Economic Evaluation of Selected Pumped Storage Power Plant Sites in Sri Lanka

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Abstract

In 1980s all most the entire requirement of electricity was generated from hydropower. As the economically viable hydropower potential in the country has now been fully utilized and owing to several other reasons, the Sri Lankan power utility, Ceylon Electricity Board (CEB) had to build thermal power plants to meet the growing demand. Many thermal plants operating on liquid fuel were commissioned during the peroid 1995-2007, and according to the CEB Long Term Generation Plan 2008-2021, more than 3500 MW of coal fired power plants are expected to be connected to the power system in the period up to 2021. Owing to this high proportion of coal-fired power plants, the option of building a pumped storage power plant (PSPP) could be feasible for Sri Lanka in the future. There are many sites suitable for consideration for development of a PSPP. This paper analyses the economic feasibility of four selected pumped storage power plant sites in two areas. The findings show that the sites referred to as Kiriketi Oya may be developed first.

Introduction

Method of Calculation [1]

Calculations were done using the measured values based on layouts done on 1:10,000 scale topographical maps and formulae based on the quantities of existing facilities. Formulae used were developed in Japan for the purpose of the hydropower potential study. These formulae were prepared for each facility such as the intake weir, intake, headrace, etc. The quantities of works were calculated for main work items such as excavation, concrete, embankment, reinforcement bars, gates, screens, and steel conduits.

The following symbols and units are used in the calculation.

V_e: Excavation volume (m^3),
V_c: Concrete volume (m^3),
V_f: Dam embankment volume (for fill dam) (m^3),
W_r:Weight of reinforcement bars (ton),
W_g: Weight of gate (ton),
W_p: Weight of steel conduit (ton),
W_s: Weight of screen (ton).

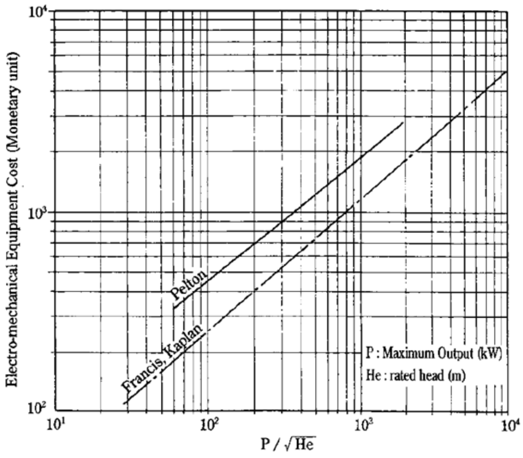
Quantities of work items other than the main work items were not calculated. However, their costs were calculated as "others" in a lump-sum at a certain ratio against the total cost of main work items. Quantities of works of headrace tunnels and penstock were calculated based on their inner diameters. The inner diameter adopted in this paper is the economic cross section based on the prices of commodities in Japan. Although there may be differences due to the price levels in the relevant developing countries, such differences are neglected in this paper.

Conditions for Construction Cost Estimate

Construction costs calculations are described in Table 5 for Kiriketi PSPP I. In the preparatory works, access roads cost was calculated based on the quantity of work and unit costs, while the costs of the office and camp facilities are calculated making reference to actual costs of similar projects. For pumped storage type 2% of the cost of civil works was estimated for preparatory works, access roads. Environment mitigation cost was assumed to be 3% of the total cost of the civil works. The cost of civil works and hydraulic equipment were calculated by multiplying the quantity of main items of works by unit cost which is described in Table 3 and Table 4 for Kiriketi PSPP I. The work quantity was obtained from tables, diagrams and numerical formula. In this evaluation, the main work items of structures of civil works are excavation, concrete, embankment, and reinforcement bars and those of hydraulic equipment are gate, screen, and steel pipe. The costs of other items of work, other than the main items, were calculated as "Others" in a lump-sum at a certain ratio against the total cost of the main work items. Unit costs were obtained by making reference to the latest data of similar works in Sri Lanka's Upper Kotmale hydropower project.

The construction costs of turbines, generators, control devices and main transformers, etc. were appropriated in a lump-sum in "Electro-mechanical equipment". There is a relationship that is almost as a straight line on logarithmic paper between electro-mechanical equipment cost according to each turbine type and $P/\sqrt{He}$ (P: maximum output in kW, He: effective head in meters), as shown in the example in Figure 1.

