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ORIGINAL ARTICLE

Cost–Benefit Analysis of Samanalawewa Hydroelectric Project in Sri Lanka: An Ex Post Analysis

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Abstract

Cost–benefit analysis was applied for 120 MW Samanalawewa hydroelectric reservoir plant in Sri Lanka. Valuation methods were applied to estimate losses in agriculture, natural vegetation, water losses and benefits of avoided carbon emissions. The project resulted in a negative net present value under the standard conditions stipulated and possible changes to the variables to make the project positive were investigated. The study highlights the importance of valuing environmental and social impacts where large-scale transformation of land uses in sensitive areas is involved. It outlines a framework for a composite tool that could accommodate environmental externalities, social inequities and uncertainties along expanded temporal and spatial scales.

Keywords Hydropower · Cost–benefit analysis · Environmental valuation · Carbon prices · Renewable energy

1 Introduction

Renewable energy sources play an increasingly important role in providing energy services in a sustainable manner and, in particular, in mitigating climate change. Additional benefits of renewable power in enhancing rural economies, alleviating poverty (Martinot 2001), low cost and local availability (Bugaje 2006) have been highlighted. IHA (2015) emphasizes hydropower's ability to provide flood protection and mitigate drought impacts in the face of increasingly frequent extreme hydrological events. Renewables mitigate climate change by offsetting the use of fossil fuels and support other variable renewables (wind and solar) by providing energy storage. However, there is evidence of improper location of hydropower giving rise to significant negative impacts (Gunawardena 2010).

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Hydropower raises specific environmental and socio-economic issues (Kibler and Tullos 2013), which are often ignored in development policy-making (Zhang et al. 2015). Environmental issues are related to the transformation of land use and of river flow patterns and the impacts vary substantially from one geographic context to another.

The Samanalawewa Hydroelectricity Reservoir (SHER) along with building of a dam started in 1988 and completed in 1992 which uses Walawe River water for electricity generation (TEAMS 1992a; Udayakumara and Shrestha 2011). When the reservoir was being filled, a disastrous leak in the Right Bank flank occurred on October 1992. It caused a landslip approximately 300 m downstream of the dam. This generated serious concern amongst the local residents that the dam was failing and there would be serious loss of life. The water level was reduced to 430 m and maintained at or below this level until the present time. The flow of the original leak was estimated to be 7.5 m^3/s; however, it is presently estimated to be 2 m^3/s. The area of ingress was identified to be along the slopes and in the Walawe River. To minimize the above leak, remedial measures (wet blanketing) were undertaken from March 1998 to January 1999 (CEB 2006; Udayakumara and Shrestha 2011).

Currently, out of the water released for agriculture, two-third leaks through and only one-third is being released through the irrigation release valve (IRV). The surplus water from the leak during the paddy harvesting period creates a significant loss in terms of foregone power generation. Ceylon Electricity Board (CEB) expected to curtail this loss by installing two mini-hydroelectric projects to harness water from the leak (550 kW) as well as the IRV (1275 kW) (Lakshman 2007).

Although there have been few geologists who have cast doubts on the potential geological issues in the area during the planning stages, the authorities seem to have ignored such warnings. Further, during the implementation of the project, no precautionary measures were undertaken. The construction of SHER has, therefore, inevitably resulted in numerous adverse environmental and socioeconomic issues. The project did not require an environmental impact assessment since the relevant legislation has not been enacted by then. Thus, this study intends to estimate main costs and benefits associated with the SHER project to include them in a cost–benefit framework to judge the viability of the project from environmental and national economy points of view. The paper is organized as follows. The following section provides a brief overview of hydropower development of Sri Lanka followed by an overview of impacts of hydropower. The next section of the introduction discusses evaluation of environmental impacts of hydropower and tools and frameworks available for their incorporation into decision-making. Introduction is followed by methodology, results, discussion and conclusions of the study.

1.1 Energy Sector Developments in Sri Lanka

The Sri Lankan power system has a total dispatchable installed capacity of 3500 MW and biomass (45%), petroleum (40%) and hydro (8%) are the major primary energy sources. Estimated potential of hydro-resource is about 2000 MW, of which more than half has already been harnessed. The average per capita electricity consumption in 2014 was 535 kWh per person (CEB 2015).

Electricity was first introduced to Sri Lanka in 1895 with diesel generators. Then the Kelani River and its tributaries (Kehelgamu Oya and Maskeli Oya) were developed for hydropower and a thermal plant was also commissioned at Kelanitissa in 1960–1962. The Mahaweli diversion at Polgolla to provide irrigation water and to generate 38 MW at Ukuwela was the second major step in hydro-development in the country. Then, accelerated Mahaweli development programme contributed 665 MW to the national grid, capable of generating on average 2030 GWh of electricity annually. Then Samanalawewa hydroelectric plant with an installed capacity of 120 MW on Walawe River was commissioned in 1992 (Fernando 2002). The present electricity-generating system of the CEB is mostly based on hydropower (1376.95 MW hydro out of 2820.95 MW of total CEB installed capacity). Details of the existing hydrosystems are provided in Table 1.

Table 1 Existing hydropower plants in Sri Lanka *Source* CEB 2015

Hydropower plant	Capacity (MW)	Expected annual average energy (GWh)
Canyon	60	160
Wimalasurendra	50	112
Old Laxapana	53.5	286
New Laxapana	116	552
Polpitiya	75	453
Laxapana total	354.5	1563
Upper Kotmale	150	409
Victoria	210	865
Kotmale	201	498
Randenigala	122	454
Ukuwela	40	154
Bowatenna	40	48
Rantambe	49	239
Mahaweli total	812	2667
Samanalawewa	120	344
Kukule	70	300
Small hydro	20.45	–
Samanalawewa total	210.45	644
Total	1376.95	4874

1.2 Impacts of Hydropower

River ecosystems are adapted to the natural hydrological regime and many components of those systems rely on floods for the exchange, not just of water, but also energy, nutrients, sediments and organisms. Hydropower dams constitute obstacles for longitudinal exchanges along fluvial systems. Dams could modify the river hydrology in the downstream reaches and modifications of river flow patterns may also affect ecological and morphological changes in downstream rivers, estuaries, and coastal waters (Mei et al. 2017). It has been increasingly recognized that all elements in a flow regime are important, including floods and low flows and changes to the flow regime will have an impact on the river ecosystem one way or the other (Acreman and Dunbar 2004).

