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Sustainable locating of petroleum refinery projects

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ABSTRACT

The Petroleum Refinery Industry (PRI) is notorious for its significant contribution to environmental degradation. Operations of refineries in local neighborhoods often lead to adverse impacts on the surrounding community and environment. However, PRI projects also yield positive effects on local, national, and international economies. Mitigating the negative consequences of refinery operations necessitates a scientific and quantitative approach to selecting refinery locations. This process should consider a multitude of parameters and alternatives, encompassing social and environmental resiliency, transportation factors, and product markets throughout the refinery life cycle, in an integrated manner. Quantifying the impact of these parameters on the triple bottom line is essential for informed decision-making.

In this study, we employ a previously developed integrated sustainability assessment framework in conjunction with a Multiple Attribute Decision Making (MADM) based scenario model to evaluate the impact of various location alternatives on the three pillars of sustainability. Despite the complexities inherent in refinery location decisions and the unpredictability of long-term and short-term parameters, this study's life-cycle approach offers a valuable tool for locating petroleum refineries.

1. Introduction

Petroleum Refinery Industry (PRI) projects are significant contributors to both environmental degradation and economic development globally. With an estimated 88 Million Metric Tons (MMT) of CO2 emitted annually [1], also regarding the toxic emissions released to the environment which is listed by EPA [2], petroleum refineries are central players in the energy sector, exerting considerable influence on both local and global scales. Despite their adverse environmental impacts, petroleum refineries play a vital role in driving economic growth, with purchases exceeding $693 billion in 2013 alone [3]. Also, this economic impact is expected to be increased. Despite the unpredictable crude oil price and its market supply and demand dependencies, North Sea Brent crude oil spot prices are predicted to rise to 204 dollars by 2040 [4]. On the other hand, in contrast to the common belief, PRI projects can have negative economic impacts as well. As an example, PRI projects produce emissions and wastes as byproducts which can have negative impacts if not dealt with properly [5]. However, the geographical distribution of petroleum refinery units, workforce allocation, typical products, and annual financial metrics have not been comprehensively addressed in the existing literature. Therefore, in this study, we aim to bridge this gap by providing a comprehensive overview of the geographical coverage of petroleum refinery units, workforce allocation, and financial data at regional, national, and international levels.

PRI projects are subjected to many sustainability assessment studies. For instance, petroleum refinery projects are investigated to comprehensively assess and calculate a sustainability index [6]. Also, in the assessment procedure, some decision environments have been created and a dynamic assessment framework has been developed to customize the assessment process to the specifics of any proposed PRI project [7]. In this study, our goal is to focus on the location of the refinery. Given the complexity of the process for selection of the location of the refinery, we will freeze all other parameters, such as the source of crude oil, the product(s) being produced, the plant process, and targeted markets, as

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each of these parameters may be governed by various economic, social, or political considerations which would complicate the study further.

Petroleum refineries are integral components of the global energy landscape, with significant implications for both environmental sustainability and economic development [8]. Understanding the geographical distribution, workforce allocation, and financial performance of petroleum refinery units is essential for comprehensively assessing their impact and significance. In this context, the authors present three tables providing empirical data on these key aspects of petroleum refinery operations. Table 1 offers insights into the geographical coverage and production capacity of refineries across different regions, drawing from authoritative sources such as the U.S. Energy Information Administration and the International Energy Agency.

Table 2 sheds light on workforce allocation within petroleum refineries, highlighting the substantial employment opportunities generated by this sector.

Financial data, including annual revenue and expenditure figures, are presented in Table 3, sourced from reputable sources such as The World Bank and S&P Global Platts.

Collectively, these tables offer a nuanced understanding of the multifaceted nature of petroleum refinery operations, informing discussions on sustainability, economic impact, and strategic decision-making in the energy sector.

2. Literature review

Petroleum refineries, with their intricate processes and diverse product outputs, inherently pose sustainability challenges. However, the aim of this study, along with similar research endeavours, is to evaluate sustainability and quantify environmental impacts to develop more sustainable alternatives with reduced adverse effects on the environment. A plethora of studies contribute invaluable insights into the measurement and mitigation of these environmental impacts.

2.1. Refinery literature

For instance, Almerud et al. [14] conducted a study on the Swedish Petroleum Refinery Industry (PRI), revealing encouraging findings regarding low personal exposure to benzene and 1,3-butadiene, suggesting potential advancements in occupational health and safety practices within refinery operations. Similarly, Anirudhan and Ramachandran [15] demonstrated the efficacy of surfactant-modified bentonite in mitigating water pollution, particularly in removing 2,4,6-trichlorophenol from water bodies and petroleum refinery industry effluents.

Addressing another critical facet, Rodrigues et al. [16] shed light on the challenges associated with air emissions management in petroleum refineries, emphasizing the complexities involved in obtaining permits for modernization projects. Additionally, Avci et al. [17] highlighted the impact of petroleum refinery industry activities on biodiversity, evidenced by peroxidation in the muscle and liver tissues of fish inhabiting a contaminated river.

Wastewater management is another crucial aspect, as highlighted by Kyriakopoulos [18], who explored the effects of immediate treatment on water quality, focusing on policies and protection perspectives. This study offers valuable insights into policies and strategies aimed at safeguarding water quality and protecting aquatic ecosystems.

Table 1
Geographical coverage of petroleum refinery units.

REGION	NUMBER OF REFINERIES	TOTAL ANNUAL CAPACITY (MILLION BARRELS PER DAY)
NORTH AMERICA	134	18.5
EUROPE	98	15.2
ASIA	265	32.7
MIDDLE EAST	110	26.8
AFRICA	50	9.6

Data sourced from Ref. [9,10]

Table 2
Workforce allocation in petroleum refinery units.

REGION	TOTAL WORKFORCE (THOUSANDS OF WORKERS)
NORTH AMERICA	210
EUROPE	150
ASIA	400
MIDDLE EAST	280
AFRICA	130

Data sourced from Ref. [9,11]

Table 3
Financial data of petroleum refinery units.

