




# Integrating an Option-Oriented Attitude Analysis into Investigating the Degree of Stabilities in Conflict Resolution

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## Abstract

Despite the influences on one's thoughts and actions, the attitude has usually been overlooked in conflict analysis. The purpose of this paper is to develop a new systematic methodology for the graph model for conflict resolution that can be employed to study real-world conflict situations and gain enhanced insights. More specifically, the proposed method starts with the development of an expanded option-oriented preference structure that is derived from decision makers' attitudes toward others. Then based on this attitude-driven preference structure, the general concepts of stabilities are extended to contain the definitions of different degrees of stabilities under attitude. In addition, the proposed method is embedded in a decision support system, called NUAAGMCR, to facilitate the analytical process. Through a detailed case study of the two-stage environmental conflict of post-Fukushima controversy in Japan, the predicted resolutions are demonstrated to be more accurate and stable than those derived by the general stability analysis.

**Keywords** Attitude-driven analysis · Option-oriented · Degree of stabilities · Graph model for conflict resolution · Post-Fukushima controversy

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## 1 Introduction

A conflict exists whenever the involved decision makers (DMs) have incompatible objectives or actions. The ever-changing situations necessitate comprehensive methodologies to realistically analyze real world conflicts. The graph model for conflict resolution (GMCR) (Kilgour et al. 1987) is a formal analytical methodology developed on the basis of the classical game theory (Von Neumann and Morgenstern 1944) and the metagame theory (Howard 1971). Compared with other decision-making methods (Cristoni et al. 2010; Lewis and Butler 2010; Moskowitz et al. 2011), the largest advantage of GMCR is its strict mathematical structure and limited requirement of information, which allows GMCR to be employed by various parties, including the conflict participants or a third party (a mediator, regulator, or any other party who is interested in the outcome of the conflict), to capture the key characteristics of the conflicts and thus to provide decision supports (Kilgour and Hipel 2005). Examining conflicts through a systematic view, GMCR can be applied in a broad range of fields (Gopalakrishnan et al. 2005; Hipel and Kilgour 2005; Ma et al. 2005), especially in environmental conflicts (Hipel et al. 1997; Obeidi et al. 2002; Noakes et al. 2003).

The two main investigation phases of GMCR are modeling and analysis. At the modeling stage, several input parameters are identified: (1) DMs (the participants of the conflict), (2) options (DMs' options to satisfy their own objectives), (3) states (the outcomes or scenarios formed by a combination of DMs' options), and (4) preference (DMs' relative favor or disfavor over all the feasible states). Once the model is properly defined, the corresponding analysis processes can be performed. As one of the major analysis in GMCR, stability analysis is used to study the DMs' moves and countermoves during the evolution of a conflict. Then the most possible resolutions are generated based on the solution concepts (Nash 1950, 1951; Howard 1971; Fraser and Hipel 1979) describing the DMs' behaviors under conflicts. The attitude, although strongly influences one's behavior, has usually been overlooked in the stability analysis. Perceiving the significance of the attitude's impacts on the degree of stabilities, the purpose of this research is to develop a new systematic framework equipped with an attitude-driven stability analysis, which can be employed to study various conflict situations and thus gain enhanced insights.

As a natural expansion of GMCR (Fang et al. 1993; Walker et al. 2012), a set of logical definitions of attitude based on states were presented in 2007 (Inohara et al. 2007, 2008; Inohara and Hipel 2009), which provided a tool for the decision analysts to scrutinize the attitudinal stabilities. However, as the number of states that a conflict may contain increases (to be specific,  $k$  options generate  $2^k$  states), a state-oriented attitude analysis becomes very challenging. To avoid such difficulties, Xu et al. (2017a) proposed a series of definitions of attitudes in regard to options, with corresponding logical and matrix representations of stability concepts. Despite the effort, that research did not consider the impact of various degrees of stabilities, which may result in inaccurate predictions and misunderstandings of the real situation.

The present study focuses on the degree of attitude-driven stabilities in GMCR, which can better describe the behavior of DMs in light of their attitudes and make the forecasted results closer to the real situation. More particularly, an expanded option-oriented preference structure is introduced to consider the strongly less preferred states

under attitude. Then, the general attitude-driven stabilities are extended to consider the degree of stabilities under attitude. Furthermore, the analytical process is embedded to an online decision support system (NUAAGMCR), which has many advantages over previously designed systems, GMCR (Kilgour et al. 1996) and GMCR II (Fang et al. 2003a, b). Finally, the proposed analytical framework is used to analyze the two-stage environmental conflict of post-Fukushima controversy (PFC) (Lipsy et al. 2013; Hosoe 2015; Okushima 2016; Hong 2017) in Japan to provide enhanced insights in figuring out the causes of Japan's restart of nuclear power plants (McCurry 2015; Mealey 2017), and thus helping the involved parties to better understand the changes and transitional situations of the conflict. To the best of our knowledge, this research is the very first one that considers the degree of stabilities on the basis of option-oriented attitudes in GMCR.

The rest of this paper is organized as follows. In Sect. 2, the general attitude-driven stabilities first introduced in Xu et al. (2017a) are presented and discussed. Section 3 develops an expanded option-oriented attitude-driven preference structure and defines different degrees of stabilities under attitude. Then, the PFC conflict is examined in detail by using the proposed attitude-driven stability analysis framework in Sect. 4. Finally, Sect. 5 concludes the study and proposes possible future research directions.

## 2 General Attitude-Driven Stabilities

As a practical decision methodology, the graph model for conflict resolution can be used to logically and mathematically lay out a conflict situation. The mathematical definition of GMCR is presented next (Kilgour et al. 1987).

**Definition 1** (*Graph model for conflict resolution—GMCR*) A graph model for conflict resolution is defined as a 4-tuple  $(N, S, (A_i)_{i \in N}, (>_i, \sim_i)_{i \in N})$ , where  $N$  is the set of DMs ( $n = |N| \geq 2$ ) and  $S$  is the set of all states in the conflict ( $m = |S| \geq 2$ ).

For DM  $i \in N$ ,  $(S, A_i)$  is DM  $i$ 's graph, where  $S$  is the set of all vertices and  $A_i \in S \times S$  denotes the set of all arcs such that  $(s, s) \notin A_i$  for all  $s \in S$  and all  $i \in N$ .

$(>_i, \sim_i)$  gives DM  $i$ 's preferences on  $S$ . For  $s, t \in S$ ,  $s >_i t$  means that DM  $i$  prefers state  $s$  to  $t$ , while  $s \sim_i t$  indicates that DM  $i$  is indifferent between  $s$  and  $t$ . Relative preferences are assumed to satisfy the following properties:

- (1)  $>_i$  is asymmetric; hence, for all  $s, t \in S$ ,  $s >_i t$  and  $t >_i s$  cannot hold true simultaneously.
- (2)  $\sim_i$  is reflexive; therefore, for any  $s \in S$ ,  $s \sim_i s$ .
- (3)  $\sim_i$  is symmetric; hence, for any  $s, t \in S$ , if  $s \sim_i t$ , then  $t \sim_i s$ .
- (4)  $(\sim_i, >_i)$  is complete; therefore, for all  $s, t \in S$ , one of  $s >_i t$ ,  $t >_i s$  and  $s \sim_i t$  is true.

Based on this definition, the general attitude-driven stabilities are discussed in detail next.

**Table 1** The relationship between attitudes and behaviours

Attitudes	Behaviors	
	To oneself	To others
Positive	Selfish	Altruistic
Negative	Passive	Sadistic
Indifferent	Selfless	Indifferent

### 2.1 Option-Orientated Attitude

Attitude refers to one’s psychological tendency, which indicates a certain degree of favor or disfavor towards a particular object (person, idea, emotion, activity, or event). This psychological tendency contains subjective evaluation and behavioral tendencies of the individual. The DMs’ preferences, in a conflict, are generated by the subjective evaluation of DMs. Hence the DMs’ attitudes should be taken into account while determining their corresponding preferences. To integrate the attitude into our analysis, the mathematical definition of attitudes (Xu et al. 2017a, b) is provided as follows.

**Definition 2** (*Attitudes*) For  $i \in N$ , Let  $E_i = \{+, -, 0\}^N$  represent the set of attitudes of DM  $i$ . For  $i, j \in N$ , an element  $e_{ij} \in E_i$  is referred to as the attitudes of DM  $i$  toward DM  $j$ , where  $e_{ij} = +$ ,  $e_{ij} = -$ , and  $e_{ij} = 0$  indicate that DM  $i$  has a positive, negative, and indifferent attitude toward DM  $j$ , respectively.

This definition categorized the attitude of DMs into three types: positive, negative and indifferent. Table 1 describes the corresponding behavioral characteristics.

The following related definitions are based on the option prioritization method (Fang, et al. 2003a; Hou et al. 2015; Yu et al. 2016), which is used to derive the preferences of DMs through evaluating options. In this method, DM  $i$ ’s option statement and preferences are denoted by  $L_i$  and  $P_i (i = 1, 2, 3, \dots, n)$ , respectively.

