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Article

A Fuzzy Utility-Based Multi-Criteria Model for Evaluating Households' Energy Conservation Performance: A Taiwanese Case Study

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Abstract: Industry and economy are developed to satisfy the needs and material desires of people. In addition to making high greenhouse gas emissions the responsibility of industry, individuals and families should also be held responsible for the production of greenhouse gas emissions. In this study, we applied the Delphi method, the analytical hierarchy process, utility theory, and fuzzy logic theory to establish an energy conservation assessment model for households. We also emphasize that subsidy policy makers should consider the social responsibility of households and individuals, as well as sustainability of energy conservation.

Keywords: greenhouse gases; households; Delphi method; analytical hierarchy process; utility theory; fuzzy logic theory

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1. Introduction

Previous studies have discussed informational strategies for influencing the knowledge, perceptions, cognitions, motivations, and norms of individuals, and structural strategies for influencing the context in which decisions are made [1]. Because people and families consume energy daily, their contribution to greenhouse gas emissions cannot be ignored. However, residents do not necessarily associate their use of electricity with pollution. Therefore, their awareness of the association between environmental problems and energy issues should be raised [2]. Additionally, previous household energy use studies have focused primarily on social and psychological factors that influence the acceptance of energy-saving measures. However, the influence of physical characteristics of energy-saving measures on their acceptability is largely ignored [3]. Furthermore, the effects of housing and urban development policies on energy consumption and the effects of energy consumption policies on housing and urban development are both substantial, although they have been neglected in discussions on energy use or urban development policies [4]. It is commonly assumed that households must change their behavior to reduce the problems caused by increases in fossil energy use [1].

In 2006, Taiwan exceeded its quota for CO_2 emissions by 148 million metric tons. According to Europe's carbon market, where carbon dioxide costs 20 USD per metric ton, Taiwan would have to pay an excessive CO_2 emissions fee of approximately 3 billion USD, 1% of its annual GDP. In 2009, *per capita* emissions of CO_2 in Taiwan equaled 10.4 metric tons, more than double the global *per capita* CO_2 emissions of 4.38 metric tons. Total emissions in Taiwan have increased from 114.7 million metric tons in 1990 to 276.2 million metric tons in 2007. This rise in Taiwanese CO_2 emissions (140.9%) was 3.7 times faster than the world average. Additionally, according to the Key World Energy Statistics published by the IEA (2005), the CO_2 released from Taiwan was 245.21 metric tons in 2005, accounting for 1% of the World's emissions and ranking Taiwan in twenty-second place [5]. According to the latest statistics from Carbon Monitoring for Action for 2007, the total emissions from Taiwan's electricity industry were ranked thirteenth in the World [6]. Electricity generation is one of the major contributors to global greenhouse gas emissions [7]. Taiwan's exceedingly high CO_2 emissions means that if efficient policies are not proposed immediately, when the next Kyoto Protocol requirement managing newly industrialized nations' greenhouse gas emissions is implemented in the future, Taiwan will have to pay a significant CO_2 fee, severely damaging Taiwan's economic development. Additionally, Taiwan may also experience severe economic effects [8].

According to [9], this increase in Taiwanese CO_2 emissions is due to the proportion of coal-supplied energy sources drastically increasing from 27.4% in 1996 to 32.3% in 2006, while hydro and nuclear power, which emit no CO_2, have decreased from 2.7% and 13.0% to 1.4% and 8.3%, respectively. According to research of Kunchornrat, the transition towards a low-carbon society requires fundamental changes in both the energy systems and in the ways that society adapts to large transformations [10]. Recently, the Taiwanese government has worked continuously to decrease greenhouse gas emissions, rigorously promoting electricity, water, and oil saving policies and implementing subsidies for household electricity and water conservation and fines for increased usage [11]. Specifically, these subsidies include a monthly household subsidy for electricity and water conservation, which can be used to purchase electricity and water-saving appliances, and a subsidy to install energy-saving equipment. Despite a large government-allocated budget, these subsidies continue to have no significant effects. The problem is that household electricity in Taiwan is extremely inexpensive (see Table 1) [12]. Therefore, the subsidies and fines have little effect on consumers. This is also associated with the ratio of people who own energy-consuming modes of transportation. According to 2005 Taiwanese transportation sector statistics, overall transportation-related CO_2 emissions account for 14.4% of Taiwan's total CO_2 emissions. This was the second-highest source of CO_2 emissions in Taiwan [13]. Additionally, one factor for Taiwan's consistently high greenhouse gas emissions is the long-term energy-wasting habits of people. This is a systemic social phenomenon that would be difficult to improve effectively and immediately through the implementation of policy. Thus, all levels of education in Taiwan have recently continued to strengthen education on energy-saving issues. Energy-saving corporate social responsibility has been reinforced and advocated [14]. The importance of personal social responsibility has also been strengthened and promoted. The objective of these actions is to enhance the efficiency of carbon reduction.

Table 1. Electricity prices for households (U.S. dollars per kilowatt hour).

