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Research Article

Exploring Promotion Effect for FIT Policy of Solar PV Power Generation Based on Integrated ANP: Entropy Model

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The photovoltaic (PV) industry is an important developmental direction of the global new energy industry, and it is also a strategic emerging industry of China with an international competitive advantage. China's PV industry has developed rapidly in recent years, and the new installed capacity of PV power generation has been ranked first in the world for 5 years. This achievement is inseparable from the support of national policy, especially the Feed-in Tariff (FIT) policy of solar PV power generation, which is a primary policy of the PV industry. This paper is a study of preference elicitation, whose goal was to identify the driving factors behind historical PV policy in China, according to the opinion of a panel of experts. On this basis, this paper proposes an integrated ANP-Entropy model to evaluate the FIT policy of China in three dimensions: environmental, energy, and economic (3E). Research results show that the environmental goal is still the most significant to the development of the PV industry in China, followed by the energy and economic goals, which account for 0.405, 0.358, and 0.237, respectively. Compared with the conventional studies on energy policy evaluations, this paper integrates subjective (Analytic Network Process) and objective (Entropy Weight Method) evaluations, which makes the evaluation results more reasonable and reliable. Additionally, the 3E evaluation index system and the ANP-Entropy model proposed in this paper are also applicable to the evaluation of other renewable energy policies.

1. Introduction

In recent years, the increase of global energy consumption and the excessive use of fossil energy have led to the rapid reduction of fossil energy reserves. Moreover, it has also caused serious environmental problems like air pollution, water pollution, and abrupt climate change. To address these problems, in April 22, 2016, the leaders of 175 countries signed the Paris agreement in New York to make arrangements for the global response to climate change after 2020 [1]. This agreement calls for improving the level of clean energy consumption, guiding and encouraging the development of renewable energy, and increasing the proportion of renewable energy sources [2]. As one of the most promising renewable energies, solar PV power generation can greatly meet the long-term climate objectives of the Paris Agreement.

It is an inevitable trend to replace traditional fossil energy with clean energy. Individually and collectively, countries need to define and implement policies for accelerated clean energy transitions that are enabled by real-world solutions, supported by analysis, and built on data. Promoting sustainable development and combating climate change have become integral aspects of energy planning, analysis and policy-making. By the end of 2016, 173 countries have formulated renewable energy development plans, and 146 countries have issued support policies. From the perspective of sustainable development, PV power generation is regarded as one of the most potential renewable energy technologies because of its unique advantages of high efficiency, clean operation, and energy savings. As a highly dependent industry on policy, the rapid development of the PV industry is inseparable from the support of relevant policies. The PV industry policy mainly includes the FIT policy, consumer subsidies, Renewable Portfolio Standards (RPS), and so on, among which the FIT policy is the most widely used industrial support policy. The FIT policy is a price-driven strategy that guarantees a fixed price.

It claims that the electricity price will be set after considering the current costs of PV power generation and reasonable profits [3]. Then, the PV project developers sell power to grid enterprises at such a price. The difference between the selling price and the local desulfurization coal thermal power unit on-grid benchmarking price will be distributed to the entire grid to compensate the grid companies.

Driven by the policies of governments from various countries, the capacity of the PV industry has continued to expand. As of the end of 2017, the total installed capacity of PV power in the world exceeded 400 GW, including approximately 100 GW of new installed capacity. From the global point of view, the main countries with the largest installed capacity and market share of PV power generation are China, the United States, India, Japan, Germany, and the United Kingdom. The total new installed capacity of these main countries was up to 21% of the total new installed capacity in the world in 2017. Figure 1(a) shows the new installed capacity of PV power generation in the main areas of the world.

As for the solar PV industry in China, it started relatively late. The "12th Five-Year plan" of the electric power industry proposed to develop solar energy and pay attention to the research and development of solar power generation technology. Based on this, China has built demonstration projects of solar PV power plants in several provinces, including Gansu, Qinghai, Xinjiang, and Inner Mongolia. The lighting resources in these areas are very abundant, which is conducive to the development of PV power generation. With the continuous expansion of the scale and the cumulative learning effect of technology, China gradually formed an industrial technology system with independent characteristics and became the world's largest PV market [4]. By the end of 2017, the accumulative installed capacity of PV power in China reached 130 GW, of which the new installed capacity was 53 GW. Figure 1(b) shows the new installed capacity of PV power generation in the main areas of China.

Although China's PV industry has developed rapidly in recent years, and a series of achievements have been made, the current PV industry policy has not completely reached the expected goal. The phenomenon of "discard light" is essentially a kind of overcapacity, which is mainly concentrated in the central and western regions of China. The light resources in these areas are abundant and the cost of PV power generation is very low, but the power consumption capacity is far from enough. As a result, the generating capacity of PV power plants exceeds the sum of the maximum transmission power and load absorption of the power system, resulting in the waste of light resources. The ratio of wasted generating capacity to total generating capacity of PV power plants is "the discard light rate." For example, in 2017, the discard light rate of Gansu and Xinjiang has reached 20% and 22%, respectively. Facing serious problems of PV waste and a huge subsidy gap in renewable energy, the regulatory policy of the PV power market needs to be adjusted greatly. Limiting the scale, limiting the indicators, and reducing subsidies have become the main themes. According to the annual equivalent utilization hours of light resources, the Chinese government classified the whole country into three regions. The annual equivalent utilization hours in region I are more than 1600 hours, the annual equivalent utilization hours in region II are between 1400 and 1600 hours, and the annual equivalent utilization hours in region III are between 1200 and 1400 hours. Different regions are applicable to different PV benchmark electricity prices. According to the current situation of PV industry development, the relevant ministries and commissions issued a notice on matters relating to PV power generation on May 31, 2018, which reduced the tariff levels to 0.5, 0.6, and 0.7 CNY/kWh for Regions I, II, and III, respectively, in order to further improve the mechanism of PV electricity generation and accelerate the decline of the PV electricity price [5]. With respect to the short-term effect, the new PV policy seems too arbitrary and strict. Although it can solve some problems, it is also likely to cause some PV companies to fall into crisis and even go bankrupt. Moreover, it will make the domestic PV manufacturing industry bear the pressure of idle capacity. However, in the long run, the new PV policy has slowed down the rapid development of China's PV industry by "stepping on the brakes." It will force technological progress, give full play to the mechanism of survival of the fittest, and eliminate a batch of small enterprises that have no superior capacity and technology to leave the developmental space for high-quality PV projects.

