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Integrating Solar PV with Pumped hydro storage in Nepal: A case study of Sisneri-Kulekhani pump storage project

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Abstract
Nepal's largest natural resource is potential for hydropower. The potential for hydropower could help to solve the poor economic situation in Nepal, but in spite of optimistic hydropower development plans produced by the government, progress has been slow. The main purpose of this master thesis is to investigate the feasibility of integrating renewables with pumped hydro storage in Nepal. The main criteria is that it must be economically profitable which will be beneficial for sustainable development in Nepal. The work has been conducted under the hypothesis that integrating Solar PV with pumped hydropower plants are profitable. In order to evaluate the hypothesis, a case study on Sisneri-Kulekhani pumped hydropower project was done. This project is recently halted by Nepal Electricity Authority due to its high initial investment. First necessary data were acquired and three different cases were identified. Data from one daily peaking and one seasonal storage hydropower were compared with that of Sisneri-Kulekhani hydropower. The cost of two pumped hydropower are calculated based on the same numbers used by Sweco in the original project which is collected from SN power office (Norway). Using the total cost and the current discount factor economic analysis were done. Then, levelized cost of electricity is calculated which is found to be higher in normal pumped hydropower compared with that of pumped hydropower integrated with Solar PV. Similarly, through literature and questionnaire survey various social and environmental implications of integrating solar PV were studied. Due to high investment and pumping cost the project will face deficit but after Solar PV is integrated it will be economically profitable.

Keywords
Pumped Hydropower, Solar PV, Economic Analysis, NPV, LCOE, Sustainability

1. Introduction

The world grapples dual challenges of increasing electrical energy supply while transitioning to a carbon free future. This will minimize negative consequences for people and the environment. The need for a reliable power supply in supporting economic development and advancement, as well as the necessity for clean, low-carbon electricity, is undeniable. Renewable energy sources such as wind, solar, etc. have created a significant incentive to build large-scale electrical energy storage. Renewable energy consumption was promoted in industrialized countries through government initiatives backed by subsidies. In various nations around the world, it is currently competitive without subsidies. Additionally, Nepal is also working to improve the output of clean energy sources like solar and wind. On the other hand, green energy is highly reliant on the environment and hasn't yet shown much promise in balancing the power system. In order to diversify Nepal's portfolio of electricity generation, green energy should be developed. Meanwhile, this electricity generation scenario in Nepal aids in the efficient utilization of transmission line infrastructure and the capture of surplus energy.

Electricity itself cannot be stored. It can be converted to another forms of energy that can be stored and then reconverted to electricity. The national grid performs an elaborate act of balancing supply and demand. Storing electricity during the periods of high production and low demand, and releasing back to the power grid during low production and high demand, can help balance fluctuations in electrical supply and demand.

1.1 Problem Statement

In 2000s, Nepal's economy growth rate was less than 4 percent per annum, attribute to electricity supply difficulties. This situation has been changing, with growth averaging around 6 percent in 2013 and 7.75 percent on average from 2017 to 2019, with a considerable slowdown in 2020 due to the effects of Covid-19. Improvements in energy supply to the industrial and service sectors are said to have led to improved economic growth. Along with increased urbanization and a growing number of energy-intensive companies, this upward trend in the electrical industry is projected to continue. Unrestricted electricity demand is forecast to rise from 7,318 gigawatt hours (GWh) in 2020-2021 to 31,196 GWh in 2029-2030 [1].

There used to be load-shedding in Nepal, which lasted about 17 hours each day. It was later phased out upon the introduction of new management which maintain demand and supply chain in the residential and industrial sectors. However, power imports play a significant role. NEA's generation amounted for 31.77 percent of total available energy, while imports from India and domestic IPPs accounted for 31.31 percent and 36.92 percent, respectively [1]. Furthermore, during peak demand, the marginalized cost of electricity is high, which has a substantial impact on a country's economy. Though pumped hydropower manages peak and off-peak demand, it is not an ideal solution because there is a cost of energy involved in pumping water from the lower reservoir to the upper reservoir. Thus, integrating renewables will help to lower the cost of energy involved in pumping water.

2. Research Objectives

Main Objective

- Study the feasibility of Integrating Solar PV to optimize pumped hydroelectric power plant.

