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Analysis of the dilemmas of solar energy application for Taiwan building with Fuzzy AHP approach

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Abstract. Energy is a key indicator to show economic development and improved quality of life in countries. Thus, it is also an essential factor to achieve sustainable development. Therefore, renewable energy can play a significant role in satisfying the future energy need and supply. Taiwan is highly vulnerable in energy security, but geographic conditions for the development of solar energy applications have created a considerable advantage. However, the total installed solar energy capacity is far less than might be expected. Consequently, this study proceeds to explore the dilemmas that affect solar energy application concerning Taiwan buildings. Through the evaluation decision-making system model and expert decision-making groups giving fuzzy evaluation values and feedback, access the relative importance of each dilemma factors by using Fuzzy AHP. The study found the critical factor and propose strategies for solar energy development in the future to improve the quality and quantity of renewable energy applications and competitiveness of national energy. This research, in addition to providing references to relevant environmental energy systems for deployment and technological R&D, it also provides developing and underdeveloped countries access to applications of solar energy technology assessment and forecasts for the future.

1. Introduction

Global environmental concerns and the escalating demand for energy, coupled with steady progress in renewable energy technologies, are opening up new opportunities for utilization of renewable energy resources. In order to overcome negative impacts on the environment, many countries have changed the use of environmental friendly alternatives. Solar energy is one of the best renewable energy (RE) sources with least negative impacts on the environment. Different countries have formulated solar energy policies to reducing dependence on fossil fuel and increasing domestic energy production by solar energy.

Solar energy is one of the best renewable energy sources with least negative impacts on the environment. Different countries have formulated solar energy policies to reducing dependence on fossil fuel [1]. The International Energy Agency (IEA) envisaged solar power accounting for 11% of global electricity production by 2050 and solar electricity contributing about 20% of the world's energy supply by 2050 and over 60% by 2100. Solar energy will play an important role in the future of energy. In accordance with the Bureau of Energy under the Ministry of Economic Affairs "New Energy Policy", "Energy Development Program" indicated that the key project of RE development and application in

the future was solar energy. Taiwan is a very densely populated island, so the application of solar energy is mainly combined with buildings [2].

Taiwan depends on a ratio of imported energy up to 98%, but geographic conditions have favorable conditions for the development of solar energy applications [3]. Nevertheless, the total installed solar energy capacity is far less than might be expected. In 2017 the total cumulative installed capacity of RE was only 5276 MW. Moreover, its occupied total installed capacity ratio was only 10.6% (shown in Fig. 1) [3]. The analysis showed that the RE had an average effectiveness of only 293.12 MW/Year and an average growth index of only 0.005 per annum, with a total cumulative installed solar energy capacity of only 1767.7 MW. Its occupied total installed capacity ratio was only 3.5%, while the solar thermal system installation penetration rate was only 7.12% of residential houses (shown in Fig. 2).
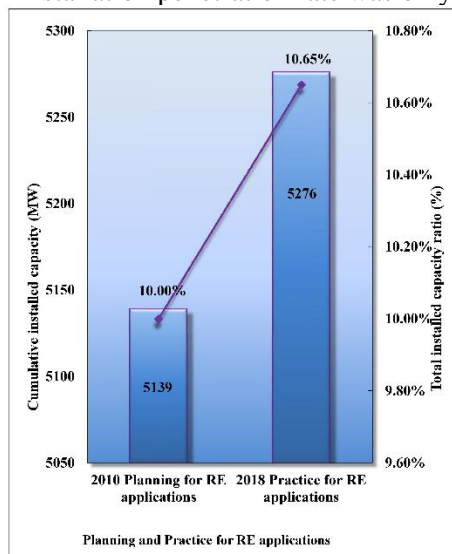

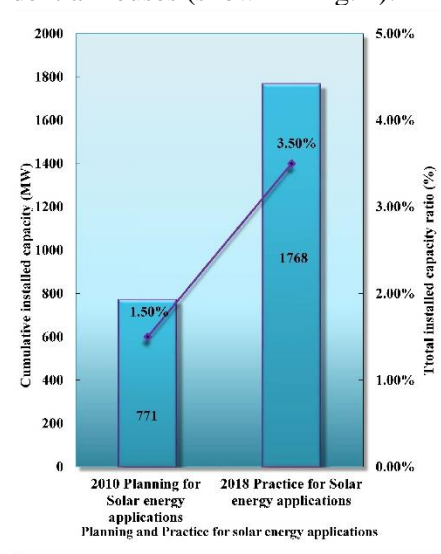Fig. 1. Taiwan planning objectives and practical for RE applications.

