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Key Factors and Recommendations for Adopting Renewable Energy Systems by Families and Firms

Chiung-Wen Hsu*
Graduate Institute of Management of Technology, Feng Chia University, Taiwan

Abstract

The photovoltaic (PV) power system is currently the most commonly applied renewable energy technology. Some nations have enforced government policies supporting the use of these systems. Effective policies must reflect the knowledge of factors driving installation of PV power generating systems. This study analyzes factors involved in the adoption of these systems by businesses and families. The fuzzy analytic hierarchy process was used to analyze data obtained from questionnaires filled out by firm executives. The questionnaires were administered to 10 businesses and 10 families that had adopted a PV power generating system. The results indicate that key factors differ significantly between businesses and families. Business users prioritized reduction in carbon emissions and social responsibility; family users prioritized system cost and installation subsidies. Thus, customized programs promoting adoption may be necessary for these two sets of users.

Key words: photovoltaic (PV) power generation system; adoption policy; fuzzy analytic hierarchy process (AHP)

JEL classification: Q28

1. Introduction

Because of the impact of climate change and the demand for sustainable energy, governments have begun implementing policies that address such issues. The International Energy Agency (IEA) reported that achievement of the goal set by the United Nations to reduce 50% of global greenhouse gas emissions by 2050 will require that photovoltaic (PV) power generation maintains an average annual growth rate of 22% (IEA, 2011). However, as of 2011, PV power generation accounted for less than 1% of the total global power supply (Solangi, 2011). The Taiwanese government, for example, set 2,500 megawatts (MW) as the target for the cumulative capacity of PV power systems by 2030; however, at the end of 2011, the actual capacity was only 88 MW.

*Correspondence to: Graduate Institute of Management of Technology, Feng Chia University, 100 Wenhwa Road, Seatwen, Taichung 40724, Taiwan. E-Mail: cwenhsu@fcu.edu.tw. The author appreciates suggestions for improvement of this paper made by Professor Lee-Lien Huang and Chao-Chan Wu.

Use of PV power generation systems is low because costs are high compared to other renewable energy sources (Jager, 2006). Because such systems are unpopular, installation costs have increased, further hindering their adoption. To promote PV systems, governments have adopted various policies (Solangi, 2011) such as feed-in tariffs, system equipment subsidies, R&D funding, and preferential interest rates. Midttun and Gautesen (2007) considered the feed-in tariff system the most suitable and economically effective method in the early phase of replacing conventional power generation systems with their PV counterparts. Dusonchet and Telaretti (2010) argued that governments should make use of related policies to support certain industries and stimulate market demand in their efforts to increase solar energy adoption. Whether these policies can promote the popularity of PV power systems is a subject of intense research.

Some previous studies concentrated on the adoption of solar energy technologies by families. For example, Caird et al. (2008) reported that for the average family, socioeconomic position, consumer education background, product properties, and communication channels play important roles in the adoption of low-carbon or zero-carbon emission technologies. Using the Delphi method, Cesta and Decker (1978) identified other factors, including product cost, government support, product quality, cost of traditional petrochemical energy use, and people's awareness of solar energy as an infinite and free power source. In a study of consumer behavior, Jager (2006) discussed ways to stimulate the Dutch to adopt PV power generating systems and concluded that government subsidies and awareness of environmental changes played crucial roles. Faiers and Neame (2006) also reported that environmental consciousness played a key role in shaping favorable attitudes toward the adoption of such systems in England. In fact, the population studied in this research identified environmental consciousness as the most decisive factor for adopting such technology, even overtaking concerns about the cost of adoption and conversion efficiency.

Related studies on adoption factors for business users have been conducted. Kaplan (1999) researched the decision-making process involved in the adoption of innovative products and discussed how businesses may be encouraged to adopt PV power generating systems. The main factors cited by the author for influencing such decisions included local sun hours; progress regarding development of power generation systems; enterprise size and image; and education, knowledge level, and seniority of decision makers.

As noted by the National Consumer Council of the UK (2006), differences among types of consumers in product assessment are to be expected in decisions to adopt and use products. Relevant studies have identified various factors influencing businesses and families for and against the adoption of PV power generating systems.

However, studies have not focused on the classification of promotional policy tools. For example, consider the feed-in tariff system, regarded as one of the biggest drivers for the development of renewable energy power in the United States and Europe. Twenty EU members adopted this system by 2009 (Campoccia et al., 2009).

Dusonchet and Telaretti (2010) conducted research on policy development supporting solar energy technology in Western Europe, and they found that 12 countries used the funding subsidy to promote the use of PV power generation. The current study distinguishes family users from business users to explore the key factors in adoption of policies for PV power generation systems.

