J SYST SCI SYST ENG
Vol. 0, No. 0, 0, pp. 1–40
DOI: https://doi.org/10.1007/s11518-024-5602-3

ISSN: 1004-3756 (paper), 1861-9576 (online)
CN 11-2983/N

Energy Conflict Resolution for Sustainable Resource Production in Ghana Using a Hybrid DEMATEL-GMCR Model

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Abstract. The production of fossil energy resources is central to economic development for developing economies such as Ghana, with abundant natural resources, despite the interrelated socio-ecological disruptions. Owing to the value of the newly found oil and gas resources, disputes are sourced from a tradeoff between financial gains and socio-ecological sustainability among multiple decision-makers (DMs) in the Western Region enclave. Strategic negotiations to formally analyze the stability behavior of the government, "fisherfolks," and oil companies as major DMs with extensive interrelated strategies are necessary for resolving the ongoing conflict. This research proposes a hybrid decision-making trial and evaluation laboratory (DEMATEL) - graph model for conflict resolution (GMCR) method for multiple DMs to analyze complicated conflicts. The DEMATEL method is used to identify critical strategies based on their interrelationship and then analyze the multiple DMs' stability behavior using an extended matrix-based algorithm within the GMCR model. An algorithm for the proposed hybrid method is put forward and applied to resolve the case of the energy-resource production dispute in Ghana to demonstrate its procedure. The analysis objectively simplifies a complicated conflict and provides strategic insights for policymakers on the stability behavior of multiple DMs that promote sustainable energy resource production.

Keywords: Hybrid DEMATEL-GMCR, matrix representations, strategic conflicts, strategy interrelationship, behavioral analysis, sustainable resource production

1. Introduction

The production of fossil energy resources is central to economic development for developing economies with abundant natural resources, despite the interrelated socio-ecological disruptions (Xu et al. 2020). Owing to its value, energy resource conflicts are common in oil-producing countries due to stakeholder competition (Brunnschweiler et al. 2021, Yang et al. 2022). The sustainable management of these natural resources is challenging as their discovery often becomes a resource "curse" and renders communities conflict-prone. Conflicts over oil and gas resources are mostly complex, involving multiple decision makers (DMs) with extensive interrelated factors.

Ghana recently joined the African oil-producing countries and is already experiencing disputes between the central government, fishing communities (fisherfolks), and oil companies due to competition over coastal resources in the Western Region enclave. As a developing economy, the energy-resource production dispute is a tradeoff between financial gains and socio-ecological sustainability among multiple decision-makers. Strategic negotiations to effectively analyze the behavior of the DMs and resolve the conflict are important for social security and the long-term sustainable production of energy resources. In conflict resolutions based on negotiations, each DM controls a strategy or set of strategies that may or may not be selected. A conflict strategy is defined as a cause of action controlled by a single DM that may or may not be selected based on the value system. Strategic negotiation is therefore defined as a decision-making process of engagement between two- or multi-party decision-makers over conflicting interests or strategies to either gain self or mutual interest or agree or disagree (Elard 2020).

Some earlier proposed distinct methodologies to formally analyze strategic conflicts and negotiations are game theory (Neumann et al. 1944), metagame analysis (Howard 1971), and conflict analysis (Fraser and Hipel 1984). The conflict analysis method was further improved to constitute the graph model for conflict resolution (GMCR) (Kilgour et al. 1987). The GMCR method is robust and straightforward in predicting results. Compared with other decision-making theories, the GMCR method only requires relative preference information to characterize the decision-maker's behavior over feasible states and predict the outcome (Walker and Hipel 2017). In GMCR, a feasible state may be defined as a possible combination of strategies or options selected by all DMs that could practically occur in the real world. This method is, therefore, convenient in analyzing the stability behaviors of DMs for Ghana's recent energy production conflict with limited information.

The traditional GMCR process has been further enhanced to exploit emerging societal problems. Bashar et al. (2014) proposed an uncertainty-based option prioritization within the GMCR framework. Xu et al. (2009) developed a matrix representation of the solution concepts of GMCR, which allowed for easy coding into a decision support system (DSS). Some multi-criteria decision-making (MCDM) models have been utilized within the GMCR framework in analyzing strategic conflicts (Ke et al. 2012, Silva et al. 2019, Dowlatabadi et al. 2020). However, most of these combinations are motivated by improving DMs' preference ranking. The graph model is limitless in its application, for instance, in areas such as energy, climate change, politics, industry, and military science (He et al. 2020, Garcia et al. 2016). Although the GMCR is improved and applied to resolve diverse societal problems, there exists the following research gaps:

1) The existing GMCR method cannot explicitly deal with the real-life interrelationships between DM options/strategies.

2) Existing research mainly focuses on combining the multicriteria method and the GMCR to improve the preference ranking of DMs over a set of feasible states, and very little attention has been committed to multiple DMs with extensive interrelated options or strategies.

3) Besides, if k is the number of interrelated strategies, there are 2^k states. We connote that DMs' choices over extensively identified interrelated strategies yield many feasible states, complicating the stability calculations and analysis. It is crucial to reduce these strategies and avoid omitting critical factors.

4) Furthermore, the graph model has not been formally applied to resolve and analyze the stability behaviors of the multiple DMs in

Ghana's energy production conflict.

Ghana's energy-resource production dispute is unique, with the host communities (fishing communities) having extensive interrelated strategies due to the sustainable impact, and single methods may fail to analyze comprehensively. An integrated approach is favored to produce a reliable outcome by considering a broader spectrum of conflicting objectives. However, the existing research gaps and the unique problems in Ghana have led to the following problems that need to be resolved.

1) How can the many interrelated strategies be reduced empirically, necessary for GMCR computations?

2) How can the stability behaviors of the multiple DMs be analyzed by considering diverse competing interrelated factors?

Addressing the above-mentioned research gaps primarily motivated the proposal of an integrated negotiation framework to solve a complicated conflict in this paper. Ergo, a hybrid decision-making trial and evaluation laboratory (DEMATEL) - graph model for conflict resolution (GMCR) method for multiple DMs, is proposed. The Analytic Hierarchy Process (AHP) and Interpretive Structural Modeling (ISM) are famous evaluation models. However, they are ineffective in assessing the interrelated factors (Lin et al. 2009, Xu et al. 2020). The DEMATEL method introduced by the Geneva Research Centre of the Battelle Memorial Institute in 1971 is robust for interrelated system analysis of factors (Zhao et al. 2021). One of the main contributions of this method was to establish the causal relationship among factors in a system (Addae et al. 2019). Those found in the cause group tend to dispatch effect to the other factors (effect group) in the system. The cause group factors, therefore, are considered critical by policymakers. Therefore, the DEMATEL is integrated within the GMCR framework to reduce the extensive interrelated strategies for the fishing communities. The strategies found in the cause group are therefore considered critical strategies in this paper. Different from previous literature, this paper introduces strategy interrelationships and extended matrix-based stability behavior analysis for multiple DMs within the GMCR framework. In summary, the hybrid DEMATEL-GMCR model designed in this paper is novel in the following ways:

1) Identify the extensive interrelated strategies for the DMs based on sustainable impacts.

2) Select the critical strategies of the conflict to replace the extensive interrelated strategies using the DEMATEL method, which is used in the GMCR modeling.

3) Extend the stability definitions within the GMCR using a matrix algorithm and create a stability function to explain the behavior of multiple DMs.

4) Construct an algorithm for the proposed hybrid method and apply it to the case study of an energy-resource production dispute in Ghana to demonstrate its procedure in calculating the equilibria for solving the conflict.

The remaining part of the paper is put in the following order: Section 2, the literature review is presented. Section 3, constructing proposed hybrid methodology. The analysis of the energy-resource production conflict using the proposed DEMATEL-GMCR model is presented in Section 4. Then, the discussion and conclusion of the results are presented in Sections 5 and 6, respectively.

2. Literature Review

2.1 Energy Resource Production Conflict and Sustainable Development Nexus

Sustainable resource production and management can elevate a country's economic status, transform natural resources into financial assets, and solve developmental challenges (Wang et al. 2020). However, its overexploitation and mismanagement can exacerbate economic inequalities and cause conflicts by parties who seek to control power owing to its value (Addae et al. 2019). The production of energy resources is central to human development, and conflicts over these resources within a country and even across territorial borders are more likely to be intense as countries seek control and management to meet the demands of their citizens (Herdiansyah et al. 2014). Conflicts over energy resources can be argued from the "paradox of plenty" or "resource curse" (Dauvin and Guerreiro 2017), as they can be a blessing or a curse. Hence, the resolution and management of conflicts are crucial in sustainable energy resource production and development. The management of energy resources is complex due to the interrelationship with socioecological systems, and the decision-making process is critical in diverse ways because it ascertains the path toward or away from sustainable development (Bolis et al. 2017).

The impact relationship between energy, economy, and the environment has generated scholarly attention. Several research have attempted to investigate how one of these major themes affects the other. For instance, many scholars have tried to analyze the direct relationship between economic development and renewable and non-renewable energy consumption (Muoneke et al. 2023). Also, some literature has focused on the linkage between energy resources and environmental challenges and the linkage between natural resources and sustainable development (Zhang et al. 2023). Fewer literature has focused on the nexus between conflicts and sustainable energy resource production. Hence, this section seeks to contribute to the literature on the links between conflicts and sustainable energy resource production. Energy resources often have direct and indirect impacts on conflicts and vice-versa, especially in natural resource-endowed countries, as they are mostly weaponized to gain an advantage in conflicts (Chen et al. 2023).

Energy resource production conflicts impact the economy and environment (see Figure 1), and with nations heavily dependent on energy, it is mostly weaponized to gain a strategic advantage in conflicts (Shen and Hong 2023). The control of such wealth means sustaining conflicts for a longer period. Chen et al. (2023) evaluated the impact of energy sanctions on global energy trade and macroeconomic activities caused by the Russia-Ukraine war. The interrelationships among energy conflicts, the economy, and the environment make decision-making complex. Hence, the United Nations Development Program (UNDP) favors sustainable development being inclusive by involving everyone to participate in decision-making to achieve collective results (Hedelin et al. 2017).

A consequence of energy resource conflicts requires negotiation strategies that are inclusive and address the interrelated impacts on the social, economic, and environmental aspects of sustainable development.

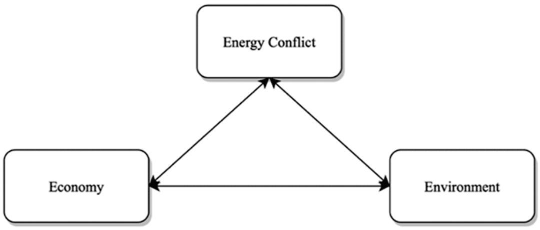


Figure 1 Energy Conflict Impact Interrelationship with the Economy and Environment

2.2 Decision-makers Interrelated Strategies in Energy Resource Conflicts

Strategies play a crucial role in the strategic decision-making process in achieving the social, environmental, and economic objectives of sustainable development (Bartkus et al. 2022). The rise in environmental challenges, such as climate change, has presented strategy dilemmas for scholars and stakeholders but has also unified global leaders to formulate strategies for the sustainable development of natural resources (Guan et al. 2023). Strategic conflicts arise due to a lack of coordinating preferences of multiple DMs over conflicting strategies for sustainable energy resource production and management (Ohmura and Creutzburg 2021). These strategies may be interrelated as energy resource conflicts are comprised of socioecological interrelationships and synergies over tradeoffs (Ohmura and Creutzburg 2021). For instance, Ghana's energy resource production conflict in the Western Region is characterized by diverse conflicting interrelated strategies for multiple DMs due to a tradeoff between socio-ecological challenges and economic gains (Addae et al. 2021). To achieve a collective resolution, aligning the preferences of the DMs over the conflicted strategies is important in the negotiation. Decision-makers use these strategies to gain a competitive advantage in the conflict. Similar to the game of chess, a DM strategy reflects his foresight towards the conflict. A strategy for a DM may be comprised of several factors that translate into an action or set of actions. Therefore, conflicts can be viewed as multicriteria or multi-attribute problems that require a multi-approach analysis (Vargas et al. 2021). DM strategies in conflict cannot be assumed to be simple as, in reality, these strategies may be too many and interrelated. In conflicts, finding the strategies of the multiple DMs is important in the negotiation process as it may impact the resolution outcome. However, finding the key strategies for multiple DMs can be a daunting task, given extensive strategies with interrelationships (Young et al. 2016). There may exist the risk of omitting critical strategies in identifying DM strategies subjectively. A negotiation model to quantitatively identify key strategies is important in simplifying complex conflicts and analyzing them more objectively. A hybrid approach that identifies key strategies based on the interrelation and analyzes the stability behaviors of the multiple DMs may provide a robust negotiation approach.

