Prioritization of Decentralized Renewable Energy Technologies for Rural Areas of Bundelkhand Region, India Using Analytical Hierarchy Process (AHP)

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Abstract-Bundelkhand region is located in the central part of India and its rural energy demand depends mainly on the non-renewable energy resources while renewable energy resources are abundantly available in this region. The utilization of renewable sources is the demand of time because non-renewable energy resources are limited in amount and cause environmental pollution. Energy from decentralized renewable energy technologies can play a major role to fulfill the demand the rural areas. The objective of this research is met by the identification and prioritization of the potential renewable energy technologies for rural areas of this region. Prioritization of decentralized renewable energy technologies for this region is done with the help of Analytical Hierarchy Process (AHP). AHP is one of the most widely used multi-criteria decision-making (MCDM) tool for sustainable energy planning. This research focuses on the decentralized renewable energy technologies namely anaerobic digestion, solar photovoltaic and biomass gasification. Four main criteria categorized as technical, economic, environmental and social are selected for this research. The result of this research shows that solar photovoltaic (0.404943) has gained the highest final ranking followed by anaerobic digestion (0.34407) and biomass gasification (0.25099). The results of this research can play a vital role in sustainable development of this region. AHP model is used first time to prioritize the decentralized renewable energy technologies for rural areas of this region. This research may also show a direction to various stake holders for analyzing rural energy technologies in the most effective and efficient way in their future efforts.

Keywords: Solar Photovoltaic, Anaerobic Digestion, Biomass Gasification, Rural Energy Planning, Bundelkhand Region, Analytical Hierarchy Process

1. Introduction

Energy is universally recognized as the most crucial aspect of economic growth and human development in any country. In India, the consumption of energy is increased very rapidly due to the population growth and development of economy as well. At present most of the energy requirement is fulfilled by the utilization of fossil fuels. Excessive utilization of fossil fuels is not recommended because they are in limited amount and leads to the degradation of environment. Energy from renewable resources will play an important role in this situation. India has sufficient potential of renewable energy resources which can reduce the load of fossil fuel. Selection of right technology is of utmost important because each renewable energy technologies have their own limitations. In India, there is a dedicated ministry for the promotion of renewable energy named as ministry of new and renewable energy. Renewable energy generation capacity is expected to reach 175,500.0 MW in 2022.India stands fifth in renewable energy generation in the world after America, China, Germany and Spain [1-3].

India is predominantly a rural country. As per the 2011 census, 68.8% of the total population lives in rural areas. From 2001 to 2011, India's rural population has increased by 12.18%. The rural population is mostly reliant on biomass sources like crop residue, animal dung, wood, etc. to fulfil their energy requirements. In the rural area, the domestic sector holds 75% of total energy consumption [4-5]. A large part of this energy consumption is used in the cooking process while others are engaged in an agricultural field and these are highly dependent on biomass resources to fulfil their energy needs. In rural areas the energy mainly required for the domestic, agriculture, and irrigation purpose. The main energy source is biomass and it is available in the form of animal excreta, biodegradable waste, agricultural waste, forest residue, woody plants, etc. Most rural India depends on biomass sources such as fuel wood for cooking, water heating, etc. These available biomass supplies approximately 75% of the energy demand in rural India [6]. The decentralized renewable energy technologies can play a significant role to meet out the rural energy demand of the country as having greater potential as compared to the non renewable centralized supply. Biomass is considered as suitable option of renewable resource for the decentralized energy systems due to the availability in the remote areas [7].

Bundelkhand region is situated in the north central part of India which covers two states Uttar Pradesh and Madhya Pradesh including 13 districts. This region is located at latitude ranging from 23°10′ N to 26°27′ N and longitude from 78°40′ E to 81°34′ E. The total area of this region is around 30,000 km^2. The population of Bundelkhand region is approximately 50 million out of which 80% population depends on agriculture. The continuous damage to the environment from unsustainable utilization of natural resources causes the decline in the quantity of water available for irrigation and other human activities purposes. This has affected agriculture most severely, burdening the already struggling small and marginal farmers [8-9].

