SELECTION OF ALTERNATE FUEL FOR ELECTRICAL POWER GENERATOR USING HYBRID MULTI CRITERIA DECISION MAKING TECHNIQUE

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Nowadays, biodiesel is considered as one of the main sources of energy for rural electrification. Efficiency of the diesel power generator depends on the fuel input. The selection of suitable biodiesel is a difficult task based on the conflicting nature of the parameters. This paper describes the application of Hybrid Multi Criteria Decision Making (MCDM) technique for the selection of the best biodiesel for a diesel power generator. There are two models proposed to evaluate the best biodiesel. The first model, Analytical Hierarchy Process (AHP) is integrated with Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Second model Fuzzy Analytical Hierarchy Process (FAHP) is integrated with TOPSIS. The AHP and FAHP are used to analyze the structure of the problem and determine the weights of the each criterion. TOPSIS is used to obtain the final ranking of the alternatives. This study focuses on seven alternatives and seven evaluation criteria to select the best biodiesel

Keywords: AHP, FAHP, TOPSIS, MCDM, Biodiesel, Power Generator

1. Introduction

Day by day the energy consumption is increasing due to narrow growth of world population, proliferation of technology advancement and improved standard of living. In most of the countries, the energy requirements are met out through fossil fuels. These sources are limited and will be consumed shortly[1]**.**Coal is the primary source in electrical power generation, but combustion of coal produces high carbon dioxide and leads to environmental problems[2]**.** Environmental problems can be suppressed by the use of renewable energy sources such as solar, wind, hydroelectric, biomass and geothermal energy [3]**.** Biodiesel is also an ideal choice to meet the energy requirement and energy depletion, with renewable and bio-degradable properties [4]. Biodiesel is environment friendly and can be synthesized from both edible and non-edible oils

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[5]. The demand of biodiesel is expected to increase in the future and the using of non-edible oil seeds is the reliable and sustainable feed stock for biodiesel production [6], [7].The biodiesel is used as an alternative fuel for operating I.C engines, boilers and diesel generator etc. T. Eevera have used biodiesel derived from groundnut oil as a fuel for operating the generator and reported that the voltage regulation and frequency are similar to diesel [8]. Merve cetinkaya et.al, have used the waste cooking oil for power generation and also observed the improvement of performance and emission characteristics [9]. T. Eevera 2013 utilised cotton seed oils in a generator and found good electrical efficiency [10]. Osmano Souza Valente has reported that the fuel consumption of the diesel generator is less when using soya bean biodiesel compare to castor oil biodiesel and diesel [11]. J.M.Kennedy applied rapeseed methyl ester as a fuel for an electric generator and observed the emission characteristics [12]. More than 350 oil crops are identified as potential sources for biodiesel production [13]. To select apt one from the 350 crops, we need a mathematical model. In this paper Hybrid MCDM models are developed and proposed for evaluation and selection of optimum fuel for operating the diesel power generator.

2. Materials and Methods

A Biodiesel Preparation

The non-edible oils which are extracted from the seeds or kernels of Flax, Mahua, Jatropha, Cotton, Neem, Pongamia and Meusa Ferra. Extraction of oil from seeds can be done by an engine driven screw press; it can extract 68–80% of the oil from seeds [14]**.** The extracted oil needs further treatment of filterization and degumming for removal of dirt and other inert materials. The problems with crude vegetable oils are characterized by high viscosity, low volatility and polyunsaturation. These problems can be overcome by transesterification [15]**.** Transesterification is regarded as one of the best method among various approaches due to its low cost and simplicity [16]**,** using this method high purity and better yield of biodiesel in a short time can be achieved [17]**.** The various properties of selected alternative biodiesels are listed in *Table 1*.