Specific Objectives

- Economic analysis for integrating Solar PV with PHES.
- Social and environmental factors for integrating renewables with PHES.
- Comparing floatovoltaics (floating type solar panel) and land-based solar panels.

3. Methodology

The viability of adding solar PV in a pumped hydropower plant is investigated using a quantitative analytical approach. The challenges are first identified, and then the goals are set. Then a checklist is created, which includes variables that may have an impact on the research goal. The checklist includes various technical specifications required for economic analysis. Also, questionnaire is developed and survey was done among the locals about the social and environmental implications of hydropower. Various data will be collected during the field visit. The collected data from the field will be examined, and various findings will be acquired. The research is based on correlational research. It is a non-experimental research method where a researcher quantifies two variables, and understands and builds up the statistical relationship between them. It investigates the possibility of a relationship between variables and also describes the degree to which two or more quantitative variables are related. The variables in this research are the economic analysis of pumped storage with and without integrating renewables. The research holds descriptive analysis of various research that has been conducted worldwide.

4. Literature Review

4.1 Introduction to Hydropower in Nepal

There is large potential for hydropower in Nepal. Nepal lies in a subtropical monsoon climate zone, and the precipitation is highly variable between the dry and the wet season. The estimate for the total hydropower potential is 83000 MW, and technically and economically feasible projects are estimated to 43000 MW [1]. Nepal suffered from power deficit and is forced to operate load-shedding. In 2017, upto 16 hours of loadshedding was implemented in capital city of Nepal. One of the largest problem is highly variable seasonal precipitation. Due to most of the electricity being generated from run of the river hydropower, the power stations cannot operate to full capacity during the dry season. The result is the large difference in electricity production in dry and wet season. To solve this, reservoir with seasonal storage is necessary. Today, Kulekhani Hydropower project is the only project with a reservoir capable of seasonal storage.

4.2 Pumped Hydroelectric Storage

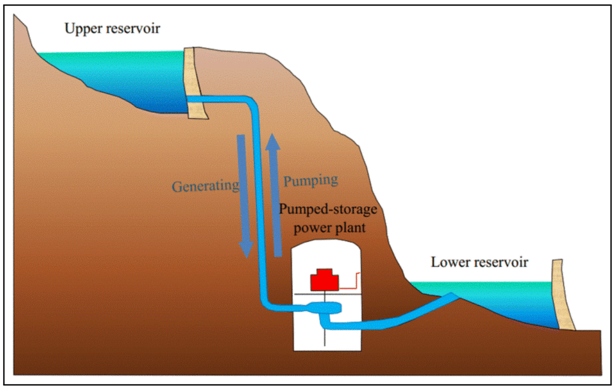

Figure 1: Pump Hydroelectric Concept

With a powerhouse serving as an intermediate station, it comprises of two water levels, one at high tailrace level and the other at low tailrace level. Depending on whether it is in the pumping or producing phase, water passes through a reversible pump turbine from higher level to lower level and vice versa. For a short period of time, this kind of plant is employed to provide the sudden peak load. It is a technology created to benefit from the differential cost in electricity generation between peak and off-peak hours [2].

4.3 Prospects of Storage and pumped storage hydropower in Nepal [3]

An Integrated Power System should have electrical energy generating plants for base load and peak load: work in coordination in such a way that the demand is met in time. In Nepal, Hydropower dominates integrated power systems. Thus, there is a critical need and prospects of Storage type Hydropower Projects. There used to be load shedding due to lack of ample storage-type projects to operate when power demands are highest. The annual peak power demand in Nepal is steadily increasing. Thus, it is imperative to develop storage power projects to fulfill the country's need for peak load demand and to balance its system of electricity generation. Pumped Storage Hydropower (PSH) can be used for load balancing using low-cost off-peak energy. There is vital need of PSH in Nepal as it is efficient and can have optimal use.

A case study of begnas-rupa pumped storage hydropower It is located at Kaski district, Nepal. A topographical survey at the site showed that the gross head between two reservoirs (Begnas-upper; Rupa lower) is 60 meters. After performing several trials, the plant capacity was fixed at 100 MW which can operate for five hours. The topography of Begnas-Rupa is naturally located with the head of 60 m. Thus, the cost for artificial reservoir is reduced. But lately NEA has cancelled the project due to its high investment cost.