In recent years, the multicriteria decision method is widely used in the field of renewable energy with multiple evaluation indicators, especially when some of the indicators conflict. Shen Lin et al. [6] used the fuzzy analytic hierarchy process (FAHP) to assess the Renewable Energy Development Bill which was passed by Taiwanese government in 2009. And they found that the environmental goal was the most important one to develop renewable energy so as to meet the 3E policy goals. Li Chi et al. [7] evaluated multilayered capital subsidy policy for the PV industry in China. They built 19 evaluation indicators involving economic, environmental, and energy factors and calculated the weights of each indicator by EWM. Then they used TOPSIS (Technique for Order of Preference by Similarity to the Ideal Solution) method to sort the 31 provinces and municipalities in mainland China to find regional differences about the promotion effect of PV policy.

This paper is a study of preference elicitation, whose goal was to identify the driving factors behind the FIT policy of solar PV power generation in China, according to the opinion of a panel of experts. And we use the integrated ANP-Entropy model to evaluate the effect of the FIT policy so as to provide decision support for decision-makers and other relevant departments. First, we design an evaluation index system from the three dimensions of the energy, the environment, and the economy according to expert advice and the 3E goals of renewable energy proposed by the International Energy Agency (IEA): energy security, environmental protection, and economic development [8]. On this basis, 12 subcriteria and the interactions between the criteria are identified. Second, we use ANP and the EWM to obtain the subjective weights and objective weights of the above criteria, respectively. Third, the least squares method is used to integrate the obtained subjective and objective weights into final comprehensive weights. Then, the driving factors behind

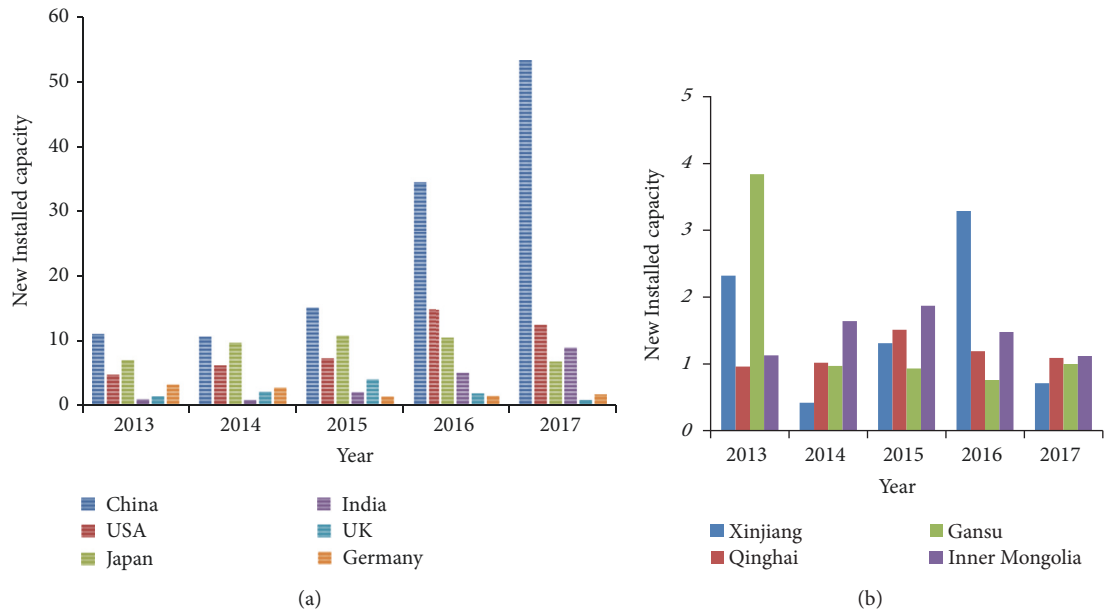

Figure 1: New installed capacity of PV power generation in the main areas of the world (a) and China (b) (Units: GW).

historical PV policy are determined, and policy guidance and industrial development proposals are proposed based on the analysis of the policy effects. Our work can solve the problem of the deviation between the promotional effect of the FIT policy and the established target.

Our main contributions of this paper are twofold. From the methodology level, this paper uses the ANP-Entropy model to analyze and evaluate the energy policy, which combines subjective and objective evaluation methods in order to make the evaluation results more accurate, reasonable, comprehensive and effective. From the aspect of the research problem, there are few relevant studies on the issue of China's PV power generation policy evaluation. Most of the existing studies are carried out from the perspective of the cost-benefit and the risk management of PV projects, which usually uses the Net Present Value (NPV) method [3] or Real Option (RO) method [9–11]. The NPV and RO methods are usually employed to assess the economic feasibility of PV policies and show the degree of economic incentives of PV policies [12]. Besides, using these two methods to evaluate the implementation effect of PV policy often involves detailed economic information such as installation cost, electricity price, PV electricity output, tax rate, discount rate, and so on. And they often provide range of economic indicators for PV policy optimization, for instance, the piecewise feed-in tariff of PV power generation and the scope of suitable subsidy standard, while the ANP and EWM methods used in this paper can explore the driving factors and key elements behind PV policy from 3E dimensions and not only evaluate the economic benefits of PV policy implementation. This article can be seen as a valuable supplement to this kind of research, and it can provide a more comprehensive and flexible energy policy evaluation method under the uncertain evaluation environment. In addition, the 3E evaluation index system and the ANP-Entropy model proposed in this paper can also be applied to other renewable energy policy evaluation problems.

The organization for the remainder of this paper is as follows. Section 2 briefly introduces the concept and application fields of the ANP and EWM. The selection of the relevant evaluation index and the construction of the evaluation index system are presented in Section 3. Section 4 illustrates the evaluation methods in detail and introduces the operation rules of the ANP and EWM as well as their specific applications in this paper. Finally, Section 5 discusses the research results and findings of the study and draws some conclusions.

2. Overview of the Methods

2.1. Analytic Network Process. Analytic Hierarchy Process (AHP) is one of the most applied methods of Multiple Attribute Decision Making (MADM), which was proposed by Professor Saaty of the University of Pittsburgh in the early 1970s using the theory of network systems and multi-objective comprehensive analysis. The most prominent advantage of the AHP approach is its ability to transform a complex problem into a clear hierarchal structure including goals, criteria, subcriteria, and alternatives. It is a mathematical technique based on the pairwise comparison matrix. By use of the pairwise comparison method, it can give the order of the alternatives (or weights) using subjective judgments and scientific calculations.

However, the AHP method does not take into account the dependency and feedback among various factors. Thus, Saaty [27] presented the ANP as a developed method of the AHP. ANP is a decision-making method that adapts to the nonindependent hierarchical structure and considers the interaction between various factors or adjacent levels and

uses "supermatrix" to analyze the factors that interact and influence comprehensively to get the mixed weights and the importance degree of each factor to decision objectives. As a widely used decision modeling method, the main advantages of the ANP are as follows:

(i) The ANP can address interdependent relationships within a multi-criteria decision-making model. In the network structure of the ANP model, all possible relationships can be characterized [28, 29].