Fig. 2. Taiwan planning objectives and practical for solar energy applications.

However, in the statistics on the cumulative installed capacity of RE in Taiwan there is a considerable gap between planning objectives and practical solar energy applications. In order to explore the main resistance and key factors influencing solar energy applications and diffusions, this study composed as follows: (1) Establishment of dilemma factor variables; (2) Establishment of an evaluation decision-making system model, and fuzzy weight fraction and sequence of significance of each criterion is determined; (3) Draw up energy development strategy for the future.

2. Methodology

2.1. Research framework and methods

Laarhoven and Pedrycz (1983) proposed the Fuzzy Analytic Hierarchy Process in 1983, which was an application of the combination of Analytic Hierarchy Process (AHP) and Fuzzy Theory [4]. Therefore, Fuzzy AHP converts the opinions of experts from previous definite values to fuzzy numbers and membership functions, presents triangular fuzzy numbers in paired comparison of matrices to develop Fuzzy AHP, thus the opinions of experts approach human thinking model, so as to achieve more reasonable evaluation criteria. The research process adopted methodologies and phased achievements as follows.

- *First stage: Literature survey and analysis.* Systematic analysis of solar energy applications status, trends and challenges in global and Taiwan proceed to classification of main dilemma and key influence indicators of variable sets.
- *Second stage: Systems engineering analysis (SEA).* According to the Taiwan's sustainable energy policies, proceed to establish an evaluation decision-making system model.

- *Third stage: Fuzzy Analytic Hierarchy Process (Fuzzy AHP).* Using Fuzzy AHP expert questionnaires proceed obtained the fuzzy weight fraction of criterion of each hierarchy by applied the calculating mode of Fuzzy AHP.
- *Fourth stage: Similarity Aggregation Method (SAM).* As for the experts' opinions, this study adopted the SAM proposed by Hsu and Chen (1996) to integrate experts' weight values for various evaluation criteria, and then the sequence of significance of each criterion is determined based on the hierarchy series connection and defuzzification mode [5].

2.2. Apply of Fuzzy Theory and Fuzzy AHP

Based on the above, the opinions of decision-makers are converted from previous definite values to fuzzy numbers and membership numbers in Fuzzy AHP, so as to present in Fuzzy AHP matrix. The application steps of this study based on Fuzzy AHP method were as follows:

