An AHP Based Approach for Evaluating Renewable Energy Source for Investment Decision

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***Abstract*— The percentage of the population remaining to get connected to electricity has decreased from 35 % to 4.5 % in this decade. However, 1.3 million out of 29 million Nepal's population still need to be connected to an electricity supply. As most of this population lives in Karnali State, exploitation of renewable energy needs serious attention in this region as other energy sources are expensive and beyond reach. Choosing a suitable renewable energy technology that is economically feasible and environmentally acceptable is a topic of interest among researchers. Using one of the Decision Support systems helps in making easier choice for policy makers and government levels. In this case the research here-within evaluates among three renewable energy options, i.e., Micro-hydro, Solar Power and Wind power. The research shows that Micro-hydro would be best suited option in case of Jumla.**

Keywords—AHP, renewable energy, decision making,

I. INTRODUCTION (*HEADING 1*)

In a decade timeframe Nepal has seen dramatic and staggering slip in the total number of people who are yet to get connected to electricity. 10 years back more than 10 million people were living without electricity[1]. But now this number has decreased to 1.3 million. Nevertheless, there are still roughly 4.5% population in Nepal without electricity[2]. Though the country has scaled up its transmission line and production capacity with huge hydropower under construction, the remaining 4.5% are yet to get connected which will still take more than a decade time[3]. This is mainly because of two reasons. The first being accessibility and second being ineffective policy structure[4-6].

With all the above ordeal we do have a humongous task ahead us as a country in solving energy demand. Before the National grid reaches, we do have a challenge to fulfill the energy demand for that fraction of time. In this case, we have option to ponder upon based on available renewable energy. But the task is often tormented with difficulty in identifying the right source of energy. In this research we will try to solve this difficulty with use of decision tools in our display. For our research we will select one of a district within Nepal with highest energy deficiency. Further we will explore the notion on which renewable energy source will be best to solve the issue of energy demand. This is as per the evaluation of best renewable energy source.

For the purpose of research, we have taken a district called Jumla situated in Karnali state within Nepal. Rationale behind the selection of Jumla will be elaborated in the research process and justification section. Our main goal/objective in this research is to identify the main criteria upon which the evaluation of renewable energy will be dependent based on literature review for Jumla Nepal and select the best decision tool for the decision-making task. Moreover, carry out the data collection, data analysis and interpretation for the research and Finally, point out the findings and its future implication for further research is also the main goal of this research.

II. LITREATURE REVIEW

Choosing a suitable renewable energy technology that is economically feasible and environmentally acceptable is a topic of interest among researchers working in this field because of the availability of different kinds of renewable energy sources in the region [2]. Researchers have argued that renewable energy technologies such as micro and mini hydropower, solar, and wind are not only technically feasible and financially viable solutions but also suitable energy sources for rural and remote areas in developing countries like Nepal[7]. The literature review was carried out to explore the factors/alternative pertaining to our research. Mainly to find main criteria upon which the evaluation of renewable energy will be dependent we have identified four research papers.

The first paper is recent one published in 2020. In this research the study is based on Jumla and it exactly aligns with the scope of our study on identifying the best energy sources. The research carried outlines three available and possible renewable energy sources in

Jumla, i.e. Micro Hydro, solar power and wind power. But it does not make use of decision-making tool nor explores broadly in the identification of right energy sources. The paper is focused on exploring wind energy generation and it briefly states which all energy sources meets the demand of Jumla [2]. The technical as well as economic aspects are the main criteria upon which other sub-criteria are laid out.

In this paper authors used Fuzzy Analytic Hierarchy Process (AHP) to prioritize investment planning of renewable power plants in Turkey and five different kinds of power plants under the visual pollution criteria based on amount of CO2 emission released, environmental damage, capital costs, space requirement and provided employment were evaluated[8].

The second paper studied was from Libya. The authors used AHP, a decision tool to select an appropriate power generation technology. This paper presents the idea of determination of these parameters, which influence the selection of power generation technology in particular for developing countries. The paper identifies four main criteria that is economic, environmental, technical and social. A sub-criteria are also included to support decision making process. The performances of six technologies of a power generation are evaluated by Analytic Hierarchy Process (AHP) using expert choice software and the best technology is selected. Particularly out of all the six technologies solar power generation is the found to be best technology. Further, as per the sensitivity analysis, it was found that the best alternative is not sensitive to a change in the weights estimated by the AHP[9].

