An efficient intuitionistic fuzzy approach for location selection to install the most suitable energy power plant

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Abstract. This paper develops a decision support system for multi-factor based energy plant installation in various locations. As, the conditions to implement an energy plant in different locations varies a lot, therefore, based on these conditions specific type of power generation plant should be installed. But, because of environmental sustainability, social, and economical issues, some restrictions are imposed in building all types of power plants in every location which may create difficulties to satisfy the demand of energy for those locations. Thus, there must be a suitable methodology to decide the most appropriate power generation plant to be installed in the most appropriate place. In this respect, this paper develops an efficient process for building the most appropriate energy production plant based on intuitionistic fuzzy logic. The study is inspired by Sanchez’s approach which was initiated to diagnose some medical conditions. The Sanchez’s method is adopted here and utilized to obtain the degree of membership functions to choose the proper location for the proper plant. The entire methodology was illustrated with the algorithm and flowchart. To validate the model, data of seven Indian states are collected from several sources. The study concluded that the proposed methodology can obtain the degrees of appropriateness which specifies how much a specific power plant is suitable to be implemented in a particular location.

1. Introduction

Developing an infrastructure of renewable energy production system has now become a very important aspect for achieving the ambition of renewable energy. Industrialization is the primary reason for some country's financial growth, which improves the need of electricity indirectly. Energy requirements are not only necessary for economic development, but also to raise living standards in every nation [1]. India plans to raise its installed capacity for sustainable energy from 78 Gigawatt to 175 Gigawatt (1 GW= 1000 MW) by March 2022. It is assumed that out of 175 GW of renewable energy, 100 GW would be solar power. In addition, India wants to nearly double the complete installed ability of renewable energy to 40% by 2030. Selecting the site to implement a power plant or power plant project is a very complicated decision-making problem. In India, due to the wrong selection of location, many such projects stop functioning or needs to be restarted [2]. The different factors involved in the problem of selecting a suitable site are:

- Resource availability
- Environmental factors
- Economic conditions
• Number of river and dams
• Availability of energy transport facility
• Population density
• Open land space

There are many problems for decision making in site selection with existing processes which makes the strategical decisions hardly conform to the real situations. In case of problems with the choice of the energy site, cloudiness is usually observed. The selection of the power plant site is also carried out prior to the actual construction. As a result, difficult situations and unexpected factors make it difficult to accurately predict the information needed for accurate forecasting. It is also difficult for policy makers to assess the exact level of satisfaction or dissatisfaction. These judgments are ambiguous. For this reason, the decision to choose an energy site must be made in an incomplete and ambiguous information environment.

Sometimes, during the comparison phase, incomplete decisions exacerbate the failure of decisions due to loss of information and data, which omits possible approaches to separating priorities at different levels. In this study, the intuitionistic fuzzy model of energy location selection provides decision-makers with basic information to analyze and selects the best location for energy plant. The system uses intuitionistic fuzzy sets to handle the ambiguous and incomplete information.

2. Review of Literature

The notion of fuzzy sets was first implemented by Zadeh [3]. Fuzzy sets deal very effectively with the problems having uncertainty and vagueness. Every component of the fuzzy set is always connected with the membership grade, which lies between zero and one. The sum of membership and non-membership grades of an element in a fuzzy set is always equal to one but this concept is not always true in real life situations as there may be some degree of hesitation. Atanassov [4] proposed the generalization of fuzzy sets and introduced firstly the intuitionistic fuzzy sets (IFS) which can handle the degree of hesitation. He explained the degree of hesitation as the sum of membership and non-membership degree, subtracted from 1(one). Atanassov [5], [6]; Szmidt and Kacprzyk [7] described the utility of intuitionistic fuzzy sets in circumstances where the representation of a problem by a linguistic variable tends to be too rough. Since IFS is more flexible in dealing with uncertainty, it can be used under imprecise facts and vague knowledge as a tool for consistent human reasoning.

Szmidt and Kacprzyk [8] also solved some problems of group decision-making using intuitionistic fuzzy sets. Szmidt and Kacprzyk [8], De et al. [9] provided an intuitionistic fuzzy set method in medical diagnosis. Wu and Chen [10] created a new technique called the intuitionistic fuzzy ELECTRE method. ELECTRE stands for “ELimination and Choice Expressing REALity”. The primary use of this technique is to rank and find out the best possible option for all alternative scenarios. The authors suggested the technique so that inadequate knowledge of information can also be used to cope with the issue of decision-making.

