Renewable Energy Opportunities in India and Multicriteria Analysis of the Renewable Energy Sources using Analytic Hierarchy Process Applicable to Decentralized Energy Generation for Rural Electrification

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ABSTRACT— ***Although official estimates indicate that 95% of Indian villages are electrified, fewer than 50 % of Indian households actually consume electricity. Until recently, the main policy has been to extend the grid to villages in rural areas in order to emphasize productive uses for agriculture. Today, there is a new emphasis on making sure rural households have access to and adopt electricity. Renewable energy technologies can help countries meet their policy goals for secure, reliable and affordable energy to expand electricity access and promote development. Off grid renewable energy technologies satisfy energy demand directly and avoid the need for long distribution infrastructures. Several studies have been performed in last many years as to which type of energy source would be the most appropriated choice for Decentralized Energy generation (DCRE) systems. Solar PV, Wind, Biomass, Fuel cells and micro turbines are the ideal options for decentralised generation systems and these green sources are inexhaustible, environmentally friendly and have government incentives for development in majority countries including India. Energy planning using multi-criteria analysis has attracted the attention of decision makers for a long time. Multi-Criteria Decision Making (MCDM) techniques are attractive in problems having multiple and conflicting objectives. This article develops a methodological framework providing insights to suitability of multi-criteria techniques in the context of operation of renewable energy sources – Biomass, wind generators, micro turbines, Solar photovoltaic cells and fuel cells. Several parameters like, power range, costs, efficiency, impact on the environment were investigated. Based on the scheme developed by Saaty – the Analytical Hierarchy Process (AHP) - these multi-criteria are evaluated. Two scenarios namely – environment scenario and cost scenario were considered for the analysis. Finally alternatives for renewable energy generation were ranked based on the AHP. The results indicate that wind energy is the ideal choice for energy generation in a decentralised way and is a possible solution for eliminating energy poverty.***

Keywords— Rural Electrification, Renewable Energy, decentralised generation, AHP.

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1. INTRODUCTION

Today one cannot imagine life without some form of energy such as electricity. The main source of energy has been fossil fuels, which provide 85-90 % of energy. Oil is the most important with 35 %, and coal and natural gas are equally represented. Almost 13.5 % of energy is derived from nuclear power plants, and only 9.8 % of energy comes from renewable sources. Still, in the world there are many places that have no access to electricity. Today, renewable energy is increasingly being considered as one of the key factors in the development of planet Earth. [1, 2].

With about 1.3 billion people in the world (or about 1 in 5) without access to electricity in 2010 the challenge of providing reliable and cost-effective services remains one of the major global challenges facing the world in this century [3]. In 2012, despite a slowing global economy, India's electricity demand continued to rise. India's electricity demand is projected to more than triple between 2005 and 2030. In the recently released National Electricity Plan (Twelfth Plan 2012) the Central Electricity Authority projected the need for 350-360 GW of total generation capacity by 2022 [4]. Despite major capacity additions over recent decades, power supply struggles to keep up with demand. As on the end of 2014 India has an installed power generation capacity of over 250000 MW but many plants are facing shortage of fuel supply resulting in lower production. About 53 million homes in the country are yet to get electricity and many industries depend on diesel generator sets to meet their energy requirements. Fig 1 shows source wise installed capacity [5,6].

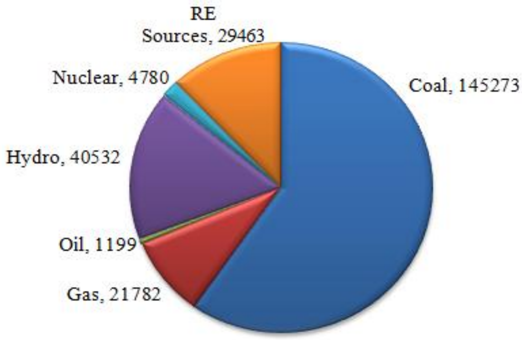


Figure 1: Sourcewise Installed Power –India. March 14 [6]

Though the government has announced it would improve fuel supply to gas based plants, it need to workout a plan and compliment it with some relief measures since the plants have been struggling without the fuel [7]. The installed capacity of renewables is shown in Table 1.