Isolated individual impacts of hydropower could often lead to multiple impacts and cumulative impacts. Common negative impacts are effects on downstream migrating fish (Winter et al. (2006), emission of greenhouse gases from inundated vegetation, scarcities of water downstream (Sachdev et al. 2015), and increase of waterborne diseases. Beneficial effects including flood control, water supply, low-cost energy and recreational opportunities are usually resulted from conversion of terrestrial ecosystem to an aquatic ecosystem (Frey and Linke 2002). Multiple impacts include energy impacts, water resource impacts, agricultural impacts, social and environmental impacts (de Almeida et al. 2005) and variety of impacts related to resettlement (Fujikura et al. 2009; Manatunge and Takesada 2013).

According to (Brismar 2004), cumulative impacts of large hydroprojects are generated through complex impact pathways which involve multiple root causes leading to lower and higher order effects. Some of the first-order impacts include destruction of terrestrial ecosystems through inundation which may lead to dissolved oxygen exhaustion. Higher order impacts include changes in primary production due to the changes in thermal regime, water quality and land–water interactions. Changes in sediment transport may lead to changes in river, floodplain and even coastal delta morphology several hundred kilometres away from the site of the dam (McCartney et al. 2000).

Many impacts of hydropower often lead to intergenerational and intragenerational externalities. Many intragenerational inequality issues are originated from divergence between national and local priorities between urban and rural areas which lead to changes on access to natural resources (Siciliano et al. 2015), involuntary resettlement (Manatunge et al. 2009) and from disproportionate shares of environmental impacts (Gunawardena 2010). There is an almost universal location for these large-scale and capital intensive hydropower development projects in the midst of the poor, often isolated social groups. The benefits of additional power have been harvested usually by the wealthier groups leading to non-sustainable development.

There have been attempts globally to address major hydropower-related impacts. The World Commission on Dams documented a global concern over unintended environmental and social impacts due to imbalances in planning of large-scale hydropower projects (WCD 2000). At the national level, although the EIA provides many provisions for identifying impacts on biophysical and social environment, the present EIA practice of Sri Lanka is often crippled with many issues including lack of consideration of adequate number of alternatives, inadequate emphasis on sensitive biodiversity components and public consultation (Zubair 2001). In addition, under the current EIA guidelines, estimation of environmental impacts, their monetary evaluation and internalization within the cost–benefit framework is not mandatory. However, EIA is often the only instance where the projects are undergoing an economic analysis for its entire life cycle.

1.3 Evaluation of Environmental Impacts of Hydropower

Environmental impacts of hydropower have been quantified, and estimated in monetary terms using a variety of different approaches. Gunawardena (2013) evaluates loss of water sports, loss of historical monuments and recreation losses, loss of non-timber products and lost home garden productivity from a run of river development in Sri Lanka. Recent literature has special emphasis on carbon emissions and adoption of life cycle assessment (LCA) tool which have demonstrated lower greenhouse gas (GHG) emissions from renewable energy technologies (4–46 g CO_2 eq/kWh) compared to fossil fuel options (469–1001 g CO_2 eq/kWh) (Sample et al. (2015).

According to Gagnon and van de Vate (1997), however, full lifecycle assessment of GHG emissions from various energy options requires details on building of dams, dikes and power stations, decaying biomass from flooded land and thermal backup power. They further assume that worldwide emission factors to be 20 g CO_2 equivalent/kWh for hydropower and 720 g CO_2 equivalent/kWh for fossil fuel generation that it replaced.

Besides carbon dioxide emissions, hydropower also avoids the other emissions associated with thermal power generation. Difficulties in full cost accounting of environmental and social costs will result in long-term costs to the nation as a whole (IHA 2015).

1.4 Application of CBA and Its Variants in Hydropower Project Analysis

CBA has its first uses in analysing water sector projects and providing judgments on economic efficiency. CBA involves several essential steps: identifying impacts of the project which are economically relevant, physically quantifying impacts, calculating monetary values, discounting, weighting and sensitivity analysis. CBA faces many challenges in treating long-term effects, irreversibilities, risks and uncertainties (Hanley and Spash 1993; Pearce and Turner 1990) and equality across and within generations and such issues are found to be very common among hydropower development projects (Gunawardena 2013).

Adjustments have been proposed for the basic CBA structure to improve its scope and to add multiple dimensions. It is important to note that most of these adjustments have been applied for energy sector and for hydropower projects mainly. Issue of environmental sustainability has been addressed by Kotchen et al. (2006) where cost–benefit analysis tool was applied with environmental constraints. Intragenerational inequality resulting from the hypothetical compensation of potential Paretian improvement has been addressed by applying distributional weights (Gunawardena 2010). Krutilla–Fisher algorithm (Krutilla and Fisher 1985) addresses temporal (intergenerational) dimensions of inequity of CBA by double discounting development benefits and adding a growth rate for the preservation benefits. This approach has been applied by Hanley and Craig (1991) for peat bog exploitation.

1.5 Incorporation of Risk and Uncertainty of Hydropower Projects Within Cost–Benefit Analysis Framework

Treatment of risk and uncertainty within analytical framework of projects is important due to various types of risks associated with hydropower projects. Major components include risks of construction costs, operational and maintenance cost risks and revenue risks. It is very common for the costs of major construction projects to be underestimated in appraisal (Head 2000). Geological conditions or sub-surface risks, which involve issues of slope stability, ground treatment, depth of excavation, and rock support, present the largest and most fundamental risk in hydropower project construction where unforeseen properties in the physical rock can lead to massive delays and cost overruns.