REGION	ANNUAL REVENUE (BILLIONS OF DOLLARS)	ANNUAL EXPENDITURE (BILLIONS OF DOLLARS)
NORTH AMERICA	520	360
EUROPE	380	250
ASIA	620	400
MIDDLE EAST	750	480
AFRICA	300	200

Data sourced from Ref. [12,13]

Apart from environmental impacts, the literature also focuses on refinery processes and environmental legislation. For instance, Drechsel et al. [19] discussed the challenges associated with implementing new source review requirements in petroleum refinery projects, while Kyriakopoulos [20] delved into environmental legislation in European and international contexts, particularly focusing on legal practices and social planning toward the circular economy.

In the broader context, Kikasu [21] explored the impact of the international environment on the development, restructuring, and upgrading of the petroleum refinery industry in the Democratic Republic of Congo, shedding light on the global factors influencing refinery industry development.

Innovative approaches to environmental restoration are also offered in the literature, such as Zamparas et al. [22], who provided valuable insights into the potential application of novel composite materials for lake restoration. Similarly, Zamparas et al. [23] examined the application of novel composite materials as sediment capping agents, highlighting their potential to mitigate sediment contamination and promote sustainable remediation practices.

Technology advancements in refineries are also crucial, as highlighted by Matsuo et al. [24], who discussed the selection of appropriate materials for desulfurizing plants within the petroleum refinery industry to ensure operational efficiency and longevity. Additionally, the application of blockchain technology in the complex supply chain of oil and gas operations was scrutinized [25]. Another applicable technology potentially can be digital twins, which also can be used in locating problems through real-time simulation. In this regard, a recent study researched the application of digital twins in future construction projects [26].

Finally, sustainability frameworks integrating the triple bottom line assessment are proposed in the literature, such as the quantitative sustainability assessment framework for petroleum refinery projects proposed by Hasheminasab et al. [27], providing a systematic approach to evaluating environmental and social impacts.

2.2. Locating literature

Finding the best location is one of the popular problems in operation research and one of the traditional optimization examples. Urban design in development and construction, as well as its integrated sustainability implications, have garnered researchers' attention in this area [28]. Additionally, construction development and increased urban density inevitably result in an increase in carbon intensity [29]. Besides, urban design with a higher level of city logistic centers is considered in the optimization of locating problems [30]. Site selection in construction projects is a strategic decision which is made at the very beginning stage of the project. The locating problem influences the stakeholders, local communities, local environment, natural resources, biodiversity, and is affected, in turn, by climate, topography, access to utilities, human resources, raw materials, and targeted markets. Another perspective is the result of the construction and development layout, contributing to creating 10 % of GDP while consuming 30 % of global energy and producing 40 % of GHG emissions. The application of technologies like machine learning, AI, and cloud computing can enhance the sustainability profile of cities and urban development endeavours and inform strategic locating problems [31].

There are a variety of studies conducted to find the best location for various types of construction projects. Locating energy industry projects, for instance, has been a frequent topic in the literature from renewable energies such as ocean thermal energy [32], solar power plants [33], wave energy plants [34], and wind energy farm [35] to nonrenewable energy projects such as optimal site selection for oil spill response centre [36] and locating a gas power plant [37]. Another important category belongs to infrastructural projects. As infrastructure and public utility services such as roads, medical facilities, and water distribution networks play an important role in improving the local quality of life, these projects are always investigated in locating research to improve the decision-making process. For instance, to find the best location for a hospital, scientific methods can be used [38] or a port project, as a major transportation infrastructure project can be located based on the existing research [39]. A construction site layout and the location of important site elements such as tower cranes [40], concrete batching plants [41], etc. can be determined as well. A proper construction site layout can contribute to construction productivity, safety, and other site requirements simultaneously.

The complexity of a locating problem would be greatly increased if the targeted project is a multidisciplinary mega-project such as a Petroleum Refinery Industry (PRI) project. For instance, the large production volume and the variety of products that are at stake, add transportation concerns to the list of parameters that need to be considered when locating such projects. PRI projects have been the subject of a variety of studies (e.g. Ref. [36,42]).

Selecting a sustainable location for a project site is undertaken at strategic decision-making levels before one starts dealing with specific design features of the site and the project. The considerations at the locating stage can include local climate conditions, access to public transportation, access to wastewater disposal systems, etc. Finding the most sustainable location for construction projects, programs, or portfolios is among the contemporary issues discussed in the locating literature from landfills [43] to wastewater plants [44] and so on.

A sustainable locating problem has to deal with the requirements of all three pillars of sustainability while catering to the diverse needs and interests of various stakeholders; as such the problem has to deal with a multitude of criteria. This is why Multiple Attribute Decision Making (MADM) is one of the popular methodologies applied to solve locating problems [33,35,43].

Besides, as finding the most sustainable location for a construction project is a strategic decision and affects all subsequent decisions, predicting the future is an important issue to be addressed in these problems. Thus, to cope with future uncertainties in this problem, a MADM-based scenario is applied in this study that puts more emphasis on scenarios compared to regular MADM's fixed decision framework. This methodology was developed by Hashemkhani and is applicable to scenario-based problems where every scenario can have independent and/or common criteria [45].

3. Methodology and data

In a recent publication, the authors of this paper developed a sustainability assessment indicator-based framework specifically for PRI projects [46]. In this study by using the developed framework, the location parameter has been focused on and investigated, while keeping other parameters fixed. To do so, as can be seen in Table 4, a focus group was organized and a brainstorming session was held, in which several available locations were suggested and discussed while keeping other parameters such as the source of the crude oil, the main products of the refinery, the targeted markets, and overall objectives fixed.

Subsequent to this step, the Fuzzy Delphi technique was utilized to calculate an index and rank the available locations to choose three of the most suitable alternatives. Afterwards, a MADM-based scenario, namely Weighted Aggregated Sum Product ASsessment (WASPAS) methodology, was used to compare the three location alternatives that were selected during the Fuzzy Delphi step. Scenarios are considered in three phases of the life cycle of the petroleum refinery which are Cradle-to-Gate, Gate-to-Gate, and Gate-to-Grave as defined in Table 5. In the following paragraphs, an introduction will be provided for the Fuzzy Delphi technique, MADM-based scenarios, and the WASPAS method.

