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A Two-Stage Multiple Criteria Decision Making for Site Selection of Solar Photovoltaic (PV) Power Plant: A Case Study in Taiwan

CHIA-NAN WANG[1], NGOC-AI-THY NGUYEN[1], THANH-TUAN DANG[1,2], AND JULIUS BAYER[1]

[1]Department of Industrial Engineering and Management, National Kaohsiung University of Science and Technology, Kaohsiung 80778, Taiwan
[2]Department of Logistics and Supply Chain Management, Hong Bang International University, Ho Chi Minh 723000, Vietnam

Corresponding author: Ngoc-Ai-Thy Nguyen (thy.logistics@gmail.com)

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ABSTRACT At the heart of Covid-19 responses, the transition from fossil sources to green energy is an urgent issue for nations to address the crisis and secure sustainable economies. As a country in a seismically active zone that relies heavily on imported fossil fuels, Taiwan is vigorously taking the next step in renewable energy development, which is pivotal to securing its position in global supply chains. Solar energy is today the most suitable renewable energy source for Taiwan. However, land prices and policies, and challenges of scale still hinder its development. In this context, identifying optimal sites for solar photovoltaic (PV) construction is a crucial task for major energy stakeholders. In this paper, a two-stage approach, combining the data envelopment analysis (DEA) models and the analytic hierarchy process (AHP), has been done for the first time to identify the most suitable locations among 20 potential cities and counties of Taiwan for constructing solar PV farms. DEA models were applied to filter out the areas with the most potential by measuring their efficiency indices with temperature, wind speed, humidity, precipitation, and air pressure, as inputs, and sunshine hours and insolation, as outputs. The locations with perfect efficiency scores were then ranked with the AHP method. Five selected evaluation criteria (site characteristics, technical, economic, social, and environmental) and sub-criteria of each were utilized to prioritize the locations with solar energy potential. AHP was used to determine the relative weights of the criteria and sub-criteria and the final weights of the areas. For criteria weighting results, ''support mechanisms,'' ''electric power transmission cost,'' and ''electricity consumption demand'' with weights of 0.332, 0.122, and 0.086, respectively, were found as the most significant sub-criteria. The final ranking suggests Tainan, Changhua, and Kaohsiung as the top three most suitable cities for constructing solar PV energy systems.

INDEX TERMS Renewable energy, Taiwan, solar photovoltaic (PV) power plant, site selection, decision making, DEA, AHP.

I. INTRODUCTION

A. GLOBAL RENEWABLE ENERGY SITUATION

Catastrophic dependence on fossil fuels of the world for energy demand has so far created 60% of total global greenhouse gas emissions, the major cause of warming effects [1]. To stop climate change and the essential risks it poses to humankind and nature, the Paris Climate Agreement was signed in 2015 to limit global warming to well below 2 °C, respectively 1.5 °C above pre-industrial levels [2]. Towards this end, many countries are aiming for 100% renewable electricity by 2045 or 2050, along with Europe, which announced the European Green Deal in 2019, intending to reduce net greenhouse gas emissions to zero by 2050 [3]. The benefits of the transition to renewable energy systems are thereby indisputable for many countries to advance economic development, enhance energy access, and mitigate climate change. The unprecedented crisis caused by the Covid-19 disease has exposed the profound gaps of the world in the access to modern, affordable, and sustainable energy. For public health emergencies, electricity is the cornerstone, yet hundreds of millions worldwide remain unreachable [4].

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Governments now have to bridge the energy access gap and put renewable energy on national stimulus packages and recovery measures [5]. Renewable electricity has been the most resilient energy source for lockdown measures for Covid-19. By the end of 2020, amid the supply chain and construction delays caused by the Covid-19 crisis, renewable electricity production had risen by 5%, mainly due to the implementation of new wind and solar energy projects and because renewables are generally captured prior to other energy sources [6].

B. THE POTENTIAL OF SOLAR ENERGY

Solar power, as a ubiquitous, predictable, and inexhaustible source of energy, plays an important role in renewable energy [7]. Due to technological progress as well as mass production, the price of photovoltaic modules has decreased by 25% for every time that the production has doubled from 1980 to 2019 [8]. Relatively stable prices for conventionally generated electricity have resulted in solar power already being cost-competitive in many regions of the world or expected to be so in the near future [9]. Considering future uncertainties such as political will, societal acceptance, and energy system costs, studies show that 100% of renewable energy is feasible globally by 2050 at moderate electricity costs, with solar power capable of generating the majority of energy at more than 20 terawatts (TW) [7], [10], [11]. However, the results of models, as well as scenarios predicting the deployment of solar energy by 2050, vary widely [12]. Researchers argue that the potential of solar energy is thereby often underestimated, despite its excellent characteristics [13], [14].

C. MOTIVATION AND INCITEMENT

Taiwan is an island directly affected by the impacts of global warmings, such as rising sea levels, and has almost no autonomous energy sources [15]. Furthermore, the Taiwanese government declared in 2017 that nuclear power will be phased out by 2025 [16], reporting that renewable energy would replace nuclear power by 2025, which accounts for approximately 4.43% of its total energy supply (or 8.30% of total electricity supply). This situation raises questions about Taiwan's energy stability and market vulnerability, leading to a surge in interest in domestic renewable energy sources. There are also desires to reduce greenhouse gas emissions, which makes renewables more attractive. The development of renewable energy for stable energy supply, continued economic growth and industrial advancement in Taiwan is a critical national mission. The Taiwanese government is striving to develop renewable energies and has presented the ''Five Plus Two'' plan in 2016 [17]. The plan foresees 20% of Taiwan's power to be generated by renewables until 2025, aiming to become more independent of energy imports and contribute to environmental protection. Solar power is the most suitable renewable energy source for Taiwan due to the availability of intense sunlight and available substantial areas suitable for solar PV energy installation [16]. Therefore, it also plays a significant role in the ''Five Plus Two'' plan, as 66.3% of the energy is to be covered by solar energy (20 GW), consisting of 14 GW by ground-mounted systems and 6 GW by rooftop systems [17], [18]. To achieve the 20 GW target, the government is promoting the installation of roof panels in industrial parks and is including farms, ranches, and aquaculture facilities in solar power production. Furthermore, rural as well as central regions will be promoted, and relevant laws and regulations for the construction of solar plants will be refined.

More than two-thirds of Taiwan's land area has an excellent mean annual solar radiation of more than 145 W/m2, especially southern Taiwan with Tainan and Kaohsiung [16]. Besides, the island is the world's second-largest solar PV producer, with a potential for solar cell production [19], [20]. These favorable conditions offer great benefits for Taiwan to expedite solar PV systems. However, since the ''Five Plus Two'' plan was unveiled in 2016, only 4.7 GW of solar energy had been installed by the end of July 2020 [21]. In this, several problems have detrimentally affected the development of solar energy in Taiwan. Most notably, land issues are the leading causes of the slow progress of solar deployment [22], [23]. With two-thirds of the territory covered by mountain terrain and a high population density of 650 people per km^2 widespread land is limited [22], [24]. Installing solar energy on rooftops in urban areas is challenging due to the many stakeholders involved, as it is in rural areas where landowners are numerous [25], [26]. Furthermore, large amounts of land are required for utility-scale solar facilities, and the manufacturing of solar PV has negative environmental consequences depending on their location, such as land degradation and habitat loss, which stems from the use of numerous hazardous materials. For the above reasons, the identification of the most suitable sites for solar PV farm construction plays a central role in resolving some issues with the production of solar PV energy in Taiwan since it affects the potential of electricity manufacturing and future socio-economic benefits.

Despite the proven potential for solar energy development and the critical and complicated task of solving solar farms site selection, exemplary studies for Taiwan are still finite [27], [28]. Taiwan possesses the industrial prowess to stimulate this proportion. Thus, this article aims to determine the preferred locations to install PV power plants while examining the most influential and conflicting criteria. The authors believe this is a critical step to obtain benefits from solar energy and contribute to the spread of their implementation in Taiwan. In addition to economic aspects, the site evaluation and selection process of renewable energies include various crucial factors such as environmental, technical, and social factors in many recent studies to identify well-rounded sustainable locations for renewable energy development [29]. Thus, to solve the facility location selection, multi-criteria decision-making (MCDM) approaches have proved applicability and efficacy to handle many alternatives and conflicting criteria that may be of different significance in making the decision.