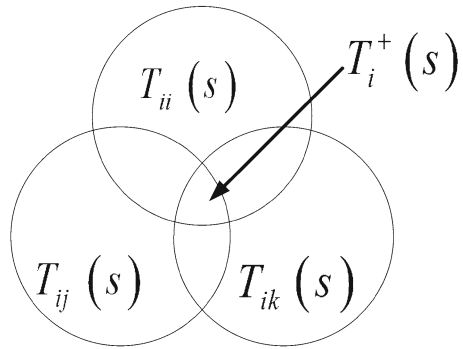
**Definition 3** (*Positive attitude-driven option statement*) If  $e_{ij} = +$ , DM  $i$  makes option statement that is beneficial to DM  $j$ , denoted by  $L_i(e_{ij} = +) = L_j$ .

**Definition 4** (*Negative attitude-driven option statement*) If  $e_{ij} = -$ , DM  $i$  makes option statement that is harmful to DM  $j$ , denoted by  $L_i(e_{ij} = -) = -L_j$ .

**Definition 5** (*Indifferent attitude-driven option statement*) If  $e_{ij} = 0$ , DM  $i$  is neutral about his option statement under this attitude, denoted by  $L_i(e_{ij} = 0) = I$ .

Particularly, if DM  $i$  has a positive preference toward DM  $j$ , then DM  $i$ ’s option statement are the same as the DM  $j$ ’s option statement, which is beneficial to DM  $j$ . On the other hand, when DM  $i$  has a negative attitude towards DM  $j$ , the option statement of DM  $i$  are the opposite of DM  $j$ ’s option statement, which are unfavorable for DM  $j$ . In addition, the indifferent attitude indicates that DM  $j$ ’s option statement has no impact on DM  $i$ ’s option statement. Given these concepts, the attitude option statement can also be defined.

Fig. 1 Venn diagram for total attitude-driven preference



**Definition 6** (*Attitude-driven option statement*)

$$L_{ij} = \begin{cases} L_j & \text{if } e_{ij} = + \\ -L_j & \text{if } e_{ij} = - \\ I & \text{if } e_{ij} = 0 \end{cases}$$

where  $L_{ij}$  denotes DM  $i$ 's option statement under his attitude toward DM  $j$ .

### 2.2 Attitude-Driven Preferences

**Definition 7** (*Attitude-driven preference*) According to  $L_{ij}$ , the attitude-driven preference of DM  $i$ , denoted by  $T_{ij}$ , can be obtained. For  $s, t \in S, t \in T_{ij}(s)$  if and only if (iff)  $t >_i s$  satisfies  $T_{ij}$ .

**Definition 8** (*Total-attitude-driven preference*) The total attitude-driven preference of DM  $i$  is defined as  $T_i^+$  such that for  $s, t \in S, t \in T_i^+(s)$  iff  $t \in T_{ij}(s)$  for all  $j \in N$ .

Here, DM  $i$ 's total-attitude-driven preference satisfies all attitude-driven preferences. As shown in Fig. 1, if there are three DMs ( $i, j, k$ ),  $T_{ii}(s)$ ,  $T_{ij}(s)$ , and  $T_{ik}(s)$  respectively denote DM  $i$ 's attitude-driven preferences at state  $s$  towards DMs  $i, j$ , and  $k$ . The intersection of them,  $T_i^+(s)$ , is the total attitude-driven preference for DM  $i$  at state  $s$ .

**Definition 9** (*Set of less or equally preferred states under total attitude*) The set of less or equally preferred states under total attitude for DM  $i$  is defined as  $T_i^{-=}$  such that for  $s, t \in S, t \in T_i^{-=}(s)$  iff  $t \notin T_i^+(s)$ .

**Definition 10** (*Reachable list*) For  $i \in N, s \in S$ , DM  $i$ 's reachable list from state  $s$  is the set  $\{t \in S | (s, t) \in A_i\}$ , denoted by  $R_i(s) \subset S$ .

The reachable list is a record of all the states that a given DM can reach from a specified starting state in one step.

**Definition 11** (*Unilateral improvement list for a DM under attitude*) The unilateral improvement list for DM  $i$  under attitude is defined as the set  $\{t \in (R_i(s) \cap T_i^+(s))\}$ , denoted by  $T_i^*(s)$ .

The state in  $T_i^*(s)$  is reachable and preferable for DM  $i$  at state  $s$ .

### 2.3 Coalition Consideration

**Definition 12** (*Reachable list for a coalition*) The reachable list for coalition  $H \subseteq N$  at state  $s \in S$  (Fang et al. 1993) is defined inductively as set  $R_H(s)$  that satisfies the next two conditions:

- (1) If  $i \in H$ , and  $s_1 \in R_i(s)$ , then  $s_1 \in R_H(s)$ , and  $i \in \Omega_H(s, s_1)$ .
- (2) If  $s_1 \in R_H(s)$ ,  $i \in H$  and  $s_2 \in R_i(s_1)$ , then, provided  $\Omega_H(s, s_1) \neq \{i\}$ ,  $s_2 \in R_H(s)$  and  $i \in \Omega_H(s, s_2)$ .

Note that, if  $s_1 \in R_H(s)$ ,  $\Omega_H(s, s_1)$  is the set of the last DMs in all legal sequences of unilateral movements from  $s$  to  $s_1$ . In addition, the reachable list can be obtained iteratively. First, according to (1), the states reachable from  $s$  are identified and added to  $R_H(s)$ . Next, based on (2), all states reachable from those states are identified and added to  $R_H(s)$ . Then the process is repeated until no further states are added to  $R_H(s)$ . Because  $R_H(s) \subseteq S$ , and  $S$  is finite, this process must complete in finite steps.

**Definition 13** (*Unilateral improvement list for a coalition under attitude*) The unilateral improvement of coalition  $H \subseteq N$  under attitude for state  $s \in S$  is defined inductively as set  $T_H^*(s)$ , which satisfies the next two conditions:

- (1) If  $i \in H$ , and  $s_1 \in T_i^*(s)$ , then  $s_1 \in T_H^*(s)$ , and  $i \in \Omega_H^{T^*}(s, s_1)$ .
- (2) If  $s_1 \in T_H^*(s)$ ,  $i \in H$  and  $s_2 \in T_i^*(s_1)$ , then, provided  $\Omega_H^{T^*}(s, s_1) \neq \{i\}$ ,  $s_2 \in T_H^*(s)$  and  $i \in \Omega_H^{T^*}(s, s_2)$ .

Definition 13 is identical to Definition 12 except that all moves are required to be unilateral improvements under attitude. Similarly, if  $s_1 \in T_H^*(s)$ , then  $i \in \Omega_H^{T^*}(s, s_1)$  is the set of the last DMs in all legal sequences of unilateral improvement under attitude from  $s$  to  $s_1$ .

### 2.4 General Attitude-Driven Stabilities

**Definition 14** (*Attitude-driven Nash stability—ANash*) If  $T_i^*(s) = \emptyset$ , then  $s \in S_i^{ANash}$ .

A state  $s$  is ANash stable for DM  $i$ , iff  $i$  has no unilateral improvement under attitude from this state, i.e., DM  $i$  stays at state  $s$  if  $i$  sees no unilateral improvement relative to  $s$  with DM  $i$ 's attitude.

**Definition 15** (*Attitude-driven general metarationality—AGMR*) If for all  $h \in T_i^*(s)$  and  $R_{N \setminus \{i\}}(h) \cap T_i^-(s) \neq \emptyset$ , then  $s \in S_i^{AGMR}$ .

A state  $s$  is AGMR stable for DM  $i$  if  $i$  knows that the opponent ( $N \setminus \{i\}$ ) may make a move (regardless of the opponents' own benefits) that sanctions DM  $i$ 's unilateral improvements under DM  $i$ 's attitude. The definition describes the situation where DM  $i$  does have a unilateral improvement state  $h$  based on attitude from state  $s$ , but the countermoves ( $R_{N \setminus \{i\}}(h)$ ) of opponents from state  $h$  may lead to less or equally preferred states for DM  $i$  with respect to the initial state  $s$  under attitude ( $T_i^{-}(s)$ ). So DM  $i$  stays at state  $s$ .

**Definition 16** (*Attitude-driven symmetric metarationality—ASMR*) If for all  $h \in T_i^*(s)$ , exist  $y \in R_{N \setminus \{i\}}(h) \cap T_i^{-}(s)$  and  $z \in T_i^{-}(s)$  for all  $z \in R_i(y)$ , then  $s \in S_i^{ASMR}$ .

If DM  $i$  cannot escape the opponent' sanction on DM  $i$ 's unilateral improvements under attitude, then DM  $i$  stays on the initial state. ASMR looks ahead one step further than AGMR: DM  $i$  considers not only the responses of opponents but also his/her own counter-responses under its attitude. To be specific, when the countermoves ( $R_{N \setminus \{i\}}(h)$ ) of opponents ( $N \setminus \{i\}$ ) can lead all DM  $i$ 's unilateral improvement states under attitude ( $h \in T_i^*(s)$ ) to less or equally preferred states ( $y \in T_i^{-}(s)$ ), DM  $i$  may still be able to escape this sanction from the opponents through his/her own moves. But if all states that DM  $i$  can reach ( $z \in R_i(y)$ ) are less or equally preferred states for DM  $i$  ( $z \in T_i^{-}(s)$ ), the escape is meaningless. So DM  $i$  stays at the initial state  $s$ .

