**Solar Power Plant Location Selection Problem by using ELECTRE-III Method in Pythagorean Neutrosophic Programming Approach**

(A case study on Green Energy in India)

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**Abstract:** India dropped its target of generating 500 GW of renewable energy capacity from non-fossil fuel sources by 2030. Its responsibilities to the United Nations Framework Convention on Climate Change [UNFCCC], and reducing carbon radiations by one billion tonnes by the end of the decade at the COP26 conference, held in Glasgow in November 2022. Researchers are continually searching for inexhaustible and reasonable energy sources. Solar energy is one of the greenest sources of energy and is also one of the cleanest. The most important factor in using solar energy is the location of the solar power plant. The main objective of this study is to find the best location for a new solar power plant in a specific region called Bundelkhand region of Uttar Pradesh in India. Here we offer an extension of ELECTRE III method as two-phase Pythagorean neutrosophic elimination and choice translating reality (PN-ELECTRE-III) method to adapt with fuzzy, ambiguous, unsure, and indeterminate criteria. The Pythagorean neutrosophic numbers [PNNs] used by the group decision support system of PN-ELECTRE III to measure performance of the alternatives. The options are entirely outclassed in the subsequent stage in view of the past stage's evaluations of them. By defining PNN we describe the technique of indifference threshold, preference threshold and veto threshold functions, which provide a more stable basis to drop outranking relations. By calculating the concordance credibility, discordance credibility and net credibility degrees of each alternative, the ranking module of the PN-ELECTRE III approach is made simpler. In order to confirm the applicability of the strategy suggested in this paper, the location selection problem for solar plants is finally solved.

***Keywords:*** Solar Power Plant, Multi-Criteria Decision-Making, Pythagorean Neutrosophic Sets, ELECTRE-III Method.

1. **Introduction**

With the expansion in environmental concerns and the exhaustion of non-sustainable power assets, renewable energy sources are well known. Solar energy is one of the most abundant renewable energy sources. However, the location of the solar plant is critical as it affects the efficiency and profitability of the plant. A suitable site for the solar plant should have high solar irradiance, flat terrain, and adequate space. Consequently, choosing the right location for the solar plant is a crucial task. In decision making for selecting the suitable location for the solar plant is a multi-criteria decision-making [MCDM] problem [1], [2]. The MCDM problem deals with selecting the best alternatives based on multiple criteria. The ELECTRE-III method is a widely used MCDM method that considers multiple criteria and ranks alternatives based on the criteria [3], although the ELECTRE-III method does not consider uncertainty and vagueness in the decision-making process.

Fuzzy set theory is an extension of the traditional crisp set theory [4]. This makes it a useful tool in MCDM problems, where the criteria can frequently be uncertain or imprecise. By giving the logical framework for fuzzy set [FS], whose distinctive feature is to show cryptic data by the dint of membership function, Zadeh made an extraordinary commitment in this area [4]. In order to rank Sicily's international airports and vendors, respectively, Aleskerov F. and Monjardet B., presented modified versions of the ELECTRE-III process in fuzzy environment [5]. Gao et, al., analysis of the competitiveness of China's Quanzhou port combined the fuzzy-AHP and ELECTRE-III techniques [6]. The fuzzy ELECTRE-III method was used by La Fata et. al. [7], to examine a situation involving Italian public healthcare.

In 1986 [8], Atanassov developed the basis for a realistic model with a changed structure, namely, intuitionistic fuzzy set [IFS], to explain the ambiguous information using satisfaction and dissatisfaction degrees under the given constraints. With the use of the ELECTRE-III approach for intuitionistic fuzzy models, Wu et al., investigated a case for the selection of the most suitable location for an offshore wind power station [9], [10]. IFS theory is a further extension of the traditional fuzzy set theory. It allows elements to have degrees of membership and non-membership that are not necessarily equal to one another, making it a useful tool in dealing with uncertainty in MCDM problems [11]. Further Pythagorean fuzzy subset as the extension of IFS, made problems more advanced[1, 11–24].

Neutrosophic set theory [NST] as an extension of the traditional crisp, fuzzy, and intuitionistic fuzzy set theories introduced by Smarandache F., in 1998 [23]. It allows elements to have degrees of membership, degrees of non-membership, and degrees of indeterminacy that are independent of one another, making it a useful tool in dealing with incomplete or inconsistent information in MCDM problems. By introducing a new neutrosophic outranking relation based on the concept of truth-membership, falsity-non-membership, and indeterminacy-membership degrees, the ELECTRE-III method has been further extended to handle neutrosophic sets [26–36].