Risks are being incorporated into the project through sensitivity analysis and the simplest form of sensitivity analysis involves the creation of 'what if' scenarios to reflect the principal risks surrounding the project. Estimation of switching values (defined as the percentage change to a particular variable which can make the NPV equal to zero) helps the analyst to provide an indication of robustness of the project to each variable. However, applying switching values is complicated when several variables are acting simultaneously. Monte Carlo simulation is useful in such cases which is a form of a quantitative risk analysis. Kucukali (2011) proposes new approach for risk assessment of river-type hydropower plants using fuzzy logic where the relative importance of risk factors was determined from expert judgments.

The present study sought to carry out an ex post cost–benefit analysis of a hydropower plant in Sri Lanka along with the estimation of project-related environmental and social costs and benefits. It also sought to investigate variables that are closely linked to project Net Present Value (NPV). The ex post nature of the analysis enables use of actual values rather than predicted and the study emphasizes the need to develop better frameworks in incorporating disaster vulnerabilities, inequalities and economic non-viabilities related to power sector projects.

2 Study Area

The study area is situated in the Ratnapura District of Sri Lanka, which stretches from the north at 80.588–80.928 longitude to the east at 6.568–6.808 latitude, and covers an area of about 536 km^2 (Fig. 1).

Samanalawewa Hydroelectric Reservoir (897 ha) lies in the Intermediate zone within two Divisional Secretariat Divisions (DSDs), namely Imbulpe and Balangoda and the Hydropower Station is situated in the DSD of Weligepola (Laksiri et al. 2005; Udayakumara and Shrestha 2011). The mean annual temperature of the study area varies from 25 to

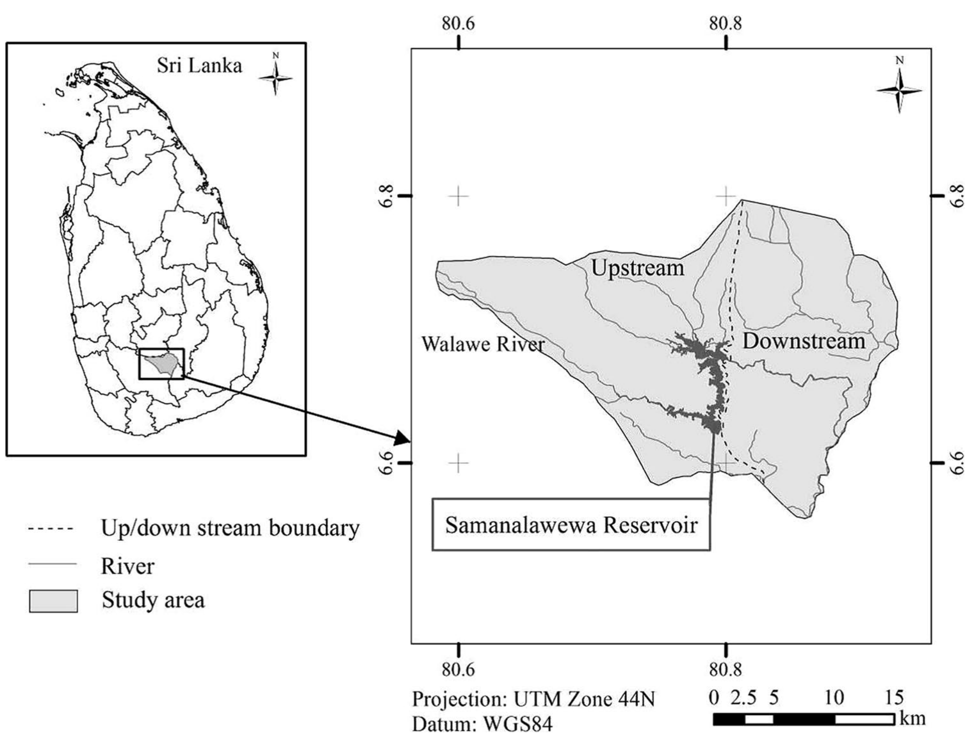


Fig. 1 Map of the study area Source: Udayakumara and Shrestha (2011)

28.8 °C. Geologically, the region consists of rocks belonging to Highland group which comprise quartzites, marbles and undifferentiated meta-sediments (TEAMS 1992a; Udayakumara et al. 2010; Udayakumara et al. 2012).

The affected area belongs to Balangoda DSD and consists of five Grama Niladhari Divisions (a village level administrative unit), viz. Kaltota, Madabadda left, Madabadda right, Welipotayaya and Koongahamankada mainly irrigated by Walawe River and located downstream of the Samanalawewa reservoir. Agriculture is the predominant occupation in the study area.

3 Methodology

Identification and estimation of costs and benefits involved various valuation methods which are described in the following sections. A cost–benefit analysis was conducted along with the sensitivity analysis to test the economic viability of the project.

3.1 Estimation of Economic Loss from Reduction of Paddy Yields and Land Area at Selected Downstream Areas due to Damming

Construction of the dam has resulted in shortage of water for the immediate downstream area resulting in loss of paddy yields. Highly affected villages such as Kaltota, Madabadda left, Madabadda right, Welipotayaya and Koongahamankada were purposively selected to estimate the losses. The sample selected represented about 10% of the population of each village. A structured questionnaire was administered among randomly selected 155 farm household heads of the affected villages. On few occasions where household heads were unavailable, the next most experienced person was interviewed. In general, an interview lasted 1–1.5 h. The questionnaire was mainly designed to collect information on land extent, yield (current and past), paddy varieties, types of fertilizers and machineries. Discussions were held with key informants including village leaders, members of the Village Committees and traders to obtain further information. Secondary data on land use pattern (lowland and upland land extents), number of families, irrigation systems, number of agricultural societies, etc. were also collected.

3.2 Estimation of Economic Value of the Lost Carbon Sequestration Function

The reservoir covers an extent of 897 ha at high water level (460 m MSL). The submerged area consisted of various land uses such as home gardens (7.2%), rubber (1.3%), tea (9.9%), paddy (4.6%), shifting cultivation (24.5%), grasslands and scrubs (16.0%), forests (34.7%), bare lands (0.3%) and other types (1.5%) (TEAMS 1992a). Such vegetated landscapes could perform significant carbon sequestration function.