Figure 1- Example of Electro-Mechanical Equipment Cost [1]



Example of Electro-mechanical Equipment Cost

In this paper, the construction cost of transmission lines was not considered. The following are included in the costs of "administration", "engineering service", "contingencies", which were calculated by multiplying the direct construction cost by an appropriate ratio. The administration cost includes personnel expense and expenses to maintain the construction office. The engineering service cost includes expenses related to technical services such as design work and construction supervision conducted by consultants. In this evaluation, 15% of the direct construction cost was appropriated as the cost of administration and engineering services. The contingency includes physical contingency which is the increase of quantities of work, and 10% of the direct construction cost was appropriated for the contingencies. Interest during construction was calculated based on the following conditions.

Interest rate (i) was calculated taking into account the ratio of local currency and foreign currency. For example, if the local and foreign currency portions were 25% and 75% respectively the calculation is as follow.

$i = i_1 \times 0.25 + i_2 \times 0.75 = 6\%$
i_1 : Interest rate for local currency = 20%
i_2 : Interest rate for foreign currency =1.4%

Interest during construction = (cost of preparatory works + cost of environmental mitigation + cost of civil works + cost of hydraulic equipment + cost of electro mechanical equipment + cost of administration and engineering service + contingency) × 0.4 × i × T

where,
T : Construction period (years) = 5 years
The value of 0.4 is a cash flow coefficient which is an empirical value based on similar projects.

Quantities of work for Kiriketi PSPP I

Upper Dam

(1) Structural Design [3]
Concrete gravity type dam was adopted because (i) of the possibility of using the sound rock for the dam foundation, (ii) the river span is narrow, (iii) convenience is allowing to overflow during flood periods, (iv) convenience in the transportation of concrete. Dam dimensions are Crest Elevation: 1729 m, Crest Length: 300 m, Dam Height (H_d): 84 m.
Data such as Creager's curve should be used to calculate the design flood discharge, if available. In case such data is not available, it is estimated by using annual rainfall, and the following simplified formula should be used as reference.

$$Q_f = q \times A$$

$$q = a \times A^{\left(A^{-0.05}-1\right)}$$

where, Q_f : Design flood discharge (m^3/s), q: Specific discharge ($m^3/s/km^2$), a: Region coefficient = 100 (For Haputale area), A: Catchment area (km^2) : 0.4 km^2
Therefore,

$$Q_f = 100 \times 0.4^{(0.4^{-0.05}-1)} \times 0.4 = 38 \text{ m}^3/\text{s}$$

(2) Quantity of work [1]
Excavation volume and volume of the dam were obtained by the following equations.

$V_e = 10.0\times H_d \times L$

In the case :

$H_d{}^2 \times L > 100\times 10^3$

$V_c = 0.34\times (H_d{}^2 \times L) \quad (B/L = 0.5)$

$V_c = 0.30\times (H_d{}^2 \times L) \quad (B/L = 0.4)$

$V_c = 0.27\times (H_d{}^2 \times L) \quad (B/L = 0.3)$

$V_c = 0.21\times (H_d{}^2 \times L) \quad (B/L = 0.2)$

$V_c = 0.16\times (H_d{}^2 \times L) \quad (B/L = 0.1)$

$W_g = 0.13\times Q_f$

where, B: River bed width (m) : 100 m, L: Crest length (m) : 300 m, Q_f : Design flood discharge: 38 m^3/s, H_d: Dam height (m)

Therefore,

$V_e = 10.0\times 84\times 300 \approx 252{,}000$ m^3

$V_c = 0.27\times(84^2\times 300) \approx 571{,}550$ m^3

$W_g = 0.13\times 38 \approx 5$ ton

Cost of other items of civil works such as grouting and coffering, not included in the main items above, were estimated to be 20% of the main items.

Lower Dam

(1) Structural Design [3]

A concrete gravity type dam was adopted for the same reason as for the upper dam. Dam specifications are Crest Elevation: 944 m, Crest Length: 230 m, Dam Height (H_d): 74 m.

Data such as Creager's curve should be used to calculate the design flood discharge if available. In case such data is not available, it is generally estimated by using annual rainfall, and the following simplified formula should be used as reference. [1]

$Q_f = q\times A$

$q = a \times A^{\left(A^{-0.05}-1\right)}$

where, A : Catchment area (km^2) : 14.1 km^2

Therefore,

$Q_f = 100 \times 14.1^{(14.1^{-0.05}-1)} \times 14.1 = 1016$ m^3/s

(2) Quantity of work [1]

Excavation volume and volume of dam was obtained by the following equations.