2.3 Energy Production Conflict Case Study in the Western Region of Ghana

The energy resource production conflict in Ghana recently followed the country's discov-

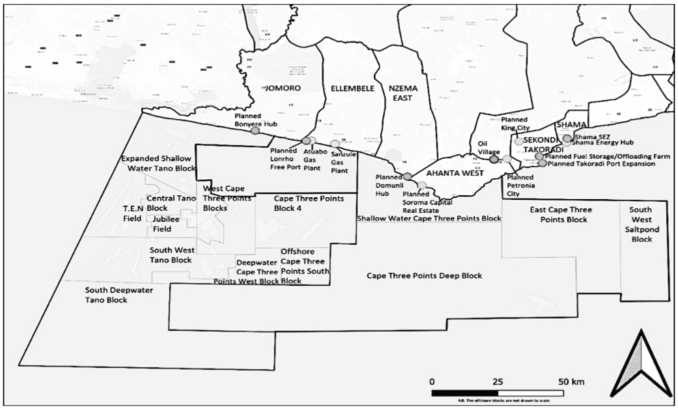


Figure 2 Map Showing Oil Fields along the Coast of the Western Region of Ghana

Source: https://www.sciencedirect.com/science/article/pii/S0016718520301275

ery and commercialization of oil and gas resources in its Western Region (Ellembelle, Jomoro, and Sekondi-Takoradi) to bolster economic development, Figure 2. The conflict is predominantly seen between the Central Government (CG)-DM1, the Fishing Communities or "*fisherfolks*" (FC)-DM2, and the Oil Companies (OCs)-DM3. The country's hopes for an economic boost in the short term were high, especially for the communities within the Western Region enclave. What preceded these heightened expectations were a high employment rate, poverty alleviation, increased educational infrastructure, good roads, hospitals, electricity availability, and affordable living conditions for the citizens. That isn't the case, as the country still faces an infrastructure deficit. Since the commercialization, several conflicting issues have been raised, such as environmental pollution and poverty. As earlier indicated, a tradeoff between financial gains and socio-ecological sustainability has been the major cause of dispute among the multiple DMs.

The affected coastal communities in this area, predominantly the fishing communities (*fisherfolks*), have been impacted mainly with farmlands being lost, fish farming activities reduced, and people displayed to give way for the oil and gas resource development project. The issue of environmental pollution has led to the death of some aquatic species being washed to the shores. Even though that is the case, the government reaps the economic benefits of the oil resources for national growth. The case of energy-resource conflict is very sensitive, learning from its devastating outcome in countries that have experienced it. Several clashes and internal conflict cases have been reported between stakeholders in the oil production communities. There's the possibility of an open conflict (Hedelin et al. 2017), and much effort is needed to avoid that from happening.

Concerns have been raised by the affected community, where the petroleum resources are extracted. The discovery has impacted the people directly. Their primary occupation, farming, has been affected since the extraction. Farmlands have been lost to developing oil infrastructure with key players such as the OCs. The people have been displaced from their current settlement due to these extractions. Activities of fish farmers have been reduced due to restricted fish farming zones. Unlike other countries where offshore activities span about 200km, Ghana's Jubilee field is closer to the shore, about 60km in the Exclusive Economic Zone (EEZ) (Addae et al. 2021). Again, the fish farmers complain of little or no fish catch when they go to sea, and they blame the intensity of lights used by offshore rigs that they claim attract the fish. These challenges have adversely affected the sustainable livelihood of the coastal communities. This has resulted in disputes and, in some cases, minor clashes between them, the government, and some OCs. There are claims by the communities of no direct benefit from the oil revenues. Yet, they have to sacrifice generational inheritance to pave the way for the development of oil-related projects. The existential power imbalance between major decision-makers has led to disproportionate sustainable gains. This has led to one party feeling "cheated" and "robbed" of generational inheritance. Sustainable factors are fueling the conflict that should be analyzed. The discovery of oil means adding extra revenue, which could be used to tackle some developmental deficits. However, that isn't the case now, and stakeholders should cooperate to avoid an open energy-resource conflict.

2.4 Decision-makers

DM1, DM2 and DM3 were identified as major players in this dispute. The government with sovereign power controls, extracts, and distributes revenues from oil rents towards national development. The government gives the production and development rights of these energy resources to the OCs, while it plays a supervisory and management role through state institutions and companies. The OCs, attitude in this conflict is profit-making.

The fishing communities seek to benefit directly from the oil rent or assume their everyday life by utilizing coastal resources. Their reasons are simple: the oil was found on their land or jurisdiction. Also, it has adversely impacted their sustainable livelihood and widened economic inequalities. There are no alternative jobs besides farming and other small fish-related businesses to support their living expenses. Disagreements are reported when the coastal communities realize the government uses sovereign powers in decisions that don't benefit them. These communities where the energy resources are discovered see themselves as "custodians" and expect direct benefits from the resources if not allowed to compete fairly for coastal resources. When this isn't the case, disputes are reported.

The trajectory now is that there's been no significant improvement in the people's lives in the area since the oil discovery. Petroleum-related activities have affected the sustainability of coastal communities (*fisherfolks*). Preliminary analysis towards resolving this conflict revealed that the coastal communities (DM2) have extensive interrelated conflict strategies compared with the government (DM1) and the OCs (DM3). This is due to the unequal power between major DMs, the disproportionate benefit of petroleum revenue, and asymmetric sustainable impact. Hence, the affected communities feel cheated and largely affected. Yet more, these coastal communities will be more vulnerable to an open conflict than other major DMs. Analyzing the conflict from the sustainable impact standpoint comprehensively addresses the social, economic, and environmental concerns that may represent the concerns of environmental groups. Therefore, DM1, DM2, and DM3 are focused on in this research.

3. Constructing Hybrid DEMATEL-GMCR Model

This section introduces the proposed hybrid methodology with the model framework in Figure 4. However, the basic concepts of the DEMATEL and GMCR are first explained.

3.1 DEMATEL Model

The various steps in the traditional DEMATEL calculations are bellowed:

Step 1: Construct a direct relation matrix by measuring the relationship between the factors.

Experts with the required knowledge and experience of the context should be chosen to assess the impact of each factor pair. The direct relation matrix $D = [d_{xy}]_{m\times m}$ is generated, where is the number of factors. The D is an $m \times m$ non-negative matrix. The direct impact of the factor x on factor y can be represented by d_{xy}. However, when $x = y$, diagonal elements take zeros as their value, which indicates $d_{xy} = 0$ is no effect (Bartkus et al. 2022). For example, assume that the initial direct relation matrix by an expert is as follows.

$$D = \begin{bmatrix} 0 & 1 & 2 \\ 4 & 0 & 3 \\ 1 & 2 & 0 \end{bmatrix}$$

Step 2: The direct relation matrix can be normalized.

The normalized direct relation matrix $B = [b_{xy}]_{m\times m}$ can be obtained using the following Formula:

$$B = [b_{xy}]_{m\times m} \tag{1}$$

$$b_{xy} = \frac{d_{xy}}{\max\limits_{1\le x\le m} \sum_{y=1}^{m} d_{xy}} \tag{2}$$

Following Step 1, the direct relation matrix can be normalized using Formula (2):

$$B = \begin{bmatrix} 0 & 0.1 & 0.3 \\ 0.6 & 0 & 0.4 \\ 0.1 & 0.3 & 0 \end{bmatrix}$$

Step 3: The total relation matrix is calculated.

After the normalized direct relation matrix B is achieved, it is possible to compute the total relation matrix $T = [t_{xy}]_{m\times m}$ using Formula (3), by summing the direct effects and all of the indirect effects among factors. The normalized direct relation matrix B continues multiplying to add the indirect influence B^h between all factors. The original DEMATEL assumes that B^h would converge to a zero matrix as given in Formula (3). Lee et al. (2013) proposed a revised DEMATEL to resolve the case where $\lim\limits_{h\to\infty} B^h = [0]_{m\times m}$ is non-inevitable.

$$T = \lim_{h\to\infty} \left(B + B^2 + \cdots + B^h\right) = (I - B)^{-1} \tag{3}$$

in which the I represents the identity matrix, and the element t_{xy} indicates the direct and indirect effects between the factors. Following Step 2, the total relation matrix can be computed using Formula (3):

$$T = \begin{bmatrix} 0.254 & 0.321 & 0.496 \\ 0.904 & 0.371 & 0.846 \\ 0.438 & 0.438 & 0.313 \end{bmatrix}$$

Step 4: The results of DEMATEL are acquired.

The sum of the matrix rows and columns are designated through Formulas (4) and (5), respectively,

$$e_x = \sum_{y=1}^{m} t_{xy}, y = 1, 2, \cdots, n \quad (4)$$

$$z_y = \sum_{x=1}^{m} t_{xy}, x = 1, 2, \cdots, n \quad (5)$$

where e_x refers to any direct influence provided to all other factors by factor x , and z_y indicates the degree of influenced or indirect impact. Let $x = y$, then $e_x + z_x$ reflects the degree of relative significance that the factor x has in the total system, called "prominence." The "prominence" means the relative importance of each factor. The $e_x - z_x$ shows the net effect has on the system, named "relation." The "relation" shows the dependence relation of each factor. If the value of $e_x - z_x$ is positive, the factor x can be clustered under the cause factors; otherwise, it is classified as an effect factor (Addae et al. 2019). Following Step 3, $e_{x_1} = 1.071$, $e_{x_2} = 2.121$,$e_{x_3} = 1.188$ and $z_{x_1} = 1.596$, $z_{x_2} = 1.5129$, $z_{x_3} = 1.189$,Accordingly,$e_{x_1} + zx_1 = 2.667$, $e_{x_2} + zx_2 = 3.25$,$e_{x_3} + zx_3 = 2.841$, and $e_{x_1} - zx_1 = -0.525$, $e_{x_2} + zx_2 = 0.992$ and $e_{x_3} + zx_3 = -0.467$.

Step 5: A relation diagram is plotted in terms of the value of cause-and-effect factors.

The $e_x + z_x$ and $e_x - z_x$ diagram is plotted to visualize the complex interrelation of factors.

3.2 Graph Model for Conflict Resolution

When using the graph model framework to solve actual conflict problems, it is first necessary to analyze the background of the conflict event and extract the decision-makers and their options for the conflict problem. Secondly, select at least one option, considering that decision-maker options cannot be selected simultaneously (Yu et al. 2015). Analyze through logical rules to eliminate infeasible states to determine all feasible states of the decision-maker. A state transition diagram can then be constructed. Then, a corresponding preference rank is generated based on the preference information by the decision-maker. Next, stable solutions for the decision-makers are determined under specific stability definitions, and the equilibrium solution is the state stable under all the stability definitions. Finally, conflict resolution is analyzed to provide decision-makers with valuable strategic policies for negotiations and decisions.

3.2.1 Basic Theory of the GMCR

The method can be summed up under the following components.

(A)The main components of the GMCR

The graph model in a conflict is usually written as $V = \{N, S, P, G\}$, in which four key elements are contained (Xu et al. 2009):

1) $N = \{1, 2, \cdots, i, \cdots, n\}$ is a finite nonempty set of all decision-makers (DMs) participating in a conflict where i indicates the i -th DM i and n represents the total number of DMs;

2) S is a finite non-empty set of all feasible states;

3) P reflects the preference information of DMs;

4) $G = (S, A)$ is a direct graph with S as a vertex set and A as an oriented arc set.

In a graph model, the preference of DM i over the set of states S can be expressed by a pair of relations $\{\succ_i, \sim_i\}$. The preference relations of DM i is assumed to have the following

Table 1 The GMCR General Preference States

Preference expression	Description
$\Phi_i^+(s) = \{q : q \succ_i s\}$	Denotes the set of states more preferred to the initial state s by DM i.
$\Phi_i^=(s) = \{q : q \sim_i s\}$	Denotes the set of states equally preferred to the initial state s by DM i.
$\Phi_i^-(s) = \{q : s \succ_i q\}$	Denotes the set of states less preferred to the initial state s by DM i.

Table 2 The GMCR Reachable Preference Lists

Reachable preference lists	Description
$R_i^+(s) = R_i(s) \cap \Phi_i^+(s)$	Indicates the reachable lists of DM i from the initial state s by a unilateral improvement (UI);
$R_i^=(s) = R_i(s) \cap \Phi_i^=(s)$	Represents the reachable lists of DM i from the initial state s by an equally preferred move;
$R_i^-(s) = R_i(s) \cap \Phi_i^-(s)$	Specifies the reachable lists of DM i from the initial state s by a less preferred move.

properties:

1) $\succ_i$ is asymmetric;

2) $\{\sim_i\}$ is reflexive and symmetric;

3) $\{\succ_i, \sim_i\}$ is strongly complete.

(B)Reachable list of DM i

Definition 1 (Preference relation) *Let DM $i \in N$ and state s , $q \in s$. According to the preference relations, the state set S can be divided into the following three subsets as shown in Table 1 (Xu et al. 2009).*

To facilitate the calculation of stability, the set of states less or equally preferred to the initial state s by DM i is denoted as following

$$\Phi_i^{-,=}(s) = \left\{q : s \succeq_i q\right\} = \Phi_i^-(s) \cup \Phi_i^=(s) \quad (6)$$

where "∪" is the union operation.

Definition 2 (Reachable list) *Let $i \in N$ DM , states s , $q \in S$ and A_i be the arc set of DM i . The reachable list that DM i can unilaterally move one step from the initial state s , which is called a unilateral move (UM), can be denoted as*

$$R_i(s) = \{q \in S{:}(s, q) \in A_i\} \quad (7)$$

The reachable preference lists of DM i from the initial state s in terms of the above sets can be expressed as shown in Table 2, where "∩" denotes the intersection operation.