(ii) By establishing the relationships between a set of elements (inner dependence) and among different sets of elements (outer dependence), the ANP approach ensures the accuracy of the computation and makes the results more believable [30].

(iii) Unlike the AHP, the more flexible network structure of the ANP makes it possible to describe the correlation between the elements freely, so that any complex problem or decision can be presented without considering the order of events [30, 31].

2.2. Entropy Weight Method. Entropy Weight Method is a multiobjective decision making evaluation method which is based on Shannon entropy [32]. Entropy is a thermodynamic concept. Shannon first introduced the concept into the information field to express the uncertainty of information, which was formulated in terms of probability theory. The concept of entropy is very suitable for measuring the relative intensities of contrast criteria to represent the intrinsic information used for decision-making [33]. In the past decades, the EWM has already been applied to many research fields such as clinical neurophysiology [34], transport systems [35], environmental conflict analysis [36, 37], and fault detection [38]. In these areas, entropy is applied as a measure of disorder or the extent of dependency (or complexity) of a system. In evaluation problems, the uncertainty of signals in the communication processes is called information entropy. The lower the information entropy, the higher the weight. The entropy weight of the index is determined by the relative intensity of the object's performance rating with respect to each criterion. In other words, it is based on the concept of context-dependent informational importance. As one of the widely used objective evaluation methods, the EWM is a comprehensive evaluation method that eliminates the influence of subjective factors and the relative weight is obtained based on the actual data of the indicator. EWM can provide objective weights information to evaluate the impact of different factors on decision objectives.

2.3. Integrated ANP-Entropy Model. The ANP is an evaluation method that determines indicator weights, and it mainly relies on subjective judgments and expert experience to obtain the weight of the indicator. The EWM is an objective method that determines weights according to the actual data of the indicator and the degree of information stability. To a certain extent, it can solve the problem of subjective bias and the subjective deviation. The proposed ANP-Entropy model in this paper is an organic combination of ANP and EWM. It means that both the subjective evaluation method of ANP and the objective evaluation method of EWM are used to make a comprehensive evaluation of the research object, so that a more reasonable and reliable evaluation result can be obtained. We adopt a linear combination weighting model based on the EWM and ANP to achieve the unity of the objectivity and subjectivity. From the perspective of the methodology, some researchers have applied the ANP-Entropy model in other fields before. Cao et al. [39] adopted the EWM to select the evaluation indexes about resource-based cities' innovative capacity and then determined the index weights by the ANP model. Wang et al. [40] provided a scientific crane training evaluation model based on the combination of the ANP and EWM, which considered both the objective attribute of each indicator and the opinions of decision-makers or specialists. Li and Zhang [41] proposed the emergency plan assessment method based on the ANP and EWM in order to solve the assessment problems of emergency plans. The subjective indicators' weights with respect to emergency plans were determined by the ANP, and the EWM was used to objectively correct the obtained weights of the criteria.

Although the ANP-Entropy model has been used in many fields, it has rarely been applied to the evaluation of energy policies, especially in the field of PV power generation policy evaluation. Therefore, the purpose of this paper is to use a comprehensive, reliable and scientific method that combined the subjective and objective evaluation methods to evaluate the FIT policy of solar PV power generation in China and then discover the key policy elements to promote the healthy development of the photovoltaic industry. Figure 2 gives the proposed framework.

3. Data Collection and Evaluation Index System

3.1. Data Collection. The twelve evaluation criteria in this paper are constructed from both public sources and the information collected from surveys and interviews. The relevant data are partly derived from the statistical reports of the National Bureau of Statistics of China, the National Energy Administration (NEA), and IEA, such as the installed capacity of solar PV, the research and development expenditures, and the scale of electricity consumption (detailed information can be found at http://www.stats.gov.cn/, http://www.nea.gov.cn/, and https://www.iea.org/). Some data used in this paper comes from the Photovoltaic System Engineering Research Center of China and the Electricity Science Research Institute. In addition, we also use some websites to collect relevant data, such as the China new energy network (detailed information can be found at http://www.china-nengyuan.com/). It should be emphasized that, during the selection of indicators, a group of experts were consulted and their opinions were taken into consideration.

It is also necessary to elaborate that our panel consists of 15 experts with rich experience in the field of environmental and energy economics. The panel included experts from the

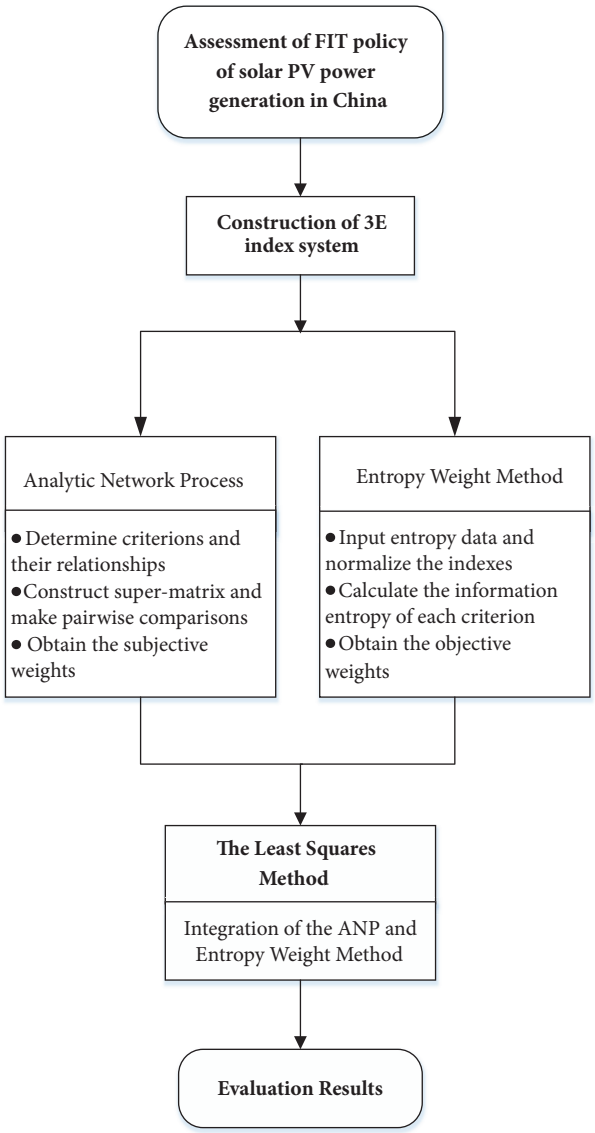

Figure 2: Article Framework.