Step 1: Set up hierarchy structure for the evaluation decision-making system: This study screened the dilemma factors conforming to target problems through Fuzzy Delphi Method (FDM) investigating experts' opinions, to set up the hierarchy architecture. Finally, the hierarchical structure contains four levels. The first level indicates the main goal. The second and third levels consist of three aspects and nine objectives (O1-O7). The fourth levels consists of twenty-seven criteria (C01-C27) (shown in Fig. 3).
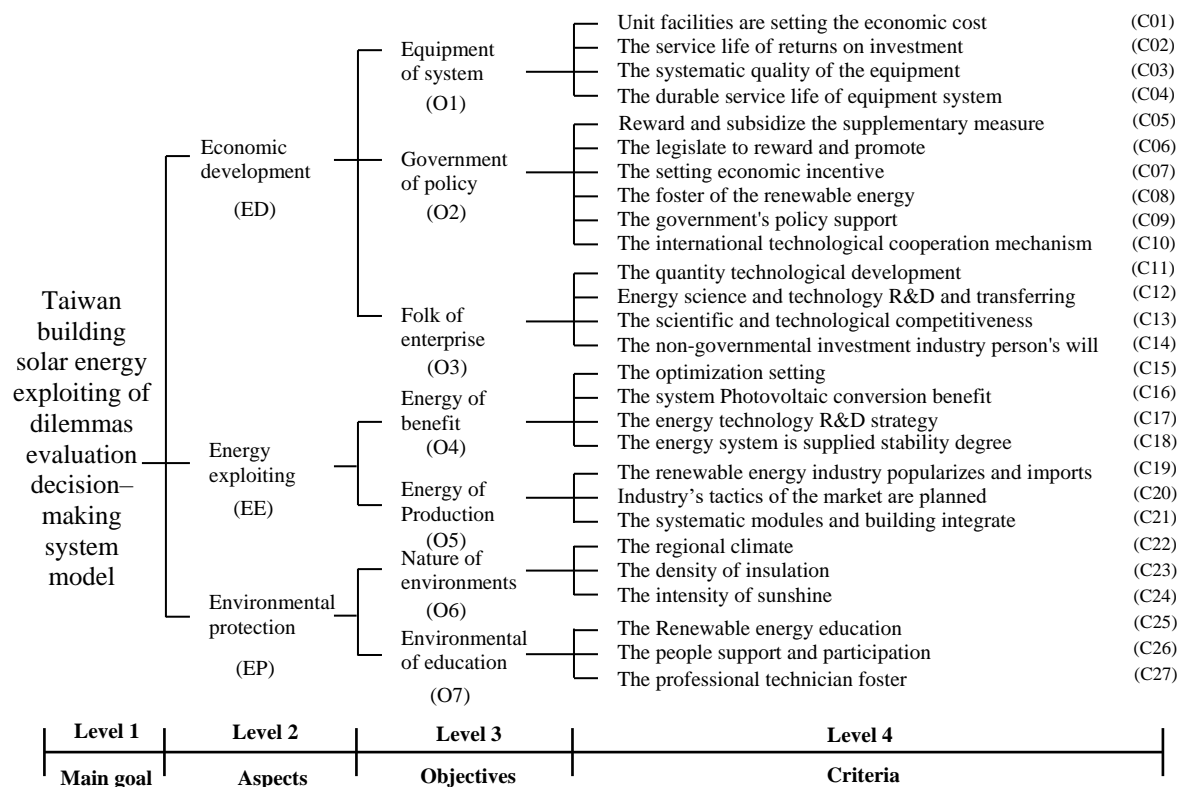

Fig. 3. Taiwan building solar energy exploiting of dilemmas evaluation decision-making system model.

Step 2: Gather opinions of the expert decision-making groups: The objective of the expert questionnaire was architecture and solar energy field. Fuzzy AHP Expert Questionnaires were given to thirty experts in industry, government, research and academic.

Step 3: Set up fuzzy paired comparison matrices: Compare the relative importance between factors given by decision-makers in pairs, set up paired comparison matrices, after the definite values are converted to fuzzy numbers according to the definitions, integrate the fuzzy evaluation values of experts based on the SAM concept.

Step 4:Calculate fuzzy weight value: The characteristic vector value of fuzzy matrix is obtained, namely the weight value of element. This study calculated these three positive and negative value matrices respectively by using the "Column Vector Geometric Mean Method" proposed by Buckley.

$$Z_i = (a_{i1} \times a_{i2} \times \cdots \times a_{in})^{1/n} \ \forall i$$
$$W_i = Z_i \emptyset (Z_1 + Z_2 + \cdots + Z_n)$$

Among which

a_{ij}: Column i row j of matrix, i; j=1; 2; . . . ; n;

Z_i: column vector mean value of fuzzy number, i=1; 2; . . . ; n;

W_i: weight of No. i factor.

