Energy Strategy Reviews 51 (2024) 101307

Contents lists available at ScienceDirect

Energy Strategy Reviews

journal homepage: www.elsevier.com/locate/esr

Multi-criteria decision making for solar power - Wind power plant site selection using a GIS-intuitionistic fuzzy-based approach with an application in the Netherlands

Gökhan Şahin [a,*], Ahmet Koç [b], Wilfried van Sark [a]

[a] Copernicus Institute of Sustainable Development, Utrecht University, Princetonlaan 8A, 3584 CB, Utrecht, the Netherlands
[b] Dicle University, Vocational School of Technical Sciences, Park and Garden Plants Department, Diyarbakır, Turkey

A R T I C L E I N F O

Handling editor: Mark Howells

Keywords:
Ecological criteria
Geographical information systems (GIS)
Intuitionistic fuzzy
Multi-criteria decision-making
Solar power plant siting map
Wind power plant siting map
Solar-wind optimal siting map

A B S T R A C T

The development of a country cannot be realized only through the amount of energy it produces and its industrialization. In a country where its people are left homeless and poor, and its cultural and natural riches are destroyed, the electricity produced is not a measure of development on its own. Development and progress must be considered from a holistic perspective that includes the country's geographical structure, all its living creatures, culture, urban and social structure as a whole. In this respect, the transition to renewable energy is imperative. One of the most widely used renewable energies in the Netherlands is solar and wind energy. For these power plants, site selection is an important factor in reducing the installation cost of the wind and solar power plant and achieving maximum efficiency during operation. This paves the way for the study of a site selection problem. In this study, we first investigate possible locations for solar-wind power plant installation for 12 regions of the Netherlands, namely Noord Holland, Gelderland, Friesland, North Brabant, Drenthe, Groningen, Zeeland (Middelburg), Utrecht, Zuid Holland, Limburg, Over Ijssel and Flevoland, using GIS as a mapping method, and then apply a Intuitionistic fuzzy-based approach to the problem to obtain the optimal locations for both solar and wind energy. Furthermore, the results of two methods (GIS and Intuitionistic fuzzy-based approach) are compared to obtain more accurate results. The results show that 35317.2 km^2 is suitable for solar power plant and 34844.5 km^2 is suitable for wind turbine, but only 34875.8 km^2 is suitable for solar-wind power plan installation.

1. Introduction

The rapid development of technology and industrialization causes the rapid consumption of fossil resources, which are already limited and will be depleted in the future. Especially in our age, with the increase in the quality of life in cities, the demand for electrical energy is increasing even more. In meeting and producing this increasing energy type, fossil resources are now being replaced by economic and environmentally friendly renewable energy sources (RES) [1]. Considering the world electricity production, it is seen that renewable energy sources already have an important place. In 2022, 29.9 % of the total global electricity production is obtained from renewable sources, and nearly 40 % of that (12.1 % in absolute terms) is provided by photovoltaic (PV) solar power plants (REN21, 2023). In the Netherlands, in 2022 40% of total electricity production came from renewable sources [2], which has increased by 20 % compared to 2021. While the amount of electricity produced in 2022 did not change compared to 2021, electricity production from fossil sources decreased by 11%. Electricity production from renewable sources increased to 47 billion kWh, with 54 % from solar and 17 % from wind resources. This was largely due to increased capacity (solar +4 GW, wind +1 GW) and better weather conditions. Spatial potential analysis of solar PV has been performed recently. For instance Ref. [3], in their research on solar energy for a sustainable future in China focused on the rapid increase in electricity demand in China and revealed that solar resources and large amounts of land are widely available in the western and northern regions of China [4]. investigated the areas where solar farms can be established in the city of Cartegena, located in southeastern Spain, using Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA) methods [5]. worked on the identification of potential areas where solar farms

* Corresponding author.
E-mail address: g.sahin@uu.nl (G. Şahin).

https://doi.org/10.1016/j.esr.2024.101307
Received 4 September 2023; Received in revised form 28 November 2023; Accepted 10 January 2024

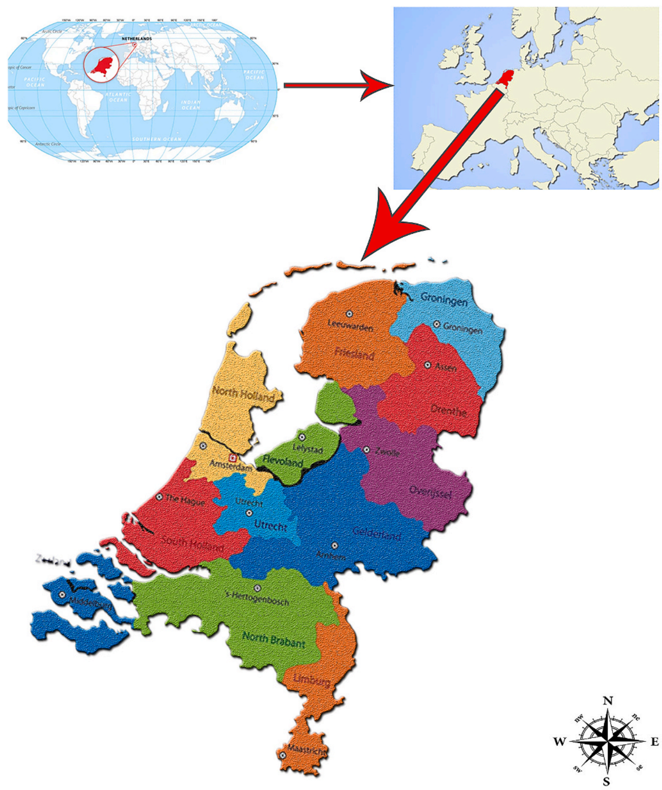

Fig. 1. Location of the Netherlands including the 12 provinces.

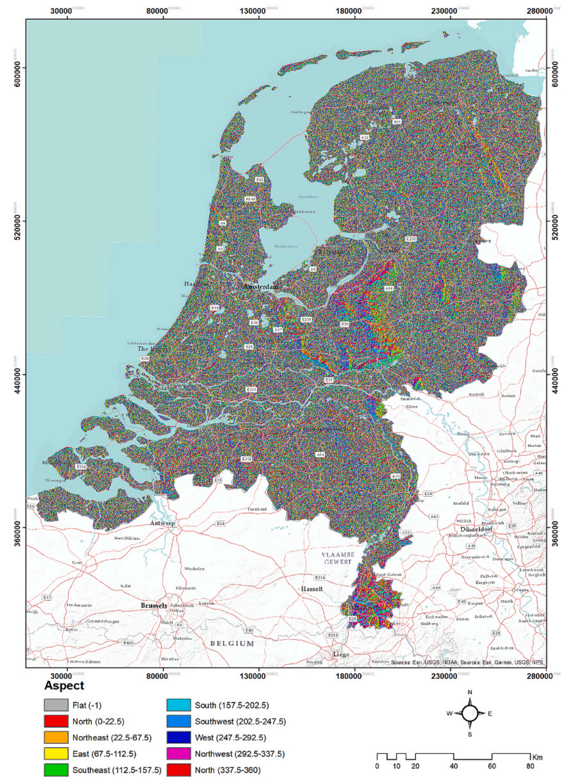

Fig. 3. The aspect map of the Netherland.

can be established in Ismailia Province, Egypt, using the shuttle radar topography task and multi-criteria decision analysis method. Recent studies by Refs. [6,7] focus on Dutch wind and solar PV power supply and these have resulted in the construction of geodatabases of spatially resolved scenario-specific, hourly onshore and offshore wind power generation profiles at an individual turbine level, as well as generation profiles for several categories of building-bound, land-bound and water-bound PV. The scenarios used were so-called eneryg transition scenarios for 2030 and 2050. These studies focus on system level location potential, less on actual local suitable areas. Some kind of decision making support process must be used to find optimal locations, taking into account many aspects, such as land-scape integration, availability of grid infrastructure etc. We propose a method based on fuzzy systems.

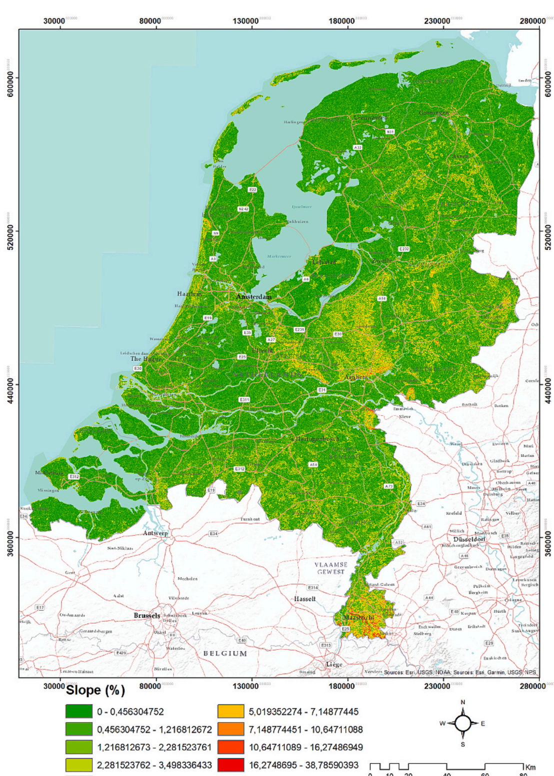

Fig. 2. The slope map of the Netherlands.

[8] investigated the suitability of Korea's Ulleung Island for solar farms using GIS in combination with fuzzy sets. This allows to support and analyse decision-making processes [9]. stated that while systems in engineering and other branches of science are modeled according to the principles of precise mathematical methods, a new way is sought for solving problems due to the uncertainty of decision-making processes. It is defined as creating decision systems that can use and make choices according to the situation [10]. describes the concepts of fuzzy logic, such as that the definitions containing "a little", are not fully understood among people. It is defined as ensuring that logic processes are executed more successfully than computer systems [11]. defined the concept of Intuitive Fuzzy Set (IFS) as a generalization of the concept of fuzzy set in his study. The first information about the concept of fuzzy and its principles was put forward by Lütfi [12]. [13] proposed the first application in fuzzy regression with their study in 1982. The analysis was performed using linear programming technique [14]. stated in their study that the linear fuzzy regression model is a more appropriate method [15]. in his study explained the fuzzy regression model developed by fuzzy logic and fuzzy logic [16]. proposed a fuzzy regression method that explains the blurring that may occur when blurring due to human judgment is not taken into consideration in the methods for subjective image quality assessment (IQA) [17]. proposed the FPC operator used for constraints in a mathematical programming problem to formulate fuzzy linear regression models with fuzzy parameters using fuzzy observations [18]. studied the elements of heuristic fuzzy sets that have a membership degree and a non-membership degree whose sum is

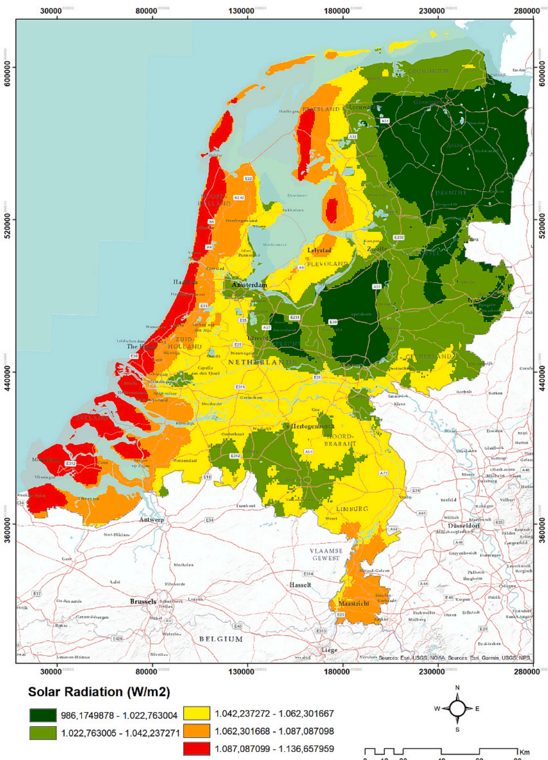

Fig. 4. The map for solar irradiance of the Netherlands.

