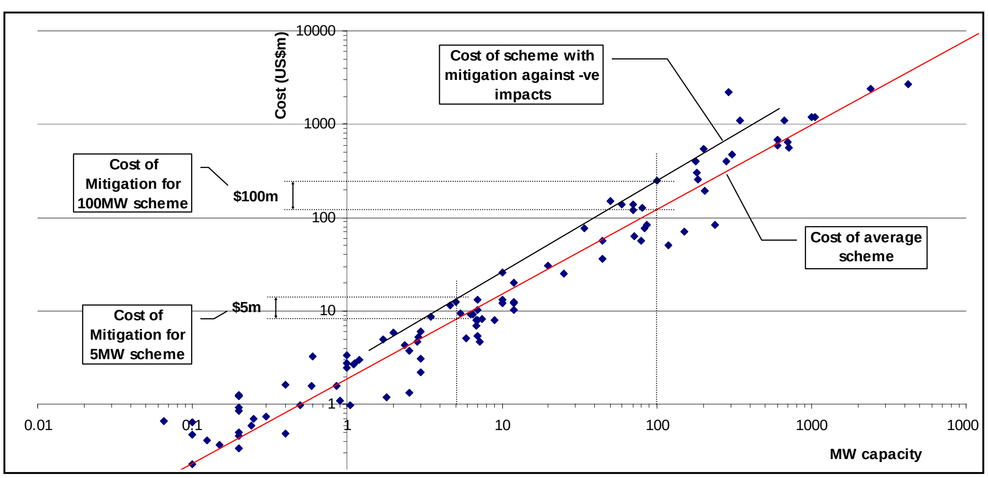


Figure 6 - Cost of mitigation.

An additional cost, to take account of mitigation measures such as fish passes and ladders, surface water pumps and measures to control sediment, was added to the average construction cost. The additional cost assumes that the more expensive schemes in Figure 5 have included such mitigation costs. By referring back to the graph used in Figure 5 (cost v capacity), a value representing the difference between the typical cost and the maximum cost likely was obtained for a 100MW scheme and for a 5MW scheme as shown in Figure 6.

Cost estimates for MV (medium voltage) transmission lines vary significantly, from $100,000 per km of 3-phase grid extension in Nigeria [11] to $16,000 per km in South Africa [12]. NRECA's research shows that MV transmission can be reduced to $4000/km for single phase and $5000 for 3-phase over level terrain increasing by about $2000 in countries where labour costs are high. These low costs represent an 'ideal' situation and are only achievable as long as best practice is followed, optimum materials are available and transport infrastructure is good. A recent case study in Uganda [13] uses $20,000/km to calculate costs. Taking account of terrain, and allowing for the cost of sub-station transformers, a typical value of $16,000/km has been used.

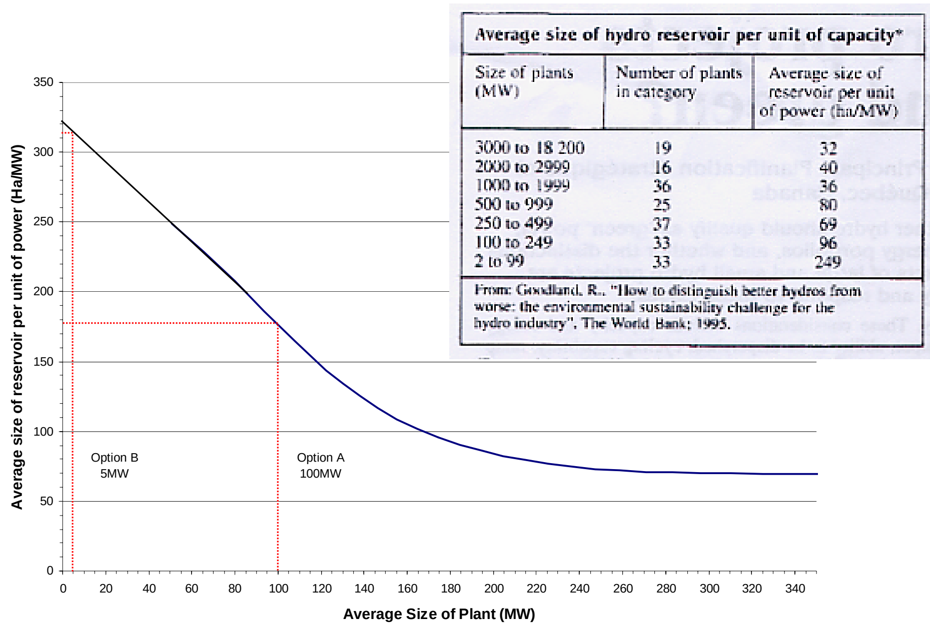
The cost of a village distribution network was obtained through analysis of two Pico hydro schemes in Kenya described by Maher et al [14]. When adjusted to include the cost of poles (which were supplied by the villagers in the above cases) the cost was $57 per house.

