USING MULTI-CRITERIA ANALYSIS IN DECISION MAKING REGARDING THE ADOPTION OF WIND PUMP FOR IRRIGATION IN BANGLADESH

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Abstract:

Multi-criteria analysis in decision making quantifies both objective and subjective factors. In the selection of the pumping system for irrigation objective factors are usually considered but subjective factors are overlooked. The selection of the best alternative may even get changed if we consider the subjective factors along with objective factors. In this paper analysis has been done to modify the Brown-Gibson Plant location model to consider the objective factors and Analytical Hierarchical Process (AHP) is applied to consider the subjective factors in the decision process of selecting wind pumping system, in place of traditional diesel and electric pumping system or in place of manual pump. To compare a wind pumping system with diesel and electric pump, a locally made wind pumping system is considered and annual useful amount of energy is calculated by writing a Computer Program. The combined analysis of both factors has shown that wind pumps get highest preference.

Keywords: Wind pump, Irrigation, Objective factors, Subjective factors, Multi-criteria Analysis.

JEL Classification: Q_{42}

1. Introduction

Due to the development of modern civilization the demand of energy all over the world is increasing day by day. Like energy, the need for water is increasing rapidly as supplies of traditional resources continue to diminish due to overuse, waste, and pollution. Unlike energy, the ability to harness local resources to produce water is not possible. However, we have the capability to use local energy resources to gain access to water supplies located underground in deep aquifers or in surface lakes, rivers, and streams.

The rural demand of water for crop irrigation and domestic water supplies is increasing. At the same time, rainfall is decreasing in Bangladesh and surface water is becoming scarce. Groundwater seems to be the only alternative to this dilemma. But the groundwater level is also declining, which makes traditional hand pumping and bucketing difficult. If these trends continue, mechanized water pumping will become the only reliable alternative for lifting water from the ground. The renewable energy sources are especially useful in remote locations where a steady fuel supply is problematic and skilled maintenance personnel are rare. Although world-wide wind resource is abundant (Van Wijk, A., Coelingh, J. P., 1993), proper utilization of these resources depends on available wind energy data, assumption about technology and available space. The wind speed and its duration are the key factors to design and to determine the use of wind energy. So before going to take any plan, accurate and reliable wind speed data must be generated by proper wind monitoring system. Also its economic and social benefit must be considered to develop framework for evaluation of wind pumping for irrigation.

Although the wind speed may vary from one location to another location, wind energy is more effective as it is free and almost available throughout the year. About twenty years ago, large numbers of experiments were done in the laboratory to develop the appropriate technology for utilization of wind energy throughout the world.

Now-a-days, wind energy conversion systems (WECS) have been extensively used in Germany, Denmark, Netherlands, UK, Russia, Spain, USA, Brazil and Australia. Asian counties, like China, India and Indonesia have also been using this technology. The wind resource assessments have been completed recently in Japan, Thailand, Srilanka and Malaysia. A few wind farms have been installed in Japan, Thailand and Srilanka. Malaysia is also going to install wind farms in wind prospective areas. Compared to other developing countries, Bangladesh is in initial stage for utilizing WECS. Some organizations like Local Government of Engineering Development (LGED), Bangladesh Centre for Advanced Studies (BCAS), Bangladesh University of Engineering and Technology (BUET) and Bangladesh Council of Scientific and Industrial Researc (BCSIR) have already started measuring wind speeds at some typical locations of Bangladesh with modern equipments.

Today in developing countries, where many regions are not connected to electric grid, the utilization of wind energy constitutes an economical and environmental friendly option for improving water supply. In developing countries majority of operating windmill is currently applied for drinking water supply and livestock watering (Ackermann, T., Soder, 2002, pp. 67-127). More recent approach is the use of windmill for irrigation. But this is a complex application.

The adoption of wind power for pumping irrigation water requires a consideration of several factors including: (a) technological development of wind machine and their associated equipment; (b) the potential harvestable wind energy in a given location; (c) the economic consideration of investment in wind machine (Gilley, J. R., Martin, D. L., Clark, R. N., 1985, pp. 133-146). There are several technological uncertainties such as performance characteristic of wind pump system like efficiency, life period, maintenance cost and economic uncertainty such as future costs of wind power system compared with alternative systems. Most of these factors are quantitative but several factors which cannot be quantified such as environmental pollution, resource prolongation, ease of maintenance, farmer's adaptability also need to be considered in making strategic decision regarding adaptation of technology. Wind pump should be compared with others alternative pumping system to make an optimum decision regarding policy guideline to use wind pump for irrigation.

2. State of the Art

Bangladesh is an agricultural country. In 2006-07 only 60.01% of total cultivated areas were irrigated by different mechanized equipment. Numbers of benefited farmer through mechanized equipment were reduced by 1.01% from the year 2005-06 due to increased price in oil, fuel and scarcity of electricity (Irrigation Equipment Survey report by Bangladesh Water Development Board, 2007).

Technical and Economical feasibility analysis of wind pump had been carried out by many researcher. To use wind energy for water supply, feasible design of wind pumping system which is accurate for location and its economical viability had been compared with conventional energy source.

Chowdhury et al. (1981, pp. 66-68) investigated that the low-cost sail-wing windmill was found to work with greater efficiency compared to other types of windmills developed in India.

Hossain, M. A. and Islam, M. Q. (1982, pp. 29-35) stated that a vertical axis sail-wing rotor having six sail was fabricated using locally available material and technology. It was couple with locally manufactured diaphragm pump to pump water for different static pressure heads. The rotor could be manufactured easily and it could pump reasonable amount of water even at low and variable speed.

