SELECTION OF RENEWABLE ENERGY SOURCES USING ANALYTIC HIERARCHY PROCESS

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Summary: *This paper presents an application of Analytic Hierarchy Process for selection of renewable energy sources and technology in context of Bangladesh. Three options – solar energy, wind energy and biogas have been evaluated based on selected criteria like per unit cost, technical (equipment design and complexity, plant design, equipment and parts availability, plant safety, maintainability, training required), location (flexibility, plant size), environment (impact on ecosystem, noise) and social impact (people's acceptability, quality of life). The importance weights of the criteria and sub-criteria as well as preferential ranking of options have been determined by eliciting expert judgment through pair-wise comparisons. The findings show that within the technological constraints, solar energy is the most preferred option followed by biogas and then wind energy. However, as time progresses and technology improves, the preferential ranking might change.*

1. Introduction

In recent years, there is a growing interest in Renewable Energy (RE) sources both in the developed and the developing countries; in the developed countries for clean energy sources and in the developing countries to meet growing demand for energy. For an energy starved country like Bangladesh, harnessing renewable energy sources is of paramount importance for sustainable economic growth so that the economic development activities of different sectors are not constrained due to shortage of energy. According to a report (Ministry of Energy, Draft Policy, 2002), less than one third of the total population in Bangladesh has access to electricity. The major energy sources as of now are biomass fuel (55%), natural gas (24%), imported coal/oil (19%) and hydro-electricity (2%). In 1996, the Government of Bangladesh (GOB) has for the first time adopted a National Energy Policy setting a number of objectives which give coverage to RE also. Some of the objectives worth mentioning here are: (i) to meet energy needs of different zones of the country and socioeconomic groups, (ii) to ensure optimum development of all the indigenous energy sources (e.g. commercial fuels, biomass fuels, and other renewable energy sources), (iii) to ensure environmentally sound sustainable energy development programs causing minimum damage to environment, and (iv) to encourage public and private sector participation in the development and management of energy sector. The Government of Bangladesh has vision to electrify the whole country within the year 2020. But, major electrification through grid expansion is not a viable option for most part of Bangladesh mainly due to inaccessibility and low consumer density. Renewable energy, on the other hand, is environmentally sustainable, socially acceptable and economically viable option in the off-grid locations. Notwithstanding the declared policy and the effort of a number of government and non-government (both local and international) organizations, there is no significant progress in the development and commercialization of renewable energy due to technical, financial and other factors. There is also a great deal of uncertainty regarding the choice of suitable source of energy at a given location.

Given the geographical location of Bangladesh, the principal sources of renewable energy are solar, wind and biogas (leaving out bio-mass which is principally used for domestic cooking and heating purposes in rural areas). The technologies for harnessing energy from these sources are now in a state where commercial exploitation is feasible. The choice of a particular RE technology, however, cannot be based solely on techno-economic factors. One has to consider social, environmental and location aspects also. Thus, the choice of a renewable energy technology is a multi-criteria decision making (MCDM) problem.

There are several techniques now available in the literature to deal with multi criteria decision-making problem (Goodwin and Wright, 1998; Saaty, 1980; Keeney and Raiffa, 1976; Van Laarhoven and Pedrycz, 1983). Some of the well known techniques are Multi Attribute Utility (MAU) model, Simple Multi Attribute Rating Technique (SMART), Analytic Hierarchy Process (AHP) and Fuzzy Hierarchical Decision Making (FHDM) method. Among these AHP is possibly the most familiar and extensively used MCDM method. It is simple and easily comprehensible. In spite of some criticisms leveled against it (Belton and Gear, 1983; Belton and Gear, 1985; Harker and Vargas, 1987), this method has been widely applied in many MCDM problems, e.g. technology selection, vendor selection, project management, plant layout, maintenance strategy selection, transportation fuels and policy etc.

The paper presents an application of AHP for selection of renewable energy sources in the context of Bangladesh. In section 2, a brief overview of renewable energy sources and technology has been given. The methodology of AHP has been briefly described in section 3, followed by a description of decision criteria and their physical significance in section 4. Detailed AHP analysis for selection of RE technology has been presented in section 5. Section 6 includes discussion and conclusion.