Country	2005	2006	2007	2008	2009
Kazakhstan	0.031	0.036	0.043	0.052	NA
Indonesia	0.058	0.062	0.063	0.061	NA
Paraguay	NA	NA	0.061	0.072	NA
Taiwan	0.079	0.079	0.080	0.086	NA
South Korea	0.089	0.098	0.102	0.089	NA
United States	0.095	0.104	0.106	0.113	0.116
Singapore	0.111	0.139	0.143	0.190	NA
Austria	0.158	0.158	0.178	0.201	NA
Japan	0.189	0.178	0.176	0.206	NA
United Kingdom	0.149	0.186	0.219	0.231	NA
Germany	0.212	0.222	0.263	NA	NA
Italy	0.198	0.226	0.258	0.305	NA

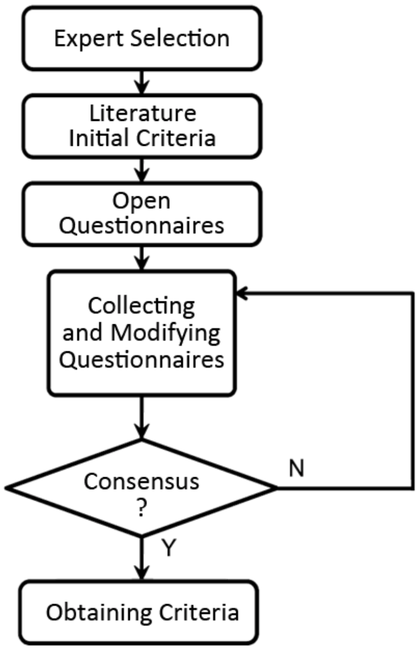
Currently, Taiwan is actively developing wind energy, hydropower, and other forms of renewable energy [15–18]. Numerous green policies, such as subsidies for individuals, families [19], and residential buildings [20] are also being promoted. However, low-income households cannot afford to switch to or purchase energy-saving appliances; thus, they cannot benefit from the subsidies provided by such policies. Furthermore, these groups already produce low levels of carbon because they cannot afford to consume excessive amounts of energy. Therefore, subsidy policies have merely become additional discounts for regular consumers. Policies face difficulties for producing immediate changes for problems that are rooted in long-term social habits. These problems involve diverse and complex influencing factors, and no successful cases for learning and emulation exist. Thus, an error-learning phase must be passed.

Because each of the four methodologies have fundamental assumptions and value in academic research and application, we have combined characteristics from the the Delphi method, the analytical hierarchy process (AHP), utility theory, and fuzzy logic theory to establish a fuzzy utility-based multi-criteria model for processing compound decision-making. Each of these theories has been widely applied in numerous fields, such as science, economics, management, education, and agriculture. We employ the Delphi method group decision-making technique [21,22] to determine the current most-suitable criteria. The AHP multi-criteria decision-making technique [23,24] is then used to investigate the relative importance of each criterion. Following this, we apply utility theory and use objective risk attitudes to investigate the assessment properties of tendencyissues [25]. Finally, we integrate fuzzy logic theory quantitative techniques to objectively establish an overall decision-making analysis that allows a simple comparison of quantitative values. This model has a high degree of adaptive convenience for future maintenance. A case study is used to show the applicability of the proposed model.

2. Model Overview

The Delphi method was developed by the U.S. RAND Corporation to assist management in predicting future events. However, its application scope is not restricted to predicting future events [20]; the Delphi method is also the best approach for obtaining the latest professional knowledge from expert groups [9], which is beneficial for increasing research reliability. The Delphi method is composed of the following steps: (1) select experts; (2) obtain initial assessment factors from previous studies; (3) design and distribute questionnaires; (4) recover and modify questionnaires; (5) if assessment factors do not reach a consensus, return to Step 4; and (6) obtain the criteria required for this study. Figure 1 shows a flowchart of the Delphi method process.

Figure 1. Delphi method operation flowchart.



The AHP method was first proposed by Saaty and has been widely used for solving multi-criteria decision-making problems. AHP is also commonly applied in social, policy, and engineering decision-making issues [26,27]. AHP can obtain only the relative weights among factors. AHP combined with utility theory can obtain expected utility values. This quantified value can be used for comparison and has reference value for decision-making.

Utility theory is a quantitative theory for analyzing human values. It was first presented by Bernoulli in 1738 [28,29]. Utility can measure the preferences of consumers and serve as a unit of personal welfare. The utility function can represent the preference and relative risk attitude of consumers [30]. Utility theory has been applied to green supply chain management [31], joint construction ventures [25], design-build projects [32], bid markup decisions [33], and devaluating build, operate, and transfer (BOT) projects [34]. Using the utility function to establish an assessment model provides the advantages of not only addressing the difficulties of building a multi-criteria model, but also supporting decision-makers by adjusting to their preferences and risk attitude to reduce the occurrence of inconsistent decisions influenced by various factors, such as emotion, environment, and information.