According to Mahar, S.A. (1983, pp. 77-81) it was possible to pump 9.12 m^3 of water per day on a pump stroke of 40.5 mm taking wind speed 5 m/s, although speed varied mostly from 3 to 5 m/s per hour.

Sarker, M. and Hussain, M. (1991, pp. 855-857) analyzed the wind speed distribution of Bangladesh and showed that a wind machine in combination with a conventional diesel backup system would be economically viable for electricity generation only for offshore islands.

Suresh, R. and Block, D. S. (1998, pp. 117-129) carried out the study includes system design, operational status, performance in the field and a financial study of deep well wind pumps installed under the demonstration program by Ministry of Non-conventional Energy Sources in India. Eight of the twenty-two systems surveyed were found functional and detailed technical evaluations were also carried out. The paper highlighted the issues and problems of both technical and policy wise, faced by this sector. Recommendations were made to improve the system performance and better propagation of the technology.

Rahman, M. F. (1996, pp. 806-809) and Islam et al. (1995, pp. 183-192) found that there is a satisfactory wind for both water pumping and electricity generation in some region of Bangladesh. According to Islam et al. (1995, pp. 183-192) for irrigation of agricultural land No. 6 hand tube well could be driven more efficiently with a high solidity horizontal axis turbine made from discarded domestic ceiling fan blade compared with Sail wing and Savonius rotor.

Local Government of Engineering Department (LGED) designed and manufactured low cost wind pump with a rated capacity of 20 m^3 of water per day at 4 m/sec wind speed. Six such prototypes are already installed at different parts of the country (Islam, A. K. M. S., Islam, M. Q., Rahman, T., 2006, pp. 677-688).

Kumar, A. and Kandpal, T. C. (2007, pp. 861-870) developed a simple frame work to estimate utilization potential of renewable energy technology of water pumping for irrigation. The factors those were considered such as renewable resource data, ground water requirement for irrigation, its availability, affordability and propensity of use to invest in renewable energy device.

Purohit, P. (2007, pp. 3134-3144) developed a frame work for financial evaluation of water pumping for irrigation and showed that renewable energy technology for irrigation water pumping were not financially attractive to the users of diesel/electric pump. But before making any decisions, both tangible and intangible factors need to be jointly considered.

According to Irrigation Equipment Survey Report of 2007, about 50% of irrigation pump in Bangladesh was operated at a head of 6 m or less, depending on the terrain of the country. For driving these pumps, either diesel engine or electric motors were used. And about 30% of total irrigated area is irrigated by hand pumps (Irrigation Equipment Survey report by Bangladesh Water Development Board, 2007). And these pumps could be driven with the help of wind turbine. The mechanical wind pump could be used to drive positive displacement pump such as hand tube-well at low speed (Islam, M.Q., 1986).

From the frequency occurs, energy histogram and velocity duration curves for different station it was found by Islam et al. (2006, pp. 677-688) that wind speed was above 3m/s or more about 2400hr in the month from March to September. This speed was suitable for irrigation purpose. The above average winds were available during the hottest and the driest months of March, April and May.

Brown, P. A. and Gibson, D. F. (1972, pp. 1-10) developed a quantified model for facility selection application to Multiplan location problem. The Brown-Gibson model was developed for evaluating alternate plant locations using certain objective and subjective factors.

Punniyamoorthy, M. and Ragavan, P.V. (2003, pp. 72–78) used an extended Brown and Gibson model for the selection of Advanced Manufacturing Technology (AMT) in place of Traditional Conventional Technology in an automobile parts manufacturing industry. They showed that when the objective factors were only involved in the decision process, Conventional Technology was chosen instead of AMT but when subjective factors were involved along with the objective factors the decision was reverse.

Punniyamoorthy, M. and Ragavan, P.V. (2005, pp. 653–658) attempted to modify the Brown and Gibson plant location model to consider both the objective factors and subjective factors in the decision process of selecting automatic storage and retrieval system (AS/RS) in place of traditional storage system. Even though the decision to implement the AS/RS system in place of existing system of storage was supported by the objective factor measure it-self. The decision maker's confidence level was further enhanced and it was shown that the right decision had been taken if the subjective factors were considered.

3. Methodology

To find out annual amount of wind energy which can be utilized for water pumping, Weibull shape parameter and scale parameter are calculated from Weibull wind speed distribution. A mechanical wind pumping system is chosen considering water resource, water availability, climatic condition and economic condition of the poor farmer. Financial analysis has been carried out to compare with other's conventional system like diesel and electric pump. Several factors which cannot be quantified such as maintenance ability of local people, system risk, and environmental emission of these systems are also compared using analytical hierarchy method. Multi-attribute decision analysis technique 'Brown and Gibson' method has been modified, to develop a model for making decision on optimum choice of pumping option considering both qualitative factors and quantitative factors.