A survey of four Small Hydro and four Micro Hydro plants in Nepal conducted by Vaidya[15] found that the operation and maintenance (O&M) cost was, on average, 50% of revenue, but this includes depreciation of equipment. Examination of a 40kW scheme in Nepal [16], a 15kW scheme in Tanzania [17], a 4kW scheme in Indonesia [18] and a proposed Sri Lankan scheme [19] shows that O&M costs are nearer $50/kW/year, and this is the estimate adopted.

Inundation Extent and Effects

Options A and B include reservoirs for water storage. Estimation of the area inundated was determined using data from the World Bank [20], which is based upon a survey of nearly 200 plants. This information was plotted on a graph (Figure 7), from which average values for reservoir sizes for a 100MW dam and a 5MW dam can be taken to be 175 and 315 ha/MW respectively.

The resultant total area flooded on this basis is 17,500 ha for the single large dam and 4,725 ha for the combined reservoirs associated with option B. Option C has no quantifiable storage. The quantity of people to be relocated was estimated from another World Bank publication [21], giving a 'typical' figure of 3.1 people/hectare.



Average size of hydro reservoir per unit of capacity*

Size of plants (MW)	Number of plants in category	Average size of reservoir per unit of power (ha/MW)
3000 to 18 200	19	32
2000 to 2999	16	40
1000 to 1999	36	36
500 to 999	25	80
250 to 499	37	69
100 to 249	33	96
2 to 99	33	249

From: Goodland, R., "How to distinguish better hydros from worse: the environmental sustainability challenge for the hydro industry", The World Bank; 1995.

Figure 7 - Basis for reservoir sizes. Graph adapted from Egre et al [22].

The cost of mitigation against potential greenhouse gases from the reservoirs was taken into account by assuming clearance of vegetation before flooding. The cost was based on cost of clearing vegetation for a power line in Virginia, USA, in 2001 [23] of \$3.70 per m^2. This figure was adapted for local wage rates, using wage rates for labouring jobs in the US and Peru from the National Bureau of Economic Research (NBER) [24] and in Pakistan from The Government of Pakistan Federal Bureau of Statistics [25]. From this data, clearing of trees in Peru costs US\$0.66/m^2 and US\$0.13/m^2 in Pakistan. Option C has no reservoirs and so no clearing costs.

The cost of resettlement from the reservoir site was given by the World Bank [26] as \$28,000 per person for resettlement, but this project was unsuccessful and over budget. Examples of more successful and more cost effective projects were found in Dixit [27], The World Bank [28] and the UK government [29] concerning the Ilisu Dam project. Cost estimates ranged from \$1000 to \$8000 per person. Through evaluation of these publications, a figure of \$3000 per person was arrived at.

Revenue and cost-benefit cash flow

The revenue collected from the sale of electricity was based on published data on electricity costs from The Energy Information Administration [30], which gives average values of \$0.101/kWh for domestic \$0.062/kWh for industrial power. For domestic power use, a very basic model was assumed, as shown in Figure 8.