Researchers have used various analytical methods to study key factors. Dickinson et al. (1985) proposed use of the interview method. Sabherwal and Kirs (2007) first conducted a literature review to sort out the influential factors; then, they used the questionnaire method to pinpoint the key factors considered by decision makers. Guynes and Vanecek (1996) proposed use of the questionnaire/survey method for conducting interviews. Shank (1989) suggested preparing customized questionnaires coupled with counseling from external experts to upgrade the efficiency and accuracy of the questionnaire. Then, they identified key factors through interviews with experts. Overall, this method helped to identify potential influential factors before finalizing the questionnaires. Influential factors were ranked in order of importance, and factors with top rankings were regarded as key factors.

According to the ranking method, each factor should be weighted (i.e., assigned a relative importance). While there are many weight calculation methods (Jia et al., 1998), the analytic hierarchy process (AHP) is commonly used (Saaty, 1980; Saaty and Vargas, 1982; Saaty, 1990), especially in multiple criteria decision-making research. The calculation method proposed by Saaty (1980) for the AHP has become an important decision-making method. However, in the practical world, it is difficult to extract precise data pertaining to measurement factors since human preferences are prone to degrees of uncertainty. Decision makers are also inclined to favor natural language expressions over exact numbers when assessing criteria and alternatives. For this reason, various researchers have used the fuzzy AHP methods, which effectively resemble human thoughts and perceptions.

Many AHP methods have been proposed based on the fuzzy set theory and hierarchical structure analysis. Van Laarhoven and Pedrycz (1983) extended Saaty's AHP method with triangular fuzzy numbers (TFNs), and Buckley (1985) extended it with trapezoidal fuzzy numbers. Boender et al. (1989) adopted a more robust approach to the normalization of local priorities by modifying the Van Laarhoven and Pedrycz method. Chang (1996) introduced a new approach for handling the fuzzy AHP—the use of TFNs for a pairwise comparison of the fuzzy AHP and the use of the extent analysis method for the synthetic extent values of the pairwise comparisons. Chang's approach is one of the most popular approaches in the fuzzy AHP field.

In this study, the fuzzy AHP method was used as a systematic approach to explore the key factors influencing the adoption of PV power generating systems by businesses and families. It is anticipated that the results of this research will be useful to the government in drafting promotional policy tools for the adoption of such systems. The rest of this paper is organized as follows. First, the fuzzy AHP method is introduced to assess businesses' and families' rankings of factors associated with adoption of PV power generation systems and to describe hierarchical structures. Second, evaluation criteria for assessing hierarchical structure are identified. Third, PV power generation systems are described to illustrate the process of using the fuzzy AHP method to assist businesses and families in determining key factors that influence the adoption of PV systems. Fourth, a discussion of policies for promoting PV power generation systems is included, as well as recommendations for applying the research findings to Taiwan. Conclusions are presented in the final section.

2. Methodology

The AHP method is a decision-making approach designed to aid in the solution of complex multiple criteria problems in a number of application domains. This method has been an effective and practical approach for considering complex and unstructured decisions. However, the fuzzy AHP approach allows a more accurate description of the decision-making process. The earliest work in fuzzy AHP compared fuzzy ratios using triangular membership functions. The logarithmic least square method was used to derive local fuzzy priorities. Later, using the geometric mean, comparisons of fuzzy priorities were determined. Decisions are made with the fuzzy AHP method by constructing hierarchies, making comparative judgments, and synthesizing priorities, as described below.

Step 1: Develop a Hierarchical Structure

In this step, a complex decision is structured as a hierarchy descending from an overall objective to various criteria, subcriteria, and so on, down to the lowest level. The overall goal (objective) of the decision is at the top of the hierarchy. The criteria and subcriteria contributing to the decision comprise the intermediate levels. Finally, the decision alternatives or selection choices appear at the bottom of the hierarchy. According to Saaty (2000), a hierarchy can be constructed through creative thinking, recollection, and various perspectives. Saaty further noted that there are no established procedures for generating the levels to be included in a hierarchy.

Step 2: Establish Comparative Judgments

Once the hierarchy has been structured, the next step is to determine the priorities of elements at each level (“element” here means each item in the hierarchy). A set of comparative matrices of all elements in a level with respect to an element of the immediately higher level must be constructed to prioritize and convert individual comparative judgments into ratio scales for measurements. Decision makers have to determine the relative weights of each criterion. Use of a questionnaire preference scale allows decision makers to make pairwise comparisons. The resulting data may appear in the form of triangular fuzzy numbers. Because the fuzzy AHP approach is a subjective methodology, information and priority weights of elements may be obtained from decision makers using direct questioning or a questionnaire. By using triangular fuzzy numbers via pairwise comparison, a fuzzy judgment matrix $\tilde{A}(a_{ij})$ may be constructed, where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ stands for a triangular fuzzy number. Let:

$$\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij}) \,, \tag{1}$$

and

$$\tilde{a}_{ji} = \frac{1}{\tilde{a}_{ij}} = \left(\frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}}\right) \text{ for } i, j = 1, \ldots, n \tag{2}$$

where in $l \le m \le u$, l and u stand for the lower and upper values of $\tilde{A}$ respectively, and m stands for the mid value.