3.1 Financial analysis of wind, diesel and electricity driven pumping system

For analysis purpose a typical rotor pump set were used as shown in Figure no. 1. It consists of a Horizontal axis rotor made from discarded ceiling fan blade and coupled with no.6 hand tube well which is suitable for our climatic condition. Annual useful energy (AUE) is calculated using Equation 1 (Purohit, P., Kandpal, T.C., 2004, pp. 263–275).

$$\text{AUE}=15.77\left(\eta_{p,wind}\gamma c_p \rho_a AK \big/ c^K\right)\left[\int_{v_{ci}}^{v_r} v^{k+2} e^{-\left(v/c\right)^k} dv + v_r^3 \int_{v_r}^{v_o} v^k e^{-\left(v/c\right)^k} dv\right] \qquad (1)$$

Where, $\eta_{p,wind}$ represents the efficiency of pump used with the wind rotor, γ the mechanical availability factor of the windmill pump accounting for downtime during maintenance etc., Cp the coefficient of performance of the wind rotor, ρ_a the density of air, A the swept area of rotor, k the shape parameter, c the scale parameter, v the wind speed, v_{ci} the cut-in wind speed, v_{co} the cut-out wind speed, and v_r the rated wind speed of the windmill. By using wind pumping system the amount of diesel or electricity saved is calculated based on 5 hp diesel and electric pump. The annual amount of diesel saved (A_{ds}) by a wind pumping system can be estimated by using Equation 2.

$$A_{ds}=AUE/(CV_d \eta_{p,dep}) \quad (2)$$

Where, CV_d represents the caloric value of diesel. Similarly, the annual amount of electricity saved (A_{es}) by a wind pumping system can be estimated by using Equation 3

$$A_{es}=AUE/(3.6\eta_{p,emp}) \quad (3)$$

The annual useful energy, AUEemp, (in MJ) delivered by 5 hp electric motor pump is determined by the Equation 4

$$AUE_{emp} = (0.746 \times 3.6)\ 8760\ CUF_{emp}\ P_{emp}\ \eta_{p,emp} \quad (4)$$

Where, CUF_{emp} represents the capacity utilization factor of the system, P_{emp} the capacity of the electric motor pump, and $\eta_{p,emp}$ the overall efficiency of electric motor pump. Similarly the annual useful energy, AUE_{dep}, (in MJ) delivered by 5 hp diesel engine pump is calculated using the Equation 5.

$$AUE_{dep} = (0.746 \times 3.6)\ 8760\ CUF_{dep}\ P_{dep}\ \eta_{p,dep} \quad (5)$$

Where, CUF_{dep} represents the capacity utilization factor of the system and $P_{dep,}$ the capacity of the diesel engine pump.

The unit cost of useful energy (UUE) can be determined as the ratio of the total annual cost of the water-pumping system to the total annual useful energy (AUE) delivered by the system. Here total annual cost of the water-pumping system consists of annualized capital cost, annual operation, repair and maintenance cost and fuel cost as shown in the Equation 6.

$$UUE = [C_0\ [d\ (1+d)^t / \{d\ (1+d)^t - 1\}] + C_i + \text{fuel cost}]/\ AUE \quad (6)$$

Where, C_0 represents the capital cost of system, C_i the annual repair and maintenance cost, d the discount rate and t the useful lifetime of the water-pumping system. Total annual costs consist of annual fixed costs and annual variable costs. Fixed cost is initial investment cost in which rotor- pump set cost, installation cost, civil work, land cost etc. are included. The unit cost of water (UCW) can be determined as the ratio of the total annual cost of the system to the annual amount of water pumped by the system as in the Equation 7

$$UCW = [C_0\ [d\ (1+d)^t / \{d\ (1+d)^t - 1\}] + C_i + \text{fuel cost}]/\ (AUE/\ \rho gH) \quad (7).$$

Sample calculations are based on the information available in the literature and of that provided by the manufacturers. Since in Bangladesh wind energy utilization is still in project level, no survey can be carried out regarding cost elements. So cost calculations are based on rotor-pump set capital cost. The annual repair and maintenance cost of windmill pump has been taken to be (1.5-2) % of the cost of windmill pump which consists the charges of regular service of the windmill, painting of the windmill to reduce the corrosion (once in 6 years) and the cost of replacement of pump valves and pump washers (once in 3 years) etc. (Islam, M. Q., Ali, M., Saha, S., 1995, pp. 183-192). For the diesel engine pump set, no major repair/replacement is required except overhauling of the engine (after 5000 hr of operation) besides cost of lubricants. The maximum annual repair and replacement cost has been taken as 10% of the capital cost of the diesel engine pump set (Ravindranath, N. H., Hall, D.O., 1995).

Taking same cut-in wind speed V_{ci} = 2.5 m/sec, the cut-out wind speed V_{co} = 7 m/sec and the rated wind speed of the windmill v_r =3 m/sec for all station annual useful energy has been calculated. Annual Useful Energy in each station varies with shape parameter and scale parameter only. During each month, each station has different value of shape parameter and scale parameter of wind speed distribution. So based on different design month, each station has different value of annual useful energy. For multi-attribute analysis unit cost of water, unit cost of energy and life time and efficiency is taken into consideration as objective factor.

