# SELECTION OF INDIA'S ENERGY RESOURCES USING FUZZY VIKOR METHOD

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 ISSN: 1923-6654 (print)
ISSN 1923-6662 (online). Available at http://www.ssrn.com/link/OIDA-Intl-Journal-Sustainable-Dev.html

***Abstract:*** An optimum selection of potential future energy resources is now need of all the nations. This study aims to rank viable energy resources for India. We consider six sources of energy namely, hydropower, solar, wind, coal & lignite, gas & liquid, and nuclear energy. The objective is to provide a quantitative analysis for the selection of most feasible and sustainable source of energy by critically analyzing them based on six criteria namely: feasibility, investment ratio, useful life, operational & management cost, risk in operation and pollutants emission. We have employed fuzzy based multiple attribute decision making (MADM) approach named Fuzzy VIKOR method in order to consider uncertainty associated with the data. The criteria understudy are prioritized using modified digital logic method and by the use of trapezoidal fuzzy numbers. Our results show that solar, hydropower and wind energy are the most effective sources of energy due to their ease of access, lack of risk and eco-friendly nature. Eventually, the research aims at providing constructive inputs to the energy policy of India for sustainable growth of nation.

***Keywords:*** Energy, Fuzzy, India, Selection, Solar

## INTRODUCTION

India is the eleventh largest economy and fifth largest energy generation capacity in the world. India's energy production is not on same pace as its economy growth. As a result, India imports net 25.65 (% energy use) in 2009 (as per World Bank report, 2010). It has very high demand for energy which is majorly fuelled by coal, oil, and hydroelectric resources. In order to fulfill future needs of the nation (as conventional energy resources are limited), India's policies are now diverted towards renewable energy resources. These energy resources are wind, solar and geothermal. There is a large potential for renewable energy in India and it is estimated over 150,000 MW. It is to be noted that conventional and renewable energy resources have their own advantages over others. Several factors such as social, economic and environmental issues play an important role in deciding appropriate energy resource. It is important to assess whether these energy resources are equally important for India? Or do they have their a hierarchical order? To answer these questions, the present study deals with ranking of energy resources based on multiple factors which namely; social, economic and technical. Selection of an alternative based on multiple attributes is a multiple attribute decision making (MADM) problem. A variety of methods are reported under MADM methods such as simple additive weighting (SAW), analytic hierarchy process (AHP) [1], VlseKriterijumskaOptimisacija I KompromisnoResenje (VIKOR) [2], technique for order preference by similarity to ideal solution (TOPSIS) [3] and ELimination Et Choix Traduisant la REalité (ELECTRE) [4]. These methods have been successfully applied to various fields such as manufacturing processes, social science decisions, financial decisions, management issues and engineering problems [5-8]. Few attempts have been made in energy selection issues for countries like

Turkey, Spain and China [9-11]. However such studies are sparse in India context.

The above mentioned MADM approaches work on crisp values of attributes, i.e., fixed numerical data for various attributes. However in the case of a real world problem, most of the attributes/properties should be defined in intervals rather than crisp values because of uncertainty that they carry in them. For this purpose, interval-based MADM approaches are proposed. These methods include I-VIKOR method [12] and Fuzzy VIKOR Method [13]. But, many a times, decision making problems have input data in the form of linguistic variables which reflect the quantitative importance of different attributes. This format of crediting variables have arisen due to the complexity and uncertainty of the objective subjects and ambiguity of human thinking. Therefore, the MADM as far as the linguistic context is concerned has been an interesting research topic which has been receiving more and more attention in recent years [14-17]. Present study investigates hierarchy of energy resources in India based of social, economic and technical factors using interval-VIKOR and fuzzy VIKOR approaches.

## ENERGY SOURCES AND THEIR SELECTION CRITERIA

According to the nineteenth issue of energy statistics (2012) given by Central Statistics Office, Ministry of Statistics and programme implementation [18]; India's power sector has a total installed capacity of approximately 1,46,753 Megawatt (MW) of which 54% is coal-based, 25% hydro, 8% is renewable and the balance is gas and nuclear-based. Table 1 shows India’s energy production from various sources for the period of 2010-2011. Here we study hierarchy of energy resources based on multiple socio-economic and technical factors as shown in Figure1.

### Energy Sources

The different forms of potential energy sources considered in the study are as follows:

#### *Hydropower*

Hydropower is the power converted from the water potential and kinetic energy. An effective production of hydropower is done when there is a sufficient discharge/head in the water. The common form of hydropower plant consists a dam on a river to store water in a reservoir. When the water released from the reservoir with a suitable pressure head, water flows through a turbine, a generator activates to produce electricity by rotating the turbines. Another type of hydropower plant stores power and is called a pumped storage. The power is sent from a power grid into the electric generators. Hydraulic energy is one of the major resources in India. So far, 20% of the total hydropower potential in India has been put into use. Exploitable potential of hydropower is about 148,700 MW out of which a capacity of 30,164 MW (20.3%) has been developed so far and 13,616 MW (9.2 %) of capacity is under construction.

#### *Solar*

Solar energy is produced using photovoltaic cell systems to convert sunlight directly into electricity which could be used to generate electricity. Majority of India receives 4-7 kWh of solar radiation per square meter per day with 250-300 sunny days in a year. India receives about 3000 hours of sunshine every year, equivalent to over 5,000 trillion kWh. India can easily utilize its Solar Power. Today the contribution of solar power with an installed capacity of 9.84 MW, is a fraction (less than 0.1 %) of the total renewable energy installed 13, 242.41 (as on 31st October 2008 by Ministry of new and renewable energy) [19].

#### *Wind*

Wind power counts up to 55% of the total potential of renewable sources of energy in India as per 19$^{th}$ issue of Energy Statistics in 2012 by Central Statistics Office, Ministry of Statistics and Programme Implementation. India now ranks as a “wind superpower” having a net potential of about 45000 MW only from 13 identified states.

#### *Coal & lignite*

India has a good reserve of coal and lignite. The estimated reserves of coal are around 286 billion tones. Coal deposits are mainly confined to eastern and south central parts of the country. The states of Jharkhand, Orissa, Chhattisgarh, West Bengal, Andhra Pradesh, Maharashtra and Madhya Pradesh account for more than 99% of the total coal reserves in the country. There has been an increase of 3.1% in the estimated coal reserves during the year 2010-11 with Madhya Pradesh accounting for the maximum increase of 5 %. The estimated reserve of lignite as on 31.03.11 was 41 billion tons, of which 80 % was in the southern State of Tamil Nadu. The increase in the estimated reserve of lignite during the year 2010-11 was 2.4%, Tamil Nadu accounting for the maximum increase of 2.7%. The approximate growth rate of coal & ignite in year 2010-11 over 2009-2010 as per ministry of coal is about 10.75% [19].