Fuzzy logic can be used to process ambiguous information from natural human language, such as uncertainty, complexity, and tolerance for imprecision [35]. Fuzzy logic theory is appropriate for use in processing complex evaluations and decision-making issues that are difficult to quantify [11], especially group decision-making [36,37]. The computing core of the fuzzy logic model is the fuzzy logic inference system (FLIS). This is an artificial intelligence model that can complete quantitative conversion programs by sending various input combinations through the fuzzifier and rule base inferences to the defuzzifier. Figure 2 shows the FLIS schematic diagram. First, establishing a FLIS requires the completion of membership function selection and defining the fuzzy scale [11,38,39].

Figure 2. FLIS quantified transformation inference calculation schematic diagram.

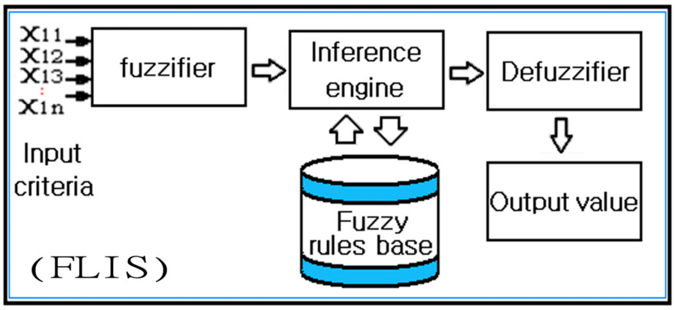
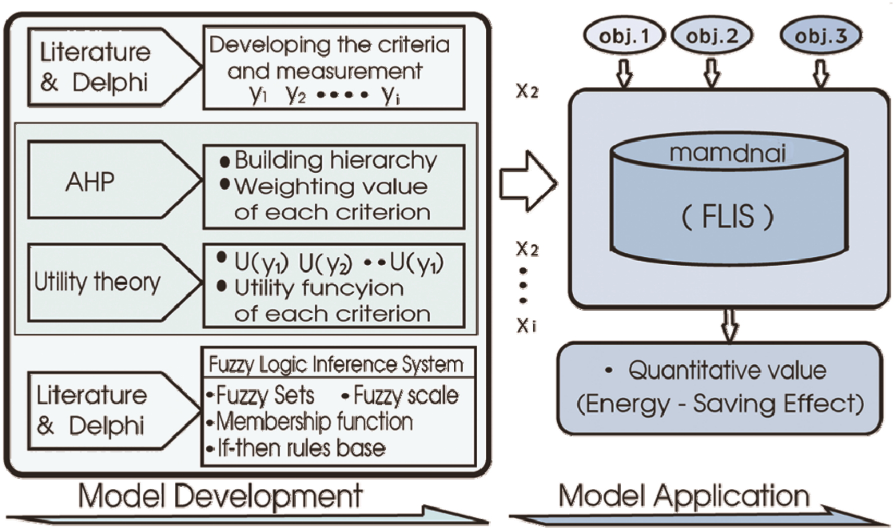


Figure 3. The framework of the evaluation model.



This study developed a model that combines the Delphi method, AHP, utility theory, and fuzzy logic theory. This model is highly rigorous and reliable because of the expert assistance we employed to examine the content and participate in group decision-making during the modeling process. The modeling process is divided into two stages: (1) model development; and (2) model application. The diagram of these stages is shown in Figure 3. Y in Figure 3 represents the subcriteria of the X_1 criterion, $U(y)$ is the utility function of each subcriterion, and Obj represents objects that require assessment. The assessed objects may be single objects or comparisons of the advantages and disadvantages of numerous objects. The quantified transformation inference calculation schematic diagram for the FLIS is shown in Figure 2. Mamdnai represents the quantified output relationships of the FLIS that present continuous changes. The Delphi expert group decision-making data obtained in this study provide important information required by the fuzzy logic model. In the environment of the fuzzy utility-based multi-criteria model, we must first select the appropriate criteria among the complex influencing factors. Next, the hierarchy of each criterion is completed, and we select the quantified membership functions of natural language and determine the fuzzy sets and fuzzy scale. After completing the FLIS if-then rules base, the fuzzy utility-based multi-criteria model is prepared for operation.

3. Model Development and FLIS Input Criteria: x_1, x_2, x_3

Recently, corporate social responsibility has become a frequently discussed topic worldwide [14]. Numerous businesses are also realizing that corporate social responsibility is a source of future business opportunities and competitive advantage [40,41]. Corporate social responsibility could be considered as a type of corporate reputational risk insurance and a prediction of damage to profits and company value to conform to the strategies required externally [42]. Although corporate social responsibility has been widely discussed and received much attention, social responsibility for household families and individuals has been rarely examined and analyzed separately because of its small sphere of influence. Today, greenhouse gas emissions are continuing to cause severe compound disasters. Corporations and the industry cannot be held solely responsible for greenhouse gas emissions. The fundamental problem is the result of people pursuing material desires and using excessive amounts of energy to achieve them. As O'Neill indicated, a national initiative to educate people about social responsibility that can be adopted across a variety of specific institutional contexts and missions is necessary [43].