2. Brief Overview of RE Sources and RE Technologies

As mentioned in the introduction, Bangladesh now faces a great problem in the field of power generation. It is now acknowledged that renewable energy sources are the only alternatives that can truly ensure a sustainable system for supply of energy. In Bangladesh extensive research and development activities have been going on in search for renewable sources of energy. Because of its location, Bangladesh possesses good potential for RE technology, but not all are practically viable. As far as power generation is concerned, the following alternative sources have been considered in this study:

- Solar Energy
- Wind Energy
- Biogas

The other renewable energy sources are still in the experimental stage and hence not considered. A brief overview of renewable energy activities in Bangladesh (Islam and Infield, 2002) is given below.

2.1 Solar Energy

Considering the geographic location of Bangladesh between $20^0\,34'$ and $26^0\,38'$ N latitude and $88^0\,01'$ and $98^0\,41'$ E longitude, experts remark that Bangladesh has good potential for solar energy. The average daily solar radiation in Bangladesh varies form 5.0 kWh / m^2 in winter to 8.36 kWh / m^2 in summer. Experts remark that it is fairly good. The period from February to June gives excellent insolation over Bangladesh followed by reasonably good sunshine during September to October. The winter months of short days during November to January and during peak monsoon during July and August, the country has less insolation. The total solar energy radiation incident in Bangladesh per year is about 17 billion TOE (ton of oil equivalent). Hence, the overall scenario of solar energy prospect in Bangladesh is good enough for application in power generation.

Amongst the various technologies developed in solar thermal system, the solar electric or photovoltaic (PV) system is the most attractive to an electric utility. The direct conversion of sunlight to electricity by means of solar cells is the PV effect. Apart from PV modules batteries, charge controllers etc. are required. Currently it is one of the fastest growing forms of electricity generation worldwide.

In Bangladesh different organizations have initiated the use of PV technology for power generation. The Rural Electrification Board (REB), Local Government Engineering Department (LGED), Rahimafrooz Bangladesh Ltd., Bangladesh Rural Advancement Committee (BRAC) Foundation, First Bangladesh Technologies (FBT), Grameen Shakti have installed this technology. Significant positive changes took place that resulted in further research and development activities related to this technology.

2.2 Wind Energy

Wind energy is another important renewable energy source. Wind is available in Bangladesh during the monsoon and around one to two months before and after the monsoon. During the months starting from late October to the late middle of February, wind either remains calm or too low to be of any use. However, using the wind turbines power can be extracted from wind. The turbine – generator coupling generates the electricity.

To generate electricity from wind energy, a wind velocity of about 7.00 m/s is required. But in Bangladesh the average wind velocity is about 3.00 m/s. However, the wind mapping is yet to be completed and the process has started very recently. The Local Government Engineering Department (LGED) has started the process of wind mapping. Hence, it is still premature to discourage the potential of wind resource. Experts remark that some parts of the coastal areas, and some districts have good prospect.

2.3 Biogas

Nowadays biogas has been recognized as an attractive and viable energy source. The development of commercial Biomass Gasification Plant for generation of electrical power as well as thermal energy from agro waste has been found quite successful. In this system, the solid biomass, controlled air and water produce a combustible gas. This gas has calorific value of about 1200 – 1250 kCal / Nm^3 which is being utilized for generation of electrical power and / or thermal energy. With the help of additional engines this electricity can be generated.

This gasification plant is highly suitable as a decentralized power station and the LGED has already initiated the technology. They have already installed a unit of small capacity (4 kW) unit that uses the poultry wastes. Experts remark that this source of energy has good prospect in the context of Bangladesh especially in the rural places.

3. The Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a decision – aiding method developed by Saaty. It provides a systematic, explicit, rigorous and robust mechanism for eliciting and quantifying subjective judgments. It is widely applicable because of its inherent capability to handle both quantitative and qualitative attributes and data uncertainty.

