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Geo-Environmental Analysis on Specifying Solar Energy Power Plant (SEPP) Fields by GIS and Different Fuzzy AHP Methods

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Abstract
The use of solar energy among renewable energy sources has started to become widespread due to its potential, the practicality of use and environmental friendliness. In assessing the installation sites of solar energy power plants (SEPPs) economic, social and environmental elements should be taken into consideration, and cultural and paleontological heritage areas should not be damaged. In order for decision-makers to show their own predilections in some ways, the subject of this research is to specify the convenient fields for SEPP installation in Yalova province with all its districts using different methods of fuzzy analytical hierarchy processes (FAHP) together with Geographic Information Systems (GIS). Buckley (1985) found that the geometric mean approach achieved an accuracy rate of 24.99% for the combination of high and medium susceptibility levels. On the other hand, using the extent analysis method proposed by Chang (1996), an accuracy rate of 7.82% was obtained. The results indicate that the Geometric mean approach by Buckley (1985) provides more realistic results compared to the extent analysis method by Chang (1996). According to the results obtained, it has been seen that Yalova province has convenient fields for SEPP sites in the center and east, including the Central and Çiftlikköy districts.

1. Introduction

The requirement for energy is increasing continuously due to population growth, industrialization, increase in welfare and technological developments. This increase is mostly direct action to the level of the development of the countries. This increase is also in question in Türkiye and this rate will rise even more in the oncoming future. In this case, energy needs mostly met by conventional methods. Conventional methods refer to the production of energy consequences of fire fuels. This case poses many economic and environmental problems. The use of sustainable and renewable energy sources for mineral fuels is of great importance in the production of sustainable electricity [1]. Through the utilization of renewable sources, it is possible to both meet the electricity need and help avoid climate change globally. Therefore, widespread use of renewable energy sources is a necessity. In this sense, solar energy can be considered as an important different energy source for future generations [2]. Being a clean energy source and operating at a low cost after installation increases the value of solar energy [3].

Considering the world electricity production, it is seen that sources of renewable energy have an important space. Renewable resources account for 29% of the total global electricity production [4]. The share of electricity generation from solar power plants (SEPP) in global electricity generation is 2.8 percent [5]. In terms of electricity generation in Türkiye, natural gas and coal resources are superior to other opportunities. While 40.7 percent of aggregate electricity generation is derived from renewable resources, the proportion of solar energy in aggregate

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electricity generation is 3.7 percent. When analyzing the distribution of electricity generation from renewable energy sources in Türkiye, it is seen that solar energy has a share of 9.1 percent [6]. This share increased by 2 percent compared to the previous year. Solar panels have started to be used to benefit from solar energy in Türkiye as well as all over the world. Solar energy has gained global importance due to its clean nature and wide availability [7]. Nowadays, source of solar power is utilized as remedies to eliminate the environmental problems produced by mineral source fuels, mostly in developed countries. Among the usage areas of solar energy, hot water and electricity production, heating of greenhouses, heating and cooling of places and heat energy for industrial establishments can be listed [3].

The choice of location is also a major factor in reducing the cost of the SEPP installation and obtaining the maximum efficiency during operation [8]. The determination of SEPP locations depends on many factors such as economics, technical and environmental. Since these criteria are mostly spatial, accurate results can be easily obtained with analyses in the Geographic Information Systems (GIS) environment. In this respect, many studies have been carried out in the GIS environment by using different multiple-criteria decision making (MCDM) methods. In the analytical hierarchy process (AHP) method, which is frequently used in MCDM mechanisms, the selection processes are made according to the predetermined criterion scoring during the decision-making phase, and focus groups affect the result [9]. Uyan [10] determined 5 criteria as environmental and economic, for the Karapınar region of Konya, he weighted these criteria using AHP and as a result of analyzes made in the GIS environment, it was detected that 40.34% of the Konya province was suitable for the setup of SEPP, and 59.66% was unsuitable. Potić et al. [11], in research to assessment the potency of solar energy of Knjazevac area in eastern Serbia, were defined 4 criteria as solstice, topography, climate and land use. Land use was obtained as 6 classes with the datum as an end of the surveys of Landsat 8 satellite images. The resulting map was created using AHP and GIS. For the purpose of defining the sites where SEPP will be installed in Iran, 11 criteria were determined in research carried out by Noorollahi et al. [12]. Fuzzy Analytical Hierarchy Process (FAHP) was used for weighting since the superiority of the factors relative to each other was not certain and SEPP suitability map for Iran was formed using GIS. Additionally, considering the 1057 regions of the country, the optimal areas for SEPP were defined. Consequence of research by Al Garni and Awasthi [13] handling GIS and AHP for the Saudi Arabia, it has been determined that the optimal regions for SEPP are the northern and northwestern locations of the Saudi Arabia. In research carried out by Asakereh et al. [14], the sites where SEPP will be installed were determined in Khuzestan, Iran use GIS and FAHP. Thanks to research, it has been determined that Khuzestan has a high potency. In research carried out by Merrouni et al. [15], 4 main and 8 sub-criteria were defined to determine the locations where SEPP will be installed in the east of Morocco, and a compatibility map was formed handling GIS and AHP. The study revealed that 19% of eastern Morocco is highly suitable for SEPP settlement. In the literature research, it has been defined that AHP and FAHP methods are common and widely used in the preparation of the suitability map with GIS. Analysis with fuzzy logic ensures a more flexible decision environment for the decision maker. For this reason, the GIS-based FAHP process was utilized to create the suitability map for the SEPP installation in Yalova, which is the subject of this research, located in the Marmara Region of Türkiye.