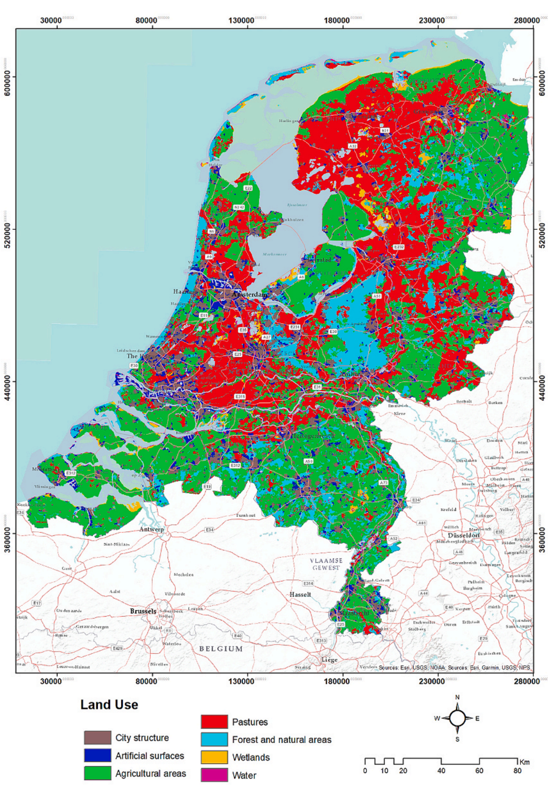

Fig. 5. The map of land use of the Netherlands.

less than or equal to 1. Intuitive fuzzy interpretations of multi-person and multi-criteria multi-criteria decision making processes are discussed in several studies [19]; [20–24]. New method for dealing with multi-criteria decision making problems based on heuristic fuzzy sets

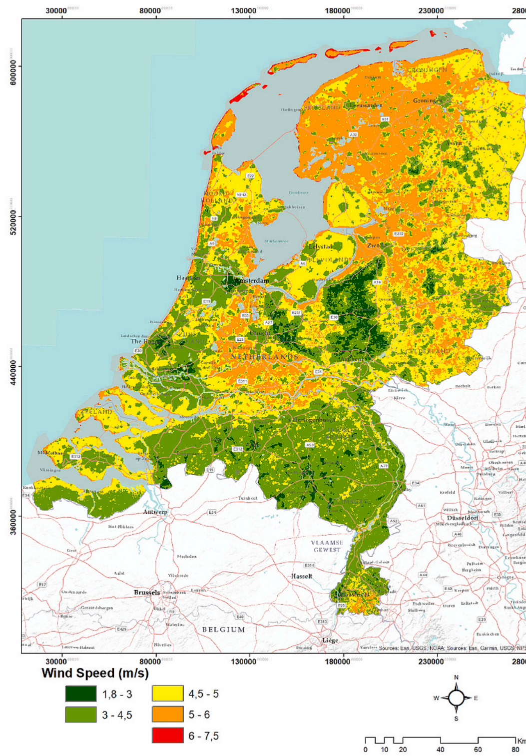

Fig. 6. The average wind speed of the Netherlands.

are reported [25–28]. This method allows the degree of availability and failure of each alternative according to the set of criteria expressed by Intuitionistic fuzzy sets.

Our research focuses on application of fuzzy sets in support of location deceision making for solar and wind plants, To the best of our knowledge, there are very few studies on the extensions of fuzzy sets due to computational complexity, and most of the researchers have been on type-1 fuzzy models. In our study, an intuitionistic fuzzy-based approach is used to support planning of solar and wind plants on optimal areas.

2. Background

This section introduces the fundamentals of the techniques used in this work including GIS as a mapping technique and intuitionistic fuzzy sets.

2.1. Mapping technique, GIS

Geographic Information Systems have been defined in different ways by different scientists. GIS has been defined as a system for acquiring, storing, controlling, processing, analyzing and displaying spatial data connected to the earth [29]. described GIS as an information system that stores, analyzes and displays spatial and non-spatial data, and [30] describes a database as a specialized information system that can contain spatially distributed attributes, activities or events that can be defined as points, lines, and areas in space [31]. defines GIS as a powerful set of tools for collecting, storing, retrieval, and displaying spatial data in the real world, and according to Ref. [32]; GIS is a tool that collects, stores, and controls geographic data around the world. It is a system that integrates, uses, analyzes and shows for the desired purpose [33]. Scientists who have done various studies on GIS in Turkey have also used different definitions of GIS. According to Ref. [34]; GIS is an information system that performs the functions of collecting, storing, processing and presenting graphical and non-graphic information obtained by location-based observations to the user in an integrated manner.

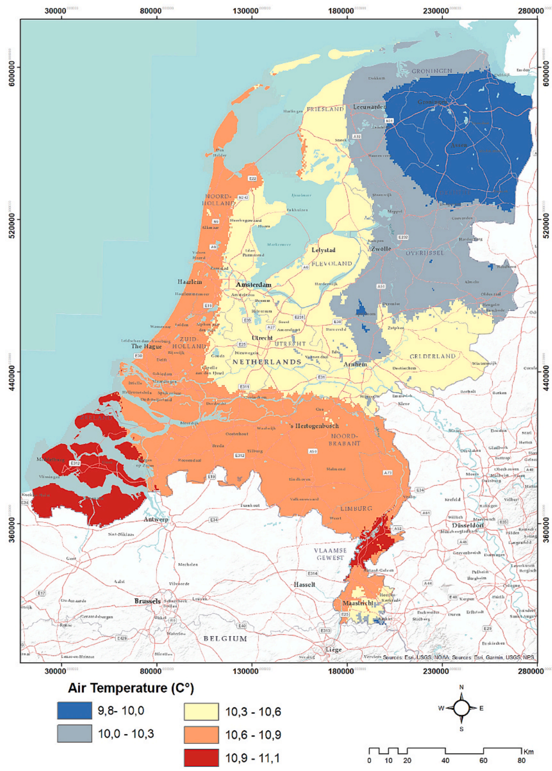

Fig. 7. The temperature map of the Netherlands.

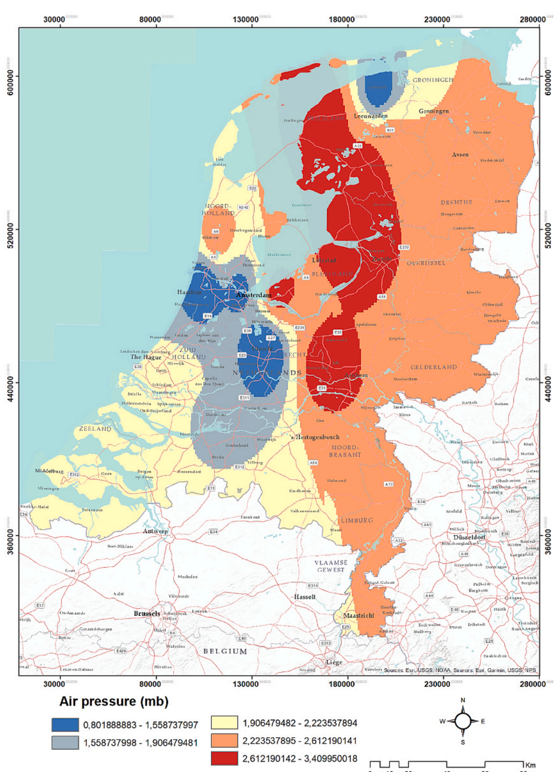

Fig. 8. The air pressure map of the Netherlands.

According to Ref. [35]. “GIS is a set of systems in which all kinds of data belonging to objects and events on earth are entered into the computer according to real coordinates and analyzed here and displayed in the form of maps, tables and graphics”. According to Ref. [36]; GIS is a

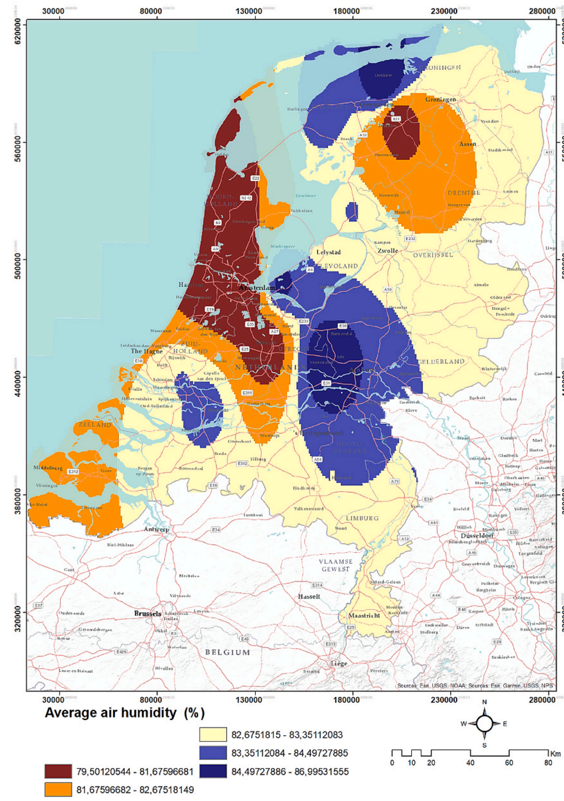

Fig. 9. The air humidity map of the Netherlands.

computer system that uses geographic data and performs various management and analysis tasks on data. According to another definition, GIS allows to enter any data with spatial characteristics (climate, vegetation, landforms, population, settlement, etc.) into a computer environment (digitization), to obtain new data by using the entered data, to use this data. questioning, arranging, analyzing, revealing their mutual relations with each other and the results obtained in graphics, maps, 3D images, etc. It is a computerized mapping system based on visualization [37,38]; Akturk et al., 2021). In this study, after the base maps were created, the result maps were created by giving class values separately for each usage map in the recclasify module in the Arc-GIS 10.8 package program to create wind maps, solar maps and wind + solar maps [9,39,40]. The data sequence and analysis in this model is shown in Fig. 15. While obtaining the base maps, slope, aspect, solar radiation and elevation maps were created in the Spatial Analysis module of the Arc-GIS 10.8 package program by combining 12 dem maps with a resolution of 12.5 m from the Alos Polsar satellite (https://asf.alaska.edu/datasets/daac/alos-palsar/). Wind speed and air temperature maps were obtained in dem format and created in the Spatial Analysis module of the Arc-GIS 10.8 package program ((https://globalsolaratlas.info/map)(https://globalwindatlas.info/en)). Unfortunately, satellite data were insufficient for the study area while creating air pressure and air humidity maps. For this reason, annual average humidity and pressure data of 28 different metrology stations within the borders of the Netherlands were obtained and processed on a point basis. Point data were converted into spatial data in the Geostatistical Analyst module of the Arc-GIS 10.8 package program. While creating surface temperature maps, surface temperature maps were obtained by using band 10, band 4 and band 5 data of Landsat 8 satellite and formulated in Arc-GIS 10.8 package program. In land use maps, CORINE level 3 maps were simplified to level 2 and digitized in Arc-GIS 10.8 program. Power lines and road lines maps were digitized from raster format in Arc GIS 10.8 program and distance coefficients were determined in Buffer module.

