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# Performance Evaluation of Hydro Power Plants of Nepal Greater Than 10 MW Using Data Envelopment Analysis

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**Abstract**

Performance evaluation of major hydropower plants of Nepal is to be carried out in this competitive market. So, this study aims at performance evaluation of power plants owned by both Nepal Electricity Authority and Independent Power Producer which are greater than 10 MW on the basis of various parameters for the year 2014-2017 A.D. The objective of this study is to measure efficiency of each plant, to identify benchmarking group for inefficient plants, to provide direction towards efficient operation through slack calculation and also to do comparative study of private and public power plants. 14 hydropower plants and 6 performance parameters like installed capacity, number of employees, operating and maintenance cost, annual generated energy, dry energy, forced outage hours have been selected. The mean technical efficiency is found to be 93%, mean overall efficiency is found to be 77% and mean scale efficiency is found to be 82% for the period of consideration. In 2016/17, 50% private plants are overall efficient and 30% public plants are overall efficient. In 2015/16, average overall efficiency was just 78% which was later increased to 86% which shows increasing trend in overall efficiency. Marsyangdi, Middle Marsyangdi, Chilime, Kaligandaki A have achieved highest level of efficiency and Marsyangdi ,Jhimruk have been benchmark for inefficient plant throughout the observation period. In 2016/17, three plants have slack in cost and six plants have slack in employees which suggests that slack in inputs should be reduced by the amount suggested by Data Envelopment Analysis.

**Keywords**

Data Envelopment Analysis, Efficiency Evaluation, Hydropower Plants

## 1. Introduction

Nepal carried out institutional and economic reforms in the hydropower field in $11^{th}$ July 2000 A.D. [1]. In this paper focus is on the performance evaluation of power plants owned by Nepal Electricity Authority and Independent Power Producers which are greater than ten megawatts on the basis of various parameters for the year 2014-2017 A.D. Jha & Karki [2] have measured efficiency of public hydropower plants and thermal power plants of Nepal Electricity Authority plants using Data Envelopment Analysis for the period of 2000-2004 A.D. and ranked the plants of Nepal on the basis of efficiency calculated under six parameters i.e. employee number, dry energy, wet energy, installed capacity, operation and maintenance cost and annual generated energy. Kaldellis et. al. [3] have concentrated on the systematic investigation of the techno-economic feasibility of Small Hydro power stations of Greece. They concluded that predicted Internal Rate of Return values are more than 18% for most plants and found that installation capacity factor, local market electricity price affected the viability of similar plants. Nasab [4] has presented preliminary financial analysis of small hydro power plants in Malaysia from the perspective of investors. He has concluded that the projects with generation capacity between 6 to 11 MW are not attractive from financial perspective.

There is lack of performance study of major power plants owned by both Nepal Electricity Authority and Independent Power Producers as in terms of various parameters. So, the need of such performance evaluation is felt here. Also in previous research works certain performance factors are lacking so, this study incorporates other important parameters as the variables.

Its main objective is to support decision making activities through the performance evaluation of power plants of Nepal Electricity Authority and Independent Power Producers in the field of power planning in coming future.

## 2. Methodology

The performance evaluation has been done for power plants owned by both Nepal Electricity Authority and Independent Power Producer which are greater than 10 MW on the basis of various parameters for the year 2014-2017 A.D. Fourteen hydropower plants have been selected for analysis purpose and the performance parameters are selected after intensive literature review which has major influence on hydropower performance.

### 2.1 Selection of Performance Parameters

The following inputs and outputs have been selected for study.

**Inputs** Installed Capacity (MW), Total Operation & Maintenance Cost (NRs), Number of Employees

**Outputs** Energy Generated (GWh), Dry Energy (GWh), Forced Outage Hours (hours/year)

### 2.2 Selection of Hydropower

The list of Nepal Electricity Authority plants and Independent Power Producers plants under the scope of study are as follows:

**Table 1:** List of Hydropower Selected for Evaluation

| NEA Plants | Capacity (MW) | IPPs Plant | Capacity (MW) |
|---|---|---|---|
| Kali Gandaki A | 144 | Sanima Mai | 22 |
| Marsyangdi | 69 | | |
| Middle Marsyangdi | 70 | Chilime | 22.1 |
| Trishuli | 24 | Jhimruk | 12 |
| Sunkoshi | 10.05 | Lower Modi | 10 |
| Gandak | 15 | | |
| Kulekhani I | 60 | | |
| Kulekhani II | 32 | | |
| Devighat | 14.1 | | |
| Modi Khola | 14.8 | | |

Note: NEA- Nepal Electricity Authority

IPP- Independent Power Producer

### 2.3 Sources of Data

The data have been assembled from the secondary sources like office of Nepal Electricity Authority, Load Dispatch Centre, Generation Directorate, Finance Department, various hydropower maintained records, publications, reports and literature studies as well. Also related information has been collected from related websites.