**Definition 17** (*Attitude-driven sequential stability—ASEQ*) If for all  $h \in T_i^*(s)$ , and  $T_{N \setminus \{i\}}^*(h) \cap T_i^{-}(s) \neq \emptyset$ , then  $s \in S_i^{ASEQ}$ .

Here, DM  $i$ 's all potential unilateral improvement moves under attitude are sanctioned by the opponents' unilateral improvement moves under attitude. Accordingly, DM  $i$  is more willing to remain at the initial state. The difference between AGMR and ASEQ is that the sanctioning responses from opponents are beneficial for themselves, namely, the opponents ( $N \setminus \{i\}$ ) can lead all DM  $i$ 's unilateral improvement states under attitude ( $h \in T_i^*(s)$ ) to the less or equally preferred states ( $T_i^{-}(s)$ ) by their unilateral improvement moves under attitude ( $T_{N \setminus \{i\}}^*(h)$ ), then DM  $i$  will stay at state  $s$ .

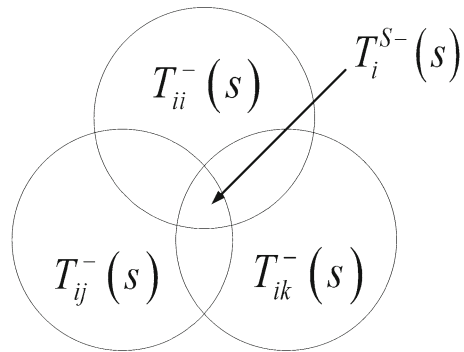
### 3 Degree of Stabilities with Option-Oriented Attitude

The attitude-driven preference discussed in Sect. 2 only takes the preferred and less or equally preferred states of DMs into account. Herein, we further expend the preference structure to consider those strongly less preferred states under the attitude of one DM toward others.

#### 3.1 Expended Attitude-Driven Preference Structure

**Definition 18** (*Less preferred states under attitude*) The less preferred states under attitude for DM  $i$  is defined as  $T_{ij}^-$  such that for  $s, t \in S$ ,  $t \in T_{ij}^-(s)$  iff  $t <_i s$  satisfies  $T_{ij}$ .

**Fig. 2** Venn diagram for strong less preferred states at total attitude



**Definition 19** (*Strongly less preferred states under total attitude*) The strongly less preferred states under attitude for DM  $i$  is defined as  $T_i^{S-}$  such that for  $s, t \in S, t \in T_i^{S-}(s)$  iff  $t \in T_{ij}^-(s)$  for all  $j \in N$ .

The strongly less preferred states under total attitude for DM  $i$  ( $T_i^{S-}$ ) is the intersection of all less preferred states under the attitude for DM  $i$ . Namely, the states in  $T_i^{S-}$  is strongly less preferred by DM  $i$ , which are less preferred under attitude of DM  $i$  towards all opponents. For example, in Fig. 2, if there are three DMs ( $i, j, k$ ), the states in the intersection ( $T_{ii}^-(s) \cap T_{ij}^-(s) \cap T_{ik}^-(s)$ ) are strongly less preferred by DM  $i$  ( $T_i^{S-}(s)$ ).

**Definition 20** (*General less or equally preferred states under total attitude*) The general less or equally preferred states under total attitude for DM  $i$  are defined as set  $t \in \{T_i^{-=}(s) \setminus T_i^{S-}(s)\}$ , denoted by  $t \in T_i^{G-}(s)$ . The relationships among attitude-driven preferences are given by the following equations:

- (1)  $S = T_i^+(s) \cup T_i^{-=}(s)$ , and
- (2)  $T_i^{-=}(s) = T_i^{G-}(s) \cup T_i^{S-}(s)$

The first equation shows the preference structure under the general stability analysis, which indicates that all states in the conflict are divided into the preferred set ( $T_i^+(s)$ ) and the less or equal preferred set ( $T_i^{-=}(s)$ ) for DM  $i$  at given state  $s$  according to his attitudes. But in the new preference structure (denoted by the second equation), the less or equal preferred set ( $T_i^{-=}(s)$ ) under attitude for DM  $i$  is segmented into the general less or equally preferred set ( $T_i^{G-}(s)$ ) and the strongly less preferred set ( $T_i^{S-}(s)$ ) at the initial state  $s$  (See Fig. 3).

Given the newly segmented preference structure, DM  $i$ 's general attitude-driven stability can be divided into strong and weak stabilities according to different levels of sanctions from other DMs' moves after referring the stabilities under strength of preference (Hamouda et al. 2004, 2006). To be specific, the opponent's moves may lead to DM  $i$ 's strongly less preferred states under total attitude (strong sanctions) or the general less or equally preferred states under total attitude (weak sanctions). Consequentially, if DM  $i$ 's unilateral improvement under attitude is strongly sanctioned



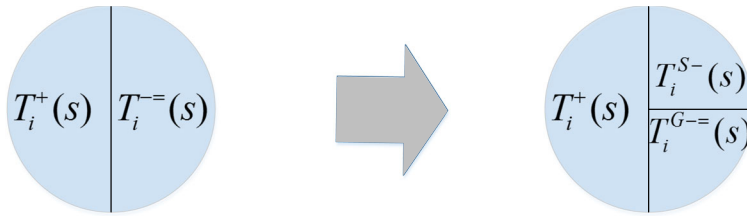


Fig. 3 Segmentation of the preference structure

by his opponent’s moves (under *AGMR*, *ASEQ*), or DM *i* cannot escape from those strongly less preferred states under total attitude (under *ASMR*), these situations are defined as strong attitude-driven stabilities, i.e., DM *i* is strongly willing to remain at the initial state. On the other hand, if DM *i*’s unilateral improvement under attitude is weakly sanctioned by his opponent’s moves (under *AGMR*, *ASEQ*), or DM *i* can escape from those strongly less preferred states under total attitude (under *ASMR*), these situations are defined as weak attitude-driven stabilities, i.e., DM *i* is weakly willing to remain at the initial state.

Compared with the weak attitude-driven stabilities, the degree of sanctions from the opponents at the strong attitude-driven stabilities is stronger, so that the DMs are more inclined to stay on the strong attitude-driven stabilities so to avoid the strong sanctions. Therefore, using strong attitude-driven stabilities to analyze the conflict is more effective than the general attitude-driven stabilities. In addition, as *ANash* does not consider the opponents’ sanctions, only *AGMR*, *ASMR*, *ASEQ* have strong and weak stabilities. Detailed definitions of strong and weak attitude-driven stabilities can be found in the next two subsections.

### 3.2 Strong Attitude-Driven Stabilities

**Definition 21** (*Strong attitude general metarationality—AGMR<sup>+</sup>*) If for all  $h \in T_i^*(s)$ , and  $R_{N \setminus \{i\}}(h) \cap T_i^{S-}(s) \neq \emptyset$ , then  $s \in S_i^{AGMR^+}$ .

A state  $s$  is *AGMR<sup>+</sup>* for DM *i* iff all *i*’s unilateral improvements under attitude are strongly sanctioned by the opponents’ moves.

**Definition 22** (*Strong attitude symmetric metarationality—ASMR<sup>+</sup>*) If for all  $h \in T_i^*(s)$ , exist  $y \in R_{N \setminus \{i\}}(h) \cap T_i^{S-}(s)$  and  $z \in T_i^{S-}(s)$  for all  $z \in R_i(y)$ , then  $s \in S_i^{ASMR^+}$ .

If all DM *i*’s unilateral improvements under attitude are strongly sanctioned by the opponents’ moves, and DM *i* cannot escape this strongly sanction, then the initial state  $s$  is *ASMR<sup>+</sup>* for DM *i*.

**Definition 23** (*Strong attitude sequential stability—ASEQ<sup>+</sup>*) If for all  $h \in T_i^*(s)$ , and  $T_{N \setminus \{i\}}^*(h) \cap T_i^{S-}(s) \neq \emptyset$ , then  $s \in S_i^{ASEQ^+}$ .

If all DM  $i$ 's unilateral improvements under attitude are strongly sanctioned by the opponents' unilateral improvements under attitude, then the initial state  $s$  is  $ASEQ^+$  for DM  $i$ .

### 3.3 Weak Attitude-Driven Stabilities

State  $s$  is weakly stable for DM  $i$  iff state  $s$  is stable, but not strongly stable for certain stability definitions ( $AGMR, ASMR, ASEQ$ ). The equivalent definitions of weak stability concepts are given below.

**Definition 24** (*Weak attitude general metarationality— $AGMR^-$* )  $S_i^{AGMR^-} = S_i^{AGMR} - S_i^{AGMR^+}$

**Equivalent definition:** If  $s \in S_i^{AGMR}$ , and for at least one  $h \in T_i^*(s)$ ,  $R_{N \setminus \{i\}}(h) \cap T_i^{S^-}(s) = \emptyset$  then  $s \in S_i^{AGMR^-}$

All DM  $i$ 's unilateral improvements under attitude are sanctioned by the opponents' moves; and at least one DM  $i$ 's unilateral improvement under attitude is weakly sanctioned by the opponents.

