An Analysis of the Social Implications of CO₂ Capture and Storage (CCS) Technology

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ABSTRACT

Background: The increasing trend of energy demand worldwide had caused the excessive natural gas production over the decades. This has substantially increased the current level of CO₂ emitted to the atmosphere and significantly aggravates global warming. As a mitigation measure, carbon capture and storage (CCS) was introduced. Several studies have been conducted globally to investigate the social implications of CCS on the society. However, no such studies have been carried out in Malaysia.

Objective: This paper has therefore proposed a study to investigate the full range of social issues that could be the major concern of the stakeholders pertaining to CCS initiatives in Malaysia by using Fuzzy Delphi Methods (FDM) and Interpretive Structural Modeling (ISM).

Results: A conceptual framework was developed to define the determining social issues that may impact on the CCS implementation in Malaysia.

Conclusion: This paper provides insights on the utilization of two sophisticated proposed methods in the investigation of societal aspect of CCS initiatives in Malaysia.

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INTRODUCTION

Malaysia is the second largest natural gas producer in Southeast Asia and the second largest exporter of liquefied natural gas [1]. In fact, Malaysia’s energy industries is playing critical role for the growth of the entire nation’s economy. The increasing trend of energy demand worldwide had induced the country’s excessive natural gas production over the decades. This has substantially increased the current level of CO₂ releases to the atmosphere and significantly aggravates global warming. Therefore, in the effort to commercialize the natural gas reserves, there is an urgent need for Malaysia to develop technologies for the effective capture, utilization and storage of CO₂.

In view of the above, Malaysia through Ministry of Natural Resources and Environment had taken the lead role in the development of a national roadmap to mitigate climate change by reducing the emissions of greenhouse gases (GHG) [2]. Serious efforts were seen from the Ministry of Energy, Green Technology and Water (KeTTHA) to conduct a Carbon Capture and Storage (CCS) Scoping Study to discover the specific potential of CCS development in Malaysia [2].

However, the implementation of CCS technologies in Malaysia would raise the concern of diverse groups of stakeholders in terms of the technologies’ suitability, viability, adaptability and majorly societal acceptability. Studies have shown that the main key driver to the successful implementation of CCS technologies is the social acceptance level regardless of how promising the technologies are in forms of its technological and economic aspects [3].

Therefore, it is crucial for Malaysia to examine the social dimensions of CCS technologies prior to its implementation. In ensuring the success of the initiative, it is essential to recognize the diverse groups of stakeholders, their involvement, their relationships among each other and their sensitivity towards social implications of the CCS implementation.

The perceptions of stakeholders towards the technologies may vary due to its associated
uncertainties and perceived risks [4]. Thus, various studies have been conducted by institutes such as Global CCS institute (GCCSI), ACCSEPT, NEARCO2 and CSIRO, to name a few. The mutual goal is to measure the social acceptance level of the CCS program. Those studies indicated that the level of stakeholder perceptions on the CCS technologies could influence the level of their acceptability towards the technology itself. Therefore, their role should not be neglected even if they are categorized as a group that has the least knowledge and experience of CCS technologies. In view of that, it is significant to incorporate and emphasize stakeholder management in CCS implementation to manage the possible issues that may concerned by all level of stakeholders.

Literature Review:
Stakeholder Theory:
Stakeholder theory has its origins in management literature [5]. The stakeholder theory was introduced when the word, “stakeholder” first appeared in a research conducted by Stanford Research Institute in 1963 [6]. Freeman personally defined stakeholders as “those group without whose support the organization would cease to exist” [6]. Since then, the stakeholder concept was further expanded into four different disciplines namely corporate planning, systems theory, corporate social responsibility and organization theory [7]. The development of stakeholder literature was continued with the emergence of a remarkable book entitled “Strategic Management: A Stakeholder Approach” written by Freeman in 1984. He defined stakeholders as “any group or individual who is affected by or can affect the achievement of an organization’s objectives”. In his book, Freeman proposed that there are at least three levels of stakeholder analysis which known as rational, process and transactional [6]. He described the three levels of stakeholder analysis as following [6]:

At the rational level, an understanding of “who are the stakeholders and what are their concerns?” is essential. At the process level, it is necessary to understand the organization processes used to either implicitly or explicitly manage the organization’s relationships with its stakeholders. In conjunction with that, it is important to consider whether these processes fit with the rational of the organization’s stakeholder map. At the transactional level, the understanding of the set of transaction and bargains among the organization and its stakeholders is important. This is due to the negotiation made must fit with the organization’s stakeholder map. According to Freeman, by understanding the legitimacy of the stakeholders and having the ability to deal with their concerns can lead to successful transaction within the stakeholders.

The stakeholder literature continued to spread whereby Donalson and Preston argued the descriptive, instrumental and normative views of stakeholder theory [8]. Further, the stakeholder literature extended into wider areas like dynamics of stakeholder and stakeholder theories [7]. The most notable work regarding on this concept was contributed by Mitchell, Agle and Wood in 1997[9]. They proposed three attributes to identify the dynamics of interaction among the stakeholders which include power, legitimate and urgency [9].

The core idea of the stakeholder theory reflected that each of the stakeholder group has its own stake and interest which should be determined. It is justified that none of a single stakeholder group in an organization should be isolated in the pursuit of the business success. Identifying the stakeholder groups and managing the groups by driving them to the same direction of the business focal point are the essence of stakeholder management.

Stakeholder management has emerged as an important weapon in solving business problems [6]. A lot of authors have highlighted the importance of stakeholder management as a key factor for project success [10],[11],[12],[13]. An array of stakeholder management approaches have been developed in different sectors such as project management [11], protected areas management [14], sustainable land management [15], to name a few. The aims of the stakeholder management in those sectors are mutual in which the approach seeks to identify the diverse groups of stakeholders and manage these stakeholder groups by creating positive relationships among them through appropriate planning and management.

Stakeholder Issues and Social Impacts of CCS:
As mentioned in the previous discussion, stakeholder management emphasized on the identification of stakeholder groups and the strategies to manage those groups for project success. In spite of that, the stakes of each of the stakeholder group in terms of their position, responsible and concerns should be determined at the prior stage for better management plans. In CCS projects, various studies have been conducted to investigate the issues raised by the stakeholders pertaining to the CCS technologies. Majority of the studies are in European context. Among the examples, stakeholder issues determined by past studies included the scope of climate change, environment, health and safety, negative and positive position of CCS, limited finance resources, limited CCS knowledge, lack of trust to government, to name a few [3], [16],[17].

Carbon Capture and Storage:
CCS is mainly consists of three processes, namely capture, transport and storage. Generally, it is defined as a process consists of the separation of CO2 from industrial and energy-related sources, transport to a storage location and long-term isolation from the atmosphere [18]. In other terms, CCS is best known as a climate change mitigation option to stabilize the
concentration of CO₂ level in the atmosphere [18]. The International Energy Agency (IEA) states that CCS could reduce global CO₂ emissions by 19% and the cost to combat climate change could be 70% more without CCS [19].

At present, there are three basic methods to separate gases which include gas separation with solvents, gas separation membranes and Cryogenic separation. The typical solvents used for gas separation is amine. By far, amine scrubbing technology is the most well established technology used to capture CO₂. Gas separations with membranes allow one component in a gas stream to pass through faster than the others. Cryogenic separation can separate CO₂ by cooling and condensation.

CO₂ transportation is a process of transporting the separated and compressed CO₂ to the storage location by using pipes or CO₂ tankers [18]. Pipelines are preferred for transporting large amounts of CO₂ for distances up to 1000km. For amounts smaller than a few million tons of CO₂ per year or for larger distances overseas, application of ships for CO₂ transportation could be more economically attractive.

