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# A Consistency-Checking Consensus-Building Method to Assess Complexity of Energy Megaprojects

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**Abstract**

World energy needs are predicted to be 50% higher in 2030 than in 2007. As a result, an increasing number of energy megaprojects are being considered by governments and enterprises. Megaprojects are defined by their size, complexity, long duration and high demands on resources and technology. The practice and outcomes of megaprojects have shown an alarming rate of failure, with complexity aspects having been recognised as one of the main causes of these failures. Existing research scarcely exhibits robust methods for complexity evaluation which can be used effectively in practice. This research aims to tackle this problem by developing a Project Complexity Assessment (PCA) tool robustly built using a mathematical Group Decision Making (GDM) method integrating consistency-checking and consensus-building processes. Firstly a taxonomy of Project Complexity Indicators (PCIs) is introduced to establish the underpinning structure of the method. Then, an approach integrating the Delphi and Analytic Hierarchy Process (AHP) was opted for to elicit the consolidated weights of the PCIs. In the process of GDM, it is required that experts reach a high level of consensus between them. Also in any decision making method, only consistent and rational information which does not entail any type of contradiction should be applied in the process. Therefore a method is proposed to integrate a new automatic consistency checking process with a consensus building system. This advises experts how to change their judgements towards an aggregated consensus. Finally, robust numerical rating criteria were developed for all PCIs, critically enabling the use of the produced PCA tool in practice. Such an application is demonstrated in an energy megaproject case study, highlighting the potential benefits of the produced PCA tool in practice.

**Keywords:** ***Energy megaprojects, complexity assessment, Delphi, Analytical Hierarchy Process, Group Decision Making, consistency checking, consensus building.***

## 1. Introduction

Energy may possibly be the most essential resource the world will be in need for in the future. The global need for energy has surged dramatically in the first decade of the twenty-first century, more than any other analogous period in human history, resulting in very large and complex energy infrastructure projects being undertaken. These so called megaprojects are commonly defined as projects with a capital investment of at least one billion U.S. dollars; they are characterised as complex, costly, with long time frames and high levels of uncertainty (Flyvbjerg et al. 2003; Merrow 2011). Typical energy megaprojects include oil and natural gas extraction fields and refineries, large hydroelectric, nuclear or other types of power stations, and renewable energy projects such as wind and solar farms.

Unfortunately, these megaprojects are experiencing alarming rates of failure in meeting their business goals, their capital budgets and their delivery schedules. The energy sector alone reported high rates of project failure. A specific report on the energy sector by the Independent Project Analysis (IPA) involving 318 projects across the

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world, clearly demonstrated a downfall in the performance of energy megaprojects (Merrow 2012). It highlighted 78% of projects were disappointing; there was an average of 33% real cost overruns and 64% of these projects experienced serious production shortfalls in the first 2 years of operation. Problematic aspects of failures are identified where the inability to adequately determine and manage project complexity was considered as the largest risk to successful delivery of energy megaprojects.

With the increasing recognition of project complexity as a critical component of project delivery, particularly in the context of energy megaprojects, an immediate need for research in this area has been recognised. However, the project complexity discipline has not been effectively understood and is often perceived as a difficult subject to communicate about. Therefore new and robust methods and tools for assessing and managing project complexity need to be developed. This research reports a new Project Complexity Assessment (PCA) tool that enables quantitative measurement of the level of complexity for any energy megaproject. The tool has been developed using a new GDM method. The paper's main focus is to tackle the common defects of existing GDM methods applied to project complexity evaluation that are: lack of comprehensive determination of project complexity indicators; lack of robust consistency and consensus processes to elicit the weighting of PCIs; and lack of effective definition of quantitative rating criteria. The practical application of the produced PCA tool is demonstrated with an energy megaproject case study.

This paper is organised as follows: section 2 reviews current approaches and methods on project complexity evaluation; section 3 introduces the GDM method adopted in this study; section 4 presents a newly developed taxonomy of project complexity indicators; section 5 demonstrates the process of consistency-checking consensus-building within an integrated Delphi-AHP method to elicit the weights of indicators; section 6 presents the development of numerical rating criteria for all PCIs; section 7 demonstrates the practical application of the proposed PCA tool through a case study; and finally section 8 discusses the results and presents conclusions..