Research Center of Solar Thermal Conversion, the Chinese Academy of Sciences (five people), the Photovoltaic System Engineering Research Center of the Ministry of Education (four people), Sungrow (three people), and the Electricity Science Research Institute of Anhui province (three people). When the twelve 3E criteria were screened, the dependencies between the criteria and their influencing factors were determined according to the recommendations of the panel. Based on this, a network hierarchy has been constructed. Afterwards, an expert scoring method was used by 15 experts to evaluate the importance of twelve 3E criteria subjectively and give the initial weight matrices of ANP evaluation method. Finally, the value matrix was obtained.

3.2. Evaluation Index System. By analyzing the characteristics of the Feed-in Tariff Policy of Solar PV Power Generation and the existing evaluation index system of the renewable energy policy, this paper sets the following three basic standards for comparison: (i) environmental protection (E1), (ii) economic development (E2), and (iii) energy security (E3). We define the three standards as follows.

3.2.1. Environmental Protection. Environmental protection means ensuring the sustainable development of the economy and society. Specifically, environmental protection refers to the general term for various actions taken to solve practical or potential environmental problems to coordinate the relationship between humans and the environment. Therefore, the subcriteria within the environmental protection goal should include carbon emissions reduction, SO_2 emissions, NOx emissions, and smoke dust emissions.

3.2.2. Economic Development. Economic development refers to the improvement of the quality of economic and social life. Economic development means the improvement and optimization of the economic structure, including the technology structure, consumption structure, energy structure, etc. Therefore, the evaluation of the PV industry from the perspective of economic development requires the comprehensive consideration of inputs, outputs, costs and benefits. The subcriteria that should be considered include the PV module price, PV module output, R&D spending, and unit installation cost.

3.2.3. Energy Security. The IEA defines energy security as the uninterrupted availability of energy sources at an affordable price. Energy security has many contents, including the security of energy assets, the stability of the energy supply, investment safety, and environmental safety. The energy security considered in this article includes four aspects: the new installed capacity, the generating capacity, the electricity consumption, and the renewable power ratio.

Under the 3E goals, twelve subcriteria are determined. The details can be found in Appendix A.

Thus, the evaluation index system has been constructed (See Figure 3.).

In consideration of the interaction and dependency (See Figures 4 and 5) between the three policy goals and the 12 subcriteria proposed by the panel, we defined the internal dependency and external dependency.

4. The Method of Evaluation

4.1. ANP

4.1.1. The Description and Operation Rules of the ANP. The ANP is a decision method proposed by Professor Saaty of the University of Pittsburgh, which adapts to a nonindependent hierarchical structure. It has resolved the limitations of the AHP method by allowing feedback between the elements. The ANP uses a similar network structure to represent the relationships among elements in the system. The elements in the network layer may influence and dominate each other.

A reciprocal value is assigned to the inverse comparison. That is, $a_{ij} = 1/a_{ji}$, where $a_{ij}(a_{ji})$ denotes the importance

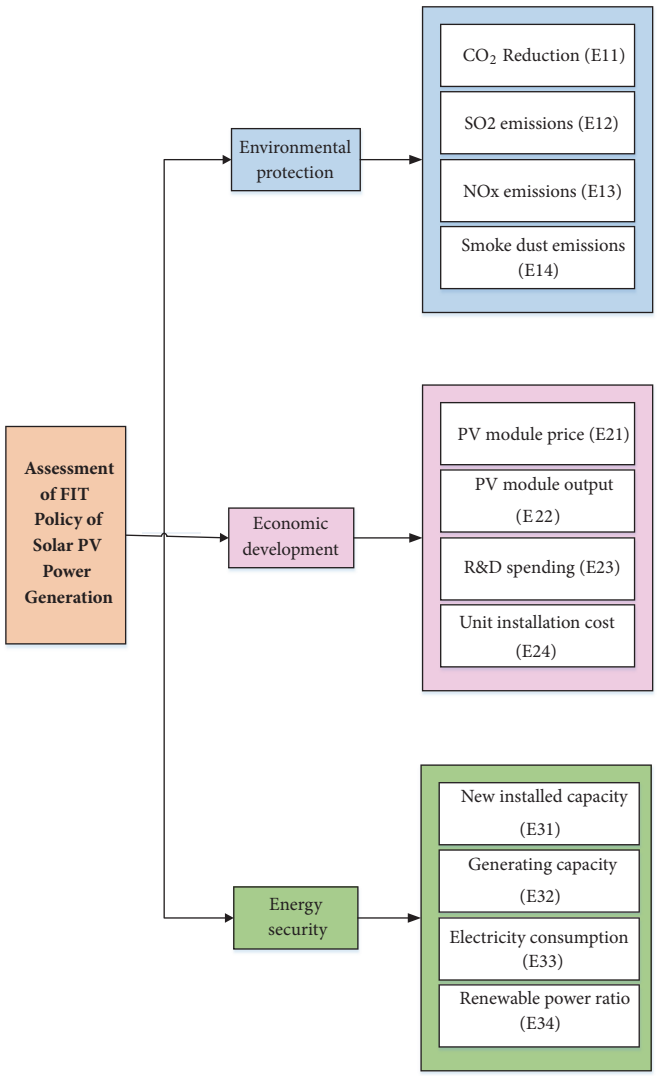

Figure 3: Hierarchical assessment model of the FIT policy in China.

of the *ith* (*jth*) element. As with the AHP, the pairwise comparison in the ANP is carried out in the framework of a matrix. Local priority vectors can be derived from the following equation to estimate relative importance associated with the elements being compared:

$$AW = \lambda_{\max} W \tag{1}$$

where A is the comparison matrix. W is the eigenvector and $\lambda_{\max}$ is the largest eigenvalue of A. Hence, A is consistent if and only if $\lambda_{\max} = n$. Normalizing the resulting vectors such that the sum of each vector becomes one is suggested.

The consistency of judgment is measured by the consistency index (CI) and the consistency ratio (CR). The CI and CR can be calculated through the following formulas:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{2}$$

$$CR = \frac{CI}{RI} \tag{3}$$

where RI is the mean random consistency index. Acceptable CR values must be less than 0.1. Decision-makers were asked to repeat the pairwise comparisons for CR values greater than 0.1.

ANP's stepwise algorithm used in this study is stated by as follows.

Step 1. Describe the decision problem thoroughly with the goals, criteria, and subcriteria. On this basis, the hierarchal structure of the general network and the detailed evaluation index is determined.

Step 2. Identify all inter- and intradependencies existing in the cluster of decision problems and the entire feedback system. Then, draw the internal dependency matrix of the factors with respect to other factors.