$V_e = 10.0\times H_d \times L$

In the case: $H_d{}^2 \times L > 100\times 10^3$

$V_c = 0.34\times (H_d{}^2 \times L) \quad (B/L = 0.5)$

$V_c = 0.30\times (H_d{}^2 \times L) \quad (B/L = 0.4)$

$V_c = 0.27\times (H_d{}^2 \times L) \quad (B/L = 0.3)$

$V_c = 0.21\times (H_d{}^2 \times L) \quad (B/L = 0.2)$

$V_c = 0.16\times (H_d{}^2 \times L) \quad (B/L = 0.1)$

$W_g = 0.13\times Q_f$

where, B: River bed width (m) : 100 m, L: Crest length (m) : 230 m, Q_f: Design flood discharge : 1016 m^3/s, H_d: Dam height (m)

Therefore,

$V_e = 10.0\times 74\times 230 \approx 170{,}200$ m^3

$V_c = 0.30\times(74^2\times 230) \approx 378{,}000$ m^3

$W_g = 0.13\times 1016 \approx 132$ ton

Costs of other items of civil works such as grouting and coffering not included in the main items above, were estimated to be 20% of the main items.

Intake

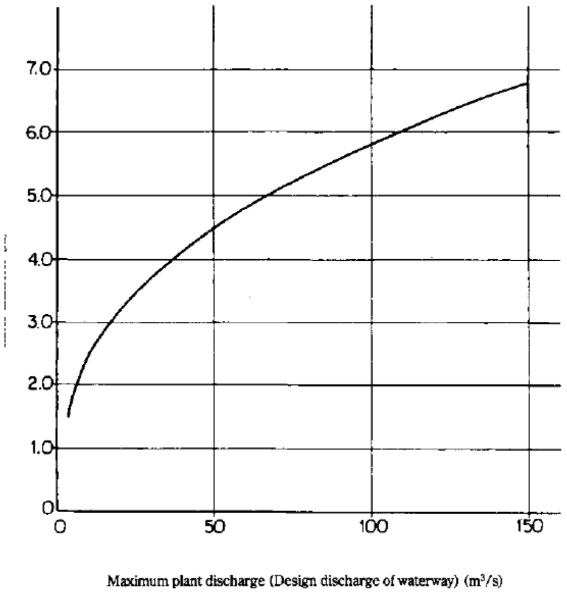
(1) Structural Design [3]

A pressure type is adopted. The inner diameter of waterway is obtained from Figure 2 by using the maximum plant discharge.

Inner Diameter: 5.4 m

where, Maximum plant discharge: 78 m^3/s

Figure 2 - Inner Diameter of Waterway [1]



(2) Quantity of work [1]

The excavation volume, concrete volume, weights of reinforcement bars, gate and screen were calculated by the following equations.

$$V_e = 130 \times \left[\{(h_a + D) \times Q\}^{1/2} \times n^{1/3}\right]^{1.27}$$
$$V_c = 56.5 \times [\{(h_a + D) \times Q\}^{1/2}\ n^{1/3}]^{1.23}$$
$$W_r = 0.04 \times V_c$$
$$W_g = 0.9 \times \left\{(h_a \times D)^{1/9}\right\} \times Q$$
$$W_s = 0.5 \times \left\{(h_a \times D)^{1/9}\right\} \times Q$$

where, h_a: Available drawdown (m) : 56 m, Q: Maximum plant discharge: 78 m^3/s, D: Inner diameter of waterway : 5.4 m, n: Number of waterway channels : 1

Therefore,
$V_e = 130\times(((56+5.4)\times78)^{1/2}\times1^{1/3})^{1.27} = 28{,}250\ m^3$
$V_c = 56.5\times(((56+5.4)\times78)^{1/2}\times1^{1/3})^{1.23} = 10{,}400\ m^3$
$W_r = 0.04\times10{,}400 = 416$ ton
$W_g = 0.9\times(56\times5.4)^{1/9}\times78 = 132$ ton
$W_s = 0.5\times(56\times5.4)^{1/9}\times78 = 74$ ton

Headrace

According to the terrain, the longitudinal alignment of water way goes down immediately after the intake. Therefore the penstock tunnel comes directly from the intake without a headrace tunnel.

Penstock

(1) Structural Design [1]
A circular fully steel lined pressure tunnel is adopted. The inner diameter of penstock is calculated assuming that a flow velocity in the penstock is 10 m/s.