Step 3: Establish a Fuzzy Pairwise Comparison Synthetic Matrix

After all the elements of the pairwise comparison matrix of $\tilde{A}$ are converted to fuzzy triangular numbers, the geometric mean method is applied to compute the prioritization of these numbers:

$$\tilde{m}_i = \left(\prod \tilde{a}_{ij}\right)^{\frac{1}{n}} \text{ for } j = 1, \ldots, n \,. \tag{3}$$

Since $\tilde{a}_{ij}$ can be defined as l_{ij}, m_{ij}, u_{ij} , we have for $j = 1, \ldots, n$:

$$m_i^l = \left(\prod l_{ij}\right)^{\frac{1}{n}} . \tag{4}$$

$$m_i^m = \left(\prod m_{ij}\right)^{\frac{1}{n}} . \tag{5}$$

$$m_i^u = \left(\prod u_{ij}\right)^{\frac{1}{n}} . \tag{6}$$

Step 4: Measure Consistency

The pairwise comparisons generate a matrix of rankings for each level of the hierarchy. The number of matrices depends on the number of elements at each level. The order of the matrix at each level depends on the number of elements at the next level to which it is linked. After all matrices are developed and all pairwise comparisons are obtained, eigenvectors or relative weights (degree of importance among the elements), global weights, and the maximum eigenvalue, $\lambda_{\max}$, for each matrix are calculated.

The $\lambda_{\max}$ value is an important validating parameter in fuzzy AHP. It is used as a reference index to screen information by calculating the consistency ratio (CR) of the estimated vector (Saaty, 1980) to determine whether the matrix for pairwise comparisons provides a valid and completely consistent evaluation. The following steps result in calculation of the CR:

1. Calculate the eigenvectors and $\lambda_{\max}$ for each matrix of order n.
2. Compute the consistency index for each matrix of order n by the formula:

$$CI = \frac{\lambda_{\max} - n}{n-1}. \tag{7}$$

3. Calculate the CR using the formula:

$$CR = \frac{CI}{RI}, \tag{8}$$

where RI is a known random consistency index obtained from a large number of simulation runs that varies depending on the order of the matrix. Table 1 shows RI values for matrices of orders 1 to 15.

Table 1. Random Consistency Index

order	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Source: Saaty (1980).

Step 5: Determine the Relative Weight for Each Factor Using Fuzzy Numbers

Findings of this study were in line with Saaty's recommendation (1980), and CR ≦ 0.1 indicated that there was consistency between the pre- and post-determinations made by decision makers; as a result, the rating values were deemed acceptable. Finally, the relative weight of every factor for an individual decision maker was calculated to determine its rank. For each of the alternatives or criteria, weights were computed as follows for $i = 1, \ldots, n$:

$$w_i^l = \frac{m_i^l}{\sum_{i=1}^{n} m_i^u}. \tag{9}$$

$$w_i^m = \frac{m_i^m}{\sum_{i=1}^{n} m_i^m}. \tag{10}$$

$$w_i^u = \frac{m_i^u}{\sum_{i=1}^{n} m_i^l}. \tag{11}$$

The weight of criterion i can be represented as $\tilde{w}_i = (w_i^l, w_i^m, w_i^u)$. Weights are shown as fuzzy triangular numbers.

Step 6: Defuzzify

To obtain the exact value of each criterion weight, a defuzzification process is conducted using the following formula for $i = 1, \ldots, n$:

$$w_i = \frac{w_i^l + w_i^m + w_i^u}{3}. \quad (12)$$

Step 7: Determine the Relative Weight for Each Factor in a Hierarchical Structure

In this step, the relative weight of every factor is calculated for the individual decision maker; then, the geometric mean method is used to compute the integrated weight for all decision makers to determine the relative weight for each factor. This approach normalizes the local weights of all factors (within the weight parameters given for a criterion or sub-criterion) to obtain the global weights of individual factors.

3. Hierarchical Structure of Adoption Factors for PV Power Generation Systems

For this study, insights from related literature and expert interviews were used to sort out the factors that were likely to influence the adoption of PV technology.