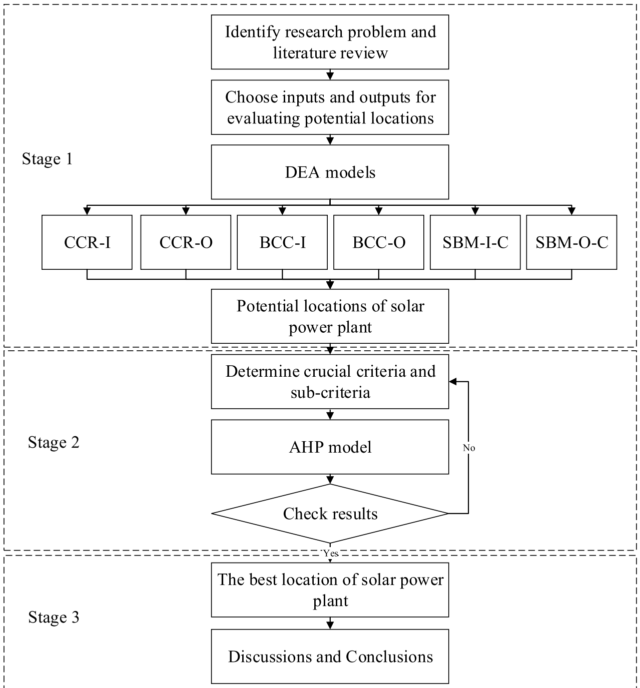

FIGURE 1. The research framework.

D. OBJECTIVES AND NOVELTY

In this study, an MCDM framework with a combination of the data envelopment analysis (DEA) models and the analytic hierarchy process (AHP) is developed to identify the most suitable sites among 20 potential cities and counties of Taiwan for constructing solar PV farms. Figure 1 details the research procedure. To describe, the authors aim to adopt DEA models in the first stage to narrow down the list of locations by measuring locations' efficiency indices where efficiency is represented by the ratio of weighted outputs to weighted inputs. Temperature, wind speed, humidity, precipitation, and air pressure are considered inputs, while sunshine hours and insolation are outputs. Two basic models, Charnes–Cooper–Rhodes (CCR) and Banker–Charnes–Cooper (BCC), and the slacks-based measure (SBM) model of efficiency in DEA, were utilized for this purpose. From the DEA results, locations with perfect efficiency scores were then ranked with the AHP method. In this stage, the weights of five selected evaluation criteria (site characteristics, technical, economic, social, and environmental criteria) and 20 sub-criteria found to influence the strategic placements were determined and utilized to prioritize the locations by ranking their final weights.

The present work is devoted to filling the gap of the existing literature of the solar PV power plant site selection. More specifically, a case study of Taiwan was investigated with a comprehensive set of criteria that can consider various aspects of determining the appropriate location. To the best of the authors' knowledge, there has not been carried out a thorough investigation examining the locations of Taiwan regarding the aforementioned purpose. Methodologically, the combination of DEA and AHP has been done for the first time to solve the problem. DEA is one of the most popular tools in location selection literature for performance measurement, while AHP is the most commonly applied approach in the field of MCDM. As a nonparametric method based on mathematical programming, DEA is a data-oriented approach for benchmarking a set of peer units called decision-making units (DMUs) in terms of their efficiency indices converting multiple inputs into multiple outputs while not requiring a priori or subjective tradeoffs [30]. The locations are considered as DMUs, i.e., alternatives for the PV site selection. Based on the defined inputs and outputs of the DMUs, DEA considers gradual nuances in the form of a quantitative measure that can attain any value between 0 and 1 (efficiency score) of the DMUs. The AHP, on the other hand, is most recognized in handling qualitative and subjective measurements of decision-makers in analyzing various location factors, evaluating location site alternatives, and making final location selections [31]. The adoption of AHP stems from the necessity to involve subjective judgments about the relative importance of common criteria that are non-monetary, intangible, and hard to assess, such as social and environmental factors. In doing so, AHP was used to weigh each of the site selection criteria and sub-criteria, incorporating decision makers' expertise/experience to rank the goodness of the locations. Thus, the integrated approach takes advantage of both methods since it allows subjective and objective evaluation while considering a holistic and influential set of criteria in the location optimization process. Overall, the proposed synergistic model is a more detailed and thorough multi-criteria decision support framework for solar PV power site selection and general location optimization problems. It is well-match for the stakeholders with both qualitative and quantitative assessments.

E. PAPER ORGANIZATION

The remainder of the paper is organized as follows. In section 2, the literature review is presented. In section 3, the procedures of DEA models and the AHP technique are explained. The case study of Taiwan is demonstrated in section 4. Results and discussion are presented in section 5. Finally, the conclusions and future works of this research are detailed in section 6.

II. LITERATURE REVIEW

In tackling the issues associated with decision-making in the energy sector, literature and practice show that multi-criteria decision-making (MCDM) techniques are receiving popularity and also becoming the main tools [32]. MCDM methods assist in dealing with multiple and conflicting criteria in a structured way and evaluate alternative solutions based on their limitations, preferences, and priorities of the decision-makers. In recent research works, therefore, MCDM methods have been used and covered various sources of renewable energy: solar, onshore wind, offshore wind, wave, and tidal. For the field of renewable energy site selection, the first systematic and latest review of MCDM applications and related criteria were performed in [29]: analytic hierarchy process (AHP) [33]–[37], technique for order preference by similarity to ideal solution (TOPSIS) [38]–[42], elimination and choice translating reality (ELECTRE) [43], [44], data envelopment analysis (DEA) [45]–[48], and other MCDM methods [49], [50]. Among these, it is found that AHP has been the most commonly used method for weighting criteria, especially for renewable energy site selection and the field of solar energy evaluation in particular. With its popularity and applicability, AHP will continue to be the first choice for researchers in site selection, and DEA has also been proven to be an adequate optimization approach for selecting the most suitable location [29]. However, DEA has appeared very sparingly in applications of renewable energy site selection.

DEA was first introduced in 1978 with the original CCR model by Charnes, Cooper, and Rhodes [51], which is an objective method to compare the efficiency of similar elements (DMUs) based on predetermined inputs and outputs. The BCC model, developed by Banker, Charnes, and Cooper (BCC), is a variable return to scale version of the CCR model [52]. The CCR model's objective is to identify the overall inefficiency, whereas the BCC model differentiates between technical efficiency and scale efficiency. A slack-based measure (SBM) of efficiency in DEA was developed by Tone in 2001 [53]. The SBM deals specifically with input excess and output shortfall, unlike the CCR and BCC steps, which are based on proportional reduction (enlargement) of input (output) vectors and do not account for slacks. For renewable energy site selection, the DEA has been used as a reliable optimization approach to prioritize the nominated locations. For example, Yokota *et al.* [46] proposed DEA models for investigating the optimal allocation of mega-solar. By modeling successful DMUs and using sensitivity analysis, the authors selected the optimal sites for a mega-solar installation. Depending on the modeled DMUs, the ranking of the optimal arrangement differed, and the results reinforced the importance of removing zero-value weighting factors and evaluating data. For decision making for plant locations of a problem in Iran, Azadeh *et al.* [54] presented an integrated fuzzy DEA model that uses predefined indicators for a wind power generation transmission plant to identify the optimum cities and regions. The results obtained indicate the significance of the proximity of consumers to the establishment of wind plants. The fuzzification of unknown indicators has been shown to contribute to a more practical approach to the facility location problem. Mostafaeipour *et al.* [55] evaluated the feasibility of a new wind power generation system for urban uses with a case study in Iran using DEA to rank the areas considering the most critical criteria with electricity production. Additionally, for assessment and ranking stations of Turkey for home-scale solar water heaters, Siampour *et al.* [56] utilized DEA models to identify the superior and inappropriate stations.

The analytical hierarchy process (AHP) was originally developed by Saaty [57], which is modeled using a hierarchy whose apex is the main objective of the problem, and the possible alternatives to be evaluated are located at the base. The AHP method has been used frequently for solving complex decision-making problems, such as water resources, agriculture, biodiversity conservation, and sustainable management, selecting appropriate strategies with different purposes. For the site selection problem, AHP has been one of the most popular MCDM methods to be applied in various studies. For example, ElQuoliti [58] adopted the AHP method to rank different sites for solar power plants in the western region of Saudi Arabia. Fourteen site selection criteria, and sensitivity analysis scenarios for both weights and scores by experts were implemented to test the robustness of the obtained results. In various site selection studies for screening optimized sites, the geographical information system (GIS) has recently become a popular application. The combination of the GIS with the MCDM-AHP method has emerged as a highly effective method for systematically dealing with abundant geographical knowledge data and manipulating essential parameters for the implementation of the best sites for solar power plants. Some recent studies of location selection for power plants based on GIS-AHP are in [34], [35], [59]–[61]. For ruling out unsuitable locations, GIS considers various constraints and limitations, while AHP is applied to assess the relative value and priority weight of each criterion.