Reducing energy consumption would have significant environmental benefits [44]. Hsueh indicated that, according to the BP Statistical Review of World Energy 2009, the earth's oil resources will be consumed by 2050, and excessive exploitation and use of energy sources will result in severe environmental pollution, climate anomalies, unpredictable natural disasters, and significant potential endangerment life worldwide. All walks of life must change their habitual energy consumption and use practices, with related governments enacting penalty measures for high energy consumption and rewards for energy-savings. The implementation of sustainable energy conservation policies and using green energy sources in response to energy-saving policies is necessary because energy policies have important effects on cities [45]. They also provide methods and strategies for securing ecological and economic sustainability [46].

We used the Delphi process to list the two primary influencing factors, that is, family member social responsibility and sustainability of energy conservation as the FLIS input criteria. These two criteria influence our living environments and economic problems.

During model development, this study first verified the three primary input criteria for the FLIS, that is, x_1, x_2, and x_3. Each criterion evaluates a different input: x_1 evaluates the household's total energy consumption (including electricity and water usage and a comparison with the previous month); x_2 evaluates the social responsibility of household members; and x_3 evaluates the sustainability of energy conservation. Of these three criteria, x_2 and x_3 confirm the energy conservation sustainable behavior and x_1 examines habits and attitudes regarding daily energy use. Because numerous factors influence criteria x_1, this study applied a multi-criteria utility theory with biased consumers to confirm the degree of energy conservation. Furthermore, the evaluation content and data properties differ for these three criteria. Therefore, combining multiple theories during model development is the most suitable method to quantify differing data properties.

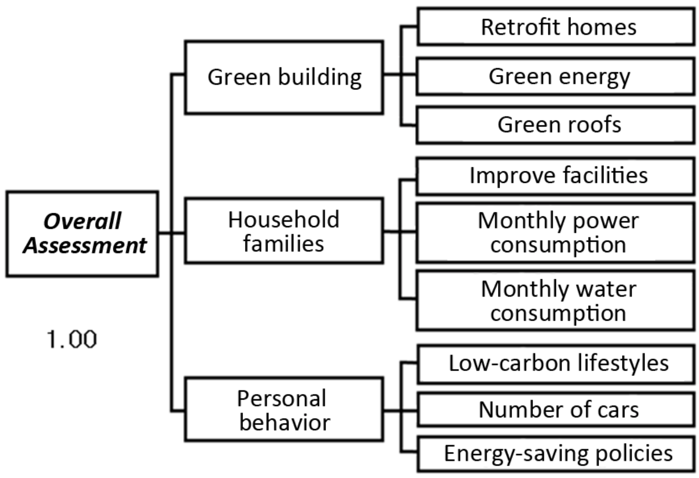
3.1. Application of AHP and Utility Theory to Examine x_1 Criterion Data Properties

The Delphi experts assisting in this study had more than ten years of practical work experience in their related fields. Three served in the public sector, three were scholars, and six were residents with master degrees or higher, for a total of 12 Delphi experts. Currently, green energy policies in Taiwan are formulated and revised by the Construction and Planning Agency. Professors from a number of reputable universities also provide research-based suggestions. Because Taiwan is small and provisions in the management department are clear, selecting appropriate expert management specialists and managers to assist with this research is easy. The three public sector managers and three scholars were core experts in their respective fields. Additionally, because Taiwan is geopolitically divided into three areas (north, central, and south), we selected two residents from each region for a total of six residents. Each was a long-term, enthusiastic participant in community building and promoting low-carbon lifestyles in their respective communities.

Anderson used design/technology strategies of net-zero energy buildings to analyze future residential system performance and found that excessive greenhouse gas emissions result from various industries [47]. Construction is not only a high-pollution industry but it also has high energy consumption. Green building and a green construction industry supply chain are not conceptual issues; instead, they are industry transitions that must occur to meet the demands of an increasingly environmentally-conscious market. Green energy limitations for the commercial construction industry have been formally included into the government procurement laws in the majority of advanced nations. Therefore, low-carbon, energy conservation initiatives must be considered for the entire construction life cycle, from design, procurement, materials, and construction techniques to maintenance and use. The x_1 criterion examines the everyday life energy consumption of household members and buildings, and is used to assess improvements to household energy consumption.

Different factors impact household energy consumption to varying degrees. For example, factors such as whether the household comprises only one person or a family of several people; factors determining whether a building is green, such as the building design, building exterior [48], ventilation design [49,50], green roofs [51,52], and the facilities and materials used; and factors regarding the different daily energy consumption or conservation habits of each member of a household, such as using natural light, energy-conserving lamps [53–55], ventilation equipment [56], air conditioning [57], heating systems [58], solar energy [59], water- or electricity-conserving equipment, the type and number of vehicles, and the planting of green plants. Because of the varying impact, we first used Delphi expert assistance to select and archive criteria for this study, and confirmed the AHP hierarchical framework for each criterion, as shown in Figure 4.

Figure 4. AHP hierarchical framework for each criterion.



