ISBN 978-9937-0-9019-3

BENCHMARKING RESULT OF NEA OWNED HYDROPOWER PLANTS GREATER THEN 2MW USING DEA MODEL IN NEPAL

Dipesh Basnet
Department of Civil Engineering
Kantipur Engineering College
Dhapakhel, Lalitpur
ba.dipesh@gmail.com

Anankit Acharya
Department of Civil Engineering
Kantipur Engineering College
Dhapakhel, Lalitpur
anankit.acharya@gmail.com

Sankalp Ghimire
Department of Civil Engineering
Kantipur Engineering College
Dhapakhel, Lalitpur
sghimire2055@gmail.com

***Abstract*—This paper evaluates the relative efficiency of hydropower plants owned by Nepal electricity authority (NEA), using basic DEA model and ranks the hydropower based on super efficiency model. Performance of hydropower plant which are greater than 2MW were analyzed for the fiscal year 2018 and 2019 using the various parameter as input and output. The objective of this study is to benchmark group for the inefficient one, provides rank to each hydropower finding Technical efficiency, Overall efficiency and Scale efficiency of each hydropower for the study period and provide an easy guide for decision makers by comparing performance for two years. Basic DEA model involves the input CCR model and BCC model which was used for finding the Overall efficiency and Technical efficiency and super efficiency model was used for ranking. 14 hydropower plants owned by NEA were selected for the analysis with 4 input parameter as total installed capacity, operation and mentainance cost, current number of employee and plant tripping and 4 output parameter as Annual energy generated, energy generated in dry, winter peaking capacity and summer peaking capacity.**

The mean technical efficiency was found to be 96.9% and overall efficiency was found to be 78.6% with scale efficiency of 80.34% and mean super efficiency value of 98.40% with Marsyangdi of highest rank being most efficient and panauti with rank 14 with efficiency score of 21%, for the considered period.

***Index Terms*—DEA, BCC model, CCR model, DMUs, NEA, super efficiency,slack, Peer, Technical efficiency, Overall efficiency, Scale efficiency**

I. INTRODUCTION

At present Nepal has the installed capacity of 1332.86 MW, out of which 626.70 MW is owned by Nepal Electricity Authority (NEA).Nepal is experiencing rising power demands and is assumed to double by 2025 as of 2018 as per recent white paper published by MOE. Most of the Nepal's hydropower projects are ROR types, so seasonal influence affects energy generation. There is necessity of performance evaluation of hydropower for the past year so that there is ease in decision making for the concerned authorities in future. Considering various parameter as input and output which effects the efficiency of plant and analyse the result for past two years in term of efficiency, slack, peer for NEA owned hydropower greater than 2MW.

The measurement of efficiency have been done in the power and energy sector for several years. Various productivity efficiency measurement techniques have been used in various reports in finding different ways to enhance the productivity. Among several techniques, DEA is perhaps the foremost widely used approach in gauging the organizational units. DEA was introduced by Charnes, Cooper and Rhodes (1978) [1] to assess the relative efficiency of organizational units with multiple inputs to produce multiple outputs. The authors of DEA define the DEA as an applied math primarily based relative efficiency activity tool that uses optimisation technique to mechanically calculate the weights appointed to the inputs and outputs of the assembly units being accessed. The particular input and output variables are crossed with the weights to find the efficiency of the DMUs.

DK.Jha [2], studied the relative efficiency of hydropower plants owned by NEA was determined for year 2000 to 2004 using modified DEA model which was compared with conventional CCR DEA model of using various parameter as input as total installed capacity, operation and maintenance cost, no of employee both temporary and permanent, plant tripping and unit tripping and output are annual energy generation, energy generated in driest month summer peaking capacity and winter capacity and sensitivity analysis was done for that year and ranking of hydropower based on the efficiency calculated was done for considered period.