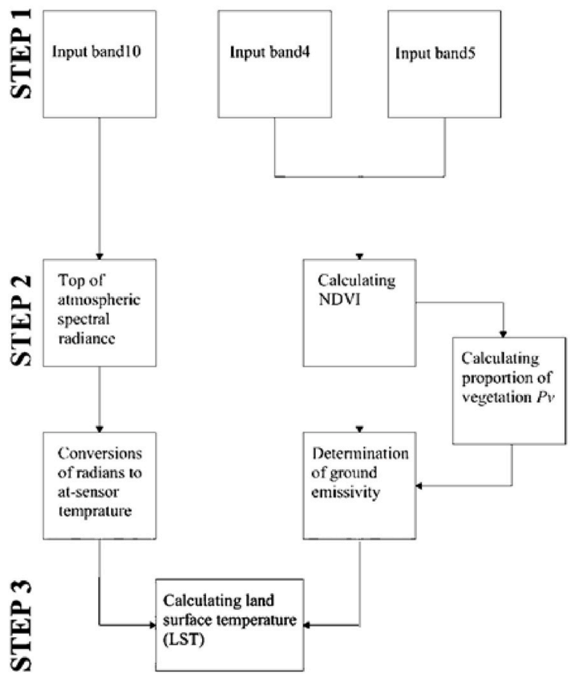

Fig. 10. Flowchart showing the stages of creating LST maps of the study area.

2.2. *Fuzzy set*

[12] was the first to propose the concept of fuzzy logic. Zadeh has shown that many concepts can be defined linguistically better than traditional mathematics, and fuzzy logic and its expressions in fuzzy sets constitute a better model of real life (Yildiz and Kişoğlu: 2014). In the classical set concept, an element with a characteristic function is either an element or not an element of a set. However, in the concept of fuzzy set, whether an apple belongs to a cluster or not is defined by a membership function that assigns a membership degree in the range [0,1] to each object [12,41].

Definition 1. Let X be a non-empty set and x ∈ X. Then for the function (x): X → [0,1]

μ_A (x), a fuzzy set A at X can be defined to show the membership degree of x; $A = \{(x, \mu_A(x)): x \in X\}$

In fact, every membership function is a function that returns the elements of a classical universal set to a number in the range [0,1].

2.2.1. *Intuitionistic fuzzy sets*

In the fuzzy set A, the degree of belonging of an element to the set is μ_A, while the degree of not belonging is 1-μ_A. Therefore, the sum of the degrees of belonging and not belonging is equal to 1. However, this situation is insufficient to explain the uncertainty in some problems. For this reason [11], proposed the Intuitionistic fuzzy set theory, which is the generalization of fuzzy set theory, see also [20].

Definition 2. Let X be a non-empty set and $x \in X$. So (x): X → [0,1] and ϑ_S:$X \to$ [0,1]

for two functions;

$$S = \{(x, \mu_S(x), (x)): x \in X\} \tag{1}$$

The set equation (1) is called the Intuitionistic fuzzy set. Here, (x) indicates the degree of belonging of the element x to the set S, while $\vartheta_S(x)$ indicates the degree to which the element x does not belong to the set S. Hesitation in a heuristic set; It is defined as $(x) = 1 - (\mu_S(x) + \vartheta_S(x))$. Therefore, equation (2) exists:

$$0 \le \mu_S(x) + \vartheta_S(x) \le 1 \tag{2}$$

A intuitionistic fuzzy set consists of intuitionistic fuzzy numbers, and a intuitionistic fuzzy number $\boldsymbol{\alpha}$ is defined as $\boldsymbol{\alpha} = (\mu_a, \vartheta_a)$. A score function can be used to rank the Intuitionistic fuzzy numbers (Chen and Tan, 1994). The score value of the Intuitionistic fuzzy number $\boldsymbol{\alpha} =(\mu_a, \vartheta_a)$ is calculated with $Score(\boldsymbol{\alpha}) = \mu_a - \vartheta_a$. The heuristic fuzzy number with a larger score value is larger.

The degree of hesitation ((x)) indicates the level of hesitation about whether an element x belongs to the set A. If the degree of hesitation is large, the belonging of that element to that cluster is relatively uncertain, and if the degree of hesitation is small, the status of belonging to that cluster is relatively more obvious. In decision-making methods, the collection of information and obtaining the results with the collected information constitute the basis. An arithmetic mean operator was developed by Ref. [42] for the collection of heuristic fuzzy data, that is, finding the mean values.

Definition 3. Let $\boldsymbol{\alpha}_i = (\mu_{ai}, \vartheta_{ai})$ (i = 1,2, …, n) be n intuitive fuzzy numbers. The arithmetic mean, where $w = (w_1, w_2, \ldots, w_n)$ is the weight vector of the given numbers, is defined as:

$$AM(\boldsymbol{\alpha}_1, \boldsymbol{\alpha}_2, \ldots, \boldsymbol{\alpha}_n) = \left(1 - \prod_{i=1}^{n} (1 - \mu_i)^{wi}, \prod_{i=1}^{n} \vartheta_i^{wi}\right) \tag{3}$$

According to the definitions given above, using heuristic fuzzy logic provides a flexible decision process in determining, for example, the financial performance of companies. In this study, we follow the proposed method by Das et al. (2014) using the following steps. In this study; $A = \{A_1, A_2, \ldots, A_m\}$ constitutes the set of alternatives, and $C = \{C_1, C_2, \ldots, C_n\}$ constitutes the set of criteria.

Step 1. Creating a Decision Matrix with "*n*" Criteria with "*m*" Alternatives

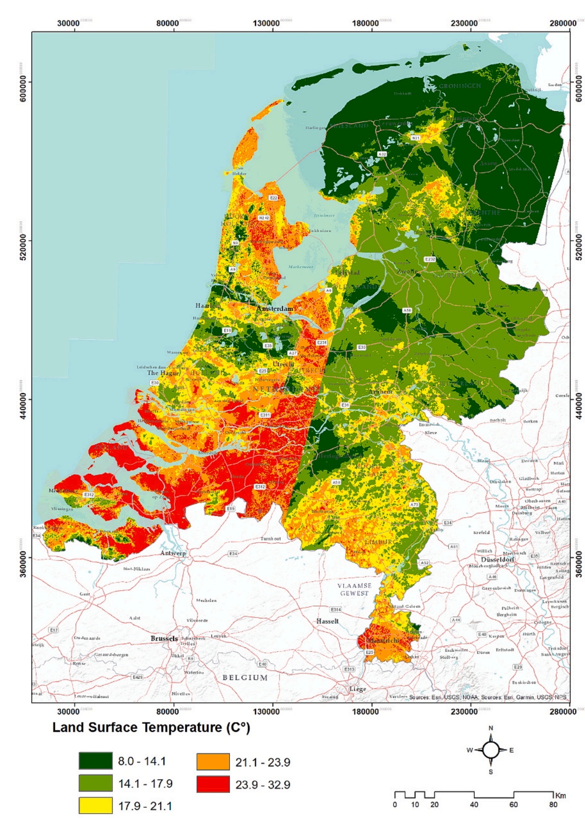

Fig. 11. The Land surface temperature (LST) map of the Netherlands.

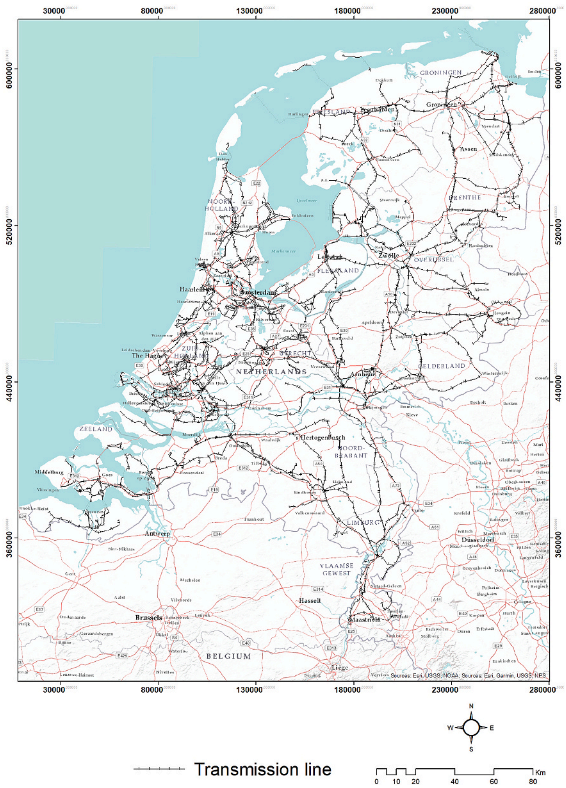

Fig. 12. The transmission lines in the Netherlands.

Fig. 13. Transportation network in the Netherlands.

For each alternative, data is collected, these data are evaluated linguistically, and these linguistic terms are transformed into heuristic fuzzy numbers to form a decision matrix (P).