Recently in 2019 Smarandache and Broumi [35] introduced the Pythagorean neutrosophic set [PNS], which was a further extension of the NST. It allows elements to have three independent values such as truth-membership, and indeterminacy-membership and falsity-membership degrees. PNS are a useful and effective tool to handle incomplete or inconsistent information in MCDM problems. Pythagorean neutrosophic programming [PNP] approach is a generalization of FS theory and NST that can handle uncertain, incomplete, and inconsistent information in the decision-making process [38, 39, 40]. In the present research problem, we are utilizing PNP approach with the ELECTRE-III technique, which can improve the decision-making process.

In this paper, we propose a two-phase decision-aiding system for the solar plant location problem using the ELECTRE-III method in the PNP approach. The first phase of the proposed system uses the PNP approach to handle uncertain and incomplete information in the decision-making process. In the second phase, the ELECTRE-III method is used to rank the alternatives based on the criteria [11]. The proposed system can provide decision-makers with a set of feasible alternatives and their ranking based on the criteria.

A case study on green energy in Bundelkhand region of India is conducted to demonstrate the effectiveness of the proposed system. The study considers seven potential sites for the solar plant, and the decision criteria are as *solar abundant* *solar radiation*, *flat & open land,* *high land and construction costs,* *demand for electricity*, *extreme weather conditions*, *higher elevation from sea level*, *proximity to transmission lines* and *average dust density to the substation.* The results show that the proposed system can provide decision-makers with a set of feasible alternatives and their ranking based on the criteria, which can help decision-makers in selecting the most suitable site for the solar plant.

* 1. **Motivation Behind the Current Study**

The increasing demand for clean and sustainable energy has led to a surge in the installation of solar power plants [41, 42, 43]. However, identifying the optimal location for a solar plant is a complex problem due to numerous factors such as weather conditions, land availability, infrastructure, and environmental impact. In this context, decision-aiding systems can assist decision-makers in identifying the best location for solar plant installation. This study aims to develop a two-phase decision-aiding system[11] using the ELECTRE-III method in the PNP approach for the solar plant location problem [29, 30, 32, 37–40, 44]. The proposed method considers the imprecise and uncertain nature of the decision-making process in the solar plant location problem. A contextual analysis on green energy in Bundelkhand region of India is conducted to demonstrate the applicability and effectiveness of the proposed method.

The consequences of this study can help policymakers and partners in pursuing informed choices in regards to the optimal location for solar plant establishment. This research also contributes to the literature on decision-making under uncertainty using PN-ELECTRE-III method.

* 1. **Objectives of Current Investigation**

The objective of this investigation is to propose a two-phase decision-aiding system for selecting suitable locations for solar plants in Bundelkhand region of India, using the PN-ELECTRE III method. The proposed system aims to consider various factors such as economic, social, environmental, and technical aspects to select the optimal location for solar plants in Bundelkhand. The first phase of the proposed system involves the development of a PN-ELECTRE III method to evaluate the suitability of potential locations for solar plants. The second phase involves the development of a decision-aiding system to prioritize the locations based on the evaluation results of the first phase. The proposed system will take into account the uncertainties and imprecision in decision-making using PNP. The study will contribute to the field of decision-making in renewable energy by developing a comprehensive decision-aiding system that considers multiple criteria and uncertain information [9, 41, 42]. The proposed system will also provide valuable insights into the selection of optimal locations for solar plants in seven districts as Banda, Chitrakoot, Hamirpur, Jalaun, Jhansi, Lalitpur and Mahoba of Bundelkhand region and help policymakers and investors to make informed decisions.

* 1. **Related Research Work**

The proposed approach builds on the existing literature on decision-making methods and multicriteria decision-making in particular. The ELECTRE III method has been widely used in previous research for decision-making in different contexts, such as supply chain management, transportation, and environmental management. For instance, Guitouni and Martel [43] applied the ELECTRE III method to select the best location for a landfill site in Quebec, Canada. Similarly, Kaya and Kahraman [44] utilized the ELECTRE-III method to evaluate and rank different wastewater treatment technologies. Moreover, the Pythagorean Neutrosophic programming approach has been used in previous research to address decision-making problems under uncertainty. Wang et al. [45] applied the Pythagorean Neutrosophic programming approach to rank different photovoltaic power plant locations in China. Additionally, Abbas et al. [46] used the Pythagorean Neutrosophic programming approach to evaluate and select the best supplier for a manufacturing company.