Diameter: $(4\times Q_{max}/10\pi)^{0.5} = (4\times127/10\pi)^{0.5} = 3.15$ m

(2) Quantity of work [1]
For embedded type of penstock, excavation volume and concrete volume are obtained by the following equation, assuming constant thickness of backfill concrete of 60 cm.

$$V_e = \frac{\pi}{4}(D_m + 2t)^2 \times L$$

$$V_c = \frac{\pi}{4}\{(D_m + 2t)^2 - D_m^2\} \times L$$

where,
D_m : Average inner diameter of steel pipe (m) = 3.15 m
t : Thickness of backfill concrete (m) = 0.6 m
L : Total length of penstock (m) :1200 m
Therefore
$V_e = \pi/4\times(3.15+2\times0.6)^2\times1200 = 17{,}825\ m^3$
$V_c = \pi/4\times((3.15+2\times0.6)^2- 3.15^2)\times1200 = 8{,}480 m^3$

Cost of other items of works such as grouting, audit, etc. not included in the main items stated above were estimated at 15% of the cost of the main items. The weight of the steel conduit was obtained by the following equations for embedded type in tunnel.

$$W_p = 7.85 \times \pi \times D_m \times t_m \times 1.1 \times L$$
$$t_m = 0.0270H \times D_m + 2$$

where, W_p: Weight of steel conduit (ton), t_m : Average thickness of steel conduit (mm), H: Design head (m) (high water level－tail water level) = 754 m
Therefore,
$W_p = 7.85\times\pi\times3.15\times0.066\times1.1\times1200 = 6{,}765$ ton
$t_m = 0.027\times754\times3.15 + 2 = 66$ mm

Underground Powerhouse [1]

(1) Structural Design
Underground type is adopted for Powerhouse.

(2) Quantity of work
The excavation volume, concrete volume, and the weight of reinforcement bars were obtained by the following equations.
$V_e = 27 \times A + 1.3 \times A \times d$
$V_c = 15 \times A$
$W_r = 0.6 \times A$
Provided that,
$A = 20 \times Q^{1/2} \times H_e^{1/3} = 20\times78^{1/2}\times754^{1/3} = 1{,}607 m^2$
where, Q : Maximum plant discharge (m3/s) = $78 m^3/s$, He: Effective head (m) = 754m, A: Area of powerhouse (m2) = $1{,}607 m^2$, d: Height of powerhouse (m) = 40m
Therefore,
$V_e = 27 \times 1{,}607 + 1.3 \times 1{,}607 \times 40 = 127{,}000\ m^3$
$V_c = 15 \times 1{,}607 = 24{,}115\ m^3$
$W_r = 0.6 \times 1{,}607 = 965$ ton
The cost of the powerhouse building and the transformer chamber were included in 50% of "Others".

Tailrace Tunnel [1]

(1) Structural Design
A circular fully lined pressure tunnel was adopted.
Diameter of tunnel is calculated assuming that a flow velocity in the tunnel is 6.0 m/s.
Diameter:$(4\times Q_{max}/6.0\pi)^{0.5}=(4\times78/6.0\pi)^{0.5} =4$ m

(2) Quantity of work
The excavation volume of the pressure tunnel, concrete volume, and weight of reinforcement

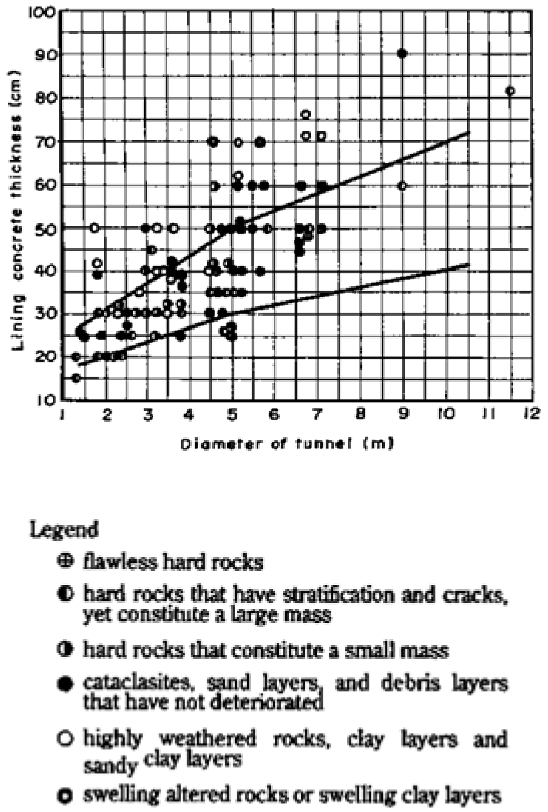
bars were calculated by the following equations.