3.2.2 Logical Representations of Stabilities for Multiple Decision Makers $(n - DM)$

In a multiple DMs conflict of $n - DM$, where $n \geq 2$, a fixed $DMi \in N$, may take into account all possible responses by all other DMs $j \in N\backslash\{i\}$ in a coalition say H. H is a nonempty subset of DMs, $H \subseteq N$ and $H \neq \varnothing$. Most importantly, a coalition is the set of opponents of a fixed DMi , namely $N\backslash\{i\}$, where \ refers to "set subtraction". Hence, the coalition of the opponent DMs may be expressed as $H = N\backslash\{i\}$. To calculate the stability of a state for $DMi \in N$, it is necessary to analyze the unilateral moves (UM) and unilateral improvements (UI) of H , that is $R_H(s)$ and $R_H^+(s)$ respectively. For a legal UMs for members of H , a DM may move more than once, but not twice consecutively. The UMs and UI are formally defined as follows:

If $s_1 \in R_H(s)$, let $\Omega_H(s, s_1)$ denote the set of

Table 3 Summary of the GMCR Logical Stabilities for Multiple DMs

Stabilities	Logical definitions
Nash	State s is Nash stable for DM i iff $R_i^+(s) = \varnothing$, denoted by $s \in S_i^{Nash}$.
GMR	State s is GMR stable for DM i iff for every $s_1 \in R_i^+(s)$, there exists at least one state $s_2 \in R_H(s_1)$ such that $s_2 \in \varnothing_i^{-,=}(s)$, denoted by $s \in S_i^{GMR}$.
SMR	State s is SMR stable for DM i iff for every $s_1 \in R_i^+(s)$, there exists at least one state $s_2 \in R_H(s_1)$ such that $s_2 \in \varnothing_i^{-,=}(s)$ and $s_3 \in \varnothing_i^{-,=}(s)$ for every $s_3 \in R_i(s_2)$, denoted by $s \in S_i^{SMR}$.
SEQ	State s is SEQ stable for DM i iff for every $s_1 \in R_i^+(s)$, there exists at least one state $s_2 \in R_H^+(s_1)$ such that $s_2 \in \varnothing_i^{-,=}(s)$, denoted by $s \in S_i^{SEQ}$.
SSEQ	State s is SSEQ stable for DM i iff for every $s_1 \in R_i^+(s)$, there exists at least one state $s_2 \in R_H^+(s_1)$ such that $s_2 \in \varnothing_i^{-,=}(s)$ and $s_3 \in \varnothing_i^{-,=}(s)$ for every $s_3 \in R_i(s_2)$, denoted by $s \in S_i^{SSEQ}$.

all last DMs in legal sequences from to s_1.

Definition 3 (Unilateral moves of H) *Let $s \in S, H \subseteq N$, and $H \neq \varnothing$. A unilateral move by H is a member of $R_H(s) \subseteq S$, defined inductively by*

1) assuming $\Omega_H(s, s_1) = \varnothing$ for all $s_1 \in S$;

2) if $j \in H$ and $s_1 \in R_j(s)$, then $s_1 \in R_H(s)$ and $\Omega_H(s, s_1) \cup \{j\}$;

3) if $s_1 \in R_H(s)$, $j \in H$, and $s_2 \in R_j(s_1)$, then, provided $\Omega_H(s, s_1) \neq \{j\}$, $s_2 \in R_H(s)$ and $\Omega_H(s, s_2) = \Omega_H(s, s_2) \bigcup \{j\}$.

It is important to note that this definition is inductive which begins first by using 2), the states reachable from are identified and added to $R_H(s)$; then, using 3), all states reachable from those states are identified and added to $R_H(s)$; and then the process is repeated until no further states can be added to $R_H(s)$ and there is no change in $\Omega_H(s, s_2)$ for any .

Definition 4 (Unilateral improvements of H) *Let , $s \in S$, $H \subseteq N$,and $H \neq \emptyset$. A unilateral improvement by H is a member of $R_H^+(s) \subseteq S$, defined inductively by*

1) assuming $\Omega_H^+(s, s_1)$ for all $s_1 \in S$;

2) if $j \in H$ and $s_1 \in R_j^+(s)$, then $s_1 \in R_H^+(s)$ and $\Omega_H^+(s, s_1) \bigcup \{j\}$;

3) if $s_1 \in R_H^+(s)$,$j \in H$, and $s_2 \in R_j^+(s_1)$, then, provided $\Omega_H^+(s, s_1) \neq \{j\}$,$s_2 \in R_H^+(s)$ and $\Omega_H^+(s, s_2) = \Omega_H^+(s, s_2) \bigcup \{j\}$.

Definition 4 is similar to Definition 3, except that all moves are required to be UIs, each move is to a state strictly preferred by the mover to the current state.

Definition 5 (Logical representations of stabilities) *Let $i \in N$ and $s \in S$, the stability definition of i , will take into account $H = N \backslash \{i\}$. The five stability definitions of Nash, GMR, SMR, SEQ and SSEQ for $n - DM$, where $n > 2$ is summarized in Table 3.*

The Nash general stability implies that if DM i has no opportunity to move unilaterally to a more preferred state from the initial state s, DM i will choose to keep the status quo, then state is NASH stable for DM i.

GMR stability takes account of the reaction of DM $i's$ opponent DM H , who may move to any reachable states to block DM $i's$ UIs regardless of the preference. Considering that DM i thinks about its moves and the opponent's possible actions, it has a two-move distance horizon in GMR stability. DM i would not move from the current state to a more preferred state s_1 if the opponent DM H chooses to move from state s_1 to state s_2, which is less preferred for DM i, even though s_2 may be worse. This makes state s is GMR stable for DM i.

Compared with SMR stability, DM i considers the counter-response based on GMR, which leads to the DM in SMR stability having a three-move distance horizon. If DM i cannot avoid his opponent's sanction by moving from state s_2 to s_3, which is also less preferred to the initial state s, he will keep it as it is, then state meets the requirements of SMR stability.

In contrast to GMR stability, SEQ stability also has a two-move distance horizon. However, the opponent DM H is rational about moving from state s_1 to s_2 to counterattack DM i only when it benefits himself.

Compared with SEQ stability, DM i in SSEQ stability still has the opportunity to retaliate against the opponent's counterattack. If DM i cannot avoid his opponent's sanction by moving from state s_2 to s_3, which is also less preferred to the initial state s, he will keep it as it is, then state s meets the requirements of SSEQ stability.

3.2.3 Matrix Representations of Stabilities for Multiple Decision Makers

The main objective of stability analysis is to identify the states of the graph model that are stable for all multiple DMs, $n - DM$, where $n \geqslant 2$, under appropriate stability definitions, or equilibria. As indicated in A), the reachability lists of a coalition H, i.e., the legal UMs, $R_H(s)$ and UI, $R_H^+(s)$ are essential inputs for stability analysis, however, the computation of these two sets are complicated. Hence, the reachability matrices M_H and M_H^+ are proposed (Xu et al. 2009), to provide an algebraic representation for $R_H(s)$ and $R_H(s)^+$, respectively. The UM reachability matrix and UI reachability matrix for H is formally defined bellow.

Definition 6 (Joint Movement and Joint Improvement Matrices) *For the graph model, the UM reachability matrix and UI reachability matrix for H are the $m \times m$ matrices M_H and M_H^+ with (s, q) entries*

$$M_H(s,q) = \begin{cases} 1, & q \in R_H(S) \\ 0, & otherwise \end{cases} \tag{8}$$

and

$$M_H^+(s,q) = \begin{cases} 1, & q \in R_H^+(S) \\ 0, & otherwise \end{cases} \tag{9}$$

respectively.

From the above, it can be deduced that, $R_H(s) = \{q : M_H(s,q) = 1\}$ and $R_H^+(s) = \{q : M_H^+(s,q) = 1\}$.

Definition 7 (Sign Function) *Given an $m \times m$ matrix M . Define the $sign(M)$ matrix with (s, q) entries as*

$$sign[M(s,q)] = \begin{cases} 1, M(s,q) > 0 \\ 0, M(s,q) = 0 \\ -1, M(s,q) < 0 \end{cases} \tag{10}$$

Let $i \in N$ and $s \in S$, the stability definition of DM i, will take into account $H = N \backslash \{i\}$. The five stability matrix definitions of Nash, GMR, SMR, SEQ and SSEQ for $n-DM$, where $n \geqslant 2$ is given below. In the next definitions for stabilities, recall that m is the number of feasible states and n denotes the number of DMs. Let E be an $m \times m$ matrix and e denote an m-dimensional column vector in both of which each entry is 1. Let e_s be an m-dimensional column vector where the s^{th} entry is 1 and all other entries are 0. Given two $m \times m$ matrices M and T, then define the Hadamard product $Q = M \circ T$ as the $m \times m$ matrix with (s, q) entry $Q(s, q) = M(s, q) \cdot T(s, q)$.

Definition 8 (Matrix Definition for Nash Stability) *Let $i \in N$ and $s \in S$, the matrix M_i^{Nash} and function $f_i^{\text{Nash}}(s)$ are defined bellow.*

$$M_i^{\text{Nash}} = J_i^+ \cdot E \tag{11}$$

The diagonal elements of matrix M_i^{Nash} are

$$M_i^{\text{Nash}}(s,s) = e_s^T \cdot J_i^+ \cdot e \tag{12}$$

State $s \in S$ is Nash stable for DM i, iff $f_i^{\text{Nash}}(s) = M_i^{\text{Nash}}(s,s) = 0$.

Definition 9 (Matrix Definition for GMR Stability) *Let $i \in N$ and $s \in S$, the matrix M_i^{GMR} and function $f_i^{GMR}(s)$ are defined bellow.*

$$M_i^{GMR} = J_i^+ \cdot \left[E - sign\left(M_H \cdot \left(P_i^{-,=}\right)^T\right)\right] \tag{13}$$

The diagonal elements of matrix M_i^{GMR} are

$$M_i^{GMR}(s,s) = \sum_{p=s_1}^{s_m} J_i^+(s,p) \cdot \left[1 - sign\left(M_H(p,q) \cdot \left(P_i^{-,=}(s,q)\right)\right)\right], \forall p \in S \tag{14}$$

State $s \in S$ is GMR stable for DM i, iff $f_i^{GMR}(s) = M_i^{GMR}(s,s) = 0$.

Definition 10 (Matrix Definition for SMR Stability) *et $i \in N$ and $s \in S$, the matrix M_i^{SMR} and function $f_i^{SMR}(s)$ are defined bellow.*

$$M_i^{SMR} = J_i^+ \cdot [E - sign\,(M_H \cdot Q)] \tag{15}$$
$$Q = (P_i^{-,=})^T \circ [E - sign(J_i \cdot (P_i^+)^T)]$$

The diagonal elements of matrix M_i^{SMR} are

$$M_i^{SMR}(s,s) = \sum_{p=s_1}^{s_m} J_i^+(s,p) \left[1 - sign\left(\sum_{p=s_1}^{s_m} M_H(p,q) \cdot Q\right)\right], \forall p \in S \tag{16}$$

$$Q = P_i^{-,=}(s,q) \circ \left[1 - sign\left(\sum_{k=s_1}^{s_m} J_i(q,k) \cdot P_i^+(s,k)\right)\right]$$

State $s \in S$ is SMR stable for DM i, iff $f_i^{SMR}(s) = M_i^{SMR}(s,s) = 0$.

Definition 11 (Matrix Definition for SEQ Stability) *Let $i \in N$ and $s \in S$, the matrix M_i^{SEQ} and function $f_i^{SEQ}(s)$ are defined bellow.*

$$M_i^{SEQ} = J_i^+ \cdot \left[E - sign\left(M_H^+ \cdot \left(P_i^{-,=}\right)^T\right)\right] \tag{17}$$

The diagonal elements of matrix M_i^{SEQ} are

$$M_i^{SEQ}(s,s) = \sum_{p=s_1}^{s_m} J_i^+(s,p) \cdot \left[1 - sign\left(M_H^+(p,q) \cdot \left(P_i^{-,=}(s,q)\right)\right)\right], \forall p \in S \tag{18}$$

State $s \in S$ is SEQ stable for DM i, iff $f_i^{SEQ}(s) = M_i^{SEQ}(s,s) = 0$.

Definition 12 (Matrix Definition for SSEQ Stability) *let $i \in N$ and $s \in S$, the matrix M_i^{SSEQ} and function $f_i^{SSEQ}(s)$ are defined bellow (Rêgo and Vieira 2017).*

$$M_i^{SSEQ} = J_i^+ \cdot [E - sign(M_H^+ \cdot Q)] \tag{19}$$
$$Q = \left(P_i^{-,=}\right)^T \circ \left[E - sign\left(J_i \cdot (P_i^+)^T\right)\right]$$

The diagonal elements of matrix M_i^{SSEQ} are

$$M_i^{SSEQ}(s,s) = \sum_{p=s_1}^{s_m} J_i^{+}(s,p) \cdot \left[1 - \mathrm{sign}\left(\sum_{p=s_1}^{s_m} M_H^{+}(p,q) \cdot Q\right)\right], \forall p \in S \quad (20)$$

$$Q = P_i^{-,=}(s,q) \circ \left[1 - sign\left(\sum_{k=s_1}^{s_m} J_i(q,k) \cdot P_i^{+}(s,k)\right)\right]$$

State $s \in S$ is SSEQ stable for DM i, iff $f_i^{SSEQ}(s) = M_i^{SSEQ}(s,s) = 0$.

Wang et al. (2017) conducted a preliminary exploration of the behavior problem of the stability concept based on the matrix expressions of Nash, GMR, SMR, and SEQ stability. By constructing a stability behavior analysis function, they distinguished different behavior patterns of DMs from the definition level. The SSEQ stability function is included herein to reflect different behavioral patterns.