1. **Preliminaries**

In this segment, some fundamentals preliminary concept of neutrosophic sets [NS] [23], single valued neutrosophic set [SVNS] [47], PNS [35] and PNN are briefly presented which will enable the conversation in the following sections.

**Definition 2.1.** [50, 51]**:** Let U be a non-empty set. A NS *P* on *U*, containing  as degree of membership,  as degree of indeterminacy and as degree of non-membership, defined as



where  such that  for all 

**Definition 2.2.** [50, 51]**:** A SVNS *P* on a non-empty universal set *U* is defined as where  such that  for all  and  is membership degree function,  is indeterminacy degree function and is non-membership degree function.

**Definition 2.3.** [38, 39 40]: Let *U* be a non-empty universal set of discourse. A PNS *P* on *U* is defined as



Where  such that  for all  and  is membership degree function,  is indeterminacy degree function and  is non-membership degree function. Here truth and falsity are dependent components and indeterminacy is an independent component. The triplet  is called a PNN.

For convenience, we represent a PNN  as , throughout in this article.

**Definition 2.4.**[49]: [Operation] Let three PNN ,  and  then the elementary mathematical operations over these PNNs are defined as:

1. Complement: 
2. Union: 
3. Intersection: 
4. Addition: 
5. Multiplication: 
6. Scalar Multiplication: 
7. Exponentiation: 

**Definition 2.5.**[50], [De-Neutrosophication]

1. Score Function: 
2. Accuracy Function: 
3. Normalized Euclidean Distance: 

**Definition 2.6.**[11, 51], [Comparison]

1. If , then  (is superior to)
2. If , then
   1. If , then  (is superior to)
   2. If ,then  (is superior to)

**Definition 2.7.**[41], [Aggregation]: Let  and 

* + - 1. PNWA Operator



* + - 1. PNWG Operator



**3. ELECTRE III Method**

Let be a set of available alternatives and be a set of criteria corresponding to each alternative for a MCGDM problem. A group  of *h* expert or Decision-Maker [DM] allocates the feasibility or performance or the evaluation information of alternative ** with respect to criterion ** as; . The more the alternative satisfy the criterion, the lower or higher the value of , which be subject to upon whether the objective is to minimize or to maximize for the criterion**. Subsequently, the performance/ feasibility information of an alternative **on the basis of multiple criteria will be represented by the vector  as all the criteria can have their own importance considering objective of the MCGDM problem thus criteria weight vector will be denoted by such that  Similarly, the importance expert weight vector will be  such that 

The ranking process of the ELECTRE-III method consists of two modules [54, 55]. After the performance evaluation of alternatives by evaluators or DM’s over multiple criteria, the establishment of preference and indifference threshold functions, the determination of concordance and discordance indices, and ultimately the revelation of credibility index come under first module in the formation of an outranking connection. Using outranking relations to deduce a comprehensive feasibility ranking of alternatives makes up the second module.

**3.1 Module I: Developing Outranking Relations**

In the MCGDM process, an alternative  outranks another alternative , represented by , if there is sufficient evidence to believe that  is at least as good as  and there are no compelling counterarguments. The ELECTRE method's fundamental tenet is to establish a preference relation—often referred to as an outranking relation—among the acts assessed across a number of criteria. The basis for establishing the outranking relation  is provided by the credibility index, which is the degree of outranking. Concordance index and discordance index, computed throughout each criterion**, are used to calculate the degree of credibility.

**3.1.1 Erection of Threshold Functions**

The ELECTRE III model's assessment technique include establishing indifference threshold function, preference threshold function and veto threshold function for disclosing concordance and discordance indices, determining the degree of credibility, and ranking the alternatives. Let be the indifference threshold function and be the preference thresholds function for corresponding criteria .

Let if for any two given alternatives ,, then,







where  is the criterion score value of the alternative , and P signifies strong preference, Q weak preference, and I indifference.