$$V_e = 3.2 \times (R + t_0)^2 \times L \times n$$
$$V_c = \{3.2 \times (R + t_0)^2 - \pi R^2\} \times L \times n$$
$$W_r = 0.04 \times V_c$$

where, R: Tunnel radius (m) = 2.0 m, t_0: Lining concrete thickness (m) = 45 cm, L: Total length of waterway channels (m) = 270 m, n: Number of waterway channels = 1

Therefore,
$V_e = 3.2 \times (2.0+0.45)^2 \times 270 \times 1 \approx 5{,}190\ m^3$
$V_c = (3.2 \times (2.0+0.45)^2 - \pi \times 2.0^2) \times 270 \times 1 \approx 1{,}800\ m^3$
$W_r = 0.04 \times 1{,}800 \approx 72$ ton
Cost of other items of works such as grouting, adit, etc. not included in the main items stated above were estimated at 15% of the cost of the main items.

Figure 3 - Relationship between Inner Diameter of Tunnel and Lining Concrete Thickness [1]



Tailrace Surge Tank [1]

(1) Structural Design
The surge tank will be provided to protect the tailrace tunnel against the pressure of water hammer.
(2) Quantity of work
The excavation volume, concrete volume, and the weight of reinforcement bars were calculated in accordance with the following equations.

$$V_e = 38 \times q \times (h_a + L)^{1/4} \times n$$
$$V_c = 11 \times q \times (h_a + L)^{1/4} \times n$$
$$W_r = 0.05 \times V_c$$

where,
q: Design discharge (m^3/s) = 78 m^3/s
L: Total length of waterway (m) = 270 m
h_a: Available drawdown of regulating pond or reservoir (m) = 56 m
n: Number of waterway channels = 1
Therefore,
$V_e = 38 \times 78 \times (56+270)^{1/4} \times 1 = 12{,}600\ m^3$
$V_c = 11 \times 78 \times (56+270)^{1/4} \times 1 = 3{,}650\ m^3$
$W_r = 0.05 \times 3{,}650 = 182$ ton
Cost of other works such as steel lining not included in the main items above were estimated to be 20% of the main items.

Tailrace Outlet [1]

(1) Structural Design
A pressure type was adopted similar to the intake.

(2) Quantity of work
During pumping operations, the tailrace outlet becomes an intake, and therefore, calculation method of the quantity of work for intake was adopted.
Therefore,
$Ve = 130 \times (((56+5.4) \times 78)^{1/2} \times 1^{\ 1/3})^{1.27} = 28{,}250\ m^3$
$Vc = 56.5 \times (((56+5.4) \times 78)^{1/2} \times 1^{\ 1/3})^{1.23} = 10{,}400\ m^3$
$Wr = 0.04 \times 6{,}700 = 416$ ton, $Wg = 0.9 \times (56 \times 5.4)^{1/9} \times 78 = 132$ ton, $Ws = 0.5 \times (56 \times 5.4)^{1/9} \times 78 = 74$ ton
Cost of other items of works including coffering and trashrack, rake, etc. not included in the main items obtained above is estimated at 25% of the cost of the main items.

Access Tunnel to Powerhouse [1]

(1) Quantity of work
Excavation volume, concrete volume, and weight of reinforcement bars of the access tunnel were obtained using the following equations. The maximum gradient of the access tunnel is l :10.

$V_e = 45 \times L\ (m^3)$
$V_c = 10 \times L\ (m^3)$
$W_r = 0.03 \times V_c$ (ton)

where, T: thickness of overburden at Powerhouse = 170 m, L: Length of access tunnel (m) = 500m
Therefore,
$V_e = 45 \times 500 = 22{,}500$ m^3
$V_c = 10 \times 500 = 5{,}000$ m^3
$W_r = 0.03 \times 5{,}000 = 150$ ton

Cost of other items of works namely grouting, adit, etc. not included in the main items stated above, were estimated at 15% of the cost of the main items.

Miscellaneous Works

Cost of miscellaneous works such as the disposal area and landscaping work was estimated at 10% of the total cost of civil works.

Economic Analysis

Benefit-Cost Method (B/C Method)

The economics of the project was analyzed on the basis of maximum output, electricity generation and the construction cost obtained.