The first study in the field of Fuzzy AHP was conducted by Yager in 1978. In this study, a method that would facilitate decision-making in multi-criteria problems under conditions of uncertainty and fuzziness was introduced to the literature [16]. In studies conducted with Fuzzy AHP in the literature, various methods are employed to determine the importance values. However, in most studies, it has been observed that methods such as geometric mean [17] and extent analysis [18] are frequently used for ranking fuzzy numbers and determining criterion weights. For this reason, in this research, geometric mean [17] and extent analysis [18] methods found in the literature as FAHP were used. To raise the electricity production installed power of Yalova province and the proportion of SEPP in this established power, it is purposed to determine convenient SEPP fields for benefitting from solar energy in Yalova. For this purpose, suitable site selection for potential SEPPs in Yalova province was formed with the GIS-based MCDM process because it is composed of a solution system for the management of multiple solution criteria. One of the innovations of this research is that, for the first time, it identified optimal locations for installing SEPPs in an area requiring clean energy. In this context, as data layers; certain factors such as solar radiation, slope, distance to power distribution centers (PDCs), land use, distance to fault lines, lithology, distance to stream, distance to lake, distance to road line, aspect and distance to residential areas have been used. Although solar radiation has not been used as an analysis parameter in other similar studies, Kırcalı and Selim [19] emphasized that solar radiation is the most important criterion for site selection and used it as a parameter in their studies. The innovative aspects of the research are the consideration of solar radiation and lithology factors as criteria for evaluation. All criteria placed in the research were formed in raster environment by GIS software, and pairwise comparison matrix fuzzy numbers and fuzzy number equivalents were produced. The weight values of each criterion were defined by the different FAHP methods. Later, the criterion maps classified by consolidation analysis were combined and a convenience consequent map was obtained displaying the optimal fields for SEPP. This research also introduces a new aspect, highlighting the utilization of GIS-based FMCDM (Fuzzy Multi-Criteria Decision Making) and FAHP (Fuzzy Analytical Hierarchy Process) methods for preliminary studies in potential locations. These methods prove to be highly effective in creating location suitability maps. Upon the establishment of solar energy production plants (SEPPs) in Yalova, it is expected that at least the energy demands of residential areas will be fulfilled using solar energy, leading to a significant advantage in terms of obtaining a clear and more cost-effective power supply for the province. In addition, this study is expected to it is expected that this study will guide the determination of SEPP installation areas in cities other than Yalova.

The next part belongs to the researched area, in section 3 the data and the method used in the study are explained. In section 4 the Application are reported, section 5 belongs to the results and discussion and section 6 is the conclusion.

2. Researched Area

The Solar Energy Potential Atlas of Türkiye (GEPA) has been presented by the Energy and Natural Resources Ministry in order to determine the potential in electricity production from solar power and to utilize solar power effectively. When the GEPA regional solar energy parameter values are examined, it is seen that almost every point in Türkiye has the opportunity to directly or indirectly benefit from solar energy [20]. The research area is Yalova province, which is spotted in the Marmara region and on the coast of the Marmara Sea. Yalova province is located between 39-40 North latitude and 28-29 East longitude [21], has an area of 826 km2 together with its districts. The Marmara Sea is located in the west and north of the province, Kocaeli in the east, Gemlik Bay and Bursa province in the south are located. Yalova province has a total of 6 districts, namely Armutlu, Çınarcık, Altınova, Çiftlikköy, Termal and Central districts (Figure 1).

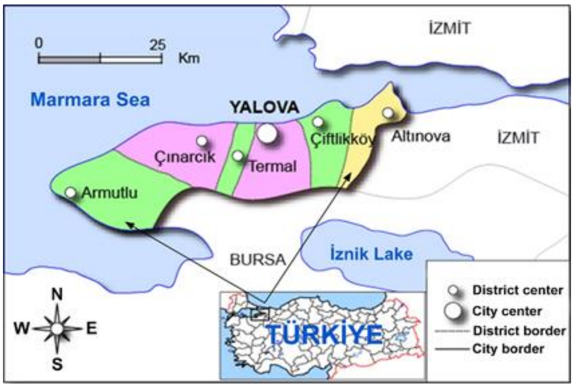

Figure 1. Location map [22]

Considering the population registration system data, it has been seen that the total population of Yalova, which was 270976 in the previous year, increased and reached 276050 people. Considering the distribution of the population by districts; the central district consists of 149330, Altınova district 30780, Armutlu district 9901, Çınarcık district 34699, Çiftlikköy district 44808 and Termal district 6532 people and it is seen that most of the population lives in the city center [23]. Approximately 5% of Yalova province is covered with forests and its climate is a transition between Mediterranean and Black Sea climates. Summers in the province are dry and hot, and winters are rainy and warm [24]. The total annual solar radiation of Yalova with its districts is between 1400-1450 KWh m^{-2}. It has been determined that the values of global radiation of all Yalova with its districts are the highest in June. It is observed that the mean density of daily radiation is about 3.7 kWh m^{-2} day^{-1}, and the annual mean value of total global radiation is about 1351 kWh m^{-2} $year^{-1}$. Additionally, the monthly and annual average daily sunshine durations in Central, Termal, Çiftlikköy and Altınova districts of Yalova are approximately 6.6 and 2409 hours and in Çınarcık and Armutlu districts, it is approximately 6.7 and 2446 hours [25]. Considering the sunshine duration, it is seen that there is an increase of approximately 1.5% in the sunshine duration toward the west of Yalova.