Step 3. By establishing the pairwise comparison and prioritization, the supermatrix is built, and the weights of the

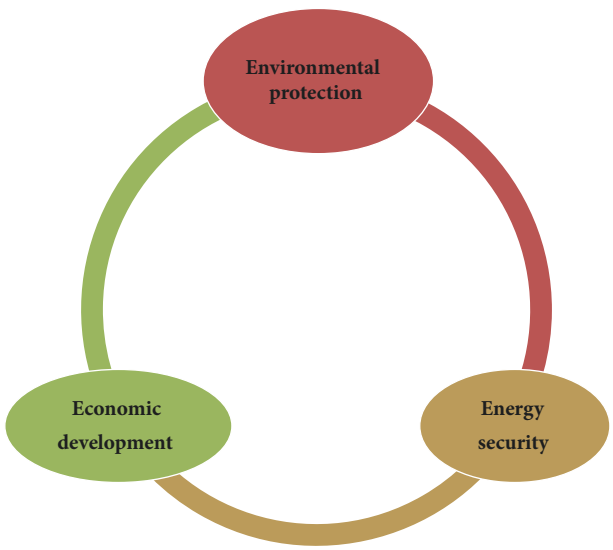

Figure 4: Internal influence relationship.

Table 1: Pairwise comparison matrix under the whole objective.

	E1	E2	E3	Weights
E1	1	2	1	0.4
E2	1/2	1	1/2	0.2
E3	1	2	1	0.4
CR=0 (Acceptable)				

Table 2: Pairwise comparison matrix for environmental protection.

	E11	E12	E13	E14	Weights
E11	1	1/2	1	3	0.235
E12	2	1	2	5	0.449
E13	1	1/2	1	3	0.235
E14	1/3	1/5	1/3	1	0.081
CR=0.0016 (Acceptable)					

criteria and subcriteria are defined while considering the interdependencies between them.

Step 4. Perform a pairwise comparison of the clusters and then rate the alternatives in light of all the criteria and subcriteria.

Step 5. Find the weighted supermatrix, and calculate and find the limit supermatrix, from which the total score for the alternatives is retrieved.

Step 6. Make the ultimate decision to choose the best alternative or to get the final ranking of the alternatives.

4.1.2. Application of ANP. Based on the evaluation of the 3E goals of the FIT policy of Solar PV Power Generation in China, we form a pairwise comparison matrix and calculate the weight of each criterion due to the experts' judgments as mentioned in Section 3.1. Then, we judge the consistency using the CR value of the matrix. The CR has to be lower than 0.1; otherwise the matrix will be considered inconsistent and the eigenvector generated from this matrix will be rejected. Table 1 shows the criteria comparison results.

The weighting matrix of the criteria is as follows:

$$\omega_1 = (0.4, 0.2, 0.4)^T \tag{4}$$

Then, according to the scores of experts, we obtained the judgment matrix of the index layer and calculated the weights of the 12 subcriteria without considering the dependency and feedback of the control layer. The pairwise comparison matrices are shown in Tables 2, 3, and 4.

After that, we consider the interactions and internal relationships between the 3E goals and obtain the inner dependency matrix. We obtain the matrix as follows:

$$\omega_2 = \begin{pmatrix} & E1 & E2 & E3 \\ E1 & 0 & 0.83 & 0.83 \\ E2 & 0.25 & 0 & 0.17 \\ E3 & 0.75 & 0.17 & 0 \end{pmatrix} \tag{5}$$

By multiplying the internal dependency matrix (ω_2) and the weight matrix of the control layer (ω_1), we can get the weight of the interdependent control criteria (ω_3).

$$\omega_3 = \omega_2 * \omega_1 = (0.5, 0.167, 0.333)^{\mathrm{T}} \tag{6}$$

Then, we can obtain the pairwise comparison matrix under the general objective criteria and calculate the weights of the subcriteria. (See Table 5.)

The weight vector is as follows:

Table 3: Pairwise comparison matrix for economic development.

	E21	E22	E23	E24	Weights
E21	1	1/3	1/2	1/2	0.125
E22	3	1	2	1	0.365
E23	2	1/2	1	1	0.233
E24	2	1	1	1	0.277
CR=0.017 (Acceptable)					

Table 4: Pairwise comparison matrix for energy security.

	E31	E32	E33	E34	Weights
E31	1	1	3	1/2	0.250
E32	1	1	3	1	0.297
E33	1/3	1/3	1	1/3	0.099
E34	2	1	3	1	0.354
CR=0.023 (Acceptable)					

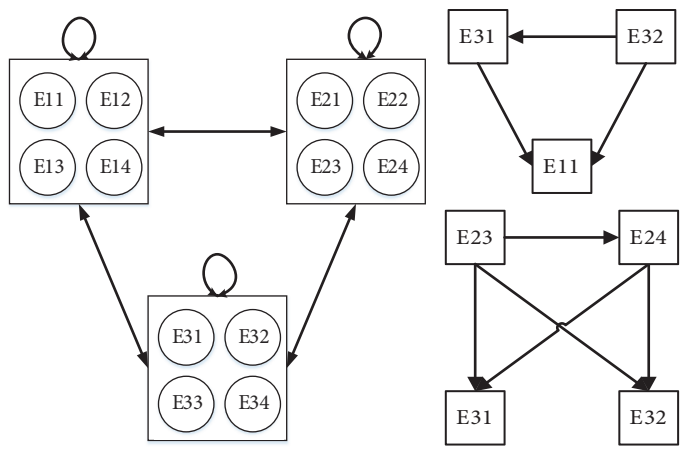

Figure 5: External influence relationship.

Table 5: Pairwise comparison matrix under the general objective criteria.

Criteria	Weights	Sub-criteria	Weights	Weights under General Goal
E1	0.5	E11	0.235	0.117
		E12	0.449	0.224
		E13	0.235	0.117
		E14	0.081	0.042
E2	0.167	E21	0.125	0.021
		E22	0.365	0.061
		E23	0.233	0.039
		E24	0.277	0.046
E3	0.333	E31	0.250	0.083
		E32	0.297	0.099
		E33	0.099	0.033
		E34	0.354	0.118

$$\omega_P = (0.117, 0.224, 0.117, 0.042, 0.021, 0.061, 0.039, 0.046, 0.083, 0.099, 0.033, 0.118)^T \tag{7}$$

On this basis, considering the dependence of the subcriteria and the feedback relationship, three external dependency matrices are obtained and the unweighted supermatrix (ω_S) (see Table 6) is formed using the calculated weights.

The final weight of criteria calculated by the ANP method is as follows:

$$\mathrm{U} = \omega_s * \omega_P = (0.090, 0.173, 0.090, 0.032, 0.016, 0.047, 0.124, 0.082, 0.109, 0.121, 0.025, 0.091)^T \tag{8}$$

4.2. EWM

4.2.1. The Description and Operation Rules of the EWM. The concept of entropy is derived from thermodynamics, which describes the degree of disorder in a system. Shannon (1948) first introduced the concept of entropy into the theory of information and created the new field of entropy in engineering and economic and social applications.