Methodology of Analysis

An economic analysis of the hydro power project was conducted to compare its benefits (B) and costs (C). The benefit of a hydro power project in Sri Lanka is the cost of an alternative thermal power plant that supplies electric power equivalent to the hydro power project. The cost of the project was derived in the previous sections of this paper. If the benefit cost ratio (B/C) is 1.0 or above, hydro power is economically more attractive than the alternative thermal power. It is also possible to judge that a certain hydro power project is economically attractive if the B/C value is outstanding among a number of hydro power projects that are compared. Yet another method is to use the latter method and calculate the Economic Internal Rate of Return (EIRR).

Selection of Alternative Thermal Power

The alternative thermal power plants available or planned in Sri Lanka are gas turbines, coal-fired steam, oil-fired combined cycle or diesel power plants.

(1) Standard Thermal Power Candidate

One method is to select the power source most commonly used in the generating system, which may be displaced by the pumped storage hydropower plant. This may be defined as the "standard thermal power candidate". This method is suitable to compare the economic viability of a number of hydro power sites according to the same criteria, and this method is used for hydro power potential surveys, master plan studies, etc. For example, in the case of an electric power system consisting mainly of coal fired thermal power plants or new coal fired plants are scheduled to be constructed, coal fired plants may be selected as the standard thermal power candidate.

(2) Alternative Thermal Power Candidate Equivalent to Hydropower

The other method is to select an alternative thermal power candidate which is equivalent to the planned hydro power project, to evaluate its position as the source of supply in the electric power system. For example, a gas turbine plant is often selected as the alternate thermal power candidate for reservoir-type hydro, pondage-type hydro and pumped storage-type hydropower plants that are designed to supply power to serve peak demands.

Benefits and Costs of Conventional Hydropower Projects

Benefit [1]

Annual benefit (B) of a hydro power project is obtained in accordance with the following formula, based on the fixed cost (mainly the equipment cost) and variable cost (mainly the fuel cost) of the alternative thermal power selected.
$B = B_1 + B_2$
$B_1 = Ph \times b_1$
$B_2 = E \times b_2$
Where,
B: Annual benefit of hydro power plant (monetary unit)
B_1: Capacity benefit (monetary unit/kW)
B_2: Energy benefit (monetary unit/kWh)
Ph: Effective output (kW), maximum output is used in the case of pumped storage type
E: Annual generation (kWh) at 2190 hours operation in a year (assuming 6 hours per day)
b_1: capacity value, which is the fixed cost per kW for alternative thermal power (monetary unit/kW)
b_2: energy value, which is mainly the fuel cost and is the variable cost per kWh for alternative thermal power (monetary unit/kWh)
Outage rate is omitted.

Calculation of Capacity Value (b_1) and Energy Value (b_2) [1]

The capacity value and energy value were calculated from the following equations for the selected power source.

$b_1 = Ct \times \beta \times \alpha$

b_2 = Heat rate (kcal/kWh) × fuel price (monetary unit/kcal) ×860 (kcal/kWh)/thermal efficiency × Fuel price (monetary unit/kcal)

Ct: Unit construction cost of thermal power (monetary unit/kW)

α= Annuity factor

β= capacity adjustment factor; correction factor owing to the difference in expected output (to account for station use, forced outage, scheduled outage) between hydro power and thermal power.

The annuity factor and thermal efficiency for a gas turbine plant are shown Table 1.

Table 1 - The Annual Factor and Thermal Efficiency for Gas Turbine Plant [1]

	Gas Turbine
Annuity Factor	Approx. 18%
Thermal Efficiency	Approx. 30%
Service life	20 years

The following equation was used to calculate more detailed annual factor.

Annual cost factor (α) = Capital Recovery Factor (CRF) + (Operation & Maintenance cost/Total Cost) (OM: fuel cost excluded) [1]

$$\alpha = CRF + OM = \frac{i(1+i)^n}{(1+i)^n - 1} + 0.03$$

Where,

i: Interest rate

n: Service life (years) (hydropower = 50 years)

Results of the economic analysis for Kiriketi PSPP I are shown in Table 2.

Improving the Economic Viability of Kiriketi sites

All Kiriketi PSPPs are of pure pumped storage type. That means inflow to the upper pond is very small. The inflow to the upper pond increases the economic condition of PSPP, because it reduces the pumping cost. The Belihuloya flows close to the upper ponds of Kiriketi PSPPs at higher elevations. This geographical situation facilitates to divert the Belihuloya to upper ponds of Kiriketi PSPPs which will increase their economic viability. Additionally, by diverting Belihuloya it is possible to construct a run of river type conventional hydropower plant, which will make Kiriketi PSPP sites more attractive.