The steps of AHP, developed by Saaty, are as follows:

1. Define the decision problem and determine its object.
2. Define the decision criteria in the form of a hierarchy of objectives. This hierarchical structure consists of different levels. The top level is the objective to be achieved. This top level consists of intermediate levels of criteria and sub-criteria, which depend on subsequent levels. The lowest level consists of list of the alternatives.
3. For making pair-wise comparisons, structure a matrix of size (n x n). The number of judgments required to develop the set of matrix is given by n (n – 1) / 2.
4. Obtain the importance of the criteria and sub-criteria from experts' judgment by making pair wise comparison. This comparison is made for all levels. Verbal judgments of preferences are shown in Table 1.

5. Determine the weight of each criterion. By hierarchical synthesis, the priority vectors are calculated. These values are the normalized eigenvectors of the matrix.
6. The consistency is determined by using the eigenvalue, λ_{max}. For finding the consistency index, CI, the formula used is; CI = (λ_{max} – n) / (n – 1), where n is the size of the matrix. The judgment consistency is checked from the appropriate value in Table 2. The consistency ratio (CR) is simply the ratio of CI to average random consistency (RI). The CR is acceptable, if it does not exceed 0.10. If it is more, the judgment matrix is inconsistent; then the matrix has to be reviewed to obtain a consistent matrix. These are calculated for all the matrices structured from the hierarchy. Some computer packages are available nowadays to implement this calculation procedure.

Table 1: Pair-wise Comparison Scale for AHP Preferences

Numerical Rating	Verbal Judgments of Preferences
9	Extremely Preferred / Important
8	Very Strongly to Extremely
7	Very Strongly Preferred / Important
6	Strongly to Very Strongly
5	Strongly Preferred / Important
4	Moderately to Strongly
3	Moderately Preferred / Important
2	Equally to Moderately
1	Equally Preferred / Important

Table 2: Average Random Consistency

Size of Matrix	1	2	3	4	5	6	7	8	9	10
Random Consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

4. Decision Criteria and Their Physical Significance

The choice of the most appropriate RE technology is influenced by various factors. The criteria and sub-criteria for assessment of RE technology have been selected after reviewing relevant literature and consulting experts in the field and have been shown in a hierarchical form (Figure 1). A concise explanation of each of them is given below to indicate their influence on the ultimate objective of this study:

1) Cost per unit of Power:
This criterion explains the financial aspects from the consumers' points of view. The cost of generating electricity is not the same and this will affect the users. For each unit of electricity (kilowatt-hour) the cost is different. This factor is taken care of by this criterion.

2) Social Impact:
This is the effect of the introduction of particular RE technology on the society. The people may experience a change due to the addition of a RE technology in their day to day lives. The sub-criteria under this, include the following:

- People's Acceptability – Any new technology always faces this phenomenon. It involves people's acceptance of the technology, especially in the case of biogas, as expressed by many experts.
- Quality of Life – Considers the extent of change in quality of life due to the introduction of technology.