#### *Natural gas*

Total reserves of natural gas accounts for 1241 Billion Cubic Meters [19]. Major part of natural gas reserves in India lies in the eastern offshores which accounts for 35%, followed by western offshore (33%) and then by states like Gujarat, Assam, Tripura, Rajasthan and Tamil Nadu. The approximate growth rate of year 2010-11 over 2009-2010 as per ministry of petroleum and natural gas is about 9.95%.

***Nuclear energy***

Nuclear energy is energy due to the splitting (fission) or merging together (fusion) of the nuclei of atom(s). Currently India's 2.07% of power consumption is satisfied by nuclear power with 4800 MW of production annually [20].

The above mentioned energy resources are investigated in view of multiple criteria including feasibility, investment ratio, useful life, operation/maintenance costs (O/M costs), risk, and pollutants' emission.

**Selection Criteria**

There are a number of criteria which are considered for deciding hierarchy of energy sources described as follows.

***Feasibility***

It anticipates possibility for implementation of the energy plant. It includes geographical and social factors associated with energy sources.

***Investment ratio***

This criterion analyses the total cost of the energy investment in order to be fully operational for any plant.

***Useful life***

It estimates the overall life of an energy plant that the source of energy could serve.

***Operation/maintenance costs (O/M costs)***

After the completion of building and running phase of a plant, it is always necessary to evaluate the operation and maintenance cost for a smooth operation.

***Risk***

The risk criterion evaluates the failure possibility of energy plant considering multiple factors.

***Pollutants' emission***

It deals with the influence of energy plant on the environment. It includes various pollution factors such as water, noise, air and land pollutions.

## DATA AND METHODOLOGY

**Preparation of initial data**

The updated data of all the attributes for all the energy sources is obtained from various sources [18, 21]. Table 2 shows values for investment ratio, useful life and operational & maintenance cost for all the energy resources understudy. Others criteria including feasibility, risk and pollutants' emission are assigned linguistic terms in context of India.

**Preparation of data for Interval VIKOR method**

As the initial data consist of both quantitative as well as qualitative terms, for the application of Interval VIKOR method; these are brought on to a single scale. These qualitative values (linguistic terms) are converted into crisp intervals using fuzzy approach. The numerical ratio and linguistic interval scales are related using the approach developed by Shen-Lin Chang [22]. This approach has also been used in conversion of linguistic terms into fuzzy numbers for weighing parameters in the domain of renewable energy [23]. On converting the linguistic interval scale, a linguistic rating is represented using a linguistic term with a grade of "1". The numerical ratio scale and the linguistic scale is used to obtain the cardinal information. The corresponding scale could be seen in figure 2. Also, it is to be noted that these values associated with various criteria are dynamic and change over period of time. Therefore, an interval is formed by considering +5% of the data defining the upper range and -5% of the values defining the lower range as depicted in Table 3.

**Preparation of initial data for Fuzzy VIKOR method**

While considering fuzzy approach to find the most viable source of energy for India, a set of linguistic terms are defined for each attribute determined against each alternative energy source. A trapezoidal distribution [13] (Table 4) for each of the values is considered and the initial data (Table 2) of previous process (Interval VIKOR), which is a combination of numbers and linguistic terms is mapped to this distribution by the inputs from experts. These values are presented in linguistic form in Table 5. These linguistic terms are mapped and replaced with values described in Table 4 based on the relation mentioned. Hence, Table 6, which contains decision matrix (discussed later) is used as initial data for application of Fuzzy VIKOR method.

**Subjective weights**

It is to be noted that all the attributes understudy cannot be assumed to be equally important and hence require subjective weights. Effective weights can be assigned using modified digital logic (MDL) method [24]. The MDL technique is used to evaluate objective weight based on the user discretion and priority input. It has been derived from Digital Logic (DL) approach which compares two attributes at a time to determine the relative importance of one over another.

**Table 1**: Energy Production in India (Year 2010-11)

| Energy source | Energy production(MW) |
|---|---|
| **Hydropower** | 37367 |
| **Coal & lignite** | 115649 |
| **Gas or liquid fuel** | 17706 |
| **Nuclear** | 4800 |
| **Solar** | 1030 |
| **Wind** | 17644 |

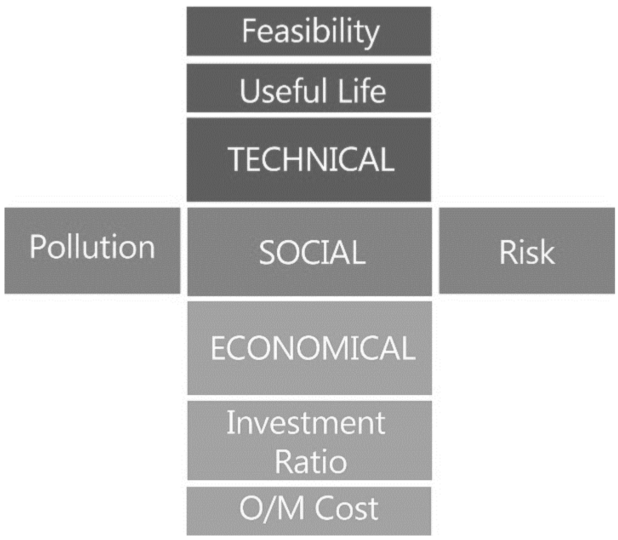


**Figure 1:** Different class of attributes used to select most viable energy source.

**Table 2:** Initial data containing linguistic terms and numerical values to be used for Interval VIKOR Method

| Attributes ------------------------- Sources | Feasibility | Investment Ratio (Rs. (INR) /KW) | Use full Life (Years) | O/M Cost (Rs. $10^{-3}$/KW) | Risk | Pollutants' Emission |
|---|---|---|---|---|---|---|
| **Hydro Power** | Above | 40,000 | 30 | 5.5 | Above Medium | Very Low |
| **Coal & Lignite** | High | 50,000 | 25 | 3.1 | Below Medium | Very high |
| **Gas & Liquid** | Above Medium | 30,000 | 20 | 3.5 | Above Medium | High |
| **Nuclear** | Below Medium | 70,000 | 35 | 1.2 | Very High | Very high |
| **Solar** | Low | 1,50,000 | 40 | 10 | Very Low | Very low |
| **Wind** | **Below Medium** | **60,000** | **25** | **3.2** | **Low** | **Low** |