## 2. Research background

Complexity is recognized as one of the main idiosyncratic attributes of megaprojects and, at the same time, a cause of failure in energy megaprojects. Sovacool & Cooper (2013) mentioned complexity as the most unknown and pathless attribute of megaprojects that needed to be addressed. This issue has led to many works on project complexity being carried out in recent years. But the efforts to date seem to have generated more confusion than precision, as complexity and project complexity have been interpreted in many different ways. This research considers a more specific realisation of project complexity, introduced by Williams (1999), as it explains that project complexity increases as a result of swift changes in the environment, enlarged product complexity and increased project-time pressure. Recent research (Bosch-Rekveldt et al. 2011) demonstrated project complexity is characterised by a number of indicators, but their categorisation has not been consistent or agreed.

In addition, criticism has been directed towards current research for its inability to be implemented in practice. Little et al. (1998) and Williams (2002) have expressed the significance of objective and quantitative evaluation of complexity; also it has been suggested that any practice driven complexity assessment method should entail explicit objective measures (Remington & Pollack 2007). Yet, until recently, studies on project complexity have been mostly devoted to the conceptual aspects of project complexity (Maylor et al. 2008; Kardes et al. 2013). Recent research has been designed to measure levels of project complexity (Vidal et al. 2011; He et al. 2014). The GDM method was selected as the main methodology of these works; however their accuracy, practice applicability and completeness are challenged by the following three issues: (1) The indicators contributing to project complexity are not fully identified and haven not been organized in a standard categorisation, or taxonomy; (2) The proposed methods mainly neglected the process of consistency checking and consensus building, resulting in imprecise final results; (3) The development of objective and numerical rating criteria for all PCIs has been entirely omitted from those.

This study aimed to address the defects of current methods of project complexity assessment by proposing a new method. The main focus of work reported in this paper is on the process of consistency checking and consensus building via a GDM method and then demonstrating the practical application of the method. Other elements, such as taxonomy of PCIs and rating criteria, are briefly explained, with more details available in (Kian M.R & Sun 2014) and another forthcoming publication.

## 3. Research method

The methodology adopted in the research has three steps:

*Step1- Establishing taxonomy of project complexity*
A comprehensive literature review produced a compiled list of PCIs. Then a qualitative synthesis was carried out to merge similar indicators and obtain a final list of 51 PCIs. Those PCIs were then categorized within a logical hierarchical semantic structure. The outcome is a taxonomy of PCIs for megaprojects.

*Step2- Eliciting consolidated weights of PCIs*
An integrated GDM Delphi-AHP method has been implemented with a panel of 20 experts (10 academics and 10 industry practitioners). AHP matrices were used to get the comparative ranking weightings for different indicators. To gain an acceptable level of consensus, two rounds of the Delphi method were carried out.

*Step3- Quantifying level of project complexity*
Rating criteria are essential components in the process of quantifying project complexity. Numerical rating criteria for all PCIs are defined on the basis of the comprehensive literature review and synthesis. Accordingly, the project complexity level can be quantified using a spreadsheet PCA tool.

## 4. Taxonomy of project complexity in megaprojects

A taxonomy is a classification of a large number of related concepts into a logical hierarchy. The taxonomy of PCIs for megaprojects is established to provide a clear, simple and effective structure to understand the factors influencing project complexity. The PCI taxonomy is also essential for the next step of the PCA tool development process, which involves establishing a weight for each PCI using the AHP method.

The development of the taxonomy followed the principle of the PRINCE2 project management standard (Office of Government Commerce 2009). It adopts a hierarchical structure with several levels. At Level 1, two distinct categories of PCIs are distinguishes: Internal and External PCIs. External indicators are mainly those outside the direct control of the project delivery organisation and relate to external stakeholders like governments or markets. In contrast, internal indicators are those within the control of the project management team. Figure 1 shows the taxonomy structure, with the levels 1-2 of external PCIs and levels 1 to 3 of internal PCIs. As an example, Table 1 presents the detailed taxonomy of all external PCIs. The development of the taxonomy and presentation of internal indicators are discussed in (Kian M.R & Sun 2014).

