Original Article

Analysis of climate change mitigations by nuclear energy using nonlinear fuzzy set theory

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ABSTRACT

Following the climate-related disasters considered by several efforts, the nuclear capacity needs to double by 2050 compared to 2015. So, it is reasonable to investigate global warming incorporated with the fuzzy set theory for nuclear energy consumption in the aspect of fuzziness and nonlinearity of temperature variations. The complex modeling is proposed for the enhanced assessment of climate change where simulations indicate the degree of influence with the Boolean values between 0.0 and 1.0 in the designed variables. In the case of OIL, there are many 1.0 values between 20th and 60th months in the simulations where there are 10 times more for a 1.0 value in influence. Hence, the temperature variable can give the effective time using this study for 100 months. In the analysis, the 1.0 value in NUCLEAR means the highest influence of the modeling as the temperature increases resulting in global warming. In detail, the first influence happens near the 8th month and then there are four times more influences than effects in the early part of the temperature mitigation. Eventually, in the GLOBAL WARMING, the highest peak is around the 20th month, and then it is stabilized.

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1. Introduction

It investigated global warming incorporated with the nonlinear algorithm as the fuzzy set theory in the aspect of the nuclear energy consumption where the complex modeling is proposed for the enhanced assessment of the climate change. The greenhouse effect is a major cause of climate change that could produce environmental hazards with the abnormal atmospheric temperature increasing. Hence it is not easy to estimate consequences and the nonlinear algorithms could be utilized for analyses. The previous studies show basic variables in this work where the human factor is one of the major considerations [1,2]. In the study, the focus matter is on the temperature variations. Fig. 1 shows the feature of global warming by temperature where the temperature is one of the main factors producing the global warming. Some more studies have been presented [3,4].

In the United Nations (UN), the former Secretary-General Mr. Ban said that by acting on climate, they advanced the Sustainable Development Goals and the 2030 Agenda where the greenhouse gases were determined [5]. This means that the climate-related disasters would be considered by several efforts. According to Paris Agreement, it is needed to keep the temperature increase below 2 °C [6]. Following this temperature condition, the nuclear capacity needs to double around 950 GW by 2050 compared to 2015 [7,8]. As it is well known, the situations are variable following the status of each nation after the Fukushima nuclear accident in 2011. Hence, the complicated matters should be considered to analyze global warming associated with nuclear energy which the economic factor could be another kind of important factor in the modeling of this study.

Considering artificial intelligence (AI), there are some algorithms such as the neural networking method as well as fuzzy set theory. The fuzzy set algorithm is mainly expressed by the linguistic fuzziness which can be related to many kinds of variables in our lives. Otherwise, the neural networking is analyzed for the structure of the biological body where the neural structure is equipped and the networking has several roles to connect the information entering from the outer world. In addition, considering the systematic algorithm, the system dynamics (SD) can give the dynamic descriptions of the designed systems in which the feedback-based event flows are quantified. This tool could be applied to a nonlinear and ambiguous issue that can be expressed by the time step. It is performed easily and conveniently. In this study, the
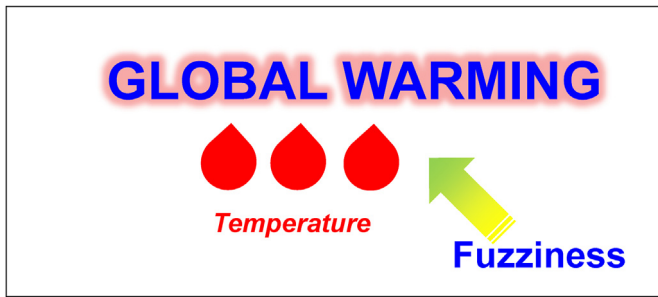
Fig. 1. Feature of global warming by Temperature.

nonlinear and ambiguous aspects of the event are treated by the membership function of a fuzzy set where the complex meaning of the event could be solved much more effectively by its characteristics.