Kiliç et al. [26] in their research where they handed annual wind speeds and solar radiation to supply the electric load need of the University campus in Yalova, performed hybrid energy production simulations. Gül and İzgi [27], analyzed low voltage panels and wind-solar hybrid energy systems separately in order to select the hybrid system configuration for an industrial facility to be established in Yalova-Esadiye Village. A notation based upon geographical and meteorological data has been enhanced by Sözen et al. [28] in order for assessment the potential of solar energy by taking Artificial Neural-Networks (ANNs) in 18 places in Türkiye, including Yalova province. On the other hand, Türkdoğan et al. [29] set up a hybrid power order in a farmhouse placed on the Erikli Plateau by utilizing wind and sun and they emphasized that this research will encourage the engage of renewable sources in the field of agriculture-livestock farming. There are total of 7 power plants in Yalova, 1 thermal, 5 wind and 1 SEPP completed by the Yalova Wastewater and Sewerage Infrastructure Facilities Management Association (YASKİ), producing approximately 327 GWh of electricity annually. Among these power plants, the rating of SEPPs with a total installed capacity of 294 MWe is only 1 MWe [30]. The construction of capacity power plants started in 2009 in Armutlu district, which was deemed suitable for the operating of wind energy facilities [31]

3. Material and Method

3.1. Location Specification and Identification of Restriction Sites

SEPP site specification parameters directly affect the activities from the setting cycle to the running cycle of power facilities and the costs of electricity generation. While choosing the location, legal regulations, efficiency status and environmental impact assessment criteria are taken into consideration. In the development process, efficiency comes to the fore in general, and environmental effects are unfortunately relatively ignored. However, it is important in this process to examine laws and regulations in terms of restrictions and incentives [32]. Environmental, technical and economic parameters have an impact on the area of SEPP installation [33]. Certain conditions must be met in order for a SEPP to be established in a region. These conditions vary according to the purpose and region of the study. In order to determine the restriction regions in this research, five conditions specific to the researched location were used in the direction of the literature research [12]-[14], [32]. These conditions are listed below:

- Not to be proximate than 500 m to areas of settlements, prohibited and protection,
- Not to be proximate than 400 m to lakes and streams,
- Not to be in locations with a slope of more than 11%,
- Not to be in forest fields,
- Not to be proximate than 100 m to motorways.

It is also not correct to establish SEPP or any power generation facility in cultural and paleontological heritage sites or in their immediate surroundings. The work from the building state to the production stage of such facilities negatively affects these areas. At the same time, ignoring these locations will adversely impress the SEPP establishment period. Therefore, the SEPP installation is not allowed in these areas [34]. Considering the determined criteria, a separate buffer zone analysis was carried out for each parameter. Thus, restriction fields were defined and these fields were united in the second step. In this unitization process; if an area is restricted in terms of any criteria, it is considered to be restricted in terms of other criteria. Then, the process of determining the suitability degrees for the areas deemed suitable was started.

3.2. Criteria Specification

The experiences gained so far in choosing a suitable place have led to the formation of some criteria [32]. In this research, as a result of the literature and field work, certain factors such as solar radiation, slope, proximity to PDCs, land use, proximity to fault lines, lithology, proximity to stream, lake and road line, aspect and proximity to residential areas were used and the suitable fields where SEPP will be established have been determined. It is possible to see ducks and many bird species in Hersek Lagoon located in Altınova district of Yalova and separated from the Marmara Sea by a narrow coastline [35]. Hersek Lagoon, which is the habitat of 206 bird species and is on the migratory bird route, in the analysis, it was evaluated within the distance to the lake parameter due to the fact that it remains on the edge of the research area, and proximity to the emigration ways factor is not evaluated owing to the migratory bird route passes through the shore of Lake Iznik [36].

Modeling, achievement survey and design of solar power systems adhere data of solar radiation [2], [37]. The most vital parameter for the performance of systems working with solar power is the radiation reflected in that area. For this reason, information of solar radiation was utilized as a criterion in research, and the map of solar radiation utilized is presented in Figure 2a.

One of the most vital parameters in determining the location of SEPPs is the slope criterion. Generally, regions above 11% are considered unsuitable. A slope of 4% or less is considered quite suitable. Efficiency may be affected as excessive inclination will cause the solar panels to dark each other. In addition, the rise of slope raises the establish price of the SEPP [12]. The slope input of the research field was created from the numerical elevation pattern of the area. The produced inclination map is parted into 5 grades (Figure 2b).

The distance to PDC is an important economic factor. As the act far from the head, the transfer of the generated electricity to the centers will be more cost. In the studies, it is not desired that the distance of the areas where the facility will be established to the PDCs exceeds 10 km [38]. The distance from the PDC to the research field was assessed under five grades (Figure 2c).

Land use refers to settlements and locations of restricted and protected. SEPPs are required to be at a certain distance from these areas. Because the settlements are growing day by day. In the long term, there is a possibility that SEPPs will remain within these areas. Since the establishment of SEPP will affect the wildlife there, facility should be at a definite space from the conservation regions. In addition, land use is an important criterion, because the natural vegetation in the area to be selected for the SEPP can increase shading and this can reduce productivity. In this respect, areas covered by trees, maquis, bushes and reeds, where natural vegetation can create an obstacle, are not primarily preferred in site selection. In addition, cleaning these areas causes additional costs [32]. Therefore, it is generally accepted that SEPPs should be located at distance greater than 500 m from these zones. In the research land use was examined in 9 grades, namely heathland, lakes, chestnut, pasture, forest, farming area, non-farming area, olive grove and meadow [39]. The land use map of the research field is shown in Figure 2d.