Chen and Li [11] have introduced a Dynamic Multi-Attribute Decision Making (DMADM) model to tackle vagueness and ambiguity where all decision data takes the form of Triangular Intuitionistic Fuzzy Numbers (TIFN). TIFN conveys data that is more efficient and versatile. Zhang and Luo [12] proposed a weighted interval-valued fuzzy (IVF) reasoning algorithm for managing decision-making problems. For the representation of unknown information, the definition of interval-values fuzzy sets (IVFS) and interval-valued fuzzy (IVF) decision rules are used in this algorithm. In order to choose the best possible alternative to energy technology, Kaya and Kahraman [13] suggested a modified fuzzy TOPSIS method. TOPSIS is a multi-criteria decision-making technique (MCDM) that
determines the best alternative to measure the distance between ideal negative and positive solutions according to expert judgment. The authors applied the method to the decision-making problems of energy planning. Lee et al. [14] applied the integrated multi-criteria decision-making approach in two stages which includes the use of hybrid diffuse analytical hierarchy (AHP) process and the data envelope analysis (DEA) model, to determine the relative efficiency of hydrogen energy technologies. Azadeh et al. [15] suggested the hierarchical fuzzy data envelopment analysis (DEA) model to optimize the location of wind plant. The researchers tested the given model on 25 different Iranian cities where each city was divided into 5 different regions. A decision mechanism has been created by Yunna and Geng [16] for the site selection of solar-wind hybrid power plants using the Analytic Hierarchy Process (AHP).

Onar et al. [17] conducted the assessment of wind energy investment and provided a method to choose the best wind energy technology to assist stakeholders. An interval-valued intuitionistic fuzzy approach is used to handle vagueness and uncertainty in systems of human evaluation processes. A robust decision making (RDM) method was proposed by Das et al. [18]. In this method they used intuitionistic trapezoidal fuzzy number (ITrFN) and Fuzzy linguistic quantifier (FLQ) to measure the uncertain optimism degree of the decision maker. Rouyendegh et al. [19] aimed to find a solution for the choice of wind power plants. Four alternative wind power plant sites were recognized for this purpose. To assess the options, 10 four-dimensional criteria are chosen such as wind potential, place, price, and social remuneration. To accomplish this objective, the TOPSIS technique coupled with intuitionistic fuzzy set was used. The TOPSIS method's primary aim is to rank options in the worst possible manner. Zhou et al. [20] suggested a group decision model for the choice of plans for the treatment of wastewater. An intuitionistic fuzzy set is used to test the treatment plan for wastewater efficiently. Ahmed and Sarkar [21] developed a supply chain framework by using triple bottom line approach to manage next generation energy. Sarkar et al. [22] created a model for energy-efficient manufacturing system. They considered multi-item and time dependent holding cost. Jemai and Sarkar [23] developed an optimum transportation scheme for least energy consumption in a healthcare supply chain system. Dhiman and Garg [24] used fuzzy reliability analysis for industrial system with improved arithmetic operation. Chandrawat et al. [25] used fuzzy LPP for production cost optimization in an industrial problem.

3. Problem definitions

Depending upon the nature of locations, some sites are sensitive towards various parameters like environmental parameters such as hilly or forest area. The amount of carbon emission in these locations is very less. Thus, renewable resources should be the appropriate choice for these areas. On the other hand, in industrial areas where the demand of electricity or energy is very high, needs high production power plant like thermal. Also, environmental sustainability is required to be maintained properly. The economic and social conditions of a location are affected by various factors and the factors are affected by the choice of the energy resources (Figure 1). As an example, if thermal power plant is established in a naturally rich location, the environment will be harmed by extreme carbon emission or if only solar plant is installed in such an area with heavy river-flow, the hydro resources will be unutilized. Under all such constraints it becomes very difficult to select the proper location to install suitable energy plant. In this paper, we apply Sanchez's approach [26], [27] for energy resources selection using the concept of IFS theory. This approach includes intuitionistic fuzzy relationships as described in Bustince and Burillo [28]. We also use the flow chart to summarize the technique.
Figure 1: Relation among energy resources, factors, and locations

4. Case study

India has become one of the largest possible countries in the world for potential renewable energy plant installation. The demand of energy is also increasing due to industrialization. Non-renewable energy resources like coal, petroleum, and natural gases can produce sufficient energy to satisfy the growing demand of energy. But non-renewable sources produce a huge carbon emission in the environment. Due to environmental or socio-economic factors, energy plants should be installed according to the requirement of these factors. Any incorrect choice of energy resources may damage the natural habitat of a particular location.