4.4 Integrating renewables with pumped hydro storage in Brazil [4]

Brazil has favorable economic performance and resource availability, thus the contribution of variable renewable electricity is likely to increase. It is led by wind and solar projects, along with existing hydropower to sustain. 67 percent of total energy generation is from hydropower and 18 percent is from biomass, wind and solar.

4.4.1 Dealing with short term variability

Power systems must be able to respond to short term variations. Various performance attributes needed in Electric Power supply are: Stability, Reliability, Flexibility, Robustness, and Resiliency.

4.4.2 Pump hydroelectric projects

In order to support the entire linked grid, a suitable combination of pumped storage alternatives should be carefully researched and planned.

4.4.3 Hybrid Solar Pumped Hydropower project

It provides system stability, reliability, and flexibility. The space requirement for PV or wind plants is significant. Floatovoltaics system can be used which has higher efficiency than land based solar system. But it also has some practical limits like motorboats, water skiing, jet skis, and fishing.

4.5 Energy storage utilizing hydro-pump and battery technologies [5]

There is power fluctuations and uneven energy production in renewable energy as it is unstable and affected by fairly unpredictable factors such as weather. Following are the energy storage techniques used.

4.5.1 Hydro pump energy storage

Pumped Hydro Storage (PHS) is already a well-developed technology on the market, and is a part of the renewable energy sources and its ecosystem. It has two water reservoirs. A tunnel convey water from one reservoir to another. It has a reversible pump/turbine. Then power transmits to transformer and then to transmission lines.

4.5.2 Battery Energy Storage

Battery is an electrochemical device that stores energy, then supplies it as electricity. It utilize a large-scale rechargeable battery. It consist of two electrodes and when ion from one electrode interact with ions from other, the chemical reaction occurs. Currently used battery technologies are Lithium-Ion (Li-ion) batteries, Flooded Lead-Acid (LA) batteries, Vanadium Redox (VR) batteries, Sodium/Sulfur (Na/S) batteries.

4.5.3 Proposed Innovation

Dual tube System It consist of two water levels and two different tubes are used to pump and release water from one reservoir to another. There renewables are integrated to pump water from lower reservoir to upper reservoir.

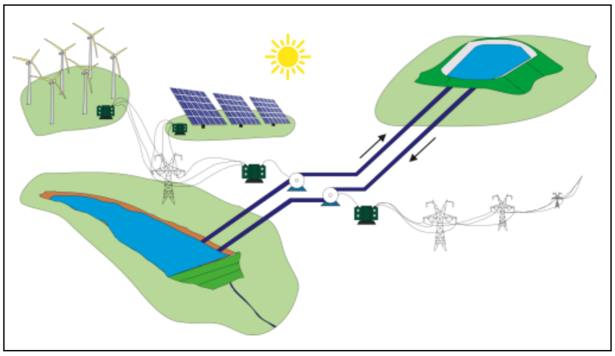

Figure 2: Dual-tube System

Hybrid hydro pump/battery storage In this system, the battery storage system is combined with the original system having AC-DC-AC converter in between. This combination gives the hybrid system ability to reduce cost of energy consumption from the grid since the battery can be used during daytime when the cost is high and charged during night time.

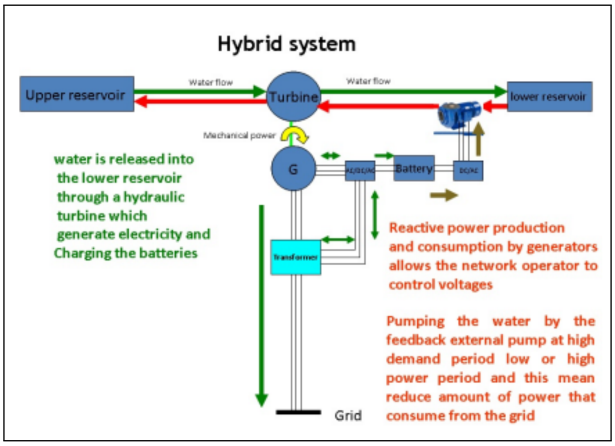

Figure 3: Hybrid hydro pump/battery storage

Small island and off-grid systems In this off-grid scenario, the installed capacity of the RES (PV and wind) has to be equal to or more than the average grid consumption in the isolated location. The grid is continuously powered by wind farms since the wind power generation is not directly controlled by time of day. The main benefits of the system are the possible usage of renewable energy continuously, and the accumulation of excess energy useful as the output of the RES diminishes. Secondly, the system provides independence from conventional power plants to decrease the COx emissions. Also, the excess of renewable energy can be used in water desalination or charging the batteries in electric cars, which could also be turned into a possible part of future Smart Grid.