In Figure 4, two levels are divided under overall assessment. The first level has the following three criteria: green building, household families, and personal behavior. Each main criterion is subdivided into three subcriteria. Because AHP questionnaires frequently result in invalid responses, the AHP process is time-consuming. According to Hseuh more than one year is required to complete the AHP process. We requested professionals to assist with the AHP questionnaires and obtain complete and valid questionnaire data. We adopted a strict attitude in completing the AHP process. The experts who assisted with the 35 valid questionnaires during the AHP process all had ten years or more work experience in their related fields. The scholars were a vice chancellor, a dean, and a senior professor at universities ranked in the top five of all universities in Taiwan. The industry experts were an architect, a CEO, and a project manager with master's degrees. The majority of the government officials also had master's degrees who were all also family members. This study took approximately one year to complete the AHP process. Tables 2 to 5 shows the relative weight calculations for each x_1 criterion for each level. Table 6 shows the relative weight for each criterion in the overall assessment.

Table 2. Weighting value of main criteria.

Comparison of Personal behavior, Household families and Green building			
Attributes	Personal behavior	Household families	Green building
Personal behavior	1	1	2
Household families	1	1	1
Green building	1/2	1	1
Eigenvector	0.41	0.33	0.26

Table 3. Weighting value of Green building.

Comparison of Retrofit homes, Green energy and Green roofs			
Attributes	Retrofit homes	Green energy	Green roofs
Retrofit homes	1	1	1
Green energy	1	1	1
Green roofs	1	1	1
Eigenvector	0.33	0.33	0.33

Table 4. Weighting value of Household families: comparison of improved facilities, monthly power consumption and monthly water consumption.

Attributes	Improved facilities	Monthly power consumption	Monthly water consumption
Improve facilities	1	2	1
Monthly power consumption	1/2	1	4
Monthly water consumption	1	1/4	1
Eigenvector	0.39	0.39	0.22

Table 5. Weighting value of personal behavior: comparison of assorted energy-saving policies, low-carbon lifestyles and number of cars**.**

Attributes	Assort energy-saving policies	Low-carbon lifestyles	Number of cars
Assort energy-saving policy	1	1/2	1/3
Low-carbon lifestyles	2	1	1
Number of car	3	1	1
Eigenvector	0.17	0.39	0.44

Table 6. Weighting value of each criterion.

Main-Criteria (*wi*)	Sub-Criteria (*wi*)	*wi*	*Wi* %
Green building (0.26)	Retrofit homes (0.33)	0.086	8.60%
	Green energy (0.33)	0.086	8.60%
	Green roofs (0.33)	0.086	8.60%
Household families (0.33)	Improve facilities (0.39)	0.129	12.9%
	Monthly power consumption (0.39)	0.129	12.9%
	Monthly water consumption (0.22)	0.073	7.30%
Personal behavior (0.41)	Low-carbon lifestyles (0.39)	0.160	16.0%
	Number of cars (0.44)	0.180	18.0%
	Energy-saving policies (0.17)	0.070	7.0%
Wi = *wi* * 100%		1	99.9%

Because utility theory can define the function properties and risk value range of each criterion based on the decision maker's experience and preferences, this study applied the straight-line relationship utility function technique to establish the utility function of each criterion [25,33]. Each criterion has an exclusive linear utility function $u_i(y_i) = Ay_i + B$ and a fuzzy scale value between (y_u, y_L), where y_{ma} within the $y_u - y_L$ range is the most preferred point, $u_i(y_{ma}) = 1$ and y_{mi} is the worst point, $u_i(y_{mi}) = 0$.

First, A and B values in the $u_i(y_i) = Ay_i + B$ were computed.

Because $u_i(y_{mi}) = 0$; $u_i(y_{ma}) = 1$, we can obtain the following equations:

$$u_i(y_{mi}) = A \times y_{mi} + B = 0 \quad , \quad B = -Ay_{mi}$$

$$u_i(y_{ma}) = A \times y_{ma} + B = 1 \quad , \quad A = 1 \big/ (y_{ma} - y_{mi})$$

The expected utility value equals the sum of each criterion's relative ratings u_i (y_i) * weighting value (W_i) and can be obtain using the following equation (u_i (y_i) = u_{ri}):

$$\text{Expected Utility Value (EUV)} = \sum_{i=1}^{n} (u_{ri} \times W_i)$$

After defining the fuzzy scale for (y_u, y_L) and the values for y_{mi} and y_{ma}, the constants A and B and the utility function for each criterion can be obtained using the above equation (See Table 7). Next, the expected utilities obtained by AHP and utility theory were applied (See Table 8). Higher expected utility indicates higher energy conservation activity for household members. Therefore, using this single assessment, higher quantified utility values can obtain a higher subsidy if x_2 and x_3 criteria have a similarly optimal evaluation value.

Table 7. Range, Most preferred point, A/B constants, and UF for criteria.

Criterion	y_u	y_L	y_{mi}	y_{ma}	A	B	Utility function u_i (y_i) = Ay_i + B
Retrofit homes	100	0	30	100	0.014	−4.26	u_i (y_i) = 0.014y_i − 4.26
Green energy	30	0	5	30	0.04	−0.2	u_i (y_i) = 0.04y_i − 0.2
Green roofs	20	0	5	20	0.067	−0.34	u_i (y_i) = 0.067y_i − 0.34
Improve facilities	50	0	10	50	0.025	−0.25	u_i (y_i) = 0.025y_i − 0.25
Monthly power consumption	30	−20	5	30	0.04	−0.2	u_i (y_i) = 0.04y_i − 0.2
Monthly water consumption	20	−20	5	20	0.067	−0.34	u_i (y_i) = 0.067y_i − 0.34
Low-carbon lifestyle	100	0	60	100	0.025	−1.5	u_i (y_i) = 0.025y_i − 1.5
Number of cars	100	0	60	100	1.025	−1.5	u_i (y_i) = 0.025y_i − 1.5
Energy-saving policies	100	0	50	100	0.2	−1	u_i (y_i) = 0.02y_i − 1

Table 8. Expected utility value for criteria.