III. MATERIALS AND METHODS

A. DATA ENVELOPMENT ANALYSIS (DEA)

This section presents a brief mathematical model of data envelopment analysis (DEA) including CCR-I, CCR-O, BCC-I, BCC-O, SBM-I-C, SBM-O-C. The list of symbols and notations used in the model is shown as follows.

n : number of decision-making units (DMUs)

DMU_i : the i-th DMU, $i = 1, 2, \ldots, n$

DMU_0 : the DMU target

$a_0 = (a_{01}, a_{02}, \ldots, a_{0p})$: input vector of DMU_0

$b_0 = (b_{01}, b_{02}, \ldots, b_{0q})$: output vector of DMU_0

$a_i = (a_{i1}, a_{i2}, \ldots, a_{ip})$: input vector of DMU_i, $i = 1, 2, \ldots, n$

$b_i = (b_{i1}, b_{i2}, \ldots, b_{iq})$: output vector of DMU_i, $i = 1, 2, \ldots, n$

$u \in R^{p\times 1}$: weight-input vector

$v \in R^{q\times 1}$: weight-output vector

1) CHARNES-COOPER-RHODES MODEL (CCR)

CCR model is the initial DEA model, which is defined as follows [51]. The multiplier model of the CCR input-oriented (CCR-I) is shown in model (1) as follows.

$$\begin{aligned} Max\ \gamma &= \sum_{r=1}^{q} u_r b_{r0} \\ \text{such that } &\sum_{r=1}^{q} u_r b_{re} - \sum_{i=1}^{p} v_i b_{ie} \leq 0 \\ &\sum_{i=1}^{p} v_i a_{i0} = 1 \\ &u_r, v_i \geq \beta > 0 \end{aligned} \quad (1)$$

The multiplier model of the CCR output-oriented (CCR-O) is shown in model (2) as follows.

$$\begin{aligned} &Min\ \delta = \sum_{i=1}^{p} v_i a_{i0} \\ &\text{such that } \sum_{i=1}^{p} v_i a_{ie} - \sum_{r=1}^{q} u_r b_{re} \geq 0 \\ &\sum_{r=1}^{q} u_r b_{r0} = 1 \\ &u_r, v_i \geq \beta > 0 \end{aligned} \tag{2}$$

2) BANKER-CHARNES-COOPER MODEL (BCC)

The procedure of BBC input-oriented (BBC-I) is introduced in a linear model (3) as follows [62].

$$\begin{aligned} &\underset{u,v,v_0}{Max}\ \xi = v^T b_0 - v_0 \\ &\text{such that } u^T a_0 = 1 \\ &v^T b_e - u^T a_e - v_0 \leq 0, e = 1, 2, \ldots, n \\ &u \geq 0, v \geq 0 \end{aligned} \tag{3}$$

The BBC output-oriented (BBC-O) is shown in model (4) below.

$$\begin{aligned} &\underset{u,v,u_0}{Min}\ \Omega = v^T b_0 - v_0 \\ &\text{such that } v^T b_0 = 1 \\ &u^T a_e - v^T b_e - v_0 \leq 0, e = 1, 2, \ldots, n \\ &u \geq 0, v \geq 0 \end{aligned} \tag{4}$$

3) SLACKS-BASED MEASURE MODEL (SBM)

The Slacks-Based Measure model (SBM) is proposed by Tone, i.e., also referred to Tone *et al.* [53], Pastor *et al.* [63]. SBM input-oriented under constant returns-to-scale assumption (SBM-I-C). The linear model is presented, as can be seen in model (5) below.

$$\begin{aligned} &\omega_{In}^* = \underset{\alpha,s^-,s^+}{Min}\ 1 - \frac{1}{p}\sum_{i=1}^{p} \frac{s_i^-}{a_{i0}} \\ &\text{such that } \sum_{e=1}^{n} a_{ie}\alpha_e = a_{i0} - s_i^-, i = 1, 2, \ldots, p \\ &\sum_{e=1}^{n} b_{re}\alpha_e = b_{r0} + s_r^+, r = 1, 2, \ldots, q \\ &\alpha_e \geq 0, e = 1, 2, \ldots, n \\ &s_i^- \geq 0, i = 1, 2, \ldots, p \\ &s_r^+ \geq 0, r = 1, 2, \ldots, q \end{aligned} \tag{5}$$

where ω_{In}^* denotes SBM-I-C efficiency.

Its inverse, SBM output-oriented under constant returns-to-scale assumption (SBM-O-C). The linear model is presented in model (6) as follows.

$$\begin{aligned} &1/\omega_{Out}^* = \underset{\alpha,s^-,s^+}{Max}\ 1 + \frac{1}{q}\sum_{r=1}^{q} \frac{s_r^+}{b_{r0}} \\ &\text{such that } \sum_{e=1}^{n} a_{ie}\alpha_e = a_{i0} - s_i^-, i = 1, .., p \\ &\sum_{e=1}^{n} b_{re}\alpha_e = b_{r0} + s_r^+, r = 1, .., q \\ &\alpha_e \geq 0, e = 1, 2, \ldots, n \\ &s_i^- \geq 0, i = 1, 2, \ldots, p \\ &s_r^+ \geq 0, r = 1, 2, \ldots, q \end{aligned} \tag{6}$$

TABLE 1. Scale of relative importance.

Intensity of importance	Definition
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate values

B. ANALYTIC HIERARCHY PROCESS (AHP)

In this procedure, pairwise comparison matrix is used for finding priorities on each level of the hierarchy using scale of relative importance as Table 1 follows [64].

The step-by-step procedure of AHP is listed as follows.

Step 1: List the overall goal, criteria, and decision alternatives, and build the hierarchical tree as shown in Figure 2 below.

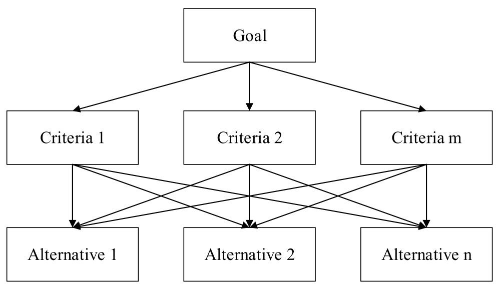

FIGURE 2. A structure of the hierarchical tree.

Step 2: Develop pairwise comparison matrices. In the pairwise comparison matrix, the importance of the criteria and sub-criteria is scored by experts. The k-by-k matrix includes k rows and k columns. The a_{ij} element denotes the importance of the row i index compared to the column j index.

$$A = (a_{ij})_{k\times k} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1k} \\ a_{21} & 1 & \cdots & a_{2k} \\ \vdots & \vdots & \vdots & \vdots \\ a_{k1} & a_{k2} & \cdots & 1 \end{bmatrix} \tag{7}$$

Step 3: Develop normalized matrices. Divide each of the numbers in a column of the comparison matrix by its column sum.

Step 4: Develop priority vector. The priority vector (f) is determined by averaging the row entries in the normalized matrix.

Step 5: Calculate consistency ratio. In this step, the relevant priorities are provided by the priority vector (f) matching to the largest eigenvector (λ_{max}).

$$A \times f = \lambda_{max} \times f \tag{8}$$

TABLE 2. The values of random index (*RI*).

n	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41
n	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
RI	1.45	1.49	1.51	1.48	1.56	1.57	1.59	

The consistency index (*CI*) is calculated based on the largest value of the eigenvector (λ_{max}) and the number of criteria (n).

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (9)$$

The consistency ratio (*CR*) is built according to the ratio of the consistency index (*CI*) and the random index (*RI*), i.e., as can be seen in Table 2.

$$CR = \frac{CI}{RI} \quad (10)$$

If $CR \leq 0.1$, the results are satisfactory. Otherwise, the pairwise comparision matrix must be re-evaluated.

Step 6: Compute the overall weight of the objective function.

$$\begin{aligned} Function\ 1 &= F_{11} \times w_1 + F_{12} \times w_2 + \ldots + F_{1u} \times w_u \\ Function\ v &= F_{v1} \times w_1 + F_{v2} \times w_2 + \ldots + F_{vu} \times w_u \end{aligned} \quad (11)$$

where w_u denotes the weight of *u-th* criterion, and F_{vu} denotes the weight of the *v-th* item according to the *u-th* criterion.

IV. CASE STUDY

In this section, the proposed integrated model is applied for location optimization of solar plants in potential sites of Taiwan. Figure 3 depicts the map of solar resources in Taiwan [65].