Table 1: Installed Capacity of Renewables: India, March 14 [6]

Sector	*Potential (MW)*	*Installed Capacity (MW)*	*% Achieved*
Wind Energy	102772	21136.2	20.57
Solar Energy	100000	2647	2.65
Small Hydro Power (SHP)	20000	3816.91	19.08
Biomass	17536	1914.5	10.92
Bagasse Cogeneration	5000	2648.4	52.97
Waste to Energy (W-E)	3880	106.6	2.75
Total	249188	32269.6	12.95

Besides the promise of round the clock electricity to all households by 2019, the government also sees investment potential of up to Rs 250 billion (4 billion US $ appx) in the energy sector in power generation, transmission, distribution and coal mining. India's total power consumption would double to 2 trillion units by 2019 [8]. Though majority of investments of providing that demand would come by private sector, the government will also be increasing its investment. Besides the government is also moving forward with plans for the renewable sector, especially solar energy where it hopes to increase power generation to 1,000,000 MW by 2022. It also aims to double the installed capacity of wind generation to more than 40000 MW by 2019. [9]. It is working to make maximum utilization of existing assets and freeing up stranded assets.

2. RURAL ENERGY SCENARIO AND RURAL ELECTRIFICATION

The government declares a village electrified ''if electricity is being used within its revenue area for any purpose whatsoever.'' So, even if one light bulb glows in a village even for an hour in a day, the village is counted as electrified. As per 2011 census, around 742 million or 72.2% people in India live in villages. Also 43% of rural households still use kerosene to light their houses compared to 6-7% people in urban areas. As of 31st March 2014 (96%) villages have got access to electricity. There are still 21,318 villages which have got no access to electricity. (REC 2012-13). Realizing this fallacy after more than half a century of power production in independent India, the government set in motion an exercise to change the definition of village electrification. [10, 7].

Over 85% of rural India is still using firewood, crop residue or cow dung as its primary source of fuel for cooking. One of the major reasons for this situation lies in the location of the villages itself which are often time in remote areas. [7] Although official estimates indicate that 95% of Indian villages are electrified, fewer than 50 % of Indian households actually consume electricity. But as per RGGVY (Rajiv Gandhi Gramin Vidyutshakti Yojana), the rate of village electrification is much lower as household connectivity has been fairly low. Villages have been a major concern as cost of electrification is fairly high. The most favored alternative to any kind of users is generation of electricity from diesel generating sets and renewable sources of energy. But the capital cost of renewable energy equipments is fairly high.

Gradually, there is a reduction in the prices of these systems due to availability of better technological options and they are becoming competitive to grid electricity. [11]

Provision of electricity from grid to all the villages of India is not possible due to remote location, high transmission and distribution loss and frequent failure of thermal power plants. The cost of generation of electricity has been increasing due increase in coal prices and poor quality coal, etc... Ultimately, the difference in cost of electricity between thermal power plants and stand-alone off-grid devices are decreasing and becoming competitive to each other. Among various stand-alone off-grid generation systems, the only easy alternative in India is still the use of diesel generating sets during power failure now. People still do not consider the other viable alternatives such as solar, biomass gasifier, etc., because of the assumption of high cost in generation of electricity.