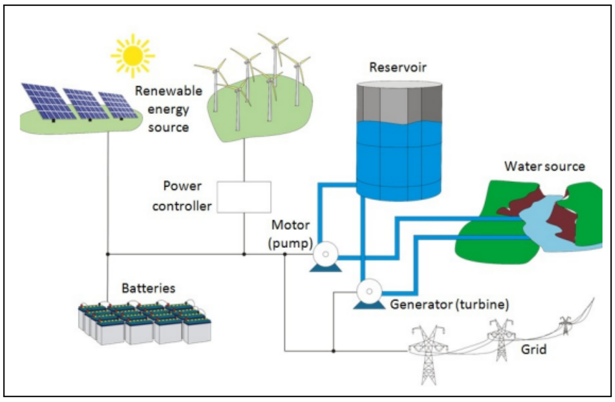

Figure 4: Small islands and off-grid system

5. Case Area

Kulekhani is located in Makwanpur District in the Narayani Zone of southern Nepal. It is the location of the Kulekhani Dam. The Kulekhani Dam is a rock-fill dam on the Kulekhani River near Kulekhani in

Makwanpur District of Narayani Zone, Nepal. The 60 MW Kulekhani I and 32 MW Kulekhani II Hydropower Stations are supported by the dam, which serves as a key source of hydroelectric power generation.

6. Framework for Case Study

Literature study was done before immersing to the case area to understand the scenario of pumped hydropower across the globe. To fulfill the objectives various relevant data should be collected. Following are the checklist.

- Present scenario of pumped hydropower projects in Nepal
- Technical aspect of Sisneri-Kulekhani Pumped Storage Project
- Energy required to pump water and energy delivered from same amount of water
- Marginalized cost of electricity
- Solar PV types and its technical aspects
- Capacity required
- Life Cycle assessment and initial investment required
- Additional equipment and their cost
- Repair and Maintenance
- Operating Cost
- Life Span
- Salvage Value
- Social and environmental factors for integrating renewables
- Compairing Floatovoltaics with land based Solar PV

After field visit, the collected data are prepared for the economic analysis. Various Capital budgeting techniques are used to study the feasibility of integrating Solar PV with Pumped hydropower.

Life cycle cost Total cost of asset over its lifespan

Annualized life cycle cost Life cycle cost per year

Levelized cost of Electricity Revenue of per unit electricity generated which will cover total capital cost

NPV Present worth of all future values

7. Data Collection and Analysis

7.1 Data Collection

Preliminary Data of Sisneri-Kulekhani Pumped Hydro Storage

- Reservoir-type hydropower
- 60 MW capacity
- Annual energy generated in fiscal year 77/78 was 195.157
- Structures in upper dam: submerged intake, headrace tunnel, headrace pipe, surge tank, penstock pipe, powerhouse, tailrace, and lower dam
- Intake with the discharge of 46.24 m3/s
- 4.5m diameter tunnel, 650m length and 4.3m steel pipe with length of 1550m headrace
- Around 1km downstream of powerhouse lower dam is suggested
- Proposed dam is 36m high from riverbed level, crest level of 1261m, the maximum water level of 1260m, total volume of 3.57 million cubic meters, and surface area of 0.244 square km.
- Minimum water level of 1255 masl, pumped with the discharge of 35.23 m3/s
- Generation/pumping type Francis turbine with capacity of 50MW