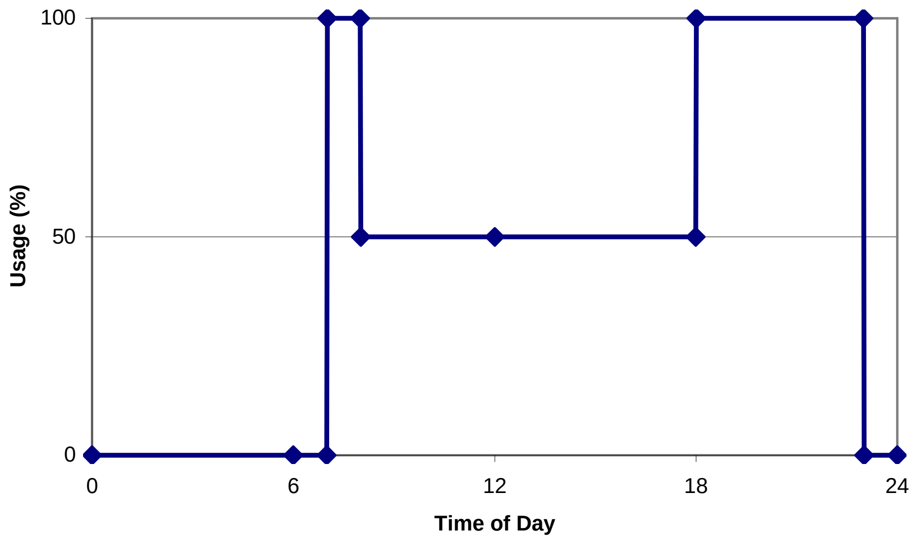


Figure 8 - Household electricity usage model

Except for the micro & pico hydro option, it was assumed that there would be demand from industry for any excess power for an average of 12 hours per day. These revenue values were then offset against the costs of each project option. The resulting financial position after each year of the project was then plotted to compare the performance of each option. This was done separately for both case studies, Peru and Pakistan; the graphs are shown below as Figure 9 (Peru) and Figure 10 (Pakistan).

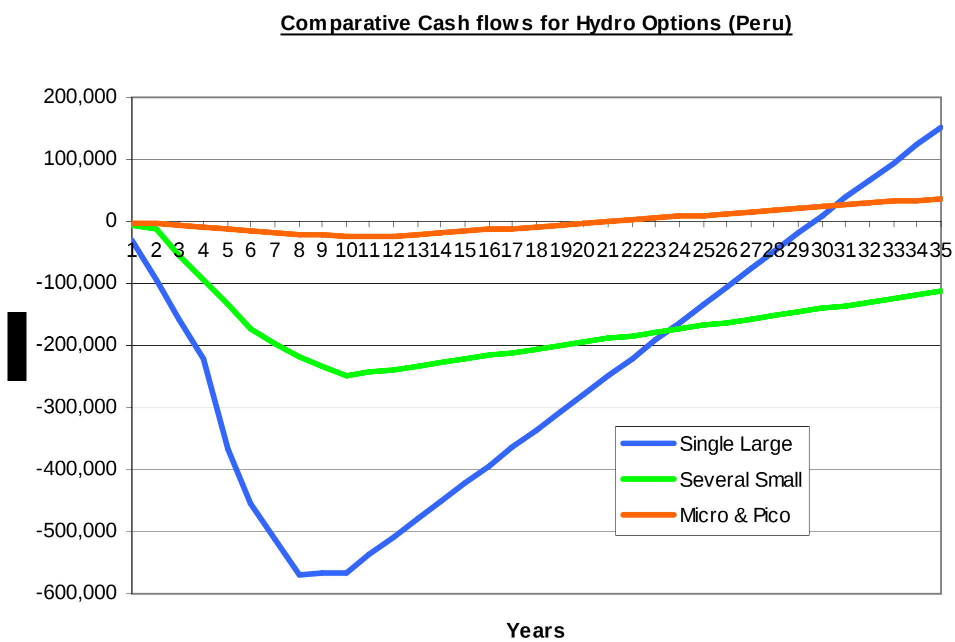


Figure 9. Cost-benefit for Peru over 35 years.