Renewable energy become a very suitable candidate in these case as it is much more cost effective and less time consuming to set up in rural areas. As per Rural electric corporation annual report 2012-13, 44171 villages have been electrified during 2012-13 and the total number of villages that have been electrified stands at 692770. The number of pumpsets energized has risen from 8207482 to 1025244 by the end of 2013. [7]. Deployment of green energy sources is vital today for the following reasons:

- These sources play a major role in decreasing emissions of the carbon dioxide (CO2) into atmosphere.
- Higher contribution of renewable energy sources enhances energetic and also helps to enhance energy delivery security by decreasing dependency on fossil fuels and importing energetic raw materials. [11]

3. MULTI-CRITERIA DECISION ANALYSIS TECHNIQUE FOR RENEWABLE ENERGY

Setting up a decentralised energy generation system (DCRE), requires an appropriate management concerning operational and technical characteristics. In this context, the use of renewable energy sources has the potential to improve system management and is catalyzed by environmental concerns and the worldwide need for electrical power generation. The intense attention directed towards sustainable energy system gives high priority to renewable energy that would have a minimal impact on the environment, human health, and the quality of life [12]. The political, social, economic, and environmental importance of energy planning, to meet the ever-increasing energy demand with an adequate energy supply, renders the evaluation of different energy projects a major challenge for policy makers. This applies in particular for renewable energy sources (RES) because their particular features (decentralized production, localized and short-term cost, distributed and long-term benefits, involvement of many stakeholders, and multiple-evaluation criteria) entail the use of specific instruments to choose the optimum option. The use of multi-criteria decision analysis (MCDA) techniques provides a reliable methodology to rank alternative RES projects in the presence of numerous objectives and constraints (Haralambopoulos and Polatidis, 2003). [13, 14]. Of late several authors have demonstrated excellent results by using large number of multicriteria decision analyses (MCDA) in energy management. ELECTRE, PROMETHEE, MACBETH, AHP and also Fuzzy sets are some familiar tools. This work presents a methodology based on the routine developed by Saaty - the AHP. [15]

Background and review of the literature: Multi-criteria decision making (MCDM) methods have been applied to several different types of energy problems over the past three decades. These techniques provide solutions to the problems involving multiple and conflicting objectives. Several methods based on weighted averages, priority setting, outranking, fuzzy principles and their combinations are employed for energy planning decisions. Criteria may include factors of financial performance in addition to technical, social, or even esthetic dimensions. Multi-criteria decision making methods and tools include Data Envelop Analysis (DEA), the Analytic Hierarchy Process (AHP), Multi-Attribute Utility Theory (MAUT), Multi-Attribute Value Theory (MAVT) and several others. Each has its strengths, weaknesses and areas of application. [16]. Pohekar and Ramachandran [17] observed that Analytical Hierarchy Process is the most popular technique followed by PROMETHEE and ELECTRE. Validation of results with multiple methods, development of interactive decision support systems and application of fuzzy methods to tackle uncertainties in the data is observed in the published literature. [15, 17]

Renewable energy technologies in this study included solar photovoltaic, wind, hydropower, fuel cells, mini-hydro turbines and biomass energy. Characteristics of renewable sources include unlimited amounts of ''fuel'' and having a low or zero carbon foot-print (except biomass). Despite these advantages, they pose certain challenges with regard to production and storage. These systems tend to be of smaller generating capacity and range from 50MW for bio-fuel to 100-150 MW for solar-PV and wind. Hydropower systems at the utility level are larger and in the range of 500 MW.

A general Multi Criteria Decision Analysis process can be divided into [18]:

1. Problem definition,	2. Determining the requirements;	3. Establishing the goals ;
4. Identifying the alternatives;	5. Define and classify criteria	6. Select a suitable MCDA method;
7. Evaluation of the alternatives;	8. Validating the solutions against problem statement.	

In the present study, to analyze the operation of renewable energy sources, AHP methods/approach has been applied and then the results have been evaluated.