The third paper studied was based on rural areas in the Caribbean region of Colombia. In this research decision-making in energy planning is approached as a problem of multi criteria decision analysis in which different types of factors are seen to be involved. The selection aspects is based on the increasing complexity of five factors. The first is social factor, secondly the technological factor, thirdly environmental factor, then comes economic factor, and finally risk factors. This paper uses the analytic hierarchy process (AHP). The research is based on the participation of experts. Total of 5 criteria along with 20 sub-criteria, and 4 alternatives. [10].

Any decision problem to be chosen as Multi-criteria should possess following nature:
-There should be goal/decision to be achieved from the decision problem
-The decision makers should have opinions and preferences pertaining to decision problem.
-The opinions/preferences should be based on multiple criteria
-The Multiple criteria can be either subjective or objective in nature
-Further, there should be decision alternative associated to each Multiple criterion

The reason for selecting the Analytical Hierarchical Process (AHP) is because no research has conducted yet on topic based on AHP for evaluation of energy source in Jumla, Nepal and this will be first step on recognizing the power of decision-making tool that will eventually help in better policy making as well as investment outlook.

III. METHODOLOGY

For the site location, we have chosen Tila village of Jumla which is at elevation of 2718 meters, at 29.275-degree latitude and 82.184-degree longitude in Nepal as shown in Fig.1. The topography of Tila village is extremely varied, with a maximum change of elevation of 1000 meters. Moreover, within a range of 16 km, the elevation varies about 2464 meters, and within a range of 80 km, the difference is about 6302 meters. The village is covered mostly by cropland, trees, and grassland. Tila village has a total of 2626 households with 13,607 inhabitants who are mostly poor [11]. The electricity they currently receive from a micro hydro system is subsidized by the government but the villagers face load shedding of several hours every day. To alleviate this problem, they have rooftop solar power installed, but during the winter season when there is less daylight solar power is unreliable. Similarly, the micro hydro system is dependent on the snowy and rainy seasons.

During those seasons, the canal experiences blockages and piping systems need significant maintenance. This is an opportunity for the government to invest in other renewable resources. So technically there are currently three renewable energy for Tila village, i.e., Micro-hydro, Solar power, and wind power.

The literature review, particularly three research reviewed pointed the AHP method to suit our purpose [8-10]. AHP which is Analytical Hierarchical Process is a decision-making tool used to solve problems with multiple criteria. In this method a hierarchy is performed. The problem to be solved is located at the top followed by intermediate level in which basis of decision-making is laid out. Further, the solution alternative is presented at the base. The steps we follow are as follows:

A. Problem hierarchy

The goal is located at the top-level. This is followed by the criteria in the second level. The criteria are further divided into sub-criteria based on the detail. The criteria allow decision maker to set preferences as per the attributes. Finally, the last level constituents all the alternatives, which are the possible solutions. This finally leads to making the final decision.

B. Set priorities for criteria

The preferences of the decision makers are based on numerical value which is assigned to all criteria. The numerical value and its scale were developed by Saaty (2008). The scale is presented in Table below. The effectiveness has been validated by numerous researchers.

TABLE I. PAIRWISE COMPARISON MATRIX USING SCALE OF RELATIVE IMPORTANCE

1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values
1/2,1/5,1/7,1/9	Values for Inverse comparison

C. Verify the consistency of the judgments

The verification of the consistency is made using Consistency index. This is mathematically defined as

$$CI = (\lambda \max - n)/(n-1) \quad (1)$$

To verify the CI values, a comparison is made with the random consistency index (RI). This parameter is defined as an average of the CIs of a large set of matrices with random inputs[12]. In addition, Saaty defines the consistency ratio (CR) = CI/RI. If CR $\leqslant$ 0.1, then the results are consistent. When CR > 0.1, the data are inconsistent and therefore the decision maker judgments must be reviewed.

D. Define priorities for sub-criteria

The priority for sub-criteria is important to establish. For this, paired comparisons must be made to establish the importance with respect to the higher level, i.e., criteria.

E. Define priorities for alternatives.

In this case, we compare between the alternatives outlined. For this, preferences among alternative is established in respect to the criteria and the sub-criteria that have been presented.