The carbon sequestration function of a forest mainly depends on species mix, organic matter content of species, and the age distribution of the stand, type of soil, climatic characteristics and below-ground biomass (Adger and Brown 1994). Bundestag (1990) and Houghton et al. (1987) provided estimates of carbon content of soils and biomass for different tropical land uses (Table 2).

Certain assumptions were made in adopting above estimates in the present study. Home gardens of the study area were considered as a forest fallow (closed); rubber and tea as permanent cultivation; shifting cultivation as shifting cultivation (year 1); grass, paddy and scrub lands as pasturelands; forests as closed secondary forests and other lands as forest fallow (open). These assumptions were based on similarities found among land uses. The estimation of carbon sequestration value was based on the value of damage caused by a ton of carbon released into the atmosphere.

3.3 Estimation of Economic Value of Lost Hydropower Generation due to the Leak

People of study area mainly depend on irrigation water of Walawe River and leaking water from the reservoir for the

Table 2 Carbon content of soils and biomass for different tropical land uses *Source* Bundestag (1990) and Houghton et al. (1987)

Type of land use	Biomass carbon (t/ha)	Soil carbon (t/ha)	Total carbon (t/ha)
Closed primary forest	167	116	283
Closed secondary forest	85–135	67–102	152–237
Open forest	68	47	115
Forest fallow (closed)	28–43	93	121–136
Forest fallow (open)	12–18	38	50–56
Shifting cultivation (year 1)	10–16	31–76	41–92
Shifting cultivation (year 2)	16–35	31–76	47–111
Permanent cultivation	5–10	51–60	56–70
Pasture	5	41–75	46–80

cultivation of crops and for domestic consumption. During paddy harvesting periods (months of April at Yala season, September and October at Maha season), irrigation water is not released for the downstream. However, leaking water flows constantly (~ 2 m^3/s) throughout the year and except for domestic uses, water is wasted. If this is curtailed, it can be utilized for power generation and can be added to the national grid. The economic value of leaking water in terms of forgone hydropower was calculated considering the water requirement to produce 1 KWh.

3.4 Benefits of the Project

Since this is a single-purpose project, only benefit is power generation and associated avoided costs of thermal power generation. The present hydropower project will avoid alternative means of power generation especially thermal power generation. The avoided release of carbon dioxide to the atmosphere due to the present project has been estimated and valued. A range of carbon prices were tested in the sensitivity analysis.

3.5 Cost–Benefit Analysis

Costs and benefits described above were analysed using cost–benefit analysis. Direct costs of the project including capital costs, costs for reservoir remedial works (wet blanketing) and operational and maintenance costs were collected from secondary sources. Project life time was taken as 50 years and a 10% discount rate was used. For each cost and benefit of the base case, changes of monetary values during the lifetime of the project were considered. Up to the year 2015, actual prices were used and future prices were projected on the basis of past trends. Paddy prices were subjected to 2% increase and energy prices were subjected to 3.6% increase. Growth rates were not applied for carbon prices but four different price levels of carbon were applied for both lost carbon from the vegetations and for avoided carbon. Sensitivity analysis considered further variations of prices. Future electricity price variations were modelled along with changes of the carbon prices to test the economic viability of the project. The existing exchange rates were used for the conversion of US$ to LKR up to year 2015 and 1 LKR increase each year was assumed afterwards.

4 Results and Discussion

4.1 Economic Losses due to Reduction of Paddy Yields

Table 3 depicts comparison of yields with and without the project for villages which are directly irrigated by the Walawe River and located downstream of the Samanalawewa reservoir. According to *t* test values, most of the villages showed yield reduction at 5% significance level except for Madabadda left village.

Table 3 Yield reduction of the surveyed villages

Village	*N*	Mean	SD	*T* value	*P* value
Kaltota	30	− 12.57	10.07	− 6.83	0.00
Madabadda left	21	− 6.67	21.93	− 1.39	0.08
Madabadda right	23	− 12.48	16.44	− 3.64	0.00
Welipotayaya	42	− 17.98	18.01	− 6.47	0.00
Koongahamankada	39	− 12.31	13.37	− 5.57	0.00

Mean—reduction of the yield (bushels) per year

n number of selected families from each village, *t* test of mean and test of mean = 0.00 vs mean < 0.00

Due to the scarcity of water, about 11.5% (757,362.3 kg) of yield reduction has been resulted in each year (Fig. 2). These values were converted to monetary values based on the past paddy prices of each year up to 2015 and projections were made from year 2016 onwards.

4.2 Economic Losses due to Land Reduction

Wilcoxon sign rank test was carried out to test the significance of reduction of cultivated land with and without the project. Except Welipotayaya village, all other villages showed significant cultivated land reduction due to the scarcity of water. Total reduction of land available for cultivation (mainly paddy) is 163.7 ha (25%) (Fig. 3). Economic values were derived based on the paddy prices.

In addition to the main issue of water scarcity, unsuitable land use practices, poor agricultural extension programs have also contributed to the land reduction. In addition, dam construction has resulted in loss of silt during the floods of the Walawe River which brought additional nutrients for the soil. Lack of water has created increase of salinity in the downstream which has also contributed to yield reduction.

4.3 Estimated Economic Value of Lost Carbon Sequestration Function

Due to the filling of the reservoir, 897 ha of different vegetation types have been inundated and a total of 102,320.7 tons of carbon was lost (Table 4).