AHP is a multi-criteria decision making tool which provides to structure complex problems in a hierarchic manner, as a result it simplifies evaluating all of the criteria which are relevant with the decision that must be given (Saaty, 1980). All of the alternatives are compared pairwise based on each criterion by using a preference scale and a priority list of alternatives is achieved for each criterion (Taha, 2003). Most widely used preference scale is 1-9 scale which lies between "equal importance" to "extreme importance". AHP enables the decision analyst to give more realistic scores for alternatives for the cases in which there are lots of uncertainties. [19, 20]

The analytic hierarchy process (AHP) is a multi-criteria decision making tool to deal with complex, unstructured and multi-attribute problems. This method is distinguished from other multi-criteria methods in three ways: a) Construction of the hierarchy structure b Pairwise comparisons of different criteria. c) Weighing with respective to the overall objective. In AHP, decision makers quantify the importance of criteria by using Cheng's 1-9 scale as in Table 2.

Table 2: Preferences on 1-9 Scale [16]

AHP scale of importance for comparison pair	*Numeric Rating*	*Reciprocal (decimal)*
Extreme Importance	9	1/9 (0.111)
Very strong to extremely	8	1/8 (0.125)
Very strong importance	7	1/7 (0.143)
Strongly to very strong	6	1/6 (0.166)
Strong importance	5	1/5 (0.200)
Moderately to strong	4	¼ (0.250)
Moderate Importance	3	1/3 (0.333)
Equally to moderately	2	½ (0.500)
Equal importance	1	1 (1.000)

AHP methodology steps can be defined as (Saaty, 1980)

1. Stating the problem;
2. Broadening the objectives of the problem;
3. Identifying the criteria that influence the behavior;
4. Structuring the problem in a hierarchy (criteria, sub-criteria and alternatives);
5. Comparing each element in the corresponding level with 1-9 scale;
6. Performing calculations to find the max. Eigen value, consistency index (CI), consistency ratio (CR), and normalized values for each criteria;
7. Finally, if the max. Eigen value, CI and CR are satisfactory, decision is taken, else the procedure is repeated until reaching the desired range. [19]

Analyses were made following the completion of pairwise comparisons. The first of analyses is to check the consistency of judgments. In the AHP method, the consistency of matrixes in a pairwise comparison should be ensured. If the matrix is inconsistent, evaluating must be made until a consistency is achieved. The consistency ratio (CR) wanted to be smaller than 0.10. The consistency ratios in our study varied between {0 and 0.1}. The second stage of analysis is to calculate relative weights of both main criteria and sub-criteria. Historical data on the financial, technical, environmental and socio/economic/political characteristics associated with each of the energy technologies was used. Data sources were selected for overall validity from different sources. [16]

4. MCDM METHODOLOGY ASPECTS

In the present work a methodology was developed for two different scenarios under six criteria. These are analysed using five types of renewable energy sources. The basic objective of this work is to find the most appropriate type of renewable system to be used in each scenario. The criteria description is presented below:

A) Quantitative parameters include:

- Efficiency (EF) in %;
- Costs (CS): energy related costs in US$/ MWh;
- Life Expectancy (LE) in years.

B) Qualitative parameters (expressed through weights): These weights are defined according to the analysis of the actual database, in the interval from 0 to 1.0.

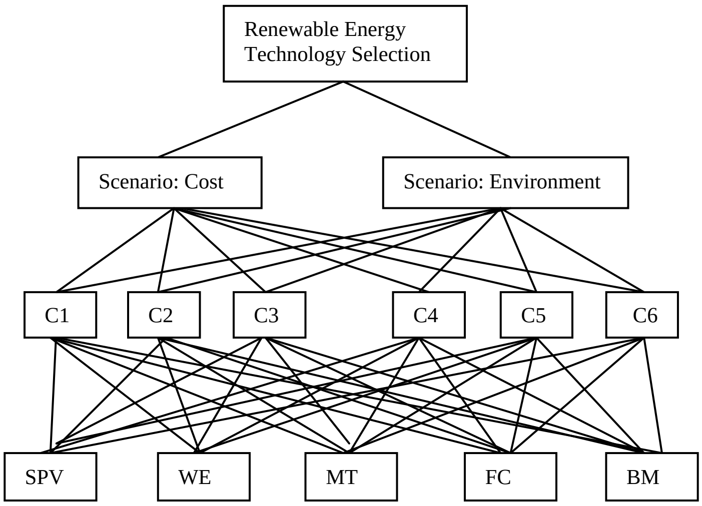
- Technological Advancement (TA);
- Impact on Environment (IE) : Physical/biological, presence of toxic elements, and GHG emissions;
- Power range (PR): usual limit of power (MW).