These concerns, along with the negative impact of burning fossil fuels, have created an environmentally and socially conscious mindset amongst different sets of economic stakeholders, including consumers, investors, firms, and governments. In this region, solar energy and biomass energy are the most important renewable energy resources which can be utilized with the help of appropriate energy planning.

Anaerobic digestion and biomass gasification have selected for this region as gross availability of biomass and the present conventional technologies are grossly incompetent. Biofuels derived from these technologies could be used in IC engines for motive power or electric power generation. One more renewable technology is solar photovoltaic has selected on the basis of regional geographical condition. The whole Bundelkhand region is very hot during the summer and actual local temperature is much higher due to radiation from outcrops. The unavailability of water is also a major concern in this region and photovoltaic technology has not required water for electricity generation. Following technologies are the renewable energy technologies have selected based on resources available in the rural area of Bundelkhand region.

1.1. Anaerobic Digestion

Organic materials are transformed into gas in an anaerobic digestion in the lack of air or oxygen is called biogas. These gases are the mixture of methane (CH_4), carbon dioxide (CO_2) with combination with a tiny amount of hydrogen sulfide (H_2S) and other trace gasses. It is completed in three processes - (i) Hydrolysis which breaks down the insoluble solids into soluble monomers (ii) Acidogenesis or acid formation that transforms the soluble monomers into volatile fatty acids and (iii) Methane formation in which the acids and a residue or sludge are transformed into biogas. Depending on the procedure and its working circumstances, the optimum temperatures for anaerobic digestion are either 35°C or 55°C while pH values are 8.0±0.5.

Biogas could meet all energy demand and, if necessary, additional energy requirements can be met through additional biomass processing, such as biomass gasification or animal power. Advantages of anaerobic digestion are mainly the utilization of waste material, fuel used in cooking, heating or electricity production and fertilizer used in farming, manage environmental risks like reducing greenhouse gas emission and global warming, the investment cost is low as compared to other renewable technologies and helpful in rural development. It is possible to supply biogas generated by dairy cattle dung to widespread rural sectors such as milk processing, food processing, nursery raising, etc. These actions are strongly related to one another. To make them economical, they can be carried out in one complex [10-11].

1.2. Solar Photovoltaic

Solar energy is a very capable source of renewable energy due to various advantages. It can be used as a potential source of decentralized energy generation. Sunlight can be directly converted into electricity with solar photovoltaic technology. The devices used for conversion are very simple in design and need very less maintenance. Electricity is produced when sunlight (in the form of photon) drops on these components of the semiconductor. The application in various fields of this renewable technology is increasing continuously due its rewarding features. The maximum power generated by the solar photovoltaic array is extracted at all times while the charging discharge controller is responsible for preventing overloading of the battery bank needed to store solar power during sunless time. A stand-alone system does not have a connection to the grid. The government of India is also indorsing solar energy and launched a national solar mission program in which installed solar power will be increased up to 100GW at the end of 2022 [12-13].

1.3. Biomass Gasification

Biomass gasification is a very promising thermo chemical conversion route of biomass to biofuel. It includes various processes to get the fuel from gasification of biomass. In this complete process, solid fuel converted by thermo-chemical transformation into gaseous fuel without leaving any solid carbonaceous residue. In the presence of gasifying agents, i.e., air, steam, oxygen, carbon dioxide, or a mixture of this biomass gasification process transforms biomass into gas. The most prevalent raw materials are agricultural waste, forest residual waste, etc. It is also feasible to handle some difficulty in biomass which has elevated ash content such as rice husk etc. The yield and composition of produced gases are affected by the feedstock biomass material, particle size, gasifying agent, catalyst, operating pressure, temperature and design of the reactor. Fixed bed gasifiers are used for smaller scale application from 5kW units upwards to a few MW while fluidized bed gasifiers are used for larger scale production. Biomass gasification must be utilized at larger scale for the decentralized power generation for rural energy demand [14-15].