7.2 Data Analysis

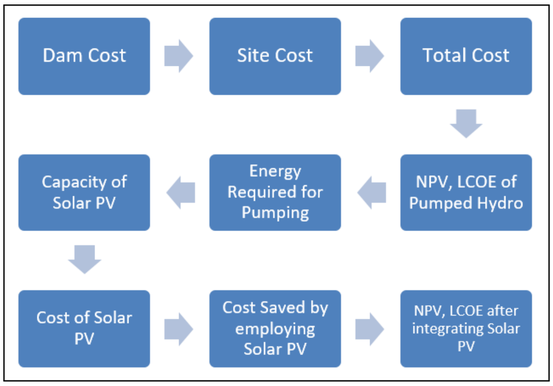

Figure 5: Flowchart of data analysis

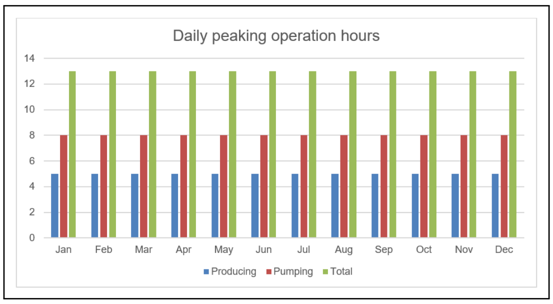

Figure 6: Daily Peaking

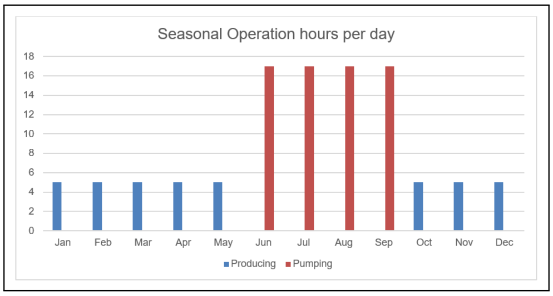

Figure 7: Seasonal Storage

7.3 Calculations

Here three different cases were identified. Data from one daily peaking (A) and one seasonal storage hydropower (B) were compared with that of Sisneri-Kulekhani hydropower (C). The cost are calculated based on the numbers used by Sweco. These are collected from SN power office and later compared with the Norwegian cost estimate for hydropower plants (NVE, 2010).

7.3.1 Dam Features

Table 1: Dam and Reservoir

Alternative	A	B	C
Dam Height (m)	70	130	36
Dam Width (m)	200	240	100
Reservoir Length (m)	1100	3200	800
Reservoir Average Width (m)	150	500	125
Average Live Depth (m)	10	30	10
Reservoir Volume $(mill.m^3)$	2	48	1
HRW $(masl)$	1740	1800	1260
LRW $(masl)$	1720	1720	1255
Resulting Head (m)	240	300	125

7.3.2 Tunnel Features

For seasonal schemes, the maximum production has been calculated in order to produce power five hours every day during the dry season. And for daily peaking schemes, the maximum production has been in order to produce power twelve hours every day.

- Seasonal

$$T_{production} = 5h * 8months * 30days = 1200hrs \quad (1)$$

$$Q_{maxproduction} = \frac{V}{T_{production} * 3600} \quad (2)$$

- Daily

$$T_{maxdaily} = 12hrs \quad (3)$$

$$Q_{maxproduction} = \frac{V}{T_{maxdaily} * 3600} \quad (4)$$

Table 2: Tunnel Discharge and Cross Section

Alternative	A	B	C
L (m)	3600	3600	2200
Q (m^3/s)	38	11	35.23
M $(m^{1/3}/s)$	49	49	45
A (m^2)	21	18	15.9
H (m)	4.5	0.5	2.7
I (m/m)	0.00124	0.00014	0.0012

- M (Manning's Number)
- L (Length)
- Q (Discharge)
- A (Area)
- H (Head)
- I $(\frac{H_{loss}}{L})$

7.3.3 Capacity

The maximum pumping discharge is calculated with following equation.

$$Q_{maxpump} = \frac{P}{n_{pump} * p * g * H_{gross}} \quad (5)$$

- P (Power)
- n (Efficiency)
- p (Density)
- g (Gravity)

Table 3: Installed Capacity

Alternative	A	B	C
Storage $(mill.m^3)$	2	48	1
$Q_{maxproduction}(m^3/s)$	38	11	35.23
$Q_{maxpump}(m^3/s)$	23	7	20
$H_{gross}(m)$	240	300	125
P (MW)	76	28	100