The simulated scenarios in this study are evaluated by the previous priority classification of the criteria, according to different constrains. Costs and environment boundaries are therefore used in both AHP and fuzzy simulations. The classification of priority facilitates the development of simulation steps and makes the understanding of the methodology by the decision makers easier. These both aspects are essential to corroborate the final solutions. From the above mentioned indicators, criteria and renewable energy sources, the model for sustainable energy planning in this work is established. The rated data and the weights used in AHP simulations are showed in Table 3.

Table 3: Data used in AHP analysis

Criteria	***PV***	***Wind***	***MT***	***FC***	***BM***
Quantitative	**Rated data**				
LE (Years)	28	25	20	08	18
EF (%)	15	30	35	50	20
Costs(US $/ MWh)	900	150	200	300	180
Qualitative	**Weights – "the higher the better"**				
Technological Advancement	0.50	0.80	0.60	0.70	0.70
Impacts on Envt	0.75	0.85	0.40	0.45	0.75
PR (MW)	0.50	1.00	0.40	0.80	0.70

The hierarchical structure for the selection of the renewable energy technology is presented in Figure 2.



C1-EF, C2-CS C3-LE C4-TA C5-IE C6-PR
SPV: Solar Photovoltaic, WE: Wind Energy, MT: Mini-Turbines, FC: Fuel Cells, BM: Biomass

Figure 2: The hierarchical structure for the selection of the renewable energy technology

5. AHP ANALYSIS

Analyses were made following the completion of pairwise comparisons. The first of analyses is to check the consistency of judgments. In the AHP method, the consistency of matrixes in a pairwise comparison should be ensured. If the matrix is inconsistent, evaluations must be made until a consistency is achieved. The consistency ratio (CR) wanted to be smaller than 0.10. The consistency ratios in this study varied between {0 and 0.1}. The second stage of analysis is to calculate relative weights of both main criteria and sub-criteria. [15, 16]

After identifying the criteria and the alternatives, they must be placed into an AHP hierarchy, which is then used to construct the pairwise comparison matrix (PCM). For this, it is necessary to estimate the weights of the decision's criteria. This is done via measurement of AHP, which is based in the theory defined by Saaty [19], presented in Table 2. Therefore, as shown in a set of tables (Table 4), it is assumed one weight to each pairwise comparison. It is considered in this way all criteria and each final possible alternative (renewable energy sources), according to the data presented in Table 3. The results of relative weights (RW) and the consistency ratio (CR) computed by the simulation of AHP method according to criteria 1 to 6 (C1-C6) are presented in set of Table 4.

Table 4: (Criteria 1 – 6: Set of tables) – Alternative x Alternative

CRITERIA 1: EFFICIENCY (EF)						
	PV	WE	MT	FC	BM	**RW**
PV	1.00	0.33	0.33	0.14	1.00	**0.0585**
WE	3.00	1.00	1.00	0.20	3.00	**0.1491**
MT	3.00	1.00	1.00	0.20	3.00	**0.1491**
FC	7.00	5.00	5.00	1.00	9.00	**0.5883**
BM	1.00	0.33	0.33	0.11	1.00	**0.0549**
CR = 0.09767						

CRITERIA 2: COSTS						
	PV	WE	MT	FC	BM	**RW**
PV	1.00	0.11	0.14	0.13	0.14	**0.0304**
WE	9.00	1.00	0.50	3.00	0.50	**0.2221**
MT	7.00	2.00	1.00	3.00	1.00	**0.3125**
FC	8.00	0.33	0.33	1.00	0.33	**0.1226**
BM	7.00	2.00	1.00	3.00	1.00	**0.3125**
CR = 0.078003						