Criterion	*Wi*	*Wi* %	u_{ri}		u_{ri} * (W_i)	
			Optimal	Worst	Optimal	Worst
Retrofit homes	0.086	8.60%	0.99	−4.26	8.51	−36.64
Green energy	0.086	8.60%	1	−0.2	8.6	−0.2
Green roofs	0.086	8.60%	1	−0.34	8.60	−0.34
Improve facilities	0.129	12.9%	1.25	−0.25	16.13	−0.31
Monthly power consumption	0.129	12.9%	1	−1	12.9	−12.9
Monthly water consumption	0.073	7.3%	1	−0.47	7.3	−0.47
Low-carbon lifestyle	0.16	16.0%	1	−1.5	16	−24
Number of cars	0.18	18.0%	1	−1.5	18	−27
Energy-saving policies	0.07	7.0%	1	−1	7	−7
Expected utility value					103.04	−108.86

3.2. The Fuzzy Logic Inference System

In the previous section, AHP and utility theory were used to obtain the fuzzy range for x_1 criteria, and the fuzzy range defined values for x_2 and x_3 criteria are shown in Table 6. Fuzzy logic theory was applied to better manage uncertainty, complexity, and tolerance for imprecision in natural language to define the fuzzy range value for two criteria. As shown in Table 9, the quantified definition and conversion for social responsibility and sustainability of energy conservation were completed using good, ordinary, and poor in natural language.

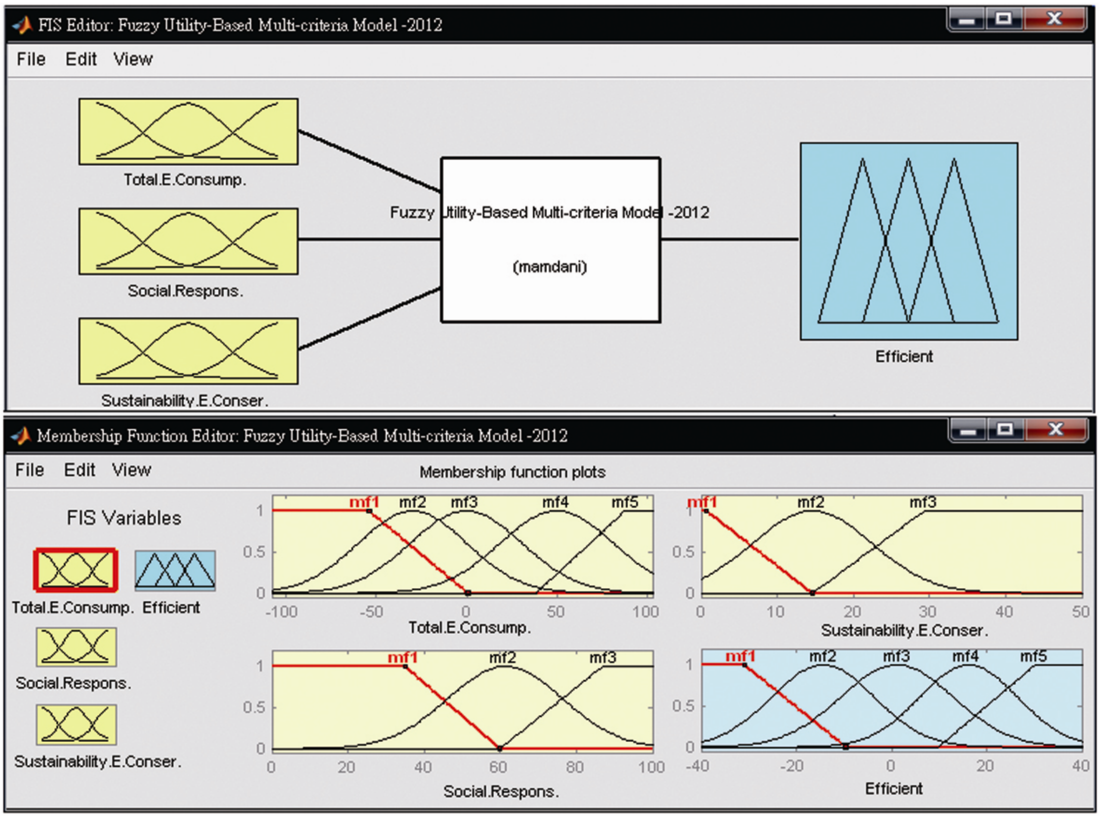
Table 9. Fuzzy set, fuzzy range, and output value.