**3.1.2 Calculating the Concordance Index of the Assertion ****

For each pair of alternatives, the comprehensive concordance index is where  represent the weight of criteria and  represent the partial concordance indices over the criteria  is calculated as



Thus 

**3.1.3 Calculating the Discordance Index of the Assertion ****

For each criterion, the discordance index  is calculated



Thus .

**3.1.4 Disclosure of Credibility Index**

The credibility index, denoted by the notation , is used to determine the degree of outranking relation ******is defined as



where 

**3.2 Module II: The Exploitation of Outranking Relations**

The standard ranking approach of ELECTRE III employs a structured algorithm via two intermediate ranking procedures, one of which is descending distillation, where the alternatives are ranked from best to worst, and the other of which is based on ascending order from worst to best alternative (ascending distillation). In contrast, a new ranking approach based on the introduction of three concepts such as *the concordance credibility* *degree, the discordance credibility degree, and the net credibility degree* is used.

According to Li and Wang [52]

1. For each alternative, the concordance credibility degree defined asThe concordance credibility degree represents outranked  (demonstrating how  outperforms over all of its alternatives in ).

2. For each alternative, the discordance credibility degree defined as The discordance credibility degree represents outranked  (demonstrating how  outperforms over all of its alternatives in ).

3. For each alternative, the net credibility degree defined as 

The attractiveness of alternative  increases with the value of net credibility degree. Consequently, based on the level of net credibility, the possible alternatives can be ranked in decreasing order.

**4. Two-Phase Pythagorean Neutrosophic ELECTRE III Method (Algorithm)**

In this part, the two-phase PN-ELECTRE III group decision support system is created by combining the PNSs and traditional ELECTRE-III approach.

In Pythagorean neutrosophic environment, let for a multi-criteria group decision making [MCGDM] problem, be a set of available *f* alternatives and be a set of *g* criteria assigning to each alternative. A group  of *h* expert or DM assigns the feasibility information of alternative **with respect to criterion **as;  All the criteria can have their own and unequal importance considering objective of the MCGDM problem thus criteria weight vector will be denoted by such that  Similarly, the importance expert weight vector will be such that . Let the subscript set of criterions i.e.

**4.1 Phase I: Pythagorean Neutrosophic Evaluation Phase**

**Step-1.** First, we establish some linguistic variables/terms in the form of PNN for the evaluation of, feasibility ratings of alternatives, importance weights of criterion, importance weights of experts and establishment of threshold functions.

**Step-2.** Systematically assessing each alternative with respect to each criterionExpert provides his/her evaluation information in the form of Pythagorean neutrosophic decision matrix [PNDM] , as in table 1. where is the PNN allocated by the DM , with  is membership degree function,  is indeterminacy degree function and  is non-membership degree function. Here truth and falsity are dependent components and indeterminacy  is an independent component.

**Table 1**: PNDM by DM



**Step-3.** Weight of expert can be determined by the following Eq.

,

Where the satisfy the normalized condition 

**Step-4.**The distinct opinions of DM or experts required to be combined into a collective opinion to construct aggregated PNDM by using Pythagorean Neutrosophic weighted averaging [PNWA] operator [40, 51]. Where  is the PNDM of the expert .







where , and consequently, the matrix can be ready as in table 2.

**Table 2**: Aggregated PNDM



**Step-5.** Let  and  represent the corresponding collections of criteria that are of the benefit-type and cost-types. The aggregated PNDM, , can be converted into the normalized aggregated PNDM,  which displays the evaluation information of each alternative with respect to each benefit or cost criterion, in standard form, for additional calculations. PNN for can describe as follows:



Table 3 demonstrates how the matrix *M* is built.

**Table 3:** Normalized Aggregated PNDM



**Step-6.** Not all criteria might have equally significant. Let  represent the PNN that the expert  assigned for the relative weight of criterion. By aggregating the opinions of experts on  determine the PN weight  as follows:





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Thus, the following criteria weight row matrix can be obtained.



It is established the weight matrix for the criteria. The following equation is used to determine the normalized weights of each criterion based on the total weights of the criteria, which adhere to the condition.



**Step-7.** The weighted normalized aggregated PNDM,  is created as shown in table 4 in the order of integrating the data from the normalized aggregated PNDM and the criteria weight matrix  may be generated by using the specified multiplication operator [18],





**Table 4:** Weighted Normalized Aggregated PNDM



**4.2 Phase II: Pythagorean Neutrosophic Ranking Phase (PN-ELECTRE-III)**

The first phase of the Pythagorean decision support system collects the PN assessment data for each alternative, and the second step uses the PN-ELECTRE-III approach, which uses the aggregated evaluations to produce the whole ranking of alternatives.