**Definition 25** (*Weak attitude symmetric metarationality— $ASMR^-$* )  $S_i^{ASMR^-} = S_i^{ASMR} - S_i^{ASMR^+}$

**Equivalent definition:** If  $s \in S_i^{ASMR}$ , and for at least one  $h \in T_i^*(s)$ , every  $y \in R_{N \setminus \{i\}}(h)$  satisfies  $\{y\} \cap T_i^{S^-}(s) = \emptyset$ , then  $s \in S_i^{ASMR^-(a)}$ ; If  $s \in S_i^{ASMR}$ , and for at least one  $h \in T_i^*(s)$ , there exists  $y \in R_{N \setminus \{i\}}(h) \cap T_i^{S^-}(s)$  such that  $R_i(y) \cap T_i^{G^-(s)} \neq \emptyset$ , then  $s \in S_i^{ASMR^-(b)}$ .

Note that  $S_i^{ASMR^-} = S_i^{ASMR^-(a)} \cup S_i^{ASMR^-(b)}$ , i.e., at least one unilateral improvement under attitude of DM  $i$  is either (a) weakly sanctioned; or (b) strongly sanctioned but DM  $i$  can escape this strong sanction to a weak sanction.

**Definition 26** (*Weak attitude sequential stability— $ASEQ^-$* )  $S_i^{ASEQ^-} = S_i^{ASEQ} - S_i^{ASEQ^+}$

**Equivalent definition:** If  $s \in S_i^{ASEQ}$ , and for at least one  $h \in T_i^*(s)$ ,  $T_{N \setminus \{i\}}^*(h) \cap T_i^{S^-}(s) = \emptyset$ , then  $s \in S_i^{ASEQ^-}$ .

State  $s$  is  $ASEQ$  for DM  $i$ , but at least one DM  $i$ 's unilateral improvement under attitude is weakly sanctioned by the opponents' unilateral improvements under attitude.

### 3.4 Matrix Representation of Strong Attitude-Driven Stabilities

In this section, the logical definitions of strong attitude-driven stabilities are converted to the matrix representations, which make the stabilities easier to be encoded

**Table 2** Notation list

Notation	Explanation	Notation	Explanation
$n$	Number of DMs	$e_s$	The $s$ th standard basis vector of the $m$ -dimensional Euclidean space
$m$	Number of states	$J_i$	Matrix of reachable list for DM $i$
$E$	An $m \times m$ matrix with each element being 1	$J_H$	Reachability matrix for coalition $H$
$\circ$	The Hadamard product	$T_i^*$	Matrix of unilateral improvement list under attitude for DM $i$
$sign$	Sign function		

**Table 3** Construction of strong attitude-driven stability functions

Stability	Stability vector function ( $V_i^{ADS^+}$ )
AGMR <sup>+</sup>	$V_i^{AGMR^+}(h) = 1 - sign[(e_h^T J_{N-i}) \cdot (e_s^T T_i^{S^-})^T]$
ASMR <sup>+</sup>	$V_i^{ASMR^+}(h) = 1 - sign[(e_h^T J_{N-i}) \circ (e_s^T T_i^{S^-})] \cdot G$ , with $G = [e_s^T E - sign((e_s^T (E - T_i^{S^-}) \cdot j_i^T)]^T$
ASEQ <sup>+</sup>	$V_i^{ASEQ^+}(h) = 1 - sign[(e_h^T T_{N-i}^*) \cdot (e_s^T T_i^{S^-})^T]$

into a DSS. Compared with the matrix form of general attitude-driven stabilities (Xu et al. 2017a), calculating the strong attitude-driven stabilities needs to define the matrix presentation of the general less preferred states under attitude  $(T_{ij}^- = \begin{cases} 1 & \text{if } t <_i s \text{ satisfies } T_{ij}; \\ 0 & \text{otherwise.} \end{cases})$ , which is required in calculating the strongly less preferred states under total attitude ( $T_i^{S^-}$ ). The matrix representation of strong attitude-driven stabilities is defined in the Theorem 1, and corresponding notation is listed in the Table 2.

Let  $V_i^{ADS^+}$  denote DM  $i$ 's strong attitude-driven stability row vector function. Table 3 presents the  $h$ th element of the stability vector functions for AGMR<sup>+</sup>, ASMR<sup>+</sup>, and ASEQ<sup>+</sup>.

**Theorem 1** (Matrix form of strong attitude-driven stabilities—ADS<sup>+</sup>) For  $i, j \in N$ , and  $s, h \in S$ ,

$$\text{if } (e_s^T \cdot T_i^*) \circ V_i^{ADS^+} = \mathbf{0}^T, \text{ then } s \in S_i^{ADS^+}.$$

Theorem 1 contains three matrix representations of strong attitude-driven stabilities: AGMR<sup>+</sup>, ASMR<sup>+</sup> and ASEQ<sup>+</sup>. The proof of AGMR<sup>+</sup> stability is presented as follows. Note that the proofs of ASMR<sup>+</sup> and ASEQ<sup>+</sup> are similar to AGMR<sup>+</sup>, and therefore omitted.

**Corollary 1** (Matrix form of AGMR<sup>+</sup>) For  $i, j \in N$ , and  $s, h \in S$ , let

$$V_i^{AGMR^+}(h) = 1 - sign[(e_h^T J_{N-i}) \cdot (e_s^T T_i^{S^-})^T].$$

$$\text{If } (e_s^T \cdot T_i^*) \circ V_i^{AGMR^+} = \mathbf{0}^T, \text{ then } s \in S_i^{AGMR^+}. \tag{1}$$

**Table 4** A comparison between NUAAGMCR and GMCR II

Criteria	NUAAGMCR	GMCR II
Theoretical basis	Matrix	Logical
Accessibility	Online	Offline
Portability	Any operating systems with a web browser	MS Windows installation
Evolvability	Update according to new developments	No update after the first release
Functionality	Stability analysis; coalition analysis; status quo analysis; attitude-driven stability analysis	Stability analysis

*Proof* From Definition 21, we can know that (1) is equivalent to

$$V_i^{AGMR^+}(h) = 0 \text{ for } \forall h \in T_i^*(s). \tag{2}$$

It is obvious that Eq. (2) is equivalent to  $(e_h^T J_{N-i}) \cdot (e_s^T T_i^{S-})^T \neq 0$  for  $\forall h \in T_i^*(s)$ , which implies that for all  $h \in T_i^*(s)$ , we have  $R_{N \setminus \{i\}}(h) \cap T_i^{S-}(s) \neq \emptyset$ , and thus  $s \in S_i^{AGMR^+}$ . □

### 3.5 DSS Development

NUAAGMCR is a DSS developed to facilitate the analyses in GMCR. Table 4 presents a comparison between NUAAGMCR and the previous version, GMCR II. As shown, NUAAGMCR has noticeable advantages over GMCR II based on the comparison criteria include “theoretical basis” (the foundation of the theoretical analysis), “accessibility” (the ability to access), “portability” (the possibility of running on multiple platforms), “evolvability” (the ability to adapt to new developments), and “functionality” (the range of analyses that can be conducted). To further conduct the proposed attitude-driven stability analysis, the analytical process is incorporated in the latest version of NUAAGMCR.

Table 5 shows the corresponding pseudo code based on the matrix form of strong attitude-driven stabilities. To compute  $T_i^{S-}$ , after the initialization (Step 0),  $T_i^{S-}$  is updated iteratively for all DMs ( $j \in N$ ) by intersecting all  $T_{ij}^-$  for DM  $i$  (Steps 1-3).  $AGMR^+$ ,  $ASMR^+$ , and  $ASEQ^+$ , can then be obtained accordingly.

