2014 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE)
July 6-11, 2014, Beijing, China

An Optimization Model for FML-based Decision Support System on Energy Management

Mei-Hui Wang, Pi-Jen Hsieh, Chang-Shing Lee, David Lupien St-Pierre, and Che-Hung Liu

***Abstract*—Global warming causes increasing natural disasters and gradually threatens human life and property safety. Under such an uncertain environment, efficiency and effectiveness in the energy management are an important and a difficult question. This paper aims to provide an approach for energy management that optimizes the relationship between different variables such as time, areas, countries, users, seasons, evaluation methods, and various different energy productions such as nuclear, water, biomass, wind, solar, and thermal. To achieve this goal, this paper combines the technologies of ontology and fuzzy markup language (FML) with theories about uncertainty to evaluate the applicability of the energy production based on technological innovation, economic development, social safety, environmental protection, regional characteristics, and time series. The simulation results show that the proposed approach is feasible to provide an alternative for energy management through the viewpoints of people, governments, and enterprises. It is hoped to provide the optimized energy management decision model for different decision makers and users as a reference in the future.**

I. Introduction

Analyzing and solving the problem of the climate change results in the gradual shortage of the non-renewable energy so enlarging the use of renewable energy has become an important topic of energy management in the world. Additionally, green technology has gradually become mature. If humans can further make full use of the natural resources to raise the efficiency of the renewable energy, it will be able to achieve the ideal goal of energy usage and management. Energy management varies in time, areas, countries, users, seasons, and evaluation method, and each energy has its specific features. Moreover, energy planning needs to take technological, economic, environmental, and social attributes into consideration. As a result, energy planning is a problem with a high uncertainty and has a strong relationship with time sequence and scale usage. When time changes, it is necessary to adjust energy demand and supply accordingly.

Because of this, many researchers have published related researches in energy planning, forecast, and storage. For example, Kaya and Kahraman [1] proposed a modified fuzzy technique for order preference by similarity to ideal solution (TOPSIS) methodology for the selection of the best energy technology alternative. Zafirakis et al. [2] developed a model to determine financial incentives for energy storage to promote the large-scale integration of wind energy. El-Karmi and Abu-Shikhah [3] studied the effect of introducing financial incentives to promote green electricity generation in Jordan and showed that wind energy is ranked first. Swift [4] made a comparison of the cost and financial returns for solar photovoltaic (PV) systems installed by businesses in different locations across the United States and showed that cost and financial returns vary dramatically depending on the location where they are installed. Ahmad and Tahar [5] developed an analytic hierarchy process (AHP)-based assessment model to prioritize renewable options, including hydropower, solar, wind, and biomass, by using a case of Malaysia. Zhang et al. [6] proposed three electricity supply scenarios for 2030 to demonstrate quantitatively the technological, economic, and environmental impacts of different supply policy selections and demand assumptions on future electricity systems.

Some researches about fuzzy based energy management approach also have been published. For example, Dong et al. [7] developed a fuzzy radial interval linear programming (FRILP) model to support a robust planning of energy management with environmental and constraint-conservative considerations. Bas [8] proposed an integrated strength, weakness, opportunity, and threat (SWOT)-fuzzy TOPSIS methodology combined with AHP to analyze an electricity supply chain in Turkey. Kucukali and Baris [9] forecasted Turkey's short-term gross annual electricity demand by applying fuzzy logic methodology based on general information on economic, political, and electricity market conditions of the country. Chakraborty et al. [10] presented an intelligent economic operation of smart grid environment to model the wind generation and PV generation as renewable power generation sources. Acampora et al. [11] exploited timed automata based fuzzy controllers for voltage regulation in smart grids to improve the grid voltage profile and reduce power losses. Chehri and Mouftah [12] proposed a fuzzy-based energy management controller to reduce the consumed energy of the building while respecting a fixed comfort. Xin et al. [13] proposed a genetic based fuzzy Q-learning consumer energy management controller to solve the energy management problems for demand response in electricity grid.

FML was first proposed and developed by G. Acampora and V. Loia [14]. Currently, an IEEE CIS sponsored standardization process is started in order to make FML the first standard technology in the area of computational intelligence. FML is with the following features:

The authors would like to thank the financial support by the National Science Council of Taiwan under the grant NSC 102-2221-E-024-005 and NSC 102-2911-I-024-501.

Mei-Hui Wang and Chang-Shing Lee are with the Dept. of Computer Science and Information Engineering, National University of Tainan, Taiwan. (corresponding author to provide phone: 886-6-2606123 ext. 7709; fax: 886-6-2606125; e-mail: leecs@mail.nutn.edu.tw).

Pi-Jen Hsieh and Che-Hung Liu are with Dept. of Business and Management, National University of Tainan, Taiwan.

David Lupien St-Pierre is with TAO, INRIA, France.

978-1-4799-2072-3/14/$31.00 ©2014 IEEE

understandability, extendibility, and compatibility of implemented programs as well as efficiency of programming [14, 15]. Therefore, many researchers used FML to describe the knowledge base and the rule base of the developed fuzzy inference mechanism. For example, Acampora et al. [16] proposed the timed automata based fuzzy controllers to make game bots with human-like capabilities and used FML to design and implement the bots behavior. Lee et al. [17] used FML to construct the knowledge base and the rule base to infer degrees of pleasure and arousal based on the Go game situation.