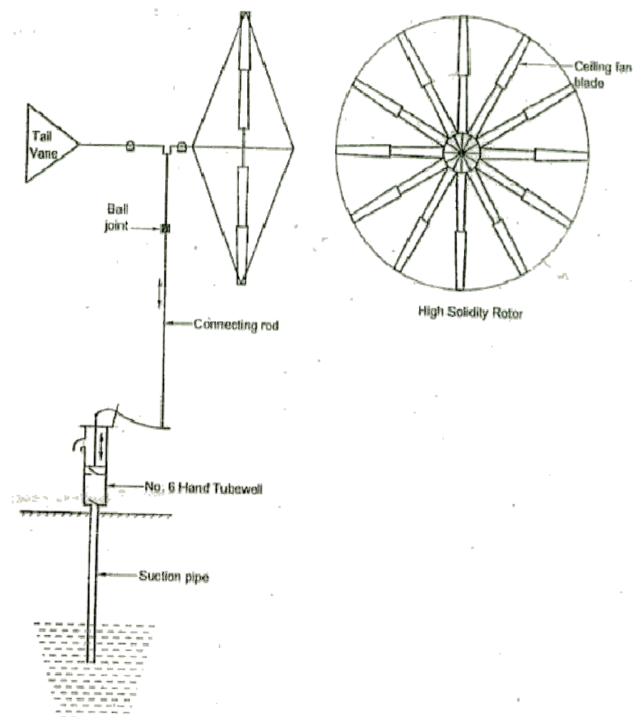

Figure no. 1. High solidity wind turbine with No. 6 hand tube well

3.2 Brown-Gibson Model (BGM)

The Brown-Gibson model (Brown, P. A., Gibson, D. F., 1972, pp. 1-10) was developed for evaluating alternate plant locations using certain objective and subjective factors. It is a quantitative model, which helps in selecting the best location from a given set of alternatives. The model is very useful in the sense that it is able to quantify the subjective factors as well. In this model, both the subjective and objective factors are converted into consistent and dimensionless indices.

If the decision under consideration consists of 'm' alternatives, then the preference measure of particular alternative 'i' is measured as expressed in the Equation 8

$$PSPM_i = CFMi \times \{\alpha \times OFM_i + (1-\alpha) SFM_i\} \quad (8)$$

Where,

$PSPM_i$ =Pumping system preference measure for alternative i;

OFM_i= Objective factor measure for alternative i= $OFE_i \times (1/\Sigma\ OFE_i)$;

OFE_i = Objective factor effectiveness of alternative i;

SFM_i= Subjective factor measure for alternative i;

CFMi= Critical factor measure for alternative i;

α = Objective factor weightage.

CFMi is assigned a value of either 1 or 0. The above expression is framed in such a manner that an alternative is not at all considered, if it does not possess the critical factor. Here necessary wind is critical factor for wind pump, diesel for diesel pump and electricity for electric pump. In the BG model's objective factor expression incorporates the factors related with the cost dimension only but the model did not spell out how to handle factors that are related with time (to be minimized or maximized), Efficiency of pumping system (to be maximized) and other non-financial objective factors that are to be minimized or maximized. Considering the above limitations, an effort has been made to develop the new objective factor expression to measure Pumping system preference measure (PSPM).

3.3 Development of New Objective Factor Expression

Objective factors related with the evaluation of different pumping option could be grouped into two types. Factors that need to be minimized such as cost and the factors those need to be maximized such as- lifetime and efficiency. The expression is framed in such a manner that the factors are converted into consistent and dimensionless indices. The sums of each index are equal to one. The newly developed objective factor expression is used to evaluate the objective factors such as Unit cost of useful energy, Unit cost of water, Lifetime and efficiency.

Objective factor effectiveness for alternative i, is calculated as in the Equation (9).

$$OFE_i = \{UUEM_i\ (\Sigma\ 1/\ UUEM_i)\}^{-1} + \{\ UCWM_i\ (\Sigma 1/\ UCWM_i)\}^{-1} +\ TM_i\ /\ \Sigma TM_i + EM_i/\Sigma\ EM_i \quad (9)$$

Where,

$UUEM_i$ = Unit cost of useful energy to be minimized for alternative i;

$UCWM_i$ = Unit cost of water to be minimized for alternative i;

TM_i = life time to be maximized for alternative i;

EM_i = Efficiency to be maximized for alternative i.

Table no. 1 shows objective factors for Kutubdia station considering March as design month.

Unit cost of useful energy and unit cost of water are treated as costs to be minimized. Life time and efficiency of pumping system are considered to be maximized.

3.4 Subjective factor measures

The subjective factors related with alternatives are evaluated using AHP to arrive at the subjective factor measure (SFM). Steps Involved in the Analytical Hierarchy Process (AHP) are as follows:

1. Identifying the subjective factors that influence the decision.
2. The subjective factors are grouped, based on their interdependence, as criteria, sub-criteria, and sub-sub-criteria etc.
3. Formulating a hierarchical structure, i.e. the objective function is arranged in the top level, criteria, sub-criteria and sub-sub-criteria and alternatives are arranged in the intermediate and lower levels.
4. For each level constructing a pair wise comparison matrix A.
5. Finding the maximum Eigen value (λ_{max}) and its corresponding Eigen vector using: Equation $AW = \lambda_{max} W$

Here,

A = observed matrix of pair wise comparison;

λ_{max} = largest eigen value of A;

W = its principal eigen vector (a measure of relative importance weightage of the criteria or sub-criteria or the alternative).

6. Then finding consistencies index (CI) using Equation, $\{(\lambda_{max} - N) / (N - 1)\}$.

Where, N is the order of the matrix A. Then from table of random consistency, value for corresponding N was taken. CR is the ratio between CI and this table value. If the CR value is 10% or less, the matrix is consistent, otherwise repeat steps 4 to 6 until consistency is achieved.

4. Results

The results are presented below.

4.1 Performance Measure

The objective factors measure shows that the weight-age of three systems are very close to each other and wind pumping system has lowest performance measure. The decision is further strengthened by considering the subjective factors and evaluating the same using the AHP, and the factors related with the justification processes is shown in Figure no. 2.