## 4 Case Study: The Two-Stage Environmental Conflict of Post-Fukushima Controversy

On March 11, 2011, a 9.0-magnitude undersea mega-thrust earthquake struck off the Pacific coast of Tōhoku, northeastern Japan. The tsunami following the earthquake triggered a nuclear accident at the Fukushima Daiichi Nuclear Power Plant. As the

**Table 5** The pseudo code for strong attitude-driven stabilities

<p>(1) <math>T_i^{S-}</math></p> <p>0: Let <math>j = 0, T_i^{--} = E</math>;          1: <math>j \leftarrow j + 1</math>;          2: <math>T_i^{S-} \leftarrow T_i^{S-} \circ T_{ij}^-</math>;          3: If <math>j = n</math>, end; otherwise, return to step 1</p>	<p>(2) AGMR<sup>+</sup></p> <p>0: Let <math>h = 0</math>;          1: <math>h \leftarrow h + 1</math>;          2: <math>V_i^{AGMR^+}(h) = 1 - \text{sign}[(e_h^T J_{N-i}) \cdot (e_s^T T_i^{S-})^T]</math>;          3: If <math>h = m</math>, continue; otherwise, return to step 2;          4: If <math>(e_s^T \cdot T_i^*) \circ V_i^{AGMR^+} = \mathbf{0}^T</math>, DM <math>i</math> is AGMR<sup>+</sup> at state <math>s</math></p>
<p>(3) ASMR<sup>+</sup></p> <p>0: Let <math>h = 0</math>;          1: <math>h \leftarrow h + 1</math>;          2:  <math display="block">G = \left[ e_s^T E - \text{sign} \left( \left( e_s^T (E - T_i^{S-}) \right) \cdot J_i^T \right) \right]^T</math>;  <math display="block">V_i^{ASMR^+}(h) = 1 - \text{sign} \left( \left[ (e_h^T J_{N-i}) \circ (e_s^T T_i^{S-}) \right] \cdot G \right)</math>;          3: If <math>h = m</math>, continue; otherwise, return to step 2;          4: If <math>(e_s^T \cdot T_i^*) \circ V_i^{ASMR^+} = \mathbf{0}^T</math>, DM <math>i</math> is ASMR<sup>+</sup> at state <math>s</math></p>	<p>(4) ASEQ<sup>+</sup></p> <p>0: Let <math>h = 0</math>;          1: <math>h \leftarrow h + 1</math>;          2: <math>V_i^{ASEQ^+}(h) = 1 - \text{sign}[(e_h^T T_{N-i}^*) \cdot (e_s^T T_i^{S-})^T]</math>;          3: If <math>h = m</math>, continue; otherwise, return to step 2;          4: If <math>(e_s^T \cdot T_i^*) \circ V_i^{ASEQ^+} = \mathbf{0}^T</math>, DM <math>i</math> is ASEQ<sup>+</sup> at state <math>s</math></p>

worst nuclear incident since Chernobyl, the Fukushima nuclear disaster displaced approximately 156,000 people after radioactive material leaked into the air, soil, and sea (World Nuclear Association 2017). By the end of 2011, about one-third of the 133,000 Japanese children who had been examined were suffering from thyroid nodules and cysts, and this proportion rose to more than 40% in 2012. A World Health Organization (WHO) report released in 2013 indicated that the most at-risk group is the infants in the most affected area, who would experience an absolute increase in the risk of cancer of all types during their lifetime (WHO 2013). Moreover, the perceived radiation exposure and dislocation also caused significant mental health challenges (Yang and Wang 2014). According to several recent environmental research, (Bueseler et al. 2011; Tsumune et al. 2012), there is no sufficient data fully evaluate the impacts of this accident on the ocean, but concerns regarding biological uptake and seafood consumption are still not resolved and require further studies.

Due to the tremendous impact of the nuclear disaster on the public health and environment, the public strongly demanded the government to shut down all nuclear plants in order to prevent the same disaster from happening again. However, despite the high anti-nuclear sentiment, Japan broke out a two-stage environmental conflict, which led the country to move from “zero-nuclear” to “nuclear-restart” (Fig. 4). This section applies the proposed attitude stability analysis to study the two-stage conflict of the post-Fukushima controversy in Japan, and thus to provide enhanced insights into the causes of Japan’s “nuclear-restart” policy.

### 4.1 The First Stage

The first-stage conflict involves three DMs, the Nuclear Power Group (N), the Government (G), and the Public (P). To be specific, N is a group that gains profit from

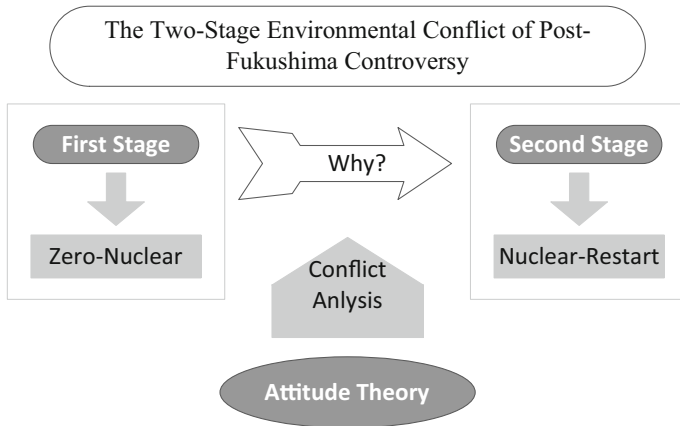


Fig. 4 The purpose of using attitude theory to analyze two-stage environmental conflict of PFC

promoting the nuclear energy. Given the obvious financial interest, N would like to put pressure on the government to keep the nuclear power plants (Option 1: Put pressure). From G’s point of view, closing all nuclear power plants is one option (Option 2: Zero-nuclear policy), especially under the enormous public concerns. But because most of electricity in Japan is provided by the nuclear power plant, and the significant economic benefits related to nuclear power, G may also choose to defend nuclear power by declaring that the earthquake and tsunami should be responsible for the disaster (Option 3: Defend nuclear power). Contrary to the other two DMs, P is the one that suffered the most from the disaster, and therefore determinedly insists in banning all nuclear power. P’s options include continuing escalating civil unrests to push towards a “zero-nuclear” policy (Option 4: Appeal) and expulsing the incumbent government during the next election (Option 5: Elect alternate leadership).

Logically, given 5 options, there are  $2^5 = 32$  states. But certain states are not reasonable, and thus should be eliminated. For example, the government cannot choose options 2 and 3 simultaneously. Also, if G chooses option 2, other DMs’ options become meaningless, and thus those states can be combined as one. Hence, after removing unreasonable states, 17 feasible states remain. Table 6 shows all DMs, their options, and the 17 feasible states (namely  $S_1$  to  $S_{17}$ ). Note that in Table 6, a “Y” indicates that the option is chosen by the corresponding DM, an “N” means that the option is not selected, and a “—” shows that the option can either be chosen or not.

#### 4.1.1 Graph Model of Conflict

The graph model for the first stage conflict of PFC (Fig. 5) depicts the unilateral movements of each DM between two states. The dots represent the 17 feasible states, and the directed arcs denote that the DM can transfer from one state to another by changing his own strategy. Based on the graph model, we can obtain the reachable list for each DM, which is presented in Table 7.

**Table 6** Feasible states of the first stage environmental conflict of PFC

DMs		Feasible states																
	Options	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	S <sub>5</sub>	S <sub>6</sub>	S <sub>7</sub>	S <sub>8</sub>	S <sub>9</sub>	S <sub>10</sub>	S <sub>11</sub>	S <sub>12</sub>	S <sub>13</sub>	S <sub>14</sub>	S <sub>15</sub>	S <sub>16</sub>	S <sub>17</sub>
N	1. Put pressure	N	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	-
	2. Zero-nuclear policy	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y
P	3. Defend nuclear power	N	N	N	Y	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	-
	4. Appeal	N	N	Y	Y	N	Y	Y	Y	N	N	Y	Y	N	N	Y	Y	-
	5. Elect alternate leadership	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	-
Label		S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	S <sub>5</sub>	S <sub>6</sub>	S <sub>7</sub>	S <sub>8</sub>	S <sub>9</sub>	S <sub>10</sub>	S <sub>11</sub>	S <sub>12</sub>	S <sub>13</sub>	S <sub>14</sub>	S <sub>15</sub>	S <sub>16</sub>	S <sub>17</sub>

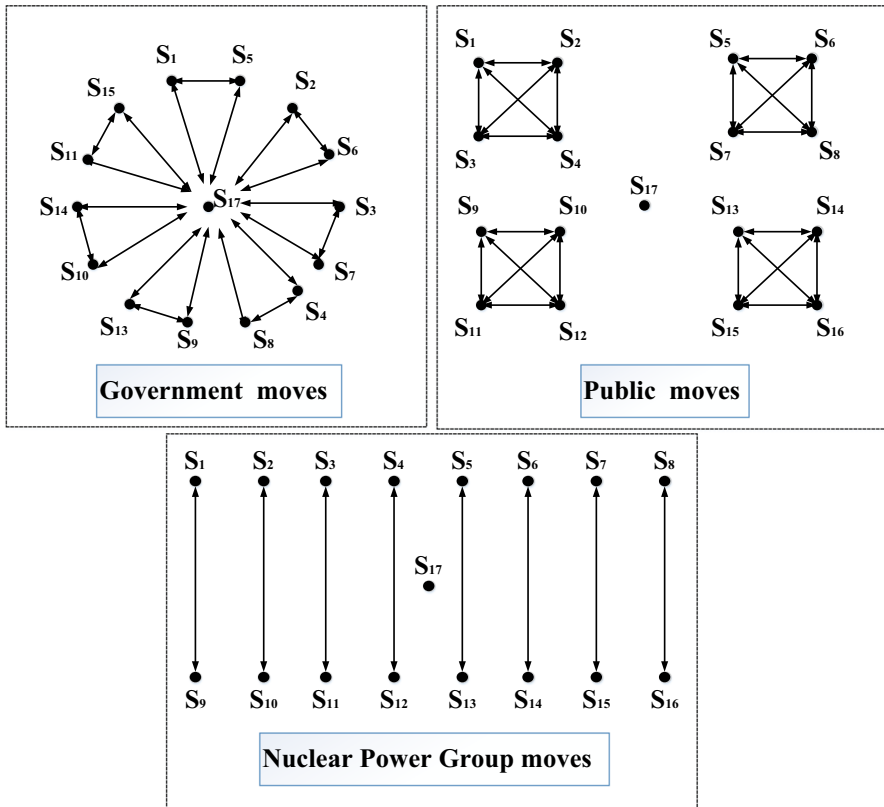


Fig. 5 Graph model of the first stage environmental conflict of PFC

### 4.1.2 Option Statements

Table 8 lists the option statements of all DMs for this conflict. Particularly, the most favorable option for N is that P does not appeal about nuclear power. Secondly, N hopes that G does not implement the “zero-nuclear” policy. Hence, N’s option statement from most to least preferred is “- 4”, “3”, “- 2”, “1”, “- 5”. Here, “- 4” denotes that N prefers the opposite of option 4, and “3” indicates that N likes option 3.