Energy planning using multi-criteria analysis has attracted the attention of decision-makers for a long time [1]. However, in the 1980s, owing to the climate change and the increase in environmental awareness, the related environmental and social issues must be incorporated into energy planning [1]. Moreover, multi-criteria decision-making (MCDM) often contains the vague information because domain experts' responses to their preference degree to an object usually exist an uncertainty about the degree. That is, their responses are usually expressed in linguistic terms [1, 18]. Incorporated with fuzzy sets, there has been considerable research on MCDM: Wu and Liu [19] proposed an interval-valued intuitionistic trapezoidal fuzzy numbers (IVITFNs) to resolve multiple attribute group decision making (MAGDM) problem. Tapia-Rosero et al. [20] proposed a shape-similarity-based method to detect similar opinions in group decision-making.

Combined fuzzy TOPSIS, this paper proposes a fuzzy markup language (FML)-based decision support system on energy management to recommend the suitable type of energy at the right time to further raise the efficiency of energy management. The remainder of this paper is organized as follows: Section II introduces the proposed FML-based decision support system. The optimization model for energy management is described in Section III. The simulation results are shown in Section IV. Finally, conclusion and future work are given in Section V.

II. FML-BASED DECISION SUPPORT SYSTEM

A. Energy Management Diagram

The objective of energy management is resource conservation, climate protection, and cost savings while the users have the permanent access to the energy they need [21]. Fig. 1 shows the energy management diagram.

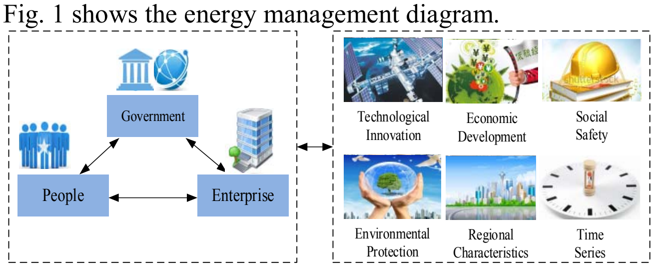

Fig. 1. Energy management diagram.

It indicates that energy management needs to consider the issues on technological innovation, economic development, social safety, environmental protection, regional characteristics, and time series from the viewpoints of three different kinds of users, including people, governments, and enterprises. Fig. 2 shows the energy species distribution in Taiwan and Penghu islands, located in western coast of Taiwan, and some descriptions are as follows:

- Wind farm is mainly located at the area along the western coastline of Taiwan.
- Hydroelectric power station is constructed near the Central Mountain of Taiwan to transfer the energy. July and August are Taiwan's typhoon season when is companied by a strong wind and a heavy rain. However, they are helpful for electricity generation if they are utilized at the right time.
- One of the necessities to construct a solar power plant is to have a rich sunshine during the daytime. With a subtropical climate, Taiwan has Asia's biggest high-concentration photovoltaic (HCPV) solar power plant [22].

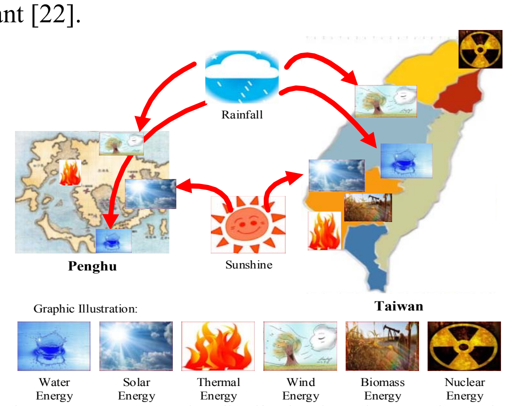

Fig. 2. Energy species distribution in Taiwan and Penghu.

B. Energy Decision Support System Ontology

Fig. 3 shows the constructed energy decision support (EDSS) ontology, including a domain layer, a concept layer, and an instance layer. The concept layer describes the EDSS by using *who*, *where*, *when*, *what*, and *how* concepts, and they are described as follows:

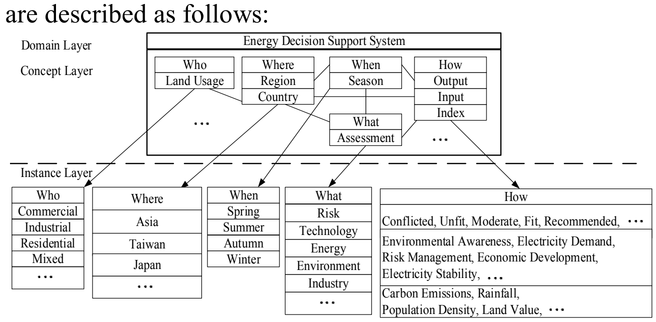

Fig. 3. Energy decision support system ontology.