There are four alternatives to store CO₂ which included transformed into solid inorganic carbonate through chemical reaction, directly used in industry or as the raw materials of many carbon chemicals, injected into the ocean deeper than 1000m and lastly injected into underground rock [18]. The last option would be most preferable due to its high potential to increase Enhanced Oil Recovery (EOR) and Enhanced Coal Bed Methane (ECBM).

**Conceptual Framework:**

The conceptual framework of this study is shown in Figure 1. The underpinning theory in this study is Stakeholder Theory. As discussed in the literature reviews, stakeholder management is vital for the success of new technology adoption. The theory itself concerns with the identification of stakeholders and their interest towards the project.

![Conceptual framework](image)

**Fig. 1: Conceptual framework**

**Methodology:**

- Data Collection
- Data Analysis
  - Stakeholder Analysis
  - Stakeholder Mapping
- Fuzzy Delphi Method (FDM)
- Result (Model)
- Recommendation
This study will be conducted using hybrid methodology via fuzzy Delphi methods (FDM) and interpretive structural modeling (ISM). FDM is applied to investigate and synthesis possible number of social issues impacted by CCS based on experts’ views (consist of diverse group of stakeholders). The synthesized social issues determined by FDM will be ranked accordingly based on their computed importance level. The critical social issues finalized by FDM will be used to develop the stakeholders’ management model using ISM via another panel of experts. Through the experts’ collective views, the model will be constructed based on the relationships among critical social issues to aid in constructive view of CCS management. The details of both of the methodologies will be explained more concisely in following sub-section. A research methodology framework is constructed in order to provide a more explicit view of the methodology flows in conducting the entire study.

A. Phase 1: Stakeholder Identification:

The aim of this phase is to identify the stakeholders that involved in Malaysia CCS project. First, the researcher will conduct an extensive literature search to obtain project background information relevant to CCS. Through the literature found, the key stakeholders of CCS project are to be identified. Next, preliminary interviews will be conducted with CCS experts such as personnel from Ministry of Energy, Green Technology and Water (KeTTHA) and academia for the purpose to identify the stakeholders involved in Malaysia CCS initiatives. Additional stakeholders will be further identified through snowball sampling.

B. Phase 2: Stakeholder Analysis:

In this phase, the researcher will conduct stakeholder analysis (SA) to investigate what are the social issues that may raised by stakeholders pertaining to CCS initiatives in Malaysia. Previously, Stakeholder Analysis (SA) was implemented within few areas such as Nature Resource Management [20], urban development [21], land management [15], hydropower projects [22], to name a few. However, in this study, the stakeholder analysis (SA) will not be conducted by implementing those traditional and practical approaches used in the past studies such as focus groups, interviews, power/interest matrix, Social Network Analysis (SNA) and Stakeholder Circle methodology. This is due to those mentioned approaches are unable to apply to rank the importance of the determining social issues impacted by CCS initiatives accordingly. Hence, Fuzzy Delphi method (FDM) will be used in this study to accomplish the study.

Fuzzy Delphi method (FDM) was introduced by Kaufman and Gupta in 1988[23]. FDM is a combination of traditional Delphi method and fuzzy set of theory [24], [25]. It is used to obtain the consensus of experts’ views on the use of quantitative methods for problem solving. The introduction of FDM as an effective measurement tool has overcome the shortfalls of the traditional Delphi method. The traditional Delphi method has been criticized due to its weaknesses of low convergence in generating results and long process of interrogation in meeting experts’ consensus which sometimes impacts on the accuracy of the data [26],[27].