According to the Energy Statistics of India (2018), state wise non-renewable and renewable energy resources and potential locations are shown in Table 1 and 2, respectively. The data shows that maximum estimated reserves of crude petroleum are found in Assam and Gujarat, respectively. Accordingly, for natural gas Assam holds the maximum reserves. In case of renewable energy resources, Rajasthan holds the first position and Gujarat holds the second.

Table 1: State wise Estimated Reserves of Crude Oil and Natural Gas in India as on 31.03.2017 (Energy Statistics of India, 2018)

| States          | Crude petroleum (million tonnes) | Natural gas (billion cubic meters) | Average total distribution of non-renewable energy (%) |
|-----------------|----------------------------------|-----------------------------------|-------------------------------------------------------|
|                 | Estimated reserves | Distribution (%) | Estimated reserves | Distribution (%) |                                          |
| Arunachal Pradesh | 1.52                | 0.25               | 0.93              | 0.07            | 0.16                                   |
| Andhra Pradesh  | 8.15                | 1.35               | 48.31             | 3.75            | 2.55                                   |
| Assam           | 159.96              | 26.48              | 158.57            | 12.29           | 19.385                                 |
| Gujarat         | 118.61              | 19.63              | 62.28             | 4.83            | 12.23                                 |
| Rajasthan       | 24.55               | 4.06               | 34.86             | 2.7             | 3.38                                  |
| Tripura         | 0.07                | 0.01               | 36.1              | 2.8             | 1.405                                 |
| Tamil Nadu      | 9                   | 1.49               | 31.98             | 2.48            | 1.985                                 |
Table 2: Source wise and State wise Estimated Potential of renewable Power in India as on 31.03.2017 (in MW) (Energy Statistics of India, 2018)

| States             | Estimated reserves | Average total distribution of renewable energy (%) |
|--------------------|--------------------|-----------------------------------------------|
| Arunachal Pradesh  | 10724              | 1.07                                          |
| Andhra Pradesh     | 49590              | 4.95                                          |
| Assam              | 14249              | 1.42                                          |
| Gujarat            | 121791             | 12.17                                         |
| Rajasthan          | 162326             | 16.21                                         |
| Tripura            | 2306               | 0.23                                          |
| Tamil Nadu         | 54089              | 5.4                                           |

Figure 2: Comparison of renewable and non-renewable energy distribution of seven Indian states

Figure 2, comparison of non-renewable and renewable energy distribution of India states, depicts the picture that the distribution of non-renewable energy is significantly high in the north eastern region of India. North-east India covers a large portion of Himalaya where environment is naturally
sound, and also this is one of the biggest natural habitats of animals, birds and other creatures. Thus, implementation of non-renewable energy plants results a harmful effect in the ecosystem of the location. Therefore, a thorough analysis and efficient process should be maintained to install any power plant in a particular location.

5. Mathematical model

To develop mathematical model some basic definitions of intuitionistic fuzzy set and its properties are necessary to describe.

Basic prerequisite theory of Intuitionistic fuzzy sets

5.1. Definition: Let $S$ be any finite set then Intuitionistic Fuzzy Set (IFS) $[4]$ $F$ in $S$ is defined as

$$F = \left\{(x, \mu_F(x), \nu_F(x)) | x \in S \right\}$$

where the function $\mu_F : S \rightarrow [0,1]$ $\nu_F : S \rightarrow [0,1]$ represents the degree of membership and degree of non-membership respectively of the element $x \in S$ to the set $F$ and satisfy the condition

$$0 \leq \mu_F(x) + \nu_F(x) \leq 1 \quad \forall x \in S$$

The amount $\pi_F(x) = 1 - \mu_F(x) - \nu_F(x)$ is called the hesitancy $[29]$ of $x$ to $F$, or called the degree of indeterminacy of $x$ to $F$. This is also called intuitionistic fuzzy index of $x$ in $F$. For every $x \in S$,

$$0 \leq \pi_F(x) \leq 1$$

Moreover, if $\pi_F(x) = 0$, for all $x \in S$ then the IFS, $F$ is reduced to a fuzzy set.