7.3.4 Annual Production and Consumption

Seasonal

$$T_{production} = 5h * 8months * 30days = 1200hrs \quad (6)$$

$$T_{pumping} = \frac{ReservoirVolume}{Q_{maxpump} * 3600} \quad (7)$$

$$E_{produced} = T_{production} * P \quad (8)$$

$$E_{consumed} = T_{pumping} * P \quad (9)$$

Daily

$$T_{production} = 5h * 365days = 1825hrs \quad (10)$$

$$T_{pumping} = \frac{Q_{maxproduction} * T_{production} * 3600}{Q_{maxpump} * 3600} \quad (11)$$

$$E_{produced} = T_{production} * P \quad (12)$$

$$E_{consumed} = T_{pumping} * P \quad (13)$$

Table 4: Annual Production and Consumption

Alternative	A	B	C
$T_{production}(hrs)$	1825	1200	1825
$T_{pumping}(hrs)$	3015	1905	3214
$E_{produced}(GWh)$	139	33	182
$E_{consumed}(GWh)$	229	53	321

7.4 Cost Estimation and Calculation (Pumped Hydropower)

Table 5: Dam Cost

Alternative	A	B	C
Dam Height (m)	70	130	36
Crest Width (m)	200	240	100
Morene Volume (m^3)	1400	3900	1200
Filter Volume (m^3)	600	1386	495
Transition zone vol (m^3)	500	950	390
Rip rap Volume (m^3)	350	590	300
Filling Volume (m^3)	6600	22700	5400
Correction factor filter	9	32	7
Correction factor filling	2	3	2
Morene cost $(mill.USD)$	8	39	7
Filter cost $(mill.USD)$	3	13	3
Transition zone $(mill.USD)$	3	10	2
Rip rap cost $(mill.USD)$	2	6	2
Support filing $(mill.USD)$	21	121	15
Foundation cost $(mill.USD)$	1	3	1
Grouting Cost $(mill.USD)$	1	3	1
Cost reduction factor general	0.9	0.85	0.9
Cost reduction factor filing	0.8	0.6	0.8
Dam Cost $(mill.USD)$	34	137	26

Table 6: Site Cost

Alternative	A	B	C
Gross Head (m)	240	300	125
Installed Capacity (MW)	76	28	100
Tunnel Lenght (m)	3600	3600	2200
Tunnel Cross section (m^2)	21	18	15.9
Maximum Discharge (m^3/s)	38	11	35.23
Number of aggregates	2	1	2
Power house vol (m^3)	16600	7300	15400
Turbine cost/kW (USD)	116	125	125
Power house $(mill.USD)$	16	13	13
Entrance Tunnel $(mill.USD)$	10	10	10
Reversible Turbine $(mill.USD)$	26	18	20
Generator $(mill.USD)$	10	4	8
Transformer $(mill.USD)$	19	17	17
Tranmission Lines $(mill.USD)$	4	4	5
Control gear $(mill.USD)$	6	3	5
Tunnel $(mill.USD)$	24	20	20
Earthfill dam $(mill.USD)$	34	137	26
Intake $(mill.USD)$	8	5	6
Reservoir Stabilization $(mill.USD)$	5	13	3
Cont/misc (30 percent)	49	73	41
Total Cost $(mill.USD)$	210	317	174

7.4.1 Cost Calculation

The following table summarizes the calculated value for energy (production and pumping) and Cost (pumping and construction).

Table 7: Cost Calculation

Alternative	A	B	C
$E_{production}(GWh)$	139	33	182
$E_{pumping}(GWh)$	229	53	321
Pumping Cost $(mill.USD)$	12	3	18
Construction Cost $(mill.USD)$	210	317	174

Table 8: Tariff Rate

Avg tariff rate	Ashd-Kart	Mang-Jest
Price per kW	10.5	11.5
Price (peak hrs)	12.30	12.30
Price (Off peak hrs)	6.75	10.80

The tariff rate is based on the average rate in commercial and residential sector from NEA annual report 2021/22

7.4.2 Pumping Cost

Pumping is done during off peak hours and the tariff used is the average off peak tariff (Table 9).