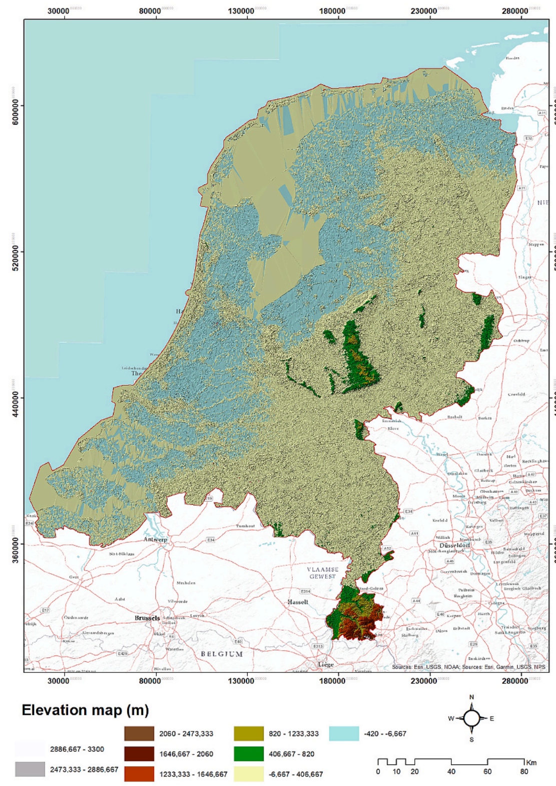

Fig. 14. The Elevation map of the Netherlands.

$$P = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{4}$$

Step 2. Calculating Criterion Weights

In multi-criteria decision making problems, the weight of each criterion is different. Some criteria may be more important, while others may be less important. In a decision process where the criteria weights are not completely known, the weight of each criterion can be calculated by following the steps given below. The entropy matrix (B) of the decision matrix (P) formed first is calculated with the help of equation (5) and is represented by the B matrix given below.

$$B = 1 - |\mu_A(x_i) - \vartheta_A(x_i)| \tag{5}$$

$$B = \begin{bmatrix} b_{11} & \cdots & b_{1n} \\ \vdots & \ddots & \vdots \\ b_{m1} & \cdots & b_{mn} \end{bmatrix}$$

Entropy refers to the disorder in the system as a word. An information measure of evaluation data using this concept can be defined by equation (6).

$$C(A) = 1–0.5(E(A) + \pi(A)) \tag{6}$$

The measurement matrix obtained with this measurement information is indicated by C.

$$C = \begin{bmatrix} c_{11} & \cdots & c_{1n} \\ \vdots & \ddots & \vdots \\ c_{m1} & \cdots & c_{mn} \end{bmatrix}$$

After constructing the C matrix, criteria weights (w_j) are calculated using equations (7) and (8).

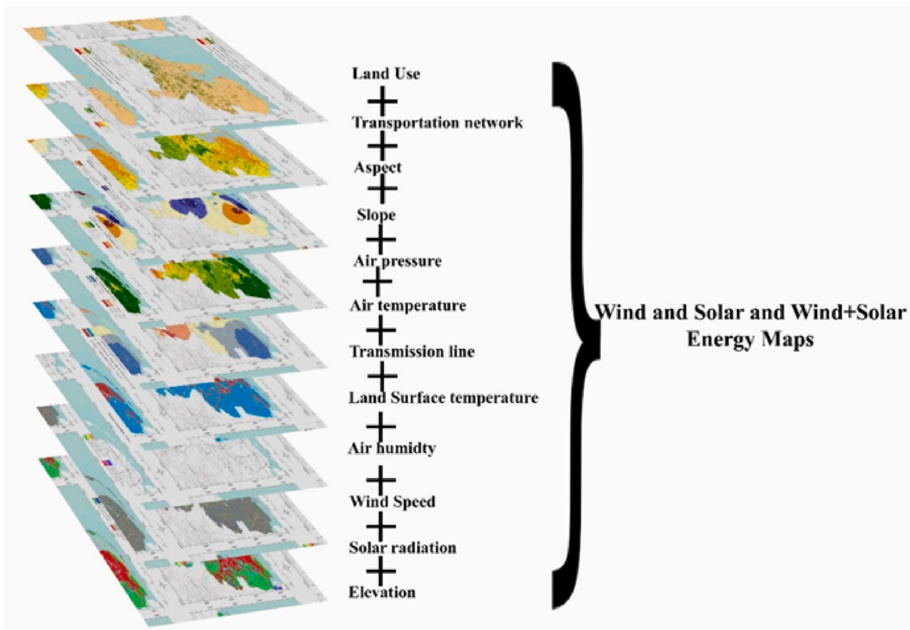

Fig. 15. Model created for study result maps (Turk et al., 2021).

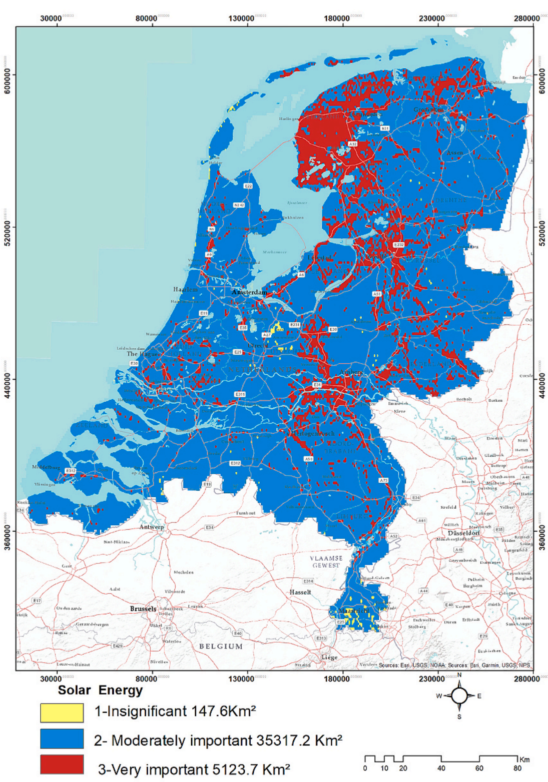

Fig. 16. The Netherlands solar energy map.

$$a_j = \sum_{i=1}^{m} k_{ij}, j = 1, 2, \ldots, \mathrm{n} \tag{7}$$

$$w_j = \frac{a_j}{\sum_{j=1}^{n} a_j} \tag{8}$$

Step 3. Build Weighted Average Values for Each Alternative

After calculating the weight of each criterion, the weighted average values $S_i = (\boldsymbol{\mu}_i)$ are calculated using equation (9).

$$S_i = \left(1 - \prod_{j=1}^{n} (1 - \mu_{ij})^{wj}, \prod_{j=1}^{n} (\vartheta_{ij})^{wj}\right) = (\mu_i, \vartheta_i) \tag{9}$$

Step 4. Ranking the Alternatives

After calculating the weighted average values, the score function defined by Chen and Tan (1994) can be used to find the score for each alternative. After calculating the scores of the alternatives, the alternative with the highest score means the best alternative.

$$\mathrm{S_{kor}}(S_i) = \boldsymbol{\mu}_i - \vartheta_i, i = 1, 2, \ldots, m \tag{10}$$

3. Methodology

This study focuses on identifying the solar and wind potential in the Netherlands. The country is located in the northwest of the European continent. It is surrounded by the North Sea to the north and west, Germany to the east and Belgium to the south. It has one of the highest population densities among EU countries. is the highest in Europe. It is the lowest country in Europe. 40% of its territory is below sea level. Tt is located between 51° and 54° north latitude and 3°–7° east longitude. The Netherlands has a warm and rainy oceanic climate. The aim of this study is to examine the 12 regions of the Netherlands - Noord Holland (A1), Gelderland (A2), Friesland (A3), Noord Brabant (A4), Drenthe (A5), Groningen (A6), Zeeland (A7), Utrecht (A8), Zuid Holland (A9), Limburg (A10), Overijssel (A11) and Flevoland (A12) - for the establishment of solar power plants and wind farms in the Netherlands. The alternatives were evaluated according to various criteria such as elevation, slope, land cover, aspect, aspect, slope, slope, geological rock type, solar radiation, air temperature, transmission line, wind speed, air pressure, air humidity, land surface temperature (LST) and transportation network using Arc-GIS mapping technique and Multi-Criteria Decision Making (MCDM), one of the heuristic fuzzy methods.

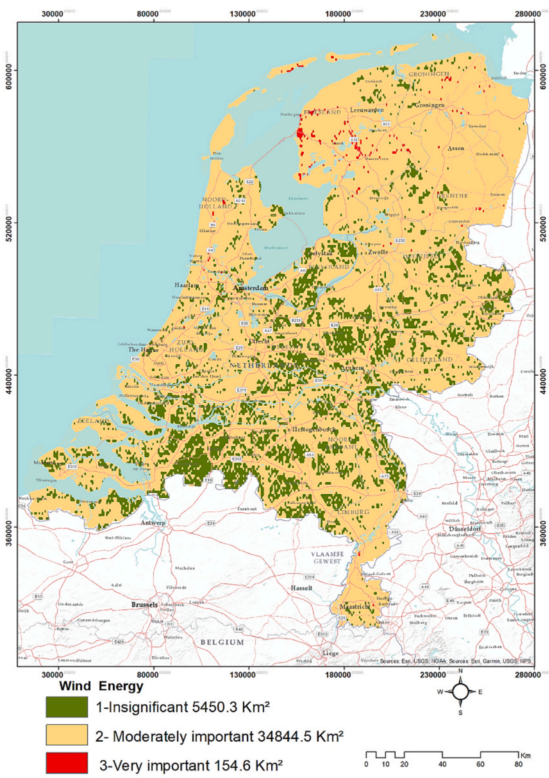

Fig. 17. The Netherlands wind energy map.

3.1. *Criteria for decision making*

We have determined 14 criteria for the optimum location of solar and wind power plants in the Netherlands, in line with the existing literature and expert opinion. These criteria are summarized below:

(C1) Slope: The slope characteristics of the topography are an important factor for RES installation (see Fig. 1). In wind power plant (WPP) suitable location selection, the slope should not exceed 20° as it causes problems in terms of transportation, installation and performance. Within the scope of the study, areas with a slope below 20° were determined as suitable for WPP site selection in terms of this criterion [43] Ozcan M.et al., 2017 [38]; Türket al. 2020; Turk et al., 2021, [44]. For the Netherlands, Fig. 2 shows the slope map. It is clear that the slope criterion is exceeded at a very low number of locations in the south-west (Limburg province) only.

(C2) Aspect: Aspect is the position of any place relative to the sun, also denoted to as orientation. It refers to the position of the slopes of the mountains relative to the sun. In the Netherlands no mountains exist, but some hilly regions can be found. With these features it provides, it is important in terms of renewable energy [43] Ozcan M.et al., 2017 [38]; Türket al. 2020; Turk et al., 2021, [44]. For the Netherlands, Fig. 3 shows the aspect map.

(C3) Solar irradiation: Solar radiation is one of the most important parameters for solar and wind energy. Solar radiation is the radiant energy that is generally emitted to the environment within a certain period of time. The unit of radiant energy falling on the unit surface is (joule/square meter, J/m^2). Solar radiation is the power per unit area received from the Sun in the form of electromagnetic radiation in the wavelength range of the measuring instrument [43] Ozcan M.et al., 2017 [38]; Türket al. 2020; Turk et al., 2021, [44]. For the Netherlands, Fig. 4 shows the solar radiation map.

(C4) Land use: Land use is the regulation of how the land in a country or region is to be used, protected and managed. Land use aims to protect the economic, social and environmental interests of the land in a balanced way. Land use includes the protection of the natural resources of the land, the planning of land use, agriculture, forestry, tourism, energy production, transportation, determination of renewable energy areas and other economic activities in accordance with land use [43] Ozcan M.et al., 2017 [38]; Türket al. 2020; Turk et al., 2021, [44]. Fig. 5 shows the map of the Netherlands in terms of land use.