Table 1

Fuel Properties

	Calorific value kJ/kg	**Viscosity mm^2/sec**	**Density kg/m^3**	**Cetane number**	**Flash point °C**	**Cloud point °C**	**Pour point °C**
Pongamia	43475	5.07	928	65	210	3.5	-3
Jatropha	40999	4.92	878	51.8	170	8	-2
Cotton Seed	39403	4.58	878.6	52.6	204	14	5

Neem	39867	5.213	839	46	76	18	2
Linseed	36867	5.3	910	54	155	-3.6	-9
Mahua	39415	4.94	920	51	131	4	7
Meusa Ferra	39654	6.2	890	54	112	16	3

B FAHP Method

Since Saaty (1980) developed the AHP (analytic hierarchy process), which is a widely popular technique employed to decision-making problem based on multiple attributes [18]. Even though the AHP is used in many decision making problems but it has some limitations of its use i.e. the ranking of AHP is not precise and cannot reflect the human thinking style [19]. To deal with the indistinctness of human thought, Zadeh introduced fuzzy set theory to express the linguistic terms in the decision making process and called it as FAHP [20]. The procedural steps involved in FAHP method are listed below:

Step 1: A complex decision making problem is structured using a hierarchy. A hierarchy has three levels: the overall goal of the problem at the top, multi criteria that define criteria in the middle and decision criteria at the bottom.

Step 2: The crisp pairwise comparison matrix *A* is fuzzified using the triangular fuzzy number .

Let C= {Cj | j =1,2,..., *n* | } be a set of criteria. The result of the pairwise comparison on "*n*" criteria can be summarized in an (*n x n*) evaluation matrix *A* in which every element □$_{i\,j}$ (i,j = 1,2,..., *n*) is the quotient of the weights of the criteria, as shown:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix},\ a_{ii} = 1,\ a_{ji} = 1/a_{ij},\ a_{ij} \neq 0 \tag{1}$$

Step 3: To normalize and find the relative weights of each matrix.

$$A_W = \lambda_{max} W \tag{2}$$

The consistency is defined by the relation between the entries of $A: a_{ij} \times a_{jk} = a_{ik}$

The Consistency Index (CI) is

$$CI = (\lambda_{max} - n) / (n - 1) \tag{3}$$

Step 4: The CR for each square matrix is obtained from dividing CI values by the Random Consistency Index (RCI) values.

$$CR = CI/RCI. \tag{4}$$

The RCI which is obtained from a large number of simulations runs and varies depending upon the order of the matrix. *Table 2* lists the values of the RCI.

Table 2

Random Consistency Index (RCI)

No	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

C TOPSIS Method

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is a unique and multiple criteria method to identify solutions from a finite set of alternatives. It is one of the MCDM methods and first developed by Hwang and Yoon (1981), additionally developed by Hwang, Lai and Liu in 1993[21]. Shanian and Savadogo reported that TOPSIS is relatively simple and fast, with a systematic procedure [22].H.H. Goh applied AHP-TOPSIS based load shedding in pulp mill for an electrical system [23]. H. Martin proposed TOPSIS methodology to assess the wind turbine floating support structures[24]. Weige Ji and Yanan Wang used AHP-TOPSIS in evaluating the student satisfaction to assist principal to comprehend their students' overall situation [25]. Kumar Anupam determined the suitability of a feed stock for pulping and papermaking by utilizing TOPSIS [26]. Ateekh Ur Rehman et al. applied AHP-TOPSIS to select an industrial robot to comply with the objective of the organization [27].Yuxian Du utilized TOPSIS to identify the influential nodes in a reliability analysis for an organizational network[28]. The procedure of TOPSIS method is as follows:

Step 1: Normalization of the evaluation matrix:

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{J} f_{ij}^{2}}} \qquad j = 1,2,3,\ldots,J,\ i = 1,2,3,\ldots,n. \tag{5}$$

Step 2: Construction of the weighted normalized decision matrix:

$$v_{ij} = w_i * r_{ij} \qquad j = 1,2,3,\ldots,J,\ i= 1,2,3,\ldots,n. \tag{6}$$

Where w_i is given by $\sum_{i-1}^{n} w_i = 1$.