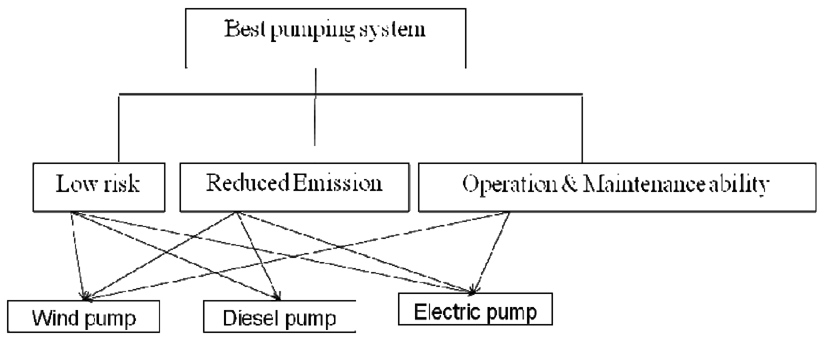

Figure no. 2. Qualitative factors related with pumping system.

Today environmental impact of technology is highly weighted globally. In respect of Bangladesh, since wind pumping is still in project level so only environmental emission are considered as one of environment related subjective factor. When a pumping option is selected for a particular area, if energy are not available while system is in operating condition then there is a chance of failure of pumping system. Moreover, operation and maintenance ability of pumping option is highly important. Preference should be from local market regarding the availability of spare parts. Also local people should maintain it. Here only one level of subjective factors is considered.

By interacting with the people concerned, the pair-wise comparison value matrix is arrived at and the relative weight-age (principal eigenvectors) between the factors is determined using the Analytical Hierarchy Process (AHP) for factors shown Table no. 2.

In the comparison matrices, the factors in a row are compared with the factors in a column and the comparison value is given in the crossing cell. When the factor in a row is stronger (more significant) than the factor in a column, then the crossing cell is strong and its corresponding cell, which compares the latter with the former, takes a reciprocal value and is weak. It is enough for the experts to give values for the strong cells. The weak cells take the value of the reciprocal of the corresponding strong cell and the diagonal cells take the value of 1. Thus, there are only 3 independent cells in the matrix shown in the Table no. 2. Similarly the pair-wise comparison matrices are formed for the three system of pumping with respect to each subjective factor shown in the Table no. 3, 4 and Table no. 5. The strong cell may take a value between 1 and 9 based on the relative importance. Table no. 6 assists in assigning values for each cell.

A group of experts are involved in determining the judgmental comparison value required by the independent cells in the comparison matrices. The relative importance perceived by the experts may differ. Hence, a single judgmental value is not aroused. Even though the perceptions of different experts are not same, and they do not converge to a single value, they will certainly narrow down to a range of values. But here only one judgmental value is used as an example. Set of comparison matrices and their respective eigen vectors, which give the relative preference of the alternatives with respect to that factors, are as shown in the Table no. 3, 4 and Table no. 5.

The subjective factor measure of an alternative is arrived at from the relative weight-age of the subjective factors (given by the eigen vector of the comparison matrix comparing the factors), and the relative score of the alternatives with respect to each of the factors (given by the eigen vector of the comparison matrices set comparing the alternatives with respect to each of the factors). The relative score of the alternative with respect to the subjective factor is multiplied by the relative weight-age of that subjective factor, and all the scores of that alternative are summed. The relative weight-age (principal eigenvectors) for three system of pumping with respect to subjective factors is shown in the Table no. 7.

The subjective factor measures are calculated for the subjective factors shown in Figure no. 2 for the alternatives are as follows.

$SFM_{wind}=0.74\times0.08+0.72\times0.74+0.74\times0.18=0.73$

$SFM_{dep}=0.16\times0.08+0.06\times0.74+0.08\times0.18=0.07$

$SFM_{emp}=0.10\times0.08+0.22\times0.74+0.18\times0.18=0.20$

By interacting, it was understood that the people concerned considered the subjective factors as a secondary one compared to objective factors. Thus there was a consensus to provide $\alpha = 0.6$ weight-age for objective factor measure and 0.4 $(1-\alpha)$ weight-age for the subjective factor measure.

The calculated objective factor measure and the subjective factor measure are substituted into Equation 8 to arrive at pumping systems preference measure.

Pumping system preference measure for wind pump = 0.44

Pumping system preference measure for diesel pump = 0.23

Pumping system preference measure for electric pump=0.33

Since wind pump has highest pumping system preference measure, so it should be chosen first. Then electric pump after that diesel pump should be selected.

5. Discussion

The annual useful energy delivered by a water-pumping windmill depends upon the design parameters of the windmill (swept area of rotor, co-efficient of performance of the wind rotor, etc.) and location specific parameters such as air density, wind speed etc. In the present analysis only variable parameter was wind speed distribution. For that reason annual useful energy delivered by wind pump varies from region to region for different design month. In each station annual useful energy delivered by diesel pump and electric pump is fixed. For this reason, annual water output, unit cost of energy and unit cost of water pumped by diesel and electric pumps are fixed.

As diesel pump and electric pump capacity are higher than wind pump, so amount of useful energy and water output of wind pump are less than that of diesel and electric pump. So if high efficiency wind pump are used in place of locally made wind pump, useful energy and water out put will be increased. Ultimately, unit cost will be reduced. As wind is free if we use wind powered pump in place of diesel or electric pump then large amount of diesel or electricity will be saved.

If only objective factors are included in the preference measure then Figure no. 3 shows that for kutubdia station, wind pumping systems objective factors measure for all design month is lower than diesel and electric pump. Similar result was found for different station. Preference measure of electric pump is higher than diesel pump because of high price of diesel and comparatively low efficiency of diesel pump. But in Bangladesh there is a scarcity of electricity, especially in remote and coastal area. As cost of diesel is increasing day by day, so diesel pumping system is not suitable for our poor farmer. Hence locally made wind pumping system can be used for minor irrigation purpose.