The results should give promptly by the global modeling including the interested variables because the climate is affected by widely ranging areas such as the international consequences. Clouds and rains are not restricted to just one nation and the carbon dioxide gases flow anywhere and anytime globally. Hence the geological restriction is not considered and should be regarded as the world factor in this study for the global warming-based modeling. In the previous works, the biofuel is investigated in the risk aspect by the climate-induced disruptions for the fuzzy thinking [9]. In addition, Chen studied forecasting the global CO_2 concentration using an applied fuzzy set and neural networking [10]. Mousavi-Avval showed the Adaptive Neuro-Fuzzy Inference System (ANFIS) which was implemented to three indices in energy consumption [11]. Furthermore, there is a relationship between energy and global warming [12−23]. Especially, Moriarty and Honnery discussed the risk of catastrophic climate change (CCC) [24]. There are research gaps considering nuclear energy. So, it is needed to analyze the variables of nuclear energy among the other energy sectors like coal, oil, and renewable energy. So, oil, coal, nuclear, and hydro energies are compared for the modeling structure.

2. Methods

It is suggested to make use of the fuzzy set theory in the analysis of the global warming incorporated with the nuclear industry, in which the nonlinear complex characteristics could be used for the subtle situation such as the environmental behavior or psychology-based linguistic matters. As it is known as the nonlinear algorithm, the fuzzy set theory is very effective in complex matters such as the atmospheric uncertainties which impact global warming. The membership value described by the membership function is expressed by the visually refined method as the SD in this work. The commercialized software of SD, Vensim, has been used in many other areas in order to enhance the integrity of the problem solutions. The other kinds of packages have also been used for the designed systems. Fig. 2 shows the procedure of the analysis where decisions of variables, membership function making, SD modeling constructions (including causes tress), simulations, and results.

2.1. Fuzzy set theory

The fuzziness is applied in the decision-making of designed information. Fuzzy set theory was introduced by Lotfi A. Zadeh in 1965 as an application of the conventional concept of the set where the mathematics-based decision-making algorithm was utilized [25].
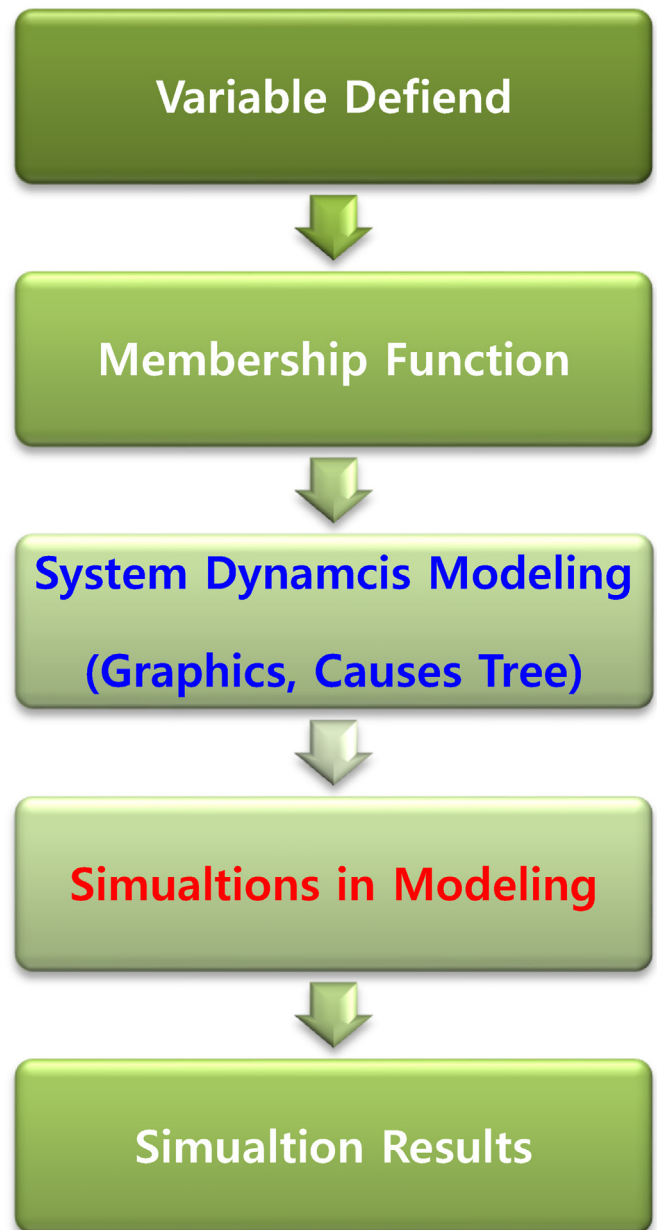

Fig. 2. The procedure of the analysis.