In the rural area, maximum populations are facing a large gap in demand and supply of energy. In this situation the rural energy planning with the implementation of decentralized renewable energy technology is one of the finest solutions for meeting the energy demand in an affordable, reliable, and environmentally sustainable way. Each type of renewable technologies has its merits and demerits, hence, to select the most appropriate option for them is very important to gain the best possible production. Multi-criterion decision making (MCDM) methods are extensively used in such type of multifaceted situation. Thomas L. Saaty has developed a technique named as Analytical Hierarchy Process (AHP). It is the one of most accepted multi criteria decision making technique in the field of sustainable energy planning due to rational decision making. The complex problem is divided into a hierarchical structure in which goal is set at the top of hierarchy, criteria, and sub-criteria in middle level and the alternative is set at the bottom of the hierarchy. AHP is used for decision making in many countries like China, Malaysia, Nepal, India, Oman, Pakistan and Indonesia for sustainable energy management [16-23]. In this research, the AHP is used for prioritizing the decentralized renewable energy technologies for rural areas of the Bundelkhand region. To reach the goal four criteria as technical, environmental, economic, and social were selected to make the finest decision. Moreover, two sub-criteria were set for each criterion. For technical criteria, technical maturity and performance consistency are evaluated as sub-criteria, for environmental criteria pollutant emission and waste reduction, for economic criteria initial cost and operational & maintenance cost and for social criteria social acceptability and village development are set as sub-criteria. Three alternatives of renewable technology are set for rural energy planning namely anaerobic digestion, solar photovoltaic and biomass gasification. The advantage of this research is to make policy for energy planning and it will provide clean and continuous energy supply to rural areas of Bundelkhand region of India.

2. Research Methodology

In this research, prioritization of decentralized renewable energy technologies for rural areas of Bundelkhand region has been accomplished with the help of AHP.

2.1. Analytic Hierarchy Process (AHP): Step wise procedure

In multifaceted decision-making situation, AHP helps the decision maker to make the finest decision. Decomposition, comparative judgement and synthesise of priority are the three principles behind AHP. The consistency of the decision maker's evaluations is also checked in this technique [24-30]. The key steps involved in AHP are given below:

2.1.1. Hierarchy Structure

In the AHP, hierarchy structure is the most significant part of decision making. The decision problem is structured in a hierarchy of levels with goal at the top level followed by criteria, sub-criteria. The alternatives or options are placed at the bottom most level.

2.1.2. Pair wise comparison

Pair wise comparison is made to capture relative judgments of elements at the some given level with respect to elements in level above, which result in comparison matrix. The priority vector from comparison matrix is obtained by raising the matrix to a sufficiently large power then summing the rows and normalizing. The pair wise fundamental scale is shown in Table 1.

Table 1. The Fundamental Scale

Intensity of Importance	Definition
1	Equally importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme Importance

It is clear from Table 1 that for pair wise comparison of each element, '1' determines equal importance while '9' shows extreme intensity of importance. Whereas '3', '5', '7' determines respectively moderate, strong and very strong intensity of importance. Intermediate values between the above values can also be given when there is a compromising situation arises between two activities.

A consistency check is applied in the concluding stage to make sure the consistent result. For this purpose, principle eigenvector is calculated. The consistency ratio is calculated by founding the principal Eigen value λ_{max} of each matrix of order n using Eq. (1):

$$\mathbf{Aw} = \lambda_{max}\,\mathbf{w} \quad (1)$$

Where, A is the vector with priorities values and w is the Eigen values of the vector A, λ_{max} is the principal eigen value and will be close to n (size of the matrix) which can be greater than or equal to n. After that the consistency index (CI) is determined using Eq. (2),

$$\mathbf{C} = (\lambda_{max} - n) / (n-1) \quad (2)$$

and the consistency ratio (CR) is the ratio consistency index (CI) and random index (RI), as shown in Eq. (3):

$$CR = \frac{CI}{RI} \quad (3)$$

The value of random index (RI) depends on the number of elements in the pair wise matrix. The values of Random Index (RI) are given below in Table 2.