The EWM is an objective weighting method. It can be used to evaluate the effectiveness of information for a system. According to the explanation of the basic principle of information theory, information can measure the degree

of order of a system, while entropy can measure the degree of disorder of a system. The bigger the entropy weight is, the more useful the information in the index is. In this study, the EWM is used to measure the quantity of the useful information of the twelve subcriteria about the FIT policy of solar PV power generation and to determine their weights.

Step 1. The input entropy data should be collected in the form of a matrix (9), which means that the performance of each alternative is considered from the perspective of each evaluation criterion.

$$X_{m\times n} = \begin{bmatrix} x_{11} & \cdots & x_{1j} & \cdots & x_{1n} \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ x_{i1} & \ddots & x_{ij} & \ddots & x_{in} \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ x_{m1} & \ddots & x_{mj} & \ddots & x_{mn} \end{bmatrix}_{m\times n} \tag{9}$$

where x_{ij} is the entity in the ith data sequence corresponding to the jth criteria.

Step 2. Standardize each criterion to eliminate the influence of different criteria dimensions on the evaluation results.

$$x_{ij} = \frac{x_{ij} - x_{j\min}}{x_{j\max} - x_{j\min}}; \quad x_{ij} = \frac{x_{j\max} - x_{ij}}{x_{j\max} - x_{j\min}} \tag{10}$$

where $x_{j\max}$ and $x_{j\min}$ are the maximum and minimum values of the jth criteria, respectively. Positive criteria use the former equation and negative criteria use the latter.

Step 3. Use the following to calculate the proportion of the jth criteria in the ith year:

$$y_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{11}$$

Step 4. Determine the information entropy and information utility of the jth criteria based on the following, respectively:

$$e_j = -K \sum_{i=1}^{m} y_{ij} \ln y_{ij}, \quad K = \frac{1}{\ln m} \tag{12}$$

$$d_j = 1 - e_j \tag{13}$$

Step 5. We can get the evaluation weight of the jth criteria according to

$$v_j = \frac{d_j}{\sum_{i=1}^{m} d_j} \tag{14}$$

4.2.2. Application of EWM. In Section 4.1, we have used the ANP method to get the weight of each evaluation index. However, the ANP method is a subjective evaluation method. The weights given are mainly based on the experience of the experts and their judgment of the reality, which means that there may be certain subjectivity in it. Therefore, in this section, we use the entropy method to objectively evaluate the FIT policy of solar PV power generation from the original data in order to effectively avoid the interference of human factors in the subjective evaluation method and make the evaluation result more reasonable.

First, we use (11) to standardize the data obtained, and the matrix is as follows:

$$X_{5\times 12} = \begin{pmatrix} 0 & 0 & 0 & 0.27 & 0 & 0 & 0 & 0 & 0 & 0 & 0.41 & 0 \\ 0.04 & 0.05 & 0.06 & 0.24 & 0.17 & 0.06 & 0.12 & 0.09 & 0.16 & 0.04 & 0.26 & 0.03 \\ 0.16 & 0.10 & 0.15 & 0 & 0.21 & 0.17 & 0.16 & 0.18 & 0.12 & 0.16 & 0.17 & 0.26 \\ 0.3 & 0.17 & 0.27 & 0.11 & 0.25 & 0.31 & 0.36 & 0.27 & 0.20 & 0.29 & 0.16 & 0.11 \\ 0.5 & 0.68 & 0.52 & 0.38 & 0.37 & 0.46 & 0.36 & 0.46 & 0.52 & 0.51 & 0 & 0.60 \end{pmatrix} \tag{15}$$

Then, (12) is used to calculate the information entropy, and the result is as follows:

$$e_j = (0.860, 0.767, 0.866, 0.952, 0.970, 0.891, 0.944, 0.916, 0.890, 0.861, 0.951, 0.803)^T \tag{16}$$

Table 6: Unweighted supermatrix.

ω_S	E11	E12	E13	E14	E21	E22	E23	E24	E31	E32	E33	E34
E11	1	0	0	0	0	0	0	0	0	0	0	0
E12	0	1	0	0	0	0	0	0	0	0	0	0
E13	0	0	1	0	0	0	0	0	0	0	0	0
E14	0	0	0	1	0	0	0	0	0	0	0	0
E21	0	0	0	0	1	0	0	0	0	0	0	0
E22	0	0	0	0	0	1	0	0	0	0	0	0
E23	0	0	0	0	0	0	1	0	0.667	0.667	0	0
E24	0	0	0	0	0	0	0	1	0.333	0.333	0	0
E31	0.5	0	0	0	0	0	0	0	1	0	0	0
E32	0.5	0	0	0	0	0	0	0	0	1	0	0
E33	0	0	0	0	0	0	0	0	0	0	1	0
E34	0	0	0	0	0	0	0	0	0	0	0	1

The information utility can be calculated with (13):

$$d_j = (0.140, 0.233, 0.134, 0.048, 0.030, 0.109, 0.056, 0.084, 0.110, 0.139, 0.049, 0.197)^T \tag{17}$$

Finally, the weight calculated by the EWM is as follows:

$$V_{12\times 1} = (0.105, 0.175, 0.101, 0.036, 0.023, 0.082, 0.042, 0.063, 0.083, 0.105, 0.037, 0.148)^T \tag{18}$$

4.3. Integration of ANP and EWM. As discussed in Sections 4.1 and 4.2, we could obtain the subjective weight vector $\mathrm{U} = (u_1, u_2, \ldots, u_m)^T$ and the objective weight vector $V = (v_1, v_2, \ldots, v_m)^T$, respectively. Then, we use the method of least squares to synthesize the subjective and objective weights into a comprehensive weight vector $\mathrm{W} = (w_1, w_2, \ldots, w_m)^T$. This method is a standard optimization method for the approximate solution of the systems, including sets of data in which there are more data than unknowns. "Least squares" means that the overall solution minimizes the sum of the squares of the errors made in the results of every single data. Thus, the goal of the combinational weighting method is to minimize the deviation between U and V using the equation of the least squares. Based on the analysis above, the objective function is constructed as follows":

$$\min \quad H(w) = \sum_{i=1}^{n}\sum_{j=1}^{m}\left\{\left[\left(u_j - w_j\right)z_{ij}\right]^2 + \left[\left(v_j - w_j\right)z_{ij}\right]^2\right\} \tag{19}$$

$$\text{subject to} \quad \sum_{j=1}^{m} w_j = 1, \quad w_j \geq 0 \ \left(j = 1, 2, \ldots, m\right) \tag{20}$$

where z_{ij} denotes the normalized indicator value.