Clearly, system installation providers and users are the ones who are mostly directly related to PV system installation; of course, practical and theoretical perspectives are valuable as well. Thus, the four experts selected for this study included a system installation provider, business user, family user, and PV academic scholar in Taiwan. Additional participants were selected randomly from the general population; they were asked by telephone if they were willing to be interviewed.

Based on the hierarchical structure of factors described by Saaty (2000), the study began with a literature review of factors affecting installation and interviews with experts. Then, these factors were classified according to their individual characteristics. Various observations were listed based on the classification of the factors. Each established their own hierarchical structure of factors, which can be divided into 4 aspects and 13 factors, as shown in Figure 1. The selection basis and content of each factor are described as follows.

3.1 Product Aspect

The product plays an important role in the adoption process. Rogers (2003) proposed that in the process of innovation diffusion, individuals or organizations usually compare a new product with an existing one to assess the potential benefits of the new one and the possibility of adoption. In their new energy adoption model, Caird et al. (2008) observed that the properties of a product influence the speed of consumers' adoption. Cesta and Decker (1978) proposed that product cost and quality influence the adoption decision. Kaplan (1999) pointed out that the development status of a PV power generating system may affect its adoption. Therefore, the following three factors related to products were considered in this study:

1. System cost: Currently, adoption of PV power generation technology is too low to drive down production costs. Consequently, Caird et al. (2008) and Jager (2006) observed that total installation costs will increase, further dampening the prospects of adoption. In this study, the cost of installation per kilowatt (kW) was calculated based on the current installation cost of this technology for Taiwan as NTD200,000–300,000 per kW on a national scale.
2. Conversion efficiency: The conversion efficiency of PV power generation technology will influence its production power volume. Caird et al. (2008) indicated that the conversion efficiency of the existing polycrystalline silicon system is, at best, about 16–18%, which is not efficient when compared to the traditional power generation method. This factor is bound to influence the adoption decision. This study used the actual conversion efficiency from the absorption of sunlight to yield solar power as the indicator for conversion efficiency. The existing conversion efficiency is 12–15%.
3. Service life: Caird et al. (2008) and Cesta and Decker (1978) remarked that the service life of the PV power generating system will influence the payback period. In this study, the service life of a product was regarded as its expected lifetime under normal operating conditions. The current average service life of such a system is 20 years.

3.2 Environmental Aspect

The PV power generation system is environmentally friendly, and it is regarded increasingly as a power generation option in many countries (Caird et al., 2008). Jager (2006) argued that people’s awareness of environmental change will influence their adoption of such a system, and Kaplan (1999) suggested that enterprise image and social responsibility would drive businesses to use this technology. Faiers and Neame (2006) surmised that rising levels of environmental consciousness would exert a greater influence on the uptake of this technology, notwithstanding its technological costs. As a result, the environmental aspect has been identified as an important part of this study and subdivided into the following three factors:

1. Reduction in carbon emissions: Timilsina et al. (2000) observed that PV power generating systems reduce carbon emissions. This study investigated the reduction in carbon emissions achieved by installing a PV power generating system of 1 kW. Findings indicated that it reduced carbon dioxide in Taiwan’s existing power supply structure by about 850 kg per year.
2. Social responsibility: Faiers and Neame (2006) and Kaplan (1999) noted that enterprises and people have become increasingly aware of their responsibilities toward the environment. They realize that installing PV power generating systems can help reduce carbon emissions, and this increases their willingness to adopt the technology. As a result, this study cites social responsibility as another important factor influencing the choice of this technology.
3. Price of electricity produced by traditional means: Cesta and Decker (1978) pointed out that the price of electricity generated by traditional means (thermal

power) will influence the willingness to adopt PV generating systems. Countries with higher electricity rates will speed up the market penetration rate of PV systems. In this study, the price of electricity produced by traditional means for 1 kilowatt-hour (kWh) is the indicator for this particular factor; currently, this price is about NTD3/kWh in Taiwan.

3.3 Installation Aspect

The size of installation space for a PV power generating system affects its installed capacity. Additionally, sun hours determine the amount of power generated and, in turn, the payback period for the system. Thus, factors related to system installation influence the willingness of users to adopt PV systems (Huang et al., 2010). There is a significant difference in solar power generation in northern and southern Taiwan because of the difference in sun hours (Huang et al., 2010). In Taipei and Kaohsiung, the daily solar power generation is 2.55 kilowatt-peak (kWp) and 3.56 kWp, respectively. This means that the trend of installing these systems is projected to increase gradually from the northeast to the southwest of Taiwan. Thus, the following three installation-related factors were considered as part of this study:

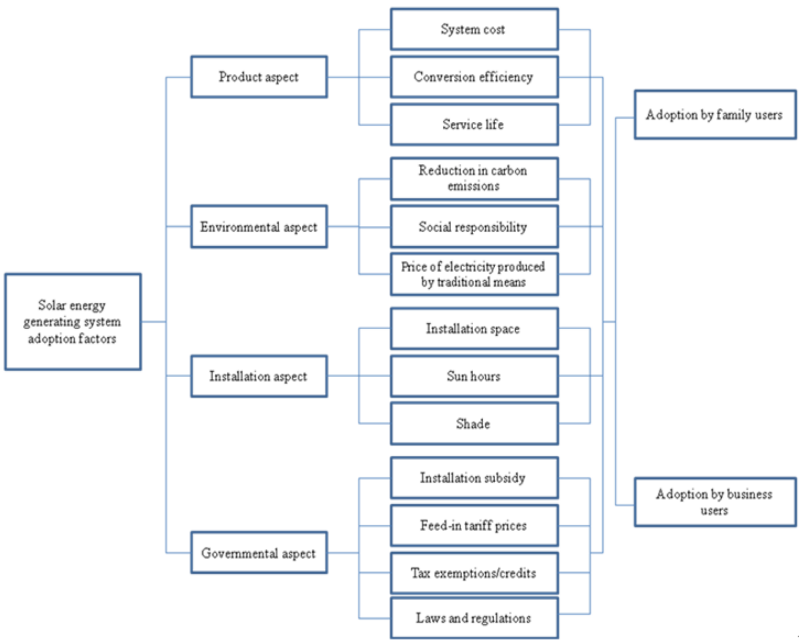
1. Installation space: Kaplan (1999) noted that the size of installation space influences system capacity. Findings of this study indicated that 10 square meters of installation space would be required for a PV power generating system to produce 1 kW of electricity.
2. Sun hours: Huang et al. (2010) and Kaplan (1999) pointed out that the number of sun hours affects the extent of power generation. In this study, the average number of daily sun hours is the indicator for this factor.
3. Shade: Huang et al. (2010) noted that the shaded area will influence the efficiency of PV power generation. In this study, area is an indicator for the installation factor.

3.4 Governmental Aspect

In the innovation diffusion model, Rogers (2003) mentioned that communication channels influence the diffusion speed of new products. Since PV power generation is considered an emerging technology, governments must play facilitating roles for users and suppliers to speed up the market penetration rate. In other words, the government must communicate the official attitude toward renewable energy technologies to influence their adoption (1978). Current installation costs of PV power generating systems are still high. Further, users must consider conversion costs. If governments can provide appropriate financial incentives, consumers will adopt the system (Jager, 2006). In addition, mandatory laws and regulations should promote PV power generation (Cesta and Decker, 1978) as financial incentives and mandatory requirements impact users. Thus, this study highlights the following four factors:

1. Installation subsidy: Faiers and Neame (2006) and Peter et al. (2006) suggested that governments provide installation subsidies dependent on installed capacities to accelerate the promotion of PV power generating systems. In this study, the installation subsidy for 1 kW of power generation is an indicator for this factor. In 2010, this subsidy was approximately NTD50,000/kW in Taiwan.
2. Feed-in tariff prices: Jager (2006) recommended that governments set a buyback price on the basis of each kWh of power generated to increase the uptake of PV power generating systems. In this study, the buyback price of each kWh of power generated has been used as the indicator for feed-in tariff prices. In Taiwan, the current buyback price amounts to NTD7.33–10.32 kWh, depending on installation capacity.
3. Tax exemptions/credits: Peter et al. (2006) indicated that tax exemptions/credits are known incentives for the adoption of PV power generating systems. This study includes research findings about the existence of tax exemptions/credits in Taiwan. Findings indicated that there are no relevant tax-based incentives currently.
4. Laws and regulations: Cesta and Decker (1978) noted the importance of mandatory laws and regulations aimed at accelerating the promotion of PV power generation. Findings of this study indicate that there are no mandatory laws and regulations currently in force in Taiwan.

Figure 1. Hierarchical Factor Structure for the Adoption of PV Power Generating Systems



4. Key Assessment Factors Influencing the Adoption of PV Power Generating Systems

This study was designed to assess the key factors influencing the adoption of PV power generating systems by businesses and families using the fuzzy AHP method. A specially devised questionnaire was administered to selected respondents who have installed such systems. An analysis of results from related studies supported a small sample size (i.e., 10 businesses and 10 families that had adopted a PV power generating system). After quantifying the importance of each factor with a pairwise comparison, relative weights were calculated and ranked to assess the priority of key factors. A description of the consistency test as well as the key factors and their rankings for businesses and families is provided as follows.