$\times$: multiply fuzzy numbers,

e.g. assuming two triangular fuzzy numbers A $= (a_1, \ b_1, \ c_1)$, B $= (a_2, \ b_2, \ c_2)$

$\tilde{A} \times \tilde{B} = (a_1, b_1, c_1) \times (a_2, b_2, c_2) = (a_1 \times a_2, b_1 \times b_2, c_1 \times c_2)$

$\emptyset$: divide fuzzy numbers,

e.g.: assuming two triangular fuzzy numbers $\tilde{A} = (a_1, \ b_1, \ c_1), \quad \tilde{B} = (a_2, \ b_2, \ c_2)$

$\tilde{A} \ \emptyset \ \tilde{B} = (a_1, b_1, c_1) \ \emptyset \ (a_2, b_2, c_2) = (a_1/a_2), (b_1/b_2), (c_1/c_2)$

Step 5: Hierarchy series connection: Connect all hierarchies in series, to obtain all factors' weights.

Step 6: Defuzzification: Convert fuzzy numbers to easy-comprehended definite values, this study adopts the center of gravity method to solve fuzzy numbers.

$$G(A) = \frac{\sum_{i=1}^{n} u_A(X_i) \times X_i}{\sum_{i=1}^{n} u_A(X_i)}$$

Step 7: Sequencing: Sequence defuzzified criteria.

3. Research content design and analysis

3.1. Establish assessment models of the framework and hierarchy

Taiwan is active in the development and application of renewable energy. In 2008, declarations of the principles of Sustainable Energy Policies stated that development of renewable energy policies should achieve the goals of economic development, energy exploitation and environmental protection (3E) [6]. This research, to explore the identification of dilemma factors for solar energy application, follows the goals of Taiwan's formulated "National Sustainable Energy Policy Programs" containing 3E aspects. Through systems engineering analysis (SEA) method a list of important dilemma factors and levels that affect solar energy application on Taiwan buildings was compiled. Then we established a systematic evaluation decision-making system model (shown in Fig. 3).

3.2. Consistency test results and analysis

Through test the consistency of each comparison matrix using C.I. and C.R. formulae. Results of the consistency test and the C.R. of the comparison matrix from thirty experts are all<0.1, indicating "consistency". Furthermore, the C.R. of the aggregate matrix is also<0.1, also indicating "consistency".

3.3. Comprehensive fuzzy computing and weight result analysis of evaluation criteria

The weight values of various dilemma factors can be obtained through the opinions of experts resulted from SAM and the Fuzzy AHP systematic steps. After sequencing, the evaluation criteria have higher significance, so decision-makers can make correct judgments more quickly. Table 1 is the evaluation criteria weight by Fuzzy AHP, the evaluation criteria weight is obtained based on Fuzzy AHP questionnaire results of experts.

The research results show that weights of aspects in Level 2, EE (0.4496) has the highest weight value in the evaluation decision-making system. Weight values from high to low are ED (0.3341), EP (0.2163). Weights of objectives in Level 3, O4 (0.3122) has the highest weight value in the evaluation decision-making system. Weight values from high to low are O1 (0.1500), O6 (0.1431), O2 (0.1414),

O5 (0.1374), O7 (0.0732), O3 (0.0427). Weights of criteria in Level 4, C15 (0.1412) has the highest weight value in the evaluation decision-making system. Weight values from high to low are C21 (0.0908), C16 (0.0784), C24 (0.0599), C01 (0.0563), C22 (0.0553), C18 (0.0478), C17 (0.0449), C09 (0.0397), C02 (0.0363), C06 (0.0357), C25 (0.0348), C20 (0.0314), C03 (0.0299), C23 (0.0278), C04 (0.0275), C26 (0.0229), C07 (0.0205), C05 (0.0203), C11 (0.0186), C10 (0.0184), C27 (0.0156), C19 (0.0153), C14 (0.0102), C12 (0.0071), C08 (0.0068), C13 (0.0068) (shown in Table 1). Through research results showed, the critical dilemma factors that affect solar energy application on Taiwan buildings, which is focus on "Aspects of the Energy exploiting" and "Objectives of the Energy of benefit".

Table 1 The evaluation criteria weight based on Fuzzy AHP Experts Questionnaire results.