Definition 13 (Formula for Behavioral Analysis) *In a graph model with n-DMs, let $i \in N$ and $s \in S$,$F_i^*(s)$, a linear function containing $f_i^{\text{Nash}}(s)$,$f_i^{GMR}(s)$, $f_i^{SMR}(s)$, $f_i^{SEQ}(s)$ and $f_i^{SSEQ}(s)$, is defined in the following formula to determine what types of behavior over the state can satisfy the output based on the input.*

$$\begin{aligned} F_i^*(s) =& sign(f_i^{\text{Nash}}(s)) + sign(f_i^{GMR}(s)) \\ &+ sign(f_i^{SMR}(s)) + 2sign(f_i^{SEQ}(s)) \\ &+ sign(f_i^{SSEQ}(s)) \end{aligned} \quad (21)$$

Theorem 1 (Theorem for Behavioral Analysis) *In a graph model with $n - DM$, let $i \in N$ and $s \in S$, $F_i^*(s)$ is the function which determines the types of behavior over the stable state with known preferences. Then,*

1) If $F_i^*(s) = 0$, the type of behavior for DM i over the stable state s must be Nash behavior, GMR behavior, SMR behavior SEQ behavior, and SSEQ behavior.

2) If $F_i^*(s) = 1$, the type of behavior for DM i over the stable state s must be SSEQ behavior, GMR behavior, SMR behavior, and SEQ behavior.

3) If $F_i^*(s) = 2$, the type of behavior for DM i over the stable state s must be GMR behavior, SMR behavior, and SEQ behavior.

4) If $F_i^*(s) = 3$, the type of behavior for DM i over the stable state s must be GMR behavior and SEQ behavior.

5) If $F_i^*(s) = 4$, the type of behavior for DM i over the stable state s must be GMR behavior and SMR behavior.

6) If $F_i^*(s) = 5$, the type of behavior for DM i over the stable state s must be GMR behavior.

7) If $F_i^*(s) = 6$, the state must be unstable for DM i.

In accordance with the definitions above, the values of $F_i^{\text{Nash}}(s)$, $F_i^{GMR}(s)$,$F_i^{SMR}(s)$,$F_i^{SEQ}(s)$ and $F_i^{SSEQ}(s)$ must be non-negatives integers. Based on Definition 13, it is obvious that $F_i^*(s) = \{0,1,2,3,4,5,6\}$. Based on the inclusion relationship between various stabilities, Han introduced the characteristics of different bounded rationality behaviors of decision-makers that can be reflected by different function values. Figure 3 shows the stable solution regions corresponding to each of the seven stable behaviors. Taking SEQ stability as an example, SEQ consists of four parts: whole Nash stable part ($F_i(s) = 0$ region), whole SSEQ stable part ($F_i(s) = 1$ region), the part where SMR stable part and SEQ stable part intersect ($F_i(s) = 2$ region), and the independent SEQ stable part ($F_i(s) = 3$ region). Then we describe the stability behavior characteristics of each independent non-intersecting part mentioned above.

1) When $F_i^*(s) = 0$, then $f_i^{\text{Nash}}(s) = f_i^{GMR}(s) = f_i^{SMR}(s) = f_i^{SEQ}(s) = f_i^{SSEQ}(s) = 0$;

2) When $F_i^*(s) = 1$, it means only Nash behavior is not stable for DM i for the state s . So, the type of behavior for DM i must be GMR, SMR, SEQ, and SSEQ behavior.

3) When $F_i^*(s) = 2$, based on Figure 3, it is obvious that $f_i^{\text{Nash}}(s) = f_i^{SSEQ}(s) = 1$, and $f_i^{GMR}(s) = f_i^{SMR}(s) = f_i^{SEQ}(s) = 0$. This region is obtained by removing SSEQ stable part from the intersection of SMR and SEQ stable part. Hence, the type of behavior for DM must be GMR, SMR, and SEQ behavior.

4) When $F_i^*(s) = 3$, from 3), it is clear that $f_i^{\text{Nash}}(s) = f_i^{SSEQ}(s) = 1$, therefore, $f_i^{SMR}(s) = 1$ and $f_i^{GMR}(s) = f_i^{SEQ}(s) = 0$. This region is obtained by removing the SEQ stable part from the SMR stable part. Hence, the type of behavior for DM must be GMR and SEQ behavior.

5) When $F_i^*(s) = 4$, from 3), it is obvious that $f_i^{\text{Nash}}(s) = f_i^{SSEQ}(s) = f_i^{SEQ}(s) = 1$ and $f_i^{GMR}(s) = f_i^{SMR}(s) = 0$. This region is obtained by removing the SMR stable part from the SEQ stable part. Hence, the type of behavior for DM must be GMR and SMR behavior.

6) When $F_i^*(s) = 5$, similarly, $f_i^{\text{Nash}}(s) = f_i^{SSEQ}(s) = f_i^{SMR}(s) = f_i^{SEQ}(s) = 1$. Hence, $f_i^{GMR}(s) = 0$. This region is obtained by removing the SMR and the SEQ stable part from GMR stable part. So the type of behavior for DM i must be only GMR behavior.

7) When $F_i^*(s) = 6$, then $f_i^{\text{Nash}}(s) = f_i^{GMR}(s) = f_i^{SMR}(s) = f_i^{SEQ}(s) = f_i^{SSEQ}(s) = 1$.

In practice, the following four steps are required to implement the behavioral analysis procedure provided in this paper for a historical or ongoing conflict:

1) Analyze the background of the conflict and construct a graph model containing all DMs, feasible states, and movements;

2) Build the matrix for each DM by determining the matrices for the preferences, unilateral movements, unilateral improvements, joint movements, and joint improvements;

3) Select an equilibrium of interest or another desired state or state of interest;

4) For the chosen state, use the results in Theorem 1 to determine the type of behavior for each DM to cause the state to be stable if it is a known equilibrium or an equilibrium if it is a state of interest.

3.3 The Proposed Hybrid DEMATEL-GMCR

The proposed hybrid framework, as shown in Figure 4, is presented in this subsection. The framework follows two main stages of modeling: real-world conflict, identifying decision makers with extended strategies, reducing strategies with DEMATEL, generating conflict states, designing reduced strategy statements, generating preferences, and analysis stage: stability analysis, calculating equilibria, follow-up analysis and information for decision making. The reduced strategies are fed into the GMCRII software to calculate the equilibria, and then the extended matrix stability presented in Subsection 3.2.3 is utilized to analyze the type of stability behavior for each DM. The algorithm for implementing the framework is presented below.

Step 1: Assuming that DM i has k_i interrelated strategies which are expressed by $O_{i1}, O_{i2}, \cdots, O_{ik_i}$, then the integrated strate-

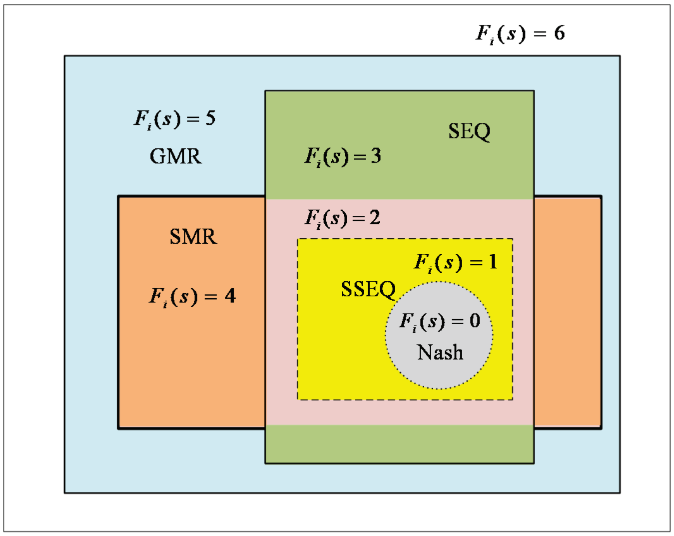


Figure 3 Different Behavioral Patterns Reflected by Five Basic Stabilities

gies can be ranked using DEMATEL, denoted by

$$O'_{i1} \succ O'_{i2} \succ \cdots \succ O'_{ik_i}$$

Select top h_i critical strategies $O_{i1}, O_{i2}, \cdots, O_{ik_i}$ which is achieved by Formula (4)-(5), shown in Figure 5, where $h_i \ll k_i$ and $\{O'_{i1}, O'_{i2}, \cdots, O'_{ih_i}\} \subset \{O'_{i1}, O'_{i2}, \cdots, O'_{ik_i}\}$.

According to the reduced strategies, feasible states are obtained after removing the infeasible, which is explained in Section 4.4.

Step 2: For each $s \in S$, every strategy statement must take a logical truth value T or F. If $\Omega(s) = T$, then state s satisfies the statement; if $\Omega(s) = F$, it does not. Let the ordered strategy statement set of DM i be $\Omega_i = \{\Omega_1^i, \Omega_2^i, \cdots, \Omega_{k_i}^i\}$, which is arranged from most preferred to least. For states $p, q \in S$,$p \succ_i q$, iff $\Omega_1^i(p) = T$ and $\Omega_1^i(q) = F$ or $0 < r < k_i$, there exists that

$$\begin{gathered}\Omega_1^i(p) = \Omega_1^i(q)\\ \Omega_2^i(p) = \Omega_2^i(q)\\ \vdots\\ \Omega_{r-1}^i(p) = \Omega_{r-1}^i(q)\\ \Omega_r^i(p) = T \text{ and } \Omega_r^i(q) = F\end{gathered}$$

States are sorted in the order of their scores from large to small by setting a "score" $\psi(s)$ for each state. For DM i, each strategy statement is given a different weight, in which that of the γ-th statement can be expressed as:

$$\Psi_r(s) = \begin{cases} 2^{k_i - r}, & \text{if } \Omega_r^i(s) = T \\ 0, & \text{otherwise} \end{cases} \tag{22}$$

For DM i, the score of state s can be given by

$$\Psi_i(s) = \sum_{r=1}^{k_i} \Psi_r(s) \tag{23}$$

Assume that the ordered reduced strategy set $O'_i = \{O'_{i1}, O'_{i2}, \cdots, O'_{ih_i}\}$ are arranged from most preferred to least. Among them, O'_{iA} and O'_{iB} represent two different strategies, where $O'_{iA}, O'_{iB} \subset O'_i$. At the same time, "$-$", "&", and " | " respectively represent non-conditional logical relations "not", "and", and "or". The conditional or double-conditional policy statement

Table 4 Truth-values for Reduced Strategy Statement Combination

O'_{iA}	O'_{iB}	$-O'_{iA}$	$O'_{iA}\&O'_{iB}$	$O'_{iA}\|O'_{iB}$	O'_{iB} IF O'_{iA}	O'_{iB} IFF O'_{iA}
T	T	F	T	T	T	T
T	F	F	F	T	F	F
F	T	T	F	T	F	F
F	F	T	F	F	T	T

consists of two non-conditional statements and the symbol "IF" or "IFF," which respectively represent "if" and "if and only if". Then, the reduced strategy statements can be designed by strategies and logical symbols (shown in Table 4).

Step 3: Generate preference based on the strategy priority method and conduct the stability analysis using the GMCR framework. Then, the equilibria are obtained, and information can be provided for making an informed strategic policy decision. The whole procedure for the hybrid DEMATEL-GMCR is given in Figure 4.

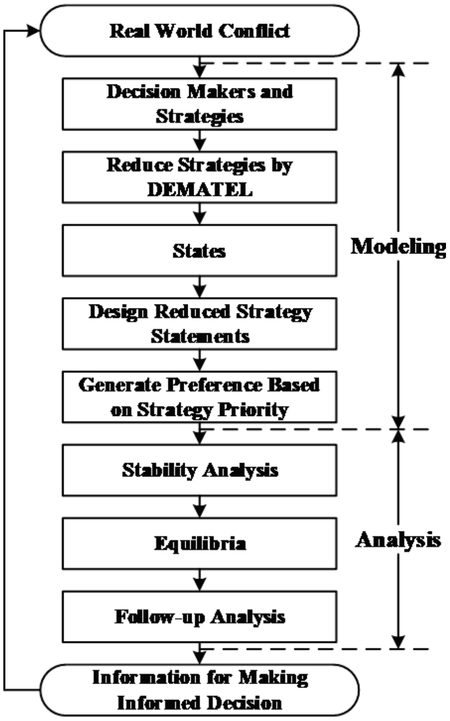


Figure 4 Framework for Hybrid DEMATEL-GMCR

4. Analyze the Energy-resource Conflict in Ghana Using the Proposed DEMATEL-GMCR Model

We try to make the proposed method application easy for a wider audience. First, we apply the DEMATEL method to reduce extensive interrelated conflict strategies, and second, the reduced strategies are used in the GMCR computation for conflict stability analysis. The strategic analysis for negotiations and decision-making is suggested based on results.

4.1 Identification of Decision-makers Strategies for Energy Resource Conflict Analysis

Secondary data were gathered from published papers to identify DM strategies. Also, some useful information about the conflict was provided by some local assembly members, Chief fishermen, and "Konkohemaa" (queen fishmongers) from the Ellembelle, Jomoro, and Sekondi-Takoradi as technical domain experts. We identified DM strategies based on energy conflict-sustainability impact factors and then constructed DM options. In this paper, we consider DM's options as strategies. Therefore, a strategy can be viewed as the action(s) a single DM can select or not select in a given conflict. For CG, two strategies were identified through technical domain experts' knowledge. These were *"modify petroleum contract to include equi-*

table shares for the coastal communities". (G_1) to ensure direct benefit from the oil and gas proceeds or to "*accept and manage the status quo of the conflict*" (G_2). OC's strategy is to "*renegotiate the modification of petroleum contract by the government*" (C_1) to exclude itself from bearing the extra cost of equitable share payment for affected communities.