The fuzzy set theory was created for the uncertainty treatment, especially for data processing [25]. A membership function is a form for the fuzzy methods where there are several quantifications for the information estimations. For example, the operations like the OR gate or AND gate in the tree-based method could be utilized in this way. One of the most important things is to construct the membership function. Classically, the triangular and rectangular forms are well-known shapes [26−30]. In operations, simple arithmetic calculations are applied. The union expresses as [31],

$$A \cup B \ \leftrightarrow \mu_{A \cup B} = \mu_A \vee \mu_B \qquad (1)$$

Similarly, the intersection is described by,

$$A \cap B \ \leftrightarrow \mu_{A \cap B} = \mu_A \wedge \mu_B \qquad (2)$$

The product could be interpreted by the algebraic form as,

$$A \cdot B \leftrightarrow \mu_{A \cdot B} = \mu_A \times \mu_B \qquad (3)$$

This summation is interpreted by the algebraic form as,

$$A + B \leftrightarrow \mu_{A+B} = \mu_A + \mu_B - \mu_A \, \mu_B \qquad (4)$$

The above algorithms are applied to the modeling in this study. Although the simple four rules calculations are used, the important meaning is to manipulate the elements of the set.

Furthermore, the multi-criteria factors are used for the land analysis for the rainfed maize using fuzzy logic [32] in which the weighting factor is introduced with maximum, minimum, and mean operators. Therefore, it is described as follows,

$$S(a_1 \cdots a_n) = \sum_{1}^{n} w_k \cdot a_{h(k)} \qquad (5)$$

where h is a permutation that decides a value. This is applied to this study for constructing the membership function which is the basic function in the fuzzy calculations. That is, the shaping of function could give the characteristics of the fuzziness in the designed situation such as the energy-related climate variations.

2.2. System dynamics (SD)

The SD has been used for the scientific-technological and human-social issues in the quantification of the designed analyses. Dr. J. Forrester created this method at MIT in the early 1960s [33,34] for the quantified analysis of the interesting scenarios. This has been used for nonlinear algorithmic analysis in the areas of social humanities. Therefore, the energy security-based assessment such as the climate change that affects the energy source to be studied. Especially, the dynamical simulations are important for the reliability improvement in the problem systems. There are particular characteristics compared to conventional assessment tools [34].

Feedback: The designed algorithm could be the backward event flow where the nonlinear sequences are performed. That is, the estimated future analysis results could be related to past or present state mathematically, which could enhance the integrity of the system. This is one of the major meanings in SD quantifications.

Stock and flow: The events make diagrams with loops in which the event quantity can be accumulated or passed in the interested structures. So, the numerical values are changeable by the designed algorithm. The importance of the modeling could be improved by quantities.