Input Scenario			Fuzzy output value	
Criteria	**Value range**	**Fuzzy sets**	**Description**	**Fuzzy sets**
(x_1) Total energy consumption	80	Very good	Quantitative value	Very good (30%↑)
	60	Good		Good (10%↑)
	0	Ordinary		Ordinary (0%)
	−40	Poor		Poor (−10%↓)
	−60	Very poor		Very poor (−30%↓)
(x_2) Social responsibility	85	Good		
	60	Ordinary		
	35	Poor		(−30%~30%)
(x_3) Sustainability of energy conservation	35%	Good		
	15%	Ordinary		
	5%	Poor		

The fuzzy logic inference method can be separated into two systems, that is, the Mamdani and the Sugeno system. Generally, the Mamdani output is continuous whereas Sugeno's is discrete. To understand the change in continuous output, this study adopted the Mamdani system. Furthermore, the fuzzy logic model requires a complete IF-THEN rules base and FLIS to possess inference and calculation functions. Therefore, valid fuzzy value definitions and precise data properties help increase model reliability. The data properties and fuzzy definitions of the three criteria in Table 9 were obtained using the multi-methodology method. Therefore, the input and output, fuzzy sets, and fuzzy scale for the three criteria are highly reliable. Additionally, the measurement scale defined in fuzzy logic is an artificially-set fuzzy scale. For example, for sustainability of energy conservation factors, 35% energy conservation is good, 15% energy conservation is ordinary, but whether 20% is good or ordinary is determined in the fuzzy logic measurement scale by membership functions. Finally, the fuzzy logic inference system is used again for defuzzification and to present the results of the quantified output.

Although multiple types of membership functions exist, the membership functions commonly used include triangular functions and bell-shaped functions [60,61]. Therefore, triangular functions and bell-shaped functions were also adopted in this study for fuzzy set membership functions. Figure 5 shows the FLIS schematic diagram for the fuzzy utility-based multi-criteria model proposed in this study.

Figure 5. FLIS of fuzzy utility-based multi-criteria model.



4. Model Development

The x_1 criteria had five scenarios and x_2 and x_3 had three each, providing a total of 45 possible input scenario compositions (5*3*3 = 45). Although the fuzzy range and fuzzy scale data properties for the three criteria differed, each evaluation combination is quantified through FLIS and corresponds to a quantified output value or ratio after defuzzification. The output values in Table 9 were between −30% and 30%. In other words, households whose energy conservation performance is optimal can receive the maximum subsidy standard of 30% set by the policy. Thus, households on the opposite extreme would be required to pay tax for extra greenhouse gas emissions.

The 45 input scenarios in this evaluation model can be quantitative values or imprecise natural language, such as good (high), ordinary (middle), and poor (low). This method demonstrates how fuzzy logic accepts different data properties, tolerates imprecision, and accepts the decision makers' (evaluaters') vague natural language and is a tool for managing multi-attribute quantification. Figure 6 shows a 3D inputs and output mapping correlation diagram, which demonstrates that the FLIS quantitative evaluation calculation is a highly complex, objective, and scientific reference. Table 10 shows the FLIS quantitative evaluation function for the optimal and worst output values and those of the three case studies. Households that achieved optimal energy conservation performance can receive the 28% reward credit subsidy standard set by the policy, whereas the worst households with excessive energy usage must pay an extra −23.4% fee (As Figure 7). As shown in Cases 1 and 3 (Figure 8), actual sustained household energy conservation efforts are required to receive greater subsidy rewards.

The fuzzy logic model is a link in artificial intelligence. It can accept various assessment scales and units. The input values for each assessment factor can also be scores or the fuzzy concepts in language, such as "good, neutral, or bad." After performing the FLIS on the assessment factors, each of them is transformed into comparable quantified values. Cases 1 and 3 were processed with eight Delphi experts and three residents with long-term experience in aiding community building to test the application functions of this model on three household families. In addition to confirming that the model had calculation functions, we also ensured that it was simple to use and highly objective. Table 10 shows the assessment results. Additionally, we learned that poor scores for the two assessment factors of social responsibility and sustainability of energy conservation had a greater influence on overall assessments. This indicates that promoting energy-saving policy benefits is not difficult because of people's long-term energy use habits. This is a potential issue that is increasingly difficult to address.

Figure 6. Input and output mapping.

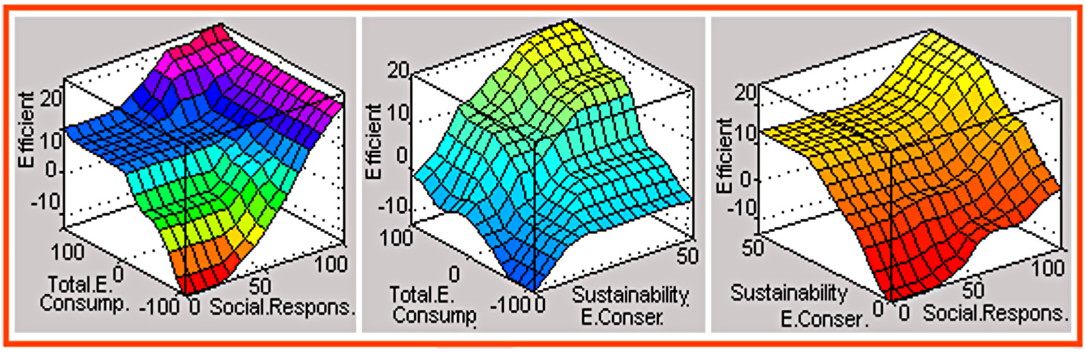


Table 10. Optimal and worst output value and the case study values.