The strategies for the "*fisherfolks*" were borne out of sustainable factors, barriers, or challenges influencing the energy resource conflict and the impact on the sustainable livelihood of the affected fishing communities (Addae et al. 2021). Amongst the many strategies for FC include "*taking legal action against the OCs for environmental pollution*" (L_1). Environmental pollution is of great concern with oil activities. The fishery folks have complained of oil spills on their water bodies due to oil extraction (Adjei and Overa 2019). Again, upon interaction, the coastal communities unequivocally stated their intention to stage a "*mass demonstration against the government*" (L_2) to register their displeasure. Demonstrating against the government is an essential tool in Ghana's democracy due to high election turnovers, and most often, the government tries to avoid this. This was included in the strategies of the coastal communities.

According to (San-Akca et al. 2020) and (Owusu 2018), strategies such as "*negotiate for job creation*" (L_3), "*demand for a lump-sum compensation for forced-displaced farmers*" (L_4), "*negotiating for infrastructural development*" (L_5), "*negotiating for investments in small and medium-scale enterprises (SMEs)*" (L_6), "*re-locate displaced fish farmers and others affected*" (L_7) were found. Also, the option of forcefully regaining control of their communities was not ruled out since the local communities favored it. Hence, the option "*move against the fishing restrictions and regain control of their communities*" (L_8) was included.

Since the activities of the community social responsibilities carried out by the OCs do not reflect the needs of the affected communities (Ayanoore 2021), there is a need for a changed strategy. The option to "*request for contract modification to include equitable shares in petroleum revenue*" (L_9) to help regain their generational inheritance loss was significant. Again, an alternative is to *"Request for a quota system to regulate employment for foreigners and locals".* (L_{11}). Other strategies found were "*negotiate for tax exemptions*" (L_{10}), "*demand for a percentage of oil-resource ownership*" (L_{12}) through its chieftaincy and local communities, "*negotiate for coastal rural-urban redevelopment and fishing port*" (L_{13}), "*negotiate for utility subsidy*" (L_{14}) and "*accepting the status quo*" (L_{15}) of the conflict (Brunnschweiler et al. 2021). The reorganized identified DM strategies are given in Table 5.

4.2 Reduce Strategies Using DEMATEL

The first stage of identifying critical strategies is established. The focus is reducing extensive interrelated strategies for the fishing communities (DM2) in this energy-resource conflict. DEMATEL questionnaires were drafted and distributed to seven experts with relevant professional backgrounds to solicit primary data by evaluating the internal relationship between factors. Three of these experts work in academia with experiences in energy, environment, and fisheries. All of whom have a working knowledge of this particular conflict case study. Two were experienced citizens in the area with a high level of education and private company owners-the last two identified as heads of two separate fishing communities and their association. The step-by-step analysis with DEMATEL is described as follows:

Step 1: Construct an overall direct relation matrix

1) Define a pair-wise influence comparison scale, including a 5-level scale (Addae et al. 2019), which is given in Table 6.

2) Seven 15×15 direct relation matrices are separately given by experts through comparing strategies in pairs; samples are shown in Tables 7-9.

3) Assuming that seven experts occupy the same weight, an overall direct relation matrix can be calculated by arithmetic average, shown in Table 10.

Step 2: Obtained a normalized direct relation matrix

The normalized direct relation matrix is achieved by Formula (1)-(2), shown in Table 11.

Step 3: Generate a total direct relation matrix

The total direct relation matrix shown in Table 12 can be calculated by Formula (3).

Step 4: Compute the result of the DEMATEL method

Based on the total direct relation matrix, the sum of rows and columns is calculated by the Formula (4)-(5). The degree of importance for a factor and the kind of factor cluster it belongs to are dependent on the values of $e_x + z_x$ and $e_x - z_x$, respectively. The results are given in Table 13.

The DEMATEL method can uniquely identify critical interrelated factors from a factor system. In its computations, results are ranked under the important factor group $(e_x + z_x)$ and the cause-effect factor group $(e_x - z_x)$. The important factor group predicts the general ranking of factors according to their calculated important weights. The cause-effect group factors are used to analyze causal relations between factors such that those found in the cause group dispatch a net influence on effect-group factors. Since the factors in the cause group can influence the effect group, they are deemed critical (see Figure 5).

From the above results, as shown in Table 13, it can be seen that the strategy "*negotiating for investments in small and medium-scale enterprises (SMEs)*" (L_6) was the most critical strategy for DM FC, with a weighted score of 3.371. This was followed closely by the strategy "*negotiate for coastal rural-urban redevelopment and a fishing port*" (L_{13}) with a weight of 3.369. In the cause-group rank, the strategy "*request for contract modification to include equitable shares in petroleum revenue*" (L_9) scored the highest weight of 1.45. This strategy influences other strategies more. The rest of the cause-group strategies are given in descending order as follows: "*mass demonstration against the government*" (L_2) > "*negotiate for coastal rural-urban redevelopment and a fishing port*" (L_{13})> "*re-locate displaced fish farmers and others affected*" (L_7) > "*negotiating for investments in small and medium-scale enterprises (SMEs)*" (L_6) with a weight of 0.72, 0.61, 0.55 and 0.34 respectively (see Figure 5 and Table 13). So the reduced strategies of the coastal communities are "*negotiating for investments in small and medium-scale enterprises (SMEs)*" (L_9), "*mass demonstration against*

Table 5 Reorganized Identified DMs Strategies for Sustainable Energy Resource Conflict Resolution

DMs	Index	Strategies	Reference
DM1	G_1	Modify the petroleum contract to include equitable shares for the affected coastal communities.	Technical domain expert's knowledge
	G_2	Accept and manage the status quo of the conflict.	Technical domain expert's knowledge
DM2	L_1	Take legal action against the OCs on environmental pollution related issues.	Technical domain expert's knowledge (Addae et al. 2021, Owusu 2018)
	L_2	Mass demonstration against the government by threatening to vote for a change of government.	Technical domain expert's knowledge
	L_3	Negotiate for job creation.	Technical domain expert's knowledge (Addae et al. 2021, Adjei and Overa 2019) (San-Akca et al. 2020)
	L_4	Demand for a lump-sum compensation for forced-displaced farmers.	Technical domain expert's knowledge (Addae et al. 2021, Adjei and Overa 2019) (San-Akca et al. 2020, Owusu 2018)
	L_5	Negotiate for infrastructural development from oil proceeds for the region from the government.	Technical domain expert's knowledge (Addae et al. 2021, Adjei and Overa 2019) (San-Akca et al. 2020, Owusu 2018)
	L_6	Negotiate for investments in SMEs from the oil proceeds through a well-established scheme.	Technical domain expert's knowledge (Addae et al. 2021, Owusu 2018)
	L_7	Re-locate displaced fish farmers and others affected.	Technical domain expert's knowledge (Addae et al. 2021, Adjei and Overa 2019) (Owusu 2018)
	L_8	Move against the fishing restrictions and regain control of their communities.	Technical domain expert's knowledge (Addae et al. 2021, Ayanoore 2021)
	L_9	Request for contract modification to include equitable shares in petroleum revenue.	Technical domain expert's knowledge
	L_{10}	Negotiate for tax exemptions or reliefs for local investors.	Technical domain expert's knowledge (Addae et al. 2021)
	L_{11}	Request for a quota system to regulate employment for both foreigners and locals.	Technical domain expert's knowledge

	L_{12}	Demand for a percentage of oil-resource ownership through its chieftaincy and local communities.	Technical domain expert's knowledge
	L_{13}	Negotiate for coastal rural-urban community redevelopment and fishing port.	Technical domain expert's knowledge (Owusu 2018)
	L_{14}	Negotiate for utility subsidies for coastal communities.	Technical domain expert's knowledge (Addae et al. 2021)
	L_{15}	Accept the status-quo.	Technical domain expert's knowledge
DM3	C_1	Renegotiate the modification of petroleum contract by the government.	Technical domain expert's knowledge

Table 6 The Linguistic Scale for the Experts' Assessments

Linguistic terms	Normal values
No influence	0
Very low influence	1
Low influence	2
High influence	3
Very high influence	4

Table 7 Direct Relation Matrix by Expert 1

Strategies	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}
L_1	0	1	2	1	2	1	1	2	1	1	1	1	1	1	0
L_2	4	0	3	4	4	3	4	3	2	3	4	3	4	3	3
L_3	1	2	0	2	2	2	2	2	1	1	1	1	1	1	1
L_4	2	2	2	0	2	2	2	2	1	1	1	2	2	1	2
L_5	1	0	2	1	0	3	2	3	2	1	2	2	2	2	1
L_6	3	3	4	4	2	0	3	3	1	3	3	3	3	4	4
L_7	3	3	3	4	3	3	0	3	1	4	3	4	4	4	3
L_8	2	2	2	2	2	2	2	0	1	2	1	1	1	1	1
L_9	4	4	4	4	3	4	3	4	0	4	4	4	4	4	4
L_{10}	3	1	1	1	2	2	2	2	1	0	2	3	2	2	2
L_{11}	1	1	2	2	3	2	2	3	2	1	0	1	2	1	1
L_{12}	1	2	1	2	1	2	1	2	1	1	1	0	2	1	2
L_{13}	3	4	4	3	3	4	2	3	2	4	4	4	0	3	4
L_{14}	2	2	2	3	2	2	3	2	2	2	3	2	1	0	2
L_{15}	1	2	0	2	0	3	2	2	1	2	2	3	3	3	0

DM CG" (L_2), "*negotiate for coastal rural-urban development*" (L_{13}), "*re-locate displaced fish farmers and others affected*" (L_7) and "*negotiating for investments in small and medium-scale enterprises (SMEs)*" (L_6). MS Excel was used in DEMATEL computations. Hereafter, the second stage begins.

Table 8 Direct Relation Matrix by Expert 3

Strategies	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}
L_1	0	1	1	1	1	1	1	2	1	1	1	1	1	1	2
L_2	3	0	3	3	3	4	4	4	2	4	4	3	4	4	3
L_3	1	2	0	2	2	2	2	2	1	1	1	1	1	1	1
L_4	3	2	2	0	2	2	2	2	1	1	1	2	2	1	2
L_5	1	0	2	1	0	3	2	3	2	1	2	2	2	2	1
L_6	2	4	4	4	3	0	3	3	1	3	3	3	3	4	4
L_7	4	3	2	4	3	4	0	3	1	4	3	4	4	4	3
L_8	2	2	2	2	2	2	2	0	1	2	1	1	1	1	1
L_9	4	4	4	4	3	4	3	4	0	4	4	4	4	4	4
L_{10}	3	1	1	1	2	2	2	2	1	0	2	3	2	2	2
L_{11}	1	1	2	2	3	2	2	3	2	1	0	1	2	1	1
L_{12}	1	2	1	2	1	2	1	2	1	1	1	0	2	1	2
L_{13}	3	4	4	2	3	4	2	3	1	4	4	4	0	3	4
L_{14}	2	2	2	3	2	2	3	2	2	2	3	2	1	0	2
L_{15}	1	2	0	2	0	3	2	2	1	2	2	3	3	3	0

Table 9 Direct Relation Matrix by Expert 5

Strategies	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}
L_1	0	2	2	2	2	2	2	2	1	2	1	1	1	1	0
L_2	4	0	4	4	4	2	4	3	1	3	4	2	4	3	3
L_3	2	2	0	2	2	2	2	1	1	1	1	3	1	1	1
L_4	3	2	2	0	3	2	2	2	1	1	1	2	2	1	2
L_5	2	1	2	1	0	3	2	3	2	1	2	2	2	2	1
L_6	3	3	3	4	2	0	3	3	2	3	3	3	4	4	4
L_7	4	3	3	4	3	3	0	3	1	4	3	4	4	3	3
L_8	1	2	2	2	2	2	2	0	1	2	1	1	1	1	1
L_9	4	4	4	3	3	4	3	4	0	4	4	4	4	4	4
L_{10}	3	2	1	1	2	2	2	2	1	0	2	3	2	2	2
L_{11}	0	1	2	2	3	2	2	3	2	1	0	1	2	1	1
L_{12}	1	2	1	2	1	2	1	2	1	1	1	0	2	1	2
L_{13}	4	4	4	4	3	4	2	3	2	4	4	4	0	3	4
L_{14}	2	2	2	3	2	2	3	2	2	2	3	2	1	0	2
L_{15}	3	2	0	2	0	3	2	3	1	2	2	3	3	3	0

Table 10 Overall Direct Relation Matrix

Strategies	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}
L_1	0	1.29	1.86	1.14	1.86	1.14	1.14	2	1	1.14	1	1	1	1	0.29
L_2	3.71	0	3.43	3.43	3.71	3	3.86	3.14	1.86	3.29	4	3	4	3.57	3.14
L_3	1	2	0	2	1.86	2	2	1.86	1	1	1	1.29	1	1.29	1
L_4	2.43	1.86	2	0	2.29	2.14	2	1.86	1	1	1.14	1.86	2	1	2
L_5	1.29	0.14	1.86	1	0	3	2	3	2.14	1.29	2	2	2	2	1
L_6	3.14	3.14	3.71	3.71	2	0	3.29	3.43	1.14	3.29	3	3	3.29	4	4
L_7	3.29	3.29	3.14	4	3.14	3.14	0	3	1	3.86	3	4	3.86	3.57	3.14
L_8	2	2	2	2	2	2	2	0	1	2	1	1	1.14	1	1
L_9	3.86	4	4	3.86	3.43	4	3.29	4	0	4	4	3.71	4	4	4
L_{10}	3	1.14	1.14	1	2	2	1.86	2	1	0	2	3	2	2	2
L_{11}	0.86	1	2	2	3	2	2	3	2	1.29	0	1	2	1.14	1
L_{12}	1.14	2	1	2	1	2	1	2	1	1	1	0	2	1	2
L_{13}	3.29	3.86	3.86	3.14	3.14	4	2	3.14	2	4	4	4	0	3.14	3.86
L_{14}	2	2	2	3	2	2	3	2	2	2	3	2	1	0	2
L_{15}	1.43	1.86	0	2	0	3	2	2.14	1	2	2.14	3	3	3	0