**4.2.1 Module I: Developing Outranking Relations**

**Step-8.** For each criterion, determine the preference threshold values  and indifference threshold values , as shown in section 3.1.1.

**Step-9.**The partial concordance indices [13, 20],  and over each criterion can be obtained using Eq. (), in table 5 as follows:

**Table 5**: Partial concordance indices over each criteria



And after that for each pair of alternatives, the comprehensive concordance index is calculated using Eq. (), in table 6 as follows:

**Table 6**: Comparative concordance index



**Step-10.**For each criterion, the discordance index and  is calculated using Eq. (), in table 7 as follows:

**Table 7**: Discordance index over each criteria



**Step-11.**The credibility index, denoted by the notation , , is used to determine the degree of outranking relation ******can be determine using Eq. ().in table 8 as follows:

**Table 8**: Credibility index



**4.2.2 Module II: The Exploitation of Outranking Relations**

To get the comprehensive preference ranking of alternatives, compute the concordance credibility degree, discordance credibility degree, and net credibility degree as described in section 3.2.

**4.3 Algorithm Diagram:**

Figure 1 presents a diagrammatic picture of the two-phase group decision-supporting system in order to provide a step-by-step process for problem-solving.

1. **A Case Study: Solar Power Plant Location Selection Problem**

Bundelkhand is a region in central India, covering parts of Uttar Pradesh and Madhya Pradesh. Bundelkhand region has a high potential for solar power generation due to its abundant sunlight and vast areas of flat land. According to the India meteorological department [IMD], Bundelkhand region falls under the "Hot and Dry" climate zone, which is characterized by high temperatures and low humidity. The region receives an average of 300-325 days of sunshine per year, making it an ideal location for solar power generation. In recent years, the government of India has also taken various initiatives to promote solar power generation in the region. The region has been identified as a potential hotspot for solar power development under the National Solar Mission.

Uttar Pradesh has a total installed solar capacity of around 29.858 GW, of which Bundelkhand region's contribution included. However, it is worth noting that the Uttar Pradesh new and renewable energy development agency [UPNEDA] has been actively promoting solar power projects in the region. In 2018, the UPNEDA invited bids for the development of a 500 MW solar park in Bundelkhand, which would have been one of the largest solar parks in the country. Furthermore, in 2019, the UPNEDA invited bids for the development of 1,000 MW of solar power projects across the state, including in Bundelkhand region.

This section identifies a case study that focuses on solving an MCGDM problem in order to highlight the applicability of the suggested technique in realistic decision-making situations. This study is conducted by one of the Indian NGOs working for solar energy in Bundelkhand region in Uttar Pradesh, INDIA. The organization, which is involved in various activities such as promoting renewable energy policies, conducting research on renewable energy technologies, providing training and awareness programs, implementing renewable energy projects, and development of solar power park /plants projects in seven districts of Bundelkhand region.

**5.1 Available Alternatives**

In this study, the districts that fall under the Bundelkhand region in Uttar Pradesh are taken as alternatives.

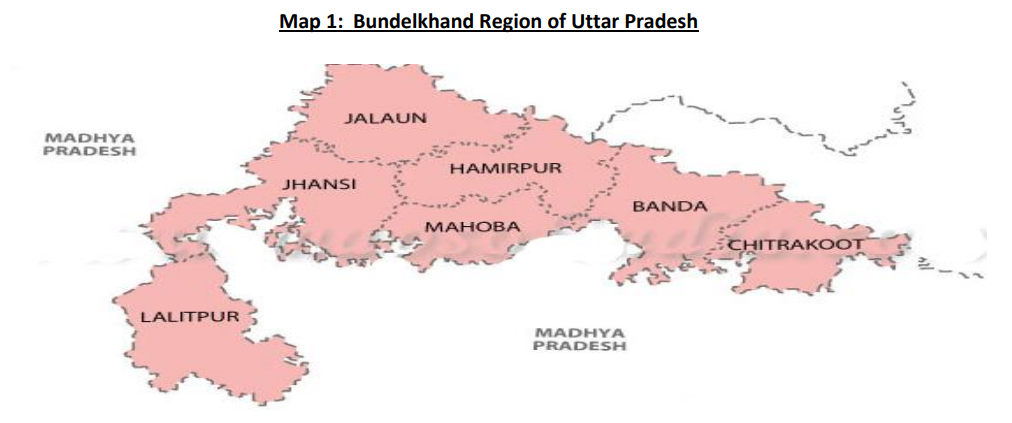


Figure 1: Bundelkhand Region of Uttar Pradesh (Source https://planning.up.nic.in/)