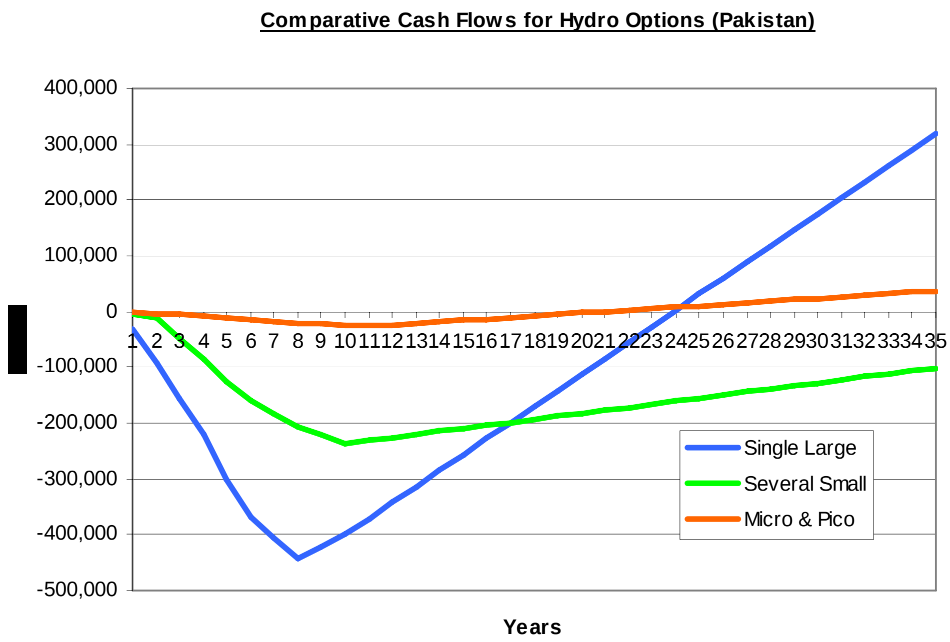


Figure 10. Cost-benefit for Pakistan over 35 years.

The graphs show that for Option A where a single large dam is built, the costs are considerable, but the benefits obtained are similarly large to result in a good eventual inflow of benefits. With the Micro & pico option (C) where very small isolated schemes are used, there are considerably fewer costs, but the benefits are relatively good and the overall payback is the fastest. The option of several small schemes (B) falls between the other two, with moderate costs; but its desirability is questionable because the scant inflow of benefits results in a very lengthy payback duration. The results for Peru and Pakistan are similar, although the costs are higher for Peru.

Limitations of cost benefit analysis

As discussed in the section entitled investing in hydropower, there are some costs and benefits of the schemes that cannot be reliably evaluated financially. These are:

- Those adverse effects of reservoirs that cannot be mitigated against i.e. the loss of unique habitats, species and ecosystems. This is a cost in option A and option B and affects the world at large.
- Direct benefits of electricity for users i.e. time savings for household chores, improved productivity for home business and less expensive use of lighting/radio. This is applicable equally in options A, B and C and affects rural populations.
- Cheaper/reliable electricity for industry/urban populations. There is an element of this in both options A and B.
- Contribution to economic growth of the country through increased industrial activity in rural areas and the potential to use electricity supply to improve schools and healthcare facilities in rural areas (i.e. a ‘trickle down’ effect). This applies equally to A, B and C.
- Reduced deforestation is relevant in all options and affects the world at large.

- Additional-purpose benefits of reservoirs i.e. irrigation, flood control, fisheries. Relevant to option A and option B; those living near to the reservoir and in some downstream areas will benefit.

Although it has not been possible to attach monetary values to all of these items, they are important and their implications need to be taken into account when planning a hydro project.

Within CBA, discounting serves to take account of the fact that £1 today is worth more than £1 next year, and this technique is commonly used to adjust value flows to reflect more closely their worth at today's rates (Net Present Value). Choice of discounting factor is quite contentious and it can have a large effect on the perceived viability of a project. This was not considered to be necessary in this analysis as its effects would not alter the result in any meaningful way because of the 'direct comparison' nature of the analysis. Similarly, it was not necessary to be concerned about the possible effects of risks and uncertainty (i.e. future demand for electricity supplies), or the macroeconomic effects, as these were considered to be equal for each option and not applicable where the analysis is general and not site-specific.

Conclusion

The research presented illustrates the strengths and weaknesses of each of the hydro options studied, suggesting where each is most applicable, based on the best evidence available. It shows that micro and pico hydro can be cost effective for supply of rural electricity, even where population densities are sparse. It also shows that large-scale hydro may be cost effective, even where the major costs of environmental mitigation are included. However, as a means of achieving rural electrification in developing countries, small hydro schemes may not be cost effective because the cost of transmission systems and the cost of environmental mitigation cannot be covered by the relatively small income from rural consumers and local industries.

The research does not provide a firm conclusion, i.e. there is no 'best option'. Instead, the relative usefulness of the three options depends upon several factors (as discussed in the conclusion) and there is some inherent uncertainty. Some of these uncertainties stem from the difficulties commonly found with CBA. Specific measures were taken to include project externalities such as environmental and social impacts, although there is scope for finding new ways of valuing some of these factors. Another area of concern in CBA is the issue of equity and distribution. The micro and pico hydro option might score well from this point of view as there would be few 'losers' from the implementation of the technology. This option would also have more potential for active participation of the beneficiaries in the process of rural electrification.

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