Table 11 Normalized Direct Relation Matrix

Strategies	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}
L_1	0	0.02	0.03	0.02	0.03	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.01
L_2	0.07	0	0.06	0.06	0.07	0.06	0.07	0.06	0.03	0.06	0.07	0.06	0.07	0.07	0.06
L_3	0.02	0.04	0	0.04	0.03	0.04	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02
L_4	0.04	0.03	0.04	0	0.04	0.04	0.04	0.03	0.02	0.02	0.02	0.03	0.04	0.02	0.04
L_5	0.02	0.00	0.03	0.02	0	0.06	0.04	0.06	0.04	0.02	0.04	0.04	0.04	0.04	0.02
L_6	0.06	0.06	0.07	0.07	0.04	0	0.06	0.06	0.02	0.06	0.06	0.06	0.06	0.07	0.07
L_7	0.06	0.06	0.06	0.07	0.06	0.06	0	0.06	0.02	0.07	0.06	0.07	0.07	0.07	0.06
L_8	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0	0.02	0.04	0.02	0.02	0.02	0.02	0.02
L_9	0.07	0.07	0.07	0.07	0.06	0.07	0.06	0.07	0	0.07	0.07	0.07	0.07	0.07	0.07
L_{10}	0.06	0.02	0.02	0.02	0.04	0.04	0.03	0.04	0.02	0	0.04	0.06	0.04	0.04	0.04
L_{11}	0.02	0.02	0.04	0.04	0.06	0.04	0.04	0.06	0.04	0.02	0	0.02	0.04	0.02	0.02
L_{12}	0.02	0.04	0.02	0.04	0.02	0.04	0.02	0.04	0.02	0.02	0.02	0	0.04	0.02	0.04
L_{13}	0.06	0.07	0.07	0.06	0.06	0.07	0.04	0.06	0.04	0.07	0.07	0.07	0	0.06	0.07
L_{14}	0.04	0.04	0.04	0.06	0.04	0.04	0.06	0.04	0.04	0.04	0.06	0.04	0.02	0	0.04
L_{15}	0.03	0.03	0	0.04	0	0.06	0.04	0.04	0.02	0.04	0.04	0.06	0.06	0.06	0

Table 12 Total Direct Relation Matrix

Strategies	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}
L_1	0.03	0.05	0.06	0.05	0.06	0.05	0.05	0.07	0.04	0.05	0.05	0.05	0.05	0.05	0.03
L_2	0.14	0.07	0.14	0.14	0.14	0.14	0.14	0.15	0.08	0.13	0.15	0.14	0.15	0.14	0.13
L_3	0.06	0.07	0.04	0.07	0.07	0.08	0.07	0.07	0.04	0.05	0.05	0.06	0.06	0.06	0.05
L_4	0.09	0.07	0.08	0.05	0.08	0.09	0.08	0.08	0.04	0.06	0.06	0.08	0.08	0.06	0.08
L_5	0.07	0.05	0.08	0.07	0.04	0.10	0.08	0.10	0.06	0.07	0.08	0.08	0.08	0.08	0.06
L_6	0.13	0.12	0.14	0.14	0.11	0.08	0.13	0.14	0.07	0.13	0.13	0.13	0.13	0.14	0.14
L_7	0.13	0.13	0.13	0.15	0.13	0.14	0.07	0.14	0.07	0.14	0.13	0.15	0.14	0.14	0.13
L_8	0.08	0.07	0.07	0.08	0.07	0.08	0.07	0.04	0.04	0.07	0.06	0.06	0.06	0.06	0.05
L_9	0.16	0.15	0.16	0.16	0.15	0.17	0.15	0.17	0.06	0.16	0.16	0.16	0.16	0.16	0.16
L_{10}	0.10	0.06	0.06	0.07	0.08	0.08	0.08	0.09	0.05	0.04	0.08	0.10	0.08	0.08	0.08
L_{11}	0.06	0.06	0.08	0.08	0.10	0.08	0.08	0.10	0.06	0.07	0.04	0.06	0.08	0.06	0.06
L_{12}	0.06	0.07	0.05	0.07	0.05	0.08	0.05	0.08	0.04	0.05	0.05	0.04	0.07	0.05	0.07
L_{13}	0.14	0.14	0.15	0.14	0.13	0.16	0.11	0.14	0.08	0.14	0.15	0.15	0.08	0.13	0.14
L_{14}	0.09	0.08	0.09	0.11	0.09	0.09	0.10	0.09	0.07	0.09	0.10	0.09	0.07	0.05	0.08
L_{15}	0.07	0.08	0.05	0.09	0.05	0.10	0.08	0.09	0.05	0.08	0.09	0.10	0.10	0.10	0.05

Table 13 DEMATEL Results

Strategies	e_x	z_x	$e_x + z_x$	Rank 1	$e_x - z_x$	Rank 2	Cause/Effect
L_1	0.73	1.39	2.13	15	–0.66	15	Effect
L_2	1.99	1.28	3.27	3	0.72	2	Cause
L_3	0.90	1.38	2.28	14	–0.47	12	Effect
L_4	1.07	1.47	2.54	7	–0.41	11	Effect
L_5	1.09	1.35	2.44	12	–0.26	9	Effect
L_6	1.86	1.52	3.37	1	0.34	5	Cause
L_7	1.90	1.36	3.26	4	0.55	4	Cause
L_8	0.97	1.57	2.54	8	–0.60	14	Effect
L_9	2.29	0.84	3.13	5	1.45	1	Cause
L_{10}	1.11	1.34	2.45	11	–0.22	8	Effect
L_{11}	1.07	1.38	2.45	10	–0.31	10	Effect
L_{12}	0.90	1.45	2.35	13	–0.55	13	Effect
L_{13}	1.99	1.38	3.37	2	0.61	3	Cause
L_{14}	1.30	1.36	2.65	6	–0.06	6	Effect
L_{15}	1.19	1.31	2.49	9	–0.12	7	Effect

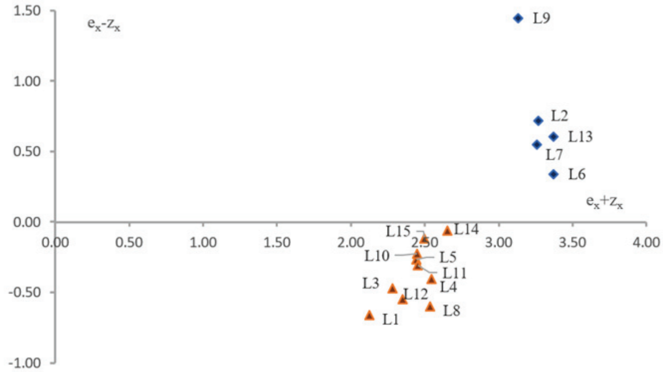


Figure 5 Digraph Showing the Causal Relationship of Strategies for Coastal Communities

4.3 The Conflict Status Quo Analysis

The status quo is simply the initial situation of the energy conflict at the time it's been analyzed. In the case of the energy conflict in Ghana, the central government is unwilling to modify any trade contract with the oil companies to directly reflect the needs of the affected communities represented by the fisherfolks. The fisherfolks want all of their extensively affected sustainable needs due to the exploration of the oil and gas resources resolved in this conflict. Also, the oil companies do not want to renegotiate any contract modification. This implies that oil production will continue, restrictions on fishing activities will be maintained, environmental pollution will exist, competition for coastal resources will continue, and minor clashes among DMs may escalate. The "Y" and "N" mean the strategy is either selected or not selected, respectively, Table 14.

4.4 Generating Feasible States

Combining DM's preference or option/choices yields a certain number of feasible states. The options given in Table 15 are now fed into the decision support system GMCRII. The system generates the states for the conflict. The symbols "Y" and "N" indicate whether the focal DM chooses the corresponding option or not. In this conflict, there are eight options in total. From a mathematical point of view, the number of states formed by the combination of different options should be $2^8 = 256$. However, some infeasible states exist because of exclusivity or relevance within factors. For example, the conflict no longer exists when the OCs select N for option 8 (renegotiate for modification), no matter the government's action or the "*fisherfolks*." In other words, if OCs select "N" for option 8, all such states coalesce into state s_{14}. Consequently, there are 14 feasible states in this conflict after removing the unreasonable (see Table 15). The graph model for individual DMs is shown in Figure 6, which depicts the feasible movements for each DM in the energy resource production conflict, where the arrows refer to the UMs among feasible states (refer to Definition 2).

4.5 DM Preference Rank Based on Option Statements

A DM can express the preference rank over the generated states or options based on their value system. The multiple DM's option statements were obtained based on the preliminary

Table 14 The Status Quo of the Energy Production Conflict in Ghana

Decision makers	Strategy number	Strategy	Status quo
DM1	1	Accept Modification	N
	2	Accept Status Quo	Y
DM2	3	Request Modification	Y
	4	Embark on Demonstration	Y
	5	Negotiate SMEs Investment	Y
	6	Negotiate Redevelopment	Y
	7	Relocate Communities	Y
DM3	8	Renegotiate Modification	N

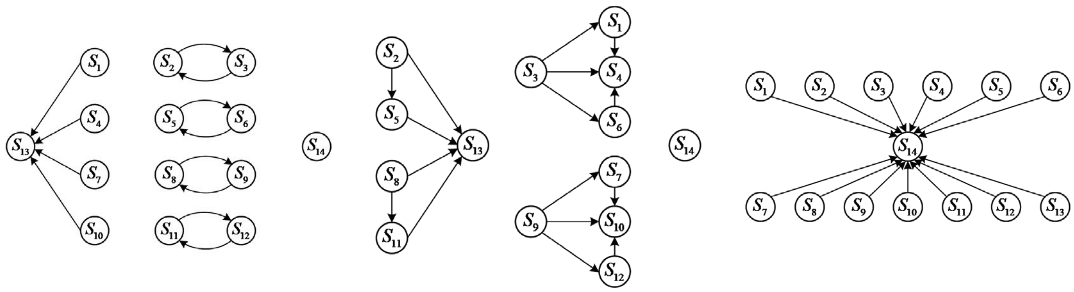
Table 15 Options and Feasible States for Energy Resource Conflict Resolution

DM	Index	Options	States													
			s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9	s_{10}	s_{11}	s_{12}	s_{13}	s_{14}
DM1	G_1	1. Accept Modification	N	Y	N	N	Y	N	N	Y	N	N	Y	N	Y	-
	G_2	2. Accept Status Quo	Y	N	Y	Y	N	Y	Y	N	Y	Y	N	Y	-	-
DM2	L_9	3. Request Modification	Y	N	N	Y	N	N	Y	N	N	Y	N	N	Y	-
	L_2	4. Embark on Demonstration	N	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	-	-
	L_6	5. Negotiate SMEs Investment	N	N	N	Y	Y	Y	N	N	N	Y	Y	Y	-	-
	L_{13}	6. Negotiate Redevelopment	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	-	-
	L_7	7. Relocate Communities	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	-	-
DM3	C_1	8. Renegotiate Modification	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N

and status quo analysis and consultations with the technical experts (see Table 16). There are several ways to represent a DM's preference statements or choices over these options to elicit preference rank. These include direct ranking, option weighting, and option ranking. Option ranking is the most convenient among the three, given a complex conflict with more than two DMs and several strategies. Hence, adopted in this research. Also, the order of the statements for each DM depicts the order of priority. For example, option statements - 1 and 2 for the government (DM1) mean the government's top priority is not to modify the contract with the OCs (DM3) and accept the status quo, respectively (see Table 15). These preference statements of all DMs, when fed into the decision support system, generate the preference rank. The preference rank information is given in Table 17, ranked from the most preferred on the left to the least on the right.

4.6 Stability Analysis

The five classical stabilities expressed in Definitions 8 to 12 are employed to implement the analysis. The results are given in Table 18. A checkmark "√" means that the state in the corresponding row is stable for a particular stability concept, while the equilibria are represented by "*" in column "Eq." And $F_i^*(s_k)$ represents different behavioral patterns of DM i about the state s. If a state is an equilibrium under all stability definitions, the state is considered to be the overall equilibrium. In



(a) DM1 (b) DM2 (c) DM3

Figure 6 Digraph Showing the Causal Relationship of Strategies for Coastal Communities

terms of Table 18, the equilibrium states for the energy-resource conflict can be summarized by the following:

1) The set of NASH equilibria is $\{s_{13}, s_{14}\}$;

2) The set of GMR equilibria is $\{s_2, s_5, s_8, s_{11}, s_{13}, s_{14}\}$;

3) The set of SMR equilibria is $\{s_2, s_5, s_8, s_{11}, s_{13}, s_{14}\}$;

4) The set of SEQ equilibria is $\{s_{13}, s_{14}\}$;

5) The set of SSEQ equilibria is $\{s_{13}, s_{14}\}$.