- *Who* describes the land-use pattern, like for an industrial, a residential, or a commercial land use.
- *Where* describes the region and country for executing energy management.
- *When* is an important issue for energy management because each region or each country has its own time zone and the characteristics of its climate. Additionally, the scale of energy usage may change over time. For example, currently, the electricity generated by renewable energy still occupies a small part of total generated electricity from thermal energy. However, technical maturity to

construct the renewable energy will be advanced over time. Therefore, the occupancy of renewable energy will be raised in the future.

- *What* defines the evaluated items, such as risk, technology, energy, environment, industry, and so on.
- *How* defines the input, output, and the referred indexes for the adopted evaluated methods. For example, carbon emission, rainfall, population density, and land value are part of the referred indexes to create variables environmental awareness, electricity demand, economic development, electricity stability, and so on.

C. *FML-based Energy Decision Support Expert System*

In this subsection, one FML-based energy decision support system (EDSS) model is constructed, where we use four criteria as the input fuzzy variables to infer the assessment status for a certain kind of energy from the regional and season characteristics [23]. Fig. 4 shows its construction and each input varies in a specific region, for example, region A, region B, or region C. Based on pre-constructed knowledge base, rule base, and ontology, FML-based energy assessment status mechanism infers the energy assessment status for a certain kind of energy (Energy Category, EC) according to the inputs, including seasonal characteristics (SC), environmental awareness (EA), electricity demand (ED), and electricity stability (ES).

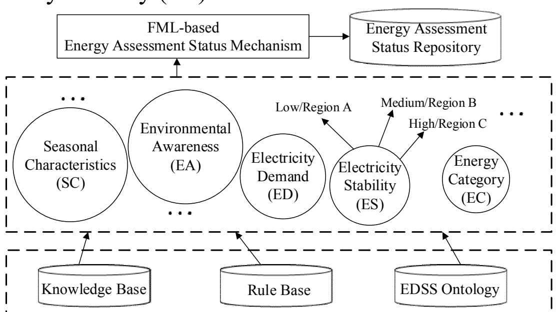

Fig. 4. FML-based energy decision support expert system.

The adopted fuzzy variables contain: (1) Seasonal Characteristics (SC): SC varies from different regions of the world and also changes over time. Countries with a long daylight in summer can consider raising the quantity of solar power plant. The heavy rainfall brought by weather events like typhoon can consider to promote the efficiency of the hydroelectricity power. (2) Environmental Awareness (EA): EA changes over time. Public concerns for natural environments increase while the concepts of low-carbon economy, green city, and zero pollution are gradually emphasized in the world. For example, currently, some developing countries do not much focus on environmental protection, but maybe their people's interest in environmental protection will slowly grow year by year. (3) Electricity Demand (ED): This feature is related to the characteristics of the region. When this region is well developed or has a high standard of living, the electricity demand for the residents becomes high. (4) Electricity Stability (ES): Land-use planning is done by the government to decide this region is for a commercial, a residential, an industrial, or a mixed area. The more diverse this region's land usage, the higher ES. (5) Energy Category (EC): It denotes a certain kind of energy, such as water, thermal, wind, solar, or nuclear. Based on the inputs of SC, EA, ED, and ES, the system can infer this energy's assessment status. (6) Best Energy Recommendation (BER): According to SC, EA, ED, and ES, the proposed expert system infers the recommended level for EC, including Conflicted, Unfit, Moderate, Fit, and Recommended. Table I lists the adopted partial FML codes.

TABLE I. PARTIAL FML CODES.

```
<?xml version="1.0"?>
<FuzzyController ip="localhost" name="">
 <KnowledgeBase>
  <FuzzyVariable domainleft="0" domainright="12" name="SC" scale="" type="input">
   <FuzzyTerm name="Winter" hedge="Normal">
    <TrapezoidShape Param1="0" Param2="0" Param3="2" Param4="3" />
   </FuzzyTerm>
   <FuzzyTerm name="Spring" hedge="Normal">
    <TrapezoidShape Param1="2" Param2="3" Param3="5" Param4="6" />
   </FuzzyTerm>
   <FuzzyTerm name="Summer" hedge="Normal">
    <TrapezoidShape Param1="5" Param2="6" Param3="9" Param4="10" />
   </FuzzyTerm>
   <FuzzyTerm name="Autumn" hedge="Normal">
    <TrapezoidShape Param1="9" Param2="10" Param3="12" Param4="12" />
   </FuzzyTerm>
  </FuzzyVariable>
…
</KnowledgeBase>
 <RuleBase activationMethod="MIN" andMethod="MIN" orMethod="MAX" name="RuleBase1" type="mamdani">
  <Rule name="Rule1" connector="and" weight="1" operator="MIN">
   <Antecedent>
    <Clause>
     <Variable>SC</Variable>
     <Term>Autumn</Term>
    </Clause>
    <Clause>
     <Variable>EA</Variable>
     <Term>Medium</Term>
    </Clause>
    <Clause>
     <Variable>ES</Variable>
     <Term>Business</Term>
    </Clause>
    <Clause>
     <Variable>EC</Variable>
     <Term>Thermal</Term>
    </Clause>
    <Clause>
     <Variable>ED</Variable>
     <Term>Medium</Term>
    </Clause>
   </Antecedent>
   <Consequent>
    <Clause>
     <Variable>BER</Variable>
     <Term>Unwell</Term>
    </Clause>
   </Consequent>
  </Rule>
…
 </RuleBase>
</FuzzyController>
```