According to the proposed methodology, PRI projects are divided into their life-cycle phases, and location alternatives are considered as different scenarios in the MADM-based scenario model which are assessed against a sustainability framework comprising quantitative factors as the set of criteria which are specifically developed for PRI projects. Thus, in addition to the site selection problem, the methodology contains other evaluations and assessments as follows.

- Independently assessing life-cycle phases for every single scenario
- Evaluating scenarios only for a single lifecycle phase (gate-to-gate for instance)
- Assessing single or multiple scenarios for a pillar of sustainability (environmental aspect for instance)
- Assessing single or multiple scenarios for one or more qualitative sustainability indicators (atmosphere and water in the environmental pillar for instance)
- Etc.

As can be seen in Table 2, life-cycle phases are divided into the following three phases. Obviously, this categorization is in line with a real refinery setting.

- **Cradle-to-Gate:** from the very beginning phase of the life cycle to the refinery entrance gate.
- **Gate-to-gate:** from the refinery entrance gate to the product gate
- **Gate-to-grave:** from the refinery product gate to the final phase of the lifecycle and disposal.

Table 4
Methodology map.

Methodology	Development Year	Phase
Literature review	Hasheminasab et al. [46]	Sustainability Indicator Framework
Focus Group (Brainstorming Session)		Generation of Location Alternatives
Fuzzy Delphi Technique	Zadeh [47]; Chang et al. [48]	Screen available alternatives
PMADM	Hashemkhani Zolfani et al. [49]	Considering sustainability and resiliency
MADM-based scenario - WASPAS	Siddiqi et al. [50]; Hashemkhani Zolfani et al. [51]	Locating a Sustainable Location
		Case Study (Real Petroleum Refinery)

Table 5

Petroleum refinery life-cycle modelling).

Phase 1		Phase 2					Phase 3			
Cradle-to-Gate		Gate-to-Gate					Gate-to-Grave			
Raw material		Pretreatment	Distillations		Enhancers		Products			
Crude oil	Procurement	De-salter	Atmospheric	Vacuum	Desulfurization	Reformer	Light Distillate	Middle Distillate	Heavy Distillate	Further Products

3.1. *Fuzzy Delphi*

Delphi is a popular MCDM technique that is widely used in different fields of science from nursing and medical to construction [52,53]. To consider ambiguities in decision-making environments, Lotfi Zade's fuzzy set theory can be readily applied [47]. Since the creation of the fuzzy set theory, different MCDM methods have been combined with fuzzy numbers to enhance the accuracy of the results. This has been done for the Delphi technique and the Fuzzy Delphi Method (FDM) is the outcome of this extension [48]. FDM is based on developing a fuzzy number based on experts' opinions obtaining the final result after defuzzification and converting the results to crisp numbers. The process is repeated until a consensus is reached in the final round. The methodology is briefly explained in the following paragraphs.

Step 1: Experts are asked to express their opinions by a grey number in a defined interval (e.g. 1 to 9). The interval would be divided into partitions and the fuzzy number would be developed based on the frequency of the experts' choices for a partition as follows:

$$y_s^{(p)} = \sum_{i=1}^{I} \delta_s^{(i.p)}$$

Where:

$y_s^{(p)}$ is the membership function of sth partition ($s \epsilon \{1, \ldots, S\}$) for the pth question ($p \epsilon \{1, \ldots, P\}$).

$\delta_s^{(i.p)}$ checks whether the ith expert's opinion about the pth question adds the frequency of the sth partition or not (q and r are the lower and upper bound of the sth partition).

$$\delta_s^{(i.\ p)} = \begin{cases} 1 & if\ x_s \in \left[q_s^{(i)}.r_s^{(i)}\right]^{(p)} \\ 0 & Otherwise \end{cases}$$

Now the fuzzy number based on the experts' opinion is developed in Fig. 1.

Step 2: Normalization of the fuzzy number to be able to compare the results as follows:

$$Y_s^{(p)} = \frac{y_s^{(p)}}{y_*^{(p)}} \quad . \quad s = 1. \ldots . S$$

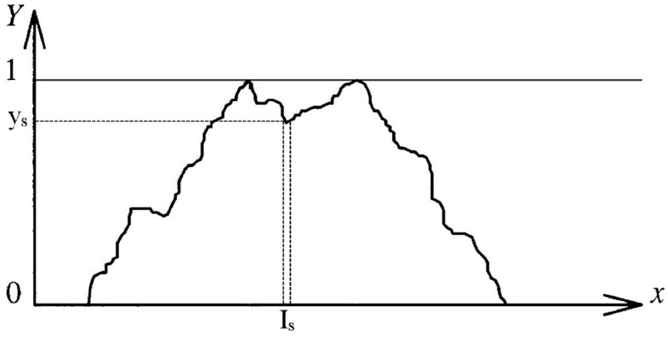

Fig. 1. Fuzzification Step

Where:

$Y_s^{(p)}$ is the normalized membership function for the pth question and sth partition.

$y_*^{(p)}$ is the largest function value for pth question among different partitions $\left(y_*^{(p)} = \max_{s=1.\ \ldots\ S}\left\{y_s^{(p)}\right\}\right)$.

Step 3: calculate the Defuzzified number which is based on Center-Of-Gravity (COG) whether in discrete or continuous conditions.

$$\text{Discrete condition}: \overline{COG^{(p)}} = \frac{\sum_s Y_s^{(p)} \times x_s}{\sum_s Y_s^{(p)}}$$

$$\text{Continuous condition}: \overline{COG^{(p)}} = \frac{\int Y^{(p)}(x_s) \times x_s \times d(x_s)}{\int Y^{(p)}(x_s) \times d(x_s)}$$

Finally, the consensus condition for every question would be checked based on the distance of each and every expert's opinion from the defuzzified numbers as follows:

$$if\ \left(COG^{(i.p)} - \overline{COG^{(p)}} < 0.7 \quad \forall i \in \{1, \ldots, I\}\right) \Longrightarrow Stop$$

3.2. *PMADM*

By definition, sustainability is related to the future and the ability of future generations to fulfil their needs from nature. This will bring about many uncertainties and complexities which need to be reflected in the applied methodologies. This is why the Prospective MADM (PMADM) has been proposed and widely used in recent years [49]. One of the important contributions of the PMADM methodology is the "Supportive-Backup" by which criteria are hierarchically defined to combine all of the future sustainability concerns in one decision matrix [54]. In this study, resiliency, as well as sustainable development, is considered in the hierarchical criteria to ensure comprehensiveness (as presented in Table 6).