In our research we would do the above-mentioned steps in one of the educational purposed software called "Expert Choice". Further software's data would be analyzed in Data Analysis section here-within the report. In the case that sub-criteria have been defined in the decision problem, it is necessary to proceed as in step 3. For this purpose, the paired comparisons must be made in order to establish the importance of the sub-criteria with respect to the higher level.

IV. RESULT AND DISCUSSION

In our case, decision problem is evaluating best renewable energy source in Jumla, Nepal. We have identified 3 different preferences pertaining to decision problem. Further, we have outlined 7 criteria based on the literature review for evaluation of best renewable energy source. In our case, first three criteria, i.e., efficiency, capacity factor and capital investment are objective in nature whereas number of civil components, time for construction, transportation and maintenance are subjective in nature depending on location, climate and requirement. As shown in hierarchical structure decision alternative associated to each criteria are Micro Hydro, Solar Power and Wind Power. Since the decision problem selected possess all the above requirements which is inferred from the para above we can say the decision problem is Multi-criteria in nature.

1) Efficiency

The efficiency of a wind turbine is about 50% and the overall distributed wind energy system has an efficiency range from 32% to 50% [13]. The efficiency of a distributed wind source is between the solar and micro hydro systems. The most efficient solar panels on the market today have efficiency ratings as high as 22.8%, whereas most panels range from 15% to 17% efficiency rating[14]. The battery of the solar system has the efficiency of about 70-90 % and the overall solar PV system has the efficiency of 15 %[15] [16]. With 50-60% efficiency, the micro hydro system has a higher efficiency than wind and solar systems.

2) Capacity Factor

The capacity factor is the amount of energy produced by a system divided by what it could produce if it functioned at peak capacity all the time. Wind, hydro, and solar capacity factors tend to vary with location and seasons since they depend on the speed of the wind, flow of water, and sunlight. According to the U.S. Energy Information Administration data provided in 2016, the wind energy system has a capacity factor of 34.7% whereas the hydropower system has 38%. The solar PV system has a capacity factor of 10-20 % [2].

3) Capital Investment

Looking at the capital investment in the wind, micro hydro, and solar power, we find that distributed wind energy systems need more investment than the other two. The micro hydro system requires about $2500/kW to $5500/kW whereas wind energy system requires about $3000/kW to $7200/kW[17] [2]. The community usually participates in the construction of a micro hydro system, and the capital cost of the project is reduced, but for the distributed wind energy system, there is not much cost that can be reduced by community participation. Thus, the distributed wind energy system is less economical than the micro hydropower system. The cost of installation of the solar PV system is around $2000 to $4000 per kW.

4) Number of Civil components

Many components of a wind energy system are less robust than those of a hydropower system. On the other hand, the hydropower system consists of more civil components than the wind power system. The only civil components in the wind power system are the

foundation and the tower while in the micro hydropower system, there are many civil components such as a weir structure, reservoir, canal, desilting basin, intake, machine foundation for the turbine and generator, etc. The third type of the alternative energy sources has few civil components. In case of solar power, we need small foundation that is easily extractable whenever it's required. So, comparing all the three energy sources micro-hydro has the highest number of civil components. This is followed by wind power with comparatively less civil components. Finally followed by solar power will lowest number of civil components.

5) Time for construction

In respect to the number of civil components as mentioned above, time of construction for micro-hydro will take the longest. As the civil components such as a weir structure, reservoir, canal, desilting basin, intake, machine foundation for the turbine and generator, etc. takes more than a year time for construction. Similarly, for wind power it takes time of six months and above. Whereas, for solar power it is more of assembling the parts pertaining the lesser time. So, time for construction is highest for micro-hydro, low for solar power and medium for wind power.

6) Transportation of components

The hilly and winding roads to Jumla make transportation of large wind turbine blades challenging. This brings a challenge for transportation especially for wind power installation. In case of other two energy sources, we have more challenges in transportation for micro hydropower with the turbines being difficult to move around the sharp turns and small roads. In case of solar power, the components can be segregated in number of parts and it can be taken to destined place even using mules. Thus, in respect of energy sources transportation is considered somewhat easier in case of solar power, followed by micro-hydro and difficult in case of wind power.