A. SCREENING POTENTIAL SITES WITH DEA MODELS

According to the research framework, for the first stage with DEA models, 20 locations of cities and counties are considered decision-making units (DMUs), as shown in Table 3. In this stage, we aim to screen the list of locations by selecting DMUs with perfect efficiency scores (equal to 1), based on five inputs (temperature, wind speed, humidity, precipitation, air pressure) and two outputs (sunshine hours and insolation), as seen in Figure 4.

Based on the expert interview and literature review, the input and output factors are selected and defined as follows.

Input factors:

- **(I1) Temperature:**A unit of measurement that objectively describes how hot or cold an object is. If the temperature of a solar module increases, the efficiency and thus also the output power of the solar module decreases [66].
- **(I2) Wind Speed:** Wind is the movement of gas particles. Solar installations must be able to withstand the

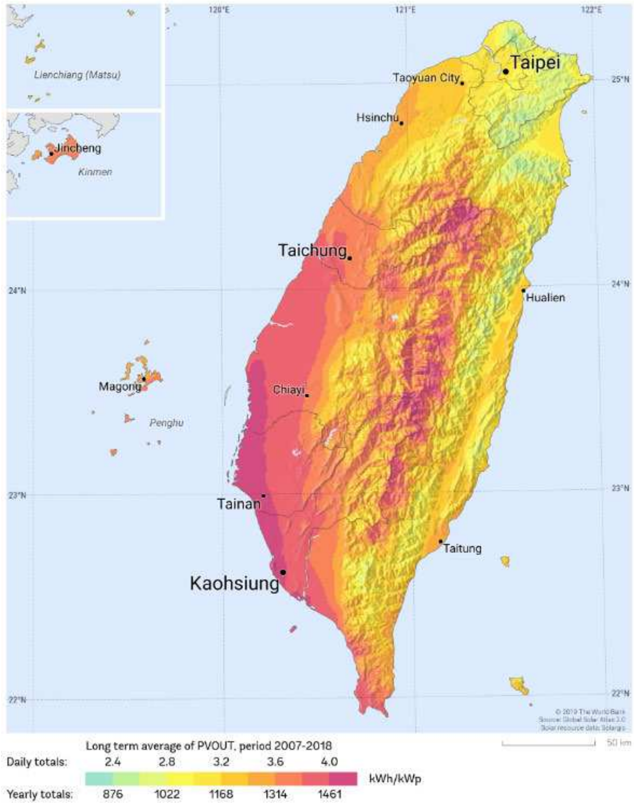

FIGURE 3. The map of solar radiation in Taiwan.

TABLE 3. The list of 20 locations (DMUs) in Taiwan.

No.	Location	DMUs	No.	Location	DMUs
1	Taipei	PL-01	11	Changhua	PL-11
2	New Taipei	PL-02	12	Yunlin	PL-12
3	Taichung	PL-03	13	Chiayi	PL-13
4	Tainan	PL-04	14	Pingtung	PL-14
5	Kaohsiung	PL-05	15	Yilan	PL-15
6	Keelung	PL-06	16	Hualien	PL-16
7	Taoyuan	PL-07	17	Taitung	PL-17
8	Hsinchu	PL-08	18	Penghu	PL-18
9	Miaoli	PL-09	19	Kinmen	PL-19
10	Nantou	PL-10	20	Lienchiang	PL-20

wind load and the uplift caused by the wind. Wind can be the cause of operational failures and contributes to the wear and tear of the systems. High wind speeds can also cause more dust particles to adhere to the surface of the solar modules, thereby reducing power output [67].

- **(I3) Humidity:** Humidity describes the amount of water vapor in the air. Water droplets in the air refract, reflect, or bend the sun's light. Air humidity thus influences the radiant intensity of sunlight and leads to lower efficiency of the solar modules [68]. High humidity can contribute to the formation of dew on the surface of the solar panel. This causes dust from the air to collect more

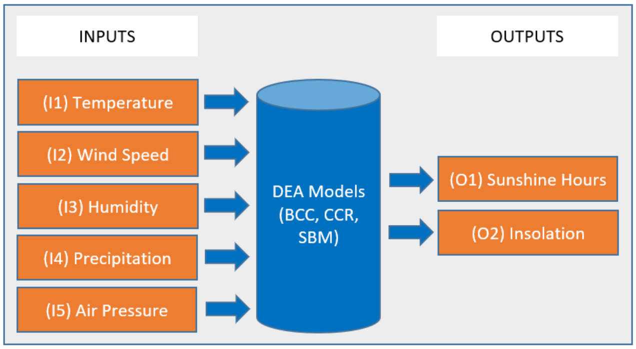

FIGURE 4. Input and output factors of DEA models.

easily on the modules [69], resulting in lower output power [70].

- **(I4) Precipitation:** The precipitation of rain, snow, sleet, or hail. Due to the darkening of the sun by clouds, the output power of the solar plants is reduced.
- **(I5) Air Pressure:** Air pressure is the force exerted on the earth's surface by the weight of the air. With increasing altitude, the air pressure decreases. As altitude increases, the ambient temperature decreases, allowing the solar system to operate more efficiently. The amount of direct sunlight is greater because there are fewer layers of air that scatter, absorb, and reflect sunlight.

Output factors:

- **(O1) Sunshine Hours:** Sunshine hours describe the duration of sunshine at a particular place over a certain period of time (year). Sunshine is defined as solar radiation of 120 W/m^2 or more [71]. The total power generated by the solar module depends on the duration of sunshine.
- **(O2) Insolation:** The amount of solar radiation (kWh) that reaches a certain area (m^2) over a certain period of time (year).

The data of input and output factors of 20 locations are collected [72], [73], as can be seen in Table 11 (Appendix A). The statistics on input and output factors data, i.e., maximum, minimum, average, standard deviation, are described in Table 4. The data will be used to carry out the CCR-I, CCR-O, BCC-I, BCC-O, SBM-I-C, and SBM-O-C models. This step will be conducted using the DEA-Solver software to determine the potential DMUs (locations) by evaluating their efficiency indices. The selected DMUs will then be analyzed in the next stage using the AHP model.

B. RANKING THE REMAINING LOCATIONS WITH AHP

In this stage, the AHP method is applied to rank the results from the DEA models. Within this step, five effective evaluation criteria, including site characteristics, technical, economic, social, environmental determinants, were analyzed. Each of the factors decomposes into four sub-criteria, so the total number of sub-criteria is 20. The criteria and sub-criteria are selected based on the experiences of the related experts and preferences from relevant previous studies, as summarized in Table 12. Then, they are labeled and described as shown in Table 5. By applying the AHP methodology, the weights of the factors (i.e., criteria and sub-criteria) and the alternatives (locations) that influence the decision-making process for PV sites will be obtained. This is supported by experts in the field of renewable energies.

TABLE 4. Statistics on input and output factors data.

Factors	Unit	Max	Min	Average	SD
(I1) Temperature	°C	26.39	19.88	23.97	1.58
(I2) Wind Speed	m/s	12.88	5.50	8.62	1.95
(I3) Humidity	%	89.08	72.17	76.76	4.05
(I4) Precipitation	mm/year	4,278.40	522.30	1,519.24	898.60
(I5) Air Pressure	hPa	1,013.55	902.55	1,000.60	29.73
(O1) Sunshine Hours	h/year	2,685.70	1,105.30	1,969.97	457.07
(O2) Insolation	kWh/m^2/year	1,865.36	987.68	1,424.83	219.70

The following procedure presents an example of weight determination (weights of eigenvector) of the main criteria (C1, C2, C3, C4, and C5) and the calculation of the consistency ratio. Similar procedures for sub-criteria and alternatives are applied to obtain their weights. The pairwise comparison matrices among the main criteria are conducted by interviewing experts in the field of renewable energy in Taiwan, as can be seen in Table 6.

To obtain the weights of the main criteria, the normalized matrix of the pairwise comparison is calculated by dividing each number in a column of the comparison matrix by its column sum. In addition, the priority vector (i.e., the weight of the main criteria) is determined by averaging the row entries in the normalized matrix, as presented in Table 7.