### 2.4 Model Formulation

Input-oriented model has been used to evaluate the performance of hydropowers, where inputs are minimized and the outputs are kept at their current levels.[5]

$$\theta^* = min\ \theta$$

subject to

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta x_{io}$$

i= 1,2,......, m;

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{ro}$$

r= 1,2,......, s;

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0$$

j= 1, 2,......., n;

where,

$DMU_0$ = One of the n DMUs under Evaluation,

$x_{io}$ =$i^{th}$ input for $DMU_0$,

$y_{ro}$ =$r^{th}$ output for $DMU_0$,

$\lambda_j$ = Non-negative weights or Intensity variables defining frontier points

Note:- DMU - Decision Making Unit

The efficiency score, $\theta^*$ of DMUs will either be equal to 1 if they are efficient and less than unity if they are inefficient. To evaluate the overall efficiency score of plant, input-oriented Constant Return to Scale model has been used. In standard input oriented DEA model, it assumed that the manager may be able to alter all the input quantities. And to evaluate the technical efficiency Variable Return to Scale model has been used. The only difference between Variable Return to Scale and Constant return to scale is in the constraints. After calculating the efficiency for each DMUs, following linear programming model has been used to determine the possible non-zero slacks.

$$max \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+$$

subject to

$$\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta^* x_{io}$$

i= 1,2,......, m;

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{ro}$$

r= 1,2,......, s;

$$\lambda_j \geq 0$$

j= 1, 2,......., n;

where,

$s_i^-$ = Input Slack,

$s_r^+$ = Output Slack

## 3. Results and Discussion

### 3.1 Efficiency calculation:

The technical, overall, slack efficiency have been calculated which are described below:

#### 3.1.1 Overall Efficiency:

These overall efficiency score of power plants show the inefficiency and the extent of inefficiency.

**Table 2:** Overall Efficiency

| Company | 2016/17 | 2015/16 | 2014/15 |
|---|---|---|---|
| Kali Gandaki A | 100% | 100% | 100% |
| Marsyangdi | 100% | 100% | 100% |
| Middle Marsyangdi | 100% | 100% | 100% |
| Kulekhani I | 47% | 48% | 34% |
| Kulekhani II | 52% | 62% | 44% |
| Trishuli | 88% | 100% | 100% |
| Gandak | 56% | 23% | 7% |
| Modi Khola | 100% | 68% | 61% |
| Sunkoshi | 100% | 70% | 66% |
| Devighat | 96% | 100% | 100% |
| Chilime | 100%% | 100% | 100% |
| Jhimruk | 100% | 89% | 99% |
| Lower Modi I | 70% | 36% | 70% |
| Mai Khola | 81% | 100% | Not in Operation |

For 2016/17: There are altogether 7 DMUs that are 100% overall efficient which are Kaligandaki A, Middle Marsyangdi, Sunkoshi, Chilime, Jhimruk, Marsyangdi and Modi Khola. The maximum value of overall efficiency score is around 100%. However, the minimum efficiency score is just around 47% during period. The average efficiency score for power plants in a year of analysis is calculated to be 85.65% which shows most of plants are overall efficient. There are plants like Jhimruk, Chilime, and Sunkoshi which have higher efficiency and plants like Khulekhani I, Khulekhani II have lower efficiencies.for 2016/17, in terms ratio 50% private plants are 100% efficient and 30% public plants are 100% efficient. Similar description can be drawn from other remaining year too.

## 3.2 Technical Efficiency:

The technical efficiency score shows the relationship between physical quantities of inputs and outputs.

**Table 3:** Technical Efficiency

| Company | 2016/17 | 2015/16 | 2014/15 |
|---|---|---|---|
| Kali Gandaki A | 100% | 100% | 100% |
| Marsyangdi | 100% | 100% | 100% |
| Middle Marsyangdi | 100% | 100% | 100% |
| Kulekhani I | 55% | 60% | 52% |
| Kulekhani II | 79% | 100% | 91% |
| Trishuli | 90% | 100% | 100% |
| Gandak | 100% | 100% | 100% |
| Modi Khola | 100% | 100% | 100% |
| Sunkoshi | 100% | 100% | 100% |
| Devighat | 100% | 100% | 100% |
| Chilime | 100% | 100% | 100% |
| Jhimruk | 100% | 100% | 100% |
| Lower Modi I | 100% | 100% | 100% |
| Mai Khola | 85% | 100% | Not in Operation |

For 2016/17:

There are Devighat and Khulekhani II hydropower that have relative efficiency score of 100% and 79%. Middle Marsyandgi, Sunkoshi, Gandak, Chilime, Jhimruk have highest efficiency of 100%. The average efficiency of hydropower plants is found to be 93.55% for this year which helps to draw conclusion that most hydropower are efficient technically as well. The technical efficiency of Devighat, Modi Khola, Marsyangdi, Gandak, Chilime, are found to be high and less is of Khulekhani I. Highest efficiency is 100% and lowest efficiency is 55.34%.In the ratio wise private hydropower are technically efficient. Similar conclusions can be drawn from other years too.

### 3.2.1 Scale Efficiency:

A scale efficient plant is one which is capable to produce a similar proportionate increase output for a proportionate increase in input.