Step 3: Determination of the positive and negative ideal solutions:

$$A* = \{v_1*,\ldots,v_i*\} = \left\{\left(\max_j v_{ij} \middle| i \in I'\right), \left(\min_j v_{ij} \middle| i \in I''\right)\right\}. \tag{7}$$

$$A^{-} = \{v_1^{-},....,v_i^{-}\} = \left\{\left(\min_j v_{ij} \middle| i \in I^{'}\right),\left(\max_j v_{ij} \middle| i \in I^{"}\right)\right\}. \quad (8)$$

Step 4: Calculation of the separation measure:

$$D_j* = \sqrt{\sum_{i=1}^{n}(v_{ij_i} - v_i^*)^2}\ , \qquad j = 1,2,3,….J. \quad (9)$$

$$D_j^{-} = \sqrt{\sum_{i=1}^{n}(v_{ij_i} - v_i^{-})^2}\ , \qquad j = 1, 2, 3, ….J. \quad (10)$$

Step 5: Calculation of the relative closeness to the ideal solution:

$$CC_j^* = \frac{D_j^{-}}{D_j^* + D_j^{-}}, \qquad j = 1,2,3,….J. \quad (11)$$

Step 6: Ranking the priority.

3. Proposed Methodology

The proposed methodology consists of three basic stages: (1) Identification of the criteria to be used in the model (2) AHP and FAHP computation (3) Ranking the alternatives using TOPSIS.

A Criteria for selecting an optimum fuel

In this stage to identify the important criteria, has to be considered for the evaluation. The criteria are identified through literature [29] and experts. The identified evaluation criteria are Density, Viscosity, Cetane Number, Calorific Value, Flash Point, Cloud Point and Pour Point.

B Computation of criteria weights using AHP and FAHP

The pair-wise comparison matrix is formed by the expert team and using crisp scale and triangular fuzzy scale from table 3 and 4 respectively and tabulated in *Table 5* and *Table 6*. Based on the values of the final comparison matrix the individual weights, CI and CR are evaluated using equations 3& 4. The calculated CI, CR and weights of the criteria for AHP and FAHP are tabulated in *Table 7.*

Table 3

Pairwise Comparison Scale

Scale of importance	Crisp score	Reciprocal of crisp score
Equal importance	1	1.00
Moderate	3	0.33
Strong importance	5	0.20
Very strong importance	7	0.14
Extremely preferred	9	0.11

Table 4

Membership function of Fuzzy numbers

Scale of Importance	Triangular Fuzzy Number (TFN) (L, M, U)	Reciprocal of TFN (1/L, 1/M, 1/U)
Just equal	(1, 1, 1)	(1, 1, 1)
Equal importance	(1, 1, 3)	(0.33, 1, 1)
Moderate	(1, 3, 5)	(0.20, 0.33, 1)
Strong importance	(3, 5, 7)	(0.14, 0.20, 0.33)
Very strong importance	(5, 7, 9)	(0.11, 0.14, 0.20)
Extremely preferred	(7, 9, 9)	(0.11, 0.11, 0.14)

Table 5

Pairwise Comparison Matrix forAHP-TOPSIS

	Calorific value	Viscosity	Density	Cetane number	Flash point	Fire point	Pour point
Calorific value	1	3	5	5	7	7	9
Viscosity	0.3333	1	3	5	7	7	9
Density	0.2	0.3333	1	3	5	5	7
Cetane number	0.2	0.2	0.3333	1	3	3	7
Flash point	0.1428	0.1428	0.2	0.3333	1	3	7
Fire point	0.1428	0.1428	0.2	0.3333	0.3333	1	5
Pour point	0.1111	0.1111	0.1428	0.1428	0.1428	0.2	1

Table 6

Pairwise Comparison Matrix for FAHP-TOPSIS

	Calorific value	Viscosity	Density	Cetane number	Flash point	Fire point	Pour point
Calorific value	1,1,1	1,1,3	3,5,7	1,3,5	5,7,9	5,7,9	7,9,9
Viscosity	0.333, 1,1	1,1,1	1,1,3	1,3,5	5,7,9	5,7,9	7,9,9

Density	0.143,0.2,0.333	0.333,1,1	1,1,1	1,1,3	3,5,7	3,5,7	5,7,9
Cetane number	0.200, 0.333,1	0.2,0.333,1	0.333,1,1	1,1,1	1,1,3	1,1,3	5,7,9
Flash point	0.111, 0.143,0.2	0.111, 0.143,0.2	0.143,0.2,0.333	0.333,1,1	1,1,1	1,1,3	5,7,9
Fire point	0.111, 0.143,0.2	0.111,0.143,0.2	0.143,0.2,0.333	0.333,1,1	0.333,1,1	1,1,1	1,3,5
Pour point	0.111, 0.111,0.143	0.111,0.111,0.143	0.111,0.143, 0.2	0.111,0.143,0.2	0.111,0.143,0.2	0.2,0.333,1	1,1,1