5.2. Fundamental operations on Intuitionistic Fuzzy sets

If $P$ and $Q$ are two IFSs of the set $S$, then fundamental operators $[30]$, $[31]$ defined on $A$ and $B$ are

1. Inclusion: $P \subseteq Q \iff (\mu_P(x) \leq \mu_Q(x)$ and $\nu_P(x) \geq \nu_Q(x)) \quad \forall x \in S$
2. Equality: $P = Q$ iff $\left(\mu_P(x) = \mu_Q(x)$ and $\nu_P(x) = \nu_Q(x)\right) \quad \forall x \in S$
3. Complement: $\overline{P} = \left\{(x, \nu_P(x), \mu_P(x)) | x \in S \right\}$
4. Addition: $P \oplus Q = \left\{ \left(x, \mu_P(x) + \mu_Q(x) - \mu_P(x) \cdot \mu_Q(x), \nu_P(x) \cdot \nu_Q(x) \right) | x \in S \right\}$
5. Multiplication: $P \otimes Q = \left\{ \left(x, \mu_P(x) \cdot \mu_Q(x), \nu_P(x) + \nu_Q(x) - \nu_P(x) \cdot \nu_Q(x) \right) | x \in S \right\}$
6. Union: $P \cup Q = \left\{ \left(x, \max(\mu_P(x), \mu_Q(x)), \min(\nu_P(x), \nu_Q(x)) \right) | x \in S \right\}$
7. Intersection: $P \cap Q = \left\{ \left(x, \min(\mu_P(x), \mu_Q(x)), \max(\nu_P(x), \nu_Q(x)) \right) | x \in S \right\}$
8. Difference: $P - Q = \left\{ \left(x, \min(\mu_P(x), \nu_Q(x)), \max(\nu_P(x), \mu_Q(x)) \right) | x \in S \right\}$
9. Symmetric difference: $P \Delta Q = \left\{ \left(x, \max(\min(\mu_P, \nu_Q), \min(\nu_P, \mu_Q), \min(\max(\nu_P, \mu_Q), \max(\mu_P, \nu_Q)) \right) | x \in S \right\}$

( where $\wedge = \min$; $\vee = \max$ )

5.3. Definition: Let $P$ and $Q$ be two sets. An intuitionistic fuzzy relation (IFR) $R$ from $P$ to $Q$ is an IFS of $P \times Q$ characterized by the membership function $\mu_R$ and non-membership function $\nu_R$. An IFR $R$ from $P$ to $Q$ will be denoted by $R(P \rightarrow Q)$. 
5.4. **Definition:** If \( A \) is an IFS of \( P \), the max-min-max composition \([32]\) of the IFR \( R(P \to Q) \) with \( A \) is an IFS \( B \) of \( Q \) denoted by \( B = R \circ A \) and is defined by the membership function

\[
\mu_{R \circ A}(q) = \bigwedge_p \left[ \mu_A(p) \land \mu_R(p, q) \right]
\]

and the non-membership function

\[
\nu_{R \circ A}(q) = \bigvee_p \left[ \nu_A(p) \lor \nu_R(p, q) \right]
\]

\( \forall q \in Q \)

5.5. **Definition:** Suppose, \( \dot{S}(P \to Q) \) and \( \dot{T}(Q \to R) \) be two IFRs. The max-min-max composition \( T \circ S \) is the intuitionistic fuzzy relation from \( P \) to \( R \), defined by the membership function

\[
\mu_{T \circ S}(p, r) = \bigvee_q \left[ \mu_S(p, q) \land \mu_T(q, r) \right]
\]

and the non-membership function

\[
\nu_{T \circ S}(p, r) = \bigwedge_q \left[ \nu_S(p, q) \lor \nu_T(q, r) \right]
\]

\( \forall (p, r) \in P \times R \) and \( \forall q \in Q \)

(where \( \land = \min; \ \lor = \max \) )

5.6. **Research Methodology**

The research methodology used in this paper, involves the basic use of intuitionistic fuzzy set theory with Sanchez’s approach. In this methodology, suppose \( R = \) set of energy resources, \( F = \) set of various factors and \( L = \) set of locations for site selection. The various steps involved are