CRITERIA 3: TECHNNOLOGICAL ADVANCEMENT (TA)						
	PV	WE	MT	FC	BM	**RW**
PV	1.00	0.20	0.20	0.20	0.14	**0.0405**
WE	5.00	1.00	3.33	1.00	0.50	**0.2559**
MT	5.00	0.30	1.00	0.33	1.00	**0.1498**
FC	5.00	1.00	3.00	1.00	1.00	**0.2730**
BM	7.00	2.00	1.00	1.00	1.00	**0.2808**
CR = 0.08547						

CRITERIA 4: IMPACT ON ENVIRONMENT (IE)						
	PV	WE	MT	FC	BM	**RW**
PV	1.00	0.33	5.00	3.00	1.00	**0.2010**
WE	3.00	1.00	7.00	5.00	3.00	**0.4691**
MT	0.20	0.14	1.00	0.33	0.20	**0.0427**
FC	0.33	0.20	3.00	1.00	0.33	**0.0862**
BM	1.00	0.33	5.00	3.00	1.00	**0.2010**
CR = 0.03919						

CRITERIA 5: POWER RANGE (PR)						
	PV	WE	MT	FC	BM	**RW**
PV	1.00	0.11	1.00	0.11	0.33	**0.0428**
WE	9.00	1.00	7.00	1.00	5.00	**0.4288**
MT	1.00	0.14	1.00	0.11	0.33	**0.0453**
FC	9.00	1.00	9.00	1.00	1.00	**0.3246**
BM	3.00	0.20	3.00	1.00	1.00	**0.1585**
CR = 0.05832						

CRITERIA 6: LIFE EXPECTANCY (LE)						
	PV	WE	MT	FC	BM	**RW**
PV	1.00	3.00	5.00	9.00	5.00	**0.5043**
WE	0.33	1.00	3.00	7.00	3.00	**0.2480**
MT	0.20	0.33	1.00	5.00	1.00	**0.1078**
FC	0.11	0.14	0.20	1.00	0.20	**0.0320**
BM	0.20	0.33	1.00	5.00	1.00	**0.1078**
CR = 0.06193						

As shown in Tables 5 and 6, it is assumed one weight to the pairwise comparisons, taking into account only the criteria, and with regards the classification of priority. Tables 5 and 6 present the relative weights (RW) and the consistency ratio (CR) computed by the simulation of AHP method according to each matrix (PCM). Results of CR must be less than 0.1 for the analysis of more than five elements (criteria) according to Saaty.

To find the classification of the energy sources, their relative weights (RW), according to each parameter presented in Table 4, are therefore multiplied by the relevant RW estimated in Tables 5 and 6.

Table 5 and Table 6: Pairwise Comparison Matrix: Environment and Costs Scenario

SCENARIO 1 ENVIRONMENT							
	EF	CS	TA	IE	PR	LE	**RW**
EF	1.00	7.00	3.00	0.33	5.00	1.00	**0.1925**
CS	0.14	1.00	0.20	0.11	0.33	0.14	**0.0260**
TA	0.33	5.00	1.00	0.20	3.00	0.20	**0.0858**
IE	3.00	9.00	5.00	1.00	9.00	3.00	**0.4318**
PR	0.20	3.00	0.33	0.11	1.00	0.20	**0.0444**
LE	1.00	7.00	5.00	0.33	5.00	1.00	**0.2194**
CR = 0.07524							

SCENARIO 2: COSTS							
	EF	CS	TA	IE	PR	LE	**RW**
EF	1.00	0.20	1.00	5.00	3.00	1.00	**0.1348**
CS	5.00	1.00	3.00	9.00	7.00	3.00	**0.4310**
TA	1.00	0.33	1.00	7.00	5.00	3.00	**0.2122**
IE	0.20	0.11	0.14	1.00	0.20	0.20	**0.0263**
PR	0.33	0.14	0.20	5.00	1.00	0.20	**0.0563**
LE	1.00	0.33	0.33	5.00	5.00	1.00	**0.1392**
CR = 0.09811							

The screened scenarios are connected with environment and costs, respectively. The results of this multiplication, the sum of these results (FRW – Final Relative Weights) and the energy source classification are shown in Tables 7 and 8.