Where $C_{S1\text{-}i}$ is the first support/backup for the ith criteria. Here the support/backup are two future parameters, namely sustainable and resilient local environment based on the proposed location (scenarios).

Table 6

Criteria with supportive-Backups for Environment pillar and Atmosphere Indicator).

	Emissions of greenhouse gases per ton of refinery product	…	C_i	…	C_6
	Sustainability	…	$C_{S1\text{-}i}$	…	…
	Local Resiliency	…	$C_{S2\text{-}i}$	…	…
Scenario 1	…	…	…	…	…
Scenario 2	…	…	…	…	…
Scenario 3	…	…	…	…	…

To provide further clarity.

- S1 pertains to sustainability aspects within the PMADM methodology framework.
- S2 addresses the local resilience of the alternative within the PMADM methodology.
- C_i *Where* $i \in \{1, \dots, 101\}$ denotes the criteria set, which is elaborated upon in subsequent steps using the WASPAS methodology. This encompasses 101 criteria identified in 15 categories, as outlined in the sustainability triple bottom line. Please refer to Table 4 for a comprehensive overview.

3.3. *MADM based scenario - WASPAS*

Dynamic MADM-based scenarios are newly developed methodologies to consider the future in the assessment process and factor in uncertainties [50,51,55,56]. In this context, MADM-based scenarios were used in the development of a sustainability assessment framework for the lifecycle model of PRI projects. The framework was tested and validated for a real refinery project [57].

The core contribution of the MADM-based scenario that is to be used here is to avoid assessing all of the alternatives against all of the criteria; instead, a set of criteria is defined and alternatives are assessed based on a subset of the criteria list wherever they are relevant; in other words in this methodology, alternatives are assessed only against relevant criteria. This means that in addition to the criteria set, another assessment criterion is the relevance of the alternative to the criteria set. The more subset list of criteria for an alternative, the more relevance, and importance in comparison to other alternatives. Accordingly, a participation ratio is defined and applied to the final scenario ranking. For more information and definition refer to the MADM-based scenario development paper [51].

In order to take into account, the sustainability triple bottom line in the locating problem, sustainability indicators are taken from the existing literature (Table 7), which form the criteria set in the MADM-based Scenario to select the proper location. The framework is developed in two levels from qualitative indicators to quantitative factors [46] to ensure the validity of the outcome, based on sustainability and resiliency considerations. Alternatives are investigated in three life-cycle phases as presented in Table 8.

Table 7
Sustainability indicators.

	Sustainability indicators		Sustainability Factors
Social	C1	Poverty & Equality	Proportion of project human resource living below national poverty line …
	C2	Health	…
	C3	Safety & Security	…
	C4	Education & Training	…
	C5	Welfare	…
Environmental	C1	Atmosphere	Emissions of greenhouse gases per ton of refinery product (CO2, CH4, N2O, HFCs, CCl4, CH3CCl3, CCl3F, CCl2F2, C2Cl3F3) …
	C2	Water(Fresh Water, Ocean, Sea, Coast)	…
	C3	Land & Soil Pollution	…
	C4	Natural Resource	…
	C5	Biodiversity	…
Economical	C1	Energy consumption	achievement rate of the designed energy usage in the operation phase …
	C2	Financial	…
	C3	Economy Performance	…
	C4	Occupation	…
	C5	Earning	…

Table 7 delineates 15 credit categories identified within the Triple Bottom Line framework. However, it is essential to note that beyond these categories, there exist 101 detailed criteria developed in the literature for the sustainability evaluation of PRI (Public Realm Infrastructure) projects. These additional criteria are not outlined in Table 7. For further elucidation on these 101 criteria, please refer to Hasheminasab et al. [46]. In this table.

- A_i is the ith alternative where $i \in \{1, 2, 3\}$ (PMADM alternatives in this study are considered as life-cycle phases which are “Cradle-to-Gate”, “Gate-to-Gate”, and “Gate-to-Grave”)
- W_i is the weighting associated with the ith criteria where $i \in \{1, \dots, 101\}$.
- I_i is the ith assessment criteria where $i \in \{1, \dots, 101\}$ (for the criteria set please refer to Table 4).

In the context of Multiple Attribute Decision-Making methodologies, such as MADM Based Scenario, the Multiple Criteria Decision Matrix (X) can be defined as follows:

$$X = [x_{ij}]$$

Where.

- i denotes the alternatives under consideration,
- j signifies the criteria being evaluated, and
- x_{ij} represents the value corresponding to the ith alternative with respect to the jth criterion.
  Step 1: Normalized decision-making table

The normalized values ($\overline{x}_{ij}$) in the decision matrix are calculated as follows:

These equations are used depending on the ’opt’ status

$$\overline{x}_{ij} = \frac{x_{ij}}{opt_i(x_{ij})} \quad . \quad \forall i \in \{1. \dots .I\}. j \in \{1. \dots .J\} \textit{ Where Opt is Max}$$

$$\overline{x}_{ij} = \frac{opt_i(x_{ij})}{x_{ij}} \quad . \quad \forall i \in \{1. \dots .I\}. j \in \{1. \dots .J\} \textit{Where Opt is Min}$$

Step 2: Calculate Weighted Normalized Values (x_{ij})

In this study, weighted normalized values are calculated using the dual weighting methodology provided by the WASPAS method. In accordance with this methodology, quantitative weighting for sustainability factors serving as assessment criteria is evaluated by experts against each other (W_j). The WASPAS method offers two types of weights, based on exponentiation and multiplication, which are respectively represented as follows:

$$x_{ij.sum} = \overline{x}_{ij} \times W_j \ . \quad \forall i \in \{1. \dots .I\}. j \in \{1. \dots .J\}$$

$$x_{ij.mult} = \overline{x}_{ij}^{\,W_j} \ . \quad \forall i \in \{1. \dots .I\}. j \in \{1. \dots .J\}$$

Table 8
Decision table for MADM Based Scenario.