Further the performance evaluation of hydropower was done for 3 years from 2014 to 2016 using basic DEA model for some NEA owned and some IPP owned HPP with input parameter as installed capacity (MW), total operation and maintenance Cost (NRs), number of employees and output as energy generated (GWh), dry energy (GWh), forced outage hours (hours/year) and slack and peer are identified that period of consideration. [3]

Seyma Eme [4] uses the values of Installed power, production capacity per year were used as input variables whereas amount of water use for electricity generation, electricity generation amount and the average number of people whose energy needs are met were used as output variables. Efficiency-measurement was performed using CCR model. They used DEA model separately for 51 HEPPs and the models were solved using GAMS package program. When the results obtained were examined, they observed that 19.61% of HEPPs were operating effectively in Turkey. They offered suggestions for improvement for inefficient HEPPs. Jiekang et al. (2014) [5], here DEA was enclosed in electromagnetism-like mechanism and a new multipurpose scheduling model was urged to realize the optimum balance between water volume and amount of electricity for production. A check system with eight electricity power plants was done to verify this new technique. Calabria et al. (2018) [6], the performances of 81 hydro power plants were evaluated by DEA method considering indicators as annual operation and maintenance costs per installed capacity, availability factor, average time to repair and failure rate.

The need of this study was acknowledged as the previous studies done in Nepal were much earlier and the present scenario could be different than the result produced then. Also we have incorporated more hydropower plants in the study and ranked them calculating super efficiency.

II. Methodlogy

The different steps involved during the performance evaluation are:

- Selection of performance parameter
- Collection of data
- Model formulation
- Calculation and Interpretations of result

A. Selection of performance parameter

Performance parameter such as Installed Capacity (MW), Total Operation and Maintenance Cost (NRs), Number of Employees and Plant Tripping (no of times) were taken as input and Annual Energy Generated (GWh), Energy Generated in Dry Season(GWh), Winter Peaking Capacity and Summer Peaking Papacity were taken as output for the formulation of model which are taken through the literature review.

B. Collection of data

Data were collected from office of Nepal Electricity Authority, NEA publications, reports and literature studies as well.

C. Model Formulation

Orientation of model taken was input oriented and Constant Return to scale model was used for calculating overall efficiency and Variable return to scale was used for calculating the Technical efficiency. [7]

$$\theta^* = min\theta \tag{1}$$

subject to

$$\sum_{j=1}^{n} \lambda_j X_{ij} \leq \theta X_{i0}; \quad j = 1, 2, ...n; \tag{2}$$

$$\sum_{j=1}^{n} \lambda_j Y_{rj} \geq Y_{r0}; \quad r = 1, 2, ...j; \tag{3}$$

$$\sum_{j=1}^{n} \lambda_j = 1; (VRS) \tag{4}$$

$$\lambda_j \geq 0; \quad j = 1, 2, ...n; \tag{5}$$

where,
X_{i0} = i^{th} unit of DMUs
Y_{r0} = r^{th} unit of DMUs

The only difference between the CRS and VRS is in the constraints. After calculating the efficiency of each DMUs, following linear programming model has been used for calculating slack.

$$max \sum_{i=1}^{m} S_i^- + max \sum_{r=1}^{s} S_r^+ \tag{6}$$

Subject to

$$\sum_{j=1}^{n} \lambda_j X_{ij} + S_i^- = \theta^* X_{i0}; \quad i = 1, 2, ...m; \tag{7}$$

$$\sum_{j=1}^{n} \lambda_j Y_{rj} - S_r^+ = Y_{r0}; \quad r = 1, 2, ...s; \tag{8}$$

$$\lambda_j \geq 0; \quad j = 1, 2, ...n; \tag{9}$$

where
S_i^- = input slacks
S_r^+ = output slacks

Peer for inefficient plant are identified with the help of weight of each DMUs calculated from both the model.

1) Model for Super efficiency: For the decision maker it is not possible to make decision when most of the unit are efficient and cannot make ranking of efficient unit so one approaches for ranking the efficient unit along with inefficient unit is supper efficiency approach where the efficient evaluated unit are removed from set of DMUs and further evaluated from updated frontier. Value of all efficient frontier is greater then 1. The SE model is as below: [8]

$$MinZ_0 = \theta; \tag{10}$$

subject to:

$$\sum_{j=1}^{n} \lambda_j X_{ij} \leq \theta X_{i0}; \quad i = 1, 2, ...n; \tag{11}$$

$$\sum_{j=1}^{n} \lambda_j Y_{rj} \geq Y_{r0}; \quad r = 1, 2, ...j; \tag{12}$$

$$\lambda_j \geq 0; \quad j = 1, 2, ...n; \tag{13}$$

θ is free

D. Calculation and Interpretations of result :

Calculated data was robust and not easily understandable so the interpretation was done after calculating which was understandable in the form of graph, table etc.