Regions that are earthquake-prone should not be decided in site selection for SEPP installation. When approaching active faults, it is inevitable that the earthquake effect will increase. Therefore, the information of fault line was procured by numerical the map of Fault proffered on the MTA General Directorate web area [40], [41] and total five dissimilar tampon space were built at 2500 m gaps (Figure 2e).

One of the parameters used in the determination of installation site alternatives is the lithological structure of the land [38]. The lithological structure of the field where the SEPP will be established directly affects the structure cost [41]. Moreover, the ground must be suitable for hammer mounting systems. The lithological units outcropping in the research area are listed stratigraphically from the oldest to the youngest as follows: Precambrian gneiss and schists (gsa), Precambrian-Palaeozoic schists (s), Cambrian-Ordovician schist and phyllite (s1), Permian marble (mr), Permian-Triassic terrestrial detritics (pt), Upper Cretaceous meta detritics and meta carbonates (f) with detritics and carbonates (k2s), Paleocene-Eocene detritics and carbonates (pn2e), Eocene granitoid (?7) and unallocated volcanites (en), Miocene terrestrial detritics (m2-3) and Upper Miocene terrestrial detritics (m3pl). Quaternary unallocated alluvium (Qal) is the youngest member of the research field [40]. Alluvium, due to its uncemented granular unit feature and its unallocated nature in the research field, it can be convenient for SEPP installation on condition that the fitting system with hammered is applied and the framework is reducted under the alluvium. Elsewise it will not be safe for SEPP installation. Carbonate units, on the other hand, require detailed field work in the SEPP installation, as they are suitable for the formation of karstic structures. Other lithological units in the research area, especially units containing volcanic rocks, provide a suitable environment for SEPP installation. The lithological map of the research field is seen in Figure 2f.

Due to conditions such as seasonal changes in rivers, possible floods, increase in flow and displacements in the river bed, the distance factor to the streams is between the major elements affecting the selection of SEPP construction sites. SEPPs should be at least 400 m far from streams in order to prevent SEPPs from being affected by floods and to provide easy access to the energy facility [8]. The closeness to the stream factor regarding the researches field was handled under 5 grades (Figure 2g).

Due to the fact that the lake volumes change at different times of the year, it is requested that the SEPPs should be at least 400 m away from the lakes in order to prevent environmental pollution and for the safety reasons to be taken against the negative effects of the floods to be experienced because of the lakes. The proximity to lakes regarding the researches field was evaluated under 5 grades (Figure 2h).

Being close to the roads at the first installation of the SEPP plant ensures low cost in infrastructure works. In addition, since there will be no need to open new roads for transportation purposes, also prevents possible damages that may result in damage to the surrounding lands [38]. However, since the wastes caused by vehicle traffic passing will unfavorable impress the panels and cause serious problems in terms of safety. It has been accepted in the literature that SEPPs should be distance than 100 m to the ways [8]. The proximity parameter to the roads regarding the research field was assessed under 6 grades (Figure 2i).

Aspect is very essential factor for SEPP. On the locations of SEPP will be formed, fields with no elevations to shade between south, west and east directions should be determined. Flat and southern fields are convenient for selection of SEPP sites. South oriented locations supply plentiful sun angle [34]. The aspect map of the research field has been handled in a way a total of 10 grades, ranging from -1 to 360 degrees (Figure 2j).

The produced energy transmission by SEPP to distant depletion areas cause loss of energy. Energy loss in transmission also reduces efficiency. For this reason, locations that are too far from residential areas, industry and working areas should not be preferred for SEPP field choice [32]. However, it is also obligatory to consider the possibility of SEPPs staying in the middle of residential lands eventually [8]. Therefore, in this research, the proximity to lands of residential has been assessed under 5 grapes (Figure 2k)