**Table 9:** Available Location (Alternatives) in Seven District of Bundelkhand Region



**5.2. Selection of Criteria**

One of the important issues in MCDM analysis is criteria selection. The main criteria that affect solar power plant location selection are economic, geographic and environmental, technical, and social. Choosing the right criteria is crucial to analyse and get accurate results. There are several favourable/ Benefit-type/ Positive (+) and unfavourable/ Cost-type/ Negative (-) criteria that can make a location suitable/unsuitable for a solar power plant. Here are some of the top criteria:

1. **Abundant Solar Radiation (+):** The first and foremost factor is the availability of solar radiation. Solar power plants require a significant amount of sunlight to generate electricity. Locations with high levels of annual solar radiation or high numbers of annual sunshine hours are ideal for solar power plants.
2. **Flat& open land (+):** Solar power plants require large, open spaces to accommodate solar panels. Flat land is ideal as it requires less grading and construction work, reducing the cost of building the solar power plant.
3. **High land and construction costs (-):** Solar power plants require large, flat spaces that are expensive to develop. Locations with high land and construction costs may not be financially viable for solar power plants.
4. **Demand for Electricity (+):** The population should have a sufficient demand for electricity to justify the installation of a solar power plant. Areas with low population density or low electricity consumption may not be suitable for large-scale solar power plants.
5. **Extreme weather conditions (-):** Extreme weather conditions such as hurricanes, tornadoes, or heavy snowfall can damage solar panels or disrupt the generation of electricity. Locations with high levels of extreme weather conditions may not be ideal for solar power plants.
6. **Higher elevation from sea level** (+): At higher elevations, the air is thinner, which can lead to lower air density and less atmospheric absorption of solar radiation. This can result in higher solar irradiance values and more direct sunlight reaching the solar panels. Additionally, the temperature at higher elevations can be lower, which can help to reduce the operating temperature of the solar panels and increase their efficiency.
7. **Proximity to transmission lines (+):** Solar power plants generate electricity that needs to be transmitted to the grid. Locations near transmission lines reduce the cost of connecting the solar power plant to the grid.
8. **Average Dust Density (-):** Dust density is a measure of the amount of dust particles in the air, and it can have an impact on solar panel efficiency. The presence of dust particles on the surface of the solar panels can reduce the amount of sunlight that reaches the cells, thereby reducing their efficiency.

**Table 10:** List of Most Effective Area



**5.3. Stepwise Procedure**

The whole PN-ELECTRE III process is used in the phases that follow to find the best location for the installation of solar power plant/park unit.

**5.3.1 Phase I: Pythagorean Neutrosophic Evaluation Phase**

***Step-1:*** *Setting-up of Linguistic terms/variables-* By using the decision support system of the suggested technique to solve the aforementioned problem, importance of weight degree to eight criteria and four experts are allocated in the form of linguistic terms/variable that are specified by PNNs as in table 11,

**Table 11**: Linguistic Terms for Importance Weights Rating of Criteria and Experts

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In table 12, specialists independently assess each location's feasibility/performance and threshold functions based on eight criteria, and the performance scores are presented using linguistic terms/variable shown.

**Table 12:** Linguistic Terms for Feasibility Rating of Alternative and Threshold Functions

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***Step-2: Computing of the weights of Decision Makers*** *–*Table 13, lists the importance rankings that the president of NGO granted to each of the field specialists/Decision Makers . Employing Eq. (14)., it is possible to determine each expert's own weight.

**Table 13**: Assigning and computing of Weights of Expert (DM)

****

***Step-3:Assigning of the Decision Makers Judgements****-*The language expressions/ linguistic terms used in table 14 to describe the individual viewpoints of each Decision Makers on the decision-making panel with regard to each alternative and all taken-into-account criteria. The Pythagorean neutrosophic decision matrics [PNDM]that highlight the unique opinions of the DM are shown in tables 15-18, respectively.