G most desires that the public does not escalate civil unrests, and then does not want to close the nuclear power plant, as the nuclear power plant plays an important role in Japan’s economic development. Accordingly, G’s option statement from most to least preferred is “- 5”, “- 4”, “- 2”, “3”, “- 1”.

P only wants G to implement the “zero-nuclear” policy to avoid such nuclear pollution incidents happen again. Therefore, P’s option statement is “2”, “- 3”, “- 1”, “4”, “5”.

### 4.1.3 Attitudes

It is intuitive that each DM cares about his own interests, and therefore has a positive attitude toward himself. More specifically, N is indifferent (denoted by “0”) about



**Table 7** Reachable list of the first stage environmental conflict of PFC

States	$R_N(s)$	$R_G(s)$	$R_P(s)$
S <sub>1</sub>	S <sub>9</sub>	S <sub>5</sub> , S <sub>17</sub>	S <sub>2</sub> , S <sub>3</sub> , S <sub>4</sub>
S <sub>2</sub>	S <sub>10</sub>	S <sub>6</sub> , S <sub>17</sub>	S <sub>1</sub> , S <sub>3</sub> , S <sub>4</sub>
S <sub>3</sub>	S <sub>11</sub>	S <sub>7</sub> , S <sub>17</sub>	S <sub>1</sub> , S <sub>2</sub> , S <sub>4</sub>
S <sub>4</sub>	S <sub>12</sub>	S <sub>8</sub> , S <sub>17</sub>	S <sub>1</sub> , S <sub>2</sub> , S <sub>3</sub>
S <sub>5</sub>	S <sub>13</sub>	S <sub>1</sub> , S <sub>17</sub>	S <sub>6</sub> , S <sub>7</sub> , S <sub>8</sub>
S <sub>6</sub>	S <sub>14</sub>	S <sub>2</sub> , S <sub>17</sub>	S <sub>5</sub> , S <sub>7</sub> , S <sub>8</sub>
S <sub>7</sub>	S <sub>15</sub>	S <sub>3</sub> , S <sub>17</sub>	S <sub>5</sub> , S <sub>6</sub> , S <sub>8</sub>
S <sub>8</sub>	S <sub>16</sub>	S <sub>4</sub> , S <sub>17</sub>	S <sub>5</sub> , S <sub>6</sub> , S <sub>7</sub>
S <sub>9</sub>	S <sub>1</sub>	S <sub>13</sub> , S <sub>17</sub>	S <sub>10</sub> , S <sub>11</sub> , S <sub>12</sub>
S <sub>10</sub>	S <sub>2</sub>	S <sub>14</sub> , S <sub>17</sub>	S <sub>9</sub> , S <sub>11</sub> , S <sub>12</sub>
S <sub>11</sub>	S <sub>3</sub>	S <sub>15</sub> , S <sub>17</sub>	S <sub>9</sub> , S <sub>10</sub> , S <sub>12</sub>
S <sub>12</sub>	S <sub>4</sub>	S <sub>16</sub> , S <sub>17</sub>	S <sub>9</sub> , S <sub>10</sub> , S <sub>11</sub>
S <sub>13</sub>	S <sub>5</sub>	S <sub>9</sub> , S <sub>17</sub>	S <sub>14</sub> , S <sub>15</sub> , S <sub>16</sub>
S <sub>14</sub>	S <sub>6</sub>	S <sub>10</sub> , S <sub>17</sub>	S <sub>13</sub> , S <sub>15</sub> , S <sub>16</sub>
S <sub>15</sub>	S <sub>7</sub>	S <sub>11</sub> , S <sub>17</sub>	S <sub>13</sub> , S <sub>14</sub> , S <sub>16</sub>
S <sub>16</sub>	S <sub>8</sub>	S <sub>12</sub> , S <sub>17</sub>	S <sub>13</sub> , S <sub>14</sub> , S <sub>15</sub>
S <sub>17</sub>	Null	All states except for S <sub>17</sub>	Null

**Table 8** Option-oriented preference statements of the first stage environmental conflict of PFC

$L_N$	$L_G$	$L_P$
-4	-5	2
3	-4	-3
-2	-2	-1
1	3	4
-5	-1	5

**Table 9** Attitudes of the first stage environmental conflict of PFC

DMs	N	G	P
N	+	0	0
G	0	+	+
P	-	0	+

other DMs. As to G, despite the preferences, the attitude is positive (indicated by “+”) toward P, considering the vast pollution caused by the disaster and concerning the result of the next election. P is obviously negative (shown by “-”) toward N given the entirely opposite standpoint, but indifferent about G. The details of the attitudes of all DMs are listed in Table 9, where each row shows a certain DM’s attitudes toward other DMs.

**Table 10** Attitude-driven option statements of the first stage environmental conflict of PFC

DMs	Attitude-driven option statements ( $L_{ij}$ )		
N	$L_{NN} = L_N (e_{NN} = +)$	$L_{NG} = I (e_{NG} = 0)$	$L_{NP} = I (e_{NP} = 0)$
	-4		
	3		
	-2	Indifferent	Indifferent
	1		
	-5		
G	$L_{GN} = I (e_{GN} = 0)$	$L_{GG} = L_G (e_{GG} = +)$	$L_{GP} = L_P (e_{GP} = +)$
		-5	2
		-4	-3
	Indifferent	-2	-1
		3	4
		-1	5
P	$L_{PN} = -L_N (e_{PN} = -)$	$L_{PG} = I (e_{PG} = 0)$	$L_{PP} = L_P (e_{PP} = +)$
	4		2
	-3		-3
	2	Indifferent	-1
	-1		4
	5		5

### 4.1.4 Attitude-Driven Option Statements

According to the DMs' attitudes, the option statements of DMs under corresponding attitudes can be obtained (Table 10). For example, due to G's positive attitude toward P ( $e_{GP} = +$ ), we have  $L_{GP} = L_P$ , i.e., G's attitude-driven option statement equals to P's option statement. Also, given the negative attitude that P has toward N ( $e_{PN} = -$ ), we have  $L_{PN} = -L_N$ , i.e., P's attitude-driven option statement is the opposite of N's option statement.

### 4.1.5 Attitude-Driven Preferences

Based on the attitude-driven option statements, the attitude-driven preferences of DMs can be then generated (Table 11). As stated in Definition 7, the total attitude-driven preference of DM  $i$  at state  $s$ ,  $T_i^+(s)$ , should satisfy every attitude-driven preference  $T_{ij}(s)$ . Take state  $S_2$  for instance, G's total attitude-driven preference at this state needs to satisfy two attitude-driven preferences ( $T_{GG}, T_{GP}$ ).  $T_{GN}$  is not included here because G is indifferent toward N. Hence, given  $T_{GG}(S_2) = \{S_1, S_3, S_5, S_6, S_7, S_9, S_{11}, S_{13}, S_{14}, S_{15}, S_{17}\}$  and  $T_{GP}(S_2) = \{S_3, S_4, S_{17}\}$ , we have  $T_G^+(S_2) = T_{GG}(S_2) \cap T_{GP}(S_2) = \{S_3, S_{17}\}$ . Also from Definitions (9) and (10), the strong less preferred states under total attitude ( $T_i^{--}$ ) for DM  $i$  is the intersection of all less preferred states under attitude ( $T_{ij}^-$ ) for the DM, and the less preferred