In this step, the largest eigenvector (λ_{max}) is calculated in order to determine the consistency index (CI), the random index (RI), and the consistency ratio (CR), as follows.

$$\begin{bmatrix} 1 & 1/3 & 1/5 & 1/7 & 1/3 \\ 3 & 1 & 1/3 & 1/5 & 1/2 \\ 5 & 3 & 1 & 1/3 & 3 \\ 7 & 5 & 3 & 1 & 5 \\ 3 & 2 & 1/3 & 1/5 & 1 \end{bmatrix} \times \begin{bmatrix} 0.047 \\ 0.094 \\ 0.243 \\ 0.494 \\ 0.122 \end{bmatrix} = \begin{bmatrix} 0.238 \\ 0.475 \\ 1.291 \\ 2.633 \\ 0.631 \end{bmatrix}$$

$$\begin{bmatrix} 0.238 \\ 0.475 \\ 1.291 \\ 2.633 \\ 0.631 \end{bmatrix} / \begin{bmatrix} 0.047 \\ 0.094 \\ 0.243 \\ 0.494 \\ 0.122 \end{bmatrix} = \begin{bmatrix} 5.103 \\ 5.033 \\ 5.037 \\ 5.335 \\ 5.160 \end{bmatrix}$$

This paper considers five main criteria. Hence, we get $n = 5$. Consequently, λ_{max} and CI are calculated as follows.

$$\lambda_{max} = \frac{5.103 + 5.033 + 5.037 + 5.335 + 5.160}{5} = 5.188$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{5.188 - 5}{5 - 1} = 0.047$$

For $n = 5$, we obtain $RI = 1.12$, and the consistency ratio (CR) is calculated as follows.

$$CR = \frac{CI}{RI} = \frac{0.047}{1.12} = 0.042$$

TABLE 5. Descriptions of criteria and sub-criteria.

Criteria and Sub-criteria	Descriptions
C1. Site Characteristics	
C11. Ecology	Description of the environmental situation, including the relationship between organisms and the nature surrounding them.
C12. Elevation	Height distance to sea level.
C13. Geology	The nature and structure of the earth's surface, as well as processes shaping and changing the earth's surface.
C14. Population density	The number of people living in a given area.
C2. Technical	
C21. Distance from power network	The distance from the solar plant (power generators) to the existing electricity network.
C22. Distance from city/urban area	The distance from the solar plant (power generators) to cities and urban areas.
C23. Distance from industrial park	The distance from the solar plant (power generators) to industrial parks.
C24. Transportation infrastructure	The distance from the solar plant (power generators) to transport infrastructure.
C3. Economic	
C31. Electricity consumption demand	The demand for electricity consumed by people and industry in a given area.
C32. Construction cost	The construction costs of the solar plant installation, including necessary infrastructure such as roads and buildings.
C33. Operation and maintenance cost	Operating costs of the solar plant, including repair and maintenance costs.
C34. Electric power transmission cost	Costs that arise when electricity is transmitted from a solar power plant to an electrical substation near the centers of consumption.
C4. Social	
C41. Life quality of resident	Influence on the quality of life through the construction of solar plants.
C42. Support mechanisms	Political commitment to support solar projects, such as feed-in tariffs, favorable financing, tax reductions, or other subsidies.
C43. Social regulatory compliance	Acceptance within the public for the construction of solar plants.
C44. Government policies and laws	Influence of laws and regulations on the construction of solar systems.
C5. Environmental	
C51. Topography	The nature of the terrain in which solar systems are to be installed. This includes existing waters, land use such as agriculture or natural plant growth, as well as buildings (e.g., cities) and traffic routes.
C52. Land availability	Available area for the construction of solar plants.
C53. Human safety condition	Impact of solar plants on human health and the aesthetics of the environment.
C54. Wildlife and habitat	Influences of solar plants on the habitat of wildlife and other organisms.

TABLE 6. Pairwise comparison matrix among criteria.

Criteria	C1	C2	C3	C4	C5
C1	1	1/3	1/5	1/7	1/3
C2	3	1	1/3	1/5	1/2
C3	5	3	1	1/3	3
C4	7	5	3	1	5
C5	3	2	1/3	1/5	1
Column Sum	19	34/3	73/15	197/105	59/6

From the result, $CR = 0.042 < 0.1$, therefore the pairwise comparison matrix is consistent, and the results are satisfactory.

TABLE 7. Normalized matrix of pairwise comparison matrix.

Criteria	C1	C2	C3	C4	C5	Weight
C1	0.053	0.029	0.041	0.076	0.034	0.047
C2	0.158	0.088	0.068	0.107	0.051	0.094
C3	0.263	0.265	0.205	0.178	0.305	0.243
C4	0.368	0.441	0.616	0.533	0.508	0.494
C5	0.158	0.176	0.068	0.107	0.102	0.122
Column Sum	1	1	1	1	1	1

Based on this procedure, the weight determination of the criteria, sub-criteria, and alternatives will be conducted using the Expert Choice software.

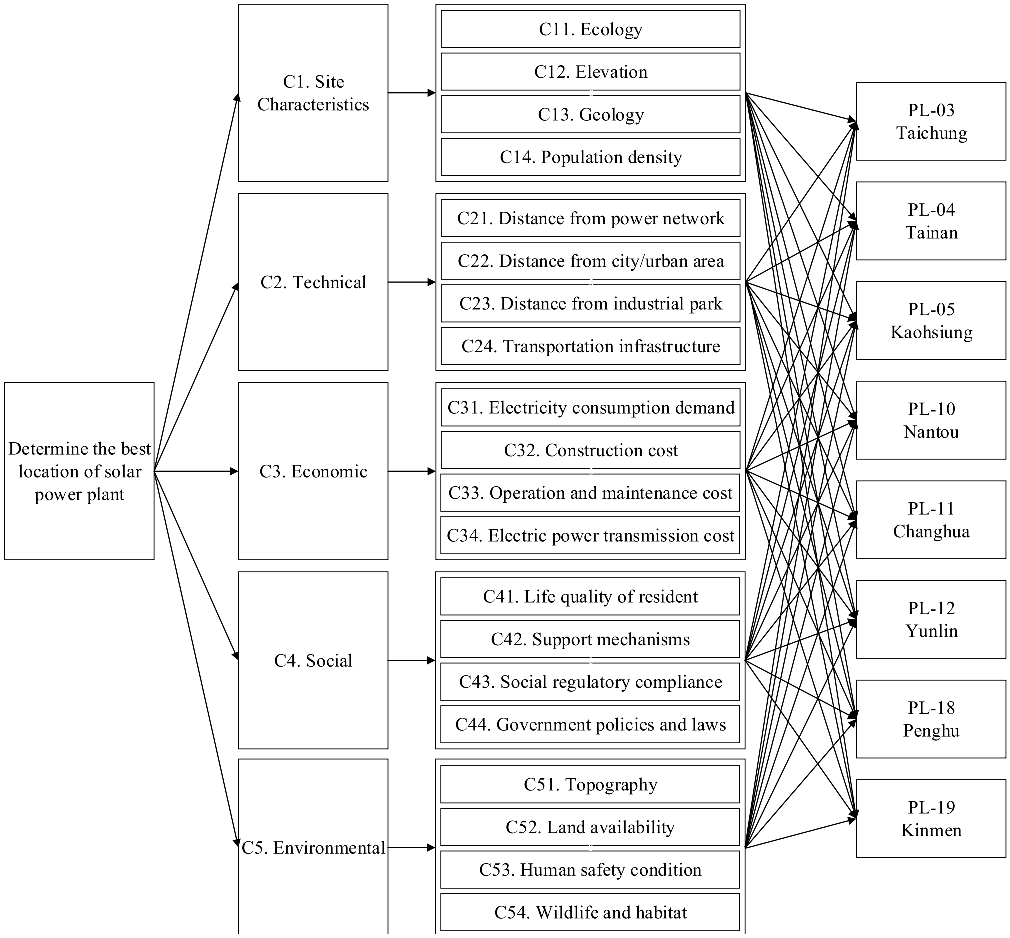

FIGURE 5. The hierarchical tree for determining solar power plants in Taiwan.

V. RESULTS AND DISCUSSION

As solar energy reduces the need for energy imports and represents a reliable and cost-effective way to generate electricity, it is part of the energy strategy of many countries. This study aims to help both governments and private investors make the most out of solar energy by providing a guideline for finding suitable locations to install solar power plants. The map of solar radiation in Figure 3 already gives an idea of suitable areas within Taiwan but shows only one aspect of many others for site selection. To address the issue in its entirety, two MCDM models were combined to consider all aspects involved in solar power plant siting decisions. In this context, 20 areas were chosen to represent all of Taiwan, including areas that seemed unsuitable at first glance.