1. First of all establish an intuitionistic fuzzy relation \( \dot{S} \) \((L \times F)\) between the set of Locations and the set of various factors which describes the degree of association and degree of non-association between various factors (environmental, economic, population density etc.) and locations of energy plant.
2. Establish an intuitionistic fuzzy relation \( \dot{T} \) \((F \times R)\) between the set of various factors and the set of various resources of energy which describes the degree of association and degree of non-association between various factors (environmental, economic, population density etc.) and resources of energy (wind energy, Solar energy, thermal energy, Hydro energy, biomass energy etc.)
3. Construct a max-min-max composition named “energy location knowledge” relation to get IFR \( \dot{U} \) \((U = T \circ S)\) which signifies the suitability of the energy plant location in terms of resources from \( L \) to \( R \).
4. Finally calculate the accuracy function for every value of \( U \) to determine the right location of energy plant based on composition of Intuitionistic fuzzy relations.

Now let us extend this concept to a finite number of locations. Consider, there are \( n \) locations \( l_i \in L, \ i = 1, 2, 3...n \); in a country. Let \( T \) be an IFR \((F \to R)\) and construct an IFR \( S(L \to F)\) from the set of locations to the set of factors. Clearly, the composition \( U \) of IFRs \( T \) and \( S \) \((U = T \circ S)\) describes the choice of locations \( l_i \) in terms of the resources as an IFR from \( L \) to \( R \) given by the membership function

\[
\mu_U(l_i, r) = \bigvee_{f \in F} \left[ \mu_S(l_i, f) \land \mu_T(f, r) \right]
\]

and the non-membership function given by

\[
\nu_U(l_i, r) = \bigwedge_{f \in F} \left[ \nu_S(l_i, f) \lor \nu_T(f, r) \right]
\]

\( \forall l_i \in L \) and \( \forall r \in R \),
From the knowledge of $T$ and $U$, we can calculate an improved description of the IFR, $T$ for which the following holds well:

1. $S_T = \mu_T - \nu_T \cdot \pi_T$ is maximum
2. hesitation is least and
3. $U = T \circ S$ is preserved.

The modified relation $T$ will be a more significant IFR as it provides the maximum degrees of association and minimum degrees of non-association of factors as well as reduced degrees of hesitation to the resources, an approach to “Intuitionistic Energy Location Knowledge”. If nearly equal values are acquired for different factors in $T$, we consider the situation where degree of hesitation is the minimum.

From the improved relation $T$, we can infer resources from factors in the form of paired values, first coordinate of which gives the degree of association and second coordinate gives the degree of non-association. In case, the analyst is not satisfied, $T$ can be further modified. A computer-based diagnostic system can be used for this purpose. A brief flow-chart for IFS energy Location Knowledge is given in Figure 3.

![Figure 3: Algorithm for solution methodology](image-url)
5.7 Solution methodology

The solution methodology is created based on the flow chart described in Figure 3. The relation between various locations and factors are shown in Table 3. Each individual value marked with the membership and non-membership grades clearly represents the relation between location and factor quantifically. In the similar manner, Table 4 represents the relation between various factors and resources.

**Table 3:** Intuitionistic fuzzy relation between the locations and factors.

| S -TABLE | Factor 1 | Factor 2 | Factor 3 | … | Factor m |
|----------|----------|----------|----------|---|----------|
| Location 1 | ($\mu_{S11}, v_{S11}$) | ($\mu_{S12}, v_{S12}$) | ($\mu_{S13}, v_{S13}$) | … | ($\mu_{S1m}, v_{S1m}$) |
| Location 2 | ($\mu_{S21}, v_{S21}$) | ($\mu_{S22}, v_{S22}$) | ($\mu_{S23}, v_{S23}$) | … | ($\mu_{S2m}, v_{S2m}$) |
| Location 3 | ($\mu_{S31}, v_{S31}$) | ($\mu_{S32}, v_{S32}$) | ($\mu_{S33}, v_{S33}$) | … | ($\mu_{S3m}, v_{S3m}$) |
| … | … | … | … | … | … |
| Location n | ($\mu_{Sn1}, v_{Sn1}$) | ($\mu_{Sn2}, v_{Sn2}$) | ($\mu_{Sn3}, v_{Sn3}$) | … | ($\mu_{Snm}, v_{Snm}$) |

where in the ordered $(\mu_{Sij}, v_{Sij})$, $\mu_{Sij}$ is membership grade and $v_{Sij}$ is non-membership grade of IFR $T(L \rightarrow F)$.