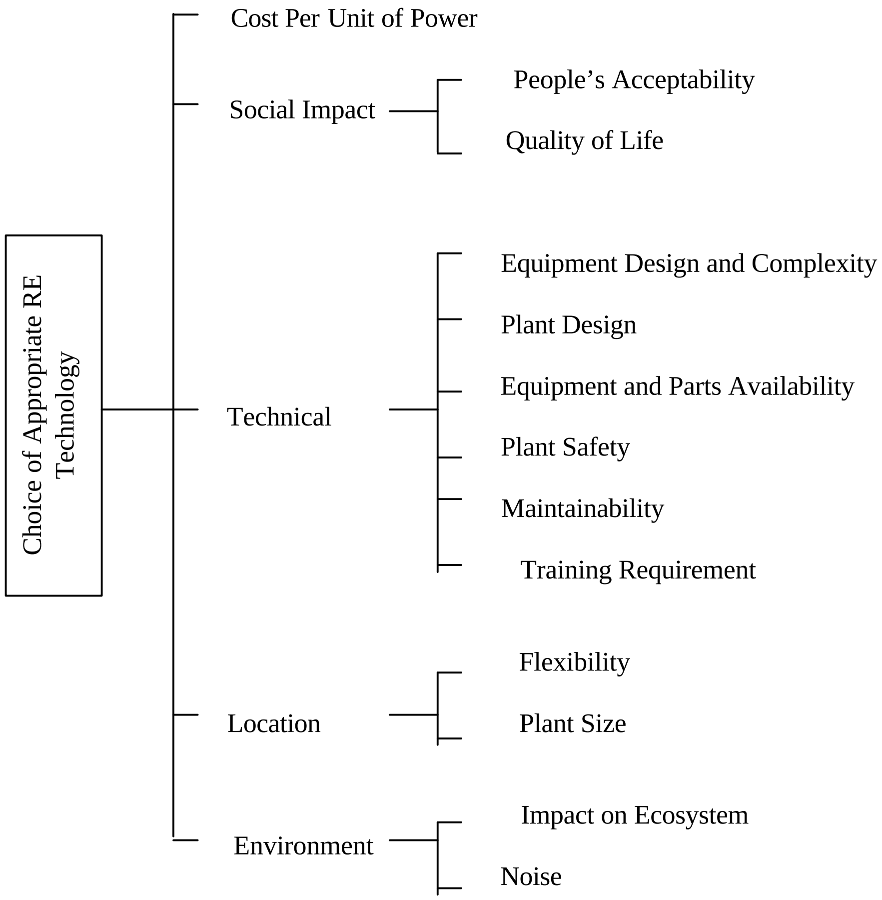

Fig. 1: Renewable Energy Technology Assessment Criteria Hierarchy

3) Technical:
This factor includes different technical and operational parameters at the initial installation as well as during running period. It covers the following:

- Equipment Design and Complexity – This implies the design and complexity of the equipment required to run the plant.
- Plant Design – Generally, the plant consists of various equipment. Whether all these can easily be integrated or not to run the plant is considered by this factor.
- Equipment and Parts Availability – This criterion considers the availability of different equipment and parts therein. This will certainly influence the choice of technology.
- Plant Safety – This considers the accident proneness of RE technology while running the plant.
- Maintainability – This implies the flexibility in maintaining the RE technology after its installation.
- Training Requirement – It is defined as the amount of training required for proper plant operation and maintenance.

4) Location:
This considers the suitability of the location for a particular RE technology based on its land requirement. It includes the following sub-criteria:

- Flexibility – It considers the location flexibility for the RE technology; whether it is in rural or urban area.
- Plant Size – It considers the size of the plant depending on the distribution area.

5) Environment:
It implies the various environmental aspects related to the introduction of RE technology. It includes the following:

- Impact on Ecosystem – This is defined as the change in the local ecosystem due to the introduction of RE technology.
- Noise – This considers the probability of noise pollution due the installation of RE technology plant.

5. Selection of RE Technology

Following the standard AHP methodology, the RE technology options have been compared with each other in turn for each sub-criterion and higher level criterion and their preferential weights have been determined. The results of the analysis are presented in Tables 3 – 21 in detail.

Table 3: Pair-wise Comparison Matrix for the 1st Level Criteria

	Cost	Social	Technical	Location	Environment	Priority Vector
Cost	1	5	2	3	5	0.438
Social	1/5	1	1/3	½	1	0.081
Technical	½	3	1	2	3	0.249
Location	1/3	2	½	1	2	0.149
Environment	1/5	1	1/3	½	1	0.081
						$\sum = 0.998$

$\lambda_{max} = 5.015$, CI = 0.0038, RI = 1.12, CR = 0.0034 < 0.1 OK.

Table 4: Pair-wise Comparison Matrix for the 2nd Level Criteria (Under Social Impact)

	People's Acceptability	Quality of Life	Priority Vector
People's Acceptability	1	1	0.5
Quality of Life	1	1	0.5
			$\sum = 1.00$

$\lambda_{max} = 2.00$, CI = 0.

Table 5: Pair-wise Comparison Matrix for the 2nd Level Criteria (Under Technical Criterion)

	Eqpt. Design	Plant Design	Eqpt. & Parts Availability	Plant Safety	Maintainability	Training	Priority Vector
Eqpt. Design	1	1	1/3	3	2	2	0.164
Plant Design	1	1	1/3	2	2	2	0.154
Eqpt & Pts Av.	3	3	1	8	5	5	0.454
Plant Safety	1/3	½	1/8	1	1	1	0.069
Maintainability	½	½	1/5	1	1	1	0.079
Training	½	½	1/5	1	1	1	0.079
							$\sum = 0.999$

$\lambda_{max} = 6.032$, CI = 0.0064, RI = 1.24, CR = 0.0052 < 0.1 OK.