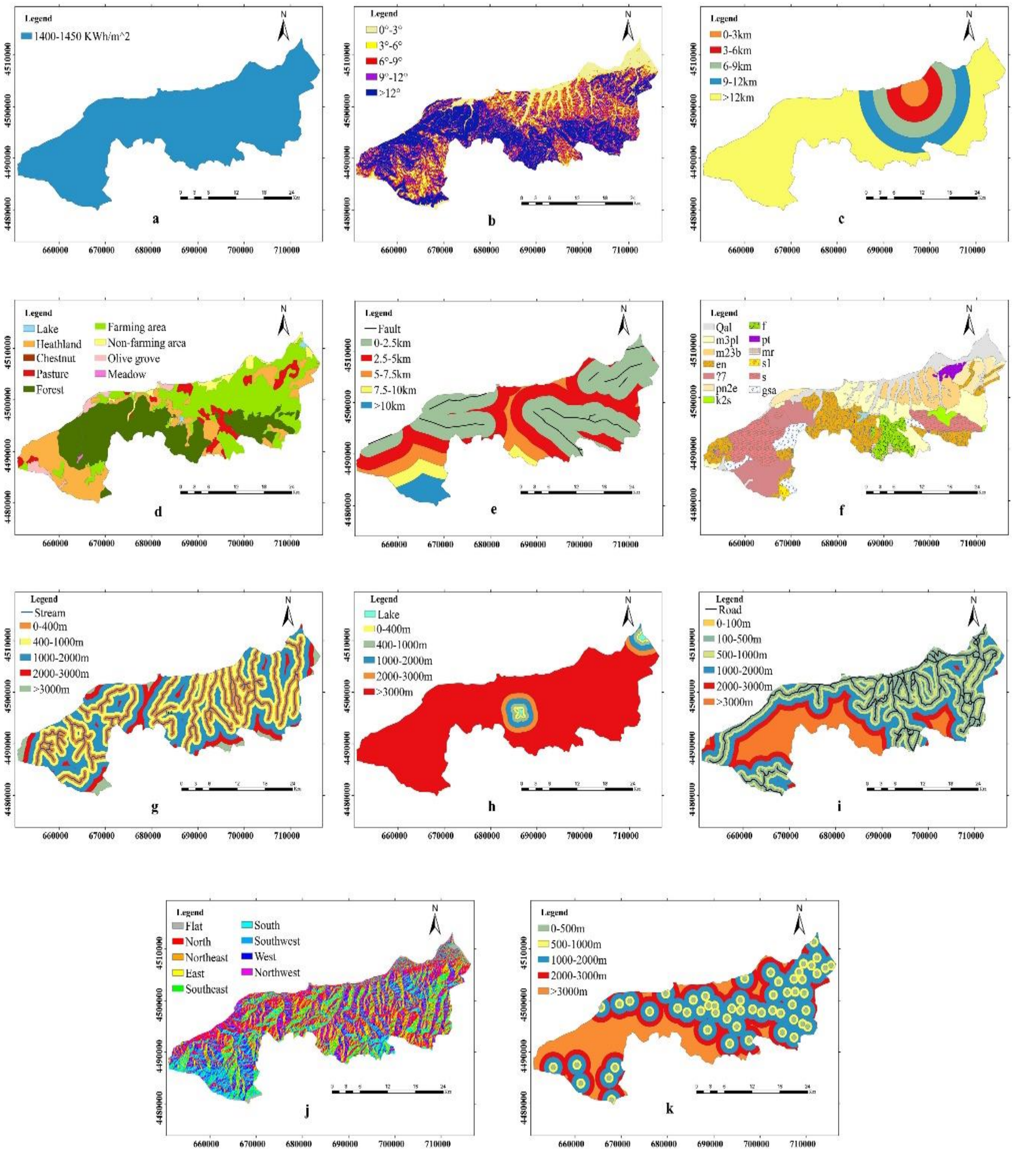

Figure 2. The criteria. a radiation, b slope, c closeness to PDCs, d land use, e closeness to fault line, f lithology, g closeness to stream, h closeness to lake, i closeness to road line, j aspect and k closeness to residential locations

3.3. Method of the Research

3.3.1 Fuzzy Logic and Fuzzy Decision Making

Fuzzy logic can be applied in situations where uncertainty exists or optimal decisions need to be reached with incomplete information. Decision making is the definition of the option or options that are determined to give the most suitable result by evaluating all aspects of one or a series of problems that must be solved at every management level [43]. Uncertainty in decision processes may also arise from the presence of verbal information and may occur in models involving subjective thoughts. In this case, eliminating the uncertainties or accepting the existence of uncertainty and adapting the analysis accordingly provides more effective results.

Analytical solution analyze with fuzzy logic supply a more flexible determination environment to the decision maker. By applying fuzzy logic, the verbally put forward information is inclusive in the resolution by acquiring its scalar provisions. Survey results and personal opinions into the model, cause the best solution to diverge to the change in the defendant personal. In this case, the decision accepted as optimal may change in the next application, or even if the decision maker remains the same, changing in the judgments of the experts whose opinions are taken may affect the suitable determination [44]. Moreover, the assessments acquired may not always include certain and fulfill knowledge. In such determination samples, analyzes can be applied with approach of fuzzy logic. In determination matters assessed by fuzzy logic, it is purposed to arrive the "best" determination that is not fuzzy as in usual matters. But the determination handled as a result of fuzzy theory does not claim to be an optimal decision and goals to indicate in which possibility each vary choice can be suitable [45]. Samples of Fuzzy were put forward as a different way by Zadeh [46] because there are certain and stable regulations in the demands and quantifiability of factors in numerical models. Fuzzy logic, which has gained increasing importance since this date, is identified as a certain array founded for the term of uncertainties and working with uncertainties [45].

3.3.2 Fuzzy Multiple Criteria Decision Making (FMCDM)

In the actual applications of MCDM models, it is seen that decision makers verbally state their judgments. AHP, one of the MCDM methods, founded pairwise matchings. Comparison weights should be treated neutrally, thinking how much more one major option is than the other. The subjective remarks are seen as a benefit of the AHP, apart from the criteria that can be measured quantitatively [47]. This individuality makes the results inadequate. In this case, the FAHP application is preferred. FAHP was first advertised by Laarhoven Van and Pedrycz [48]. In the research decisions and impacts are stated with numbers of triangular fuzzy. Buckley [17] used fuzzy logic in the normal equations of weights and suggested that a sole remedy cannot always be achieved in the study of [48] and they practiced with numbers of trapezoidal fuzzy based on the numerical process of fuzzy numbers. Their research [17] used fuzzy numbers to specify the emphasis classes of nuclear energy, hydroelectric energy, fossil energy and solar energy. In the after periods, many works have been performed, especially in industry and production in which the comparison scale was taken as fuzzy. Unlike these, Lee et al. [49] begun the notion of interspace for pairwise comparisons and they introduced a new method based on probabilistic optimization for consistency and fuzzy collations. Zhu et al. [50], further advanced the method developed by Chang [18] using synthetic grades and they introduced their new methods by applying oil exploration for China under nine main criteria and fifteen blocks determined. Kahraman et al. [51], compared three catering companies under three main elements and eleven sub-elements using FAHP. Csutora and Buckley [52], used a fuzzy comparison matrix, taking payment, benefits, placement, co-workers and promotion opportunities as criteria for new graduates' job selection. Kwong and Bai [53], established the FAHP model on the quality function expansion regarding production planning. They identified customer demands with FAHP and solved three main criteria and seven sub-criteria and nineteen second-degree sub-criteria models to ensure customer satisfaction. Enea and Piazza [54], in them research to select the best one out of three project alternatives, under four criteria, stated that they achieved more realistic results by applying FAHP. Mikhailov and Tsvetinov [55], in a problem with three alternatives with three main elements and six sub-elements, specified the optimal service provider using FAHP, and compared the results with the classical AHP results. Çanlı and Kandakoğlu [56], developed a model by applying FAHP in air power comparison. Firstly, in FAHP the question is stated in a hierarchical quality [57]. Secondly a scalar contact is founded among the aim and the parameters. In this research, geometric mean method [17] and the Extended Analysis Method [18] have been practiced.