Table 7

Crisp Weights of AHP and FAHP

	AHP Crisp Weights		**FAHP Crisp Weights**	
C1	0.4045	CI=0.131 RCI=1.35 CR=CI/RCI=0.097037	0.3426	CI=0.1120 RCI=1.3500 CR=CI/RCI=0.0830
C2	0.2533		0.2610	
C3	0.1475		0.1614	
C4	0.0869		0.1064	
C5	0.0564		0.0603	
C6	0.0337		0.0472	
C7	0.0178		0.0211	

C. TOPSIS Computations

The TOPSIS methodology is used for determining the ranking of alternatives where the best decision is made to be closest to the ideal and farthest from the non-ideal. The first step is to develop the normalization of matrix by normalizing the fuel performance parameters using equation 5 and is tabulated in *Table 8.*

Table 8

Normalized Decision Matrix FAHP-TOPSIS

	Calorific value	**Viscosity**	**Density**	**Cetane number**	**Flash point**	**Cloud point**	**Pour point**
Pongamia	0.4108	0.3688	0.3930	0.4571	0.5033	0.1179	-0.2230
Jatropha	0.3874	0.3579	0.3719	0.3642	0.4074	0.2695	-0.1487
Cotton Seed	0.3724	0.3331	0.3721	0.3699	0.4889	0.4716	0.3716
Neem	0.3767	0.3792	0.3554	0.3235	0.1821	0.6064	0.1487
Linseed	0.3484	0.3855	0.3854	0.3797	0.3715	-0.1213	-0.6690
Mahua	0.3725	0.3593	0.3897	0.3586	0.3139	0.1347	0.5203

Meusa Ferra	0.3747	0.4510	0.3770	0.3797	0.2684	0.5390	0.2230

Then the AHP and FAHP criteria weights are considered to compute the weighted, normalized decision matrix for each using equation 6 and the matrix is given in *Table 9* and *10*.

Table 9

Weighted Normalised Decision Matrix for AHP-TOPSIS

	Calorific value	Viscosity	Density	Cetane number	Flash point	Cloud point	Pour point
Pongamia	0.1662	0.0934	0.0580	0.0397	0.0284	0.0040	-0.0040
Jatropha	0.1567	0.0906	0.0549	0.0316	0.0230	0.0091	-0.0026
Cotton Seed	0.1506	0.0844	0.0549	0.0321	0.0276	0.0159	0.0066
Neem	0.1524	0.0960	0.0524	0.0281	0.0103	0.0204	0.0026
Linseed	0.1409	0.0976	0.0569	0.0330	0.0209	-0.0041	-0.0119
Mahua	0.1507	0.0910	0.0575	0.0312	0.0177	0.0045	0.0093
Meusa Ferra	0.1516	0.1142	0.0556	0.0330	0.0151	0.0181	0.0040

Table 10

Weighted Normalised Decision Matrix for FAHP-TOPSIS

	Calorific value	Viscosity	Density	Cetane number	Flash point	Cloud point	Pour point
Pongamia	0.1407	0.0962	0.0634	0.0487	0.0303	0.0056	-0.0047
Jatropha	0.1327	0.0934	0.0600	0.0388	0.0246	0.0127	-0.0031
Cotton Seed	0.1276	0.0869	0.0601	0.0394	0.0295	0.0222	0.0079
Neem	0.1291	0.0990	0.0573	0.0344	0.0110	0.0286	0.0031
Linseed	0.1194	0.1006	0.0622	0.0404	0.0224	-0.0057	-0.0141
Mahua	0.1276	0.0938	0.0629	0.0382	0.0189	0.0064	0.0110
Meusa Ferra	0.1284	0.1177	0.0608	0.0404	0.0162	0.0254	0.0047

After weighted normalization matrix both the positive ideal solution and negative ideal solution are determined for all the alternatives using equations 7 and 8. Separation measures of each alternate are computed using equations 9 and 10 to give the separation from positive ideal solution and negative ideal solution.