**Table 3:** Data obtained after substitution of Fuzzy Numbers and forming intervals.

| Attributes -------------------------------------- Sources | Feasibility | | Investment Ratio | | Use full Life | | O/M Cost | | Risk | | Pollutants' Emission | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **INTERVALS (L=Lower, U=Upper)** | L | U | L | U | L | U | L | U | L | U | L | U |
| **Hydro Power** | 0.5 | 0.67 | 38000 | 42000 | 28.5 | 31.5 | 2.75 | 8.25 | 0.5 | 0.67 | 0.01 | 0.16 |
| **Coal & Lignite** | 0.67 | 0.84 | 47500 | 52500 | 24.75 | 26.25 | 1.55 | 4.65 | 0.33 | 0.5 | 0.84 | 0.99 |
| **Gas & Liquid** | 0.5 | 0.67 | 28500 | 31500 | 19 | 21 | 1.75 | 5.25 | 0.5 | 0.67 | 0.67 | 0.84 |
| **Nuclear** | 0.33 | 0.5 | 66500 | 73500 | 33.25 | 36.75 | 0.6 | 1.8 | 0.84 | 0.99 | 0.84 | 0.99 |
| **Solar** | 0.16 | 0.33 | 142500 | 157500 | 38 | 42 | 5 | 15 | 0.01 | 0.16 | 0.01 | 0.16 |
| **Wind** | 0.33 | 0.5 | 57000 | 63000 | 23.75 | 26.25 | 1.6 | 4.8 | 0.16 | 0.33 | 0.16 | 0.33 |

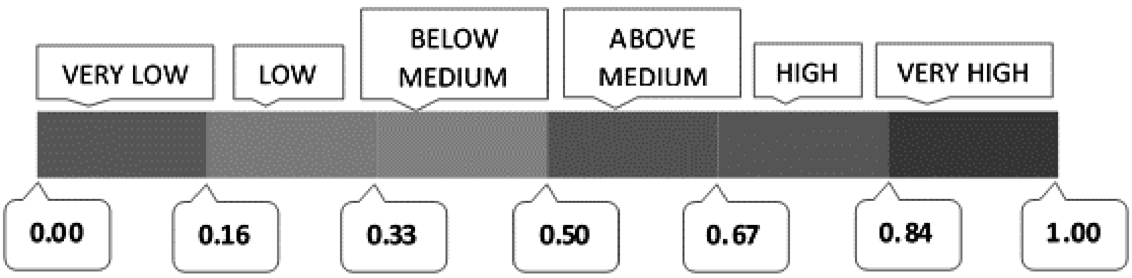


**Figure 2:** Scale mapping linguistic terms to respective interval values used in Interval VIKOR Method

**Table 4:** Linguistic terms and corresponding fuzzy numbers for each criterion

| Importance | Abbreviation | Fuzzy number |
|---|---|---|
| **Exceptionally High** | EH | (0.8, 0.9, 1, 1) |
| **Very high** | VH | (0.7, 0.8, 0.8, 0.9) |
| **High** | H | (0.5, 0.6, 0.7, 0.8) |
| **Above average** | AA | (0.4, 0.5, 0.5, 0.6) |
| **Average** | A | (0.2, 0.3, 0.4, 0.5) |
| **Very low** | VL | (0.1, 0.2, 0.2, 0.3) |
| **Extremely low** | EL | (0.01, 0.01, 0.1, 0.2) |

**Table 5:** Pre-Decision Matrix relating linguistic terms to different sources and attributes

| Attributes / Sources | Feasibility | Investment Ratio | Use full Life | O/M | Risk | Pollutants' Emission |
|---|---|---|---|---|---|---|
| **Hydro Power** | AA | A | H | H | AA | EL |
| **Coal & Lignite** | VH | AA | AA | A | AA | VH |
| **Gas & Liquid** | H | VL | A | A | H | VH |
| **Nuclear** | A | H | VH | EL | EH | EH |
| **Solar** | A | EH | EH | EH | EL | EL |
| **Wind** | A | AA | AA | A | VL | VL |

**Table 6:** Representation of Decision Matrix

| Attributes / Sources | Feasibility | Investment Ratio | Use full Life | O/M Cost | Risk | Pollutants' Emission |
|---|---|---|---|---|---|---|
| **Hydro Power** | (0.4,0.5,0.5,0.6) | (0.2,0.3,0.4,0.5) | (0.5,0.6,0.7,0.8) | (0.5,0.6,0.7,0.8) | (0.4,0.5,0.5,0.6) | (0.01,0.01,0.1,0.2) |
| **Coal & Lignite** | (0.7,0.8,0.8,0.9) | (0.4,0.5,0.5,0.6) | (0.4,0.5,0.5,0.6) | (0.2,0.3,0.4,0.5) | (0.4,0.5,0.5,0.6) | (0.7,0.8,0.8,0.9) |
| **Gas & Liquid** | (0.5,0.6,0.7,0.8) | (0.1,0.2,0.2,0.3) | (0.2,0.3,0.4,0.5) | (0.2,0.3,0.4,0.5) | (0.5,0.6,0.7,0.8) | (0.7,0.8,0.8,0.9) |
| **Nuclear** | (0.2,0.3,0.4,0.5) | (0.5,0.6,0.7,0.8) | (0.7,0.8,0.8,0.9) | (0.01,0.01,0.1,0.2) | (0.8,0.9,1,1) | (0.8,0.9,1,1) |
| **Solar** | (0.2,0.3,0.4,0.5) | (0.8,0.9,1,1) | (0.8,0.9,1,1) | (0.8,0.9,1,1) | (0.01,0.01,0.1,0.2) | (0.01,0.01,0.1,0.2) |
| **Wind** | (0.2,0.3,0.4,0.5) | (0.4,0.5,0.5,0.6) | (0.4,0.5,0.5,0.6) | (0.2,0.3,0.4,0.5) | (0.1,0.2,0.2,0.3) | (0.1,0.2,0.2,0.3) |

The total number of possible decisions or outcomes are given by $\frac{N(N-1)}{2}$ where, N represents the number of attributes under study. If the given attribute is more important than the considered attribute; 2 is assigned as the outcome of the decision else 0 is assigned. If both the given attribute and considered attribute rank equally important; 1 is assigned. It gives user a flexibility to provide lesser, more or equal importance to attributes. In this manner all the attributes are compared two at a time. The weights are determined by dividing the number of positive outcomes for a given attribute by the total number of possible outcomes. DL however has some inherent drawbacks, it can only distinguish between the given criterions as either less or more important which may not always be the case as when two properties are correlated or the user feels that they are equally important. To overcome this shortcoming MDL was first proposed by Manshadi et al [24]. The relative weights are calculated in the same manner as DL, by dividing the number of outcomes for a given attribute by the total number of outcomes of the decision matrix. The subjective weights obtained are used for both Interval VIKOR and Fuzzy VIKOR methodology.