Sustainability Indicators	Weights	Opt()	Life-Cycle Phases (Scenarios)		
			Scenario1	Scenario2	Scenario3
		Max/ Min	A1, A2, A3	A1, A2, A3	A1, A2, A3
I1, …, I15	W1, …, W15				

Step 3: weighted normalized matrix (A_i)

Final weights are calculated by averaging two normalized values through the following equation:

$$A_i = \frac{\sum_j x_{ij.sum} + \sum_j x_{ij.mult}}{2} \quad . \quad \forall i \in \{1. \dots .I\}. \, j \in \{1. \dots .J\}$$

Step 4: Final evaluation and ranking

As explained earlier, one advantage of MADM-based scenarios is that it allows for the assessment of scenarios across a set of criteria wherever relevant. Given that criteria may not be repeated across different scenarios, the weighting and ranking of each criterion must be adjusted based on the frequency of its occurrence. This correction process is essential and entails repeating the calculation for every scenario, its alternatives, and the criteria set.

$$\overline{W_i} = \frac{W_i \times I_i}{\sum_i (W_i \times I_i)}$$

$$\overline{A_i} = \frac{A_i/I_i}{\sum_i \left(A_i/I_i \right)}$$

Where.

I_i: represents the frequency of the ith criteria.
W_i: primary weights
$\overline{W_i}$: modified weights
A_i: primary ranks based on the WASPAS dual normalization methodology
$\overline{A_i}$: modified ranks based on participation ratio in addition to the primary ranking

For detailed calculations regarding these primary and secondary weightings and rankings, please consult Table 11 in the Case Study section.

4. Case study

A real refinery has been investigated during its design phase, as a case study. For the refinery, all attributes are fixed except for the location. In other words, attributes such as the main crude oil field, main product, and the target market are given. Investigating other attributes can be the subject of future studies. Following the methodology map represented in Table 4, Case study was carried out in the following steps.

1 Sustainability Indicator Framework via Literature Review

In this step, a comprehensive set of 101 criteria is considered for assessment, as outlined in the literature review discussed previously. These criteria are categorized into 15 credit categories aligned with the sustainability triple bottom line. For further details, please refer to Table 4 and consult Hasheminasab et al. [46].

2 Generation of Location Alternatives via Focus Group Method

In selecting suitable sites for the refinery projects, ten potential locations are assessed based on diverse criteria, termed 'project alternatives'. To maintain confidentiality and mitigate potential public impacts, specific geographical locations are not disclosed in this study. Instead, the focus remains on evaluating criteria such as proximity to extraction points, accessibility to target markets, and transportation infrastructure (including roads, railways, and ports), as well as considerations for workforce availability and environmental factors. Ensuring confidentiality safeguards proprietary information while prioritizing transparency and sensitivity to public concerns.

3 Screen available alternatives via FDM

In this phase, the Delphi technique, elaborated in section 3-1, is employed to screen the available locations and narrow down the selection to the three most suitable alternatives.

Table 9 presents the Center-Of-Gravity (COG) values obtained through the defuzzification process of the calculated fuzzy numbers using the membership function.

Based on these FDM results, the three most promising alternatives are identified for further assessment in the subsequent stage. This next stage involves the application of the sustainability assessment framework and consideration of the lifecycle phases of the refinery projects to rank the remaining location alternatives and ultimately select the most optimal one.

4 Considering sustainability and resiliency via PMADM

Given the intricate nature of sustainability and its enduring relevance to the future, this study employs the Prospective MADM (PMADM) methodology to navigate future uncertainties. By integrating sustainability and resilience into the decision-making process, alternatives are assessed against criteria serving as both supportive and backup measures. Expert judgment sessions confirmed the efficacy of this approach, as indicated by their feedback during the evaluation.

5 Locating a Sustainable Location via MADM-Based Scenario and WASPAS

In this phase, the MADM-based scenarios mentioned earlier are utilized. A panel of 15 experts with pertinent refinery experience has contributed to this study. Their profiles are detailed in Table 10.

Experts are tasked with completing the decision table, as depicted in Table 5. All calculations, as per methodology section 3-3, are conducted in the background, encompassing normalization, weighted normalization, and aggregation of results. Given the evaluation of three alternatives across 101 criteria in three stages, these computations are comprehensive, encompassing more than 4200 calculations.

Table 11 through 13 present the outcomes of expert judgment, which serve as the foundation for the WASPAS and MADM-based Scenario methodologies.

6 Case Study Results

Finally, the results of the scenarios and alternatives analysis, along with their first and second weightings and rankings, are presented in Table 14. These results showcase the analysis of the life-cycle phases

Table 9
FDM results after consensus.

Alternative locations	Final index (COG)[a]
Alt-1	8.5
Alt-2	8.3
Alt-3	8.1
Alt-4	6.8
Alt-5	6.2
Alt-6	5.5
Alt-7	5.4
Alt-8	4.9
Alt-9	4.7
Alt-10	4.3

[a] Dimensionless defuzzified value for ranking.

Table 10
Experts' information.

Education	BSc.	MSc.	Ph.D.
Number of experts	8	5	2
Years of experience	0–10	10–15	Over 15 years
Number of experts	6	7	2

Table 11
Social criteria evaluation for different scenarios.

	Social[a]				
	C1	C2	C3	C4	C5
Scenario1	0.2319	0.2754	0.2319	0.1594	0.1014
Scenario2	0.2462	0.2923	0.2308	0.1692	0.0615
Scenario3	0.2258	0.3065	0.2419	0.1613	0.0645
mean	0.2346	0.2914	0.2349	0.1633	0.0758
Rank	3	1	2	4	5

[a] Dimensionless weighting for the Social credit category, totalling 1.

Table 12
Environmental criteria evaluation for different scenarios.