Table 2. Values of Random Index (RI)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 2 shows the values of RI for the matrix of order 1 to 10. Random indices of sample size of 500 are approximating to get this table of random index. Consistency ratio (CR) less than ten percent is acceptable. One has to reconsider our judgment if the consistency ratio (CR) is greater than ten percent

2.1.3 Synthesis of Priorities

The global priority of a particular element is obtained by multiplying the local weights by the weights of their corresponding criteria in the level above.

2.2. Proposed AHP model

An AHP model is proposed for selecting the most suitable decentralized renewable energy technologies for rural areas of Bundelkhand region, India on the basis of field survey, experts opinion and literature survey. Each renewable energy technology is selected and compared with others depending on the sub-criteria and the higher level of criteria and the priority levels have been determined. The proposed AHP model is given below in Fig.1

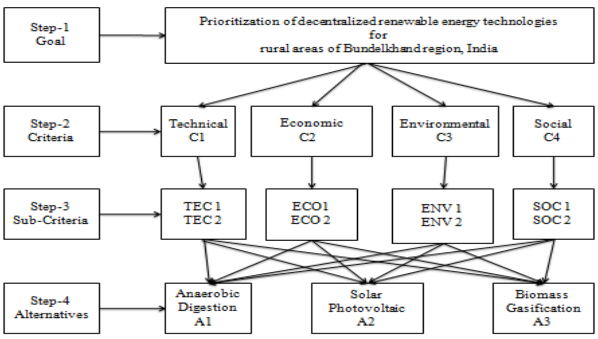

Fig. 1.Hierarchical structure for prioritization of decentralized renewable energy technologies

This model consists of four stages that are stated as a goal, criteria, sub-criteria, and alternatives. The Prioritization of decentralized renewable energy technologies for rural areas of Bundelkhand region is set as a goal of the decision model. Four main criteria and eight sub-criteria are selected to reach the goal and three different technologies of renewable energy are selected as alternatives. The description of criteria and sub criteria is given below in Table 3.

Table 3. Description of criteria and sub criteria

S. No.	Criteria	Sub criteria	Description
1	**Technical C1**	**TEC 1** Technical maturity	Fully Developed and customized renewable technologies are preferred.
		TEC 2 Performance consistency	Continuity and predictability of the performance. More consistent technologies are preferred over less consistent technologies.
2	**Economic C2**	**ECO1** Initial cost	All the costs involved until the operation starts. Less initial cost will be preferred over high initial cost.
		ECO2 Operational and maintenance cost	All the costs involved in operation and maintenance of the technology. So the option of having less operational and maintenance cost is preferred.
3	**Environmental (C3)**	**ENV 1** Pollutant Emissions	Less pollution creating technology is preferred over high emission pollution creating technology.
		ENV2 Waste reduction	The technology which plays a vital role in waste management is preferred.
4	**Social (C4)**	**SOC1** Social Acceptability	New technology is not easily adopted by the local people as their minds are set towards a certain type of conventional technology.

		SOC2 Village Development	Development of village with the use of technology that is in terms of improvement in the standard of living of people and local job creation.

The criteria and sub-criteria shown in Table 3 were chosen considering the local situation, availability of resources, environment and socio-economic standards. The measurement of criteria and sub-criteria were determined by the decision-maker for the prioritization of decentarilized renewable energy technologies for rural areas of Bundelkhand region .

3. Data Analysis and Results

The research presented here to prioritize three decentralized renewable energy technologies for rural areas of Bundelkhand region, India with four main criteria and eight sub-criteria related to various stakeholders. Results of criteria and sub criteria are discussed in section 3.1 while the results of alternatives with respect to sub criteria are discussed in section 3.2.The methodology of calculating weights and consistency ratio is explained in detail in the section 2 of research methodology.