III. OPTIMIZATION MODEL FOR ENERGY MANAGEMENT

A. *Introduction to Fuzzy TOPSIS*

TOPSIS is one of the known classical MCDM methods based on the concept that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS) [24]. Chen [25] further extended TOPSIS to fuzzy environment where the rating of each alternative and the weight of each criterion are described by linguistic terms instead of numerical values. Recently, Dymova et al. [26] proposed an approach to generalization of fuzzy TOPSIS method and Wang et al. [27] investigated the multi-attribute group decision making models under interval type-2 fuzzy environment. In this paper, a trapezoidal membership function for fuzzy set FS specified by four parameters $FS(x:a,b,c,d)$ is given in Eq. (1). Table II shows fuzzy TOPSIS algorithm.

$$FS(x:a,b,c,d)=\begin{cases}0 & x<a\\(x-a)/(b-a) & a\le x<b\\1 & b\le x\le c\\(d-x)/(d-c) & c<x\le d\\0 & x>d\end{cases}\tag{1}$$

TABLE II. FUZZY TOPSIS ALGORITHM.

Input:

1. Criteria (C) = {C_1, C_2, C_3, …, C_N} /*N denotes the number of criteria*/
2. Alternatives (A) = {A_1, A_2, A_3, …, A_M} /*M denotes the number of alternatives*/
3. Domain experts (DE) = {DE_1, DE_2, …, DE_K} /*K denotes the number of domain experts*/
4. Linguistic variables for importance weight of each criterion (LVW) = {LVW_1, LVW_2, …, LVW_P} /*P denotes the number of linguistic variables for the weight of each criterion*/
5. Linguistic variables for ratings (LVR) = {LVR_1, LVR_2, …, LVR_Q} /*Q denotes the number of linguistic variables for the rating of each alternative with respect to each criterion*/
6. Weights for all criteria defined by K domain experts = {{w_1^1, w_2^1, …, w_N^1}, {w_1^2, w_2^2, …, w_N^2}, …, {w_1^K, w_2^K, …, w_N^K}}, where w_j^k denotes the linguistic variable for importance weight, where w_j^k = (aw_j^k, bw_j^k, cw_j^k, dw_j^k) denotes the weight's linguistic variable given by the k^{th} domain expert with respect to the j^{th} criterion
7. Ratings for all alternatives with respect to each criterion defined by K domain experts = {{x_{11}^1, x_{12}^1, …, x_{MN}^1}, {x_{11}^2, x_{12}^2, …, x_{MN}^2}, …, {x_{11}^K, x_{12}^K, …, x_{MN}^K}}, where x_{ij}^k = (ax_{ij}^k, bx_{ij}^k, cx_{ij}^k, dx_{ij}^k) denotes the rating's linguistic variable given by the k^{th} domain expert for the i^{th} alternative with respect to the j^{th} criterion

Output:

Assessment status of each alternative and its ranking order

Method:

Step 1: Aggregate the weights for all criteria defined by K domain experts by

w_j=(MIN(aw_j^k), $\frac{1}{K}\sum bw_j^k$, $\frac{1}{K}\sum cw_j^k$, MAX(dw_j^k))

=(aw_j, bw_j, cw_j, dw_j)

$\mathbf{W}$ = [w_1, w_2, …, w_N]

where k = 1, 2, …, K, and j = 1, 2, ..., N

Step 2: Aggregate the ratings for all alternatives with respect to each criterion defined by K domain experts by

x_{ij}=(MIN(ax_{ij}^k), $\frac{1}{K}\sum bx_{ij}^k$, $\frac{1}{K}\sum cx_{ij}^k$, MAX($dx_{ij}^k$))

=(ax_{ij}, bx_{ij}, cx_{ij}, dx_{ij})

$\mathbf{X}$ = $[x_{ij}]_{M\times N}$

where k = 1, 2, …, K, i = 1, 2, …, M, and j = 1, 2, ..., N

Step 3: Construct the normalized fuzzy decision matrix $\mathbf{R}$ = $[r_{ij}]_{M\times N}$ by

r_{ij}=($\frac{a_{ij}}{d_j^*}$, $\frac{b_{ij}}{d_j^*}$, $\frac{c_{ij}}{d_j^*}$, $\frac{d_{ij}}{d_j^*}$) if the j^{th} criterion is a benefit criterion

r_{ij}=($\frac{a_j^-}{d_{ij}}$, $\frac{a_j^-}{c_{ij}}$, $\frac{a_j^-}{b_{ij}}$, $\frac{a_j^-}{a_{ij}}$) if the j^{th} criterion is a cost criterion

where i = 1, 2, …, M, j = 1, 2, ..., N, a_j^-=MIN(ax_{ij}), and d_j^*=MAX(dx_{ij})