Aspects	Weights of aspects	Objectives	Weights of objectives	Criteria	Weights of criteria	Ranking
ED	0.3341	O1	0.1500	C01	0.0563	5
				C02	0.0363	10
				C03	0.0299	14
				C04	0.0275	16
		O2	0.1414	C05	0.0203	19
				C06	0.0357	11
				C07	0.0205	18
				C08	0.0068	26
				C09	0.0397	9
				C10	0.0184	21
		O3	0.0427	C11	0.0186	20
				C12	0.0071	25
				C13	0.0068	27
				C14	0.0102	24
EE	0.4496	O4	0.3122	C15	0.1412	1
				C16	0.0784	3
				C17	0.0449	8
				C18	0.0478	7
		O5	0.1374	C19	0.0153	23
				C20	0.0314	13
				C21	0.0908	2
EP	0.2163	O6	0.1430	C22	0.0553	6
				C23	0.0278	15
				C24	0.0599	4
		O7	0.0733	C25	0.0348	12
				C26	0.0229	17
				C27	0.0156	22

4. Strategy proposals and discussion

4.1. Energy development of strategy proposals in the future

Based on dilemma factors a strategy was proposed. Descriptive details are as follows:

● *Economic development orientation.* Through the government's policies support should be given to actively establish regulations mechanisms and application strategies. The country should actively carry out the necessary technological R&D to reduce economic cost of facility settings and quantity designs of facilities and modules, further to increase people's willingness to use and install the technology.

● *Energy exploiting orientation.* Renewable energy equipment systems installation must ensure optimal effectiveness and system photoelectric conversion efficiency. In the stage of architectural design and planning considerations should be made for the possibility of using RE and the suitability for building space and equipment combined, applied building-integrated photovoltaic

(BIPV) combined with building energy management system (BEMS), self-sufficiency, and symbiotic potential of the main body with the natural environment.

● *Environmental protection orientation.* Through the subsidies for RE demonstration systems and public building integration of RE equipment systems on buildings, people are provided with the opportunity to experience the educational opportunities of RE and become aware of renewable energy exploitation and may offer their support and participation. Moreover, government should be in accordance with the different industry characteristics implement horizontal and vertical integration, strategic alliances and different industry integration.

4.2. Discussion
The study shows that in terms of different regions of the natural environment and geographical conditions, solar energy systems deployment must be in accordance with different geographical regions to plan and design optimal settings and improve the influence of the equipment system to achieve satisfaction with the economic benefits and system quality. In addition, government policies incentives should show appropriate innovative planning and review, in order to avoid inappropriate policies affecting the national financial and industrial markets. Consequently, the history and experience of advanced countries in the successful development of RE are important references and lessons [1]. The development and application of RE should not only be limited to technologies of R&D, simulation and evaluation predictions of research. Countries should be involved in input and import of the applications of new energy technologies at the same time, according to the present state and resource conditions to conduct preliminary planning, assessment of application, forecasts of effects of imported technology and review and elimination of import difficulties and obstacles.

5. Conclusions
Solar energy application is critical energy development project for sustainable energy development in Taiwan. According to the current state of solar energy utilization and the implicit constraints of the policy, it is urgent to establish a scientific solar energy application evaluation-decision system, further remove the limitations of institutional barriers and the exclusion of application constraints.

This study investigates the critical dilemma factors which affect the application of solar energy systems by combining SEA, FDM, SAM, Fuzzy AHP, and establishes objective and standardized references. A total of twenty-seven dilemma factors influencing solar energy application selection are analysed through FDM experts' opinions investigation. SAM and Fuzzy AHP were used to integrate experts' opinions to obtain the significance evaluation of various evaluation criteria given by experts in group decision. Based on the evaluation values of expert decision-making groups and Fuzzy AHP statistical analysis results to provide an operational evaluation decision-making system model. Through the evaluation decision-making system model for the future of solar energy system application assessment, environment energy system deployment and technical R&D, it will be able to access assessment of preliminary technical planning and forecast the technology importing before and after implementation, promote Taiwan go forward to the goal of sustainable energy environment (5E)[6].

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