**Table 11** Attitude-driven preference of the first stage environmental conflict of PFC

DMs	Attitude	Attitude-driven preference ( $T_{ij}$ )
N	$e_{NN} = +$	$T_{NN}$ $S_{13} > S_{14} > S_5 > S_6 > S_9 > S_{10} > S_1 > S_2 > S_{17} > S_{15} > S_{16} > S_7 > S_8 > S_{11} > S_{12} > S_3 > S_4$
	$e_{NG} = 0$	$T_{NG}$ Indifferent
	$e_{NP} = 0$	$T_{NP}$ Indifferent
G	$e_{GN} = 0$	$T_{GN}$ Indifferent
	$e_{GG} = +$	$T_{GG}$ $S_5 > S_{13} > S_1 > S_9 > S_{17} > S_7 > S_{15} > S_3 > S_{11} > S_6 > S_{14} > S_2 > S_{10} > S_8 > S_{16} > S_4 > S_{12}$
	$e_{GP} = +$	$T_{GP}$ $S_{17} > S_4 > S_3 > S_2 > S_1 > S_{12} > S_{11} > S_{10} > S_9 > S_8 > S_7 > S_6 > S_5 > S_{16} > S_{15} > S_{14} > S_{13}$
P	$e_{PN} = -$	$T_{PN}$ $S_4 > S_3 > S_{12} > S_{11} > S_8 > S_7 > S_{16} > S_{15} > S_{17} > S_2 > S_1 > S_{10} > S_9 > S_6 > S_5 > S_{14} > S_{13}$
	$e_{PG} = 0$	$T_{PG}$ Indifferent
	$e_{PP} = +$	$T_{PP}$ $S_{17} > S_4 > S_3 > S_2 > S_1 > S_{12} > S_{11} > S_{10} > S_9 > S_8 > S_7 > S_6 > S_5 > S_{16} > S_{15} > S_{14} > S_{13}$

states under attitude for a DM is the supplementary set of the attitude-driven preference. So given  $T_{GP}^-(S_2) = \{S_1, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}\}$  and  $T_{GG}^-(S_2) = \{S_4, S_8, S_{10}, S_{12}, S_{16}\}$ , we have  $T_G^-(S_2) = T_{GP}^-(S_2) \cap T_{GG}^-(S_2) = \{S_8, S_{10}, S_{12}, S_{16}\}$ . Collectively, we can derive G’s attitude-driven preferences at each state (Table 12), and other DMs’ preferences under attitude can also be generated in a similar way.

### 4.1.6 Attitude-Driven Stability Analyses

Based on the derived attitude-driven preferences and the corresponding reachable list, the equilibria of the first stage conflict for PFC can be obtained. The strong attitude-driven stabilities of all states are listed in Table 13, where “√” denotes that the state is stable for a particular DM under the corresponding stability, and “\*” indicates the equilibrium. As shown, the state  $S_{17}$  is stable for all DMs.

We can also calculate the general attitude-driven stabilities, which indicate four equilibria,  $S_1, S_5, S_9,$  and  $S_{17}$  (Table 14). Comparing the strong, weak and general attitude stability analyses (Table 15),  $S_{17}$  is undoubtedly the most stable state, and is also what really happened in Japan. Actually, after the Fukushima nuclear power plant accident, the Japanese nuclear power plant reactors stopped running due to periodic inspection and other reasons. In May 2012, Japan fully implemented the “zero-nuclear” policy. This fact demonstrates that the DMs tend to be more stable at the equilibria of strong attitude-driven stabilities rather than the weak ones. Therefore, strong attitude-driven stability can analyze the conflict more accurately comparing with the general attitude-driven stabilities.

**Table 12** Attitude-driven preferences of G in the first stage environmental conflict of PFC

States	$T_G^+$	$T_G^{S-}$
S <sub>1</sub>	Null	S <sub>6</sub> , S <sub>7</sub> , S <sub>8</sub> , S <sub>9</sub> , S <sub>10</sub> , S <sub>11</sub> , S <sub>12</sub> , S <sub>14</sub> , S <sub>15</sub> , S <sub>16</sub>
S <sub>2</sub>	S <sub>3</sub> , S <sub>17</sub>	S <sub>8</sub> , S <sub>10</sub> , S <sub>12</sub> , S <sub>16</sub>
S <sub>3</sub>	S <sub>17</sub>	S <sub>2</sub> , S <sub>6</sub> , S <sub>8</sub> , S <sub>10</sub> , S <sub>11</sub> , S <sub>12</sub> , S <sub>14</sub> , S <sub>16</sub>
S <sub>4</sub>	S <sub>17</sub>	S <sub>12</sub>
S <sub>5</sub>	Null	S <sub>13</sub> , S <sub>14</sub> , S <sub>15</sub> , S <sub>16</sub>
S <sub>6</sub>	S <sub>1</sub> , S <sub>3</sub> , S <sub>7</sub> , S <sub>9</sub> , S <sub>11</sub> , S <sub>17</sub>	S <sub>14</sub> , S <sub>16</sub>
S <sub>7</sub>	S <sub>1</sub> , S <sub>9</sub> , S <sub>17</sub>	S <sub>6</sub> , S <sub>14</sub> , S <sub>16</sub>
S <sub>8</sub>	S <sub>1</sub> , S <sub>2</sub> , S <sub>3</sub> , S <sub>9</sub> , S <sub>10</sub> , S <sub>11</sub> , S <sub>17</sub>	S <sub>16</sub>
S <sub>9</sub>	S <sub>1</sub>	S <sub>6</sub> , S <sub>7</sub> , S <sub>8</sub> , S <sub>14</sub> , S <sub>15</sub> , S <sub>16</sub>
S <sub>10</sub>	S <sub>1</sub> , S <sub>2</sub> , S <sub>3</sub> , S <sub>11</sub> , S <sub>17</sub>	S <sub>8</sub> , S <sub>16</sub>
S <sub>11</sub>	S <sub>1</sub> , S <sub>3</sub> , S <sub>17</sub>	S <sub>6</sub> , S <sub>8</sub> , S <sub>10</sub> , S <sub>14</sub> , S <sub>16</sub>
S <sub>12</sub>	S <sub>1</sub> , S <sub>2</sub> , S <sub>3</sub> , S <sub>4</sub> , S <sub>17</sub>	Null
S <sub>13</sub>	S <sub>5</sub>	Null
S <sub>14</sub>	S <sub>1</sub> , S <sub>3</sub> , S <sub>5</sub> , S <sub>6</sub> , S <sub>7</sub> , S <sub>9</sub> , S <sub>11</sub> , S <sub>15</sub> , S <sub>17</sub>	Null
S <sub>15</sub>	S <sub>1</sub> , S <sub>5</sub> , S <sub>7</sub> , S <sub>9</sub> , S <sub>17</sub>	S <sub>14</sub>
S <sub>16</sub>	S <sub>1</sub> , S <sub>2</sub> , S <sub>3</sub> , S <sub>5</sub> , S <sub>6</sub> , S <sub>7</sub> , S <sub>8</sub> , S <sub>9</sub> , S <sub>10</sub> , S <sub>11</sub> , S <sub>17</sub>	Null
S <sub>17</sub>	Null	S <sub>2</sub> , S <sub>3</sub> , S <sub>4</sub> , S <sub>6</sub> , S <sub>7</sub> , S <sub>8</sub> , S <sub>10</sub> , S <sub>11</sub> , S <sub>12</sub> , S <sub>14</sub> , S <sub>15</sub> , S <sub>16</sub>

## 4.2 Attitude Modeling and Analysis for the Second Stage

After the shutdown of reactors, resource-poor Japan had to turn to expensive fossil fuel to fill the resulted energy gap. The extremely high cost of the fossil fuel and poor economy situation made the government start to reconsider their nuclear policy. According to the Prime Minister of Japan, Shinzo Abe, the country “cannot do without nuclear power to secure the stability of energy supply while considering what makes economic sense and the issue of climate change.” But Abe also indicated that only the reactors that meet the new standards can be restarted (AFP 2016). Despite the changing attitude of the government, the public was still strongly opposed to restarting any nuclear reactors. Thus, the second-stage environmental conflict of PFC arose (Yang and Wang 2014; Li 2015).

Same DMs are involved in the second stage. While the government’s strategy changes this time, the other two DMs keep their original strategies. The only option that the government has at this stage is to restart the nuclear power plants after meeting the new safety standards. After eliminating the unreasonable states, 16 feasible states remain in the second-stage conflict (Table 16). The graph model and reachable list can be obtained as well.

### 4.2.1 Option Statements

For N, the most preferred situation is that the government can restart the nuclear power plant, and then N also hopes that P does not resist the nuclear power. Hence, the option

**Table 13** Strong attitude-driven stabilities for the first stage environmental conflict of PFC

Stabilities	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	S <sub>5</sub>	S <sub>6</sub>	S <sub>7</sub>	S <sub>8</sub>	S <sub>9</sub>	S <sub>10</sub>	S <sub>11</sub>	S <sub>12</sub>	S <sub>13</sub>	S <sub>14</sub>	S <sub>15</sub>	S <sub>16</sub>	S <sub>17</sub>
<i>AGMR</i> <sup>+</sup>																	
N	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
G	✓				✓				✓			✓	✓				✓
P				✓			✓				✓					✓	
E																	*
<i>ASMR</i> <sup>+</sup>																	
N	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
G	✓				✓				✓			✓	✓				✓
P				✓			✓				✓					✓	
E																	*
<i>ASEQ</i> <sup>+</sup>																	
N	✓	✓			✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
G	✓				✓				✓			✓	✓				✓
P				✓												✓	
E																	*

**Table 14** General attitude-driven stabilities for the first stage environmental conflict of PFC

Stabilities	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	S <sub>5</sub>	S <sub>6</sub>	S <sub>7</sub>	S <sub>8</sub>	S <sub>9</sub>	S <sub>10</sub>	S <sub>11</sub>	S <sub>12</sub>	S <sub>13</sub>	S <sub>14</sub>	S <sub>15</sub>	S <sub>16</sub>	S <sub>17</sub>	
<i>ANash</i>																		
N									✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
G	✓				✓				✓	✓	✓	✓	✓				✓	✓
P				✓				✓				✓	✓			✓	✓	✓
E												✓						*
<i>AGMR</i>																		
N	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
G	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓
P	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓
E	*			✓	*				*			✓						*
<i>ASMR</i>																		
N	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
G	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓
P	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓
E	*			✓	*				*			✓						*
<i>ASEQ</i>																		
N	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
G	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓
P	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓
E	*			✓	*				*			✓						*

**Table 15** Comparison of equilibria for the first stage environmental conflict of PFC

Stabilities	General		Reality
	Strong	Weak	
Equilibria	$S_{17}$	$S_1, S_5, S_9$	$S_{17}$

statement of N from most to least preferred is “2”, “1”, “- 4”, “- 3”. As to G, boosting the economic development by restarting the nuclear power plant is the most preferred, and G does not want to see pressures from any other parties. So G’s option statement is “2”, “- 4”, “- 1”, “- 3”. P still hopes that G continues to implement the “zero-nuclear” policy, otherwise certain actions will be taken. Thus P’s option statement from most to least preferred is “- 2”, “3”, “4”, “- 1”. Table 17 lists all DMs’ option statements.