Step 4: Construct the weighted normalized fuzzy decision $\mathbf{V}$ = $[v_{ij}]_{M\times N}$ by

v_{ij}=$r_{ij}\times w_j$=(av_{ij}, bv_{ij}, cv_{ij}, dv_{ij})

where i = 1, 2, …, M, j = 1, 2, ..., N

Step 5: Define fuzzy positive-ideal solution (FPIS) $\mathbf{A}^*$ = [v_1^*, v_2^*, …, v_N^*], where v_N^*=(MAX(dv_{iN}), MAX(dv_{iN}), MAX(dv_{iN}), MAX(dv_{iN})) and i = 1, 2, …, M

Step 6: Define fuzzy negative-ideal solution (FNIS) $\mathbf{A}^-$ = [v_1^-, v_2^-, …, v_N^-], where v_N^-=(MIN(av_{iN}), MIN(av_{iN}), MIN(av_{iN}), MIN(av_{iN})) and i = 1, 2, …, M

Step 7: Calculate the distance of each alternative from $\mathbf{A}^*$

$d_i^*=\sum_{j=1}^{N} d(v_{ij},v_j^*)$, where i = 1, 2, …, M

Step 8: Calculate the distance of each alternative from $\mathbf{A}^-$

$d_i^-=\sum_{j=1}^{N} d(v_{ij},v_j^-)$, where i = 1, 2, …, M

Step 9: Calculate the closeness coefficient (CC) of each alternative

$CC_i=\frac{d_i^-}{d_i^*+d_i^-}$, where i = 1, 2, …, M

$\mathbf{CC}$ = [CC_1, CC_2, …, CC_M]

Step 10: Sort $\mathbf{CC}$ in an ascending order and store the results into the ranking matrix $\mathbf{RK}$ = [RK_1, RK_2, …, RK_M]

Step 11: End

B. Fuzzy TOPSIS-Based Energy Decision Support Expert System

FML-based energy decision support expert system only considers the energy management from the viewpoints of regional characteristics and time series. However, in this subsection, we further extend the considered variables because energy management is a complex task and involves in many issues. Fig. 5 shows the criteria that are related to the optimization of energy management for different types of energy according to six different viewpoints, including technological innovation, economic development, social safety, environmental protection, regional characteristics, and time series. Table III shows the brief descriptions of the adopted sub-criteria in this paper, where "*" denotes this criterion is a benefit criterion and "-" denotes this criterion is a cost criterion. The bigger the cost criterion value, the more disadvantaged for a certain kind of energy. On the contrary, the bigger the benefit criterion value, the more advantaged for a certain kind of energy. Table IV shows six energy alternatives discussed in this paper.

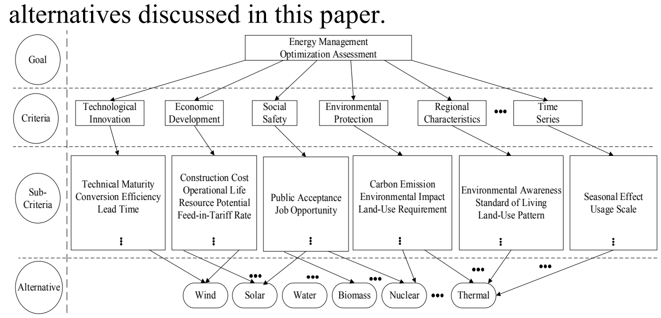

Fig. 5. Factors related to energy decision support optimization.

TABLE III. DESCRIPTIONS OF THE ADOPTED SUB-CRITERIA.

No.	Name	Description
		Technological Innovation
C12*	Technical Maturity	Technical development stage for a certain kind of energy
C7*	Conversion Efficiency	Efficiency converting energy from one form to another one for a certain kind of energy
C2-	Lead Time	Spent time from construction to operation for a certain kind of energy power plant
		Economic Development
C3-	Construction Cost	Invested cost from construction to operation for a certain kind of energy power plant
C9*	Operational Life	Total time from operation to phase out for a certain kind of energy power plant
C11*	Resource Potential	Potential storage capacity that has not yet used for a certain kind of energy
C10*	Feed-in-Tariff Rate	Subsidized prices coming from the government for a certain kind of energy
		Social Safety
C6*	Public Acceptance	Level for the public acceptance for a certain kind of energy

C8*	Job Opportunity	Creation in employment for constructing a certain kind of energy power plant
Environmental Protection		
C1-	Carbon Emission	CO_2 emission caused by a certain kind of energy
C5-	Environmental Impact	Level of ecological damage caused by a certain kind of energy
C4-	Land-Use Requirement	Land requirement for constructing a certain kind of energy power plant
Regional Characteristics		
C13*	Environmental Awareness	Level of environmental awareness for residents in this region
C14*	Standard of Living	Residents' standard of living in this region
C15*	Land-Use Pattern	Land-use pattern in this region
Time Series		
C16*	Seasonal Effect	Seasonal effect on a certain kind of energy
C17*	Usage Scale	Usage scale for a certain kind of energy

TABLE IV. DESCRIPTIONS OF SIX ENERGY ALTERNATIVES.