Casual loop: As it is mentioned in the above parts, the events flow by the loop typed design where the cause and result are expressed by the arrow marks. The connectivity of each event can produce a networking relationship, which can make the social networking modeling.
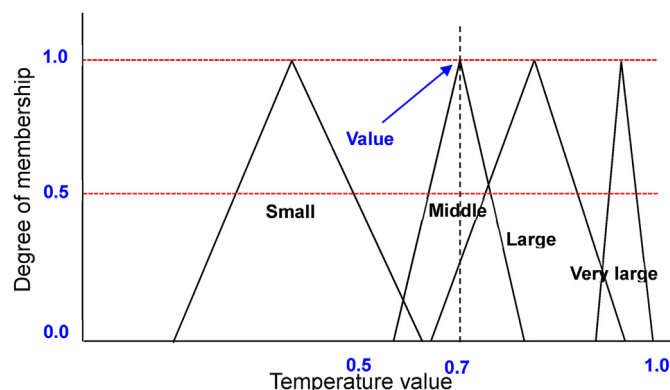
So, the graphical user interface (GUI) based software has been developed for commercial purposes and there are many useful products. Prevention Impacts Simulation Model (PRISM) was developed for the governmental purpose of the Centers for Disease Control and Prevention (CDC) and the National Heart, Lung, and Blood Institute (NHLBI). It applies to national health management such as smoking, nutrition, weight loss, physical stuff, medical care, air pollution, and so on. For climate control, Climate Rapid Overview And Decision Support (C-ROADS) has been developed for global warming-based climate matters. C-ROADS-based analysis of Intended Nationally Determined Contributions (INDC) was reported for the climate summit in Paris, France [35].

In the operations of the SD, the differential equation can be described as follows [34],

$$\frac{d}{dx}x(t) = f(x) \qquad (6)$$

in which the cumulative values are analyzed as the sum in the OR gate of the tree-based quantification. So, using equations (1) and (4) could be shown as,
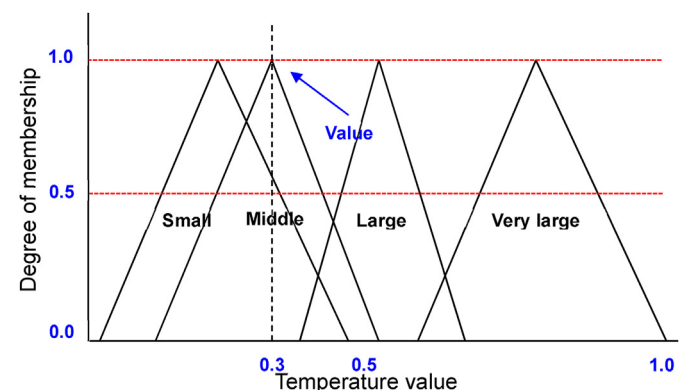
Table 1
List of element.

Element	Value
POLITICS	if then else(random 0 1 () < 0.7, 0, 1)
GNP	if then else(random 0 1 () < 0.3, 0, 1)
POPULATION	if then else(random 0 1 () < 0.4, 0, 1)
OIL	GNP*POLITICS*POPULATION * if then else(random 0 1 () < 0.3,0,1)
COAL	GNP*POLITICS*POPULATION * if then else(random 0 1 () < 0.7, 0, 1)
NUCLEAR	GNP*POLITICS*POPULATION * if then else(random 0 1 () < 0.5, 0, 1)
HYDRO	GNP*POLITICS*POPULATION *if then else(random 0 1 () < 0.4, 0, 1)
WATER	(COAL + HYDRO + NUCLEAR + OIL) * if then else(random 0 1 () < 0.4, 0, 1)
AIR	(COAL + HYDRO + NUCLEAR + OIL) * if then else(random 0 1 () < 0.6, 0, 1)
SUNSHINE	(COAL + HYDRO + NUCLEAR + OIL) * if then else(random 0 1 () < 0.5, 0, 1)
RAIN	(COAL + HYDRO + NUCLEAR + OIL) * if then else(random 0 1 () < 0.7, 0, 1)
TEMPERATURE	AIR + RAIN + SUNSHINE + WATER
MITIGATIONS	if then else(random 0 1 () < 0.4, 0, 1) * NUCLEAR
GLOBAL WARMING	if then else(random 0 1 () < 0.6, 0, 1) + TEMPERATURE - MITIGATIONS

Fig. 3. Graph for membership function in Politics.

Fig. 4. Graph for membership function in Oil.