## MADM Techniques

While selecting the most suitable solution for the problem dealing with practical situations; especially the ones which have a lot of stakeholders associated with it, different attributes need to be considered while deciding the appropriate choice out of given solutions. Similar is the case when we deal with different energy sources which have a lot of implications on socio-economic development of any society. Altogether with these different attributes which are effecting the selection, a degree of uncertainty is observed while dealing with these attributes if practical impacts of past as well as future's technical and economic development are considered. This causes variation in data & leads to indeterminate outcomes. Therefore, to solve this problem; fuzzy MADM methods namely interval VIKOR [12] and fuzzy VIKOR [13] are used. These methods are discussed below.

### *Interval VIKOR*

VIKOR was extended for decision models with interval data by Sayadi et al. [12] It was claimed that representation of the ranking index in the form of crisp or integer form could result in loss of data. Hence, in interval VIKOR the ranking index is calculated in the form of interval only. The following steps are used for the application of interval VIKOR:

Step 1: Determination of the positive and negative ideal solutions.

$$A^* = \{(\max f_{ij}^u, j \in I) or (min\, f_{ij}^l,\ j \in J)\} = \{f_1^*, \dots, f_n^*\} \quad (1)$$

$$A^- = \{(\min f_{ij}^u, j \in I) or (max f_{ij}^l,\ j \in J)\} = \{f_1^-, \dots, f_n^-\} \quad (2)$$

Here, $I$ is associated with benefit criteria and $J$ is associated with cost criteria.

Step 2: Computation of $[S_i^u, S_i^l]$ and $[R_i^u, R_i^l]$ intervals.

$$S_i{}^l = \Sigma_{j \in I} w_j \left(\frac{f_j^* - f_{ij}^u}{f_j^* - f_j^-}\right) + \Sigma_{j \in J} w_j \left(\frac{f_{ij}^l - f_j^*}{f_j^- - f_j^*}\right) \quad (3)$$

$$S_i{}^u = \Sigma_{j \in I} w_j \left(\frac{f_j^* - f_{ij}^l}{f_j^* - f_j^-}\right) + \Sigma_{j \in J} w_j \left(\frac{f_{ij}^u - f_j^*}{f_j^- - f_j^*}\right) \quad (4)$$

$$R_i{}^l = Max\left\{w_j \left(\frac{f_j^* - f_{ij}^u}{f_j^* - f_j^-}\right) j \in I; w_j \left(\frac{f_{ij}^l - f_j^*}{f_j^- - f_j^*}\right) j \in J\right\} \quad (5)$$

$$R_i{}^u = Max\left\{w_j \left(\frac{f_j^* - f_{ij}^l}{f_j^* - f_j^-}\right) j \in I; w_j \left(\frac{f_{ij}^u - f_j^*}{f_j^- - f_j^*}\right) j \in J\right\} \quad (6)$$

Step 3: Compute the ranking interval $Q_i = [Q_i^l, Q_i^u]$.

$$Q_i{}^l = \nu \left[\frac{S_i{}^l - S^*}{S^- - S^*}\right] + (1-\nu) \left[\frac{R_i{}^l - R^*}{R^- - R^*}\right]; \ \forall\, i \quad (7)$$

$$Q_i{}^u = \nu \left[\frac{S_i{}^u - S^*}{S^- - S^*}\right] + (1-\nu) \left[\frac{R_i{}^u - R^*}{R^- - R^*}\right]; \ \forall\, i \quad (8)$$

Here, $Q_i$ represents the $i^{th}$ alternative VIKOR value, $\nu$ is the group utility weight, it is generally taken as 0.5 (unsupervised);

$$S^* = Min_i(S_i{}^l); S^- = Max_i(S_i{}^u); \quad (9)$$

$$R^* = Min_i(R_i); R^- = Max_i(R_i); \quad (10)$$

These intervals may now be compared using interval comparison methods as per the requirements of the decision maker. Under the comparison of two interval numbers, $[a^l, a^u]$ and $[b^l, b^u]$ the following four conditions may exist.

a.) If these interval numbers have no intersection, the minimum interval number is the one that has lower values. In other words: If $a^u \leq b^l$, then we choose $[a^l, a^u]$ as the minimum interval.

b.) If two interval numbers are the same, both have the same priority. In situations that $a^l \leq b^l \leq b^u \leq a^u$, we select the minimum interval as: if $\alpha*(b^l-a^l) \geq (1-\alpha)(a^u-b^u)$, then $[a^l, a^u]$ is selected as the lower interval else $[b^l, b^u]$ is selected as the lower interval.

c.) In a condition where $a^l < b^l < a^u < b^u$, if $\alpha*(b^l-a^l) \geq (1-\alpha)(b^u-a^u)$, then $[a^l, a^u]$ is selected as the lower interval else $[b^l, b^u]$ is selected` as the lower interval.

Here α is used as the optimistic weight of the user. For a rational user the value of α is taken as 0.5. While a value higher than this is used to favour the larger intervals and a smaller value is used when smaller intervals are preferred.