No.	A1	A2	A3	A4	A5	A6
Name	Water	Thermal	Biomass	Wind	Solar	Nuclear

C. *Optimization Model for Energy Management*

In this sub-section, we plan to propose an optimization model for energy management in the future. Fig. 6 shows the concepts of the optimization model for energy management. In Section II.C, the proposed expert system outputs a recommended "*energy category* (EC)." In order to use an optimizer like particle swarm optimization (PSO) model, the proposed expert system takes as input a probability distribution over the energy category vector like wind, solar, water, biomass, nuclear, and thermal. Then, the system returns a value such as unit commitment, reserve margin, or price/social cost for the given distribution. After that, PSO could look for the best distribution over the energy category vector.

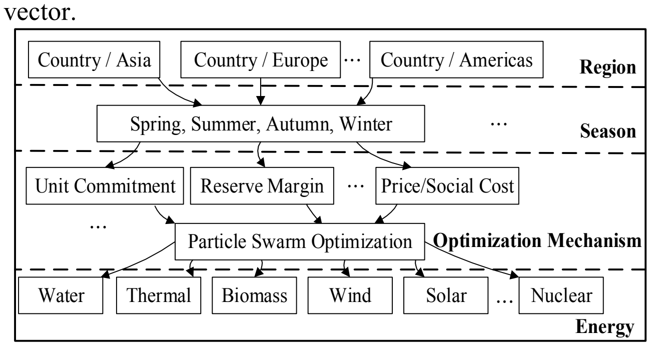

Fig. 6. Optimization model for energy management.

In the future, we could plan do the following optimizations: (1) Optimize across several geographic locations, for instance, optimizing for the entire country located in different regions according to the features of the climate. Then, we could use PSO to optimize the distribution of power plant. (2) Optimize the weight given for each criterion and sub-criteria in Sections II.A and II.B through simulations. The different weights were taken from the literature. Moreover, if we have direct access to the value of these weights, then a simple gradient descent would give us the optimal solution.

IV. SIMULATION RESULTS

In this section, some simulation results are given to show the performance of the proposed system. There are two parts of the simulation results. One part is done by executing the proposed fuzzy TOPSIS-based energy decision support expert system and another part is provided by FML-based energy decision support system. After that, we make a comparison about these two-part simulation results.

People, governments, and enterprises often have a different thought on energy management. Generally speaking, the main concern for people is about the impact on their surroundings when a power plant was scheduled to construct near their residence. But, enterprises much emphasize on the profits after investing an amount of money to construct a power plant or doing a business in energy management. Compared to people and enterprises, the governments require considering the policies that will benefit the society as a whole to meet the requirements of people and enterprises. Based on such an assumption, we simulate three domain experts (DE_1, DE_2, and DE_3) to give the importance weight of the criteria and ratings of the six alternatives with respect to each criterion to represent Taiwanese people, governments, and enterprises, respectively. Table V shows the basic information of four simulations (Exps. 1, 2, 3, and 4) by executing the fuzzy TOPSIS-based energy decision support expert system. In our simulations, there are seventeen criteria (Table III) and six energy alternatives (Table IV) are considered.

TABLE V. DESCRIPTIONS OF FOUR SIMULATIONS.

Exp. No.	Description
1	The opinions of DE_1, DE_2, and DE_3 are aggregated together to show the ranking order of the alternatives.
2	Only the opinions of DE_1 are considered to show the ranking order of the alternatives.
3	Only the opinions of DE_2 are considered to show the ranking order of the alternatives.
4	Only the opinions of DE_3 are considered to show the ranking order of the alternatives.

Fig. 7 shows the closeness coefficient (CC) for six energy alternatives with different experiments. Table VI shows the ranking order of six alternatives for Exps.1-4. Fig. 8 shows the radar chart for six energy alternatives' ranking order. It indicates the following results: (1) Solar energy is the first recommended energy alternative for Exps. 1, 2, and 3. Additionally, the second alternative is wind energy for these three experiments. (2) From the viewpoint of enterprises (Exp. 4), the first rank is biomass energy and the second one is thermal energy. (3) Nuclear energy is not welcome from the viewpoint of the people (Exp. 2). (4) For aggregating people, governments, and enterprises' thoughts (Exp. 1) or only considering people's thoughts, the first three energy alternatives are all renewable energy.

Table VII shows the simulation results from the FML-based energy decision support system by considering the following situations: It is summer, people's environmental awareness is medium, standard of living is high for this region, and the land use is a residential pattern [23]. Compared to Exp. 3, the ranking order roughly matches with each other. The best recommended energy alternative is solar energy, next one is wind energy and nuclear energy. Currently, Taiwan's government is promoting solar energy and encouraging Taiwanese people, especially those who live in southern Taiwan, to install solar Photovoltaic (PV) on the roof of their houses by providing some financial incentives like a feed-in tariff (FIT) [28]. Therefore, solar energy is welcome for Taiwanese people, which meets the simulation result.