In Table 1 the triangular fuzzy scale performed in research has been established.

Table 1. The scale of fuzzy AHP pair-wise comparison [58]

Fuzzy triangular	Reciprocal fuzzy	Definition
(1, 1, 1)	1, 1, 1	Equally important
(1, 2, 3)	1/3, 1/2, 1/1	Mediate amount between 1 and 3
(2, 3, 4)	1/4, 1/3, 1/2	lightly significant
(3, 4, 5)	1/5, 1/4, 1/3	Mediate amount between 3 and 5
(4, 5, 6)	1/6, 1/5, 1/4	Significant
(5, 6, 7)	1/7, 1/6, 1/5	Mediate amount between 5 and 7
(6, 7, 8)	1/8, 1/7, 1/6	Severely significant
(7, 8, 9)	1/9, 1/8, 1/7	Mediate amount between 7and 9
(8, 9, 9)	1/9, 1/9, 1/8	Highly significant

After the fuzzy synthesis figures are deliberated, these figures are matched to each other and the preference figures of the parameters are set. With the normalization of the vector, the exact preference vector is achieved.

4. Application

The literature review conducted shows that the choice of the parameters to be handled in MCDM issues in the renewable energy area also requires the method to be used [59]. The common feature of decision-making issues is uncertainty, and FAHP allows decision-performers to state own choices in proximate or proper practices [60,61]. Moreover, usual MCDM practices cannot sufficiently show the uncertainty of human thinking [62]. Researches on renewable energy sources are very valuable for urban energy planning [63]. Hereby the FAHP method was practiced in this research. The fuzzy number equivalents of the linguistically expressed criteria were determined by the specialists and literature review, and the pairwise comparisons of the criteria obtained with the specialists and literature review opinions are shown in the pairwise comparison matrix given in Table 2.

Table 2. Pairwise comparison matrix for FAHP (a radiation, b slope, c closeness to PDCs, d land use, e closeness to fault line, f lithology, g closeness to stream, h closeness to lake, i closeness to road line, j aspect and k closeness to residential locations)

	a	b	c	d	e	f	g	h	i	j	k
a	1 1 1	1 2 3	2 3 4	7 8 9	7 8 9	6 7 8	6 7 8	6 7 8	5 6 7	2 3 4	6 7 8
b	1/3 1/2 1	1 1 1	1/4 1/3 1/2	1 2 3	5 6 7	3 4 5	4 5 6	4 5 6	3 4 5	2 3 4	4 5 6
c	1/4 1/3 1/2	4 3 2	1 1 1	3 4 5	7 8 9	5 6 7	6 7 8	6 7 8	4 5 6	1 2 3	5 6 7
d	1/9 1/8 1/7	1/3 1/2 1	1/5 1/4 1/3	1 1 1	4 5 6	3 4 5	3 4 5	3 4 5	2 3 4	1/5 1/4 1/3	3 4 5
e	1/9 1/8 1/7	1/7 1/6 1/5	1/9 1/8 1/7	1/6 1/5 1/4	1 1 1	1/3 1/2 1	1/3 1/2 1	1/3 1/2 1	1/4 1/3 1/2	1/6 1/5 1/4	2 3 4
f	1/8 1/7 1/6	1/5 1/4 1/3	1/7 1/6 1/5	1/5 1/4 1/3	1 2 3	1 1 1	1/4 1/3 1/2	1/4 1/3 1/2	1/3 1/2 1	1/5 1/4 1/3	1 2 3
g	1/8 1/7 1/6	1/6 1/5 1/4	1/8 1/7 1/6	1/5 1/4 1/3	1 2 3	2 3 4	1 1 1	1 1 1	1/4 1/3 1/2	1/4 1/3 1/2	1 2 3
h	1/8 1/7 1/6	1/6 1/5 1/4	1/8 1/7 1/6	1/5 1/4 1/3	1 2 3	2 3 4	1 1 1	1 1 1	1/4 1/3 1/2	1/4 1/3 1/2	1 2 3
i	1/7 1/6 1/5	1/5 1/4 1/3	1/6 1/5 1/4	1/4 1/3 1/2	2 3 4	1 2 3	2 3 4	2 3 4	1 1 1	1/7 1/6 1/5	3 4 5
j	1/4 1/3 1/2	1/4 1/3 1/2	1/3 1/2 1	3 4 5	4 5 6	3 4 5	2 3 4	2 3 4	5 6 7	1 1 1	3 4 5
k	1/8 1/7 1/6	1/6 1/5 1/4	1/7 1/6 1/5	1/5 1/4 1/3	1/4 1/3 1/2	1/3 1/2 1	1/3 1/2 1	1/3 1/2 1	1/5 1/4 1/3	1/5 1/4 1/3	1 1 1

The fuzzy weights and weights for the criteria used the geometric mean practice proposed by Buckley [17] are given in Table 3.