Table 6: Pair-wise Comparison Matrix for the 2nd Level Criteria (Under Location)

	Flexibility	Plant Size	Priority Vector
Flexibility	1	5	0.833
Plant Size	1/5	1	0.167
			$\sum = 1.000$

$\lambda_{max} = 2.001$, CI = 0.001.

Table 7: Pair-wise Comparison Matrix for the 2nd Level Criteria (Under Environment)

	Impact on Ecosystem	Noise	Priority Vector
Impact on Ecosystem	1	½	0.333
Noise	2	1	0.667
			$\sum = 1.00$

$\lambda_{max} = 2.001$, CI = 0.001.

Table 8: Pair-wise Comparison Matrix for Cost per Unit of Power

	Solar Energy	Biogas	Wind Energy	Priority Vector
Solar Energy	1	2	5	0.582
Biogas	½	1	3	0.309
Wind Energy	1/5	1/3	1	0.109
				$\sum = 1.00$

$\lambda_{max} = 3.002$, CI = 0.001, RI = 0.58, CR = 0.0017 < 0.1 OK.

Table 9: Pair-wise Comparison Matrix for People's Acceptability

	Solar Energy	Biogas	Wind Energy	Priority Vector
Solar Energy	1	2	3	0.539
Biogas	½	1	2	0.297
Wind Energy	1/3	½	1	0.164
				$\sum = 1.00$

$\lambda_{max} = 3.009$, CI = 0.0045, RI = 0.58, CR = 0.0078 < 0.1 OK.

Table 10: Pair-wise Comparison Matrix for Quality of Life

	Solar Energy	Biogas	Wind Energy	Priority Vector
Solar Energy	1	3	2	0.525
Biogas	1/3	1	1/3	0.142
Wind Energy	½	3	1	0.434
				$\sum = 1.101$

$\lambda_{max} = 3.102$, CI = 0.051, RI = 0.58, CR = 0.0879 < 0.1 OK.

Table 11: Pair-wise Comparison Matrix for Equipment Design and Complexity

	Solar Energy	Biogas	Wind Energy	Priority Vector
Solar Energy	1	2	5	0.582
Biogas	½	1	3	0.309
Wind Energy	1/5	1/3	1	0.109
				$\sum = 1.00$

$\lambda_{max} = 3.002$, CI = 0.001, RI = 0.58, CR = 0.0017 < 0.1 OK.

Table 12: Pair-wise Comparison Matrix for Plant Design

	Solar Energy	Biogas	Wind Energy	Priority Vector
Solar Energy	1	2	4	0.458
Biogas	1	1	3	0.416
Wind Energy	1/4	1/3	0	0.126
				∑ = 1.00

λ_{max} = 3.009, CI = 0.0045, RI = 0.58, CR = 0.0078 < 0.1 OK.

Table 13: Pair-wise Comparison Matrix for Equipment and Parts Availability

	Solar Energy	Biogas	Wind Energy	Priority Vector
Solar Energy	1	2	4	0.458
Biogas	1	1	3	0.416
Wind Energy	1/4	1/3	0	0.126
				∑ = 1.00

λ_{max} = 3.009, CI = 0.0045, RI = 0.58, CR = 0.0078 < 0.1 OK.

Table 14: Pair-wise Comparison Matrix for Plant Safety

	Solar Energy	Biogas	Wind Energy	Priority Vector
Solar Energy	1	1/4	1	0.175
Biogas	4	1	3	0.633
Wind Energy	1	1/3	1	0.193
				∑ = 1.001

λ_{max} = 3.007, CI = 0.0035, RI = 0.58, CR = 0.0060 < 0.1 OK.