III. Result and Discussion

The efficiency of the hydropower is calculated in term of overall efficiency, technical efficiency and slack efficiency and super efficiency which is described below:

A. Overall Efficiency:

The overall efficiency is calculated from input oriented constant return to scale which is considered at operating in optimal scale. The value of efficiency for 2018 and 2019 is shown in fig. 1. In the year 2018/19,

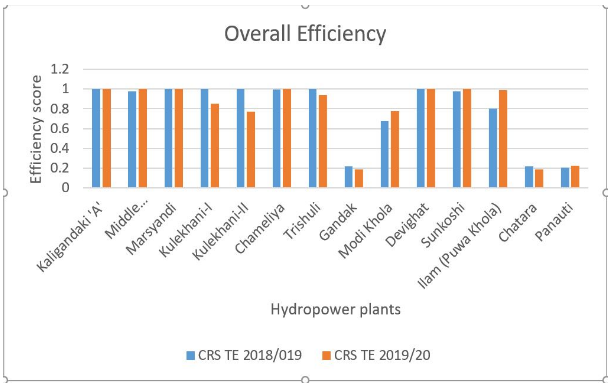

Fig. 1. Overall efficiency of different hydro power plants

6 out of 14 hydropower is efficient with efficiency score 100% having mean efficiency 79.1% with minimum efficiency of 20.9% of panauti hydropower which is most inefficient plant among considered hydropower plants. 3 hydropower plant have efficiency score in the range of 20-30% which are considered most inefficient plant and 3 plant have efficiency score of 90-100%. Similary in year 2019/20, 6 hydropower are efficient with mean efficiency of 72.8%. 2 of the hydropower, gandak and chatara are considered most inefficient plant having efficiency score in the range of 10-20%. All the inefficient plant can still increase its efficiency by decreasing its input for same level of output.

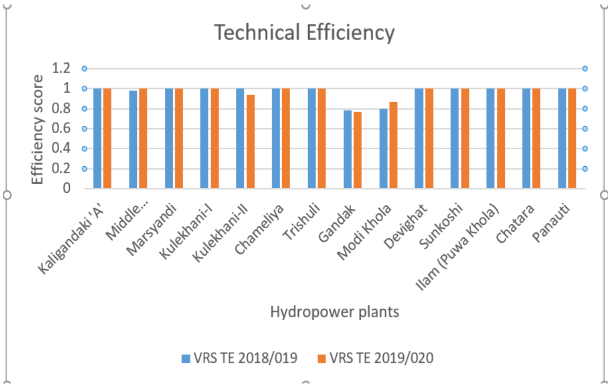

Fig. 2. Technical efficiency of different hydro power plants

B. Technical Efficiency:

The technical efficiency for year 2018 and 2019 is shown in fig. 2. In the year 2018/019, 11 out of 14 hydropower are found to be technically efficient with mean efficiency of 96.8% 2 hydropower have efficiency score in between 70-80% which are most inefficient and are Gandak and modi khola having efficiency score of 78.3% and 79.4% respectively. Similarly in year 2019/020, again 11 out of 14 hydropower found to be efficient with mean efficiency score 97% which is greater then in last year. only 1 hydropower have efficiency score in between 70-80% which is least value among all unit considered.

C. Scale efficiency:

The plant is scale efficient if the plant operates at most productive scale size. The scale efficiency of plants is given in fig. 3. In the year 2018/019, the 6