**Table 4:** Intuitionistic fuzzy relation between the factors and resources.

| T -TABLE | Resource 1 | Resource 2 | Resource 3 | … | Resource r |
|----------|-----------|-----------|-----------|---|-----------|
| Factor 1 | ($\mu_{t11}, v_{t11}$) | ($\mu_{t12}, v_{t12}$) | ($\mu_{t13}, v_{t13}$) | … | ($\mu_{t1r}, v_{t1r}$) |
| Factor 2 | ($\mu_{t21}, v_{t21}$) | ($\mu_{t22}, v_{t22}$) | ($\mu_{t23}, v_{t23}$) | … | ($\mu_{t2r}, v_{t2r}$) |
| Factor 3 | ($\mu_{t31}, v_{t31}$) | ($\mu_{t32}, v_{t32}$) | ($\mu_{t33}, v_{t33}$) | … | ($\mu_{t3r}, v_{t3r}$) |
| … | … | … | … | … | … |
| Factor m | ($\mu_{tn1}, v_{tn1}$) | ($\mu_{tn2}, v_{tn2}$) | ($\mu_{tn3}, v_{tn3}$) | … | ($\mu_{tnr}, v_{tnr}$) |

where in the ordered $(\mu_{tij}, v_{tij})$, $\mu_{tij}$ is membership grade and $v_{tij}$ is non-membership grade of IFR $T(F \rightarrow R)$.
Table 5: Intuitionistic fuzzy relation between the locations and resources.

| U -TABLE | Resource 1       | Resource 2       | Resource 3       | …        | Resource r    |
|-----------|------------------|------------------|------------------|----------|---------------|
| Location 1| (μ_{u11}, ν_{u11}) | (μ_{u12}, ν_{u12}) | (μ_{u13}, ν_{u13}) | …        | (μ_{u1r}, ν_{u1r}) |
| Location 2| (μ_{u21}, ν_{u21}) | (μ_{u22}, ν_{u22}) | (μ_{u23}, ν_{u23}) | …        | (μ_{u2r}, ν_{u2r}) |
| Location 3| (μ_{u31}, ν_{u31}) | (μ_{u32}, ν_{u32}) | (μ_{u33}, ν_{u33}) | …        | (μ_{u3r}, ν_{u3r}) |
| …        | …                | …                | …                | …        | …             |
| Location n| (μ_{un1}, ν_{un1}) | (μ_{un2}, ν_{un2}) | (μ_{un3}, ν_{un3}) | …        | (μ_{unr}, ν_{unr}) |

Table 5 depicts the relation between locations and resources in intuitionistic fuzzy grades where in the ordered pair \( (μ_{uij}, ν_{uij}) \), \( μ_{uij} = ∨_{f∈F} [μ_S(l_i, f) ∧ μ_T(f, r)] \) is membership grade and \( ν_{uij} = ∧_{f∈F} [ν_S(l_i, f) ∨ ν_T(f, r)] \) is non-membership grade of \( U = T ⊡ S \).

Table 6: Preference table for resources to locations.

| S_T TABLE | Resource 1       | Resource 2       | Resource 3       | …        | Resource r    |
|-----------|------------------|------------------|------------------|----------|---------------|
| Location 1| S_{T11}          | S_{T12}          | S_{T13}          | …        | S_{T1r}       |
| Location 2| S_{T21}          | S_{T22}          | S_{T23}          | …        | S_{T2r}       |
| Location 3| S_{T31}          | S_{T32}          | S_{T33}          | …        | S_{T3r}       |
| …        | …                | …                | …                | …        | …             |
| Location n| S_{Tnr}          | S_{Tnr}          | S_{Tnr}          | …        | S_{Tnr}       |

Table 6 presents the relation between locations and resources by a single digit instead of the pair of membership and non-membership values through the following relation
\[ S_{Tij} = μ_{uij} - ν_{uij} \cdot π_{uij} \] and \( π_{uij} = 1 - (μ_{uij} + ν_{uij}) \) \( ∀i, j \)

Table 6 shows the complete picture of the suitability of energy production plants with the locations. The adaptability of a specific power plant in the most appropriate location can be identified.

6. Numerical experimentation

The numerical experiment is performed by considering seven Indian States. The set of locations, factors, and energy resources are illustrated as:
Set of locations: {Andhra Pradesh, Assam, Gujarat, Rajasthan, Tamil Nadu, Arunachal Pradesh, Tripura}

Set of factors: {Environmental, Economic, Availability of energy transport facility, Dams, Population density, Open land space}

Set of energy resources: {Thermal energy, Wind energy, Solar energy, Biomass energy, Hydro energy}.