When subjective factors are analyzed, for different location relative weightage between each factor are same and pumping system are also given same weightage corresponding to each factor. Subjective factors measure shows that wind pump is most preferable among the three pumping System. Then electric pump and after that diesel pump as shown in the Figure no. 4.

When subjective factors and objective factors are combined to find out pumping system preference measure, it is striking to notice that wind pumping system get highest preference measure compared with electric pump and diesel pump although objective factors are given more weightage than subjective factors. Figure no. 5 shows that for design month June, July and August preference measure of wind pump is increased.

When alternative system preference are measured considering both subjective factor and objective factors and if objective factors are given more elevated weight-age compared with subjective factor measure then the Figure no. 6 shows that preference measure of wind pumping system are reduced. The higher the objective factor weight-age the more preference is given to electric pumping system. In most case diesel pumping preference level are lower than wind pump. So it can be concluded that in remote location where no diesel and electricity is available, wind powered pump can be used for irrigation where mean annual wind speed is 2.5 m/sec or more. Also sometime wind pump is best option when diesel and electricity is available. As number of wind pump increases, unit cost will be reduced.

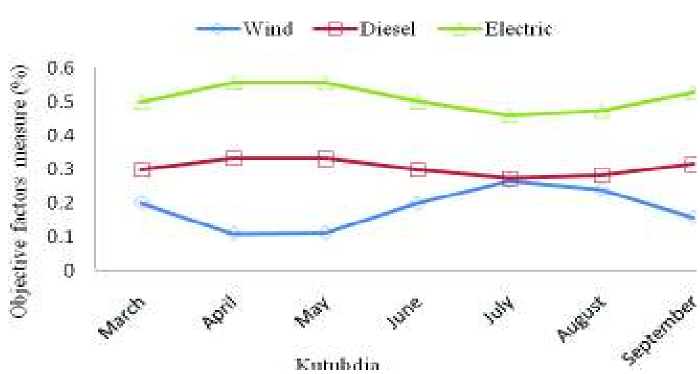

Figure no. 3. Objective factor measure of different system

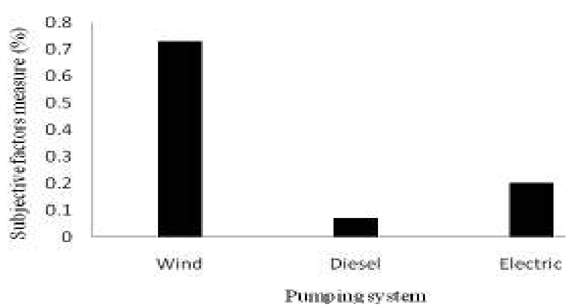

Figure no. 4. Subjective factor measure of different system

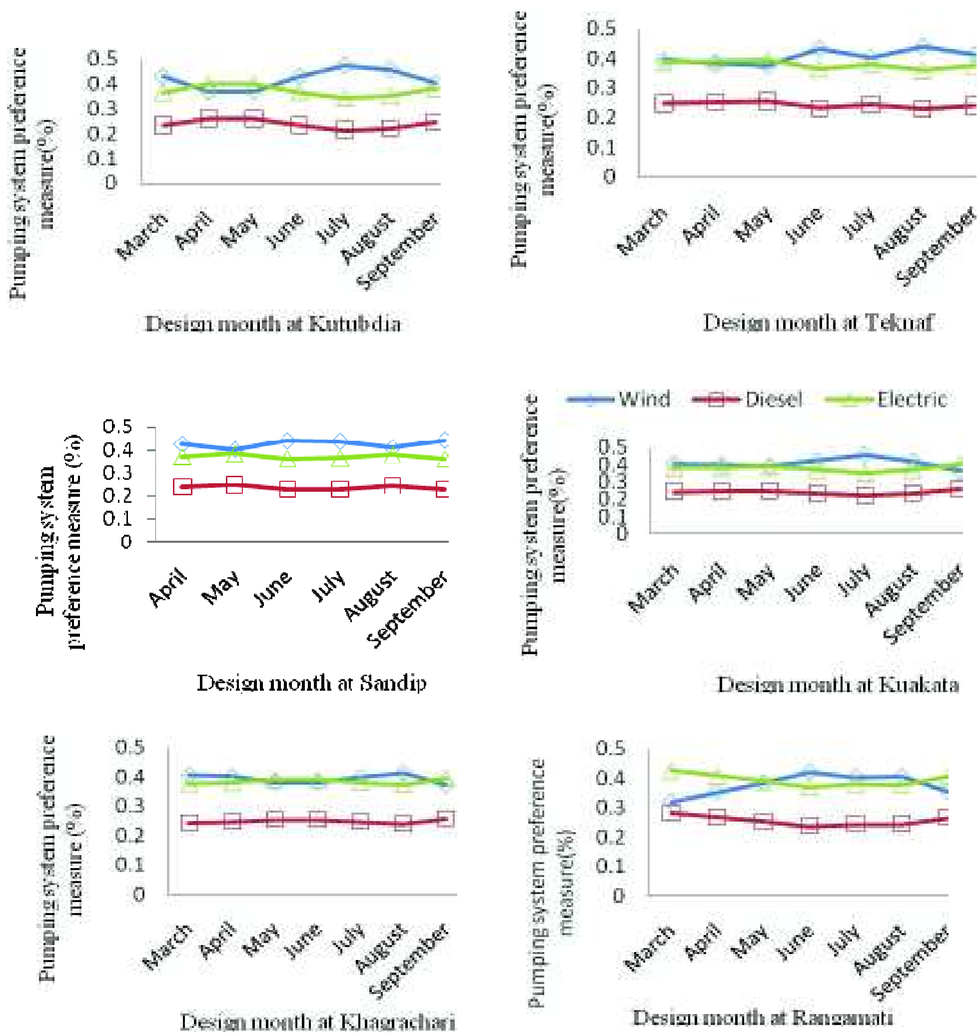

Figure no. 5. Pumping system preference measure for different location

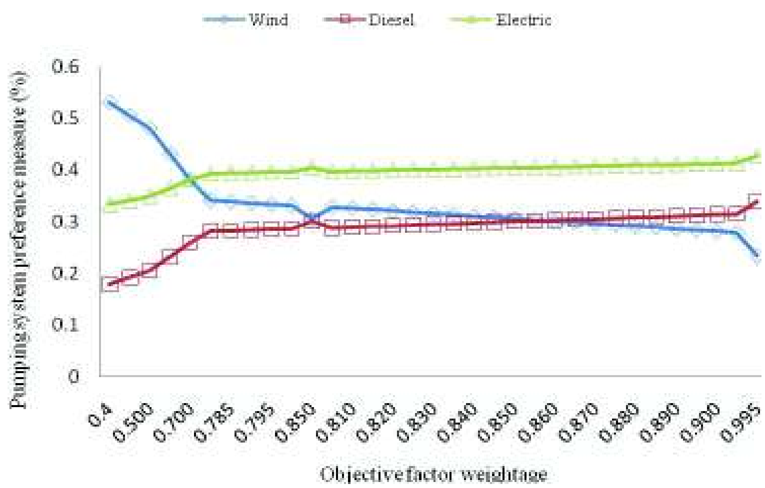

Figure no. 6. Pumping system preference measure with respect to objective factors weight-age

6. Conclusions

In regard to the present analysis the following conclusions are drawn:

(i) Amount of annual useful energy vary with wind data and wind pumping system. Annual amount of useful energy by wind pumping system is less than diesel pump or electric pump. Annual amount of useful energy will be increased if higher performance wind pump is selected with same speed. Again, if wind speed increases annual useful energy will also increase.

(ii) If initial investment is increased in wind pump then annual useful energy will increase. But unit cost of energy and water output will not increase with the same ratio. In the present analysis unit cost of energy and unit cost of water output is higher for wind pump compared to other relevant pumps (Example, for March Kutubdia 5.53Tk / MJ and 0.54Tk/ m^3).