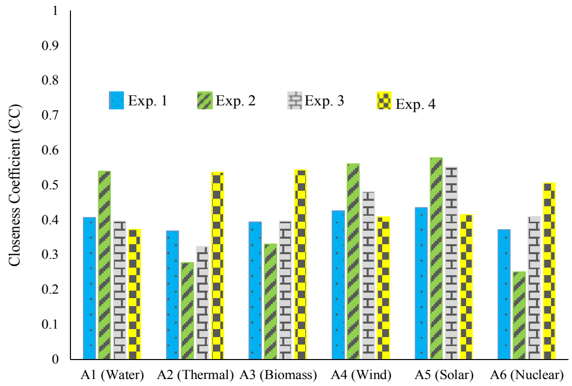

Fig. 7. Closeness coefficient (CC) for six energy alternatives.

TABLE VI. RANKING ORDER FOR SIX ENERGY ALTERNATIVES.

Exp. No	Energy Alternative					
	A1 Water	A2 Thermal	A3 Biomass	A4 Wind	A5 Solar	A6 Nuclear
1	3	6	4	2	1	5
2	3	5	4	2	1	6
3	4	6	5	2	1	3
4	6	2	1	5	4	3

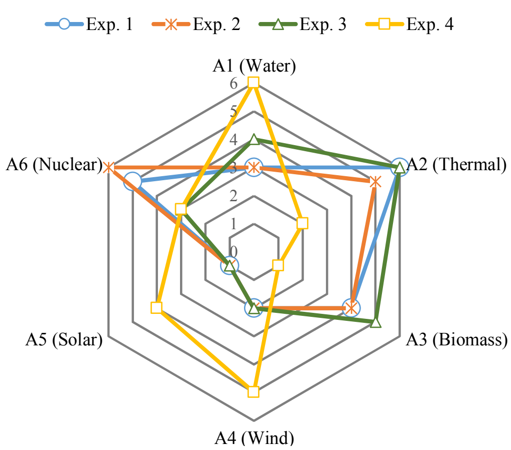

Fig. 8. Radar char displaying the ranking of six energy alternatives.

TABLE VII. SIMULATION RESULTS.

FML-based energy decision support expert system		
Energy Alternative	BER	Assessment Status
Water	1.27	Conflicted
Thermal	1.27	Conflicted
Wind	5.5	Moderate
Solar	7.5	Fit
Nuclear	5.5	Moderate
Ranking Order: Solar > Wind, Nuclear > Water, Thermal		
Exp. 3: Fuzzy TOPSIS-based energy decision support expert system		
Ranking Order: Solar > Wind > Nuclear > Water > Biomass > Thermal		

V. CONCLUSION AND FUTURE WORK

This paper aims to provide an approach for energy management that optimizes the relationship between different variables and various different energy productions. The simulation results show that the proposed approach is feasible to provide an alternative for energy management through the viewpoints of people, governments, and enterprises. However, the simulation results still have some space to further improve in the future. For example, (1) optimize across several geographic locations by using PSO, (2) optimize the weight given for each criterion and sub-criteria, and (3) incorporate the technologies of the artificial intelligence into the proposed system to improve the performance. Additionally, we will also try to set genetic algorithm (GA) or differential evolution (DE) to optimize the performance of the system and apply the proposed approach to some real-world experiments.

ACKNOWLEDGMENT

The authors would like to thank Mr. Chin-Yuan Hsu and Dr. Giovanni Acampora for their providing the developed FML system to implement the FML-based energy decision support expert system.

REFERENCES

[1] T. Kaya and C. Kahraman, "Multicriteria decision making in energy planning using a modified fuzzy TOPSIS methodology," *Expert Systems with Applications*, vol. 38, no. 6, pp. 6577-6585, Jun. 2011.

[2] D. Zafirakis, K. J. Chalvatzis, G. Baiocchi, and G. Daskalakis, "Modeling of financial incentives for investments in energy storage systems that promote the large-scale integration of wind energy," *Applied Energy*, vol. 105, pp. 138-154, May 2013.

[3] F. Z. El-Karmi and N. M. Abu-Shikhah, "The role of financial incentives in promoting renewable energy in Jordan," *Renewable Energy*, vol. 57, pp. 620-625, Sept. 2013.

[4] K. D. Swift, "A comparison of the cost and financial returns for solar photovoltaic systems installed by businesses in different locations across the United States," *Renewable Energy*, vol. 57, pp. 137-143, 2013.

[5] S. Ahmad and R. M. Tahar, "Selection of renewable energy sources for sustainable development of electricity generation system using analytic hierarchy process: A case of Malaysia," *Renewable Energy*, vol. 63, pp. 458-466, Mar. 2014.

[6] Q. Zhang, K. N. Ishihara, B. C. Mclellan, and T. Tezuka, "Scenario analysis on future electricity supply and demand in Japan," *Energy*, vol. 38, no. 1, pp. 376-385, Feb. 2012.

[7] C. Dong, G. H. Huang, Y. P. Cai, and Y. Liu, "Robust planning of energy management systems with environmental and constraint-conservative considerations under multiple uncertainties," *Energy Conversion and Management*, vol. 65, pp. 471-486, Jan. 2013.