**Fuzzy VIKOR**

This method includes a set of numbers within the interval [0, 1], which describes the smallest possible, most promising and largest possible values [13] as illustrated in figure 3. In this method, initially all comparisons are done using linguistic variables. Further, these linguistic variables are assigned fuzzy values in order to have comparable numerical values without any ambiguity. For this, here we have used trapezoidal fuzzy numbers $(a_1, a_2, a_3, a_4)$ (as discussed in section 3.1.2) for $\{a_1, a_2, a_3, a_4 \in \mathbf{R}; a_1 \leq a_2 \leq a_3 \leq a_4\}$. It is one of the most common and simplest kinds of division used for fuzzy numbers. The membership function $\mu_a(x)$ of trapezoidal fuzzy number is defined as

$$\mu_a(x) = \begin{cases} \dfrac{x-a_1}{a_2-a_1}, & x \in [a_1, a_2] \\ 1, & x \in [a_2, a_3] \\ \dfrac{a_4-x}{a_4-a_3}, & x \in [a_1, a_2] \\ 0, & \text{Otherwise} \end{cases} \quad (11)$$

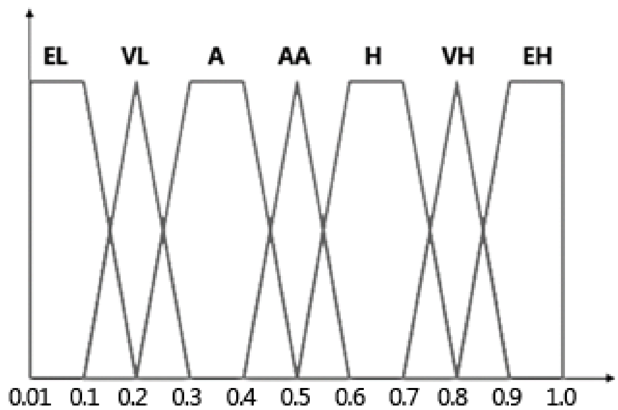


**Figure 3:** Linguistic Terms described as trapezoidal Fuzzy Numbers used in Fuzzy VIKOR Method.

The stepwise operation involved in Fuzzy VIKOR analysis is given below:

Step 1: Identify and define linguistic terms.

A set of appropriate linguistic variables is needed to estimate the fuzzy rates of alternatives assigned by decision makers. Therefore, a range of linguistic terms is defined based on trapezoidal fuzzy number distribution (figure 3).

Step 2: Construction of a decision matrix.

Let the fuzzy rating for i^th alternative regarding j^th criterion of k^th decision maker be shown as $x_{ijk} = (x_{ijk1}, x_{ijk2}, x_{ijk3}, x_{ijk4})$.

Hence, the pre-assigned fuzzy numbers are aggregated using following Eqs. (12)–(16) [17]:

$$x_{ij} = \{x_{ij1}, x_{ij2}, x_{ij3}, x_{ij4}\} \tag{12}$$

Where, $x_{ij}$ is the fuzzy aggregated rating for *M* materials.

$$x_{ij1} = \min\{a_{ijk1}\} \tag{13}$$

$$x_{ij2} = \frac{1}{M}\sum a_{ijk2} \tag{14}$$

$$x_{ij3} = \frac{1}{M}\sum a_{ijk3} \tag{15}$$

$$x_{ij4} = \max\{a_{ijk4}\} \tag{16}$$

Therefore, the values obtained above form the decision matrix Eq.17.

$$D = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{17}$$

The aggregate subjective importance weights $W_{oj} = (w_{o1}, w_{o2}, w_{o3}, w_{o4}, w_{o5})$ are calculated using modified digital logic (figure 4) as discusses earlier and the weight $W_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4})$ is produced by taking a variation of 5% to form a trapezoidal fuzzy distribution (figure 5). Table 7 represents the subjective weights in form of fuzzy numbers formed using this trapezoidal distribution.

**Table 7:** Subjective Weights in form of Trapezoidal Fuzzy Numbers

| **Attributes** | **$W_1$** | **$W_2$** | **$W_3$** | **$W_4$** |
|---|---|---|---|---|
| **Feasibility** | 0.158333 | 0.1667 | 0.1667 | 0.175 |
| **Investment Ratio** | 0.095 | 0.1 | 0.1 | 0.105 |
| **Useful Life** | 0.095 | 0.1 | 0.1 | 0.105 |
| **O/M Cost** | 0.031667 | 0.0333 | 0.0333 | 0.035 |
| **Risk** | 0.253333 | 0.2667 | 0.2667 | 0.28 |
| **Pollutants** | 0.316667 | 0.3333 | 0.3333 | 0.35 |

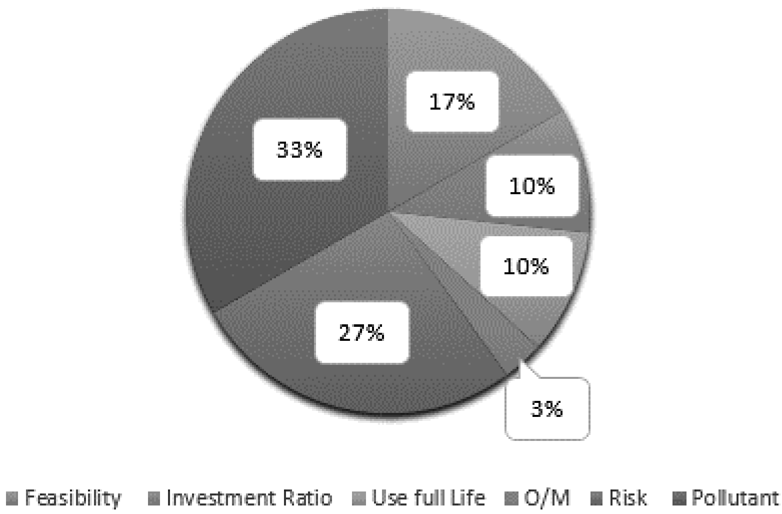


**Figure 4:** Resultant distribution of weights obtained from Modified digital logic (MDL).

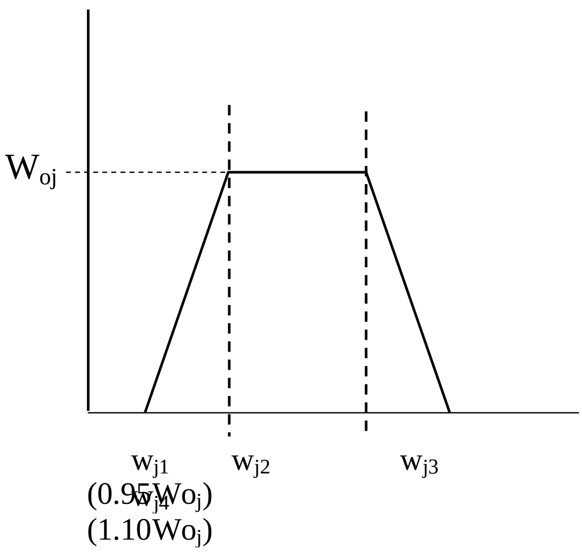


**Figure 5:** Trapezoidal Fuzzy distribution for subjective weight ($W_j$) used in Fuzzy VIKOR method

Step 3: Scaling cost criteria to benefit criteria

To scale the cost criteria to benefit criteria at an early stage of operation, the fuzzy numbers in are substituted with symmetrically opposite fuzzy numbers such that the cost criteria for an alternative would behave as a benefit criteria. The explanation is more evident in figure 6. The resultant decision matrix formed which will be used in further steps is shown in Table 8.