Table 1: Taxonomy of PCIs - External factors

| Level1 | Level2 | Level3 |
|---|---|---|
| External (E) | Economy (EC) | Changing economy |
| | | Market competition |
| | | Market unpredictability and uncertainty |
| | Environmental (EN) | Stability of project environment |
| | | Interaction of technology system and external environment |
| | Legal & regulations (LE) | Local laws and regulations |
| | Politics (PO) | Political influence |
| | Social (SO) | Cultural configuration and variety |
| | | Cultural differences |
| | | Significance on public agenda |

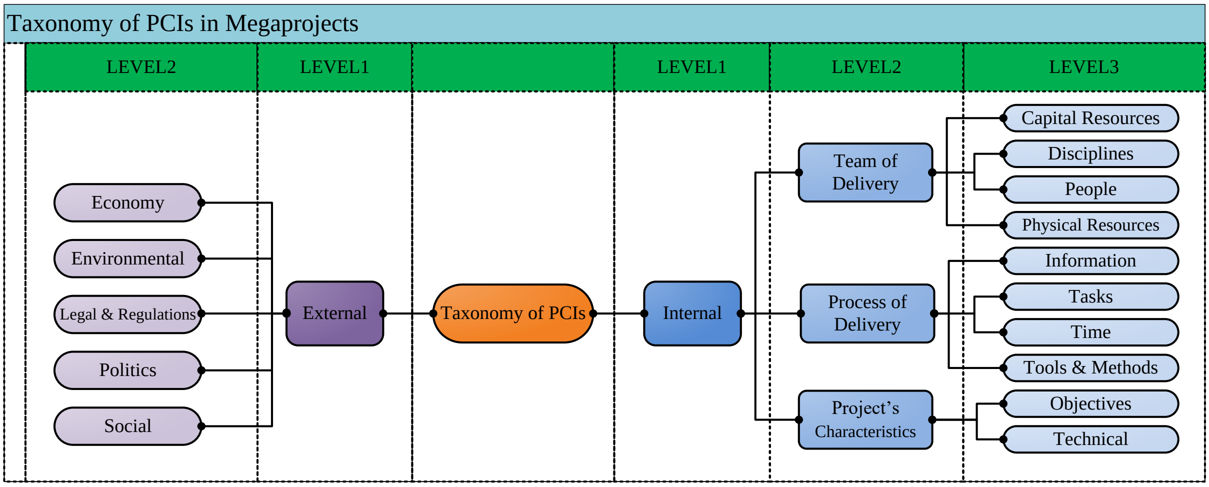


Figure 1: Taxonomy of Project Complexity of Megaprojects

## 5. Eliciting Consolidated Weights of PCIs

The various PCIs may have different levels of significance. Therefore, different weights should be attributed to these indicators in order to reach a reliable assessment. In complicated problems like eliciting weights of PCIs, as the problem becomes more complex and the problem environment becomes larger and interconnected, the process of problem solving requires knowledge and information from many disciplines; probably no single opinion is adequate (Krishnaswamy & Sivakumar 2009). The Group Decision Making (GDM) method is a process to find a plural answer to a decision problem, where a group of experts exhibit their judgments about multiple alternatives (Zhang et al. 2014). There are two processes to carry out before obtaining the final solution (Herrera-Viedma et al. 2002): (1) the selection process, and (2) the consensus process. To execute the selection process, AHP is often used, and has been highlighted as the most appropriate tool for measuring the complexity of projects (Vidal et al. 2011). AHP is an approach which is based on the relative evaluation and ranking of alternatives, more specifically pairwise comparisons of alternatives, which results in the calculation of a weight for each alternative (Saaty 1989). AHP compares all indicators, but only two indicators at a time. It is therefore possible that successive pairwise judgments are inconsistent and may even contradict with one another. This study adapted the method of Chiclana et al. (2008) to automatically identify and resolve such inconsistences. The consensus building process refers to how to achieve the maximum degree of consensus or agreement within a group of experts on the solution-set of alternatives. The Delphi method is often used for the consensus process (Skulmoski et al. 2007). The Delphi method is a survey technique for obtaining consensus among anonymous experts via an organised feedback process (Krishnaswamy & Sivakumar 2009). Consequently, this research developed a Delphi-AHP method to elicit weights of indicators, while maximum consensus and consistency are regarded.