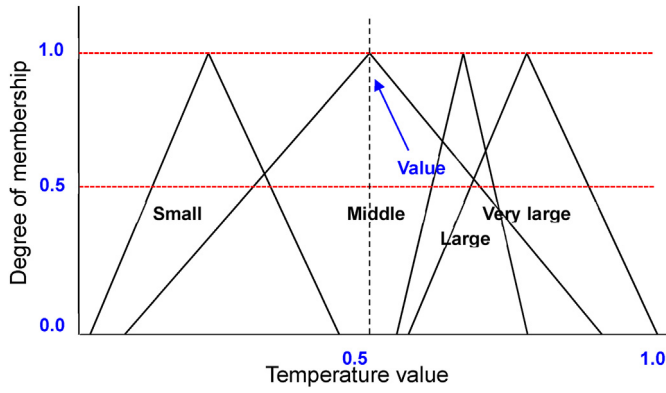**Fig. 5.** Graph for membership function in Temperature.

$$ln(Global\ Warming)_i \approx F(x) = Variable1 + Variable2 + \cdots \quad (7)$$

where Variable1 and Variable2 are the arbitrary numbers. Otherwise, in the case of AND gate, using equations (2) and (3) it is described as follows,

$$ln(Global\ Warming) \approx F(x) = Variable1 \cdot Variable2 \cdot \cdots \quad (8)$$

In addition, the Level logic in the SD method can be used for the accumulations by the dynamical order. By transforming from Gate
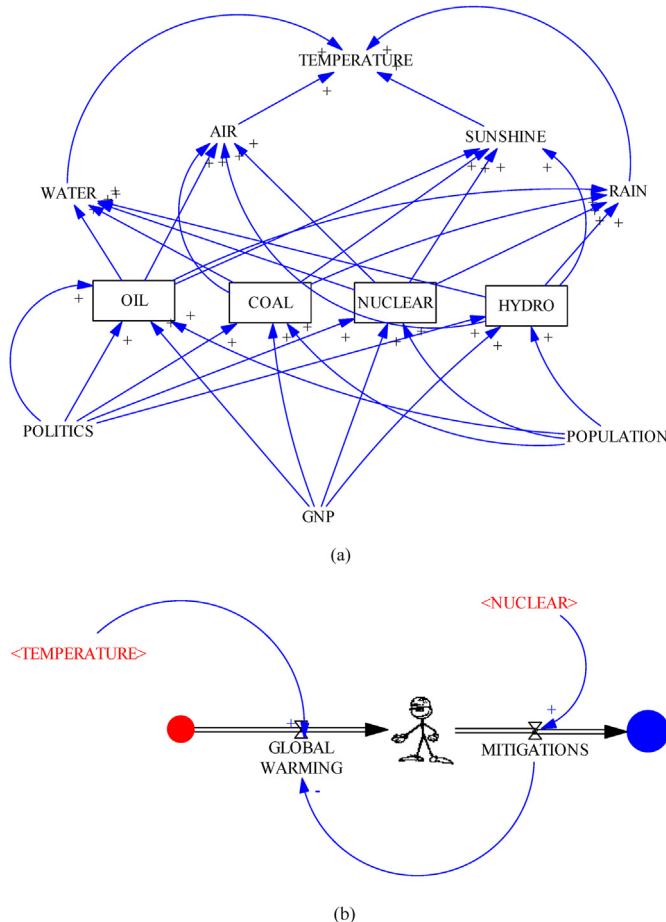
values to arithmetic values, the event scenarios are successfully described in the SD. In the previous work, the social dynamics of climate change were discussed [36–41]. In addition, a climate change-related population study was performed [42].