**Table 8:** Conversion of Cost Criteria into Benefit Criteria by exchanging fuzzy numbers

| **Attributes** ------------------- **Sources** | **Feasibility** | **Investment Ratio** | **Use full Life** | **O/M Cost** | **Risk** | **Pollutants' Emission** |
|---|---|---|---|---|---|---|
| **Hydro Power** | (0.4,0.5,0.5,0.6) | **(0.5,0.6,0.7,0.8)** | (0.5,0.6,0.7,0.8) | **(0.2,0.3,0.4,0.5)** | (0.4,0.5,0.5,0.6) | **(0.8,0.9,1,1)** |
| **Coal & Lignite** | (0.7,0.8,0.8,0.9) | (0.4,0.5,0.5,0.6) | (0.4,0.5,0.5,0.6) | **(0.5,0.6,0.7,0.8)** | (0.4,0.5,0.5,0.6) | **(0.1,0.2,0.2,0.3)** |
| **Gas & Liquid** | (0.5,0.6,0.7,0.8) | **(0.7,0.8,0.8,0.9)** | (0.2,0.3,0.4,0.5) | **(0.5,0.6,0.7,0.8)** | **(0.2,0.3,0.4,0.5)** | **(0.1,0.2,0.2,0.3)** |
| **Nuclear** | (0.2,0.3,0.4,0.5) | **(0.2,0.3,0.4,0.5)** | (0.7,0.8,0.8,0.9) | **(0.8,0.9,1,1)** | **(0.01,0.01,0.1,0.2)** | **(0.01,0.01,0.1,0.2)** |
| **Solar** | (0.2,0.3,0.4,0.5) | **(0.01,0.01,0.1,0.2)** | (0.8,0.9,1,1) | **(0.01,0.01,0.1,0.2)** | **(0.8,0.9,1,1)** | **(0.8,0.9,1,1)** |
| **Wind** | (0.2,0.3,0.4,0.5) | (0.4,0.5,0.5,0.6) | (0.4,0.5,0.5,0.6) | **(0.5,0.6,0.7,0.8)** | **(0.7,0.8,0.8,0.9)** | **(0.7,0.8,0.8,0.9)** |

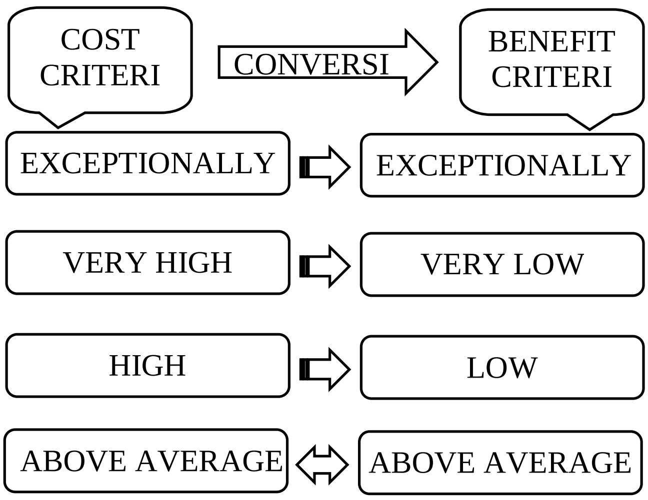


**Figure 6:** Conversion process of Cost Criteria to Benefit Criteria before apply Fuzzy VIKOR Method

Step 4: Defuzzify the decision matrix and fuzzy weights of each criterion and derive their crisp values.

To derive the crisp values of arrays of decision matrix and fuzzy weights we may use the following equations

$$f_{ij} = Defuzz(x_{ij}) = \frac{\int \mu(x) x \mathrm{d}x}{\int \mu(x) \mathrm{d}x}$$

$$= \frac{\int_{x_{ij1}}^{x_{ij2}} \left( \frac{x - x_{ij1}}{x_{ij2} - x_{ij1}} \right) x\mathrm{d}x + \int_{x_{ij2}}^{x_{ij3}} x\mathrm{d}x + \int_{x_{ij3}}^{x_{ij4}} \left( \frac{x_{ij4} - x}{x_{ij4} - x_{ij3}} \right) x\mathrm{d}x}{\int_{x_{ij1}}^{x_{ij2}} \left( \frac{x - x_{ij1}}{x_{ij2} - x_{ij1}} \right) \mathrm{d}x + \int_{x_{ij2}}^{x_{ij3}} \mathrm{d}x + \int_{x_{ij3}}^{x_{ij4}} \left( \frac{x_{ij4} - x}{x_{ij4} - x_{ij3}} \right) \mathrm{d}x} \tag{18}$$

$$= \frac{-x_{ij1}x_{ij2} + x_{ij3}x_{ij4} + \frac{1}{3}\left(x_{ij4} - x_{ij3}\right)^2 + \frac{1}{3}\left(x_{ij2} - x_{ij1}\right)^2}{-x_{ij1} - x_{ij2} + x_{ij3} + x_{ij4}}$$

Step 4: Deploy the entropy concept to derive objective weights.

In order to determine the objective weights by entropy measure, first we should normalize the decision matrix for each criterion $C_j$ (j = 1, 2, . . . , n) and calculate the projection value of each criterion called $P_{ij}$.

$$\text{Pij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{19}$$

Afterward, the entropy value can be calculated as follows:

$$\text{ej} = -\frac{1}{\ln(m)} \sum_{j=1}^{n} P_{ij} \ln(P_{ij}) \tag{20}$$

Then, to calculate the degree of divergence $div_j$ of the intrinsic information of each criterion $C_j$ (j = 1,2,. . . ,n) we may deploy the following equation

$$div_j = 1 - e_j \tag{21}$$

The value of divj represents the inherent contrast intensity of each criterion Cj. The higher the divj is, the more important criterion Cj becomes for the problem. The objective weight for each criterion Cj can be calculated as

$$wj' = \frac{div_j}{\sum_{j=1}^{n} div_j} \tag{22}$$

The entropy measure, divergence and objective weights of criteria calculated are presented in Table 9.