As highlighted above, two challenges during the process of Delphi-AHP are ensuring *consistency* of judgement of individual experts and *consensus* amongst the group of experts. Several studies have proposed consistency and consensus measures in GDM (Herrera-Viedma et al. 2002; Herrera-Viedma et al. 2014). Zhang et al. (2014) offered a comprehensive review of the advantages and drawbacks of these studies; in particular they found that the method developed by Chiclana et al. (2008) is one of the most effective ones. That method employs transitivity properties of criteria in a mathematical procedure to retain original values of judgments in an optimal level, whilst obtaining acceptable consistency and consensus levels. Therefore, this study adopted an integrated consistency-checking consensus-building method, based on the model from Chiclana et al. (2008), but with some additional developments to it. Figure 2 summarises the steps of the integrated Delphi-AHP method:

1. *Selecting experts:*

The first step is to identify, nominate and select the most appropriate experts for the panels, following a Knowledge Resource Nomination Worksheet (KRNW) method (Delbecq et al. 1975). Using the KRNW helped ensure there are no gaps in the skills of the expert panel. From 78 candidates, 20 experts including 10 academics and 10 professionals participated in the research. Experts qualified with high levels of knowledge on megaprojects and the energy sector.

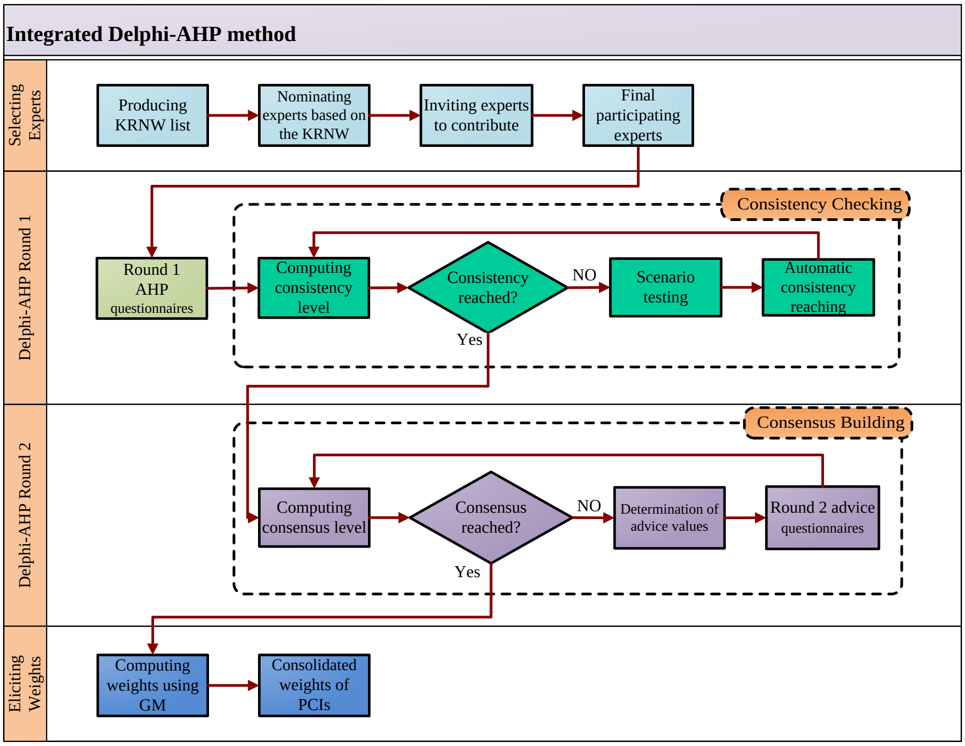


Figure 2: Integrated Delphi-AHP Consistency-checking Consensus-building method

2. *Delphi-AHP round 1:*
   To elicit the weights of the PCIs, the experts were asked to conduct pair-wise comparisons of complexity indicators in each category of the taxonomy, using a 1-9 Saati scale. Twelve AHP matrices were provided based on the taxonomy, comprising one matrix of external PCIs in level 2, one matrix of PCIs at level 3 and ten matrices of sub-categories of the internal category in level 4. Experts were asked to express their judgments based on their general knowledge/expertise rather than any specific project.
3. *Consistency checking:*
   In GDM problems, consensus of experts' judgments is usually reached on the basis of rationality principles that each expert exhibits. The requirement of rationality demands consistency of judgement from each individual expert. Therefore, the task is to evaluate the degree of consistency of each individual expert, and improve it to an acceptable level (a consistency threshold value $\beta = 0.9$) if required. To do so, inconsistent judgments are first identified from Delphi-AHP Round 1 results. They are amended with recommended values automatically generated following the method proposed by Chiclana et al. (Chiclana et al. 2008). It is critical not to violate the initial judgments of experts; therefore a scenario testing process was carried out to obtain the optimal of number of updates on inconsistent values. Overall, individual consistency of each expert was achieved by updating only 10.2% of the initial judgments.
4. *Delphi-AHP round 2 - Consensus building:*
   Consensus and common agreement should be obtained among all the experts regarding all PCIs. Although a full consensus is not always necessary in practice, a high consensus threshold $0.8 \leq \gamma \leq 0.9$ is defined. Firstly,