**Table 4:** Average Efficiencies

| Company | Average Overall Efficiency | Average Technical Efficiency | Average Scale Efficiency |
|---|---|---|---|
| Kali Gandaki A | 100% | 100% | 100% |
| Marsyangdi | 100% | 100% | 100% |
| Middle Marsyangdi | 100% | 100% | 100% |
| Kulekhani I | 43% | 56% | 77% |
| Kulekhani II | 48% | 90% | 54% |
| Trishuli | 96% | 97% | 99% |
| Gandak | 32% | 100% | 32% |
| Modi Khola | 76% | 100% | 76% |
| Sunkoshi | 79% | 100% | 79% |
| Devighat | 99% | 100% | 99% |
| Chilime | 100%% | 100% | 100% |
| Jhimruk | 95% | 100% | 95% |
| Lower Modi I | 35% | 67% | 53% |
| Mai Khola | 83% | 95% | 88% |

For 2106/17, Kaligandai A, Marsyangdi, Devighat show the good scale efficiency and Lower Modi, Gandak, Khulekhani I show the lower scale efficiency.

## 3.3 Slack Calculation:

Slacks are the excess of inputs used in plants.

For 2016/17: It can be observed that slacks for 100% efficient plants are zero. There are three plant having slacks in operating and maintenance cost. There are six plant that have slack values in employees. Slack analysis shows the amount of inputs to be further reduced for an inefficient power plant after incorporating efficiency scores to become technically efficient. The model seeks the reduction in excess inputs for inefficient plants. Devighat to become efficient in comparison with its peer group it should decrease its employee number by 19 and must decrease operating and maintenance cost by NRs.133,514. Similar conclusions can be derived from this table for other plants as well and also for other years too.

**Table 5:** Slack Calculated

| | 2016/17 | | 2015/16 | | 2014/15 | |
|---|---|---|---|---|---|---|
| Company | Operation & Maintenance Cost | Employees | Operation & Maintenance Cost | Employees | Operation & Maintenance Cost | Employees |
| Kali Gandaki A | 0 | 0 | 0 | 0 | 0 | 0 |
| Marsyangdi | 0 | 0 | 0 | 0 | 0 | 0 |
| Middle Marsyangdi | 0 | 0 | 0 | 0 | 0 | 0 |
| Kulekhani I | 0 | 14 | 0 | 5 | 0 | 9 |
| Kulekhani II | 0 | 11 | 0 | 0 | 0 | 6 |
| Trishuli | 0 | 30 | | 0 | 0 | 0 |
| Gandak | 0 | 9 | 0 | 3 | 0 | 1 |
| Modi Khola | 0 | 0 | 0 | 0 | 0 | 2 |
| Sunkoshi | 0 | 0 | 62,536,927 | 18 | 15,398,058 | 13 |
| Devighat | 133,514 | 19 | 0 | 0 | 0 | 0 |
| Chilime | 0 | 0 | 0 | 0 | 0 | 0 |
| Jhimruk | 0 | 0 | 0 | 16 | 0 | 23 |
| Lower Modi I | 177,150 | | 22 | 10 | 0 | 22 |
| Mai Khola | 15,431 | 28 | 0 | 0 | 0 | 0 |

### 3.4 Peer identification:

These are the benchmarking groups for inefficient plants.

**Table 6:** Peer Group

| Inefficient Company | Peer Group for 2016/17 |
|---|---|
| Kulekhani I | Marsyangdi, Gandak Jhimruk |
| Kulekhani II | Marsyangdi, Gandak Jhimruk |
| Trishuli | Marsyangdi, Modi Khola Chilime, Jhimruk |
| Mai Khola | Marsyangdi, Devighat Jhimruk |

Similarly in 2015/16 only Khulekhani I has peer groups Marsyangdi, Khlekhani II and Gandak and in 2014/15, Khulekhani I and Khulekhani II has peer groups Marsyangdi and Gandak. Marsyangdi and Jhimruk has highest count as benchmark group. For 2016/17: For Middle Marsyangdi no peer group as it has efficiency of 100%. For Khulekhani I the peer groups are like Marsyangdi, Gandak, and Jhimruk so, if Khulekhani I adopts the weighted combination of the inputs –outputs mix of three benchmarking plants, it might become efficient. Similarly, Jhimruk has its efficiency of 100% so it has no peer groups. Similar conclusion can be drawn for other hydropower as well.

## 4. Conclusion

The technical efficiency, overall efficiency, scale efficiency, slacks have been calculated and peer groups have been identified for performance improvement. Overall efficiency of hydro power plants has improved in recent years. Result shows that for 2015/16, average overall efficiency was just 78% which was later increased to 86% in 2016/17. Efficient plants don't have slack and benchmarking group. Data Envelopment Analysis identifies peer groups for inefficient plant. If inefficient plant adopts weighted combination of input output mix of its benchmarking group then it moves towards better efficiency. More public plants have slacks in operating and maintenance cost and other have slacks in number of employees which concludes that they are using excess of inputs.

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