To employ FDM, a detailed list of possible determining social issues impacted by CCS initiatives will be created through an extensive review of literatures. Next a set of questionnaires pertaining to the determining social issues will be constructed and distributed to the selected panel of experts. Those experts will be asked to rank each of the social issues by using a 7-point linguistic scale. Approximately 10 to 15 experts will be invited to participate in this study to obtain the FDM result. According to Adler and Ziglio, the involvement of 10 to 15 experts in the Delphi method is considered as appropriate for the study [28]. Once the researcher completed collecting all the expert’s views from the questionnaires, the researcher will initiate data analysis by using Fuzzy Delphi method (FDM). In this study, the researcher will adapt and follow the steps of using FDM proposed by Mohd Ridhuan [24]. The whole process of using FDM involves six (6) steps as following:

(1) Make assumption, K. Assume K experts are invited by the researcher to determine the importance of the evaluation criteria of the variables (social issues) that will be measured by using linguistic variables.

(2) Convert all the linguistic number to triangular fuzzy number. Assume that the fuzzy numbers are \( r_{ij} \) variable for each of the criteria for experts K for \( i = 1, \ldots, m; j = 1, \ldots, n; k = 1 \ldots K \) and \( r_{ij} = 1/K (\pm r_{ijL} \pm r_{ijM} \pm r_{ijU}) \). Table below shows the seven-point scale of linguistic variables that will be applied in this study.

<table>
<thead>
<tr>
<th>Linguistic Variable</th>
<th>Fuzzy Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely unimportant</td>
<td>0.0</td>
</tr>
<tr>
<td>Not very important</td>
<td>0.0</td>
</tr>
<tr>
<td>Not important</td>
<td>0.1</td>
</tr>
<tr>
<td>Fair</td>
<td>0.3</td>
</tr>
<tr>
<td>Important</td>
<td>0.5</td>
</tr>
<tr>
<td>Very Important</td>
<td>0.7</td>
</tr>
<tr>
<td>Extremely Important</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Table 1: Seven-Point Scale of Linguistic Variables
(3) **Determine the threshold value.** The distance between two fuzzy numbers represents the threshold value, d. Therefore, apply the vertex method to calculate the average distance between $r_j$ for each of the experts involved. The distance between two fuzzy numbers $m = (m_1, m_2, m_3)$ and $n = (m_1, m_2, m_3)$ is computed using the following formula:

$$d(m, n) = \sqrt{\frac{1}{3}(m_1-n_1)^2+(m_2-n_2)^2+(m_3-n_3)^2}.$$

(4) **Determine the group consensus.** If the threshold value, $d$ is less than 2 ($d \leq 0.2$), this means that the expert consensus has been reached [29]. Furthermore, the percentage of achieving group consensus among the experts must be more than 75% in order to proceed to the next step [30]. If the data is found less than 75% of expert consensus, the second round of FDM is required.

(5) **Aggregate fuzzy assessments.** Determine the aggregate fuzzy evaluations by summing up all the fuzzy number for each variable and sub-variable.

(6) **Defuzzification process.** For each alternative, fuzzy evaluation $A_i = A_j = (a_1, a_2, a_3)$ in defuzzification with $a_3 = \frac{1}{4} (a_1 + 2a_2 + a_3)$. Alternative ranking order of preference can be determined according to the value of $a_i$.

**C. Phase 3: Stakeholder Mapping:**

In this phase, the researcher will apply the Interpretive Structural Modeling (ISM) to develop a model for stakeholder management relating to social implications of CCS initiatives in Malaysia. This model would allow to map and analyze the interrelationships among the social issues impacted by CCS initiatives that finalized by Fuzzy Delphi Method (FDM) at the previous phase. Interpretive Structural Modeling (ISM) was developed by Warfield in 1973 for managing and structuring complex problems [31]. Warfield defined ISM as “a computer-assisted learning process that enables an individual or a group user to develop a structure or map showing interrelations among previously determine elements according to a selected contextual relationship”[32]. It is a powerful and reliable decision-making tool due to its application that incorporating experts’ views and judgments to understand the interconnections among the criteria (social dimensions) and sub-criteria (social issues) in a study [33].