2.3. Modeling

The modeling is constructed by the SD method where the commercialized software, Vensim [43], is used in which the user interface-oriented graphical enhancement is equipped. The particular importance of this study is to make the basic event which is constructed by SD variable with random sampling incorporated with the fuzziness as membership function. That is, the randomly selected data are substituted with the surveyed data which are usually used in the social humanity matters such as the climate change issue. It is reasonably innovative that random sampling is used instead of inquiring surveying people, because the surveyed data could be followed by the statistical manner with the mean and variance. So, the SD method makes use of a mathematical way in the survey data collecting where the restrictions for the data set are decided by the expert's judgment in selecting mean and variance values. The membership function in Politics is similar to GNP and Population in Fig. 3 where there are four functions of small, middle, large, and very large of the Temperature variable by the degree of membership that represents the membership number. That is, the middle one is the representative value. Subsequently, this is expressed by the SD. So, the random number is selected by the condition of the middle value. As is in Table 1, if the random number between 0.0 and 1.0 is lower than 0.7, it is 0.0. Otherwise, it is 1.0.
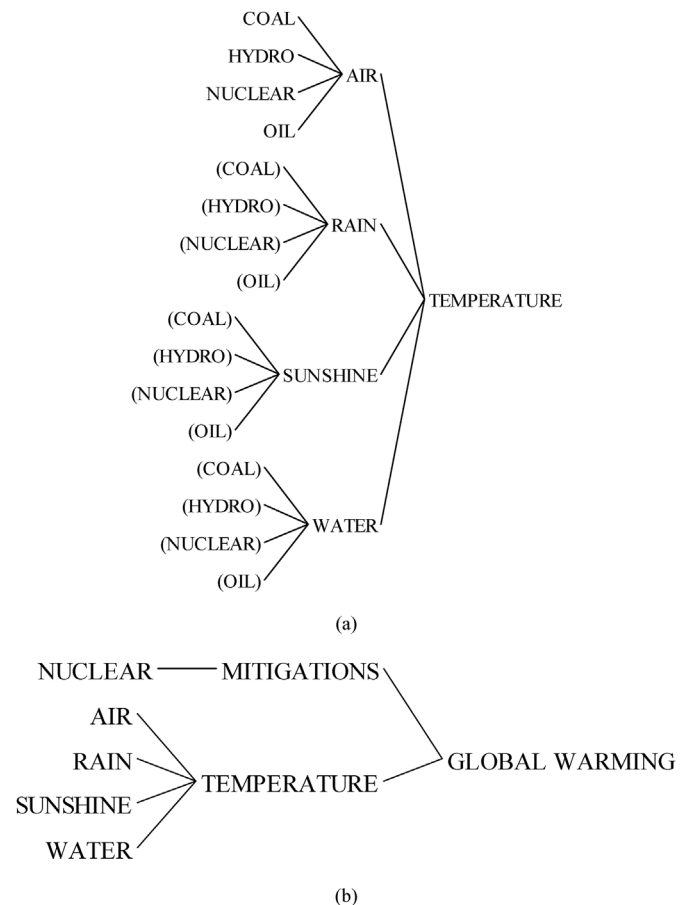

(a)

(b)

Fig. 6. Modeling of the global warming by SD (a) Basic elements and (b) Global warming.

(a)

(b)

Fig. 7. Causes trees (a) Temperature and (b) Global warming.

Additionally, there is the membership function in Oil which are similar to Coal, Nuclear, and Hydro in Fig. 4. Fig. 5 is the graph for membership function in Temperature. The scenario is shown in Fig. 5 as the modeling of global warming. Especially, the minus sign is seen in the MITIGATIONS which reduces the temperature-based global warming effects in Fig. 6 (b). Especially, two important factors of TEMPERATURE and NUCLEAR could give the situational decisions that are made by the random number-based values. This is considered as a role of the SD style weighting factors. The causes tree for the global warming is in Fig. 7 which shows the event connectivity and event flows.