A. DEA RESULTS

DEA models were applied to filter out the areas with the most potential so they can be looked at in further detail. In doing so, efficiency indices of the DMUs (locations) were measured using temperature, wind speed, humidity, precipitation, and air pressure as inputs, and sunshine hours and insolation as outputs. For the concept of DEA, the more the outputs increase and the more the inputs decrease, the better efficiency a DMU achieves. In the case study, the inputs wind

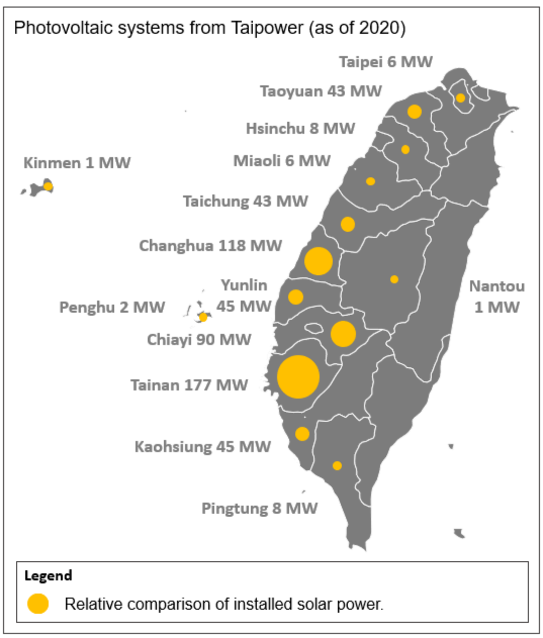

FIGURE 6. Map of solar power plants operated by Taipower.

speed and precipitation were described as decreasing the efficiency of the PV system. In fact, wind also has a cooling effect

TABLE 8. Efficiencies of the 20 locations.

No.	Location	DMUs	CCR-I	CCR-O	BCC-I	BCC-O	SBM-I-C	SBM-O-C
1	Taipei	PL-01	0.5892	0.5892	0.9904	0.5949	0.5492	0.5859
2	New Taipei	PL-02	0.6639	0.6639	0.9749	0.6693	0.6106	0.6555
3	Taichung	PL-03	1	1	1	1	1	1
4	Tainan	PL-04	1	1	1	1	1	1
5	Kaohsiung	PL-05	1	1	1	1	1	1
6	Keelung	PL-06	0.6516	0.6516	0.9628	0.6665	0.5490	0.6438
7	Taoyuan	PL-07	0.8220	0.8220	0.9452	0.8370	0.7404	0.8196
8	Hsinchu	PL-08	0.9044	0.9044	0.9992	0.9087	0.8944	0.9036
9	Miaoli	PL-09	0.7976	0.7976	0.9790	0.8146	0.6253	0.6204
10	Nantou	PL-10	1	1	1	1	1	1
11	Changhua	PL-11	1	1	1	1	1	1
12	Yunlin	PL-12	1	1	1	1	1	1
13	Chiayi	PL-13	0.9839	0.9839	0.9926	0.9866	0.9733	0.9093
14	Pingtung	PL-14	0.9169	0.9169	0.9751	0.9169	0.8664	0.9168
15	Yilan	PL-15	0.6361	0.6361	0.9514	0.6584	0.5837	0.6245
16	Hualien	PL-16	0.6811	0.6811	0.9680	0.6830	0.6370	0.6716
17	Taitung	PL-17	0.9691	0.9691	0.9733	0.9693	0.9238	0.8773
18	Penghu	PL-18	1	1	1	1	1	1
19	Kinmen	PL-19	1	1	1	1	1	1
20	Lienchiang	PL-20	0.8676	0.8676	1	1	0.7713	0.8568

that enhances the efficiency of PV modules, where 1 degree Celsius decrease in the temperature of the solar module can result in a 0.5% increase in efficiency [74]. Precipitation can help PV solar modules to operate more efficiently by washing away dirt, dust, or pollen [75]. Despite the above facts, the negative effects of wind speed and precipitation are found to massively outweigh the positive effects. As previously outlined, high winds can cause PV system operational outages, and the obscuring of the sun by clouds during rain reduces the output power of PV systems. Although temperatures vary comparatively little across Taiwan, with moderate differences in the north and south, Taiwan's diverse geography and climate result in different conditions for solar power that vary by location. The resulting difference in temperature makes some locations more suitable for solar power generation than others. Therefore, the case study also considers temperature as a criterion for solar power plant efficiency.

By choosing the inputs and outputs of the DEA models, a balanced set of constraints was established to cover the most impactful aspects. This also ensured to ignore sites that had high scores in only one aspect but were deficient in other aspects. Table 8 shown the efficiency scores achieved by the DMUs. As can be seen, eight DMUs achieve perfect efficiency scores of 1 in all DEA models, which are Taichung (PL-03), Tainan (PL-04), Kaohsiung (PL-05), Nantou (PL-10), Changhua (PL-11), Yunlin (Pl-12), Penghu (PL-18), and Kinmen (PL-19). These eight DMUs are considered the most potential alternatives of locations for PV sites so that they are selected for analysis in the next stage of the AHP model.

B. FINAL RANKING RESULTS FROM AHP

The AHP method was applied to compare and rank the results from the DEA models. Because the AHP allows both qualitative and quantitative factors to be considered, the study used a broad set of criteria to look at the topic from all aspects. This made it possible to consider social criteria such as the acceptance of solar energy in the population as well as site characteristics, technical criteria, economic and ecological criteria together. To obtain reliable results, studies and experts relevant to the implementation of the AHP were consulted. The hierarchical tree of the AHP method with the sites obtained from the DEA models is shown in Figure 5. The priorities and synthesized priorities of the criteria and sub-criteria used for the final ranking within the AHP methodology are presented in Table 9. A calculation for this was shown in the case study. For criteria weighting results, social (C4) has the most priority (0.494) among the five criteria. Elevation (C12), distance from the solar plant (C23), electric power transmission cost (C34), support mechanisms (C42), and topography (C51) are the most significant sub-criteria in their set. According to the synthesized ranking, "support

TABLE 9. Priorities and synthesized priorities of criteria and sub-criteria.

Criteria	Sub-criteria	Priorities	Rank	Synthesized Priorities	Synthesized Rank
C1. Site Characteristics (0.047)	C11	0.040	4	0.002	20
	C12	0.553	1	0.025	12
	C13	0.315	2	0.014	13
	C14	0.092	3	0.004	19
C2. Technical (0.094)	C21	0.057	4	0.005	18
	C22	0.403	2	0.037	8
	C23	0.432	1	0.039	7
	C24	0.108	3	0.010	14
C3. Economic (0.243)	C31	0.354	2	0.086	3
	C32	0.037	4	0.009	15
	C33	0.111	3	0.027	11
	C34	0.498	1	0.122	2
C4. Social (0.494)	C41	0.060	4	0.030	9
	C42	0.663	1	0.332	1
	C43	0.143	2	0.072	5
	C44	0.134	3	0.067	6
C5. Environmental (0.122)	C51	0.647	1	0.077	4
	C52	0.062	3	0.007	16
	C53	0.059	4	0.007	17
	C54	0.232	2	0.028	10

mechanisms,'' ''electric power transmission cost,'' and ''electricity consumption demand'' with weights of 0.332, 0.122, and 0.086, respectively, were found as the most significant sub-criteria.

The AHP results, based on the final performance of the DMUs, are summarized in Table 10 with the final ranking of the sites based on their scores according to the selected criteria and sub-criteria. The most optimal location for implementing solar PV projects is PL-04 (Tainan) with a final score of 0.186, followed by PL-11 (Changhua) and PL-05 (Kaohsiung). Figures 7 to 12 (Appendix A) demonstrate the weights of the alternatives according to criteria and sub-criteria. It can be observed that although Tainan ranked the first overall, Changhua, Kaohsiung, and Taichung perform similarly well in the main criteria. This applies in particular to the criteria ''site characteristics'' and ''environment'', where these sites score very comparably. Yunlin and Nantou, as less densely populated areas with little industry and consequently lower electricity demand, rank comparatively lower. The largely mountainous terrain in Nantou, with a smaller power grid, also results in higher power transmission costs. Kinmen and Penghu scored low on all criteria. Since this study aims to identify the most promising areas for solar energy in Taiwan, the authors would exclude these two sites in future research to look at other areas that could achieve a higher score within an AHP ranking.

TABLE 10. The final ranking order of solar power plants in Taiwan.