4.1 Consistency Test

The maximum eigenvalue calculated in this study from the pairwise comparison matrix between businesses and families is the basis for determination of CR values (Saaty, 1980). Results are shown in Table 2. A CR of less than 0.1 for each factor indicates consistency in adoption factors chosen by businesses and families between the pre- and post-assessments; as a result, the assessed weight value can be regarded as valid and consistent (Saaty, 1980).

Table 2. Consistency Ratios for Various Factors

Factors	CR (Businesses)	CR (Families)
Adoption factors	0.011	0.027
Product aspect	0.001	0.007
Environmental aspect	0.001	0.028
Installation aspect	0.008	0.004
Governmental aspect	0.022	0.013

4.2 Key Factors Influencing Adoption by Businesses

In this study, the local eigenvector was calculated from the pairwise comparison matrix of 10 businesses using the geometric mean to compute the local and global weights for the 13 assessment factors. Weight was used to establish the importance rankings (Table 3).

In the adoption hierarchy, the governmental aspect had the highest relative weight (value of 0.3325), followed by the environmental aspect (0.3120). These two aspects accounted for more than 60% of the total weight. Business users viewed the government as an important facilitator in the adoption of PV power generation. They also emphasized the importance of the environmental aspect; with increasingly urgent environmental issues such as global warming, businesses seek renewable technologies to appear environmentally friendly. Indeed, they recognize such green labels as a strategic advantage for gaining an edge on the competition. Therefore, governmental and environmental factors are influential in the adoption of the referenced technology.

This study identified the top five weighted assessment factors as the keys for influencing businesses to adopt PV power generating systems. The top five factors in decreasing order of importance were reduction in carbon emissions (0.1399, environmental aspect), social responsibility (0.1261, environmental aspect), laws and regulations (0.1224, governmental aspect), tax exemptions/credits (0.1054, governmental aspect), and feed-in tariff prices (0.0782, governmental aspect). Therefore, this study predicts that reduction in carbon emissions and social responsibility will affect businesses' rate of adoption. Additionally, laws and regulations focusing on the link between environmental protection and PV power generation systems, along with government-backed incentives (e.g., tax exemptions/credits) will increase the willingness of businesses to install these systems.

Table 3. Weight and Ranking of Adoption Factors for Businesses

Factors	Weights	Ranking	Subfactors	Weights (Global)	Ranking (Local)	Ranking (Global)
Product aspect	0.1748	4	System cost	0.0444	3	11
			Conversion efficiency	0.0739	1	7
			Service life	0.0565	2	9
Environmental aspect	0.3120	2	Reduction in carbon emissions	0.1399	1	1
			Social responsibility	0.1261	2	2
			Price of electricity produced by traditional means	0.0488	3	10
Installation aspect	0.1777	3	Installation space	0.0774	1	6
			Sun hours	0.0622	2	8
			Shade	0.0381	3	12
Governmental aspect	0.3325	1	Installation subsidy	0.0267	4	13
			Feed-in tariff prices	0.0782	3	5
			Laws and regulations	0.1224	1	3
			Tax exemptions/credits	0.1054	2	4

4.3 Key Factors Influencing Adoption by Families

This study identifies the local eigenvector calculated from the pairwise comparison matrix of 10 families as the basis for computing the local and global weights of 13 assessment factors using the geometric mean. Then, this study used the weights to determine the priority ranking (Table 4).

In the adoption hierarchy for families, the governmental aspect carried the highest relative weight (0.2987), followed by the product aspect (0.2974); the weight of these two aspects accounted for more than 50% of the total of all four aspects. Thus, high costs continue to obstruct the adoption of this emerging technology. However, the installation subsidy has the potential to promote affordability and access to PV power generating systems for ordinary individuals. Furthermore, future improvements in conversion efficiency will help decrease the payback period and buyback prices; therefore, the product aspect is important to families.

This study relied on the top five rankings to identify key factors influencing families to adopt PV power generating systems. In order of decreasing importance, the factors are system cost (0.1366, product aspect), installation subsidy (0.1241, governmental aspect), reduction in carbon emissions (0.0936, environmental aspect), service life (0.0855, product aspect), and tax exemptions/credits (0.0770, governmental aspect). For families, cost considerations and economic relevance (denoted by system costs and installation subsidies) are the most important factors influencing their willingness to adopt this technology.