3. Results and discussion

Simulations for global warming are for Oil, Coal, Nuclear, Hydro, and Temperature in Fig. 8 where the values indicate the degree of influence. This is obtained by the Boolean value between 0.0 and 1.0 where 1.0 means the influenced time by the designed variable in which the influence can be meant as the social effect such as favor or antipathy. For example, in the case of OIL, there are many values between 20th and 60th months in the simulations. So, there are 10 times more for a 1.0 value in influence. Hence, the temperature value can give the effective time using this study for 100 months. This reflects that oil energy has higher influences compared to the other energy sectors. Especially, the initial time starts from the 20th month. So, this time is meaningful as the antipathy against the carbon-producing energy source in this modeling.
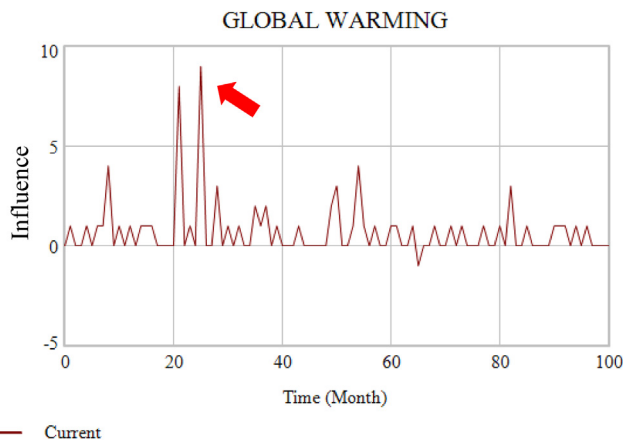

Fig. 9. Simulations for the global warming.

Otherwise, the 1.0 value in NUCLEAR means the highest influence of the modeling as the temperature increases resulting in global warming. In detail, the first influence happens near the 8th month and then there are 4 times more influences than the effect on the early part of the temperature mitigation in Fig. 8 (e). This means that nuclear energy has influences happened in the early period and the frequencies are lower compared to the oil energy sector. The antipathy against nuclear energy could be the anti-nuclear mind.
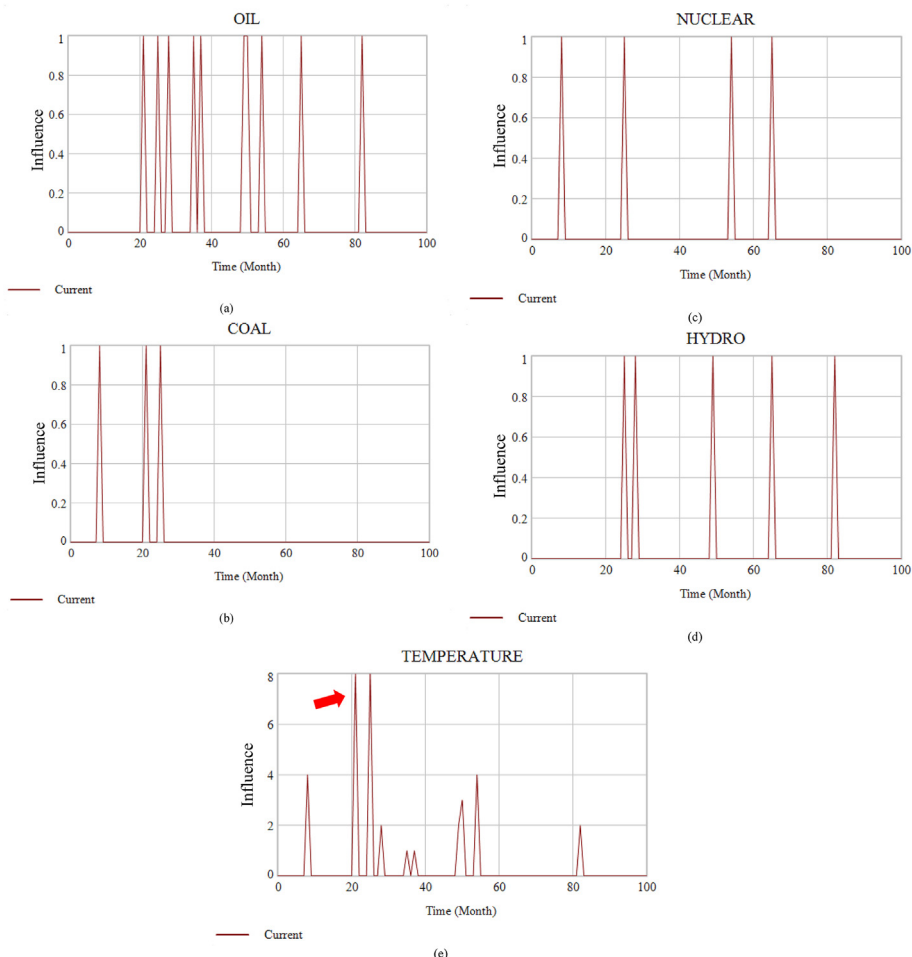

Fig. 8. Simulations (a) oil, (b) coal, (c) nuclear, (d) hydro, and (e) temperature.