Even though forests have multiple functions such as climate and water regulation, soil erosion control and nutrient recycling, this study focused only on carbon sequestration function. Actual ecosystem service value of the inundated area will be much higher if all such values have been taken into consideration. Economic value of the lost carbon was

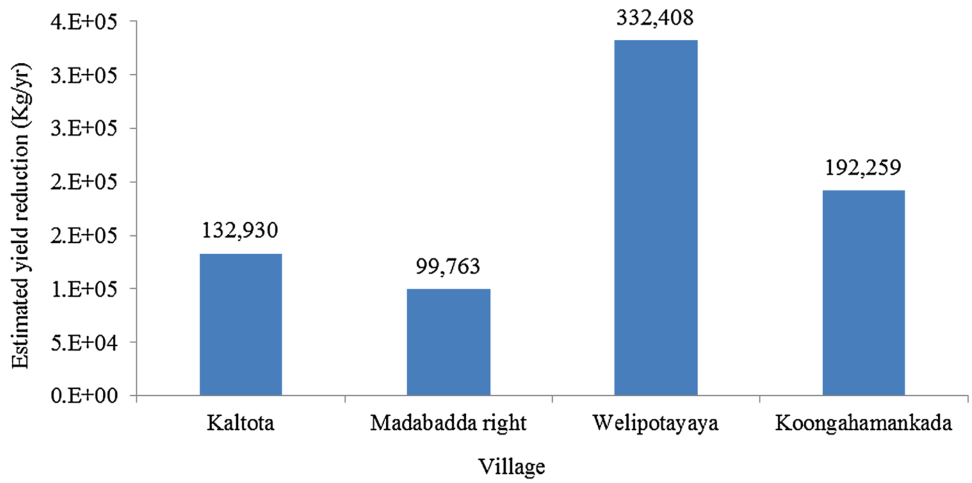


Fig. 2 Quantities of paddy yield reduction in each of the affected village per year

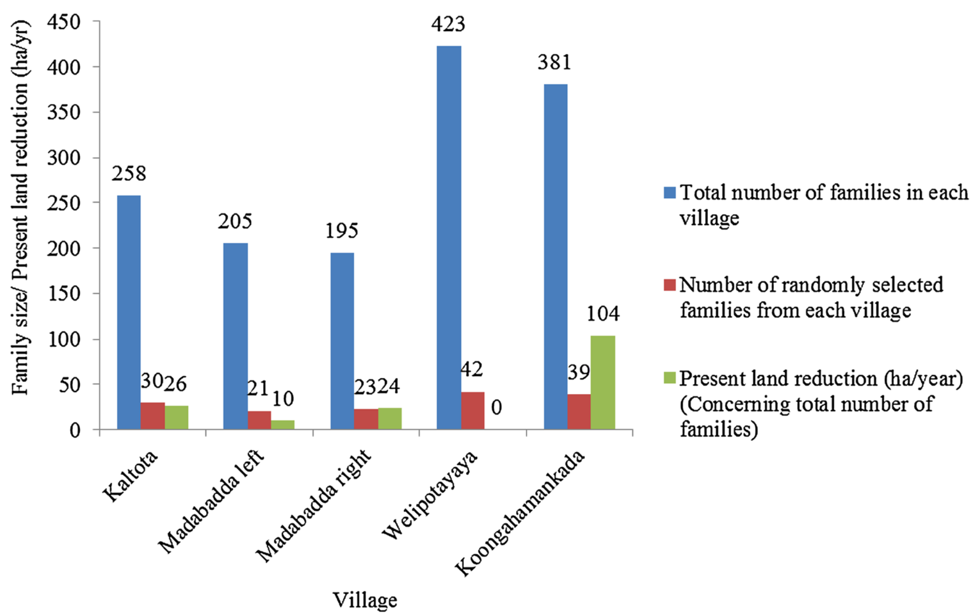


Fig. 3 Land area reduction due to scarcity of water in each of the affected village per year

Table 4 Global warming damage cost of different land uses

Land use	Average (%)	Affected land extent of each land use type (ha)	Total average carbon amount of each land use (t/ha)	Total carbon amount of each land use (t)
Homestead garden	7.2	64.2	128.5	8249.7
Rubber	1.3	11.5	63	724.5
Tea	9.9	89.0	63	5607
Paddy	4.6	40.9	63	2576.7
Shifting cultivation	24.5	219.9	66.5	14,623.35
Grasslands and scrubs	16.0	143.9	63	9065.7
Forests	34.7	311.6	194.5	60,606.2
Bare lands	0.3	2.33	63	146.79
Other	1.5	13.6	53	720.8
Total	100	897.0	–	102,320.7

LKR 43,506,779 when $10 is taken as the global damage cost (Pearce et al. 1989) of a ton of carbon.

The lost carbon from the incremental growth of forests in subsequent years and the associated costs has not been incorporated into the calculations due to unavailability of data.

Studies have reported that several reptile and amphibian species with possible genetic traits adapted to the very special climatic conditions of the area have been lost after filling the reservoir. These studies have used the Kalu Ganga basin as a control case to compare the biodiversity in Samanalawewa environs after the dam construction (Lakshman 2007).

4.4 Economic Value of Surplus Water from the Leak

About 12.4 MCM of water is lost daily due to the leak during the paddy-harvesting seasons. About 0.08 MCM is consumed daily by people of five affected villages and, therefore, amount of water lost/surplus water is about 12.32 MCM. This surplus water could have been used for power generation. CEB requires 1.292 MCM for production of 1 GWh. Therefore, due to the leak 9.5 GWh is forgone each year. The economic value was calculated based on the energy prices for each year.

Table 5 Carbon dioxide emissions from different electric power generation sources *Source* FAO 1997

Energy source	Carbon dioxide (tons per GWh)
Conventional coal	1058.2
Fluidised bed coal	1057.1
Hydropower	6.6

4.5 Benefits of Hydropower Generation

Samanalawewa hydropower station generates on average 210 GWh (Nandalal and Sakthivadivel 2002). The economic value was derived using energy prices of each year. Generating power using hydropower avoids equivalent amount of power generation from coal. This is an environmental benefit of the project (benefits of avoided coal power generation) (Table 5).

Power generation from hydropower avoids 1051.6 tons of carbon per GWh. The average annual power generation for the proposed project is 210 GWh. Therefore, the project avoids 220,836 tons of carbon released into the atmosphere. Figure 4 illustrates the benefit under three levels of carbon prices.

According to Fig. 4, a $5 increment of the carbon prices has increased the present value by nearly LKR one billion. Although the benefit of avoided carbon emissions has been assumed for the entire life of the project (1998–2037), the actual operations of the carbon markets only start when the Kyoto protocol entered into force in 2005.