Table 4. Weight and Ranking of Adoption Factors for Families

Factors	Weights	Ranking	Subfactors	Weights (Global)	Ranking (Local)	Ranking (Global)
Product aspect	0.2974	2	System cost	0.1366	1	1
			Conversion efficiency	0.0752	3	6
			Service life	0.0855	2	4
Environmental aspect	0.2119	3	Reduction in carbon emissions	0.0936	1	3
			Social responsibility	0.0482	3	12
			Price of electricity produced by traditional means	0.0700	2	9
Installation aspect	0.1920	4	Installation space	0.0535	3	11
			Sun hours	0.0679	2	10
			Shade	0.0705	1	8
Governmental aspect	0.2987	1	Installation subsidy	0.1241	1	2
			Feed-in tariff prices	0.0716	3	7
			Laws and regulations	0.0263	4	13
			Tax exemptions/credits	0.0770	2	5

4.4 A Comparison of Key Adoption Factors for Businesses and Families

The results presented in Tables 3 and 4 show how the key factors influencing uptake of PV power generating systems differ for businesses and families. For example, laws and regulations are priority factors for businesses. However, for family users, the regulatory factor ranks last. To provide an understanding about the significant differences in perceptions of businesses and families and their subsequent effects on the drafting of effective policies, use of the Spearman rank correlation test is foundational in this study.[1] Test results showed no correlation at the 5% significance level for business users and family users. There were significant inconsistencies in the factor rankings by business and family users, demonstrating that the prioritization of factors is different for the two.

It is important to note that reduction in carbon emissions and tax exemptions/credits are among the top five priorities for both businesses and families (Table 5). Therefore, it would be prudent for the government to devise a PV power generating system policy to drive down installation costs and thereby increase the willingness to adopt the technology. Regarding the carbon emissions factor, families and businesses should be educated about the need to reduce carbon emissions and protect the environment. Therefore, sustained efforts and advocacy by the government are required. In time, such efforts will lead to an increase in use of the technology.

Table 5. Weight and Ranking of All Factors for Businesses and Families

Ranking	Businesses		Families	
	Factors	Global Weights	Factors	Global Weights
1	Reduction in carbon emissions	0.1399	System cost	0.1366
2	Social responsibility	0.1261	Installation subsidy	0.1241
3	Laws and regulations	0.1224	Reduction in carbon emissions	0.0936
4	Tax exemptions/credits	0.1054	Service life	0.0855
5	Feed-in tariff prices	0.0782	Tax exemptions/credits	0.0770
6	Installation space	0.0774	Conversion efficiency	0.0752
7	Conversion efficiency	0.0739	Feed-in tariff	0.0716
8	Sun hours	0.0622	Shade	0.0705
9	Service life	0.0565	Price of electricity produced by traditional means	0.0700
10	Price of electricity produced by traditional means	0.0488	Sun hours	0.0679
11	System cost	0.0444	Installation space	0.0535
12	Shade	0.0381	Social responsibility	0.0482
13	Installation subsidy	0.0267	Laws and regulations	0.0263

Table 6 summarizes the key factors affecting the adoption of PV power generation systems by businesses and families in Taiwan.

Table 6. Key Factors Influencing the Adoption of PV Power Generating Systems by Businesses and Families in Taiwan

User	Key Factors	Description
Businesses	Reduction in carbon emissions	Businesses are encouraged to reduce carbon emissions, curb global warming, and brand themselves as green, as consumers have been known to prefer green businesses.
	Social responsibility	Adoption of PV power generating systems is promoted as the means whereby businesses can fulfill their social responsibilities.
	Laws and regulations	Business users are encouraged to conform to laws and regulations regarding land use, building, power source, etc., by installing PV power generating systems.
	Tax exemptions/credits	Tax exemptions/credits provided by the government are effective in motivating businesses to adopt the technology.
	Feed-in tariff prices	Prices are set by the government to drive down the costs of the technology.
Families	System cost	Cost of the PV power generating system can influence users to adopt the technology.
	Installation subsidy	An installation subsidy for a PV power generating system is provided by the government.
	Reduction in carbon emissions	Families are encouraged to reduce carbon emissions, curb global warming, and protect the environment.
	Service life	Service life of the PV power generating system can influence user willingness to adopt the technology.
	Tax exemptions/credits	Tax exemptions/credits are provided by the government to encourage families to adopt the technology.

5. Policies to Promote PV Power Generating Systems in Taiwan

Taiwan began promoting PV power generating systems over a decade ago. In May 2000, the government established a subsidized grid-connected PV power demonstration system. The subsidy per kWp capacity was NTD110,000 maximum. The off-grid PV power generates a subsidy of NTD150,000 maximum. The government mandated that the subsidy should not exceed 50% of the total cost of establishing the power generation system. This demonstration subsidy ended in 2004. From July 2006, the government established subsidies for installation capacities of a kWp or more; a new set of PV power system users would receive subsidies. The subsidy standard for each kWp installation capacity was NTD150,000 maximum.