**Table 9:** Calculated entropy measure, divergence and objective weights of criteria.

| Attributes<br>------------- | Feasibility | Investment Ratio | Use full Life | O/M Cost | Risk | Pollutant |
|---|---|---|---|---|---|---|
| $e_j$ | 0.969 | 0.932 | 0.974 | 0.925 | 0.918 | 0.864 |
| $div_j$ | 0.031 | 0.069 | 0.026 | 0.075 | 0.082 | 0.136 |
| $w_j'$ | 0.074 | 0.163 | 0.061 | 0.179 | 0.196 | 0.325 |

Step 5: Calculate the overall performance evaluation.

$$U = [u_{ij}]_{mxn} \tag{23}$$

$$u_{ij} = (x_{ij1}, x_{ij2}, x_{ij3}, x_{ij4})$$

$$F = [f_{ij}]_{mxn} \tag{24}$$

$$f_{ij} = defuzz\ (u_{ij}\ x\ W_j)$$

$$f_{ij} = \frac{\int \mu(x).xdx}{\int \mu(x)dx} = \frac{\int_{u_{ij1}w_{j1}}^{u_{ij2}w_{j2}}\left(\frac{x-w_{j1}}{u_{ij2}w_{j2}-u_{ij1}w_{j1}}\right).xdx+\int_{u_{ij2}w_{j2}}^{u_{ij3}w_{j3}} xdx+\int_{u_{ij3}w_{j3}}^{u_{ij4}w_{j4}}\left(\frac{w_{j4}u_{ij4}-x}{u_{ij4}w_{j4}-u_{ij3}w_{j3}}\right).xdx}{\int_{u_{ij1}w_{j1}}^{u_{ij2}w_{j2}}\left(\frac{x-u_{ij1}w_{j1}}{u_{ij2}w_{j2}-u_{ij1}w_{j1}}\right)dx+\int_{u_{ij2}w_{j2}}^{u_{ij3}w_{j3}} dx+\int_{u_{ij3}w_{j3}}^{u_{ij4}w_{j4}}\left(\frac{w_{j4}u_{ij4}-x}{u_{ij4}w_{j4}-u_{ij3}w_{j3}}\right)dx}$$

$$= \frac{-(u_{ij1}u_{ij2})(w_{j1}w_{j2})+(-u_{ij3}u_{ij4})(w_{j3}w_{j4})+\frac{1}{3}(u_{ij4}w_{j4}-u_{ij3}w_{j3})^2-\frac{1}{3}(u_{ij2}w_{j2}-u_{ij1}w_j)^2}{-u_{ij1}w_{j1}-u_{ij2}w_{j2}+u_{ij3}w_{j3}+u_{ij4}w_{j4}} \tag{25}$$

Step 7: Determine the best $f_j^+$ and the worst $f_j^-$ values of all criterion ratings.

$$f_i^* = max\ (f_{ij})\ \forall\ i \tag{26}$$

$$f_i^- = min\ (f_{ij})\ \forall\ i \tag{27}$$

$$S_i = \sum_{j=1}^{n}\left(w_j' \frac{(f_i * - f_i -)}{(f_i * - f_i -)}\right) \tag{28}$$

$$R_i = max\left(w_j' \frac{(f_i * - f_i -)}{(f_i * - f_i -)}\right) \tag{29}$$

Step 8: Compute the values $Q_i$ as follows:

$$S^- = max\ \{S_i\} \tag{30}$$

$$S^* = min\,\{S_i\} \tag{31}$$

$$R^- = max\,\{R_i\} \tag{32}$$

$$R^* = min\,\{R_i\} \tag{33}$$

$$Q_i = v\,\frac{(S_i - S^*)}{(S^- - S^*)} + (1-v)\frac{\left(R_i - R^*\right)}{(R^- - R^*)}\quad \forall i \tag{34}$$

$v$ is introduced as a weight for the strategy of maximum group utility, whereas 1-$v$ is the weight of the individual regret. Generally, value of $v$ is taken as 0.5.

Step 9: Rank the alternatives sorting by values Q in an ascending order.

**Table 10:** Attributes provided values using Modified Digital Logic

| MDL | Feasibility | Investment Ratio | Useful Life | O/M Cost | Risk | Pollutants' Emission |
|---|---|---|---|---|---|---|
| **Feasibility** | 1 | 2 | 1 | 2 | 0 | 0 |
| **Investment Ratio** | 0 | 1 | 1 | 2 | 0 | 0 |
| **Useful Life** | 1 | 1 | 1 | 1 | 0 | 0 |
| **O/M Cost** | 0 | 0 | 1 | 1 | 0 | 0 |
| **Risk** | 2 | 2 | 2 | 2 | 1 | 0 |
| **Pollutants** | 2 | 2 | 2 | 2 | 2 | 1 |

**Table 11:** Outcomes and weighted factors for different attributes

| Outcomes<br>--------------------------------<br>Attributes | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Positive Decisions | Weighted Factors |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Feasibility** | 2 | 1 | 2 | 0 | 0 | | | | | | | | | | | 5 | 0.166667 |
| **Investment Ratio** | 0 | | | | | 1 | 2 | 0 | 0 | | | | | | | 3 | 0.1 |
| **Useful Life** | | 1 | | | | 1 | | | | 1 | 0 | 0 | | | | 3 | 0.1 |
| **O/M Cost** | | | 0 | | | | 0 | | | 1 | | | 0 | 0 | | 1 | 0.033333 |
| **Risk** | | | | 2 | | | | 2 | | | 2 | | 2 | | 0 | 8 | 0.266667 |
| **Pollutants** | | | | | 2 | | | | 2 | | | 2 | | 2 | 2 | 10 | 0.333333 |