S and T table is created by considering the numerical values of membership and non-membership grades. The grade values are obtained from different data sources collected by various regulatory bodies. The highest values of the factors corresponding to the locations are preferred as highest membership values and the other values are considered by scaled on the highest value. Moreover, the significance of the factors with locations and energy resources are defined in Table 7. The data for various factors are collected from Census India 2011, Statistics related to climate change-India 2015, and Open Government data (OGD) India.

**Table 7: Significance of Factors with Location and Energy resources.**

| Factors                     | Location                                                                 | Energy resources                                                                 |
|-----------------------------|--------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Environmental factor        | Defined by the amount of carbon emission in a state or location.          | Defined by the effect on environment by an energy plant which can be measured by the amount of carbon emission by the energy source. |
| Economic factor             | Defined by the GDP of a state or location.                               | Defined by the effect of economic condition of the people in a specific location after installing an energy plant. |
| Number of river and dams    | Defined by the number of dams of the location.                           | Defined by the importance of river dams for implementing the power plant.       |
| Availability of energy transport facility | Defined by the total number of grid lines situated in an area.           | Defined by the availability of accommodation for transporting energy to other sites. |
| Population density          | Defined by total number of households and population density in a location. | Defined by how many numbers of households or agricultural land is supposed to be affected by installing the plant. |
| Open land space             | Defined by the area of open space like seashore, grass-field, or desert.  | Defined by how far an open space is necessary to open the power plant.           |
Table 8: S Table.

| S Table       | Environment | Economic | River dams | Availability of energy transport facility | Population density | Open land space |
|---------------|-------------|----------|------------|------------------------------------------|--------------------|-----------------|
| Assam         | (0.78, 0.22)| (0.14, 0.86)| (0.391, 0.509)| (0.879, 0.11) | (0.64, 0.22) | (0.1, 0.79) |
| Tamil Nadu    | (0.822, 0.15)| (0.9, 0.01)  | (0.821, 0.0782)| (0.745, 0.25) | (0.9, 0.02) | (0.89, 0.04) |
| Andhra Pradesh| (0.767, 0.21)| (0.45, 0.356)| (0.645, 0.2543)| (0.784, 0.16) | (0.499, 0.35) | (0.39, 0.5) |
| Arunachal Pradesh| (0.41, 0.56)| (0.131, 0.7694)| (0.156, 0.7434)| (0.682, 0.26) | (0.027, 0.72) | (0.07, 0.82) |
| Rajasthan     | (0.632, 0.32)| (0.518, 0.35)| (0.645, 0.254)| (0.932, 0.02) | (0.324, 0.53) | (0.49, 0.4) |
| Gujarat       | (0.723, 0.17)| (0.651, 0.236)| (0.9, 0.05)  | (0.839, 0.15) | (0.499, 0.36) | (0.58, 0.31) |
| Tripura       | (0.415, 0.35)| (0.025, 0.884)| (0.097, 0.802)| (0.918, 0.02) | (0.567, 0.23) | (0.03, 0.86) |

Table 9: T Table.

| T Table                  | Wind power | Solar power | Biomass | Hydro power | Thermal power |
|--------------------------|------------|-------------|---------|-------------|---------------|
| Environment              | (0.35, 0.52)| (0.14, 0.82) | (0.24, 0.74)| (0.21, 0.72) | (0.63, 0.15) |
| Economic                 | (0.62, 0.32)| (0.82, 0.1)  | (0.84, 0.15)| (0.54, 0.34) | (0.46, 0.54) |
| River dams               | (0.15, 0.82)| (0.53, 0.31) | (0.11, 0.82)| (0.83, 0.14) | (0.55, 0.43) |
| Availability of energy transport facility | (0.41, 0.52)| (0.42, 0.46) | (0.42, 0.37)| (0.21, 0.32) | (0.42, 0.31) |
| Population density       | (0.23, 0.71)| (0.52, 0.31) | (0.42, 0.53)| (0.31, 0.62) | (0.32, 0.41) |
| Open land space          | (0.68, 0.11)| (0.76, 0.13) | (0.23, 0.57)| (0.13, 0.82) | (0.63, 0.32) |
### Table 10: U Table.