The price of carbon represents the long-term damage done by a ton of carbon dioxide emissions in a given year. This figure also represents the value of damages avoided for a small emission reduction. The figure is considered to be a comprehensive estimate of climate change damages, for example, changes in net agricultural productivity, human health, property damages from increased flood risk and changes in energy system costs (EPA 2016).

4.6 Direct Costs of the Project

Table 6 provides a summary of the direct cost items of the project. Capital costs spread across the initial 5 years.

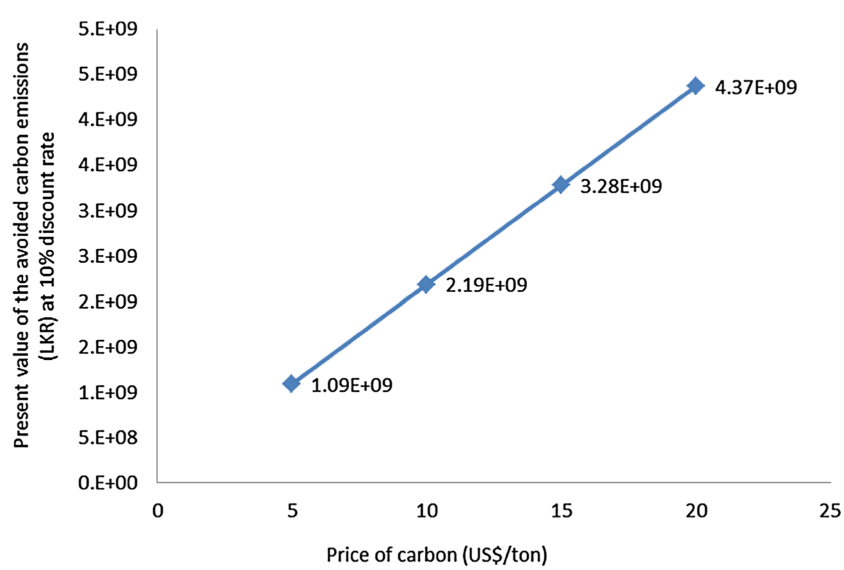


Fig. 4 Variation of benefit of avoided thermal generation under different prices of carbon

Operation and maintenance costs increased by nearly six times from year 2013. The reservoir remedial work represents about 6% of the total capital cost. It is a known fact that if appropriate migratory measures have been adopted, this entire cost could have been saved.

4.7 Economic Analysis

Table 7 presents the present values of the identified costs and benefits. Costs of paddy yield reduction and cultivated land reduction are incurred throughout the life of the project. Lost carbon from forest inundation represents one time cost in the initial year. Among the cost items shown in Table 7, present value of forgone electricity benefits from leakage water represents the highest cost indicating the need to reutilize this water.

Benefit of avoided thermal generation and benefits from power generation appear from the 5th year and runs for the entire life of the project. The results show that the present value of power generation benefits are nearly ten times higher than the benefit of avoided thermal generation cost.

The most significant community impact is the negligence of the agricultural water needs of the Walawe basin downstream farmers by the project planners in the project design phase thus creating conflict between Ceylon Electricity Board and downstream farmers. The irrigation release valve is the only feature of the project which acknowledges requirements of the downstream farmers.

Table 8 presents results of the cost–benefit analysis under different carbon prices and varying discount rates. Present value was derived for the starting year of the project (1988). The project resulted in a positive net present value (NPV) with a 5% discount rate for all the carbon price levels considered. A 10% discount rate has yielded mostly negative NPVs except for the carbon price of $20. The economic internal rate of return (EIRR) and the benefit–cost ratio of the project also confirm that carbon prices below $20 are not economically efficient.

The project is not economically efficient at 10% discount rate for carbon prices below $20. This indicates that implementation of the project is not an effective allocation of resources under low carbon prices. Even exclusion of costs of remediation work of the dam results in a negative NPV of

Table 6 Cost components of the project

Cost item	Source	Value (LKR million)	Period
Capital	(CEB 1996; TEAMS 1992b)	18,647.9	1988–1992
Reservoir remedial works/wet blanketing	(Udayakumara and Wijeratne 2004)	1128.5	1998–1999
Operation and maintenance[1]	(CEB 1996; TEAMS 1992c)	59.00	1992–2037

Table 7 Summary of the identified costs and benefits

Item	Present value (LKR at 10% discount rate)
Costs	
Global warming (lost carbon sequestration in the initial year)	39,551,616
Yield reduction	89,917,006
Land reduction	64,116,403
Leakage water (during harvesting period)	672,981,339
Benefits	
Benefits from power generation	19,784,690,285
Benefit of avoided thermal generation (valued at US$10 per ton)	2185,105,572

Table 8 Results of the cost–benefit analysis

Item	Value of a ton of carbon (US$)			
Criterion	5	10	15	20
Net present value (LKR) @ 5%	25,946,507,773	27,961,595,799	29,976,683,824	31,991,771,850
Net present value (LKR) @ 10%	−1,986,098,432	−1,259,645,987	−533,193,541	193,258,904
Net present value (LKR) @ 12%	−5,443,155,010	−4,921,879,916	−4,400,604,822	−3,879,329,728
EIRR	9.23%	9.52%	9.80%	10.07%
Benefit–cost ratio	0.878	0.923	0.967	1.012

LKR −873,102,993 at 10% discount rate. NPV of the project excluding all environmental costs is LKR −606,405,650 at 10% discount rate.

The project provides a clear case where environmental impacts are both neglected and uncompensated. The costs outweigh the benefits implying the erroneous decisions made in the past. It is evident that many negative impacts are due to the single-purpose nature of the project. During the project design stage, the project could have easily been converted to a multipurpose project inclusive of facilities of irrigation, infrastructure and agricultural extension for surrounding farmers thus avoiding many negative impacts. However, the project has managed to yield the expected contribution to the national electric power grid.

4.8 Sensitivity Analysis: Estimating Switching Values for the Project

Since the project was not economically efficient under the standard base case situation, the variations that could be applied to selected variables were investigated to make the project just positive. According to Table 9, the project requires a US$18.669 minimum price of carbon or a minimum discount rate of 9.5168 or 2.752148% annual increase of energy prices to produce a just positive NPV.