Table 9: Pumping Cost

Parameters	Off peak tariff
Pumping Cost per kW (NRs)	8.5
Energy Consumed (kWh)	321000000
Cost of pumping (NRs)	2728500000

Capacity	100	MW
Investment	208800	NRs/kW
Annual O&M cost	3%	of investment
Load Factor	0.5	
Period	20	years
Selling Price	11	/kWh
Discount Rate	16%	
Cost of equity	20%	
Interest rate	14%	
Capacity	876000000	kWh
Total investment	20,880,000,000	
Total annual O&M cost	626400000	
Annual energy generation	438,000,000	kWh
Selling Price	4599000000	
Net cash flow	1244100000	
PV of net cash flow	7,376,070,963	
NPV	(13,503,929,036.87)	
PV of Pumping Cost	16,176,842,394.43	
PV of Total annual O&M cost	3,713,825,939.48	
Total cost	40,770,668,333.91	
PV of energy consumption	2,596,832,314.00	
LCOE	15.700154	

Figure 8: LCOE of pumped hydropower

7.5 Solar PV cost calculations

Figure 9: Sunshine hours of Nepal

This is the figure showing average sunshine hours in Nepal

7.5.1 Cost of Solar PV

Energy Consumption in pumping	321000000	kWh
Load Factor	12%	
Annual Average Sunshine hours	2555	hrs
Capacity	1046966.732	kW
Solar PV cost per kW	7.2	per kWh
Total Cost	2311200000	

Figure 10: Cost of Solar PV

The required capacity of Solar PV will be same as that of the energy consumed in Pumping.

Total Investment	20,880,000,000
Solar PV cost	2,311,200,000
PV of Total annual O&M cost	3,713,825,939.48
Total Cost	26905025939.48
PV of energy consumption	2596832314.00
LCOE	10.36070977

Figure 11: LCOE after integrating Solar PV

8. Results and Discussion

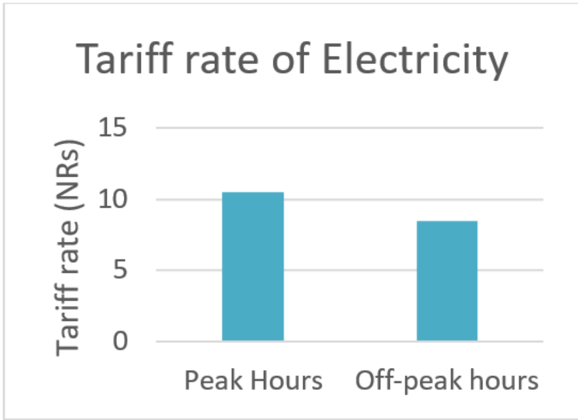

Figure 12: Tariff Rate

Figure above shows the tariff rate of electricity during peak and off-peak hours. In Nepal, the time from 5 p.m. to 11 p.m. is considered as peak hours. During these hours the cost of electricity is high. Pumped hydropower manages these peak and off-peak hours to fulfill the demand for the electricity. During off-peak hours the water from lower reservoir is pumped into upper reservoir and is released during peak hours where cost of electricity is high. Though the cost of pumping is higher than cost of producing, by managing peak and off-peak energy demand, revenue can be generated through pumped hydropower. The calculations show that Net Present Value of pumped hydropower is negative: -13,503,929,036.87. Marginalized cost of electricity is actual selling price of electricity and Levelized cost of electricity is the cost of electricity at which the total cost and revenue is level. LCOE (NRs 15.7) of pumped hydropower is higher than Marginalized cost of electricity (NRs 11). Thus, the project is not feasible. After that the calculation is done after integrating Solar PV with pumped hydropower. Here, Solar PV is used to pump water from lower reservoir to upper reservoir. This will reduce the cost of pumping which is higher than the cost of producing. For that, capacity of Solar PV is calculated and after that cost is determined. Finally, LCOE after integrating Solar PV is calculated which is found to be NRs 10.36.