3.1. Results of criteria and sub criteria

The criteria-wise preference analysis is shown in Table 4 shows that economy criteria was the most preferred, followed by technical, environmental and social criteria.

Table 4. Ranking of criteria with respect to goal

	TEC	ECO	ENV	SOC	Weights	Rank
TEC	1.000	1.000	3.000	2.000	**0.34744**	**2**
ECO	1.000	1.000	3.000	3.000	**0.37678**	**1**
ENV	0.333	0.333	1.000	2.000	**0.15494**	**3**
SOC	0.500	0.333	0.500	1.000	**0.12084**	**4**
Consistency ratio=0.04						

Based on the responses obtained from the experts and field survey, the highest percentage of weight was given to economy 0.37678 followed by the technical 0.34744, environmental 0.15494 and social 0.12084.The consistency ratio for this analysis was found 0.04, which is below than 0.1. The analysis implies that for the rapid development of decentralized renewable energy technologies for rural areas of Bundelkhand region, the utmost focus should be on the economic and technical criteria. The environmental and social criteria also play important factor in making efficient decentralized renewable energy technologies. Particularly, criteria based on environmental concern are of very importance as it becomes the challenge for mankind in present scenario. The results of local weight and global weight of sub criteria w.r.t. their respective criteria are presented in Table 5.

Table 5. Local weight and global weight of sub criteria

Criteria	Global priority weighting	Sub criteria	Local weight of sub criteria	Global weight of sub criteria
TEC	**0.34744**	TEC 1	**0.67**	**0.23162**
		TEC 2	**0.33**	**0.11581**
ECO	**0.37678**	ECO 1	**0.5**	**0.18839**
		ECO 2	**0.5**	**0.18839**
ENV	**0.15494**	ENV 1	**0.25**	**0.03873**
		ENV2	**0.75**	**0.11620**
SOC	**0.12084**	SOC 1	**0.25**	**0.03021**
		SOC 2	**0.75**	**0.09063**

The global weights of sub criteria are calculated by multiplication of local weight of sub criteria to the global weight of those particular criteria. It is clear from the table 5 that technical maturity (TEC 1) is reported as the most imperative sub criteria by obtaining 0.23162 weights. The second highest sub criteria are initial cost and operational & maintenance cost, both have also got a substantial weight of 0.18839. For the waste reduction and performance consistency as can be seen in the results presented in table 5 are respectively 0.11620, 0.11581. Within the social criteria, village development was found to be the most prominent sub criteria with weights 0.09063. Pollutant emissions and social acceptability have obtained the respective weights of 0.03873 and 0.03021.

Elaborative discussion of sub criteria priority is discussed in detail with the help of Fig. 2.

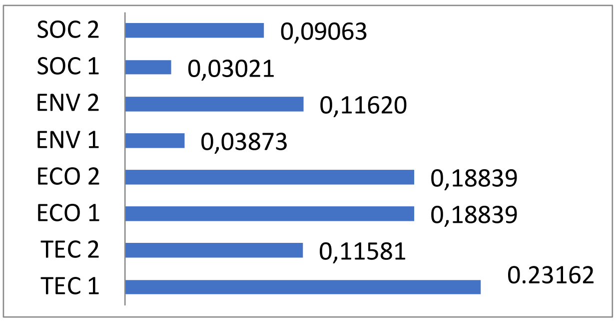

Fig.2: Global weights of Sub criteria with respect to Criteria

The emphasis on the technical maturity shows that renewable technology must be mature enough and having a customized solution.The importance of initial cost and operational &

maintenance cost illustrate the significance of economics in selecting decentralized renewable energy technologies. Waste reduction technologies are preferred because ultimately this will help the village clean and green. Performance consistency of particular renewable technology has also got significant amount of weight as the end user of the technology wants a trouble-free solution. The focus on village development illustrates the willingness of improvement in the standard of living of people and local job creation is also an important factor. Process emissions and social acceptability have also significant role in choosing the most appropriate decentralized renewable energy technologies for the rural areas of Bundelkhand region.