To solve the object function (19), the Lagrange function is introduced and is defined as follows:

$$\mathrm{L} = \sum_{i=1}^{n}\sum_{j=1}^{m}\left\{\left[\left(u_j - w_j\right)z_{ij}\right]^2 + \left[\left(v_j - w_j\right)z_{ij}\right]^2\right\} + 4\lambda\left(\sum_{j=1}^{m} w_j - 1\right). \tag{21}$$

In addition, let

$$\frac{\partial L}{\partial w_j} = -\sum_{i=1}^{n} 2\left(u_j + v_j - 2w_j\right)z_{ij}^2 + 4\lambda = 0 \quad \left(\mathrm{j} = 1, 2, \ldots, m\right) \tag{22}$$

$$\text{and} \quad \frac{\partial \mathrm{L}}{\partial \lambda} = 4\left(\sum_{j=1}^{m} w_j - 1\right) = 0.$$

Alternatively, it can be represented by the following matrix (24):

$$\begin{bmatrix} \mathrm{A} & e \\ e^T & 0 \end{bmatrix}\begin{bmatrix} W \\ \lambda \end{bmatrix} = \begin{bmatrix} B \\ 1 \end{bmatrix} \tag{23}$$

where

$$\begin{aligned} \mathrm{A} &= \mathrm{diag}\left[\sum_{i=1}^{n} z_{i1}^2, \sum_{i=1}^{n} z_{i2}^2, \ldots, \sum_{i=1}^{n} z_{im}^2\right] \\ e &= [1, 1, \ldots 1]^T \\ \mathrm{W} &= [w_1, w_2, \ldots, w_m] \\ \mathrm{B} &= \left[\sum_{i=1}^{n} \frac{1}{2}(u_1 + v_1) z_{i1}^2, \sum_{i=1}^{n} \frac{1}{2}(u_2 + v_2) z_{i2}^2, \ldots, \right. \\ &\quad \left. \sum_{i=1}^{n} \frac{1}{2}(u_m + v_m) z_{im}^2\right]^T \end{aligned} \tag{24}$$

Through solving (24), the combined weight vector W is calculated as the following formula:

$$\mathrm{W} = A^{-1}\left[B + \frac{1 - e^T A^{-1} B}{e^T A^{-1} e} e\right] \tag{25}$$

The weight data obtained from Sections 4.1 and 4.2 are calculated according to the above formulas, and the comprehensive weights that are obtained are shown in Table 7.

The results above indicate that the environmental protection goal is the most significant one of the 3E policy goals, which accounts for 0.405. The ultimate goal of developing renewable energy is to solve the increasingly severe environmental problems, and so the environmental protection goal must be given priority in the evaluation of the PV power generation policy. From the perspective of environmental protection, the importance of SO_2 emissions ranks first, the importance of CO_2 reduction was ranks second, and the importance of NOx emissions ranks third. The emissions of SO_2 and NOx are the major sources of air pollution, especially SO_2, which is very harmful to human beings and animals. Moreover, under the constraint of carbon emissions from various countries, global emissions of the greenhouse gas carbon dioxide have not increased in the past three years. Therefore, the utilization of renewable energy should focus on their capabilities in promoting environmentally sustainable development and reducing pollutant emissions.

As shown in Table 7, the energy security goal ranks second, which accounts for 0.358. As countries transition to renewable and less carbon-intensive sources of electricity, the power generation industry faces a number of ongoing challenges, and so the issue of energy security should be widely concerned by the relevant departments. Within the energy security goal, renewable power ratio ranks first, followed by the generation capacity and the new installed capacity, respectively. The strategic goal of China's energy structure transformation requires that by 2020, the renewable power ratio will reach 27% of the total electricity generation. Meanwhile, the generation capacity and new installed capacity of PV power generation will also increase significantly. Long-term energy security requires a timely energy supply according to the needs of economic development and environmental protection.

According to Table 7, the economic development goal ranks third among the 3E goals, which accounts for 0.237. In the future, sustained economic growth will be constrained by the environmental capacity and energy stocks. Therefore, economic development goal should be considered after the comprehensive consideration of the environmental protection and energy security goals. Regarding the subcriteria within the economic development goal, the first is R&D spending, the second is unit installation costs, and the third is PV module output. In recent years, stimulated by the support of national policy and the increase of R&D spending, the PV power industry has made great technological progress, not only in the expansion of the power generation scale and the PV module output but also in the gradual reduction of the unit installed costs. As a promising emerging field of economic growth, it can achieve the economic development goals while vigorously developing renewable energy in order to achieve environmental protection and energy security goals. Figure 6 shows the ranking results of comprehensive weights.

5. Discussion and Conclusions

This paper used the integrated ANP-Entropy model to evaluate the implementation effects of China's Feed-in Tariff Policy of Solar PV Power Generation from the three dimensions of environmental protection, economic development, and energy security by combining qualitative and quantitative methods. Research results show that the environmental protection goal is still the most important for the development of solar PV power generation in China and is followed by the energy security and economic development goals. The calculated comprehensive weights indicate that, among the twelve subcriteria, the first three important criteria are SO_2 emissions, the renewable power ratio and the generating capacity, which totally account for 0.406. Most of the SO_2 emissions are caused by the burning of fossil fuels. As a clean way of power generation, PV power can effectively alleviate the environmental pollution caused by the emissions of SO_2 and other pollutants. According to statistics, the generating capacity of renewable energy accounted for 26.4% of the total generating capacity in 2017, which almost reached the goal of renewable energy development in 2020. The ranking results of the 3E goals obtained by the subjective evaluation method (ANP) and objective evaluation method (EWM) are the same. This confirms the conviction that experts' opinions and judgments have been reasonable and coherent.

Compared with previous works, this article has contributed to the literature in two ways. First, in the view of the methods, the integrated ANP-Entropy model that combined qualitative and quantitative analyses uses a dual research process, thus making the research results more reasonable and precise. It provides ideas not only for the solar PV power generation field but also for other fields. Second, from the perspective of the research objects, there are few studies devoted to the policy evaluation of solar PV power generation. In this paper, China's Feed-in Tariff Policy of Solar PV Power Generation is selected as the research object. This

Table 7: The comprehensive weights of each criterion.