7) Maintenance

There are fewer maintenance problems in the wind energy system than in the micro hydropower system. If we observe current scenario in Jumla, people face power cuts in the rainy season, and there are also other power outages arising from failure of different civil components of the micro-hydro system. Whereas the solar panel does not need much maintenance. Nevertheless, in the solar PV system there is a huge cost associated with frequent battery replacement. So, in regards of the preference we make in maintenance, we can infer the fact that there is more maintenance issue in micro hydro and wind power followed by solar power. Solar power is kind of expensive due to its frequent battery replacement issue.

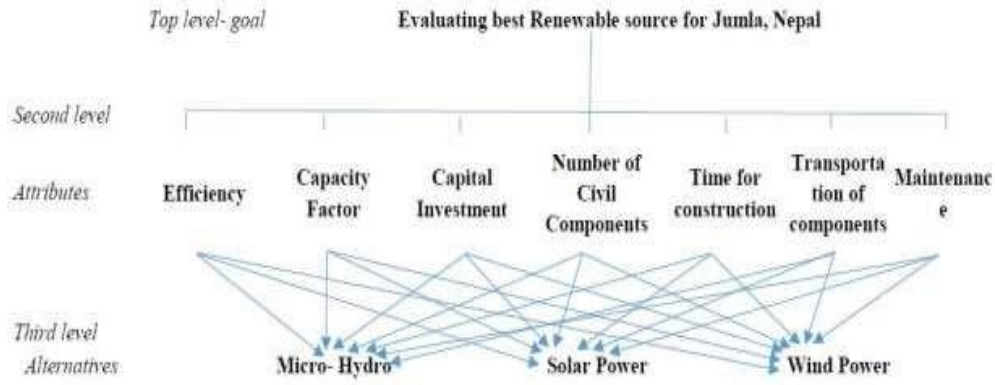

Fig. 1. A hierarchical structure

A hierarchical structure with a goal at the top level, the attributes at the second level and the alternatives at the third level is constructed as figure 1. The expert choice software was used for the data analysis, i.e., executing AHP. The pairwise comparison was done as as shown in figure 2.

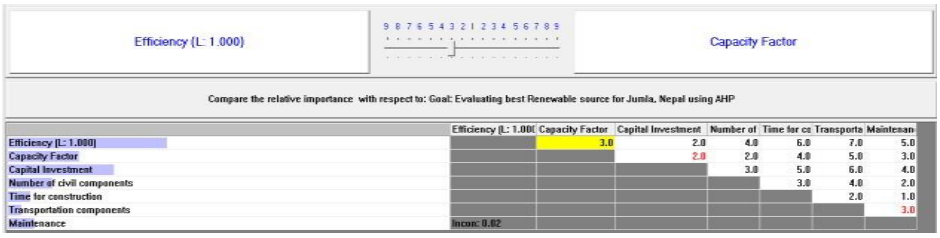

Fig. 2. Compare the relative importance with respect to goal

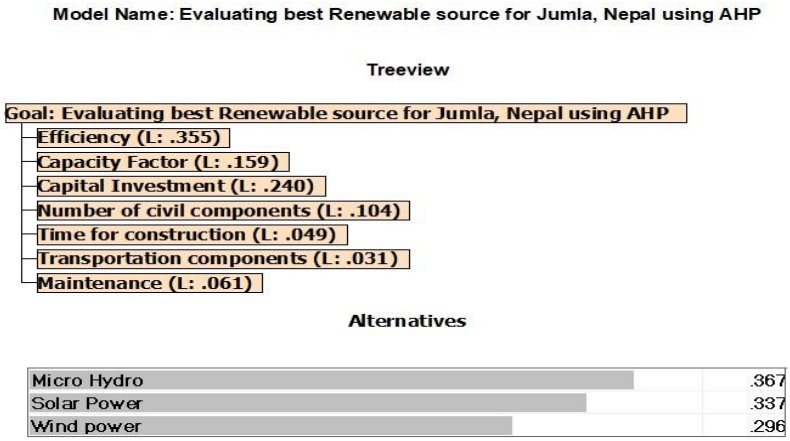

Fig. 3. Result in expert choice software

As shown in the figure 3, the generated result by the expert choice software, the micro-hydro is best alternative with highest score of 0.367 among solar power with 0.337 and wind power of 0.296 score.