3.2. Results of renewable energy technology alternatives with respect to sub criteria

In this section, result of renewable energy technology alternatives with respect to sub criteria is discussed. Local weights of alternatives w.r.t. sub criteria are described in subsection 3.2.1 while in subsection 3.2.2; global weights of alternatives with respect to sub criteria are explained.

3.2.1. Local weights of Alternatives with respect to Sub criteria

Anaerobic digestion, solar photovoltaic and biomass gasification are evaluated on the basis of each sub criteria. Color coding has been done in given Table 6 of local weights of alternatives with respect to sub criteria. Green colour is taken for highest ranking, yellow colour for second priority and red colour coding for least weights. Table 6 shows the results of local weights of alternatives with respect to sub criteria. From the point of view of technical maturity and performance consistency, solar photovoltaic have given the most significant weight of **0.62501**.On the foundation of economy criteria, biomass gasification has given the most significant weight of **0.44343** w.r.t. initial cost while solar photovoltaic has given the most significant weight of **0.59363** w.r.t. operational and maintenance cost. While on the basis of both environmental sub criteria, anaerobic digestion has given the most significant weight respectively **0.63699** and **0.67381**. Solar photovoltaic has got weight of **0.67381** on the basis of social acceptability while anaerobic digestion has got the weight **0.66942** w.r.t. social criteria.

The consistency ratio for all eight evaluations is well below than acceptable range of 0.1.The dominance of alternatives w.r.t. each subcriteria is also shown in Fig.3.

Table 6. Local weights of Alternatives with respect to Sub criteria

	Anaerobic Digestion	Solar Photovoltaic	Biomass Gasification	CR
TEC 1	0.23849	0.62501	0.13650	0.01
TEC 2	0.13650	0.62501	0.23849	0.01
ECO 1	0.38737	0.16920	0.44343	0.01
ECO 2	0.15706	0.59363	0.24931	0.05
ENV 1	0.63699	0.10473	0.25828	0.03
ENV 2	0.67381	0.10065	0.22554	0.08
SOC 1	0.22554	0.67381	0.10065	0.08
SOC 2	0.66942	0.08795	0.24264	0.01

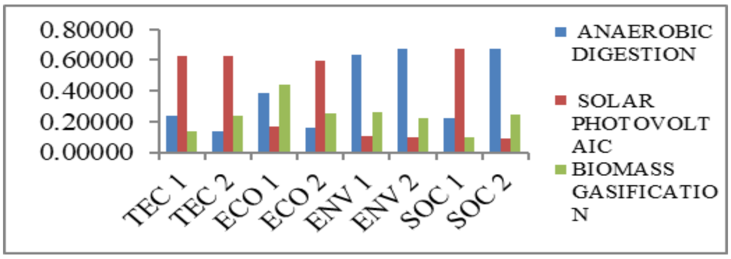

Fig. 3: Dominance of Alternatives with respect to Subcriteria

It is clear from the above figure, that solar PV has given the most significant weight with respect to both sub criteria of technical criteria, while AD has given dominance with respect to both sub criteria of environmental criteria.

3.2.2. Global weights of alternatives with respect to sub criteria

The global weights of alternatives are obtained by the multiplication of global weights obtained by sub criteria with respect to criteria and local weights obtained by alternatives with respect to each sub criteria as shown in Table 7.

Table 7: Global Weights of alternatives with respect to Sub criteria

	Anaerobic digestion	Solar PV	Biomass gasification
TEC 1	0.05524	0.14477	0.03162
TEC 2	0.01581	0.07238	0.02762
ECO 1	0.07298	0.03188	0.08354
ECO 2	0.02959	0.11184	0.04697
ENV 1	0.02467	0.00406	0.01000
ENV 2	0.07830	0.01170	0.02621
SOC 1	0.00681	0.02036	0.00304
SOC 2	0.06067	0.00797	0.02199
Global weight	**0.34407**	**0.40494**	**0.25099**

On the basis of global weights obtained, solar photovoltaic ranked first followed by anaerobic digestion and biomass gasification. The priority weight of solar photovoltaic is 0.40494, followed by 0.34407 for anaerobic digestion and 0.25099 for biomass gasification respectively.