DMUs	Location	Final Score	Ranking Order
PL-04	Tainan	0.186	1
PL-11	Changhua	0.174	2
PL-05	Kaohsiung	0.148	3
PL-03	Taichung	0.144	4
PL-12	Yunlin	0.133	5
PL-10	Nantou	0.112	6
PL-18	Penghu	0.071	7
PL-19	Kinmen	0.032	8

Figure 6 shows solar power plants operated by the state-owned utility Taipower [76]. Since the map does not include private solar power plants, it cannot reflect the overall situation in Taiwan, but it still provides a good basis for comparing the final AHP results, since the largest solar power plants are operated by Taipower. The largest power plants are thereby located in Tainan (177 MW) and Changhua (118 MW). Most of the installed capacity in Tainan and Changhua comes from two 150 MW and 100 MW solar power plants, respectively. The plant in Tainan utilizes former salt fields for this purpose and can supply 55,000 households with electricity

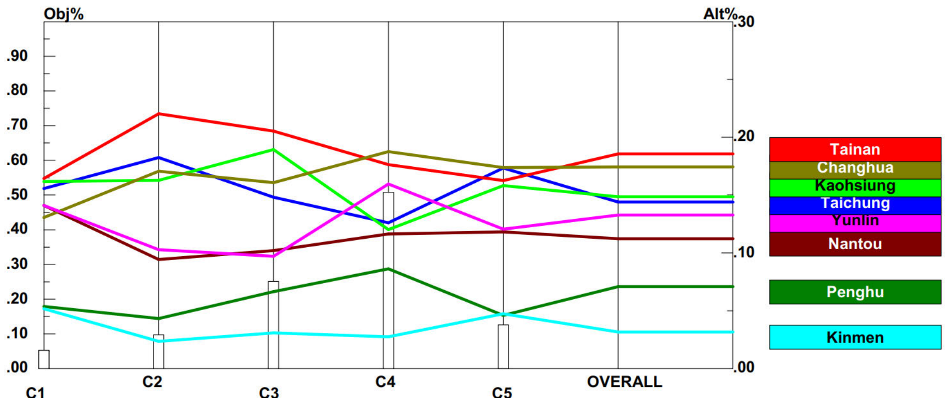

FIGURE 7. The weights of the alternatives according to five main criteria.

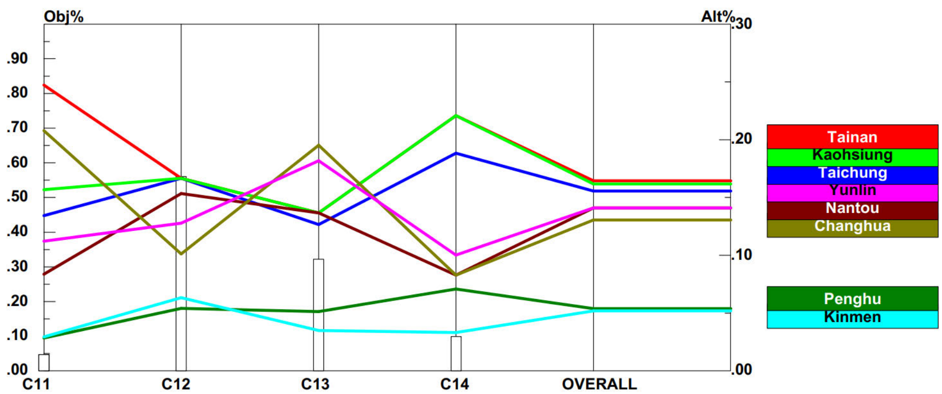

FIGURE 8. The weights of the alternatives according to sub-criteria (site characteristics).

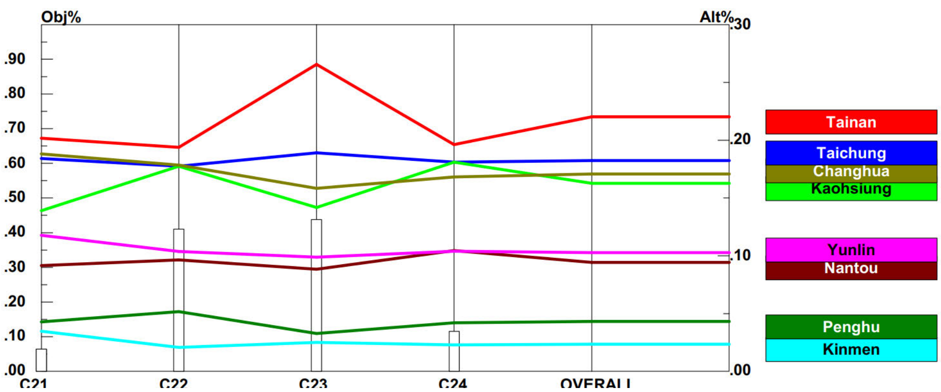

FIGURE 9. The weights of the alternatives according to sub-criteria (technical).

annually [77]. As Taiwan continues to expand solar energy, another 320 MW power plant is planned for Changhua [78] and a 500 MW solar power project for Kaohsiung [79]. To achieve Taiwan's self-imposed energy goals as well as to contribute against climate change, solar energy must be expanded throughout Taiwan. However, in view of the results, the authors recommend further analysis of the Tainan, Changhua, Kaohsiung, and Taichung areas, as these regions are very promising.

VI. CONCLUSION AND FUTURE WORKS

Global warming, as well as recent developments such as the Covid-19 pandemic, pose major challenges to countries around the world. However, for every challenge, there are also opportunities that both governments and private investors can take advantage of. Renewable energy is such an opportunity as it helps reduce dependence on fossil fuels, boosts the economy, and contributes to the further growth and development of countries. Like many other countries, the Taiwanese government wants to seize this opportunity and is promoting renewable energy as part of the ''Five Plus Two Plan'' and other national policies. As a low-cost and abundant form of energy, solar power is planned to make the largest contribution within the ''Five-Plus-Two'' plan and is receiving much attention worldwide due to its positive attributes. To make the most out of solar energy, choosing the right place for

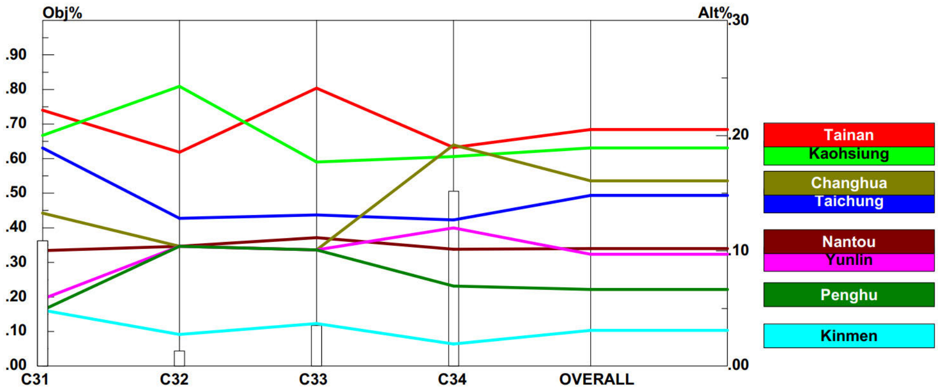

FIGURE 10. The weights of the alternatives according to sub-criteria (economic).

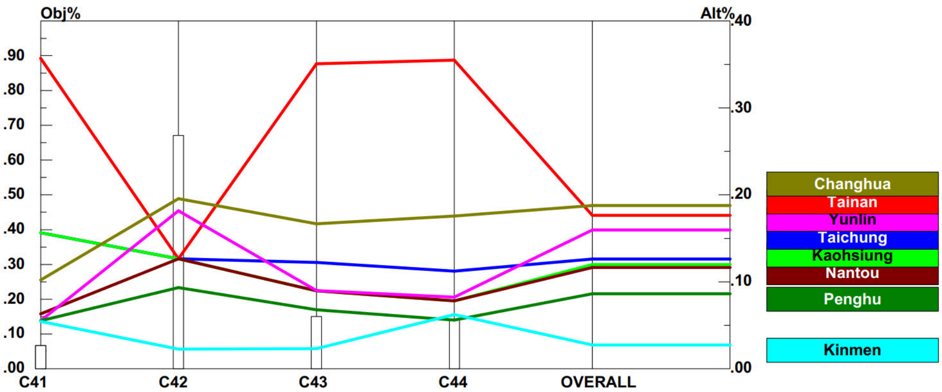

FIGURE 11. The weights of the alternatives according to sub-criteria (social).