| U Table               | Wind power | Solar power | Biomass | Hydro power         | Thermal power |
|-----------------------|------------|-------------|---------|---------------------|---------------|
| Assam                 | (0.41,0.52)| (0.52,0.31) | (0.42,0.37)| (0.3913,0.32)     | (0.63,0.43)   |
| Tamil Nadu            | (0.68,0.32)| (0.82,0.1)  | (0.84,0.15)| (0.8217,0.14)     | (0.63,0.14)   |
| Andhra Pradesh        | (0.4542,0.356)| (0.53,0.31)  | (0.454,0.356)| (0.6457,0.254)   | (0.63,0.254)  |
| Arunachal Pradesh     | (0.41,0.11)| (0.42,0.46) | (0.42,0.37)| (0.21,0.32)       | (0.42,0.32)   |
| Rajasthan             | (0.5181,0.35)| (0.53,0.31)  | (0.5181,0.35)| (0.6456,0.254)   | (0.63,0.254)  |
| Gujarat               | (0.62,0.32)| (0.651,0.236)| (0.651,0.236)| (0.83,0.14)      | (0.63,0.14)   |
| Tripura               | (0.41,0.11)| (0.52,0.31) | (0.42,0.37)| (0.31,0.32)       | (0.42,0.32)   |

### Table 11: S\_T Table

| S\_T table            | Wind power | Solar power | Biomass | Hydro power | Thermal power |
|-----------------------|------------|-------------|---------|-------------|---------------|
| Assam                 | 0.540      | 0.467       | 0.342   | 0.298       | 0.614         |
| Tamil Nadu            | 0.68       | 0.812       | 0.838   | 0.816       | 0.598         |
| Andhra Pradesh        | 0.387      | 0.480       | 0.387   | 0.620       | 0.600         |
| Arunachal Pradesh     | 0.357      | 0.365       | 0.342   | 0.060       | 0.337         |
| Rajasthan             | 0.472      | 0.480       | 0.472   | 0.620       | 0.601         |
| Gujarat               | 0.606      | 0.625       | 0.625   | 0.825       | 0.598         |
| Tripura               | 0.357      | 0.467       | 0.342   | 0.192       | 0.337         |
Figure 4 represents the graphical distribution of the suitability of energy resources in the seven states and Figure 5 represents the percentage values in the pie chart. If we arrange the gradation of energy resources in descending order, then the following result is obtained.

- **Assam**: Thermal > Wind > Solar > Biomass > Hydro
- **Tamil Nadu**: Biomass > Hydro > Solar > Wind > Thermal
- **Andhra Pradesh**: Hydro > Thermal > Solar > Wind = Biomass
- **Arunachal Pradesh**: Solar > Wind > Biomass > Thermal > Hydro
- **Rajasthan**: Hydro > Thermal > Solar > Wind = Biomass
- **Gujarat**: Hydro > Solar = Biomass > Wind > Thermal
- **Tripura**: Solar > Wind > Biomass > Thermal > Hydro
Figure 5: Graphical representation of % distribution of energy resources in various Indian States
7. Conclusion

The quantitative analysis and compatibility chart represent a thorough image of the perfect locations for desired power plant. It is observed that Andhra Pradesh, Rajasthan, and Gujarat receive the highest membership values for the installation of hydro power plant. Arunachal Pradesh, and Tripura have the highest membership values for the installation of solar power plant whereas Tamil Nadu and Assam obtain the highest values in biomass and thermal, respectively. The results suggest the implementation of a greater number of renewable energy plants than non-renewable. However, in case study of current situation of energy sources of these seven states depicts that a significant amount of non-renewable energy sources has been utilized in Assam and Tripura. Although, there is an opportunity to increase the number of renewable energy plants in these states. The study developed a methodology to design a proper structure of developing energy plants into the most suitable location based on fuzzy intuition. The Sanchez approach was utilized to obtain the results which showed a comparative study between suggested and current scenario of various renewable and non-renewable energy plants in several states. The numerical data was obtained by incorporating the membership and non-membership values from different data sources. Nevertheless, the obtained results may vary with changing membership and non-membership values between various factors and locations. Moreover, there are many other factors which directly or indirectly influence the installation of an energy power plant. Therefore, this research can be extended with incorporation of additional factors. Although, it is not enough to install a single source energy power plant in a location to satisfy the entire demand. Thus, energy hybridization is also necessary to satisfy both demand and environmental and social sustainability. The study can also be expanded to develop an efficient method to hybridize energy.

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