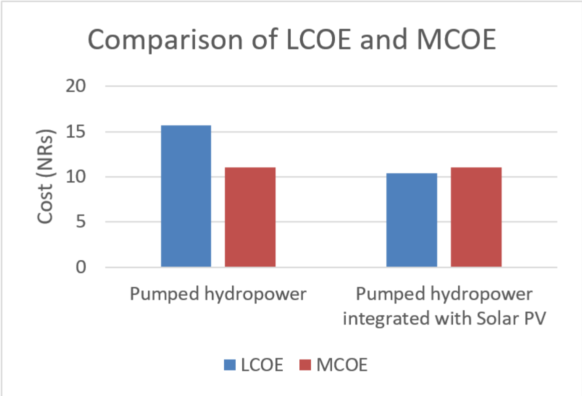

Figure 13: Compairing LCOE and MCOE

Various environmental and social impacts of integrating Solar PV with renewables were studied.

Environmental Impacts	
Land Use	• Requires large chunk of land
Water Use	• For cleaning • Cooling Purpose
Biodiversity	• Vegetation cleared off • Disturb free movement of wildlife • Sometimes affect local climate by altering temperature and changing rainfall pattern
Disposal of waste	• Hazardous and toxic e-waste • Short life 20-25 years

Figure 14: Environmental Impacts of Solar PV

Social Impacts	
Community Concerns	• Land acquisition
Employment	• Operation and maintenance require skilled manpower
Occupational health and safety impacts	• Several pollutants: arsenic, chrome, lead, cadmium in batteries

Figure 15: Social Impacts of Solar PV

Employing floatovoltaics will help to mitigate some of the impacts yet some economic, environmental and social implications of Solar Floatovoltaics were further discussed and are presented on the table below.

Parameters	Description
Economic	• Higher cost than ground-mounted of similar size • High labor cost: specific expertise required but outbalanced by more standardized installation process • High land value: FPV better
Environment	• Physical: Solar radiation receipts, water body temperatures, evaporation • Chemical: Nutrient concentration, gas exchange due to reduced evaporation • Biological: Phytoplankton, Zooplankton, and Fish.
Social	• Tourism and recreational • Existence Values

Figure 16: Environmental and Social implications of Floatovoltaics

9. Conclusion and Recommendation

Conclusion Capital budgeting technique is used for the economic analysis of integrating Solar PV with pumped hydropower. The cost of pumping will affect the economic feasibility of pumped hydropower because the energy required for pumping will be higher than that of energy produced and also managing peak and off-peak load will not solve the problem with the current tariff rate of Nepal. Employing Solar PV will minimize the energy required for pumping. The calculation above shows that the levelized cost of electricity will decrease below marginalized cost of electricity after employing Solar PV. Most of the developed countries with a topography like Nepal are developing pumped hydropower projects. This will help to change the future electricity generation portfolio in Nepal. This will also gradually reduce electricity imports and will help to improve the economic stability of the country. Various social and environmental implications may arise during the project lifecycle and to overcome this proper co-ordination with local stakeholders, municipality is must. Also, if floatovoltaics are used instead of land based solar panels some social implications can be eliminated but this might affect the properties of water and marine life.

Recommendation Hydropower will be more beneficial if the project is implemented with existing reservoirs, as this will minimize the cost of constructing artificial dam. The example is Begnas-Rupa pumped hydropower project. Mapping the topography of Nepal using Geographic information system will ensure a proper evaluation of possible reservoir sites, also mapping sites for Solar PV installation can be done.

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References

[1] NEA. Nea annual report 2021. Technical report, Nepal Electricity Authority, 2021.

[2] Shafiqur Rehman, Luai M Al-Hadhrami, and Md Mahbub Alam. Pumped hydro energy storage system: A technological review. *Renewable and Sustainable Energy Reviews*, 44:586–598, 2015.

[3] Neeraj Kumar Sah, Madhab Uprety, Sangharsha Bhandari, Prativa Kharel, Saurav Suman, and Ramesh Kumar Maskey. Prospects of storage and pumped-storage hydropower for enhancing integrated nepal power systems. *Hydro Nepal: Journal of Water, Energy and Environment*, 15:37–41, 2014.

[4] Rafael Kelman and David Harrison. Integrating renewables with pumped hydro storage in brazil: a case study. 2019.

[5] S Holmbacka, D Silva, R Chvalek, J Konecny, and AO Kareem. Energy storage utilizing hydro pump and battery technologies. *Proceedings, ICCES8*, 2012.