[8] E. Bas, "The integrated framework for analysis of electricity supply chain using an integrated SWOT-fuzzy TOPSIS methodology combined with AHP: The case of Turkey," *Electrical Power and Energy Systems*, vol. 44, no. 1, pp. 897-907, Jan. 2013.

[9] S. Kucukali and K. Baris, "Turkey's short-term gross annual electricity demand forecast by fuzzy logic approach," *Energy Policy*, vol. 38, no. 5, pp. 2438-2445, May 2010.

[10] S. Chakraborty, T. Ito, T. Senjyu, and A. Y. Saber, "Intelligent economic operation of smart-grid facilitating fuzzy advanced quantum evolutionary method," *IEEE Transactions on Sustainable Energy*, vol. 4, no. pp. 905-916, Oct. 2013.

[11] G. Acampora, V. Loia, and A. Vitiello, "Exploiting time automata ased fuzzy controllers for voltage regulation in smart grids," in *Proceeding of 2011 IEEE International Conference on Fuzzy Systems* (*FUZZ-IEEE 2011*), Taipei, Taiwan, Jun. 27-30, 2011, pp. 223-230.

[12] A. Chehri and H. T. Mouftah, "FEMAN: Fuzzy-based energy management system for green houses using hybrid grid solar power," *Journal of Renewable Energy*, vol. 2013, pp. 1-6, 2013.

[13] L Xin, Z. Chuanzhi, Z. Peng, and Y. Haibin, "Genetic based fuzzy Q-learning energy management for smart grid," in *Proceeding of the 31st Chinese Control Conference* (*CCC 2012*), Hefei, China, Jul. 25-27, 2012, pp. 6924-6927.

[14] G. Acampora and V. Loia, "Fuzzy control interoperability and scalability for adaptive domotic framework," *IEEE Transactions on Industrial Informatics*, vol. 1, no. 2, pp. 97-111, May 2005.

[15] G. Acampora, C. S. Lee, M. H. Wang, and V. Loia, *On the Power of Fuzzy Markup Language*, Springer-Verlag, Germany, Jan. 2013.

[16] G. Acampora, V. Loia, and A. Vitiello, "Improving game bot behaviours through timed emotional intelligence," *Knowledge-Based Systems*, vol. 34, pp. 97-113, Oct. 2012.

[17] C. S. Lee, M. H. Wang, M. J. Wu, Y. Nakagawa, H. Tsuji, Y. Yamazaki, and K. Hirota, "Soft-Computing-based emotional expression mechanism for game of Computer Go," *Soft Computing*, vol. 17, no. 7, pp. 1263-1282, Jul. 2013.

[18] Z. Yue, "A group decision making approach based on aggregating interval data into interval-valued intuitionistic fuzzy information," *Applied Mathematical Modelling*, vol. 38, no. 2, pp. 683-698, Jan. 2014.

[19] J. Wu and Y. Liu, "An approach for multiple attribute group decision making problems with interval-valued intuitionistic trapezoidal fuzzy numbers," *Computers & Industrial Engineering*, vol. 66, vol. 2, pp. 311-324, Oct. 2013.

[20] A. Tapia-Rosero, A. Bronselaer, and G. Detre, "A method based on shape-similarity for detecting similar opinions in group decision-making," *Information Sciences*, vol. 258, pp. 291-311, Feb. 2014.

[21] Wikipedia, Energy management, 2013 [Online]. Available: http://en.wikipedia.org/wiki/Energy_management.

[22] Kaohsiung solar power plant, Taiwan, power-technology.com, 2013 [Online]. Available: http://www.power-technology.com/projects/kaohsiungsolarpower/.

[23] B. R. Hsieh, M. H. Wang, C. S. Lee, and C. H. Liu, "Study on intelligent energy management decision support system," *2013 Conference on Technologies and Applications of Artificial Intelligence* (*TAAI 2013*), Taipei, Taiwan, Dec. 6-8, 2013. (in Chinese)

[24] P. Luukka, "Fuzzy similarity in multi-criteria decision-making problem applied to supplier evaluation and selection in supply chain management," *Advances in Artificial Intelligence*, vol. 2011. pp. 1-9, Jan. 2011.

[25] C. T. Chen, "Extensions of the TOPSIS for group decision-making under fuzzy environment," *Fuzzy Sets and Systems*, vol. 114, no. 1, pp. 1-9, Aug. 2000.

[26] L. Dymova, P. Sevastjanov, and A. Tikhonenko, "An approach to generalization of fuzzy TOPSIS method," *Information Sciences*, vol. 238, no. pp. 149-162, Jul. 2013.

[27] W. Wang, X. Liu, and Y. Qin, "Multi-attribute group decision making models under interval type-2 fuzzy environment," *Knowledge-Based Systems*, vol. 30, pp. 121-128, Jun. 2012.

[28] M. H. Wang, Y. T. Tsai, K. H. Lin, C. S. Lee, and C. H. Liu, "FML-based decision support system for solar energy supply and demand analysis," *2013 IEEE International Conference on Fuzzy Systems* (*FUZZ-IEEE 2013*), Hyderabad, India, Jul. 7-10, 2013.