Table 15: Pair-wise Comparison Matrix for Maintainability

	Solar Energy	Biogas	Wind Energy	Priority Vector
Solar Energy	1	3	2	0.525
Biogas	1/3	1	1/3	0.142
Wind Energy	½	3	1	0.434
				∑ = 1.101

λ_{max} = 3.102, CI = 0.051, RI = 0.58, CR = 0.0879 < 0.1 OK.

Table 16: Pair-wise Comparison Matrix for Training Requirement

	Solar Energy	Biogas	Wind Energy	Priority Vector
Solar Energy	1	2	5	0.582
Biogas	½	1	3	0.309
Wind Energy	1/5	1/3	1	0.109
				∑ = 1.00

λ_{max} = 3.002, CI = 0.001, RI = 0.58, CR = 0.0017 < 0.1 OK.

Table 17: Pair-wise Comparison Matrix for Flexibility

	Solar Energy	Biogas	Wind Energy	Priority Vector
Solar Energy	1	½	6	0.349
Biogas	2	1	7	0.580
Wind Energy	1/6	1/7	1	0.070
				$\sum = 0.999$

$\lambda_{max} = 3.032$, CI = 0.016, RI = 0.58, CR = 0.0276 < 0.1 OK.

Table 18: Pair-wise Comparison Matrix for Plant Size

	Solar Energy	Biogas	Wind Energy	Priority Vector
Solar Energy	1	2	5	0.582
Biogas	½	1	3	0.309
Wind Energy	1/5	1/3	1	0.109
				$\sum = 1.00$

$\lambda_{max} = 3.002$, CI = 0.001, RI = 0.58, CR = 0.0017 < 0.1 OK.

Table 19: Pair-wise Comparison Matrix for Impact on Ecosystem

	Solar Energy	Biogas	Wind Energy	Priority Vector
Solar Energy	1	2	6	0.612
Biogas	½	1	2	0.269
Wind Energy	1/6	½	1	0.118
				$\sum = 0.999$

$\lambda_{max} = 3.019$, CI = 0.0098, RI = 0.58, CR = 0.0169 < 0.1 OK.

Table 20: Pair-wise Comparison Matrix for Noise

	Solar Energy	Biogas	Wind Energy	Priority Vector
Solar Energy	1	1	7	0.487
Biogas	1	1	5	0.436
Wind Energy	1/7	1/5	1	0.078
				$\sum = 1.001$

$\lambda_{max} = 3.013$, CI = 0.0065, RI = 0.58, CR = 0.0112 < 0.1 OK.

Table 21: Priority Matrix for Choice of Appropriate RE technology (Final Result)

	Cost (0.438)	Social Impact (0.081)		Technical (0.249)						Location (0.149)		Environment (0.081)		Overall Priority Vector
		PA (0.5)	QL (0.5)	EDC (0.164)	PD (0.154)	EPA (0.454)	PS (0.069)	M (0.079)	TR (0.079)	Flex. (0.833)	PS (0.167)	IE (0.333)	Noise (0.667)	
SE	0.582	0.539	0.525	0.582	0.458	0.458	0.175	0.525	0.582	0.349	0.582	0.612	0.487	0.517
Biogas	0.309	0.297	0.142	0.309	0.416	0.416	0.633	0.142	0.309	0.580	0.309	0.269	0.436	0.359
WE	0.109	0.164	0.434	0.109	0.126	0.126	0.193	0.434	0.109	0.070	0.109	0.118	0.078	0.128

In Table 21, the overall priority vector shows the preferential ranking of the RE technology. It appears that in the context of Bangladesh, solar energy is the most preferred option followed by biogas and wind energy.

6. Discussion and Conclusion

Choice of RE technology is a complex decision making problem. It requires a thorough survey of all the factors as well as alternatives. AHP provides flexibility in such decision making problems. The analysis shows that solar energy possesses a good prospect in this country followed by biogas and wind energy.

Solar energy technology offers an exciting potential for development of a sustainable and eco-friendly energy system. As power can be available anywhere, this acts an effective means of leapfrogging the existing prohibitively expensive process of grid electricity extension. This new emerging power source is an attractive alternative for use in remote rural locations because of its modular nature, low maintenance and availability. However, some experts opine that as time progresses the biogas will get more acceptability especially in the rural parts of the country.

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