There was an existing 3.6% price increase which has already been incorporated into the analysis (from year 2015 onwards) in the base case. The increase in electricity prices that was calculated under the sensitivity analysis was in addition to the above increase and, therefore, the total increase in energy price is 6.35%.

The study has estimated environmental and social impacts to the extent possible. The magnitude of the values that were not estimated, however, could be significant. There could have been many other ecosystem service benefits that were impaired due to the forest destruction in addition to the carbon sequestration. Damages could have been resulted due to the landslip that occurred when the reservoir was being filled, but there were no records on that. In addition, the risks associated with the leak especially the risk of dam failure have not been estimated. The probability of dam failure or the potential costs to that effect have not been estimated.

Presently, although the dam is being adequately monitored, there is an uncertainty component that dam might fail. In a situation of a dam failure, additional mitigation measures would be required leading to further increase of project costs. However, analysis on such uncertainties has not been attempted in this study due to unavailability of predicted probabilities and the expected outcomes of such events including the multiple and cumulative impacts. However, in essence, the sensitivity analysis should have been also enriched with an analysis of uncertainty based on a physical risk assessment.

5 Conclusions

Development projects need to emphasize on issues related to economic efficiency, social acceptance and environmental sustainability to avoid environmental disasters and social conflicts.

The study highlights the importance of valuing and incorporation of environmental costs and benefits in the project framework and the usefulness of such analysis essentially before the project and at least after the project to estimate the true contribution of a project to the national economy. The ex post nature of the analysis connotes that benefit estimation is based on actual, rather than forecasted values. Such analysis also helps to overcome often-cited problems of hydropower projects such as overestimation of benefits and cost overruns.

It can also be recommended that incorporation of risks and uncertainties including disaster probabilities within project frameworks would be essential in large-scale transformation of land uses in sensitive areas. A new composite tool that encompasses analysis on externalities, equity, ethics, and risk (EEER Framework) in large-scale development projects is proposed. This tool draws much from the standard cost–benefit analysis framework but emphasizes on certain subcomponents as essential as follows.

Identification and estimation of both positive and negative externalities along with the income group that experiences the impact (a quantitative analysis); applying a social cost–benefit analysis to compensate for the intergenerational equity issues (a quantitative analysis); analysis of

Table 9 Changes required for selected variables (minimum values) to make the project viable

Parameter	Condition	Value
Carbon price	Base case situation—(discount rate 10%; energy prices increase by 3.6%; carbon prices were applied to the lost carbon as well as avoided carbon)	US$18.7
Discount rate	Carbon price US$10 per ton and no change in energy prices	9.5%
Energy price increase (additional increase from year 2015)	Discount rate 10%; carbon price US$10 per ton	2.8%

intergenerational equity along expanded temporal scales (a qualitative analysis); analysis on risks and uncertainties resulting from multiple and cumulative impacts along expanded temporal and spatial scales on both environmental and social systems—for scales beyond the project boundaries and timeframes beyond the project period (quantitative and qualitative analyses).

Such a composite tool could provide essential safeguards for dealing with a plethora of multiple and cumulative impacts associated with large-scale development projects located in ecologically sensitive areas and inhabited by socially marginalized groups along expanded temporal and spatial scales.

References

Acreman M, Dunbar MJ (2004) Defining environmental river flow requirements? A review. Hydrol Earth Syst Sci Discuss 8(5):861–876

Adger WN, Brown K (1994) Land use and the causes of global warming. John Wiley, Hoboken

Brismar A (2004) Attention to impact pathways in EISs of large dam projects. Environ Impact Assess Rev 24(1):59–87

Bugaje I (2006) Renewable energy for sustainable development in Africa: a review. Renew Sustain Energy Rev 10(6):603–612

Bundestag G (ed) (1990) Protecting the tropical forests: a high priority international task. Bonner Universitats-Buchdruckerei, Bonn

CEB (1996) Samanalawewa hydroelectric project completion report. Nippon Koei Co. Ltd., Electrowatt Engineering Services Ltd, Tokyo

CEB (2006) Long-term generation expansion planning studies 2006–2015. Transmission and Generation Planning Branch, Ceylon Electricity Board (CEB), Colombo

CEB (2015) Long-term generation expansion plan 2015–2034. Transmission and Generation Planning Branch, Ceylon Electricity Board (CEB), Colombo

de Almeida AT, Moura PS, Marques AS, de Almeida JL (2005) Multi-impact evaluation of new medium and large hydropower plants in Portugal centre region. Renew Sustain Energy Rev 9(2):149–167

EPA (2016) The social cost of carbon estimating the benefits of reducing greenhouse gas emissions. https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html Accessed 15 Apr 2018

FAO (1997) Energy and environment basics. FAO Regional Wood Energy Development Programme in Asia, Bangkok

Fernando S (2002) Meeting Sri Lanka's future electricity needs. Energy Sustain Dev 6(1):14–20

Frey GW, Linke DM (2002) Hydropower as a renewable and sustainable energy resource meeting global energy challenges in a reasonable way. Energy Policy 30(14):1261–1265

Fujikura R, Nakayama M, Takesada N (2009) Lessons from resettlement caused by large dam projects: case studies from Japan, Indonesia and Sri Lanka. Water Resour Dev 25(3):407–418

Gagnon L, van de Vate JF (1997) Greenhouse gas emissions from hydropower: the state of research in 1996. Energy Policy 25(1):7–13

Gunawardena UADP (2010) Inequalities and externalities of power sector: a case of broadlands hydropower project in Sri Lanka. Energy Policy 38(2):726–734

Gunawardena UADP (2013) An inquiry into ethical foundations of cost benefit analysis. J Environ Prof Sri Lanka 1(2):1–15

Hanley N, Craig S (1991) Wilderness development decisions and the Krutilla–Fisher model: the case of Scotland's 'flow country'. Ecol Econ 4(2):145–164

Hanley N, Spash CL (1993) Cost-benefit analysis and the environment. Edward Elgar Aldershot, Cheltenham

Head CR (2000) Financing of private hydropower projects, vol 420. World Bank Publications, Washington, DC