(C5) Wind speed: Horizontal directional air movements moving from areas of high pressure to areas of low pressure are called winds. In other words, the wind is formed due to the pressure difference between two points and the wind continues to blow until this pressure difference decreases. The device that measures wind speed is called anemometer [43] Ozcan M.et al., 2017; Koç A et al., 2019; Türket al. 2020; Turk et al., 2021, [44]. The annual average wind speed map of the Netherlands is demonstrated in Fig. 6.

(C6) Air Temperature: The average (kinetic energy of a particle) of the kinetic energies of the particles that make up a substance is called temperature. Since the particles that make up matter transfer their kinetic energies as a result of collision with each other, the kinetic energy of each particle is different and when they hit each other, their kinetic energies change constantly. Since the kinetic energies of the particles of the substance at the same temperature are different, the temperature is the average of the kinetic energies of all of the particles, not a single particle. Air circulation in hot places with sun result when the panel temperature decreases energy production and efficiency increase, air circulation energy production and it was determined that the efficiency decreased (Homadi, 2016). After the air temperature maps of the study area were obtained from "Global Atlas" numerically, they were used in Arc-GIS 10.2 package program to form a structure compatible with the working scale by reclassification on the Reclass button in the Spatial Analyst Tool module [43] Ozcan M.et al., 2017 [38]; Türket al. 2020;

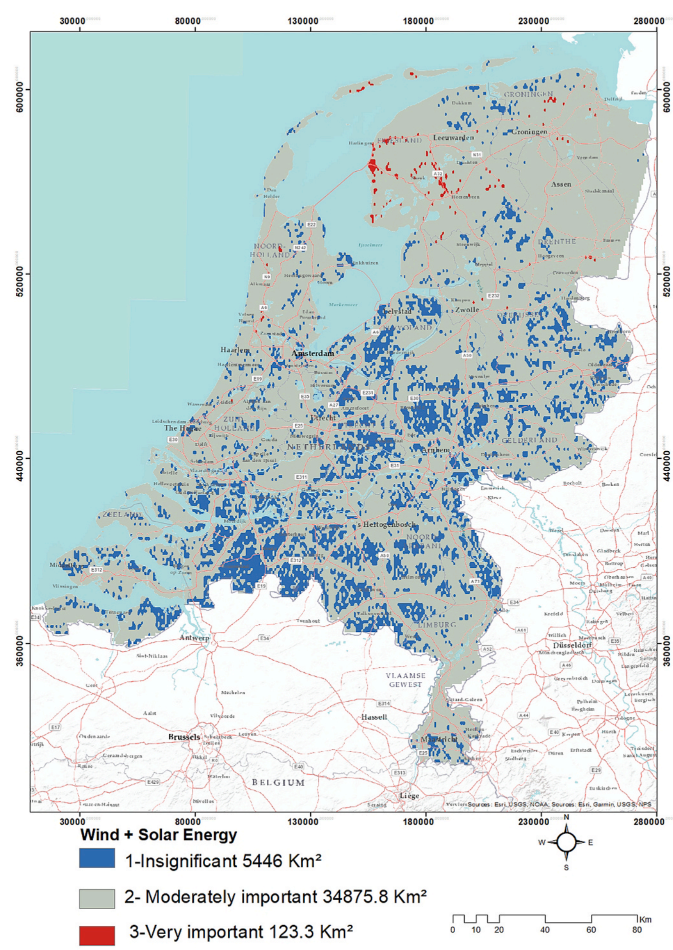

Fig. 18. The Netherlands optimal solar-wind energy map.

Table 1
Suitable location for Solar Power Plant Scoring values created by experts for each layer [61]; Ozdemir S. et al., 2018; A. Tunc et al., 2019 [38].

Energy Types	Evaluation factor	Selected sub-units	Relevance Number
Solar Energy	Elevation	697–1000 m	4
		1000–1500 m	1
		1500–2000 m	1
		2000–4257 m	1
	Slope	Flat	4
		Slightly sloping	4
		Sloping	3
		Very Sloping	1
	Land cover	Industrial Commercial and Transports	1
		Mine and Construction Areas	1
		Non-Agricultural Artificial Green Areas	2
		Fields Suitable for Agriculture	1
		Continuous Products	1
		Pasture Area	3
		Heterogeneous Agricultural areas	1
		Forests	1
		Shrubbery Areas	2
		Areas Without Vegetation	3
		Interior Wet Areas	1
		Wet Areas Near the Shore	1
		Inland Waters	1
		Water surfaces	1
		Grassland	4
		Farmland	1
		Natural meadows	4
		Infrastructure of cities	1
	Aspect	North	1
		Northeast	1
		East	2
		Suoutheast	2
		South	4
		Southwest	3
		West	1
		Northwest	1
	Inclination	Flat (0–2%)	1
		Slightly inclined (2–6%)	1
		Middle (6–12 %)	1
		Steep (12–20 %)	1
		Very Steep (20–30 %)	1
		scarped 30+%)	1
	Solar irradiation 1000 kWh/m2/year	Irradiation Excess >1100 kWh/m2	4
		Irradiation Too 1050–1100 kWh/m2	3
		Irradiation Normal 950–1050 kWh/m2	2
		Irradiation Low <950 kWh/m2	1
	Air Temperature	Hot	2
		A Bit Hot	4
		Normal	4
		Cool	2
	(distance to) Transmission Line	0–500 m	4
		500–1000 m	3
		1000–1500 m	2
		1500–2000 m	1
		2000 m>	1
	Wind Speed	Hard Wind (10–12)	3
		Windy (8–10)	4
		Wind Light (5–8)	4
		No Wind or Low (0–5)	1
	Air Pressure	High	4
		Normal	3
		Low	2
		Very Low	1
	Air Humidity	High	1
		Normal	2
		Low	3
		Very Low	4
	Land Surface Temperature (LST)	Very Hot	1
		Hot	2
		Normal	3
		Cool	4
	Transportation Network	0–500 m	4
		500–1000 m	4
		1000–1500 m	3
		1500–2000 m	2
		2000 m>	1

Turk et al., 2021, [44]. In Fig. 7, the Netherlands average air temperature map is shown.

(C7) Air Pressure: The water vapor carried by the air is called humidity. The amount of moisture, that is, water vapor, that the air can carry varies with temperature and pressure. An increase in temperature increases the amount of moisture that can be transported. Moisture maps of the study area were obtained by digitizing the point data obtained from stations in 12 different locations in the Arc-GIS 10.2 package program and using the "Kriging" method in the Geostatistical Analyst module (Sahin F et al., 2020). Fig. 8 shows the result.

(C8) Air **Humidity:** The gases surrounding the earth have a weight. The force exerted by the gases forming the atmosphere on the earth under the influence of gravity is called air pressure. The Air Pressure map was digitized in the Arc-GIS 10.2 package program and obtained using the "Kriging" method in the Geostatistical Analyst module [45,46], see Fig. 9.

(C9) Land Surface Temperature: Land surface temperatures are an important parameter in terms of climate and are used in climate models. It is successfully used to determine the land surface temperature (LST) values and changes and to investigate their effects [34,47,48]. Land Surface Temperature differs according to land cover and usage and is frequently used in determining the changes in the land [49]. Urban heat island [50], climate [51], agriculture (Özelkan, 2014), drought, forestry, maritime and in many other studies, LST data is an important and effective data source [52–55]. In order to calculate the LST value successfully, data such as atmospheric effects values, sensor parameters, and ground surface emissivity are needed to assist in the calculation of LMS [56]. Single-channel, Multi-angle, Multi-channel, Split Window methods are used in the calculation of LST [57]. In the single channel method, the radiation change on the earth emitted from the atmosphere is directly proportional to the data detected in two different channels. In this way, atmospheric effect and surface radiation values can be reached [58]. Atmospheric temperature, humidity, water vapor and brightness temperature values obtained from thermal satellite images are used [59, 60]. Land surface temperatures ranging from −38.407 °C to 37.052 °C were studied in the study area. Due to the temperate oceanic climate of the Netherlands, winters are warm and summers are cool. Rainfall in the Netherlands continues throughout the year, so there is no dry period. Average annual precipitation in the Netherlands ranges from 736.6 mm to 838.2 mm. It is seen that the surface temperature of a large part of the Netherlands is 20–30 °C. The places where the surface temperature is low are the places with high precipitation. This is a situation we do not want for Solar and Wind energy. This causes a decrease in the friction force close to the ground, the wind intensity and, accordingly, the Coriolis force. This reduces the average movement of the atmosphere and wind generation [43]; Özcan M. et al., 2017 [38]; Türket et al., 2020; Turk et al., 2021, [44]. Fig. 10 show the land surface temperature. We obtain the LST as follows (Figs. 10 and 11).

Band data of Landsat 8 satellite was analyzed as in the diagram above and Arc GIS 10.8 program was used for analysis (Chander and Groeneveld, 2009; Jimenez-Munoz et al., 2014 [38]; Rozenstein et al., 2014;

Table 2
Suitable location for Wind Power Plant Scoring values created by experts for each layer [61]; Ozdemir S. et al., 2018; A. Tunc et al., 2019 [38].

Energy Types	Evaluation factor	Selected sub-units	Relevance Number
Wind Energy	Elevation	697–1000 m	2
		1000–1500 m	3
		1500–2000 m	4
		2000–4257 m	4
	Slope	Flat	4
		Slightly sloping	4
		Sloping	3
		Very Sloping	1
	Land cover	Industrial Commercial and Transports	1
		Mine and Construction Areas	1
		Non-Agricultural Artificial Green Areas	2
		Fields Suitable for Agriculture	1
		Continuous Products	1
		Pasture Area	3
		Heterogeneous Agricultural areas	1
		Forests	1
		Shrubbery Areas	2
		Areas Without Vegetation	3
		Interior Wet Areas	1
		Wet Areas Near the Shore	1
		Inland Waters	1
		Water surfaces	1
		Grassland	4
		Farmland	1
		Natural meadows	4
		Infrastructure of cities	1
	Aspect	North	1
		Northeast	2
		East	4
		Suoutheast	2
		South	1
		Southwest	1
		West	4
		Northwest	2
	Inclination	Flat (%0–2)	4
		Slightly inclined (%2–6)	4
		Middle (%6–12)	4
		Steep (%12–20)	4
		Very Steep (%20–30)	4
		scarped (%30+)	4
	Solar irradiation	Irradiation Excess >42000000 W/m2	4
		Irradiation Too\42000000-3000000 W/m2	3
		Irradiation Normal3000000-1000W/m2000	3
		Irradiation Low <100000 W/m2	1
	Air Temperature	Hot	2
		A Bit Hot	4
		Normal	4
		Cool	2
	Transmission Line	0–500 m	4
		500–1000 m	3
		1000–1500 m	2
		1500–2000 m	1
		2000 m>	1
	Avarage of wind speed	Hard Wind (10–12)	4
		Windly (8-10)	4
		Wind Light (5–8)	4
		No Wind or Low (0–5)	1
	Air Pressure	High	4
		Normal	3
		Low	2
		Very Low	1
	Air Humidity	High	1
		Normal	2
		Low	3
		Very Low	4
	Land Surface Temperature (LST)	So Hot	1
		Hot	1
		Normal	1
		Cool	1
	Transportation Network	0–500 m	4
		500–1000 m	4
		1000–1500 m	3
		1500–2000 m	2
		2000 m>	1

Turk et al., 2021). In the first stage of the study, the satellite images of Landsat 8 in different bands were classified and the following equation was used to obtain the atmospheric radiation value in the stage.