Criteria	ANP Weights	Entropy Weights	Comprehensive Weights
Environmental protection	**0.385**	**0.417**	**0.405**
CO_2 reduction	0.090	0.105	0.098
SO_2 emissions	0.173	0.175	0.175
NOx emissions	0.090	0.101	0.097
Smoke dust emissions	0.032	0.036	0.035
Economic development	**0.269**	**0.210**	**0.237**
PV module price	0.016	0.023	0.018
PV module output	0.047	0.082	0.065
R&D spending	0.124	0.042	0.082
Unit installation costs	0.082	0.063	0.072
Energy security	**0.346**	**0.373**	**0.358**
New installed capacity	0.109	0.083	0.096
Generating capacity	0.121	0.105	0.112
Electricity consumption	0.025	0.037	0.031
Renewable power ratio	0.091	0.148	0.119

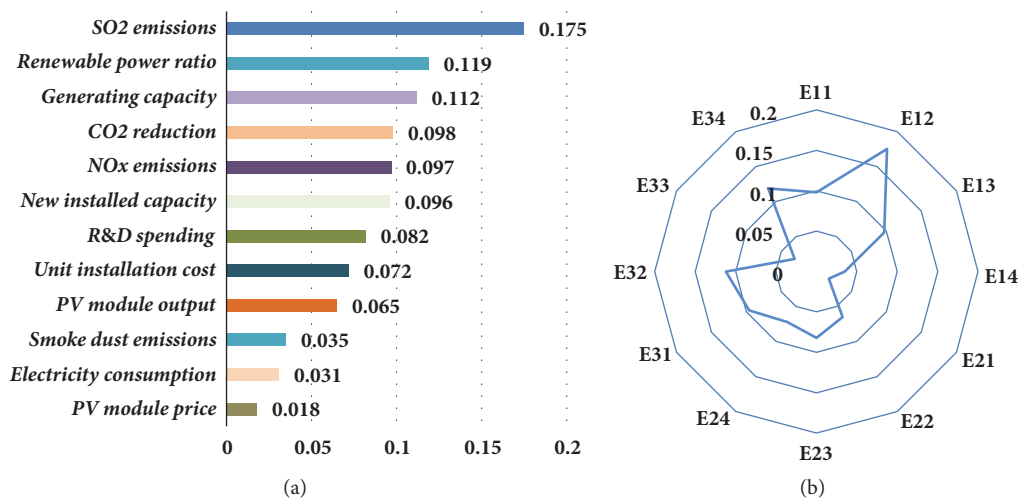

Figure 6: Ranking results of comprehensive weights.

is because the more specific the research object is, the more reliable the evaluation result will be. This work can make up for some gaps and provide a meaningful reference for scholars in similar fields. In addition, the 3E evaluation index system and the comprehensive ANP-Entropy evaluation method are also applicable to the evaluation of other renewable energy policies.

The ranking results of this paper are somewhat different from previous studies. Previous results show that the environmental goal is the most emphasized policy goal, followed by the economic and energy goals, respectively [6]. Meanwhile, the rankings of the 3E goals in this paper are environmental protection, energy security, and economic development. The differences between the research results can be explained in three ways. First, with the continuous breakthroughs in industrial technology and the influence of the learning effect, the output of PV modules increased gradually, and the cost of PV power generation continues to decline. Next, the energy security goal becomes increasingly more significant with the emergence of energy crises and the transformation of the energy structure. Last, the government can formulate relevant policies and guide the development of the PV industry through economic means to solve the problems of the environment and energy.

After exploring the promotional effect for the FIT policy of solar PV power generation, this paper provides policy suggestions and optimization paths from the following three aspects. First, the FIT policy should give priority to the environmental protection goal, which is essential to the long-term healthy development of the PV industry. Relevant departments can control the emissions of carbon dioxide, sulfur dioxide, nitrogen oxides, and other pollutants by limiting emission indicators. Second, the government should take full consideration of the environmental carrying capacity and energy security in the pursuit of economic goals. The management departments can solve the market and cost

Table 8: Criteria descriptions and sources.

Policy Goal	Criteria	Description	Sources
Environmental protection	CO_2 reduction	Annual reduction of carbon dioxide emissions caused by PV power generation	[13, 14]
	SO_2 emissions	The quality of sulfur dioxide emitted by power generation throughout the year.	[15, 16]
	NOx emissions	The quality of N_2O, NO, NO_2, N_2O_3, N_2O_4 and N_2O_5 emitted by power generation throughout the year.	[6, 16]
	Smoke dust emissions	Quantity of particulate matter entrained in flue gas and solid suspended solids with particle size less than 75μm generated by power generation fuel	[6, 16]
Economic development	PV module price	The unit price of solar panels such as monocrystalline silicon solar cells, polycrystalline silicon solar cells, amorphous silicon solar cells, etc.	[17, 18]
	PV module output	The output of solar cells such as monocrystalline silicon solar cells, polycrystalline silicon solar cells, amorphous silicon solar cells and other solar panels.	[6, 17]
	R&D spending	Research and development expenditure in electric power industry	[17, 18]
	Unit installation cost	Unit installed costs calculated according to total investment and total installed capacity of a PV power station.	[19, 20]
Energy security	New installed Capacity	The total rated capacity of the generators installed in the newly installed PV stations.	[21, 22]
	Generating capacity	The total amount of energy produced by solar PV power station	[21, 22]
	Electricity consumption	The total electricity consumption in all fields which includes industry, agriculture, commerce, residential, etc.	[23, 24]
	Renewable power ratio	The proportion of renewable energy generation in total power generation	[25, 26]

Table 9: The inner dependency matrix.

E1	E2	E3	Relative Dependency
E2	1	1/3	0.25
E3	3	1	0.75
		CR=0	
E2	**E1**	**E3**	**Relative Dependency**
E1	1	5	0.833
E3	1/5	1	0.167
		CR=0	
E3	**E1**	**E2**	**Relative Dependency**
E1	1	5	0.833
E2	1/5	1	0.167
		CR=0	

Table 10: Pairwise comparison matrix on new installed capacity.

E31	E23	E24	Weight
E23	1	2	0.667
E24	1/2	1	0.333
		CR=0	

problems by introducing a pricing mechanism, a market competition mechanism, and an economic compensation policy to lead the better development of the PV industry. Third, policy-makers should vigorously increase the utilization ratio of renewable energy to promote the reform of the energy structure. Policy-makers should enact more targeted supporting policies to stimulate the positive development of photovoltaic power, wind power, hydroelectric power, etc. in order to further enable the development of renewable energy to achieve the 3E goals of environmental protection, energy security, and economic development.

Table 11: Pairwise comparison matrix on generating capacity.

E32	E23	E24	Weight
E23	1	2	0.667
E24	1/2	1	0.333
		CR=0	

Table 12: Pairwise comparison matrix on CO_2 reduction.

E11	E31	E32	Weight
E31	1	1	0.5
E32	1	1	0.5
		CR=0	

Appendix

A.

See Table 8.

B.

See Table 9.

C.

See Tables 10, 11, and 12.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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