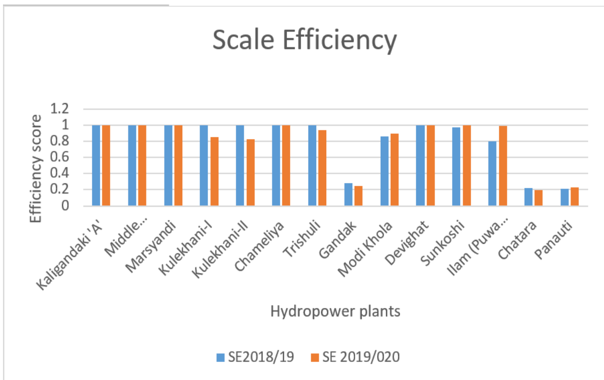

Fig. 3. Scale efficiency of different hydro power plants

out of 14 hydropower are scale efficient with mean efficiency of 80.92% and the most inefficient plant is panauti with 20.9% efficiency. In year 2019/020, 6 out of 14 hydropower is scale efficient with mean efficiency of 79.77%.and minimum efficiency 19.03% of chatara hydropower which is most inefficient.

D. Slack calculation:

The excess value of input which is used in plant is called slack. Slack for the year 2018/2019 is in table

I and for year 2019/2020 is in table II. where,
TIC = Total installed capacity(MW)
TOAMC = Toal operation and mantainance cost(NPR)
NOE = Number of employee
PT = Plant tripping(no of times)

SN.	HPP	TIC	TOAMC	NOE	PT
1	Kaligandaki 'A'	0	0	0	0
2	Middle Marsyangdi	0	407488.91	0	0
3	Marsyandi	0	0	0	0
4	Kulekhani-I	0	0	0	0
5	Kulekhani-II	0	0	0	0
6	Chameliya	0	0	0	0
7	Trishuli	0	0	0	0
8	Gandak	5.79	14081.98	0	0
9	Modi Khola	0	0	1	120
10	Devighat	0	0	0	0
11	Sunkoshi	0	0	0	0
12	Ilam (Puwa Khola)	0	0	0	0
13	Chatara	0	0	0	0
14	Panaut	0	0	0	0

TABLE I
SLACK CALCULATED FOR YEAR 2018/2019

SN.	HPP	TIC	TOAMC	NOE	PT
1	Kaligandaki 'A'	0	0	0	0
2	Middle Marsyangdi	0	0	0	0
3	Marsyandi	0	0	0	0
4	Kulekhani-I	0	0	0	0
5	Kulekhani-II	0	3467.11	13	0
6	Chameliya	0	0	0	0
7	Trishuli	0	0	0	0
8	Gandak	5.11	12578.527	0	72
9	Modi Khola	0	15244.69	0	0
10	Devighat	0	0	0	0
11	Sunkoshi	0	0	0	0
12	Ilam (Puwa Khola)	0	0	0	0
13	Chatara	0	0	0	0
14	Panaut	0	0	0	0

TABLE II
SLACK CALCULATED FOR YEAR 2019/2020

For year 2018/019: slack is found on all input of 3 hydropower Middle marsyangdi, gandak and modi khola for the Middle Marsyandgi to be efficient with respect to its peer group it should reduce its input in operating and maintenance cost by 407488.91 nepali rupees and 11 employees and tripping times by 7 it make it efficient. Gandak have its slack of 5.79 in total installed capacity which means that for the both particular year gandak is not operating with its full capacity. similarly conclusion can be made for other plant and other year.

E. Peer identification:

By decreasing the excess input for the inefficient plant to efficient frontiers peers can be identified for each inefficient plant where peer are the efficient plant which lies in efficient frontier.The peer for 2018/2019 is given in table III and peer for 2019/2020 is given in fig. 4. table

For year 2018/19: for Middle Marsyangdi peer group is Marsyangdi and for Gandak peer group are Chameliya, Chatara and Panauti .by reducing the input

Inefficient group	Peer1	Peer2	Peer3
Middle Marsyangdi	Marsyangdi	0	0
Gandak	Chameliya	Chatara	Panauti
Modi Khola	Marsyandi	Puwa Khola	Panauti

TABLE III
PEERS FOR YEAR 2018/2019

Peer for year 2019					
Inefficient Group	Peer1	Peer2	Peer3	Peer4	Peer5
Modi Khola	Marsyandi	Chameliya	Devighat	Puwa Khola	Panauti
Gandak	Chameliya	Chatara			
Kulekhani-II	Chameliya				

Fig. 4. PEERS FOR YEAR 2019/2020

from middle Marsyangdi to its peer group so to make Gandak efficient it should use the weighted combination of input and output of its peer group. Similar conclusion can be made for all other inefficient unit and another year.