The dominance of alternatives on the basis of global weights with respect to each sub criteria is shown in Fig.4. It is understandable from the figure given below, that solar photovoltaic has dominance on the basis of TEC 1, TEC2, ECO2 and SOC1 while anaerobic digestion has got maximum global weights on the basis of ENV1, ENV2 and SOC2 sub criteria. Biomass gasification has got dominance only on the basis of ECO1.

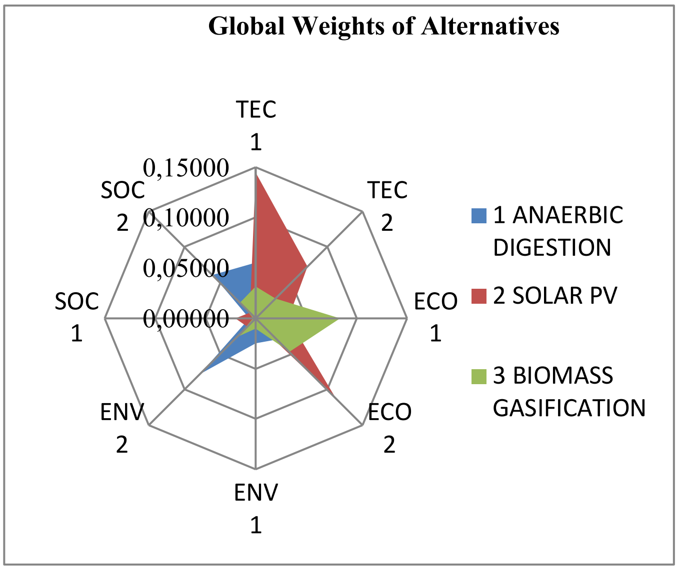

Fig. 4: Dominance of alternatives on the basis of global weights

Solar photovoltaic alternative has attained maximum overall weight and thus determined as most suitable decentralized renewable energy technologies for rural areas of Bundelkhand region, India.

4. Conclusion

An AHP based selection approach is proposed for the assessment to determine the most suitable decentralized renewable energy technologies for this region. Four criteria and eight sub-criteria are used for the evaluation of three decentralized renewable technologies in this research.

In this research, it was found that the economy criteria ranked first with weights 0.37678 followed by the technical criteria with weights of 0.34744 while environmental criteria and social criteria have gained weights respectively 0.15494, 0.12084. The emphasis on the technical criteria and economic criteria demonstrate the importance of these criteria in sustainable energy planning. Technical concerns are very important in the planning of renewable energy technology. Technical criteria are associated with the level of technical maturity and performance consistency of the technology. The reliability and performance of the technology depend on technology criteria. Therefore, technically sound solutions are necessary for sustainable utilization of renewable energy technology. The technology will be more lucrative to investors and local residents if it found suitable on the basis of economy criteria. It suggests that the technically sound and economically viable decentralized renewable energy technology is preferred over others.

On the basis of global priorities obtained by alternatives, the results showed that amongst all renewable technologies, solar photovoltaic (0.40494) has achieved the highest score followed by anaerobic digestion (0.34407) and biomass gasification (0.25099). The utilization of these decentralized renewable energy technology can reduce the reliance on fossil fuels. It would also improve energy availability in this region and create new job opportunities in this region.

This research is specific to the rural areas of Bundelkhand region of India and its results may have useful implications for various stakeholders involved in the planning of renewable energy technologies. This research may play a significant role in understanding of various aspects related to prioritization of renewable energy technologies in Bundelkhand region of India. The results of this research can be compared by using different multi criteria decision making methods in future research. In the conclusion, it is recommended that adoption of AHP methodology is very helpful in sustainable energy planning order to obtain a finest solution.

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