Since the extent analysis practice that will be applied, needed to work the worth of fuzzy synthetic extent as far the i th factor [18] shown in Eq.1. S_i are synthetic extent value and $M_{g_i}^{j}$ are triangular fuzzy numbers in Equation 1.

$$S_i = \sum_{j=1}^{3} M_{g_i}^{j} \odot \left[\sum_{i=1}^{7} \sum_{j=1}^{3} M_{g_i}^{j}\right]^{-1} \quad (1)$$

where all the $M_{g_i}^{j}$, j=1,2,3 are triangular fuzzy numbers located in Table 2.

$$S_1 = (49{,}59{,}69) \odot \left(\frac{1}{318.10}, \frac{1}{257.43}, \frac{1}{201.57}\right) = (0.154{,}0.229{,}0.342)$$

Table 3. The fuzzy weights and weights for the criteria in accordance with Buckley (1985) [17] practice

i	Factors	Fuzzy weights ($\tilde{w}_i$)	Weights (w_i)
1	Radiation	0.176; 0.270; 0.420	0.270
2	Slope	0.086; 0.140; 0.239	0.145
3	PDC	0.136; 0.199; 0.298	0.197
4	Land Use	0.049; 0.076; 0.128	0.078
5	Closeness to fault	0.014; 0.023; 0.039	0.023
6	Lithology	0.015; 0.026; 0.046	0.027
7	Closeness to river	0.021; 0.033; 0.055	0.034
8	Closeness to lake	0.021; 0.033; 0.055	0.034
9	Closeness to road	0.030; 0.048; 0.081	0.049
10	Aspect	0.069; 0.131; 0.193	0.122
11	Closeness to residential fields	0.012; 0.020; 0.035	0.021

The triangular membership function is defined with three parameters. If these parameters are taken as l, m, and u, the equation of the triangular membership function is given below [18].

$$V(S_i \geq S_j = \begin{cases} 1, & if\ m_i \geq m_j \\ (\dfrac{u_, - l_j}{u_i - m_i) + (m_j - l_j)}, & if\ l_j \leq u_i \\ 0, & Others, \end{cases}$$

The fuzzy synthetic extent figures and normalized weights for the factors are seen in Table 4.

Table 4. The fuzzy synthetic extent figures and weights for the factors are in accordance with Chang (1996) [18] practice

i	Factors	Synthetic extent values ($\tilde{S}_i$)	Weights (w_i)
1	Radiation	0.154, 0.229, 0.342	0.37
2	Slope	0.087, 0.139, 0.221	0.16
3	PDC	0.133, 0.192, 0.280	0.28
4	Land Use	0.062, 0.101, 0.163	0.09
5	Closeness to fault	0.015, 0.026, 0.047	0.00
6	Lithology	0.015, 0.028, 0.051	0.00
7	Closeness to river	0.022, 0.040, 0.069	0.00
8	Closeness to lake	0.022, 0.040, 0.069	0.00
9	Closeness to road	0.037, 0.067, 0.111	0.00
10	Aspect	0.075, 0.121, 0.193	0.10
11	Closeness to residential fields	0.010, 0.016, 0.030	0.00

5. Results and Discussion

As a result of the weighting made with FAHP, the parameter of radiation has the ultimate weight, then, it was calculated that this was followed by the closeness to the PDCs, slope, aspect, land use, closeness to road line, stream and lake, lithology, closeness to fault line and residential fields. Thinking the weights of the criteria calculated with FAHP, the maps in Figure 2 were unified and the restricted lands were distracted from this map and the optimal SEPP sites map was handled for the research field (Figure 3).

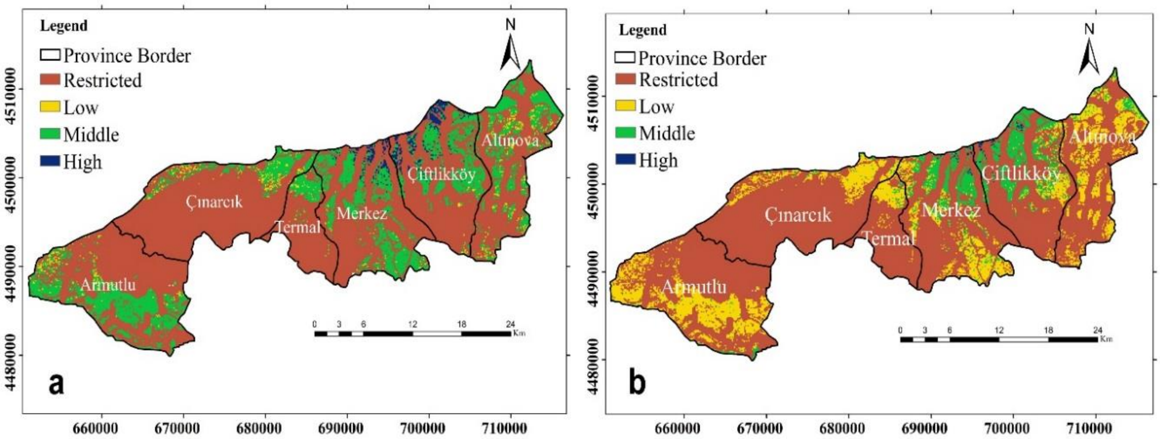

Figure 3. Susceptibility map generated for SEPPs sites. a. the geometric mean practice by Buckley [17], b. the extent analysis practice by Chang [18]

This resulting map obtained is expressed with four values as restricted, low, middle and high. The susceptibilities obtained as a result of the analyze performed are found as in Table 5.