	Environmental[a]				
	C1	C2	C3	C4	C5
Scenario1	0.3284	0.2388	0.1642	0.2239	0.0448
Scenario2	0.3385	0.2462	0.1538	0.2154	0.0462
Scenario3	0.3492	0.2540	0.1587	0.1905	0.0476
mean	0.3387	0.2463	0.1589	0.2099	0.0462
Rank	1	2	4	3	5

[a] Dimensionless weighting for the Environmental credit category, totalling 1.

Table 13
Economical criteria evaluation for different scenarios.

	Economical[a]				
	C1	C2	C3	C4	C5
Scenario1	0.1500	0.4083	0.2583	0.0917	0.0917
Scenario2	0.1513	0.4118	0.2605	0.0924	0.0840
Scenario3	0.1513	0.4118	0.2605	0.0924	0.0840
mean	0.1508	0.4106	0.2598	0.0922	0.0866
Rank	3	1	2	4	5

[a] Dimensionless weighting for the Economic credit category, totalling 1.

across different scenarios.

5. Discussion

The selection of suitable locations for petroleum refineries is a complex and multifaceted process that requires careful consideration of various dimensions, including technological advancements, environmental concerns, land use regulations, and circularity perspectives. In this discussion, the authors explore how these dimensions intersect with this study and its methodology for locating petroleum refineries in Iran and highlight areas for future research.

5.1. *Technological advancements*

Technological advancements in petroleum refining play a crucial role in enhancing efficiency, reducing emissions, and improving safety in refinery operations. In this study, advanced refining technologies were integrated into the methodology to evaluate potential refinery locations in Iran. By considering the availability of advanced technologies, such as catalytic cracking and hydroprocessing, locations that could leverage these innovations to minimize environmental impact and maximize resource efficiency were identified. However, technology and refinery processes are considered constants in this study and do not directly contribute to the assessment. Since technology can vary depending on the location's needs and requirements, future studies could further explore the specific technological requirements and capabilities of different refinery locations, including access to skilled labour, research institutions, and technological infrastructure. Additionally, investigating emerging technologies, such as carbon capture and utilization, could offer new opportunities for reducing greenhouse gas emissions and enhancing the sustainability of refinery operations in Iran.

5.2. *Environmental concerns*

According to Almerud et al. [14], studies conducted in the Swedish petroleum refinery industry indicated low personal exposure to benzene and 1,3-butadiene, suggesting potential advancements in occupational health and safety practices within refinery operations.

Environmental concerns associated with petroleum refineries include air and water pollution, soil contamination, and habitat destruction. In this paper, these concerns were addressed by incorporating environmental impact assessments and mitigation measures into the methodology to evaluate potential refinery locations in Iran. By considering factors such as proximity to sensitive ecosystems, air quality, and water resources, efforts were made to identify locations that minimize adverse environmental impacts and protect local communities and ecosystems. Future studies could focus on refining environmental impact assessment methodologies tailored to specific locations to better quantify and mitigate the environmental footprint of refinery operations. Additionally, exploring innovative technologies and practices for pollution control and waste management could further enhance environmental sustainability in the refinery industry in Iran.

Table 14
Scenarios and their alternatives evaluation).

	Scenario Ranking								
	Scenario 1			Scenario 2			Scenario 3		
	Phase1	Phase2	Phase3	Phase1	Phase2	Phase3	Phase1	Phase2	Phase3
Scenario1 Weight[a]	45.8855	46.0700	45.9180						
Scenario2 Weight[a]				44.3793	44.6239	44.4026			
Scenario3 Weight[a]							46.5907	46.6929	46.5640
Primary Ranking	3	1	2	3	1	2	2	1	3
Participation Ratio	0.9406			0.8911			0.9604		
Secondary Weight[a]	43.1596	43.3331	43.1902	39.5459	39.7638	39.5667	44.7456	44.8436	44.7199
Normal Weight[b]	0.1127	0.1132	0.1128	0.1033	0.1039	0.1033	0.1169	0.1171	0.1168
Secondary Ranking	6	4	5	9	7	8	2	1	3
Scenario Ranking	2			3			1		

[a] Dimensionless, Weighted Normalized Value (A_i), referring to section 3-3.
[b] Dimensionless weighting, totalling 1.

5.3. Land use regulations

Land use regulations in Iran govern the allocation and utilization of land resources for industrial purposes, including petroleum refineries. In this locating paper, the regulatory framework governing refinery siting decisions was examined, and land use regulations were integrated into the methodology to evaluate potential refinery locations. By considering zoning requirements, environmental impact assessments, and permitting procedures, efforts were made to identify locations that comply with regulatory requirements and promote sustainable land use practices. Future studies could delve deeper into the regulatory landscape of refinery siting in Iran, including an analysis of the effectiveness of existing regulations in balancing economic development objectives with environmental and social considerations. Additionally, opportunities for stakeholder engagement and community involvement in the decision-making process could be explored to enhance transparency and accountability in refinery siting decisions.

5.4. Circularity perspectives

Circularity perspectives in refinery operations focus on minimizing waste generation, maximizing resource efficiency, and promoting the reuse and recycling of materials throughout the refinery lifecycle. The authors considered circular economy principles in the methodology to evaluate potential refinery locations in Iran. By exploring opportunities for waste minimization, resource recovery, and product diversification, efforts were made to identify locations that embrace circularity principles and contribute to sustainable resource management. Also, circularity is assessed in the assessment framework for the case study. Future studies could further explore the integration of circularity perspectives into refinery design and operations, including the development of closed-loop systems and the optimization of material flows. Additionally, investigating the economic and environmental benefits of circular economy initiatives could provide valuable insights into the potential of circularity in the refinery industry in Iran.

6. Conclusion and policy implications

Location is one of the crucial attributes of PRI projects. These facilities are responsible for major undesirable environmental and social impacts that need to be taken into account when deciding where to build them. Deciding the best location for a refinery project is a multidimensional problem. These various dimensions range from technology, design, finance, and transportation to dynamic market demand, stakeholders, and local regulations. Besides, location scenarios may have totally different configurations from one another in terms of feed, market, and process. This study aims to cover this multidimensional environment by applying a well-suited methodology (MADM-based scenario).