Houghton R, Boone R, Fruci J, Hobbie J, Melillo J, Palm C, Peterson B, Shaver G, Woodwell G, Moore B (1987) The flux of carbon from terrestrial ecosystems to the atmosphere in 1980 due to changes in land use: geographic distribution of the global flux. Tellus B 39(1–2):122–139

IHA (2015) Hydropower status report. Int Hydropower Assoc Ltd, United Kingdom

Kibler KM, Tullos DD (2013) Cumulative biophysical impact of small and large hydropower development in Nu River, China. Water Resour Res 49(6):3104–3118

Kotchen MJ, Moore MR, Lupi F, Rutherford ES (2006) Environmental constraints on hydropower: an ex post benefit-cost analysis of dam relicensing in Michigan. Land Econ 82(3):384–403

Krutilla JV, Fisher AC (1985) The economics of natural environments: studies in the valuation of commodity and amenity resources. Resources for the Future, Washington, DC

Kucukali S (2011) Risk assessment of river-type hydropower plants using fuzzy logic approach. Energy Policy 39(10):6683–6688

Lakshman (2007). http://www2.jica.go.jp/ja/evaluation/pdf/2006_SL-P11_4_t.pdf. http://www2.jica.go.jp/ja/evaluation/pdf/2006_SL-P11_4_t.pdf. Accessed 15 Nov 2017

Laksiri K, Gunathilake J, Iwao Y (2005) A case study of the samanalawewa reservoir on the Walawe River in an area of Karst in Sri Lanka In: Proceedings of the 10th multidisciplinary conference on sinkholes and the engineering and environmental impacts of karst, held in San Antonio, Texas, September 2005, p 24–28

Manatunge J, Takesada N (2013) Long-term perceptions of project-affected persons: a case study of the Kotmale Dam in Sri Lanka. Int J Water Resour Dev 29(1):87–100

Manatunge J, Takesada N, Miyata S, Herath L (2009) Livelihood rebuilding of dam-affected communities: case studies from Sri Lanka and Indonesia. Water Resour Dev 25(3):479–489

Martinot E (2001) Renewable energy investment by the World Bank. Energy Policy 29(9):689–699

McCartney M, Sullivan C, Acreman MC, McAllister D (2000) Ecosystem impacts of large dams. Thematic Rev II 1:1

Mei X, Van Gelder P, Dai Z, Tang Z (2017) Impact of dams on flood occurrence of selected rivers in the United States. Front Earth Sci 11(2):268–282

Nandalal K, Sakthivadivel R (2002) Planning and management of a complex water resource system: case of Samanalawewa and Udawalawe reservoirs in the Walawe river, Sri Lanka. Agric Water Manag 57(3):207–221

Pearce DW, Turner RK (1990) Economics of natural resources and the environment. JHU Press, Baltimore

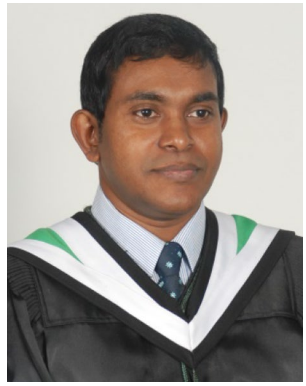
Pearce DW, Markandya A, Barbier E (1989) Blueprint for a green economy, vol 1. Earthscan, Abingdon

Sachdev HS, Akella AK, Kumar N (2015) Analysis and evaluation of small hydropower plants: a bibliographical survey. Renew Sustain Energy Rev 51:1013–1022

Sample JE, Duncan N, Ferguson M, Cooksley S (2015) Scotland's hydropower: current capacity, future potential and the possible impacts of climate change. Renew Sustain Energy Rev 52:111–122

Siciliano G, Urban F, Kim S, Lonn PD (2015) Hydropower, social priorities and the rural–urban development divide: the case of large dams in Cambodia. Energy Policy 86:273–285

TEAMS (1992a) Samanalawewa Hydro Electric Project, Environmental Post Evaluation Study-(Draft final report). TEAMS (Pvt). Ltd, Colombo
TEAMS (1992b) Samanalawewa hydro electric project, environmental post evaluation study (interim report), vol 15. TEAMS (Pvt). Ltd, Colombo
TEAMS (1992c) Samanalawewa hydro electric project, environmental post evaluation study (draft final report), vol 250. TEAMS (Pvt). Ltd, Colombo
Udayakumara EPN, Shrestha RP (2011) Assessing livelihood for improvement: Samanalawewa reservoir environs, Sri Lanka. Int J Sustain Dev World Ecol 18(4):366–376
Udayakumara EPN, Wijeratne AW (2004) Estimation of economic loss due to reduction of paddy land areas: construction of Samanalawewa Reservoir. In: Proceedings of Water Professionals' Day 2004. Geo Informatics Society of Sri Lanka (GISSL), Sri Lanka
Udayakumara EPN, Shrestha RP, Samarakoon L, Schmidt-Vogt D (2010) People's perception and socioeconomic determinants of soil erosion: a case study of Samanalawewa watershed, Sri Lanka. Int J Sedim Res 25(4):323–339
Udayakumara EPN, Shrestha RP, Samarakoon L, Schmidt-Vogt D (2012) Mitigating soil erosion through farm-level adoption of soil and water conservation measures in Samanalawewa Watershed, Sri Lanka. Acta Agric Scand Sect B Soil Plant Sci 62(3):273–285
WCD (2000) Dams and development: a new framework for decision-making. Earthscan Publication Ltd, London
Winter H, Jansen H, Bruijs M (2006) Assessing the impact of hydropower and fisheries on downstream migrating silver eel, *Anguilla anguilla*, by telemetry in the River Meuse. Ecol Freshw Fish 15(2):221–228
Zhang J, Xu L, Li X (2015) Review on the externalities of hydropower: a comparison between large and small hydropower projects in Tibet based on the CO_2 equivalent. Renew Sustain Energy Rev 50:176–185
Zubair L (2001) Challenges for environmental impact assessment in Sri Lanka. Environ Impact Assess Rev 21(5):469–478



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