(iii) If wind pump is used in place of diesel pump, then annual amount of fuel saved for a single location will be 32 litres and with respect to electric pump will be 312.5 kwh.

(iv) Decision should not be firmly taken considering only one set of parameter. Furthermore, ultimate decision depends on qualitative factor along with quantitative.

(v) When qualitative factors are considered in combination with quantitative term it has been shown that wind pumping system achieves highest performance measures than electric and diesel pump.

(vi) For remote area where wind speed is 2.5 m/s or above wind pumping system which is indigenously made can be used efficiently for irrigation purpose in plane lands with wide space.

Table no. 1

Objective factors including costs for month march, Kutubdia

Objective / Factors Pumping Options	Unit cost of useful energy (UUE). Tk / MJ	Unit cost of water (UCW). (Tk/ m^3)	Lifetime	Efficiency
Wind Pump	5.53	0.54	10 years	0.2
Diesel Pump	4.134	0.40	20,000hr	0.52
Electric Pump	3.28	0.32	20,000hr	0.40

Table no. 2

Pair wise comparison matrix and eigen vectors between subjective factors

Subjective Factors	Low Risk	Emission	Operation & Maintenance ability	Eigen vector
Low Risk	1	1/ER (weak)(1/7)	1/OR (weak)(1/3)	0.08
Reduced Emission	ER (strong)(7)	1	EO (strong)(6)	0.74
Operation & Maintenance ability	OR (strong)(3)	1/EO (weak)(1/6)	1	0.18

ER– Importance of Reduced Emission over low Risk;

OR- Importance of Operation & Maintenance ability over low Risk;

EO- Importance of Emission over Operation & Maintenance ability.

Table no. 3

Comparison matrix and eigen vector between pumping system for Low Risk

Pumping System	Wind Pump	Diesel Pump	Electric Pump	Eigen vector
Wind Pump	1	WD_r Strong (6)	WE_r Strong (6)	0.74
Diesel Pump	$1/WD_r$ Weak (1/6)	1	DE_r Strong (2)	0.16
Electric Pump	$1/WE_r$ Weak (1/6)	$1/DE_r$ Weak (1/2)	1	0.10

WD_r=Importance of wind pump over diesel pump in respect of low risk;

WE_r= Importance of wind pump over electric pump in respect of low risk;

DE_r= Importance of diesel pump over electric pump in respect of low risk.

Table no. 4

Comparison matrix and eigen vector between pumping system for reduced emission

Pumping System	Wind Pump	Diesel Pump	Electric Pump	Eigen vector
Wind Pump	1	WD_e Strong (9)	WE_e Strong (5)	0.72
Diesel Pump	$1/WD_e$ weak (1/9)	1	$1/ED_e$ weak (1/5)	0.06
Electric Pump	$1/WE_e$ weak (1/5)	ED_e Strong (5)	1	0.22

WD_e= Importance of wind pump over diesel pump in respect of reduced emission;

WE_e= Importance of wind pump over electric pump in respect of reduced emission;

ED_e= Importance of electric pump over diesel pump in respect of reduced emission.