Oil and gas projects are both producers and consumers at the same time. Lots of industries depend on their oil-based products from fuel to lubricants. Considering this interaction and reciprocal feeding of some oil and gas industries, the proximity of these projects is sometimes an important consideration. This is why PRI projects are usually developed in an industrial zone. Consequently, cumulative effects arising from the interaction of various industries would aggravate the environmental and social issues and make the situation worse. As such, local conditions in terms of environmental and social resiliency need to be taken into account as an important contribution to the decision-making process. In this study, by using a PMADM technique, future sustainability and local resiliency concerns are considered.

A real petroleum refinery has been used as a case study and a group of experts from the project's team has been selected to conduct the study. According to the results, the third alternative was found to be superior, due to its proximity to input and the simplicity of market access. Besides, the main refinery phase (Gate-to-Gate) is the most crucial phase for all three alternatives, which simply shows the relative importance of this phase among other life-cycle phases for the specific condition of the refinery project. In the superior alternative, scenario 3, the Cradle-to-Gate, is the second most important phase while in other alternatives, the Gate-to-Grave is the second most important phase.

Developed dual-side methodology assists the decision-makers in having some lateral evaluations as well. For instance, by solving the locating problem, the critical phase in the life-cycle and the highly influential part in the refinery model also can be concluded.

The results provide important policy implications that the impact of proximity to the input oilfield on the Cradle-to-Gate phase is greater than the influence of the proximity of market demand on the Gate-to-Grave phase.

Declarations

- The authors have no relevant financial or non-financial interests to disclose.
- The authors have no competing interests to declare that are relevant to the content of this article.
- All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.
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CRediT authorship contribution statement

Hamidreza Hasheminasab: Writing – original draft, Methodology, Conceptualization. **Mohammadreza Kharrazi:** Visualization, Supervision, Investigation. **Yaghob Gholipour:** Validation, Software, Data curation. **Sarfaraz Hashemkhani Zolfani:** Validation, Funding acquisition. **Dalia Streimikiene:** Writing – review & editing, Writing – original draft, Resources, Project administration.

Data availability

No data was used for the research described in the article.

References

[1] Environmental Protection Agency, Greenhouse Gas Reporting Program: petroleum and natural gas systems 2012 data summaryAccessed June 23, 2014. http://www.epa.gov/ghgreporting/documents/pdf/2013/documents/SubpartW-2012-Data-Summary.pdf, 2013.
[2] US Environmental Protection Agency (EPA), Profile of Petroleum Refining Industry, Office of Compliance, Washington, Dc, 1995.
[3] A. Belova, W.B. Gray, J. Linn, R.D. Morgenstern, Environmental Regulation and Industry Employment: A Reassessment, US Census Bureau Center for Economic Studies, 2013. Paper No. CES-WP-13-36.
[4] A. Sieminski, International Energy Outlook, Energy information administration (EIA), 2014, p. 18.
[5] EPA, Economic Impact Analysis, Petroleum Refineries Final Amendments to the National Emissions Standards for Hazardous Air Pollutants and New Source Performance Standards, U.S. environmental protection agency, office of air quality planning and standards, 2015. NC 27711.
[6] H. Hasheminasab, Y. Gholipour, M. Kharrazi, D. Streimikiene, A novel Metric of Sustainability for petroleum refinery projects, J. Clean. Prod. 171 (2018) 1215–1224.
[7] H. Hasheminasab, Y. Gholipour, M. Kharrazi, D. Streimikiene, S. Hashemkhani, A dynamic sustainability framework for petroleum refinery projects with a life cycle attitude, Sustain. Dev. (2020) 1–16.
[8] H. Hasheminasab, Y. Gholipour, M. Kharrazi, D. Streimikiene, Life cycle approach in sustainability assessment for petroleum refinery projects with fuzzy-AHP, Energy Environ. 29 (7) (2018) 1208–1223.
[9] S. Tordo, M. Warner, O. Manzano, Y. Anouti, Local Content Policies in the Oil, Gas, and Mining Sector, The World Bank, 2013.
[10] EIA, International Energy Outlook 2021, U.S. Energy Information Administration, 2021.
[11] IEA, Refinery Capacity and Utilization, International Energy Agency, 2020.
[12] B. Fattouh, A. Sen, J. Stern, The shale boom and the U.S. Economy: spillovers and time-varying effects, Energy J. 40 (2) (2019) 183–210.

[13] S&P Global Platts, Global refinery database, S&P Global Platts (2020).

[14] P. Almerud, M. Akerstrom, E.M. Andersson, B. Strandberg, G. Sallsten, Low personal exposure to benzene and 1,3-butadiene in the Swedish petroleum refinery industry, Int. Arch. Occup. Environ. Health 90 (7) (2017) 713–724.

[15] T.S. Anirudhan, M. Ramachandran, Removal of 2,4,6-trichlorophenol from water and petroleum refinery industry effluents by surfactant-modified bentonite, J. Water Proc. Eng. 1 (2014) 46–53.

[16] G.R. Rodrigues, A.F. Rozza, R. Correa, W.N. Chan, Air emissions management in petroleum refineries - challenges for modernization project's permits, Proceedings of the Air and Waste Management Association's Annual Conference and Exhibition, AWMA 3 (2010) 2107–2130.

[17] A. Avci, M. Kaçmaz, İ. Durak, Peroxidation in muscle and liver tissues from fish in a contaminated river due to a petroleum refinery industry, Ecotoxicol. Environ. Saf. 60 (1) (2005) 101–105.

[18] G.L. Kyriakopoulos, The effect of immediate treatment for water quality: policies and protection perspectives, in: M.G. Zamparas, G.L. Kyriakopoulos (Eds.), Chemical Lake Restoration – Technologies, Innovations and Economic Perspectives, 2021, pp. 49–67.

[19] C. Drechsel, J. Trinkle, T. Widboom, Implementing the new source review 'reasonable possibility' requirements at petroleum refinery projects. NPRA Environmental Conference Papers, 2010, pp. 641–650.

[20] G.L. Kyriakopoulos, Environmental legislation in European and international contexts: legal practices and social planning toward the circular economy, Laws 10 (1) (2021) 3–15.

[21] E.T. Kikasu, The influence of the international environment on oil and gas industry development, as well as on the restructuring and upgrading of the petroleum refinery industry in the Democratic Republic of Congo, Int. J. Enterpren. 25 (3) (2021) 1–23.