Lλ = Band10x0,003342 + 0,1.

Lλ = Spectral luminance at sensor aperture (W/(m 2 sr μm))

In the second step, another equation was used to convert the atmospheric irradiance value to the sensor temperature (Chander and Markham, 2003).

T_B=(1321,08/Ln((774,89/(L_λ))+1))-273,15.

Also, the following equation was used to obtain NDVI maps (Hatfield et al., 1985; Liu and Zhang, 2011; McFeeters, 1996; Zhang et al., 2006). Normalized plant density index maps are important because they show differences in temperature fluctuations of the natural surface according to plant densities (Irish, 1998; Landsat; Zanter, 2016).

NDVI=Floot(Band5-Band4)/Floot(Band5+Band4)

NDVI= Normalized plant density index maps.

In the other part of the study, the calculation of the vegetation ratio was made. The following equation was used to calculate the vegetation ratio (Landsat; Zanter, 2016).

Pv = 0,004x(NDVI)+0,986

Pv = Calculation of vegetation ratio.

In the last stage of the study, maps of surface temperature (LST) were created with a minimum margin of error.

(C10) Transmission line: Today, the most useful and economical type of energy is undoubtedly electrical energy. The demand for electrical energy, which started to be used for lighting purposes towards the end of the 19th century, reached enormous dimensions in the following years. This situation has made the need to transport energy mandatory and therefore energy transmission lines have been used. These are the lines that transmit the electrical energy obtained in a controlled and planned manner from the power plants to the distribution lines. The centers producing electrical energy (hydroelectric power plants, thermal power plants, natural gas cycle power plants, wind power plants, etc.) cannot be established near the consumption centers. Among the most important reasons for this are difficulties in raw material transportation, environmental pollution, safety, etc. The electrical energy produced will be transported many kilometers away. At this point, the importance of energy transmission lines is evident as new solar and wind parks should

Table 3
Linguistic variables for evaluating each criterion (Mondal&Pramanik, 2004; [62].

Linguistic variables	IFNs (μ, ν, π)
Very important (VI)	(1,0,0)
Important (I)	(0.75,0.20,0.05)
Medium (M)	(0.50,0.40,0.10)
Unimportant (U)	(0.25,0.60,0.15)
Very unimportant (VU)	(0.10,0.80,0.10)

Table 4
Importance of criteria according to the decision-maker for Solar power plant.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Decision Maker	I	I	I	VI	I	VI	I	VI	VI	VI	I	I

Table 5
Linguistic variables for evaluating each alternative (Mondal&Pramanik, 2004; [62].

Linguistic variables	IFNs (μ, ν, π)
Extreme high(EH)	(0.95,0.05,0.00)
Very high(VH)	(0.85,0.10,0.05)
High(H)	(0.75,0.15,0.10)
Medium high(MH)	(0.65,0.25,0.10)
Medium(M)	(0.50,0.40,0.10)
Medium low(ML)	(0.35,0.55,0.10)
Low(L)	(0.25,0.65,0.10)
Very low(VL)	(0.15,0.80,0.05)
Extreme low(EL)	(0.05,0.95,0.00)

ideally be close to these lines in Fig. 12 [43]; Ozcan M.et al., 2017 [38]; Türket al. 2020; Turk et al., 2021, [44].

(C11) Transportation Network: A long strip of hard surface used in road transportation. It may be formed by natural causes or man-made. It helps human, animal and vehicular traffic to progress quickly, easily and safely. Roads vary greatly, from footpaths created by footprints on rough terrain to multi-lane highways. Fig. 13 shows Dutch road infrastructure.

(C12) Elevation: Elevation is related to the wind speed. The vertical distance of a point of the earth from the sea level is called altitude or elevation. The elevation influences the performance of wind power as a result of an increase in wind speed (Abdulrahman,2016). Netherlands Elevation maps 1/250000 raster map plots Arc General Command GIS10.2 Spatial Analyst Package program was created as a result of digitization in the Tool module. These created maps were converted to DEM format in the Conversion Tool module in the Arc-GIS 10.2 package program [38]; Aydin et al., 2010; Turk et al., 2021). We can see elevation maps in Fig. 14.

4. Result and discussion

In this section, the steps of the GIS methodology and the proposed fuzzy logic based multi-criteria decision making method are explained.

4.1. Applying GIS

In this study, since raster data is needed for weighted registration, data in vector format were converted to raster data after distance analysis. After converting all the data to raster format, all maps in raster data type were made in equal cell size (100 x 100). Then, the criteria were divided into two classes as 1 (all suitable areas) and 0 (unsuitable areas) by giving a score between 1 and 4, the data were overlaid and a map of suitable and unsuitable areas for WPP and SPP (masking map) was obtained. Then, with the help of expert opinions, the criteria were ranked according to their importance and their weights were determined by GIS-intuitionistic fuzzy-based approach. All data were subjected to reclassification process and overlapped with the determined weights as shown in Fig. 15 in order to classify the suitable areas within themselves. This process was repeated once more with equal weighting of the criteria for a different perspective and comparison. Finally, the weighted overlap maps were overlaid with the masking map to obtain the final suitability maps, Figs. 16–18. The final suitability maps are presented in two different ways, firstly according to the weights determined by the GIS- intuitionistic fuzzy-based approach, and secondly by considering the criteria as equally weighted, and the results are interpreted.

As can be seen in the model created for classification, the weight of each layer was determined by giving a score between 1 and 4 according to the weight of the components of each layer and the layers were combined as shown in Table 1 and Table 2. After combining these layers, classification was performed and the result maps, namely the solar energy map in Fig. 16, the wind energy map in Fig. 17 and finally the optimum solar-wind energy map in Fig. 18, were created.

4.2. Applying intuitionistic fuzzy to potential locations

In this study, a heuristic fuzzy approach is used to select the most suitable site for solar and wind power plants in the Netherlands.

*__Fuzzy membership functions__.

In this study, a survey was conducted with a decision maker and 12 criteria were selected as an alternative to the solar power plant and wind power plant installation problem for the overall evaluation process of the 12 regions of the Netherlands.

First, the importance of each criterion is rated using linguistic terms such as “Very important (VI)”, “Important (I)”, “Moderate (M)”, “Unimportant (U)”, “Very unimportant (VU)”. Table 3 shows the corresponding heuristic fuzzy sets specified using a true value between 0 and 1, and Table 4 and Table 7 shows the decision maker’s linguistic judgments for the importance of the criteria.

After deciding the importance of each criterion, the decision-maker provides a performance evaluation of the geographical areas in terms of 12 criteria using the linguistic terms “Extreme high (EH)”, “Very high (VH)”, “High (H)”, “Medium high (MH)”, “Medium (M)”, “Medium low (ML)”, “Low(L)”, “Very low (VL)”, “Extreme low (EL)” and Table 5 shows the associated intuitionistic fuzzy sets for each term. Table 6 and

Table 6
Performance of alternatives according to the decision-maker for Solar power plant.

Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
A1	EH	EH	EH	M	L	MH	M	H	H	VH	MH	M
A2	EH	EH	H	M	M	H	M	M	MH	VH	MH	VH
A3	ML	M	MH	H	MH	EL	EL	M	H	MH	H	MH
A4	ML	M	H	VH	H	M	L	M	EL	H	EL	H
A5	EH	EH	VH	ML	L	VH	M	ML	H	H	H	H
A6	VL	L	EH	EL	VH	EH	VH	EL	H	MH	H	MH
A7	L	MH	M	M	M	L	L	M	VH	M	VH	M
A8	L	L	M	M	VH	L	EL	M	H	M	H	M
A9	EH	L	H	EL	L	MH	M	MH	M	H	M	H
A10	H	M	VH	M	L	H	VH	L	VL	H	VL	H
A11	ML	MH	VH	M	L	H	VH	L	L	MH	L	MH
A12	ML	MH	ML	ML	L	MH	VH	L	L	M	L	M
A13	EH	VH	H	MH	VH	L	ML	VH	MH	L	MH	L

Table 7
Importance of criteria according to the decision-maker for Wind power plant.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Decision Maker	I	I	I	VI	VI	VI	VI	I	I	VI	VI	VI

Table 8
Performance of alternatives according to the decision-maker for Wind power plant.

Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
A1	EH	ML	H	EH	EH	EH	EH	MH	M	ML	VH	EH
A2	EH	EH	H	M	M	H	M	M	MH	VH	MH	VH
A3	ML	M	MH	H	MH	EL	EL	M	H	MH	H	MH
A4	ML	M	H	VH	H	M	L	M	EL	H	EL	H
A5	EH	EH	VH	ML	L	VH	M	ML	H	H	H	H
A6	VL	L	EH	EL	VH	EH	VH	EL	H	MH	H	MH
A7	L	MH	M	M	M	L	L	M	VH	M	VH	M
A8	L	L	M	M	VH	L	EL	M	H	M	H	M
A9	EH	L	H	EL	L	MH	M	MH	M	H	M	H
A10	H	M	VH	M	L	H	VH	L	VL	H	VL	H
A11	ML	MH	VH	M	L	H	VH	L	L	MH	L	MH
A12	ML	MH	ML	ML	L	MH	VH	L	L	M	L	M
A13	EH	VH	H	MH	VH	L	ML	VH	MH	L	MH	L

Table 9
For Wind Plant Positive and negative distances, closeness coefficients and the rank of alternatives.

Alternatives	Positive-ideal	Negative-ideal	Closeness Coefficients	Rank
A1	0.2350	0.5986	0.7181	7
A2	0.2239	0.6133	0.7325	**5**
A4	0.2866	0.5533	0.6588	11
A5	0.2202	0.6136	0.7360	**4**
A6	0.1832	0.6409	0.7777	**2**
A9	0.2647	0.5627	0.6504	10
A10	0.3030	0.5254	0.6186	12
A12	0.2317	0.6047	0.7230	6
A11	0.2072	0.6281	0.7520	3
A8	0.2550	0.5803	0.6847	8
A7	0.2572	0.5770	0.6817	9
A3	0.1275	0.5770	0.8476	1

Table 10
For Solar PV Power Plant Positive and negative distances, closeness coefficients and the rank of alternatives.

Alternatives	Positive-ideal	Negative-ideal	Closeness Coefficients	Rank
A11	0.3519	0.4874	0.5807	9
A10	0.2866	0.5533	0.6588	**4**
A5	0.4031	0.4342	0.5186	12
A2	0.3828	0.4530	0.5420	11
A8	0.3356	0.5020	0.5993	8
A1	0.2767	0.5627	0.6704	**3**
A3	0.2550	0.5803	0.6947	**1**
A7	0.3030	0.5354	0.6386	**5**
A12	0.3015	0.5257	0.6356	6
A9	0.2572	0.5770	0.6917	**2**
A4	0.3326	0.5090	0.6048	7
A6	0.3646	0.4764	0.5665	10

Table 8 denotes linguistic decisions of the decision-maker for the performance of alternatives.