Conclusion

According to the economic evaluation results Kiriketi Pumped Storage Power Plant III is the best site. Kiriketi PSPP II and Halgran PSPP have about the same B/C ratio. So both sites have the equal opportunity to develop the power plant. The economic viability of Kiriketi PSPPs can be increased by diverting Belihuloya to their upper pond via a run-of-river type conventional hydropower plant.

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Table 2 – Summary of Economic Evaluation

	Kiriketi PSPP I	Kiriketi PSPP II	Kiriketi PSPP III	Halgran PSPP
Construction Cost (Civil) (USD)	419,849,253	205,890,701	110,323,887	185,439,224
Construction Cost (Hydro-Mechanical Equipment Cost)(USD)	43,175,280	43,366,920	43,869,960	47,546,400
Construction Cost (Electro-Mechanical Equipment Cost)(USD)	117,000,000	117,000,000	117,000,000	117,000,000
Project Cost per kW (USD/kW)	1,881	1,170	837	1,114
EIRR (%)	27.46	42.24	47.36	43.98
Benefit/Cost	1.71	2.06	2.15	2.09

Table 3 - Calculation of Construction Cost (Civil Cost)

Item	Cost
(1) Upper dam	185,917,593
(2) Lower dam	123,051,474
(3) Intake	4,732,859
(4) Penstock	4,948,594
(5) Powerhouse	49,029,652
(6) Tailrace	1,305,081
(7) Surge Tank (Tailrace)	3,429,777
(8) Outlet	4,732,859
(9) Access tunnel to powerhouse	4,533,248
(10) Miscellaneous	38,168,114
Total	419,849,253

Table 4 - Calculation of Construction Cost (Hydro Mechanical Equipment Cost)

Item	Cost
1. Upper Dam and spillway gate	49,500
2. Lower Dam and spillway gate	1,306,800
3. Intake	
Gate	1,095,600
Screen	318,200
4. Penstock (steel pipe)	31,795,500
5. Tailrace outlet	
Gate	1,095,600
Screen	318,200
6. Others	7,195,880
Total	43,175,280

Table 5 - Construction Cost Summary

Item	Cost (USD)	Note
1. Preparation and Land acquisition		
(1) Access road	20,992,463	(3 Civil work) × 0.05
(2) Camp & Facilities	8,396,985	(3 Civil work) × 0.02
2. Environmental mitigation cost	12,595,478	(3 Civil work) × 0.03
3. Civil Work	419,849,253	
4. Hydraulic equipment	43,175,280	Gate, Screen, Steel Penstock, etc
5. Electro-mechanical equipment	117,000,000	Turbine and Generator, Transformer, Switchyard, etc
Direct cost	622,009,458	
6. Administration and Engineering service	93,301,419	(Direct cost) × 0.15
7. Contingency	124,401,892	(Direct cost) × 0.2
8. Interest during construction	100,765,532	
Indirect Cost	318,468,842	
Total cost	940,478,300	

Installed Capacity	500,000 (kW)
Project Cost per kW	1,881 (USD/kW)

Note:

$$\text{Operation \& } Maintenance\ (under\ Cost) = \text{cost of Civil, Hydraulic and Electromechanical items } \times\ 3\%$$

$$\text{Pumping Cost (MUS\$)} = \frac{\text{Pumping Energy } \times \text{Energy Value}}{1000}$$

$$\text{Operation \& } Maintenance\ (under\ Benefit) = \frac{\text{Peak Capacity} \times \text{ Fixed O \& } M\ cost\ x\ kW\ Adjustment\ factor}{1000}$$

$$\text{Fuel Cost } = \frac{\text{Firm Energy } \times \text{ Energy Value } \times \text{ kWh Adjustment}}{1000}$$

Table 6 - Calculation of Economic Evaluation Indices (Base Case)

(Unit: US$ 1,000,000)