V. CONCLUSION

As per the AHP examined with the reference of Literature review we find that Micro-hydro best suits in our case. This is followed by Solar Power and Wind power. The sub-criteria highest priority is achieved for efficiency and lowest priority is found to be for Transportation components The CR for all the inputs made is less than 0.1. This assures that there is no inconsistency as per the research entails.

The sub-criteria traced for this research can be further sub categorized in other criteria such as Economic aspects, technical aspects, social aspects, environmental aspects, and risk aspects. The results wherein we found Micro-hydro as most suitable in our case will help policy makers as well as local. Government to make new changes for specific region. Further the use of ANP and fuzzy logic can be done to re-evaluate the findings made in this research. This will help further to quantify the results and its use.

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REFERENCES

[1] A. Gurung, O. P. Gurung, and S. E. Oh, "The potential of a renewable energy technology for rural electrification in Nepal: A case study from Tangting," *Renewable Energy*, vol. 36, no. 11, pp. 3203-3210, 2011.

[2] R. Dhakal, B. K. Yadav, N. Koirala, B. B. Kumal, and H. Moussa, "Feasibility study of distributed wind energy generation in Jumla Nepal," *International Journal of Renewable Energy Research (IJRER)*, vol. 10, no. 3, pp. 1501-1513, 2020.

[3] P. Rijal, "95.5 percent of Nepalis have an electricity connection, report says" in *The Kathmandu Post*, ed. Kathmandu, Nepal: Kantipur Publication, 2019.

[4] N. Koirala *et al.*, "Review of low head turbines system of Nepal for rural electrification," in *2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA)*, 2017: IEEE, pp. 861-869.

[5] R. Dhakal *et al.*, "Prospects of Off Grid Energy Generation through Low Head Screw Turbine in Nepal," in *2018 7th International Conference on Renewable Energy Research and Applications (ICRERA)*, 2018: IEEE, pp. 537-543.

[6] R. Dhakal, R. K. Chaulagain, T. Bajracharya, and S. Shrestha, "Economic feasibility study of gravitational water vortex power plant for the rural electrification of low head region of nepal and its comparative study with other low head power plant," in *Conference proceeding of the 11th international conference on ASEAN knowledge networks for the economy, society, culture, and environmental stability, Kathmandu*, 2015.

[7] K. C. Surendra, S. K. Khanal, P. Shrestha, and B. Lamsal, "Current status of renewable energy in Nepal: Opportunities and challenges," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 8, pp. 4107-4117, 2011.

[8] M. E. Baysal and N. C. Çetin, "Priority ranking for energy resources in Turkey and investment planning for renewable energy resources," *Complex & Intelligent Systems*, vol. 4, no. 4, pp. 261-269, 2018.

[9] S. A. Aljamel, I. A. Badi, and A. G. Shetwan, "Using analytical hierarchy process to select the best power generation technology in Libya," 2017.

[10] C. R. Algarín, "An analytic hierarchy process based approach for evaluating renewable energy sources," 2017.

[11] Collegenp. "Tila Rural Muncipality " https://www.collegenp.com/institute/tila-rural-municipality/?fbclid=IwAR2IuNpwmn2rZY5-k_LQEN2ankOgCJ8ImEP5QZnTcpZF7-uEBvchQa1sUg (accessed 4/30/2020, 2020).

[12] T. L. Saaty and L. G. Vargas, "The seven pillars of the analytic hierarchy process," in *Models, methods, concepts & applications of the analytic hierarchy process*: Springer, 2012, pp. 23-40.

[13] V. Kinhal. "Efficiency of Wind Energy." https://greenliving.lovetoknow.com/Efficiency_of_Wind_Energy (accessed 4/27/2020, 2020).

[14] Energysage. "What are the most efficient solar panels on the market?" https://news.energysage.com/what-are-the-most-efficient-solar-panels-on-the-market/ (accessed 4/27/2020, 2020).

[15] Solarwatt. "SOLAR BATTERIES." https://www.solarwatt.com/solar-batteries (accessed 4/27/2020, 2020).

[16] S. Murmson. "The Average Photovoltaic System Efficiency." https://sciencing.com/average-photovoltaic-system-efficiency-7092.html (accessed 4/27/2020, 2020).

[17] R. Dhakal *et al.*, "Technical and economic prospects for the site implementation of a gravitational water vortex power plant in Nepal," in *2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA)*, 2016: IEEE, pp. 1001-1006.