Table no. 5

Comparison matrix and eigen vector between pumping system for operation & maintenance ability

Pumping System	Wind Pump	Diesel Pump	Electric Pump	Eigen vector
Wind Pump	1	WD_o strong (7)	WE_o strong (6)	0.74
Diesel Pump	$1/WD_o$ weak (1/7)	1	$1/ED_o$ Weak (1/3)	0.08
Electric Pump	$1/WE_o$ weak (1/6)	ED_o Strong (3)	1	0.18

WD_o= Importance of wind pump over diesel pump in respect of Operation & Maintenance ability;

WE_o= Importance of wind pump over electric pump in respect of Operation & Maintenance ability;

ED_o= Importance of wind pump over diesel pump in respect of Operation & Maintenance ability.

Table no. 6

Ratio scale

Numerical Rating	Verbal judgment or preference
1	Equal importance
3	Weak importance of one over another
5	Essential or strong
7	Very strong importance
9	Absolute importance
2,4,6,8	Intermediate values

Table no. 7

Relative weighage of factors with respect to pumping system

Subjective factors	Principal eigen vector for wind pump	Principal eigen vector for diesel pump	Principal eigen vector for electric pump
Low risk	0.74	0.16	0.10
Reduced emission	0.72	0.06	0.22
Operation & Maintenance ability	0.74	0.08	0.18

References

1. Ackermann, T., Soder, (2002), *An overview of wind energy status 2002*, in: “A renewable and sustainable energy review”, vol. 6 no. 1 and 2, p. 67-127

2. Brown, P.A., Gibson, D.F., (1972), *A quantified model for facility site selection application to multi-plant location problem*, in: "AIIE Trans 4", pp. 1–10

3. Chowdhury, S.C., Ramana Rao, B. V., Sharma, P., (1981), *Performance of low-cost Sail-Wing Windmill*, in: "Journal of Agriculture Mechanization in Asia, Africa and Latin America", vol. 12, no. 1, pp. 66-68

4. Gilley, J.R., Martin, D.L., Clark, R.N., (1985), *Potential use of wind power for pumping irrigation water*, in: "Energy in agriculture", no. 4, pp. 133-146

5. Hossain, M.A., Islam, M.Q., (1982), *Sailwing Rotor for Pumping Water in Bangladesh*, in: "Renewable Energy Review Journal", vol. 4, no. 1, pp. 29-35

6. Islam, A.K.M.S., Islam, M.Q., Rahman, T., (2006), *Effective renewable energy activities in Bangladesh*, in: "Renewable Energy journal", vol. 31, pp. 677-688

7. Islam, M.Q., (1986), *A Theoretical Investigation of the Design of Horizontal Axis Wind Turbines*, in: "PhD Thesis", Vrijt Universiteit, Brussel

8. Islam, M.Q., Ali, M., Saha, S., (1995), *Low cost High Solidity Horizontal Axis Wind turbine for irrigation in Bangladesh*, in: "Journal of Energy, Heat and Mass Transfer", vol. 30, pp. 183-192

9. Kumar, A., Kandpal, T.C., (2007), *Renewable energy technology for irrigation water pumping in India: A preliminary attempt towards potential estimation*, in: "Energy 32", pp. 861-870

10. Mahar, S.A., (1983), *Use of wind power in New Zealand: Its Scope in Pakistan*, in: "Journal of Agricultural Mechanization in Asia, Africa and Latin America", vol. 14, no. 2, pp. 77-81

11. Punniyamoorthy, M., Ragavan, P. V., (2003), *A Strategic Decision Model for the Justification of Technology Selection*, in: "Journal of Advanced Manufacturing Technology", vol. 21, pp. 72–78

12. Punniyamoorthy, M., Ragavan, P. V., (2005), *Justification of Automatic Storage and Retrieval System (AS/RS) in a Heavy Engineering Industry*, in: "Journal of Advanced Manufacturing Technology", vol. 26, pp. 653–658

13. Purohit, P., (2007), *Financial evaluation of renewable energy technologies for irrigation water pumping in India*, in: "Journal of Energy Policy", vol. 35, pp. 3134-3144

14. Purohit, P., Kandpal, T.C., (2004), *Techno-economic evaluation of water pumping windmills in India*, in: "International Journal of Global Energy Issues", vol. 21, no. 3, pp. 263–275

15. Rahman, M.F., (1996), *Prospect of wind energy in Bangladesh*, in: "Proceedings of world renewable energy Congress (WREC)", 15-21 June, Denver, Colorado, pp. 806-809

16. Ravindranath, N.H., Hall, D.O., (1995), *Biomas Energy and Environment: A Developing Country Perspective of India*, Oxford University Press, Cambridge

17. Sarker, M., Hussain, M., (1991), *The potential of wind electricity generation in Bangladesh*, in: "Renewable energy journal", vol. 1, no. 5 and 6, pp. 855-857

18. Suresh, R., Block, D.S., (1998), *Field Testing of Geared Type Deep Well Wind Pumps in India*, in: "Journal of Wind Engineering", vol. 22, no. 2, pp. 117-129

19. Van Wijk, A., Coelingh, J.P., (1993), *Wind energy potential in OECD Countries*, University of Utrecht

20. Irrigation Equipment Survey report by Bangladesh Water Development Board, (2007)

21. Wind force - 10 a blue print to achieve 10% of the world electricity from wind power by 2020, Published by European Wind energy association, London, UK. Forum for Energy and Development, Copenhagen, Denmark and Greenpace international