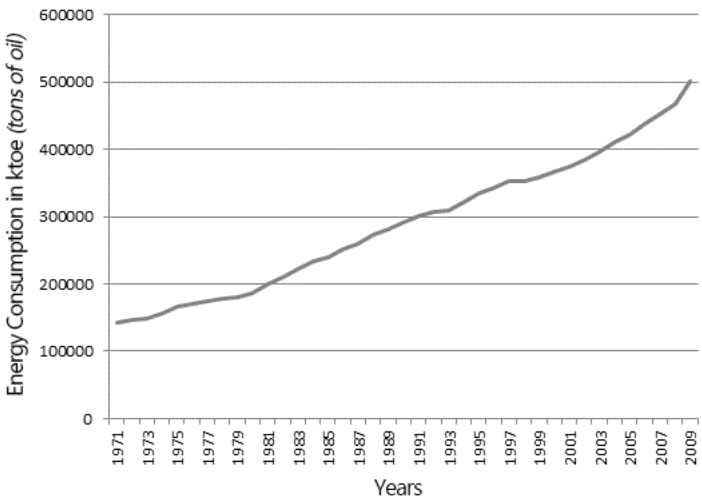


**Figure 7:** Annual data for Energy Consumption (1971-2009)

**Table 12:** Ranks of different sources of energy based on $Q_i$ values obtained using both Internal VIKOR and Fuzzy VIKOR Method

| Sources | RANKS OBTAINED | |
|---|---|---|
| | **Interval VIKOR** | **Fuzzy VIKOR** |
| Hydro Power | **3** | **3** |
| Coal & Lignite | **5** | **5** |
| Gas & Liquid | **4** | **4** |
| Nuclear | **6** | **6** |
| Solar | **2** | **2** |
| Wind | **1** | **1** |

## RESULTS AND DISCUSSION

Increasing demand for energy means that with time, there is a need of constant search for alternate sources of energy and supply needs to be increased so as to achieve the goal of sustainable development as far as energy sector is concerned. In this context, it is a good exercise to rank country's energy alternatives based on important attributes like feasibility, investment ratio, O/M costs, useful life, risk associated and pollutants' emission. There have been quite a few options before us in form of these energies but it has been difficult to place them on a common scale and bring them into practice due to various economic, environmental, topological and social reasons. Here, six energy sources viz., hydro power, coal and ignite, gas and liquid, nuclear, solar and wind are stated. There were other sources like geothermal; but as India has still not started with a geothermal plant and is planning to build one in Puga (Jammu and Kashmir) of 100MW power; it has not been considered due to lack of data. The major motivation over using alternate sources of energy is the universal supply-demand relation which depicts that energy consumption in India has increased from 141561 K toe (tons of oil equivalent) in 1971 to 366400 k toe in 2000 and to 502460 k toe in 2009. This bullish trend is plotted in figure 7. Therefore, India requires to make right decision for this huge requirement of energy as it has only 2.4% of world's land and needs to serve almost 17% of world's population. These six sources of energy are compared after weighing each of the aforementioned attribute judiciously as per Indian condition. Table 2 represents the initial data with linguistic terms and non-normalized numerical values for different sources of energy. Before comparing these sources using any of the MADM approaches (Interval VIKOR and Fuzzy VIKOR), weighing of all the attributes is done using modified digital logic (MDL) by using numbers 0, 1 and 2 for inferior, equally important and superior attributes respectively. These values are obtained with expert opinion as 0, 1, or 2 when we compare attributes. This data could be seen in Table 10. Now, these values are used to find weight factors for each attribute using the number of total positive decisions as seen in Table 11. We have weighted pollutants over any other attribute so as to choose the greenest source of energy as balance between economical profit and environmental equilibrium is essential while dealing with such a large number of stakeholders.

After weighing the attributes and stating the data with numerical as well as linguistic measures, the value of each attribute is converted to quantitative terms using the technique to convert linguistic terms into fuzzy numbers. The conversion scores are referred in figure 2. The data for each source of energy is not just represented by fixed numbers but by an interval data with 5% consideration on both ends of initial data. Therefore, the analysis is conducted on interval data as it is more reliable as well as practical in use than exact values. All the aforementioned procedure is done to prepare data for Interval VIKOR (as described in section 3.1.1).

While using Fuzzy VIKOR method, subjective weights and initial data are created using trapezoidal distribution *(as described in section 3.1.2 and section 3.1.3)*. Table 7 and Table 8 represent the subjective weights and initial data respectively. Here, interval VIKOR and Fuzzy VIKOR method are used which provides a perfect agreement with each other (Table 12). Both of the analytical methods choose the same top 3 sources of energies; namely wind, solar and hydro power over the other three (coal and lignite, gas and liquid and nuclear). Among these sources of energy, wind energy is ranked over the other two out of top 3 sources by both interval VIKOR and fuzzy VIKOR method showing the robustness of fuzzy analysis over analysis done with statistical data. At other end, both methods have ranked nuclear energy as the least-to-be-preferred source of energy due to the risk associated with its operation and pollutants' emission that it holds. Whereas, hydro power energy is ranked third is both interval VIKOR and fuzzy VIKOR method due to its geographical constraints. Whereas, solar energy is ranked second by both the methods.

As per government's estimate, India receives 5,000 Ton kWh per year, with most parts of the country receiving 4-7 kWh per square meter per day, that can be used for huge solar power production to meet the electricity need in the rural areas. Therefore, due to its ease of access, lack of risk and eco-friendly nature over its counterparts like wind energy; it is the most preferred source of energy as far this analysis is concerned. But, as innovative ways are considered these days to use hybrid technique which uses both solar as well as wind energy, such unique procedures of usage can be more fruitful [25]. It is also interesting to notice that gas and liquid is ranked better than both coal and ignite and nuclear energy which verifies the sensitivity of the used fuzzy approaches over interval based approaches as both yield same results. Such studies will be helpful in drafting energy policies for India as they provide sensitized information at the end of analysis.

## CONCLUSION

The presented analysis attempted to study different sources of energy based on different attributes. MADM approaches (Interval VIKOR and Fuzzy VIKOR) are employed to distinguish the effectiveness and viability of these sources of energy. Weights are assigned using MDL technique which provides realistic output which is aimed to follow the track of sustainable development. The result eventually shows that wind and solar energy are the most effective sources of energy due to their ease of access, lack of risk and eco-friendly nature. Whereas, nuclear energy is ranked at the least favourable spot due to ecological factors. Another significant result obtained is the effectiveness of fuzzy VIKOR over interval VIKOR as it provides same result and is more accessible to layman than statically aided interval based MADM approaches. Therefore, the hierarchy presented here at the end aims to offer an effective and realistic framework to guide energy policy and decision making in Indian context. Although, similar methodology could be used by policy makers of other developing as well as well developed nations.

## ACKNOWLEDGEMENT

We gratefully acknowledge the contribution of Dr. Rahul Vaish.

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