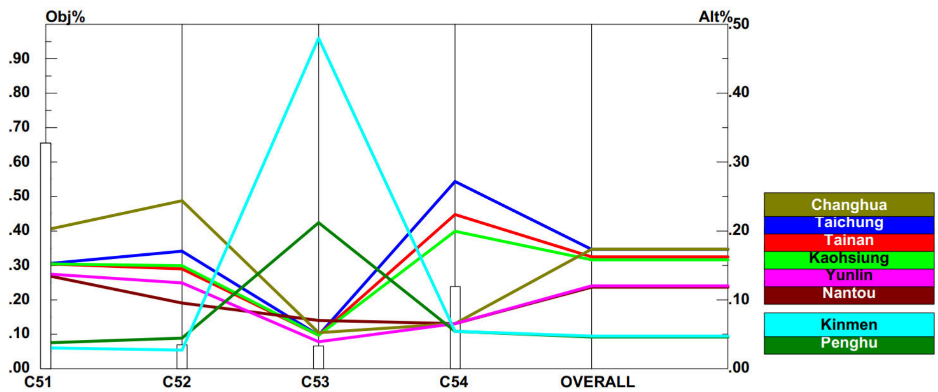

FIGURE 12. The weights of the alternatives according to sub-criteria (environmental).

the installation is important. This study aims to provide an effective guideline to facilitate the analysis of large areas to filter out a few high-efficiency sites that can then be studied in more detail. By combining the two MCDM models DEA and AHP, large areas can be analyzed according to different criteria. The DEA model is hereby used to filter out locations as a function of inputs and outputs, while the AHP model is used to rank these results with the help of experts and relevant studies. In this manner, 20 areas in Taiwan were analyzed, with the final ranking of 1st Tainan, 2nd Changhua, 3rd Kaohsiung, 4th Taichung, 5th Yunlin, 6th Nantou, 7th Penghu, and 8th Kinmen. A comparison of the results with solar power plants already built and planned in Taiwan supports the methodology used in the study. To assist Taiwan's further development, the study encourages both the government and private investors to consider Yunlin and Taichung for the installation of new solar power plants, as these areas are very promising.

The contributions of this paper can be summarized as follows. Methodologically, this paper proposes a combined DEA and AHP approach for solar resource assessment under various qualitative and quantitative factors. The case study of solar energy in Taiwan is used to demonstrate the model's effectiveness. From the literature review, there has not been

TABLE 11. Collected data of input and output factors.

No.	Location	DMUs	(I1)	(I2)	(I3)	(I4)	(I5)	(O1)	(O2)
1	Taipei	PL-01	24.3	7.6	73.3	1,686.3	1,010.6	1,431.3	987.7
2	New Taipei	PL-02	23.8	6.8	75.4	2,018.0	1,012.9	1,500.9	1144.5
3	Taichung	PL-03	24.5	5.5	72.2	1,169.5	1,003.4	2,401.3	1554.0
4	Tainan	PL-04	25.3	9.0	72.6	1,533.0	1,010.5	2,685.7	1677.4
5	Kaohsiung	PL-05	26.4	7.4	73.4	2,124.3	1,012.8	2,656.5	1508.9
6	Keelung	PL-06	23.6	9.6	77.2	3,252.6	1,011.0	1,492.8	1179.4
7	Taoyuan	PL-07	23.3	12.9	80.1	1,253.1	1,011.8	1,905.4	1451.8
8	Hsinchu	PL-08	23.8	6.2	73.3	1,120.5	1,010.5	2,091.0	1424.4
9	Miaoli	PL-09	23.8	8.7	89.1	4,278.4	921.9	1,105.3	1519.6
10	Nantou	PL-10	19.9	6.3	78.4	1,789.0	902.6	1,777.6	1865.4
11	Changhua	PL-11	23.8	12.9	75.1	593.5	1,010.6	2,579.4	1505.9
12	Yunlin	PL-12	25.8	7.2	75.0	563.8	1,006.8	1,625.4	1409.6
13	Chiayi	PL-13	24.7	7.7	74.1	1,075.3	1,009.8	2,444.1	1330.5
14	Pingtung	PL-14	26.0	10.4	79.2	1,273.5	1,010.2	2,432.2	1495.7
15	Yilan	PL-15	23.6	8.5	78.6	2,061.8	1,013.6	1,425.3	1175.3
16	Hualien	PL-16	24.4	10.3	76.3	1,285.4	1,011.8	1,656.2	1169.2
17	Taitung	PL-17	25.2	7.2	75.8	1,100.7	1,012.4	1,912.2	1605.9
18	Penghu	PL-18	24.3	9.2	82.2	819.8	1,012.4	2,279.8	1742.3
19	Kinmen	PL-19	22.7	9.5	73.0	522.3	1,011.5	2,144.4	1543.5
20	Lienchiang	PL-20	20.4	9.4	81.2	863.9	1,005.0	1,852.5	1205.4

TABLE 12. The list of criteria used in relevant previous studies.

Authors [reference]	Ecology	Elevation	Geology	Population density	Distance from power network	Distance from city/urban area	Distance from industrial park	Transportation infrastructure	Electricity consumption demand	Construction cost	Operation and maintenance cost	Electric power transmission cost	Life quality of resident	Support mechanisms	Social regulatory compliance	Government policies and laws	Topography	Land availability	Human safety condition	Wildlife and habitat
Nasab et al. [84]	x	x	x		x			x	x	x	x			x	x	x				
Suganthi [85]	x	x	x		x			x	x	x	x			x	x	x				
Thongpun et al. [86]		x							x	x					x	x		x		
Lozano et al. [58]		x			x	x	x													
Vafaeipour [87]		x							x	x	x				x	x	x	x		x
Nixon et al. [88]		x								x	x			x				x		
Zheng [89]	x		x	x							x									
Kengpol [90]	x	x	x		x	x	x	x		x	x							x		
Pambudi and Nananukul [91]				x				x	x									x		
Akkas [92]	x	x	x		x															
Lee [93]										x	x	x	x	x		x	x	x	x	x

carried out a thorough investigation examining the locations of Taiwan as demonstrated in this research using the proposed hybrid approach. This can constitute the novelty of the study and as a research gap requiring to be bridged. For managerial implications, the findings of this study could be a significant material for renewable energy stakeholders in Taiwan and other countries to expedite renewable energy development in the light of rapid technological progress, ambitious national commitments to environmental protection, and sustainable development goals. Since the tools used in the study can be applied anywhere in the world, this study can be a helpful guide for other researchers, governments, or private investors. By using the MCDM models, a basis for informed decisions is provided to save costs and resources in the planning phase of solar power plants or any other renewable energy projects.

In future research, hybrid renewable energy systems such as solar PV-wind and solar-biomass should be considered for Taiwan to obtain more cost-effective and technically feasible renewable energy source projects. Accordingly, assessing capabilities in producing such many types of renewable energy sources is almost required [80] and can make significant contributions to the renewable energy development of Taiwan. Comprehensive research can be carried out by including other evaluation criteria to enhance the proposed model, such as land price, land slope, cloudiness, and other factors that might be influential in the solar PV site selection, especially in today's situation (i.e., the post-Covid-19 pandemic). In terms of methodologies, applying other effective MCDM techniques such as TOPSIS, VIKOR, and ELECTRE, as well as conducting a comparative analysis of such methods towards an insightful understanding of the best approach, are potential directions for future research. Fuzzy MCDM or fractional fuzzy systems [81]–[83] should be adopted to consider renewable energy projects under uncertain environments.

APPENDIX

See Figures 7–12 and Tables XI and XII.

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CHIA-NAN WANG received the Ph.D. degree from the Department of Industrial Engineering and Management, National Chiao Tung University, Taiwan, in 2004. He is currently a Professor with the Department of Industrial Engineering and Management, National Kaohsiung University of Science and Technology, Taiwan. He has published around 150 journal articles and 50 patents. He achieves around 35 projects of research and academy and has some successful cases of technology transfer. He has plenty of practical experiences in many industries and provides consultant services for several stock companies in Taiwan. His research interests include manufacturing automation, industrial applications, operation research, management of technology, and systematic innovation. He was a recipient of awards from many international invention competitions, including two Gold Medal Awards, five Silver Medal Awards, and several Bronze Medal Awards.

NGOC-AI-THY NGUYEN received the M.Eng. degree in logistics and supply chain systems engineering from the Sirindhorn International Institute of Technology (SIIT), Thammasat University, Thailand, in 2020. She is currently pursuing the Ph.D. degree in industrial engineering and management with the National Kaohsiung University of Science and Technology (NKUST), Taiwan. Her research interests include operational research, supply chain management, data envelopment analysis, and procurement.

THANH-TUAN DANG received the M.Eng. degree in logistics and supply chain systems engineering from the Sirindhorn International Institute of Technology (SIIT), Thammasat University, Thailand, in 2018. He is currently pursuing the Ph.D. degree in industrial engineering and management with the National Kaohsiung University of Science and Technology (NKUST), Taiwan. He has published ten ISI journal articles. His research interests include group decision making, data envelopment analysis (DEA), multi-criteria decision analysis (MCDA), fuzzy set theory, applied operations research, forecasting, production planning and inventory control, lean manufacturing, logistics and supply chain network design, and design of experiment (DOE).

JULIUS BAYER received the bachelor's degree in business and engineering from the University of Applied Sciences Würzburg, Schweinfurt, Germany, in 2019. He is currently pursuing the master's degree in industrial engineering and management with the National Kaohsiung University of Science and Technology, Taiwan. He is very interested in applying tools to problem solving. His main subjects were electrical engineering and financial controlling. His research interests include quantitative decision science and statistical quality management.