F. Super Efficiency Calculation:

The value of super efficiency is used to rank the efficient units. The ranking and super efficiency value is given in table of fig.5. In 2018/019, Marsyangdi

	for year 2018		for year 2019		
DMU	super efficiency	Rank	super Efficiency for year 2076	Rank	Overall rank
Kaligandaki 'A'	1.2098	3	1.3986	6	3
Middle Marsyangdi	0.9777	8	1.2504	3	4
Marsyandi	2.879	1	1.4297	1	1
Kulekhani-I	1.337	2	0.8539	2	2
Kulekhani-II	1.0226	5	0.775	10	7
Chameliya	0.9949	7	2.7116	11	9
Trishuli	1.0043	6	0.9412	12	10
Gandak	0.2174	12	0.1908	7	11
Modi Khola	0.6809	11	0.7766	4	8
Devighat	1.114	4	1.1758	9	5
Sunkoshi	0.9743	9	1.0073	5	6
Ilam(Puwa Khola)	0.8008	10	0.9886	14	13
Chatara	0.2167	13	0.1904	8	12
Panauti	0.2091	14	0.2252	13	14

Fig. 5. Super efficiency of Hydropower plants

is found to be super efficient with efficiency score of 289.7 % with highest rank 1 and super inefficient, panauti with 14 rank have score of 20.9%. and have mean efficiency score of 97.41% .and for year 2019/020, again the efficiency score of marsyangdi is high and again the panauti is super inefficient. Overly mean super efficiency value is found to be 98.40%.

CONCLUSION

This study has given some different results than the previous studies. [2], [3].Our study has included calculation of various efficiencies and calculation of super efficiency for ranking the hydropower plants on the basis of parameters taken. Marsyangdi H.P. is found to be super efficient plants while Panauti H.P. remains most inefficient plant in the years of study. For inefficient plants, peers are identified by using DEA by decreasing the excess input for the inefficient plant to efficient frontiers. Few plants have shown slacks and optimization of slack input can increase the efficiency of those plants.

ACKNOWLEDGMENT

We would like to express our sincere gratitude to Department of Civil Engineering, Kantipur Engineering Campus for providing platform to do this research. We would also like to thank all those who help, motivated, encouraged, guided us to do this research.

REFERENCES

[1] A. Charnes, W. W. Cooper, and E. Rhodes, "Measuring the efficiency of decision making units," Eur. J. Oper. Res., vol. 2, no. 6, pp. 429–444, 1978, doi: 10.1016/0377-2217(78)90138-8.

[2] D. K. Jha, N. Yorino, Y. Zoka, D. Kumar Jha, N. Yorino, and Y. Zoka, "Benchmarking Results of Electricity Generating Plants in Nepal Using Modified DEA Models," no. November, 2007.

[3] S. Bohara and R. Shrestha, "Performance Evaluation of Hydro Power Plants of Nepal Greater Than 10 MW Using Data Envelopment Analysis," vol. 8914, pp. 87–92, 2017.

[4] Ş. Emeç, T. Adar, G. Akkaya, and E. Kılıç Delice, "Türkiyedeki Hidroelektrik Santrallerin Etkinliklerinin Veri Zarflama Analizi (VZA) ile Değerlendirilmesi," Eur. J. Sci. Technol., no. October, pp. 34–45, 2019, doi: 10.31590/ejosat.594716.

[5] Jiekang, W., Zhuangzhi, G., Fan, "Short-term multi-objective optimization scheduling for cascaded hydroelectric plants with dynamic generation flow limit based on EMA and DEA," 2014 International Journal of Electrical Power Energy Systems, 57:189-197.

[6] Calabria, F.A., Camanho, A.S., Zanella, "The use of composite indicators to evaluate the performance of Brazilian hydropower plants," 2014 International Transactions in Operational Research, 25 (4), 1323-1343.

[7] Rajiv D Banker, Abraham Charnes, and William Wager Cooper. Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management science, 30(9):1078–1092, 1984.

[8] A. Scientific and N. Health, "A Super-Efficiency Approach to Rank Units of a Hospital," vol. 3, no. 5, pp. 15–18, 2019.