those experts and judgment values which should be reviewed are identified. They normally are the furthest individual values from the combined panel's judgement. Secondly, the experts are provided with advice values obtained by combining all judgment values of the panel. A questionnaire is sent comprising the round 1 judgment and advice values to each expert. Once all responses are received, the level of consensus based on the modified judgement values is re-evaluated. In our case, the initial consensus rate sat at cr = 0.75. After executing the consensus advice process, it increased to cr = 0.81, a satisfactory value suggesting the effectiveness of the proposed Delphi-AHP GDM process.

5. *Calculating weights for PCIs:*
   Once both consistency and consensus of judgments are achieved, the weight of each PCI can be computed using the following geometric mean formula:

$$w_i = \prod_{j=1}^{n} p_{ij}^{1/n} \qquad (1)$$

Where, $w_i$ is the weight of indicator *i* ($\in \{1, \dots, n\}$), $p_{ij}$ is the preference relation between indicator *i* and *j* ($i \neq j$), and $n$ is the number of indicators considered in the AHP pair-wise comparison matrix containing *i* and *j*.

## 6. Development of numerical rating criteria

Defining rating criteria is a critical component of developing a PCA tool. However, this stage is very often neglected in the existing studies and methods of project complexity evaluation. This study established rating criteria for all 51 PCIs, on the basis of an extensive literature review and synthesis. For example, Locatelli & Littau (2013) and (Locatelli et al. 2014) identified performance variables of energy megaprojects based on an analysis of eleven European cases. Also Brooks (2013) determined thematic influencing criteria extracted from the analysis of a European megaprojects portfolio. A content analysis has been carried out to group the indicators and criteria and form the rating measures. This provided a set of objective criteria for the "Significance on public agenda" indicator (Table 2). A 1-5 Likert scale is used to determine the numerical score of indicators, based on the identified rating criteria, where 1 indicates the least and 5 the highest complexity level. The defined rating criteria are mostly objective and can be understood and perceived effectively by decision-makers.

With all the components of the PCA method developed (indicators, global weights and scoring criteria), a Complexity Index (CI) can now be computed for any project using the formula:

$$CI = \sum_{i=1}^{n} w_i \times s_i \qquad (2)$$

Where $w_i$ is the consolidated weight of indicator $i$ ($\forall\ i \in \{1\dots n\}$), $n$ total number of indicators and $s_i$ is the awarded score to the indicator. CI receives values between 0 and 5, therefore the minimum total complexity value of a project is 0 (where all indicators are scored 0, which corresponds to inapplicability or lack of information for all indicators ) and the maximum value is 5 (when all indicators score 5). The complexity level of each category of taxonomy can be calculated similarly.

Table 2: Rating criteria for "Significance on public agenda" indicator

| Indicator | Criteria | Scores |
|---|---|---|
| Significance on public agenda | Regarding significance of project in public, how many of the following criteria are (will be) met?<br>a. Green Peace or other international environmental activists have been involved in the project<br>b. The project has national public acceptability (no protest at national level)<br>c. The project has local public acceptability (no protest at local levels)<br>d. Previous similar national/local project were successful<br>e. Local residents are involved in the project | 0: not applicable or no information<br>1: if 4 or 5 criteria are met.<br>3: if 2 or 3 criteria are met.<br>5: if 0 or 1 criterion is met. |