Table 2
Analysis of result.

Element	Value	30%	70%
OIL	10	6	14
COAL	2	1.2	2.8
NUCLEAR	4	2.4	5.6
HYDRO	5	3	7
TEMPERATURE	10	6	14
GLOBAL WARMING	42	25.2	58.8

Eventually, the GLOBAL WARMING in Fig. 9 has the highest peak around the 20th month, and then it is stabilized. Each variable has its quantified values. The list of elements for variables is in Table 1. In addition, Table 2 shows the statistical analysis for the sensitivity of the result where the 30th and 70th percentiles are shown. In the previous studies, the fuzzy set is associated with neural networking where the three steps of the input layer, hidden layer, and output layer are composed to quantify the designed modeling [9–11]. Otherwise, this study shows the results of the Boolean value between 0.0 and 1.0 for each energy sector. Then, the major variable of GLOBAL WARMING is obtained by the cumulative values to show the relative influences. So, it is easy to know the degree of influence just by seeing the graph. Furthermore, the SD method should quantify the variables without three steps of input, hidden, and output layers in neural networking. That is, the quantification steps in SD are decided by the expert without any restrictions.

4. Conclusions

The analytic study is performed for the temperature-based global warming induced by several energy sources where nuclear energy is one of the major factors. It is shown the importance of this study as follows.

- The energy sources are investigated for global warming.
- Nonlinear algorithm of fuzzy set theory is applied to analyze the study.
- SD is incorporated with the fuzzy logic.
- Nuclear energy shows the major factor in the influence.

It is possible to verify the nonlinear algorithm for global warming by the temperature variable in this study where the energy sources are connected, although the situation of each nation could be changeable following the complicated conditions such as the politics, GNP, and populations. However, the real state could be affected by many other situations in which there are some more social-humanities matters including the international relations such as the carbon reduction corporation participation decided by the domestic state of the individual nation.

Conventional fossil fuel-based systems such as oil and coal power plants have the critical causes of global warming due to carbon dioxide-based air pollution. Although some systems could be exchanged with nuclear and renewable energies, all carbon-produced equipment can't be used in alternative ways. So, the total management system should be needed to control the climate change-related stuff. For example, the traffic prohibitions of the private car have been used on some important days by the odd or even number date. This could give better air quality to the atmosphere. Therefore, the management of the private or public system usage can be one of the successful and comparatively cheaper methods in the global warming consideration.

Furthermore, the international corporations are necessary to control following the global standards in which the periodic committee meetings are very plausible in the discussion of the air treatment. The atmosphere of a nation affects the neighboring nations directly and indirectly. The speed of the airflow is the same as the polluted air dispersions based on the fluid mechanics. A significant event such as air stagnation could increase greenhouse gas. So, the alarm of the dangerous state could be spread to the other countries. This is like the earthquake or tsunami alert system. Using the international corporations of the carbon bases concentration reductions, the average global warming gases significantly could be reduced. So, global warming is wisely able to be avoided locally or globally.

Finally, the limitations of this study are related to the fuzziness in the decision-making where the membership function could be applied to a designed issue such as global warming. If one can use much more accurate weather data, the regional weather variables are analyzed clearly. The uncertainty of the atmospheric variables could be offset using a highly effective absorbing system like the weather satellite. The view from the space can show the wide and exact image of the clouds, storms, and so on. In the future, the scientific weather facility-included study could enhance the reliability of the assessments of global warming matter.

Author contributions

Tae Ho Woo: Validation, Methodology, Software, Formal analysis, Writing. Kyung Bae Jang: Project administration, Validation, Software. Chang Hyun Baek: Conceptualization, Funding acquisition, Resources. Jong Du Choi: Validation, Formal analysis, Writing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

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