The conflict stability is carried out to explore the behavioral interactions of the multiple DMs in conflict resolution. The results show that the different sets of equilibrium solutions, individually stable for all DMs in this conflict, have been calculated under five other solution concepts. The solution concept (Nash, GMR, SMR, SEQ, and SSEQ) utilized under GMCR uses mathematical means to analyze moves and countermoves of all DMs in a conflict, thereby creating a state stable for DMs. These solution concepts consider how DMs behave in conflicts and thus predict behavioral outcomes in their results. Even though they may not be favorable for all parties involved, they provide valuable negotiation information for policymakers, analysts, and disputants.

For Nash equilibrium, states s_{13} and s_{14} were stable for all DMs. In the state s_{13}, the government considers equitable shares in petroleum revenue for the affected communities; the coastal communities contest equitable shares in petroleum revenue. The OCs renegotiate contract modifications with the government. More specifically, the government agrees to satisfy the needs of the affected communities by ignoring any associated risk with such a move. The OCs decided not to renegotiate the contract modification in state s_{14}. In other words, the OCs agree not to contest and abandon the project. Hence, the conflict ceases to exist. This situation also assumes that the petroleum resources' economic benefits will stop unless different contracts are agreed upon with other oil companies.

DMs are conservative towards risk with the set of equilibria under GMR solution concepts. State s_2 under GMR yields exciting outcomes. Even though the coastal communities do not request equitable shares in petroleum revenue, the government opts to modify the contract to provide fair shares for the affected communities, avoiding any risk. This risk avoidance may be explained by the fact that, under the same state, the coastal communities opt for a mass demonstration against the government. This is necessary for the government to avoid losing upcoming general elections. The OCs demand

Table 16 Decision-makers Option Statements for the Energy-resource Conflict Resolution

DMs	Options	Option statements	Interpretation
DM1	1. Accept Modification 2. Accept Status Quo	–1	The government declines to modify the petroleum contract to include equitable shares for the affected coastal communities.
		2	The government chooses to maintain the conflict status quo and manage it.
		–3	The government doesn't want the coastal communities to request contract modification to include equitable shares in petroleum revenue.
		–4	The government doesn't want the coastal communities to embark on a mass demonstration.
		5iff–4	The coastal communities can negotiate for investments in SMEs only and only if they don't embark on a mass demonstration.
		6iff–4	The coastal communities can negotiate for coastal development and a fishing port in the area only and only if they don't embark on a mass demonstration.
		7iff–4	The coastal communities can negotiate for relocation of affected communities only and only if they don't embark on a mass demonstration.
		8if4&1	OCs can renegotiate only if the coastal communities demonstrate and the government modifies the petroleum contract to include equitable shares for the coastal communities.
DM2	3. Request Modification 4. Embark on Demonstration 5. Negotiate SMEs Investment 6. Negotiate Redevelopment 7. Relocate Communities	3	The coastal communities choose to request contract modification to include equitable shares in petroleum revenue.
		4if2&–1	The coastal communities will go on mass demonstration for change in government if the government maintains the status quo and also decides not to modify the contract agreements.
		5	The coastal communities choose to negotiate for SME investments in the region.

		6	The coastal communities choose to negotiate for coastal redevelopment and a fishing port in the area.
		7	The coastal communities opt for relocation of affected communities as a result of the impact from the petroleum extraction activities.
		1	The government accept modification to include equitable shares of petroleum revenue for the affected coastal communities.
		−2	The coastal communities don't want the government to accept the status quo of the conflict.
		8if1	The OCs can renegotiate contract modification only if the government agrees to modify the petroleum contract to include equitable shares for the coastal communities.
DM3	8. Renegotiate Modification	8iff1	The OCs choose to renegotiate the modification of the petroleum contract if and only if the government decides to modify the contract to include equitable shares for the affected coastal communities.
		−1	The government should not modify the petroleum contract to include equitable shares for the coastal communities.
		2	The government should maintain the current petroleum contract, maintains the status quo, and choose different path for conflict resolution.
		−3	The coastal communities don't request for contract modification to include equitable shares in petroleum revenues.
		−4	The coastal communities should not demonstrate against government.
		5if2	The coastal communities can choose to negotiate for SMEs investments only if the government maintains the status quo.
		7iff−1	The coastal communities can choose to negotiate for relocation of affected communities if and only if the government doesn't modify petroleum contract.

Table 17 DMs' Preference Rank for Sustainable Energy-resource Conflict Resolution

DMs	Preference
DM1	$s_9 \succ s_3 \succ s_{12} \succ s_6 \succ s_4 \succ s_{10} \succ s_1 \succ s_7 \succ s_8 \succ s_2 \succ s_{11} \succ s_5 \succ s_{13} \succ s_{14}$
DM2	$s_{13} \succ s_4 \succ s_{10} \succ s_1 \succ s_7 \succ s_5 \succ s_6 \succ s_{11} \succ s_{12} \succ s_2 \succ s_3 \succ s_8 \succ s_9 \succ s_{14}$
DM3	$s_2 \sim s_5 \succ s_8 \sim s_{11} \succ s_{13} \sim s_{14} \succ s_{12} \succ s_6 \succ s_9 \succ s_3 \succ s_{10} \succ s_4 \succ s_7 \succ s_1$

Table 18 Stability Analysis for Sustainable Energy Resource Conflict Resolution

	States	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9	s_{10}	s_{11}	s_{12}	s_{13}	s_{14}
Nash	CG	√		√	√		√	√		√	√		√	√	√
	FC				√						√			√	√
	OCs		√			√			√			√		√	√
	Eq													*	*
GMR	CG	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	FC	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	OCs		√			√			√			√		√	√
	Eq		*			*			*			*		*	*
SMR	CG	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	FC	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	OCs		√			√			√			√		√	√
	Eq		*			*			*			*		*	*
SEQ	CG	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	FC	√		√	√		√	√		√	√		√	√	√
	OCs		√			√			√			√		√	√
	Eq													*	*
SSEQ	CG	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	FC	√		√	√		√	√		√	√		√	√	√
	OCs		√			√			√			√		√	√
	Eq													*	*
$F_i^*(s_k)$	CG	0	1	0	0	1	0	0	1	0	0	1	0	0	0
	FC	1	4	1	0	4	1	1	4	1	0	4	1	0	0
	OCs	6	0	6	6	0	6	6	0	6	6	0	6	0	0

renegotiation of the government's petroleum contract modification in this same state.

In the state s_5, the government agrees on equitable shares for the communities. However, the coastal communities demonstrate against the government negotiating for SME investment and coastal development with a fishing harbor. This could be explained due to the behavior of the OCs in this same state. In this state, the OCs renegotiate against the government's option to explicitly modify the petroleum contract to include the affected communities' requests. The influence of the OCs on this decision can be complex, following their support from the so-called "superpowers," which may force the government to maintain an excellent bilateral relationship. State s_8 under GMR is similar to state s_5 except that the coastal communities do not request equitable shares, SME investment, and coastal development. In the state s_{11} and s_{13}, similar to s_2 and s_5, it can be seen that the government is sensitive to the coastal communities' move to demonstrate against them and avoids the consequences associated with such action.

Yet more, in this conflict, state s_2, s_5, s_8, s_{11},

s_{13}, and s_{14} are both GMR and SMR stable for all individual DMs. With GMR, focal DMs consider the possibility of sanctions on their unilateral improvement by subsequent unilateral moves by opposing DMs. Under SMR, focal DMs are concerned with unilateral improvement sanctions by their opponent even after a response. The SEQ and SSEQ are the same as NASH (state s_{13} and s_{14} are stable). For SEQ, all focal DMs are concerned with subsequent unilateral improvement sanctions by their opponents. Under SSEQ, focal DMs are concerned with subsequent unilateral improvement sanctions by their opponent even after a response. A similar logical behavioral analysis of the calculated equilibria under each solution concept can be followed.

The most robust equilibria in this energy-resource conflict are s_{13} and s_{14} because they are the only states that are NASH, GMR, SMR, SEQ and SSEQ for all DMs. After substituting findings into Formula (21), we obtain $F_1(s_{13}) = F_2(s_{13}) = F_3(s_{13}) = 0$ and $F_1(s_{14}) = F_2(s_{14}) = F_3(s_{14}) = 0$. Then, according to Theorem 1, the type of behavior creating the final equilibrium is Nash, GMR, SMR, SEQ, or SSEQ behavior, which is the same as the result.

Analyzing both states, there are indications of implementation challenges of such solution concepts as they are most likely infeasible. In contrast with the status quo, the government may not settle for the community's request for equitable shares and practically will not abandon the project. Also, the services of the OCs will continually be required by the government to develop energy resources. The behavior of DMs through the preliminary analysis, as evidenced by the equilibria results, corroborates the dispute's unsustainable management. A change in the status quo will substantially move this conflict forward. Policymakers and stakeholders should respond with equal force in terms of cooperation and political will to change DM's preferences or improve strategies in the future.

5. Discussion

Energy-resource production conflicts in coastal areas are generally complex, and knowledge integration toward successful resolution is keen. This is because diverse stakeholders carry out resource utilization and management with different backgrounds (Owusu 2018). These energy resources' sustainable production and management are central to achieving the sustainable development goal-12. This is hindered by conflicting objectives from competition for the resources by the various stakeholders. There is a sustainable livelihood impact resulting from petroleum extraction activities, and it cannot be ignored. A much more comprehensive approach toward sustainable conflict resolution and energy resource development is needed for developing economies. A hybrid conflict resolution model that inclusively supports the participation of various decision-makers will improve transparency. Ergo, the innovatively proposed hybrid DEMATEL-GMCR method for multiple DMs to investigate the energy-resource production conflict in Ghana has many advantages.

With the easy use of the GMCRII DSS, the complex conflicts are modeled, and facilitators can access the dynamics of this conflict in a snapshot to assist strategic moves. For this con-

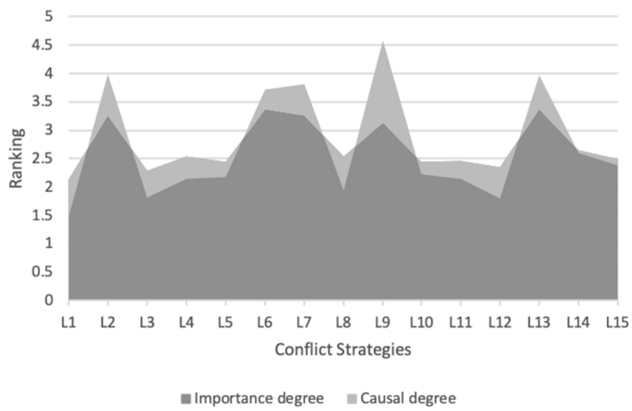


Figure 7 Sustainable Policy Implementation Direction for DM2 Based on Importance and Causal Degree

flict, the best-fit strategic approach is to resolve the dispute by committing scarce resources to address the prioritized strategies for the coastal communities (see Figure 7). Comparing the results to the status quo, the behavior of the fisherfolks (DM2) is likely to escalate the conflict in the near future due to disproportioned adverse sustainable impact. For the avoidance of an open conflict and the overall objective of preventing negative impact, specific sustainable policies are suggested as follows:

(a) Integrate coherence of state institutional frameworks

Sustainable development, as important as the terminology, has existing interrelationships among its goals, and much cooperation across sectors at the country level is ideal for successful implementation. There is a disintegration of sectoral institutional frameworks in Ghana, which must be resolved. These institutions either become government contraptions for political gains or ineffective policy implementations. The high incoherence between politics, policies, institutions, and governance is problematic. Many researchers have cited institutional weakness as a cause of developmental problems in Ghana (Addae et al. 2021). In the local communities, many promises are given but less implemented. The few implemented also do not reflect the sustainable needs of the communities.

(b) Invest in small and medium-scale enterprises (SMEs)

From the conflict results, investments in SMEs are a necessary conflict-reversal strategy. This is a sustainable policy approach with promising short- and long-term results. In reality, the government will not abandon the extraction of petroleum resources. The services of foreign oil companies will be required, and so will the sustainability of the communities be continually adversely impacted. An alternative sustainable investment mechanism is needed for poverty alleviation and sustainable livelihood. Addae et al. (2021) indicated that policymakers could support SME growth in two ways. First, they invest in alternative trade and skill enhancement for displaced farmers and the youth to acquire requisite skills in offshore oil extraction-related jobs. Second, provide financial support in soft loans to expand petty trading and other ventures through the vocational skills acquired.

(c) Rethink Local Content Policy (LCD)

and Cooperate Social Responsibility (CSR)

To avoid the negative impact of natural resource extractions, the government of Ghana partnered with Multinational Oil Companies (OCs) to establish the Enterprise Development Center (EDC). The EDC was a strategy to allow for local content development. The Local Content Policy (FC) and the Cooperate Social Responsibility (CSR) policy instrument were adopted by the government and OCs in implementing EDC. The EDC is now part of the many unsustainable policy frameworks established by the government (Ablo 2020). As necessary, CSR can be viewed as a "favor" and cannot be a reliable mechanism by the state in addressing sustainable societal needs. Therefore, stakeholders need better engagement to improve understanding and shared value for a sustainable implementation of future local content development projects.