As seen from the above table, "Wind Energy" qualifies to be the best technology for sustainable energy planning according to the AHP methodology. The same case study can be tested using fuzzy logic in MATLAB under multi-rules-based decision and multi-sets considerations. However the authors would like to take up this work in the further part of their research work.

Table 7: AHP Final Classification –Scenario: Environment

AHP FINAL CLASSIFICATION - ENVIRONMENT SCENARIO								
	EF	COST	TA	IE	PR	LE	Final RW	**CL**
PV	0.011	0.001	0.003	0.087	0.002	0.111	0.215	**2**
WE	0.029	0.006	0.022	0.203	0.019	0.054	0.332	**1**
MT	0.029	0.008	0.013	0.018	0.002	0.024	0.094	**5**
FC	0.113	0.003	0.023	0.037	0.014	0.007	0.199	**3**
BM	0.011	0.008	0.024	0.087	0.007	0.024	0.160	**4**

Table 8: AHP Final Classification: - Scenario: Costs

AHP FINAL CLASSIFICATION - COSTS SCENARIO								
	EF	COST	TA	IE	PR	LE	Final RW	**CL**
PV	0.008	0.013	0.009	0.005	0.002	0.070	0.108	**5**
WE	0.020	0.096	0.054	0.012	0.024	0.035	0.241	**1**
MT	0.020	0.135	0.032	0.001	0.003	0.015	0.205	**4**
FC	0.079	0.053	0.058	0.002	0.018	0.004	0.215	**3**
BM	0.007	0.135	0.060	0.005	0.009	0.015	0.231	**2**

6 - RESULTS AND DISCUSSIONS

Table 6 and Table 7 present the final relative weights and the classification according to the results achieved by AHP method, regarding environment and costs scenarios. By the above analysis, it can be said that multicriteria analysis using AHP is an ideal tool for selecting the best source of energy among the renewables. Accordingly, the wind generator is the most appropriate choice for both environment and costs scenarios. It is central to emphasize that this study may consider several criteria and scenarios by simply evaluating and changing the AHP (sets and rules) in each case of the analysis. Out of 30000 MW of Renewable energy installed in India, the contribution of wind power is 20000MW (66%) [21]. It is planned to increase the renewable share to 42000 MW and wind contribution to 28000MW by the end of 12th plan 2017. [8]

The AHP model ranked five renewable energy technologies in terms of overall benefits, with wind and solar–PV topping the list. We can conclude that solar, wind, hydropower, and geothermal offer the most overall benefits. We can conclude from these results that policies designed to incentivize the production of wind, solar, hydro and geothermal should be retained or expanded. Overall, wind power seemed to be the most suitable option within the major RES alternatives. Wind power ranked best in terms of cost and power range. Geothermal energy and PV seem to lie in the middle of the performance scale and this may be for the reason that they both have not yet proven substantially beneficial in terms of either CO_2 emissions or jobs creation goals. Finally, biomass is believed to be evaluated undeservedly low. Such a result is in line with the evidence that biomass conversion technologies still need to be developed more to achieve better sustainability and efficiency. The results show that wind and solar-pv provide the most overall benefits across multiple dimensions, thus lending support for policies that encourage accelerated investment in wind and solar power. Biomass is the renewable source that scores poorly, partly because of its high carbon content, and may have only a limited role in the future energy picture.

7. ACKNOWLEDGEMENT

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