#### 4.2.2 Attitudes

During the “zero-nuclear” period, the Japanese economy was greatly affected by the lack of energy, and therefore G’s attitude has undergone great changes at this stage. Now P is more positive toward N, hoping to restart the nuclear power plant to promote the economic development. But for N and P, their attitudes remain unchanged (Table 18). Note that details regarding the option statements and preference under attitudes are omitted to conserve space.

#### 4.2.3 Attitude-Driven Stability Analysis

It is convenient to obtain the equilibria under strong attitude-driven stabilities and general attitude-driven stabilities by entering the DMs’ attitudes and option statements into NUAAGMCR. Tables 19 and 20 provide the strong and general attitude-driven stability analyses, respectively. Under the strong attitude-driven stability analysis (Table 19),  $S_8$  and  $S_{16}$  are the equilibria. To be specific, for both  $S_8$  and  $S_{16}$ , G chooses to restart the nuclear; P appeals and no longer supports the current government. The difference between the two states is whether N puts pressure on G or not. It is obvious that this choice is actually meaningless for N once G has the intention to restart the nuclear power plant. Hence,  $S_{16}$  is only a temporary equilibrium, while  $S_8$  is the permanent one. On the other hand, under the general attitude-driven stability analysis (Table 20), there exist five equilibria ( $S_5, S_6, S_7, S_8$  and  $S_{16}$ ). Furthermore, considering the relationship among the general, strong, and weak attitude stabilities, the equilibria of weak attitude-driven stabilities are  $S_5, S_6, S_7$ .

In fact, in mid-July 2015, since the Japanese House of Representatives forcibly adopted the new security bill, the Abe government’s opposition rate reached 46%, while the support rate fell to 37% (Li 2015). In mid-August 2015, Kyushu’s Sendai 1 became the first reactor to restart and connect to the grid, followed by Sendai 2 in October (World Nuclear Association 2017). The restart indicated that the “zero-nuclear” state in Japan has reached the end. This fact proves once again the resolution





**Table 17** Option statements of the second stage environmental conflict of PFC

	$L_N$	$L_G$	$L_P$
	2	2	-2
	1	-4	3
	-4	-1	4
	-3	-3	-1

**Table 18** Attitudes of the second stage environmental conflict of PFC

DMs	N	G	P
N	+	0	0
G	+	+	0
P	-	0	+

predicted by strong attitude-driven stabilities is more accurate than the results from the general attitude-driven stabilities (Table 21).

### 4.3 The Evolution Analysis for the Two-stage Environmental Conflict Around the PFC

As shown in Fig. 6, the changed attitude of Japanese government led Japan from “zero-nuclear” to “nuclear-restart”. Although the restart of nuclear power plants accelerates the development of the Japanese economy, the disadvantages far outweigh the advantages from the perspective of sustainability, especially considering the earthquakes, typhoons, and other natural disasters that frequently happen in Japan. To prevent further disasters, we provide several constructive suggestions. First, the public should continue taking actions to put pressure on the government. These actions may include jointly opposing the nuclear restart, and trying to push the National Diet to select a ruling party with greater emphasis on environmental protection. Second, external assistances, for example from United Nation and/or other developed countries (such as US), may be able to force the government to adjust the nuclear policy. Third, it is necessary to investigate the possibility of developing and employing alternative sources of low-cost energy, such as marine energy, hydroelectric, wind, geothermal, and solar power.

## 5 Conclusions

In this paper, a new systematic framework equipped with an option-oriented attitude analysis of the degree of stabilities is developed for GMCR. The method can more accurately predict the conflict than the general stability analysis, and therefore, provides a more effective tool to study various conflict situations and gain enhanced insights.

**Table 19** Strong attitude-driven stabilities for the second stage environmental conflict of PFC

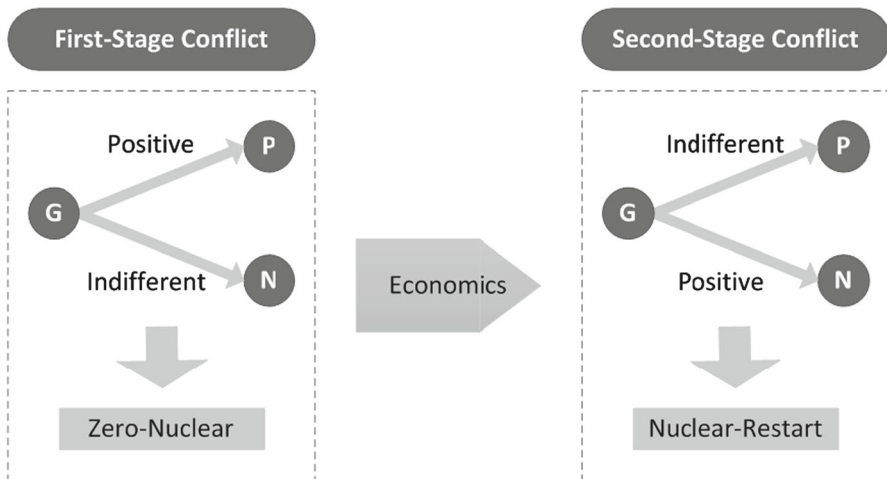
	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	S <sub>5</sub>	S <sub>6</sub>	S <sub>7</sub>	S <sub>8</sub>	S <sub>9</sub>	S <sub>10</sub>	S <sub>11</sub>	S <sub>12</sub>	S <sub>13</sub>	S <sub>14</sub>	S <sub>15</sub>	S <sub>16</sub>
<i>AGMR</i> <sup>+</sup>																
N				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
G				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
P	✓	✓	✓													
E								*								*
<i>ASMR</i> <sup>+</sup>																
N				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
G				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
P	✓	✓	✓													
E								*								*
<i>ASEQ</i> <sup>+</sup>																
N									✓	✓	✓	✓	✓	✓	✓	✓
G									✓	✓	✓	✓	✓	✓	✓	✓
P	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
E																*

**Table 20** General attitude-driven stabilities for the second stage environmental conflict of PFC

Stabilities	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	S <sub>5</sub>	S <sub>6</sub>	S <sub>7</sub>	S <sub>8</sub>	S <sub>9</sub>	S <sub>10</sub>	S <sub>11</sub>	S <sub>12</sub>	S <sub>13</sub>	S <sub>14</sub>	S <sub>15</sub>	S <sub>16</sub>
<i>ANash</i>																
N					✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
G					✓		✓	✓								
P								✓				✓	✓			
E				✓				✓				✓				*
<i>AGMR</i>																
N					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
G					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
P					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
E				✓	*	*	*	*								*
<i>ASMR</i>																
N					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
G					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
P					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
E					*	*	*	*								*
<i>ASEQ</i>																
N					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
G					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
P					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
E				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	*

**Table 21** Comparison of equilibria for the second stage environmental conflict of PFC

Stabilities	General		Reality
	Strong	Weak	
Equilibria	S <sub>8</sub> , S <sub>16</sub>	S <sub>5</sub> , S <sub>6</sub> , S <sub>7</sub>	S <sub>8</sub>



**Fig. 6** The result evolution process for two-stage environmental conflict of PFC

The contributions of this research are fourfold. First, an expanded attitude-driven preference structure based on option is presented to consider the strongly less preferred states under attitude. Second, the general attitude-driven stabilities are extended to consider the degrees of stabilities under attitude. Third, the analytical process is embedded to an online DSS (NUAAGMCR) for easier practice. Fourth, the framework is applied to the two-stage environmental conflict of the post-Fukushima controversy in Japan. The investigation reveals that the key reason for this country’s “nuclear-restart” policy is the attitude of government changed from environment-focused to economy-focused. To prevent similar situations from happening again, the public is suggested to keep on putting pressure on the government, and if possible request external assistances. Developing alternative energy sources is also recommended.

For the future research directions, we will introduce the concept of fuzzy logic to the attitude-driven stability analysis, which will facilitate the decision makers, or other relevant parties, with a more realistic and comprehensive study of conflicts.

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