**Table 14:** Judgement of Decision Expert in linguistic variables

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**Table 15:** Judgement of Decision Expert  in linguistic variables

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**Table 16**: Judgement of Decision Expert  in linguistic variables

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**Table 17:** Judgement of Decision Expert  in linguistic variables

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**Table 18:** Judgement of Decision Expert  in linguistic variables

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***Step-4:*** *Aggregation of the Decision Makers Judgements-*According to the PNWA operator and the decision-making experts' normalised weights, the individual judgements of each decision makerare combined. Table 19 contains the combined Pythagorean Neutrosophic decision matrix.

**Table 19:** Aggregated PNDM

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***Step-5:****Normalization of Aggregated PNDM-* Let  and  represent the corresponding groups of criteria that are of the benefit-type (Positive) criteria , cost type (Negative) criteria  The aggregated PNDM, , can be converted into the normalized aggregated PNDM,  which displays the evaluation information of each alternative with respect to each benefit or cost criterion, in standard form, for additional calculations. Table 20 demonstrates how the matrix *M* is built and one can describe the PNN for,

**Table 20:** Normalized Aggregated PNDM

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***Step-6:*** *Erection of weight matrix of criteria-*The decision-making panel's linguistic labels for each criterion, PN-weights, and normalised weights of the criteria are shown in table 21.

**Table 21:** Linguistic Variables to Unfold Importance of Criteria

****

****and ****

***Step-7:*** *Construction of Weighted normalized aggregation PNDM-*The weighted normalized aggregated PNDM,  is created as shown in table 22 in the order of integrating the data from the normalized aggregated PNDM and the criteria weight matrix  may be generated by using the multiplication operator, which is specified in Eq (19).

**Table 22:** Weighted Normalized Aggregated PNDM

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**Step-8:** *Computation of Score degrees with respect to WNA-PNDM*- table 23 contains the computed score values of corresponding PNNs in the weighted normalized aggregated PNDM .

**Table 23:** Score Value of Weighted Normalized Aggregated PNDM



**5.3.2 Phase II: Pythagorean Neutrosophic Ranking Phase (PN-ELECTRE III)**

**5.3.2.1Module-I: The construction of outranking relations**

***Step-9.*** *Establishment of Threshold Functions***-** For each criteria , Here are preference threshold values  and indifference threshold values and veto threshold values as shown in table 24,

**Table 24:** Assigning of PNN’s Threshold functions and its Score Values

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***Step-10.*** *Calculation of difference in the score degrees-* The differences in the score values/degrees of the feasibility of every pair of alternatives are ccomputing of , where b= 1,2,….8, in tables 25-28 as follows:







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***Step-11:*** *Calculation of Partial Concordance Indices and Concordance Matrix-* The partial concordance matrices shown in tables 29-32 as follows:









**Table 33:** Comprehensive Concordance matrix 



***Step-12:*** Calculation of Discordance Matrix in tables 34-37

Table 34



Table 35



Table 36



Table 37



***Step-13:****Calculation of Credibility Index-*

Table 38



**5.3.2.2 Module II: The Exploitation of Outranking Relations**

***Step-13:****Calculation of Credibility Index-Table Ranking of Alternatives*

Table 39







Thus, District Jalaun is the best Location in Bundelkhand region of Uttar Pradesh for Solar Power Plant/Park installation.

1. **Conclusion**

In conclusion, the research paper titled "Two Phase Decision-Aiding System for solar plant location problem using ELECTRE III Method in Pythagorean Neutrosophic programming approach: A case study on Green Energy in India" presents a novel approach to solving the solar plant location problem in India. The use of the ELECTRE III method in the Pythagorean Neutrosophic programming approach is a significant contribution to the field of decision-making under uncertainty. The paper's two-phase decision-aiding system allows for a comprehensive evaluation of potential solar plant locations, taking into account multiple criteria and stakeholder preferences. The case study on Green Energy in India demonstrates the effectiveness of the proposed method in identifying the most suitable locations for solar plants, considering economic, social, and environmental factors.

Overall, the paper highlights the importance of using advanced decision-making tools to address complex problems in renewable energy development. The proposed method can serve as a valuable resource for policymakers, investors, and stakeholders involved in the planning and implementation of solar energy projects in India and other countries facing similar challenges.

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