Tables 6 and 8 show each normalized criterion for solar power plant and wind power plant, respectively. Decision makers, the order of points according to the importance of each criterion, as in Table 9 for solar power plant and wind power plant and in Table 10 for wind power plant.

4.3. Experimental results

First of all, we calculated the score matrix so that the Netherlands can be ranked according to the scores for 12 different regions. We ranked the locations according to the obtained values. Table 11 lists the suggested locations.

Table 11
Intuitionistic Fuzzy results for solar and wind energy.

Locations	Wind Energy		Solar Energy		Average	
	Score	Rank	Score	Rank	Average	Rank
A1	0,7181	7	0,6704	**3**	0,69425	**2**
A2	0,7325	**5**	0,542	11	0,63725	10
A3	0,8476	**1**	0.6947	**1**	0,7431	**1**
A4	0,6588	11	0,6048	7	0,6318	11
A5	0,736	**4**	0,5186	12	0,6273	12
A6	0,7777	**2**	0,5665	10	0,6721	5
A7	0,6817	9	0,6386	**5**	0,6882	**3**
A8	0,6847	8	0,5993	8	0,642	8
A9	0,6504	10	0,6917	**2**	0,67105	6
A10	0,6186	12	0,6588	**4**	0,6387	9
A11	0,752	**3**	0,5807	9	0,66635	7
A12	0,723	6	0,6356	6	0,6793	**4**

According to this result, it was determined that Friesland (A3) was the best place for solar power plant and wind farm among 12 regions. When the total average of both solar and wind energy results is calculated, it has been proven that the Friesland region is the most suitable region for both solar and wind power plants.

The Solar power plant results are mapped as shown in Fig. 16 and the wind power plant in Fig. 17. The figures also give the total area for the three categories in the figures. Optimum land use maps in which solar and wind are combined are shown in Fig. 18 for the produced maps (Table 11). The solar power plant installation suitability has an area value of 35317.2 km^2. Approximately 3531.72 MW of this area corresponds to the useable solar energy potential of the Netherlands. The color blue and red are very important in this map because these colors indicate that solar energy is available. The red color indicates that it is much more important, about 5123.7 km^2.

The wind farm installation suitability has an area value of 34844.5 km2. 1 MW wind energy towers were placed in this area at 1 km intervals. Approximately 3484450 MW of this area corresponds to the current onshore wind energy potential of the Netherlands. Yellow and red color is very important in this map. because the yellow color shows that it is the most suitable area for wind energy. The red color indicates that approximately 154.6 km2 is a more suitable place.

With the combination of solar power plants and wind power plants maps, the optimal solar-wind power plant installation suitability has an area value of 34875.8 km2. This results in approximately 123.3 km^2 of wind energy (how much MW?) and 1233 MW of solar energy. The color gray and red are very important in the sun-wind map because the color indicates the proper location of the hybrid energy. The most suitable area for solar energy is the color red. It is also located in the Friesland region of areas suitable for solar-wind energy.

5. Discussion

In our study, looking at Figs. 16 and 17, we can see that every part of the Netherlands is suitable for solar power plant location and wind power plant location. When we examine our 12 environmental parameters, we can see that Friesland region contains the best areas for wind and solar energy. Let's look at the climatic conditions of Friesland; Friesland has a maritime climate. It rains every month of the year. The average annual temperature for Friesland is 12 °C and 310 mm of rain falls annually. It is dry 136 days a year, the average humidity is 81 % and the UV index is 3. Winters are cold. This characteristic characterizes a temperate climate that is not hot in summer. These weather conditions are important for solar energy efficiency. Panels that heat up slowly need to rest at night, that is, cool down and be ready for the next day. In order to give better efficiency the next day and to minimize heat and energy loss. According to N.S. Nortier et al., although the number of onshore turbines is projected to decrease slightly towards 2030 (from 2015 to 1938), their combined rated power increases significantly (from 3.48 GWp to 6.20 GWp) due to the increase in average rated power (from 1.73 MWp to 3.20 MWp). Geographical shifts in onshore turbine capacity concentration are foreseen for the provinces of Friesland (westward), Groningen (northeastward), Noord-Holland (northeastward) and Flevoland (southward). In Fig. 17 we can see that both solar and wind power plant deployment is better towards the west. In this way, the study by (N.S [6]. shows that it can be done in future studies. In our study, we can reach the same conclusion and we can see that every part of the Netherlands is suitable for building a power plant at an altitude of 100 m. When we look at the annual wind speeds, we see the most suitable wind speeds at a height of 100 m.

In total, if a full capacity wind power plant and a solar power plant are installed in the Netherlands in the coming years, they will generate a total of approximately 7016.17 MW of energy. This amount of energy will vary depending on the materials used and the installed capacity. If the wind towers we use are not 1 MW but 2 MW or higher, the energy produced will increase.

6. Conclusion

In this study, we addressed the problem of optimal solar-wind power plant siting in 12 regions of the Netherlands considering both qualitative and quantitative factors and solved the problem in two ways: Using GIS mapping technique and Intuitive Fuzzy Based approach. In this research, we first qualitatively and quantitatively surveyed 12 regions of the Dutch country and found suitable areas for optimal solar-wind power plants using two methods: GIS mapping technique and Intuitionistic Fuzzy Based approach. The consistency of the results was checked by comparing the findings of GIS mapping technique and Intuitionistic Fuzzy Based approach.

According to the results, the Netherlands has an area of 35317.2 km2 for solar energy and 34844.5 km2 for wind energy. Despite having highly suitable areas, only 34875,8 km2 are suitable for optimal solar-wind power plant installation. Another important result is that we used a different method, the heuristic fuzzy approach, to validate the mapping technique obtained in GIS. Also, according to the figures presented in this study (Figs. 16–18), it is clear that we have provided optimal and suitability maps for solar, wind and energy.The Friesland region varies as the most suitable region for the installation of optimal solar-wind power plants. To the best of the authors' knowledge, this is one of the first comprehensive studies in the Dutch context. With the inclusion of the literature of this book, more critical profits are gained in the installation of Solar Power Plants (SPP) and Wind Power Plants (WPP). The expansion of the SPP and WPP installation phase, the model, size and relationship with the natural environment of the planned SPP and WPP are evaluated in detail. In addition, the freedoms of the land parcels on the ground of the SPPs in the areas recorded as suitable for the installation of SPPs and WPPs should also be recorded. This study also emphasizes that GIS and regime options methods are very powerful in the functions of ground maps. Firstly, the application area can be extended by analyzing existing areas in Europe. Secondly, in the GIS and Intuitionistic Fuzzy-Based approach, imprecise data can be pathologically analyzed, better analyzed and separated for more reliable results. Finally, the problem can be transformed into a multi-objective change problem, where two objectives can be addressed simultaneously.

All declarations

All manuscripts should include the following sections under the heading 'Declarations'.

Ethical approval and permission to participate

This article does not require ethical approval or permission to participate.

Release permission

The authors performed this work. There was no need for a release from elsewhere.

Financing

There is no funding of sources used in this article.

CRediT authorship contribution statement

Gökhan Şahin: Conceptualization, Software, Writing – review & editing, Investigation. **Ahmet Koç:** Visualization, Writing – review & editing, Investigation. **Wilfried van Sark:** Conceptualization, Software, Writing – review & editing, Investigation.

Declaration of competing interest

Such as this articles have been many writers working, but just on this article we worked. This title "**Multi-Criteria Decision Making for Solar Power - Wind Power Plant Site Selection using a GIS-Intuitionistic Fuzzy-Based approach with an application in the Netherlands"** many peoples studied but this article only us. We declared that this work we studied. We declared that there is no conflict of interest.

Data availability

The data that has been used is confidential.