In June 2009, the Taiwanese government passed the Development Regulations for Renewable Energy Bill, adopting a feed-in tariff price system that provides a 20-year guarantee period for fixed buyback prices. Since then, the government has announced an annual buyback price every year; in 2009, for instance, it granted an installation subsidy of NTD50,000 for newly installed systems of capacity 1–10 kW, with a buyback price of NTD8.1243/kWh. There were no installation subsidies for installation capacities exceeding 10 kW, and the buyback price was set as NTD9.027–9.3279/kWh. In 2011, the government introduced installation subsidy grants of NTD50,000/kW for newly installed systems with installation capacities of 1–10kW and increased the buyback price to NTD11.1883/kWh. Those with systems that do not qualify for a subsidy are offered a buyback price of NTD14.603/kWh. For systems with an installation capacity between 10 and 500 kW, the government offers a buyback price of NTD12.9722/kWh. For installation capacities greater than 500kW, the buyback price is NTD11.1190/kWh.

In spite of these initiatives, the technology has failed to take off in Taiwan to the extent hoped; therefore, careful planning is needed to achieve this goal.

The results of this study clearly show that different users—families versus businesses—place varying degrees of emphasis on different factors in the decision to adopt this technology. Therefore, the government should focus on customizing promotional measures depending on the kind of user. For instance, the current government in Taiwan employs feed-in tariffs and installation subsidy measures that apply to both businesses and families. The results of this study show that the feed-in tariff is one of the top five factors for business users but not family users. Meanwhile, the installation subsidy is one of the top five factors for family users but not business users. The comparison of the first five key factors for both businesses and families indicates that it is advisable for the government to develop other policy measures to encourage the use of PV power generating systems.

Based on the findings of this study, recommendations include the following measures to be adopted by the government for encouraging businesses to adopt the technology:

1. Regarding the reduction in the carbon emissions key factor, regular and

sustained drives are recommended to educate businesses on the need to reduce their carbon emissions (e.g., through adoption of PV power generation).

2. Regarding the social responsibility key factor, this study supports publicizing and rewarding the efforts of businesses that install PV power generating systems, as well as encouraging such businesses to exhibit their systems to the media and general public, thereby improving their social images.
3. For the laws and regulations key factor, this study includes the following recommendations: (1) Conduct reviews and revisions of existing laws and regulations (without compromising public safety) concerned with land, buildings, electricity, etc., to enable faster uptake of PV power generation technology. (2) Where appropriate, introduce a relaxation in relevant laws for businesses to encourage installation of a PV power generation system on the top floor of a building or plant; also, include relief in regulations regarding bay windows and external walls. (3) Impose an energy tax, carbon tax, or other tax mechanism to force businesses to increase their utilization of renewable energy.
4. Regarding the tax exemptions/credits key factor, this study supports the initiation and implementation of a renewable energy credits system and tax exemptions/credits.
5. Regarding the feed-in tariff prices key factor, this study includes a recommendation for an annual review of feed-in tariffs to ensure that they continue to remain attractive for businesses (without overstepping fiscal limits).

Further, this study identifies the following measures that the government should initiate to encourage families to adopt PV power generating systems:

1. Regarding system cost and service life key factors, this study supports an elimination or reduction (within reasonable limits) of taxes on purchases of PV power generating systems.
2. Regarding the installation subsidy key factor, introducing special installation subsidies targeted at residential users, such as rural residents and those in outlying islands and mountainous areas, is recommended.
3. For the reduction in the carbon emissions key factor, another recommendation put forth in this study is to conduct regular and sustained drives to educate families on the need to reduce carbon emissions (e.g., with the adoption of PV power generation).
4. Regarding the tax exemptions/credits key factor, this study supports finalization of a comprehensive energy strategy to increase renewable energy usage, including policy and program implementation targeting individuals and families.

6. Conclusion

The fuzzy AHP method was used in this study to compare key factors influencing the adoption of PV power generating systems by businesses and families in Taiwan. The results showed that significant differences exist in the prioritization of factors by the two different user groups. Businesses prioritized reduction in carbon emissions, social responsibility, laws and regulations, tax exemptions/credits, and feed-in tariff prices. On the other hand, key factors for families were system costs, installation subsidies, reduction in carbon emissions, service life, and tax exemptions/credits. An analysis of differences indicated that governments should customize promotion policies for the adoption of PV power generating systems according to the designated users.

Using the prioritized factors revealed by the fuzzy AHP technique, this study includes specific recommendations aimed at promoting the application of the technology by businesses and families. It is anticipated that concerted efforts in this direction will help Taiwan meet its goal of producing 2,500 MW of energy through PV power generation by 2030.

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Notes

1. In the Spearman rank correlation test, d_i is the difference between the ranking of each factor for family users and business users, and n is the number of factors. I carried out the evaluation, with p = 0.2024, using the t distribution.

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