Criteria	Opt.	Worst	Case study		
			Case 1	Case 2	Case 3
Total energy consumption	Very Good	Very Poor	Ordinary	Good	Good
Social responsibility	Good	Poor	Ordinary	Ordinary	Ordinary
Sustainability of energy conservation	Good	Poor	Ordinary	Poor	Good
Output value (Profit)	28	−23.4	3.93	−1.63	16.8

Figure 7. The optimal and worst output values.

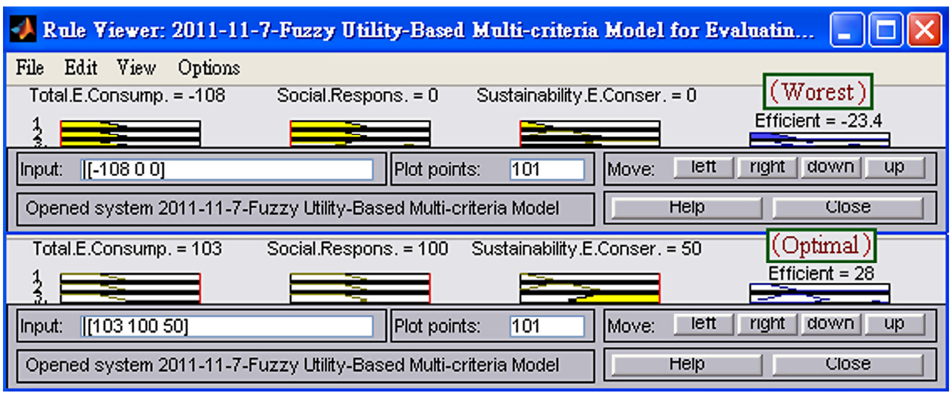
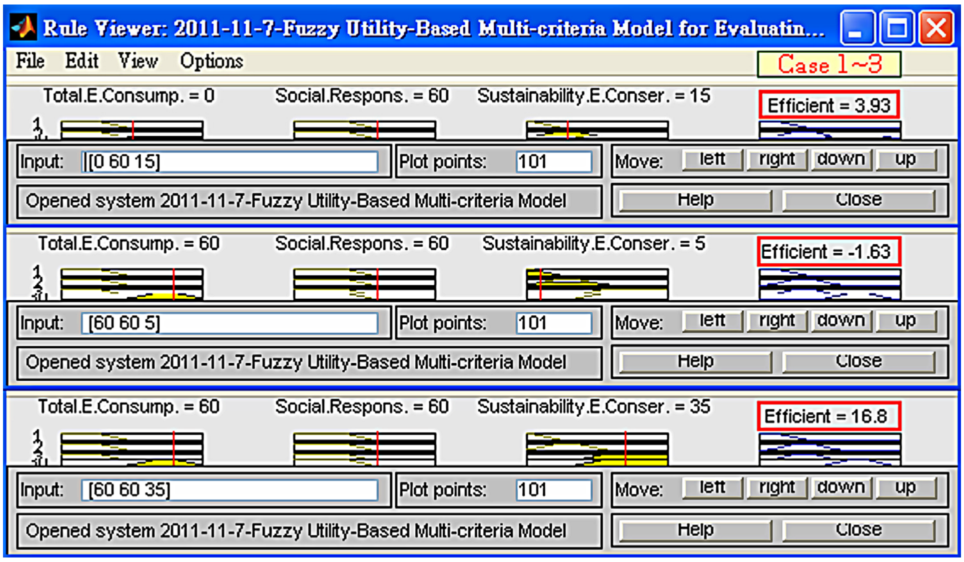


Figure 8. Case studies 1~3.



5. Conclusions

Regarding the issue of severely increased global greenhouse gas emissions, the influence of the attitudes of households and individuals toward social responsibility on greenhouse gas emissions is worthy of further investigation. This model possesses adaptive convenience for future revision and maintenance. It can be further developed as a calculation basis for investigating carbon trading for families or individuals. This would assist the implementation of consumer payments and force those who use excessive amounts of energy to purchase carbon credits from individuals, groups, or management units. This study provides reference for the public sector in establishing carbon trading policies for household families or individuals. The public sector should also reinforce social responsibility education on household families and individuals to lower greenhouse gas emissions. This would assist in enhancing the effectiveness of policy promotion.

The household energy conservation assessment model constructed in this study provides actual incentives to households that achieve conservation objectives and requires those that fail to pay an additional fee according to regulations. Furthermore, the case study statistics verified that this model possesses highly objective and scientific calculations and has actual reference value for further application of database management in government-related organizations. The model can not only increase management efficiency and effectiveness, but can also achieve quantified control management objectives and goals.

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