Year in order		Year	Cost					Benefit				
			Construction & Replacement	Operation & Maintenance	Pumping	Total		Construction & Replacement	Operation & Maintenance	Fuel Cost	Total	Net benefit
1		2015	58.00			58.00					0.00	(58.00)
2		2016	116.00			116.00					0.00	(116.00)
3		2017	174.01			174.01					0.00	(174.01)
4		2018	174.01			174.01		130.24			130.24	(43.77)
5		2019	58.00			58.00		181.20			181.20	123.20
6	1	2020		17.40	100.39	117.79			3.59	280.62	284.22	166.43
7	2	2021		17.40	100.39	117.79			3.59	280.62	284.22	166.43
8	3	2022		17.40	100.39	117.79			3.59	280.62	284.22	166.43
9	4	2023		17.40	100.39	117.79			3.59	280.62	284.22	166.43
10	5	2024		17.40	100.39	117.79			3.59	280.62	284.22	166.43
11	6	2025		17.40	100.39	117.79			3.59	280.62	284.22	166.43
12	7	2026		17.40	100.39	117.79			3.59	280.62	284.22	166.43
13	8	2027		17.40	100.39	117.79			3.59	280.62	284.22	166.43
14	9	2028		17.40	100.39	117.79			3.59	280.62	284.22	166.43
15	10	2029		17.40	100.39	117.79			3.59	280.62	284.22	166.43
16	11	2030		17.40	100.39	117.79			3.59	280.62	284.22	166.43
17	12	2031		17.40	100.39	117.79			3.59	280.62	284.22	166.43
18	13	2032		17.40	100.39	117.79			3.59	280.62	284.22	166.43
19	14	2033		17.40	100.39	117.79			3.59	280.62	284.22	166.43
20	15	2034		17.40	100.39	117.79			3.59	280.62	284.22	166.43
21	16	2035		17.40	100.39	117.79			3.59	280.62	284.22	166.43
22	17	2036		17.40	100.39	117.79			3.59	280.62	284.22	166.43
23	18	2037		17.40	100.39	117.79			3.59	280.62	284.22	166.43
24	19	2038		17.40	100.39	117.79		130.24	3.59	280.62	414.46	296.67
25	20	2039		17.40	100.39	117.79		181.20	3.59	280.62	465.42	347.63
26	21	2040		17.40	100.39	117.79			3.59	280.62	284.22	166.43
27	22	2041		17.40	100.39	117.79			3.59	280.62	284.22	166.43

28	23	2042		17.40	100.39	117.79			3.59	280.62	284.22	166.43
29	24	2043		17.40	100.39	117.79			3.59	280.62	284.22	166.43
30	25	2044		17.40	100.39	117.79			3.59	280.62	284.22	166.43
31	26	2045		17.40	100.39	117.79			3.59	280.62	284.22	166.43
32	27	2046		17.40	100.39	117.79			3.59	280.62	284.22	166.43
33	28	2047		17.40	100.39	117.79			3.59	280.62	284.22	166.43
34	29	2048		17.40	100.39	117.79			3.59	280.62	284.22	166.43
35	30	2049		17.40	100.39	117.79			3.59	280.62	284.22	166.43
36	31	2050	20.34	17.40	100.39	138.12			3.59	280.62	284.22	146.09
37	32	2051	16.02	17.40	100.39	133.81			3.59	280.62	284.22	150.41
38	33	2052	69.29	17.40	100.39	187.08			3.59	280.62	284.22	97.14
39	34	2053	38.51	17.40	100.39	156.30			3.59	280.62	284.22	127.92
40	35	2054	16.02	17.40	100.39	133.81			3.59	280.62	284.22	150.41
41	36	2055		17.40	100.39	117.79			3.59	280.62	284.22	166.43
42	37	2056		17.40	100.39	117.79			3.59	280.62	284.22	166.43
43	38	2057		17.40	100.39	117.79			3.59	280.62	284.22	166.43
44	39	2058		17.40	100.39	117.79		130.24	3.59	280.62	414.46	296.67
45	40	2059		17.40	100.39	117.79		181.20	3.59	280.62	465.42	347.63
46	41	2060		17.40	100.39	117.79			3.59	280.62	284.22	166.43
47	42	2061		17.40	100.39	117.79			3.59	280.62	284.22	166.43
48	43	2062		17.40	100.39	117.79			3.59	280.62	284.22	166.43
49	44	2063		17.40	100.39	117.79			3.59	280.62	284.22	166.43
50	45	2064		17.40	100.39	117.79			3.59	280.62	284.22	166.43
51	46	2065		17.40	100.39	117.79			3.59	280.62	284.22	166.43
52	47	2066		17.40	100.39	117.79			3.59	280.62	284.22	166.43
53	48	2067		17.40	100.39	117.79			3.59	280.62	284.22	166.43
54	49	2068		17.40	100.39	117.79			3.59	280.62	284.22	166.43
55	50	2069		17.40	100.39	117.79			3.59	280.62	284.22	166.43
56	51	2070		17.40	100.39	117.79			3.59	280.62	284.22	166.43
Total			740.20	887.44	5,119.74	6,747.38		934.32	183.26	14,311.82	15,429.40	8,682.03

Internal rate of return (EIRR):	27.46%
B/C ratio at a discount rate of 10%	1.71