In this study, the researcher will adapt and modify the process of Interpretive Structural Modeling proposed by Janes to investigate the complex social issues impacted by CCS initiatives [34]. The whole process involves six (6) steps as following:

1. **Identify issue to be studied.** It is crucial to identify clearly which issue is to be explored using ISM software from the initial of the study. As it can be seen from the conceptual framework (please refer to section IV), the main purpose of this study is to investigate the social issues impacted by the CCS initiatives. ISM technique is used to explore the priority social issues that may raise by the stakeholders and the interrelations among the set of social issues determined by FDM;

2. **Select participant group and facilitator.** The selection of the panel of experts must be assembled from the relevant field such as specialists (who with certain extent of content knowledge relevant to the studied topic) and stakeholders (who may be affected directly or indirectly by the outcome of the investigation) to ensure the reliability of the entire study [34]. The method of experts’ selection has been explained concisely at section V (A). The examples of the experts comprise of individual from different stakeholder group categories such as NGOs, policy makers, investors, regulators, etc. based on ISM technique, the group size of the participants (experts) is limited to 8-10 individuals. This is due to as the group size increase; the quality of debate deteriorates [34]. By considering each of the experts can converse with each other, the number of communications between them is presented as $n$ (n-1). Therefore, an increase in a group size from 5 to 10 will result in the number of possible communications trebling from 20 to 90 theoretically.

3. **Deciding on type of ISM to be constructed.** It is important to decide which type of structure to be constructed during the ISM session at this stage. This study will undertake to build Attribute Enhancement Structure to show the interrelationships between the set of social issues determined by FDM;

4. **Develop a structural self-interaction matrix (SSIM).** SSIM shows the relations among the elements (social issues). This is a stage where ISM software is used. The set of elements determined by FDM is entered into the computer. The software would generate the pairs of elements and next display to the experts. All experts will be asked to decide the relationship of the paired elements put by the computer through voting. The example of the question is in the form: “Would issue A has the relation to issue B?” This process will be repeated until all the elements were paired for relationship [35];

5. **Generate the model and display the ISM.** When all of the elements pairing are completed, a reachability matrix will be formed with the aid of discrete mathematic. It is computerized by the software. Next, the software will extract a multi-level digraph from the matrix. At this point, an interpretive structural model is produced and ready to be displayed to the panel of experts for further evaluation and discussion;

6. **Discussing and amending the structure.** At this stage, the facilitators will bring the group through a qualitative discussion on the constructed ISM. The facilitators will first explain the structure of the ISM to the experts so that they able to
understand clearly how to interpret it and further express their view on it. The experts are allowed to suggest amendments to the structure if any. However, the changes should only be made if there is a reasonably strong desire among the majority voice of the experts.

D. Phase 4: Policy Recommendation:

At this stage, the researcher will write the policy recommendations for CCS technology based on the constructed Interpretive Structural Model. Those policy recommendations are not solely based on researcher’s personal opinion, but they are based on the synthesis output generated by experts’ views. Therefore, it is claimed to be highly reliable.

Conclusion:

Stakeholder management is vital in determining the success of new technology adoption. Based on past studies, no matter how promising and viable is the technology from technical, economical or any other aspects, it should be socially accepted by all levels of stakeholders. Thus, it is more than essential to identify the variety of ‘stakes’ from different levels of stakeholders and take all their concerns into account in order to ensure the success of the technology implementation. This study will analyse the interrelations between all the possible social issues raised by the stakeholders using Fuzzy Delphi Methods (FDM) and Interpretive Structure Modelling (ISM).

This study highlights various levels of stakeholders’ perspectives on social issues that impacted by CCS technology which in turn could be significant for future implementation plan. The findings of this study could be useful for decision makers of CCS program in structuring CCS related policies in future. Furthermore, the outcomes of this study will be important for policy recommendation to the government on social issues implicated by CCS initiatives in Malaysia.

REFERENCES