$$D_1^* = \sqrt{(0.000714522)} = 0.026731\,; \quad D_1^- = \sqrt{(0.001897778)} = 0.43564$$

$$D_2^* = \sqrt{(0.000855821)} = 0.029254\,; \quad D_2^- = \sqrt{(0.00128572)} = 0.035857$$

$D_3^* = \sqrt{(0.001875145)} = 0.043302$; $D_3^- = \sqrt{(0.001100057)} = 0.033167$

$D_4^* = \sqrt{(0.001959846)} = 0.044270$; $D_4^- = \sqrt{(0.000918948)} = 0.030314$

$D_5^* = \sqrt{(0.000866106)} = 0.029430$; $D_5^- = \sqrt{(0.00220233)} = 0.046929$

$D_6^* = \sqrt{(0.001200679)} = 0.034651$; $D_6^- = \sqrt{(0.001279729)} = 0.035773$

$D_7^* = \sqrt{(0.002531194)} = 0.050311$; $D_7^- = \sqrt{(0.000374131)} = 0.019343$

The relative closeness of each alternative to the ideal solution is calculated using the equation 11. Finally, according to the relative closeness the ranks are preferred to the fuel and the obtained results are tabulated in *Table 11*.

$CC_1^* = \frac{0.043564}{(0.026731 + 0.043564)} = 0.619733$ $CC_2^* = \frac{0.035857}{(0.029254 + 0.035857)} = 0.550702$

$CC_3^* = \frac{0.033167}{(0.043302 + 0.033167)} = 0.619733$ $CC_4^* = \frac{0.030314}{(0.044270 + 0.030314)} = 0.406442$

$CC_5^* = \frac{0.046929}{(0.029430 + 0.046929)} = 0.614586$ $CC_6^* = \frac{0.035773}{(0.034651 + 0.035773)} = 0.507970$

$CC_7^* = \frac{0.019343}{(0.050311 + 0.019343)} = 0.277696$

Table 11

Results of Alternatives with the use of AHP-TOPSIS and FAHP-TOPSIS

Alternatives	**AHP-TOPSIS**		**FAHP-TOPSIS**	
	Performance	Rank	Performance	Rank
Pongamia	0.6303	1	0.6197	1
Jatropha	0.5742	2	0.5507	3
Cotton Seed	0.4676	5	0.4337	5
Neem	0.4518	6	0.4064	6
Lin Seed	0.5432	3	0.6146	2
Mahua	0.5060	4	0.5080	4
Meusa Ferra	0.2991	7	0.2777	7

4. Results and Discussion

The results of the proposed methodologies are tabulated in *Table 11*. The ranking order of biodiesels Pongamia > Jatropha > Linseed > Mahua > Cotton Seed > Neem> Meusa Ferra is placed in an ascending order based on closeness coefficient values of AHP-TOPSIS. The biodiesel Pongamia has the highest performance value of 0.630 using AHP-TOPSIS methodology. In FAHP-TOPSIS also the pongamia has the highest performance value of 0.619. The first ranking position of AHP-TOPSIS and FAHP-TOPSIS is similar, but the preorder is changed. The result shows that the decision makers can choose biodiesel of pongamia for operating the diesel generator. T. Hari Prasad et al. investigated the performance of electrical generators for driving the agricultural pumps and reported that the brake thermal efficiency is slightly reduced and hydrocarbon, carbon-monoxide and smoke emissions in the exhaust are reduced when fuelled with pongamia biodiesel [30]. Hence, the proposed Hybrid MCDM model has an ability to be successfully selected for the better alternative fuel from the several alternatives.

5. Conclusion

Biodiesel is a renewable source and which has nearly the same efficiency of conventional diesel, it can be used to solve the future energy crisis. Improper selection of fuel leads to the negative impact on the environment and also on the operating cost. Our proposed model has been tested by many experiments on various applications. So this model can help the decision makers to choose the best biodiesel. The highest performance in ranking results of the AHP –TOPSIS and FAHP-TOPSIS are the same, but the preorder is changed due to the elimination of uncertainty during the pairwise comparison process through fuzzy set theory. The research work can be extended with application of other MCDM techniques such as ELECTRE, VIKOR and PROMETHEE.

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