(d) Implement coastal rural-urban redevelopment and integrated coastal cohabitation system

The government should formulate sustainable policies to redevelop this area. The discovery of these energy resources should strategically attract several developmental projects. This will create new markets, attract foreign investors, and create new employment opportunities. Yet more, the newly found energy resources shouldn't be treated as the "most" prioritized activity in the area. We understand the economic value. However, other activities (fishing, agriculture, etc.) existed long before its commercial extraction. A well-formulated integrated cohabitation scheme should be implemented to manage all anthropic activities in the area. Investing in fishing ports should be prioritized to help regulate and manage fishing activities.

(e) Implement an employment quota scheme

The challenge of widening economic inequality due to petroleum extraction activities among the coastal communities should be proactively considered by policymakers in the early stages of the energy dispute. Other inequalities such as ethnicity, gender, and minorities should be envisioned and integrated into the policy frameworks. Inclusive growth is necessary to resolve this dispute sustainably. Employment quota schemes can be adopted as a policy framework to manage the situation. This will ensure shares of jobs in the oil extraction in the area for the communities. We understand the issues of the trade-offs between equity and efficiency associated with such policy; however, if properly formulated, implemented, and managed, they will help bridge societal inequalities. Implementing vocational and technical training in tandem will help reduce the risk associated with unskilled labor employment.

Next, we discuss strategic insights based on DM's preference rank and equilibrium results (see Figure 7). We focus on these two to guide policymakers further on sustainable negotiation insights. The most preferred state for the government is state s_9 from the results. In this state, the government does not modify the original trade contract but accepts the conflict's status quo. Also, under this same state, the coastal communities demonstrate and demand relocation while the OCs renegotiate for a contract modification.

Nonetheless, the coastal communities and

Table 19 Direct Relation Matrix by Expert 2

Strategies	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}
L_1	0	2	2	1	2	1	1	2	1	1	1	1	1	1	0
L_2	4	0	3	3	4	3	4	2	2	3	4	3	4	3	3
L_3	1	2	0	2	2	2	2	2	1	1	1	1	1	1	1
L_4	2	1	2	0	2	3	2	1	1	1	2	1	2	1	2
L_5	1	0	1	1	0	3	2	3	2	3	2	2	2	2	1
L_6	4	3	4	4	2	0	3	4	1	3	3	3	3	4	4
L_7	3	4	3	4	4	3	0	3	1	3	3	4	4	3	3
L_8	2	2	2	2	2	2	2	0	1	2	1	1	1	1	1
L_9	4	4	4	4	3	4	3	4	0	4	4	3	4	4	4
L_{10}	3	1	1	1	2	2	2	2	1	0	2	3	2	2	2
L_{11}	1	1	2	2	3	2	2	3	2	1	0	1	2	1	1
L_{12}	1	2	1	2	1	2	1	2	1	1	1	0	2	1	2
L_{13}	3	4	4	3	3	4	2	3	3	4	4	4	0	3	4
L_{14}	2	2	2	3	2	2	3	2	2	2	3	2	1	0	2
L_{15}	2	2	0	2	0	3	2	2	1	2	2	3	3	3	0

Table 20 Direct Relation Matrix by Expert 4

Strategies	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}
L_1	0	1	2	1	2	1	1	2	1	1	1	1	1	1	0
L_2	3	0	3	3	3	3	3	3	2	4	4	4	4	4	4
L_3	0	2	0	2	1	2	2	2	1	1	1	1	1	2	1
L_4	3	2	2	0	3	2	2	2	1	1	1	2	2	1	2
L_5	2	0	2	1	0	3	2	3	3	1	2	2	2	2	1
L_6	4	3	4	3	1	0	3	3	1	4	3	3	3	4	4
L_7	3	3	4	4	3	3	0	3	1	4	3	4	3	4	3
L_8	2	2	2	2	2	2	2	0	1	2	1	1	2	1	1
L_9	4	4	4	4	4	4	3	4	0	4	4	4	4	4	4
L_{10}	3	1	1	1	2	2	2	2	1	0	2	3	2	2	2
L_{11}	1	1	2	2	3	2	2	3	2	3	0	1	2	2	1
L_{12}	1	2	1	2	1	2	1	2	1	1	1	0	2	1	2
L_{13}	3	4	4	4	3	4	2	3	2	4	4	4	0	3	4
L_{14}	2	2	2	3	2	2	3	2	2	2	3	2	1	0	2
L_{15}	1	1	0	2	0	3	2	2	1	2	3	3	3	3	0

the OCs less prefer this state. The second most desired state for the government is the state s_3. Under this state, the government supports rolling out policies for coastal redevelopment. Yet, they do not want to modify the original trade contract, nor prefer the coastal communities negotiate a contract modification. However, the coastal communities embarked on a mass demonstration against the government under this same state. Strategic insights based on conflict equilibria and preference rank results.

The two scenarios show that the option of contract modification between the government and the OCs to include them is infeasible. For policymakers, scarce resources can be committed to the common interest between the government and the coastal communities in this state as a conflict reversal strategy. The government would prefer redeveloping the coastal communities than modifying the existing petroleum contract, which is in common

Table 21 Direct Relation Matrix by Expert 6

Strategies	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}
L_1	0	1	2	1	2	1	1	2	1	1	1	1	1	1	0
L_2	4	0	4	3	4	3	4	4	2	3	4	3	4	4	3
L_3	1	2	0	2	2	2	2	2	1	1	1	1	1	1	1
L_4	2	2	2	0	2	2	2	2	1	1	1	2	2	1	2
L_5	1	0	2	1	0	3	2	3	2	1	2	2	2	2	1
L_6	3	3	4	3	2	0	4	4	1	4	3	3	3	4	4
L_7	3	4	3	4	3	3	0	3	1	4	3	4	4	3	3
L_8	2	2	2	2	2	2	2	0	1	2	1	1	1	1	1
L_9	4	4	4	4	4	4	4	4	0	4	4	3	4	4	4
L_{10}	3	1	1	1	2	2	2	2	1	0	2	3	2	2	2
L_{11}	1	1	2	2	3	2	2	3	2	1	0	1	2	1	1
L_{12}	1	2	1	2	1	2	1	2	1	1	1	0	2	1	2
L_{13}	3	3	3	3	3	4	2	4	2	4	4	4	0	4	4
L_{14}	2	2	2	3	2	2	3	2	2	2	3	2	1	0	2
L_{15}	1	2	0	2	0	3	2	2	1	2	2	3	3	3	0

Table 22 Direct Relation Matrix by Expert 7

Strategies	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}
L_1	0	1	2	1	2	1	1	2	1	1	1	1	1	1	0
L_2	4	0	4	4	4	3	4	3	2	3	4	3	4	4	3
L_3	1	2	0	2	2	2	2	2	1	1	1	1	1	2	1
L_4	2	2	2	0	2	2	2	2	1	1	1	2	2	1	2
L_5	1	0	2	1	0	3	2	3	2	1	2	2	2	2	1
L_6	3	3	3	4	2	0	4	4	1	3	3	3	4	4	4
L_7	3	3	4	4	3	3	0	3	1	4	3	4	4	4	4
L_8	3	2	2	2	2	2	2	0	1	2	1	1	1	1	1
L_9	3	4	4	4	4	4	4	4	0	4	4	4	4	4	4
L_{10}	3	1	2	1	2	2	1	2	1	0	2	3	2	2	2
L_{11}	1	1	2	2	3	2	2	3	2	1	0	1	2	1	1
L_{12}	2	2	1	2	1	2	1	2	1	1	1	0	2	1	2
L_{13}	4	4	4	3	4	4	2	3	2	4	4	4	0	3	3
L_{14}	2	2	2	3	2	2	3	2	2	2	3	2	1	0	2
L_{15}	1	2	0	2	0	3	2	2	1	2	2	3	3	3	0

interest with the coastal communities. Since the government is likely to act rather than be unpopular through mass demonstrations, this can also be used within legal means to force the hands of the government to commit. For the government, this can be an opportunity to neutralize the negative demonstration effect by the communities whose sustainability is adversely impacted due to petroleum activities. A similar logical analysis can be drawn from the rest of the preference ranking for sustainable insights and policies.

On the contrary, the coastal community's most preferred state is s_{13} . Under this state, they negotiate for a contract modification to reflect their sustainable needs explicitly, the government modifies the trade contract, and OCs renegotiate contract modification by the government. The second most preferred state for the coastal communities is state s_{14} . Under this state, the government accepts the status quo of the contract; the coastal communities do not demonstrate against the government but negotiate for investments in SMEs and coastal redevelopment. It is complicated, unsustainable, and practically infeasible for the coastal communities to gain any tactical advantage to influence the government contract decisions with OCs. In the interest of the coastal communities, policies should focus on negotiations for investment in SMEs, rural-urban redevelopment, and relocation of affected persons. Hence, scarce resources should be committed to addressing these critical sustainable needs (L_6 and L_{13}) preferred by the coastal communities.

With the OCs, state s_2 is equally preferred to state s_5. Under this state, it can be seen that the OCs' attitude is purely profit-oriented. In other words, the OCs want to continue doing business with the government and are willing to renegotiate in both states. Their services are a necessity for the development of Ghana's energy resources. Policymakers can strategically capitalize on the profit-making appetite of the OCs in rolling out policies that encourage business yet are in the interest of the country and the citizens.

Inferring from the equilibria solutions in this energy-resource dispute, the government is unwilling to accept any direct influence by the community in the business with the OCs. Across all equilibria states (except for Nash, SEQ, and SSEQ), the government accepts to modify the petroleum contract only when the coastal communities are not requesting any fair share in petroleum revenue. In other non-equilibria states, the government declines equitable shares when the communities request it. Either way, the government's attitude here is simply not in favor of equitable shares in the petroleum revenue for the affected communities. However, the government is sensitive to improving the energy conflict status quo. This, by no surprise, depicts the political behavior of the government. They display the political will of change, yet less is implemented to avert the conflict status quo.

The study's implications can be extended to other conflict studies in various resource extraction communities in Ghana and across the Sub-Saharan region. Examples are conflicts associated with gold, diamond, and bauxite resources. The integrated method comprehensively analyses factor interrelations, sustainability impact, impact on coastal zones, extraction activities, energy resources development, and anthropic impacts. This can be easily adapted to model conflicts with robust outcomes, allowing diverse competing factors to be incorporated. Mediators can draw important perspectives on understanding the dynamics of a complex resource conflict.

6. Conclusion

A strategic analysis of an energy-resource conflict is carried out to explore possible resolutions to prevent adverse sustainable socio-ecological impacts. The energy-resource production dispute between the multiple DMs, the central government, "$fisherfolks$," and oil companies in the Western Region of Ghana is recent. Yet, conflict modeling and sustainable strategic analysis aren't found in the literature. Preliminary studies revealed some of the multiple DMs, the "$fisherfolks$" (DM2), have extensive interrelated strategies, and single methods may fail to analyze comprehensively. With the many advantages of the graph model, there is an associated computational challenge due to extensive DM strategies. Besides, the existing method cannot explicitly deal with the real-life interrelationships between DM strategies. If k is the number of interrelated strategies, there are 2^k states. We implied that DMs' choices over extensively identified interrelated strategies yield many feasible states, complicating stability calculations and analysis. How can the many interrelated strategies be reduced empirically, necessary for GMCR computations? It is crucial to reduce these strategies and avoid omitting critical factors.

Hence, the main contributions of this paper were to propose a hybrid decision-making trial and evaluation laboratory (DEMATEL) - graph model for conflict resolution (GMCR) method for multiple DMs to solve a complicated conflict in Ghana. Also, an extended matrix algorithm was utilized within the paradigm of the GMCR to explain the multiple DMs' interactive behavior in conflict resolution. The hybrid DEMATEL-GMCR model designed in this paper was novel in the following ways: firstly, we identified the extensive interrelated strategies for some multiple DMs. Secondly, the critical strategies of the conflict were selected to replace the extensive interrelated strategies using the DEMATEL method, which was used in the GMCR modeling. Thirdly, we extended the stability definitions within the GMCR using a matrix algorithm and constructed a stability behavior analysis function to explain the behavior of multiple DMs. Fourthly, an algorithm for the proposed hybrid method was applied to the case study of an energy-resource production dispute in Ghana to demonstrate its procedure for calculating the equilibria for solving the conflict.

Analyzing the behavior of multiple DMs from the calculated stability results, it is unlikely for the dispute to be resolved and likely to escalate in the future by $fisherfolks$ due to disproportionately adverse sustainable impact. Analyzing the strongest equilibria (s_{13} and s_{14}) indicates implementation challenges. In a nutshell, the government will continue to do business with multinational oil companies to extract and develop petroleum resources for its enormous economic benefits. This also implies the consequential adverse sustainability effect on the fishing communities. Restrictions imposed on the $fisherfolks$ due to the oil and gas resource production prevent the fair utilization of coastal resources. To prevent resource production waste due to an open conflict, a change in the status quo will substantially move this conflict forward. Policymakers and stakeholders should respond with equal force in terms of cooperation and political will to change DM's preferences or improve strategies in the future. Sustainable issues such as poverty alleviation, economic inequality, equity and empowerment, education, water, food security, and health should be central in conflict-reversal policies for the fishing communities. Consequently, scarce resources can be committed to these fishing communities' prioritized sustainable needs (strategies).

Acknowledgments

The authors appreciate the financial support from the National Natural Science Foundation of China 71971115 and 71471087. We also, express our profound gratitude to the Editor and the anonymous referees for their dedication to improving the quality of this research.

Data Availability

The authors of this paper confirms that all data generated or analysed during this study are included in this published article. Furthermore, primary and secondary sources and data supporting the findings of this study were all publicly available at the time of submission.

Conflicts of Interest

The authors declare no conflict of interest.

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