## 7. Case study

To demonstrate the application of the method in practice, a case study has been carried out with an offshore gas field reservoir development program. The field is considered as one of the world's largest reservoirs of natural gas condensates. Development of the field is planned in multiple phases; each phase is appraised to have an average capital cost of more than US$1 billion, and will be executed by international oil & gas contractors working in partnership with local companies. This case study is conducted on the development of two phases, referred to as A and B, which are at the tendering stage. The field development program has been delayed and interrupted due to different technical, contractual, financial and political issues. The development of the two phases is a typical example of energy megaprojects, so investigating project complexity will provide valuable information to help project management executives adopt appropriate complexity management strategies. The weighted indicators produced by the proposed PCA method are provided in a spreadsheet tool for project management executives of phases A and B. Also, in order to produce a reference, levels of complexity are computed for a set completed phases currently in operation. The level of complexity of each phase is assessed by project management executives and the final complexity level of each category is calculated. Figure 3: Weighted level of project complexity and final CIs

depicts and compares weighted aspects of project complexity and final Complexity Index (CI) of each project. The results enable decision makers to better understand the degrees of complexity in all aspects of the project, and therefore implement more effective mitigation strategies.

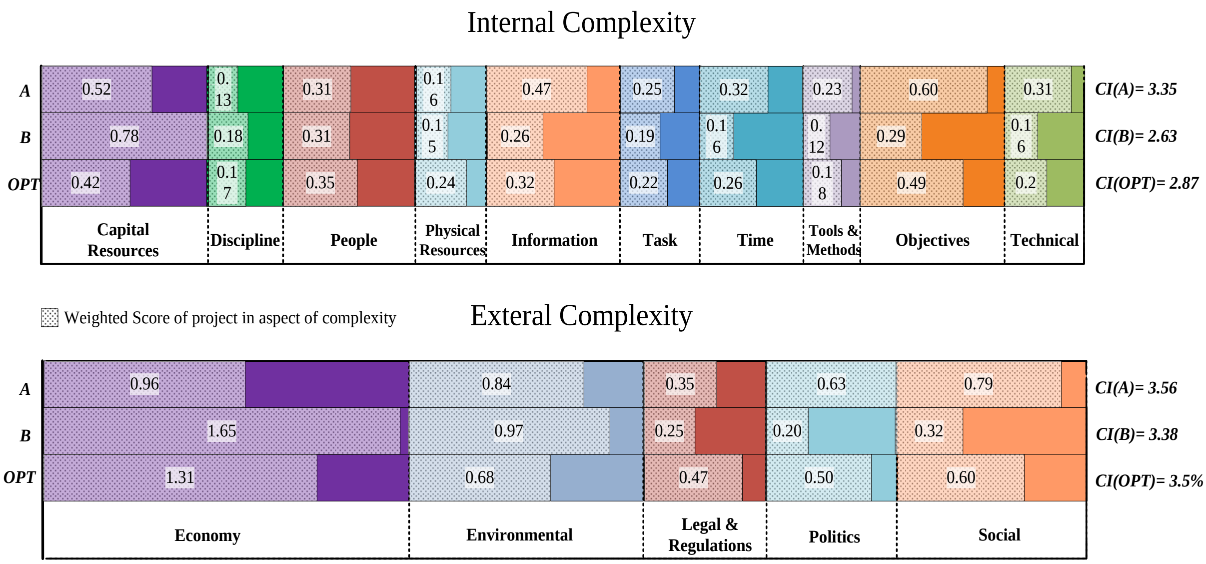


Figure 3: Weighted level of project complexity and final CIs

## 8. Conclusions

With the aim of increasing the chances of successful delivery of energy megaprojects, this research has proposed a new method to develop a PCA tool for energy megaprojects. The method comprises three stages: a) a comprehensive taxonomy of PCIs for energy megaprojects; b) an integrated Delphi-AHP method based on a robust mathematical model which effectively addresses the process of consistency- checking and consensus-building to elicit consolidated weights of PCIs; and c) the development of numerical rating criteria for each indicator, enabling managers to quantify the level of complexity in the project. This new method has shown some advantages, compared to similar research, including: completeness of the list of PCIs and the capability of the taxonomy to be used as a reference; applicability and ease of use in practice, as demonstrated in the case study; excellent reliability because of the robust theoretical background underpinning its development, and detailed rating criteria. The proposed tool can be used as a powerful aid in decision making science e.g. as a detailed input into project portfolio management, which could define a threshold value to reject or accept the project (e.g. level of project maturity of the company). One limit of this research was that only 20 experts participated in the GDM process; more participants would further increase the reliability of using the weighting obtained profile across energy megaprojects.

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