References

[1] IRENA, Renewable Capacity Statistics, 2023. https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023.
[2] CBS, Renewable electricity share up by 20 percent in 2022, https://www.cbs.nl/en-gb/news/2023/10/renewable-electricity-share-up-by-20-percent-in-2022, 2023.
[3] Q. Hang, Z. Jun, Y. Xiao, C. Junkui, Prospect of concentrating solar power in China—the sustainable future, Renew. Sustain. Energy Rev. 12 (2008) 2505–2514.
[4] J.M. Sánchez-Lozano, J. Teruel-Solano, P. Soto-Elvira, M.S. García-Cascales, Geographical information systems (GIS) and multi-criteria decision making (MCDM) methods for the evaluation of solar farms locations: case study in south-eastern Spain, Renew. Sustain. Energy Rev. 24 (2013) 544–556.
[5] H.A. Effat, Selection of potential sites for solar energy farms in Ismailia Governorate, Egypt using SRTM and Multicriteria Analysis, International Journal of Advanced Remote Sensing and GIS 2 (1) (2013) 205–220.
[6] N.S. Nortier, K. Lowenthal, S.L. Luxembourg, A. van der Neut, A.A. Mewe, W.G.J. H.M. van Sark, Spatially resolved generation profiles for onshore and offshore wind turbines: a case study of four Dutch energy transition scenarios, Renewable and Sustainable Energy Transition 2 (2022) 10037.
[7] N.S. Nortier, M. Paardekooper, C. Lucas, A. Blankert, A. van der Neut, S. L. Luxembourg, A.A. Mewe, W.G.J.H.M. van Sark, Spatially resolved generation profiles for building, land and water-bound PV: a case study of four Dutch energy transition scenarios, ADGEO 58 (2023) 199–216.
[8] J. Suh, J.R.S. Brownson, Solar farm suitability using geographic information system fuzzy sets and analytic hierarchy processes:Case study of Ulleung Island, Korea Energies 9 (2016) 648.
[9] H.Z. Al Garni, A. Awasthi, Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia, Appl. Energy 206 (2017) 1225–1240.
[10] B. Yuan, J.G. Kor, Fuzzy Sets and Fuzzy Logic Theory and Aplications, 1994. New York.
[11] K. Atanassov, Intuitionistic fuzzy sets, Fuzzy Set Syst. (20) (1986) 87–96.
[12] L.A. Zadeh, Fuzzy sets, Inf. Control 8 (1965) (1965) 338–353.
[13] H. Tanaka, S. Uejima, K. Asai, Linear regression analysis with fuzzy model, IEEE Systems, Trans. Systems Man Cybernet. SMC- 2 (1982) 903–907.
[14] J. Nowaková, M. Pokorný, Mathematics, computer science. 12th IFAC Conference on programmable devices and embedded systems the international federation of automatic control September 25-27, Fuzzy Linear Regression Analysis, in: 2013. Velke Karlovice, Czech Republic, 2013.
[15] T. Kaya, Bulanık Regresyon ve Ekonometrik Bir Uygulama (fuzzy regression and an Econometric application). Çukurova Üniversitesi, Sosyal Bilimler Enstitüsü, Yayımlanmamış Yüksek Lisans Tezi (2014).
[16] K. Chan, U. Engelke, Fuzzy Regression for Perceptual İmage Quality Assessment. *Engineering Applications of Artificial Intelligence*, 2015, p. 43.
[17] L. Chen, S. Nien, A new approach to formulate fuzzy regression models, Appl. Soft Comput. 86 (2020).
[18] J. Li, W. Zeng, J. Xie, Q. Yin, A New Fuzzy Regression Model Based on Least Absolute Deviation, vol. 52, Engineering Applications of Artificial Intelligence, 2016, pp. 54–64.
[19] K.A. Wiguna, R. Sarno, N.F. Ariyani, Optimization Solar Farm Site Selection Using Multi-Criteria Decision Making Fuzzy AHP and PROMETHEE: Case Study in Bali, 2016 International Conference on Information & Communication Technology and Systems (ICTS), Surabaya, 2016, pp. 237–243.
[20] A. Asakereh, M. Soleymani, M.J. Sheikhdavoodi, A GIS-based Fuzzy-AHP method for the evaluation of solar farms locations: case study in Khuzestan province, Iran, Sol. Energy 155 (2017) 342–353.
[21] Y. Lin, Z. Ma, K. Zhao, W. Hu, J. Wei, The impact of population migration on urban housing prices: evidence from China's major cities, Sustainability 10 (3169) (2018) 1–14.
[22] H. Yousefi, H. Hamed, Y.S. Amin, Spatial site selection for solar power plants using a GIS-based Boolean-fuzzy logic model: a case study of Markazi province, Iran, Energies 11 (2018) 1648, https://doi.org/10.3390/en11071648.
[23] Y.A. Solangi, S.A.A. Shah, H. Zameer, et al., Assessing the solar PV power project site selection in Pakistan: based on AHP-fuzzy VIKOR approach, Environ. Sci. Pollut. Res. 26 (2019) 30286–30302.
[24] A.P. Vavatsikos, A. Arvanitidou, D. Petsas, Wind farm investments portfolio formation using GIS-based suitability analysis and simulation procedures, J. Environ. Manag. (2019).
[25] H. Garg, Novel intuitionistic fuzzy decision making method based on an improved operation laws and its application, Eng. Appl. Artif. Intell. 60 (2017) 164–174. ISSN 0952-1976.
[26] C. Kahraman, I. Otay, Solar PV power plant location selection using a z-fuzzy number based AHP, International Journal of the Analytic Hierarchy Process 10 (3) (2018).
[27] L. De Santoli, F. Mancini, D.A. Garcia, A GIS-Based Model to Assess Electric Energy Consumptions and Useable Renewable Energy Potential in Lazio Region at Municipality Scale, *Sustainable Cities and Society*46, 2019.
[28] S. Geng, L. Lin, L. Zhang, X. Liu, Z. Huang, Site selection framework of fishing photovoltaic hybrid project under interval-valued intuitionistic fuzzy environment, J. Clean. Prod. 252 (2020).
[29] H.D. Parker, The Unique Qualities of geographic information system: a commentary, Photgrammetric Engeneering And Remote Sensing 54 (11) (1988) 1547–1549.
[30] K. Dueker, Land resource information systems: a review of fifteen years experience, Geo Process. 1 (1979) 105–128.
[31] P.A. Burrough, Principles of Geographic Systems for Land Resources Assessment, Clarendon, Oxford, 1986.
[32] I. Heywood, S. Cornelius, S. Carver, An Introduction to Geographical Information Systems, Longman, New York, 1998, pp. 11–12.
[33] C. Fitzpatrick, D.J. Maguıre, GIS in Schools: Infrastructure, *Methodology and Role*, 2000.
[34] T. Yomralıoğlu, Coğrafi Bilgi Sistemleri Temel Kavramlar Ve Uygulamalar (Geographic Information Systems Basic Concepts and Applications), vol. 2, Akademi Kitabevi, 2000. Baskı.
[35] M. Kawabata, Multidisciplinary cooperation in GIS education: a case study of Us Colleges and universities", J. Geogr. High Educ. 34 (4) (2010) 493–509.
[36] F. Tuna, Ortaöğretim Coğrafya Derslerinde Proje Tabanlı Öğrenimi Desteklemek Amacı İle Coğrafi Bilgi Sistemlerinden (CBS) Yararlanma (Utilizing geographic information systems (GIS) to support project-based Learning in secondary education geography lessons). Yayımlanmamış PHD Thesis, *Marmara Üniversitesi Eğitim Bilimleri Enstitüsü*, 2008. İstanbul.
[37] D. Messaoudi, N. Settou, B. Negrou, B. Settou, GIS based multi-criteria decision making for solar hydrogen production sites selection in Algeria, Int. J. Hydrogen Energy (60) (2019) 31808–31831.
[38] A. Koc, S. Turk, G. Sahin, Multi-criteria of wind-solar site selection problem using a GIS-AHP-based approach with an application in Igdir Province/Turkey, Environ. Sci. Pollut. Control Ser. (31) (2019) 32298–32310.
[39] A.A. Merrouni, F.E. Elalaoui, A. Mezrhab, A. Mezrhab, A. Ghennioui, Large scale PV sites selection by combining GIS and Analytical Hierarchy Process. Case study: eastern Morocco, Renew. Energy 119 (2018) 863–873.
[40] L. Castro-Santos, G.P. Garcia, T. Simões, A. Estanqueiro, Planning of the Installation of Offshore Renewable Energies: A GIS Approach of the Portuguese Roadmap, Renewable Energy132, 2019, pp. 1251–1262.
[41] H.E. Colak, T. Memisoglu, Y. Gercek, Optimal Site Selection for Solar Photovoltaic (PV) Power Plants Using GIS and AHP: A Case Study of Malatya Province, Turkey, Renewable Energy149, 2020, pp. 565–576.
[42] Z. Xu, Intuitionistic fuzzy aggregation operators, IEEE Trans. Fuzzy Syst. 15 (6) (2007) 1179–1187.
[43] A. Garni, Z. Hassan, Anjali Awasthi, Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia, in: Applied Energy, vol. 206, Elsevier, 2017, pp. 1225–1240. C.
[44] F. Kaya, G. Gökhan Şahin, M.H. Alma, Investigation effects of environmental and operating factors on PV panel efficiency using by multivariate linear regression, Int. J. Energy Res. 45 (2021) 554–567.
[45] F (b) Sahin, G. Işik, G. Şahin, M.K. Karaa, Estimation of PM10 levels using feed forward neural networks in Igdir, Turkey, Urban Clim. 34 (2020) 100721.
[46] F(a) Sahin, M.K. Kara, A. Koc, G. Sahin, Multi-criteria decision-making using GIS-AHP for air pollution problem in Igdir Province/Turkey, Environ. Sci. Pollut. Control Ser. 27 (2020) 36215–36230.
[47] D. Arca, Afet Yönetiminde Coğrafi Bilgi Sistemleri ve Uzaktan Algılama, Karaelmas Fen ve Mühendislik Dergisi 2 (ss) (2012) 53–61.
[48] H. Liu, D. Sun, Y. Yu, H. Wang, Y. Liu, Q. Liu, Y. Du, H. Wang, B. Cao, Evalution of the VIIRS and MODIS LST products in an arid area of northwest China, Remote Sens. Environ. 142 (2014) 111–121.
[49] R. Bayar, K. ve Karabacak, Ankara İli Arazi Örtüsü Değişimi (2000-2012)(Ankara province land cover change (2000-2012)), Coğrafi Bilimler Dergisi 15 (1) (2017) 59–76.
[50] Ü.D. Yüksel, O. ve Yılmaz, Ankara Kentinde Kentsel Isi Adasi Etkisinin Yaz Aylarinda Uzaktan Algilama Ve Meteorolojik Gözlemlere Dayali Olarak Saptanmasi Ve Değerlendirilmesi, Gazi Üniv, Müh. Mim. Fak. Der. Cilt 23 (No 4) (2008) 937–952, 2008.
[51] E. Özelkan, S. Bagis, E.C. Ozelkan, B.B. Üstündağ, M. Yücel, C. ve Ormeci, Spatial Interpolation of climatic, Avrupa Bilim ve Teknoloji Dergisi e-ISSN: 2148-2683 948 variables using land surface temperature and Modified inverse distance weighting, Int. J. Rem. Sens. 36 (2015) 1000–1025.
[52] Q. Weng, Thermal infrared remote sensing for urban climate and environmental studies: methods applicaitons, and trends, ISPRS J. Photogramm 64 (2009) 335–344.
[53] R. Hamdi, Estimating urban heat island effects on the temperature series of Uccle (Brussels, Belgium) using remote sensing data and a land surface scheme, Remote Sens 2 (2010) 2773–2784.
[54] L. Liu, Y. ve Zhang, Urban heat island analysis using the Landsat TM data and Aster data: a case study in Hong Kong, Remote Sens 3 (2011) 1535–1552.
[55] J. Zhou, Y. Chen, J. Wang, W. Zhan, Maximum nighttime urban heat island (UHI) intensity simulation by integrating remotely sensed data and meteorological observations, IEEE J. Sel. Top. Appl. Earth Obs. Rem. Sens. 4 (2011) 138–146.
[56] A. Sekertekin, S. ve Bonafoni, Land surface temperature retrieval from Landsat 5, 7, and 8 over rural areas: assessment of different retrieval algorithms and emissivity models and toolbox implementation, Rem. Sens. (2020).
[57] A. Sekertekin, Ş.H. Kutluoglu, S. Kaya, A.M. Marangoz, Uydu Verileri Ile Arazi Örtüsündeki Yer Yüzey Sıcaklığı Değişimlerinin Analizi: Zonguldak Örneği, Türkiye, TMMOB Harita Ve Kadastro Mühendisleri Odası (Analysis of Ground Surface Temperature Changes in the Land Cover with Satellite Data: the Case of Zonguldak, Turkey, TMMOB Chamber of Surveying and Cadastre Engineers), 15, Türkiye Harita Bilimsel ve Teknik Kurultayı, Ankara, 2015, p. 25. -28 Mart 2015.
[58] B. Çelik, Yeryüzü Sıcaklıklarının Uzaktan Algılama Tekniği Ile Belirlenmesi: Tek-Kanal Yöntemleri (Determination of Earth Temperatures by Remote Sensing Technique: Single-Channel Methods), İstanbul Teknik Üniversitesi Yüksek Lisans Tezi, 2013.
[59] J.C. Price, The Contribution of Thermal Data in Landsat Multispectral Classifacition, Photo, English Remote Sensing, 1981.

[60] A. Chedin, N.A. Scott, C. Whacihe, P. ve Moulinier, The ĩmproved initialisation inversion method: a high resolution physical method for temperature retrievals from the TIROS-N series, J. Clim. Appl. Meteorol. (1985).
[61] M. Ozcan, A.K. Caliskan, Engineering management program EM 599 - *TERM PROJECT*, fina report. Site Selection for Wind-Solar Hybrit Power Plant in Turkey, Middle East Technical University industrial department, 2017.
[62] S. Turk, A. Koc, G. Sahin, Multi-criteria of PV solar site selection problem using GIS-intuitionistic fuzzy based approach in Erzurum province/Turkey, Scientifc Reports 11 (2021) 5034.