Table 5. Percentage and area values of susceptibility

Susceptibility	Geometric mean practice by Buckley (1985)		Extent analysis practice by Chang (1996)	
	%	km^2	%	km^2
Restricted	72.84	601.66	72.84	601.66
Low	2.17	17.92	19.34	159.75
Medium	23.34	192.79	7.59	62.69
High	1.65	13.63	0.23	1.90

21.41% of the research area is covered by Armutlu district, 21.16% by Çınarcık district, 6.70% by Termal district, 18.63% by Central district, 16.45% by Çiftlikköy district and 15.65% by Altınova district. When the produced SEPP conformity map is considered on the basis of districts, while high suitability was observed in Çiftlikköy and Central districts, the most unsuitable value was obtained in Çınarcık and Armutlu districts (Table 6). The fact that Çınarcık district has dense forests has reduced the potential of receive sunlight. Since Armutlu district is deemed suitable for the installation of wind energy facilities [30], district is currently considered as another renewable energy type wind facilities area.

Table 6. SEPP compliance level values of Yalova districts

District	Restricted (%)		Low (%)		Middle (%)		High (%)	
	Buckley (1985)	Chang (1996)	Buckley (1985)	Chang (1996)	Buckley (1985)	Chang (1996)	Buckley (1985)	Chang (1996)
Armutlu	20.31	20.31	23.93	26.26	26.11	2.98	0.00	0.00
Çınarcık	25.19	25.19	25.62	10.80	9.67	2.67	0.00	0.00
Termal	7.61	7.61	6.38	12.76	4.36	3.84	0.00	0.00
Central	17.15	17.15	5.58	16.26	23.45	32.05	32.81	30.40
Çiftlikköy	15.39	15.39	3.89	8.18	17.32	49.95	67.19	69.60
Altınova	14.35	14.35	34.60	25.74	19.09	8.51	0.00	0.00

In our research, the results have been compared with various recent studies in the literature concerning the criteria employed and their respective weights [64,65,66].

Arca and Keskin Citiroglu [64] have produced the most suitable areas for SPP in Karabük using Geographic Information Systems (GIS) and Analytical Hierarchy Process (AHP). In their studies, they utilized the following factors: solar radiation, slope, aspect, distance to the road, distance to the river, distance to fault lines, lithology, land use, distance to settlement areas, and distance to PDCs. For all the models the most effective factors were determined as solar radiation, distance to PDCs and slope. Colak et al. [65] applied the Analytical Hierarchy Process method to calculate the weights of the 10 evaluation criteria. Solar energy potential was identified as the most critical factor, accounting for 22% of the weight in the areas suitable for Solar Power Plants (SPP). The land cover was ranked as the second most significant factor with a weight of 20%, followed by the aspect, which held the third most important position with a weight of 14%. The distribution of criterion weights in these two studies is similar to our study. Demir [66] used GIS Analyses and the AHP Method to identify areas with the potential for solar power plant installation in the Kars province. The study utilized 7 parameters, which included solar radiation, temperature, land slope, aspect, land cover and use, distance to energy transmission lines, and distance to road transportation network. In the study, the most effective factors were determined to be land cover and use, aspect, and distance to energy transmission lines. However, the distribution of criteria weights in our study differs from that in this work.

6. Conclusion

MCDM methods and GIS are tools that allow choosing the optimum option among different choices in location choice works. One of the frequently preferred decision making methods in fuzzy sets is FAHP. In this research, different FAHP approaches were used in GIS environment to assess the sites where SEPP can be installed in Yalova. Since the outcomes of the study are immediately related to the determinate parameters, eleven different criteria were used in research. FAHP should be choosen to ahead of state oral ambiguity in the process of making resolution by pairwise comparison, so that determine the importance of one parameter with regard to another parameter by the decision-maker. It is advised to apply the FAHP practice, in case of the high number of pairwise comparisons, fuzziness in the mind of the decision maker, and in cases where transactions take too long. Extended Analysis Method selects the very small weights of the criteria as zero and eliminates some values that may actually have a significant effect when calculating the result by combining the weights of the criteria. For example, if we look at the normalized weights of the main parameters, the weight of the "lithology" parameter, which takes a very small value compared to the geometric mean method, is taken as zero by Extended Analysis Method. As one of the results of this research, we can say that it is more appropriate to use Extended Analysis Method with a different sorting method.

For numerical statements of oral significations in social, economic and environmental factors and sub-factors, concretion with fuzzy connection is essential in achieving more certain outcomes. Utilizing SEPP to supply the energy necessities of Yalova province, which is close to major industrial cities such as Istanbul, Kocaeli and Bursa and has sea tourism opportunities, will contribute to the supply of both inexpensive, fresh, sustainable and renewable energy. The resulting SEPP convenience map can be utilized for anterior assessment for financiers. The center and east of Yalova province have sites convenient for SEPPs. With the increase of the criteria, it can be stated that investment areas can be determined much more precisely and contribution can be made to feasibility studies. It is hoped that the outcomes achieved from this research will support decision-makers in future research researches in field administration in the research field.

Contributions of the authors

D.A.: Investigation, Methodology, Visualization, Data curation, Conceptualization, Software, Formal analysis, Writing–review. H.K.C.: Supervision, Investigation, Methodology, Data curation, Original draft preparation and Editing.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics

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