[22] M. Zamparas, G.L. Kyriakopoulos, M. Drosos, V.C. Kapsalis, I.K. Kalavrouziotis, Novel composite materials for lake restoration: a new approach impacting on ecology and circular economy, Sustainability 12 (8) (2020) 3397.

[23] M. Zamparas, G.L. Kyriakopoulos, V.C. Kapsalis, M. Drosos, I.K. Kalavrouziotis, Application of novel composite materials as sediment capping agents: column experiments and modelling, Desalination Water Treat. 170 (2019) 111–118.

[24] H. Matsuo, J. Higuchi, S. Matsumoto, M. Yamashita, Properties of Sumitomo 347AP steel tube for use in desulfurizing plants in the petroleum refinery industry, in: EUROCORR 2008 - European Corrosion Congress: Managing Corrosion for Sustainability, vol. 292, Book of Abstracts, 2008.

[25] R.W. Ahmad, K. Salah, R. Jayaraman, I. Yaqoob, M. Omar, Blockchain in oil and gas industry: applications, challenges, and future trends, Technol. Soc. 68 (2022) 101941.

[26] T.D. Moshood, J.O. Rotimi, W. Shahzad, J.A. Bamgbade, Infrastructure digital twin technology: a new paradigm for future construction industry, Technol. Soc. 77 (2024) 102519.

[27] H. Hasheminasab, Y. Gholipour, M. Kharrazi, D. Streimikiene, A quantitative sustainability assessment framework for petroleum refinery projects, Environ. Sci. Pollut. Control Ser. 28 (12) (2021) 15305–15319.

[28] W.B. Shore, Land-use, transportation and sustainability, Technol. Soc. 28 (1–2) (2006) 27–43.

[29] F. Fan, S. Dai, B. Yang, H. Ke, Urban density, directed technological change, and carbon intensity: an empirical study based on Chinese cities, Technol. Soc. 72 (2023) 102151.

[30] C. Rao, M. Goh, Y. Zhao, J. Zheng, Location selection of city logistics centers under sustainability, Transport. Res. Transport Environ. 36 (2015) 29–44.

[31] V. Pachouri, R. Singh, A. Gehlot, S. Pandey, S.V. Akram, M. Abbas, Empowering sustainability in the built environment: a technological Lens on industry 4.0 Enablers, Technol. Soc. 76 (2024) 102427.

[32] J. Zhang, C. Xu, Z. Song, Y. Huang, Y. Wu, Decision framework for ocean thermal energy plant site selection from a sustainability perspective: the case of China, J. Clean. Prod. 225 (2019) 771–784, https://doi.org/10.1016/j.jclepro.2019.04.032.

[33] S.M. Habib, A. El-Raie Emam Suliman, A.H. Al Nahry, E.N. Abd El Rahman, Spatial modeling for the optimum site selection of solar photovoltaics power plant in the northwest coast of Egypt, Remote Sens. Appl.: Society and Environment 18 (2020) 100313, https://doi.org/10.1016/j.rsase.2020.100313.

[34] S. Choudhury, A.K. Saha, M. Majumder, Optimal location selection for installation of surface water treatment plant by Gini coefficient-based analytical hierarchy process, Environ. Dev. Sustain. 22 (2020) 4073–4099, https://doi.org/10.1007/s10668-019-00373-w.

[35] S. Moradi, H. Yousefi, Y. Noorollahi, D. Rosso, Multi-criteria decision support system for wind farm site selection and sensitivity analysis: case study of Alborz Province, Iran, Energy Strategy Rev. 29 (2020) 100478, https://doi.org/10.1016/j.esr.2020.100478.

[36] B. Koseoglu, M. Buber, A.C. Toz, Optimum site selection for oil spill response center in the Marmara Sea using the AHP-TOPSIS method, Arch. Environ. Protect. 44 (4) (2018) 38–49, https://doi.org/10.24425/aep.2018.122302.

[37] F.S. Alavipoor, S. Karimi, J. Balist, A.H. Khakian, A geographic information system for gas power plant location using analytical hierarchy process and fuzzy logic, Global Journal of Environmental Science and Management 2 (2) (2016) 197–207, https://doi.org/10.7508/gjesm.2016.02.010.

[38] O. Senvar, I. Otay, E. Bolturk, Hospital site selection via hesitant fuzzy TOPSIS, IFAC-PapersOnLine 49 (12) (2016) 1140–1145, https://doi.org/10.1016/j.ifacol.2016.07.656.

[39] K. Komchornrit, The selection of dry port location by a hybrid CFA-MACBETH-PROMETHEE method: a case study of southern Thailand, Asian Journal of Shipping and Logistics 33 (3) (2017) 141–153, https://doi.org/10.1016/j.ajsl.2017.09.004.

[40] A. Kaveh, Y. Vazirinia, Tower Cranes and Supply Points Locating Problem Using CBO, ECBO, and VPS, 2018 arXiv preprint arXiv:1811.05963.

[41] A. Artenian, F. Sadeghpour, J. Teizer, A GIS framework for reducing GHG emissions in concrete transportation, in: Construction Research Congress 2010: Innovation for Reshaping Construction Practice, 2010, pp. 1557–1566.

[42] M.N. Mokhtarian, A new fuzzy weighted average (FWA) method based on left and right scores: an application for determining a suitable location for a gas oil station, Comput. Math. Appl. 61 (10) (2011) 3136–3145, https://doi.org/10.1016/j.camwa.2011.03.104.

[43] S. Rahimi, A. Hafezalkotob, S.M. Monavari, A. Hafezalkotob, R. Rahimi, Sustainable landfill site selection for municipal solid waste based on a hybrid decision-making approach: fuzzy group BWM-MULTIMOORA-GIS, J. Clean. Prod. 248 (2020) 119186, https://doi.org/10.1016/j.jclepro.2019.119186.

[44] Y. Li, C. Lin, Y. Wang, X. Gao, T. Xie, R. Hai, X. Wang, X. Zhang, Multi-criteria evaluation method for site selection of industrial wastewater discharge in coastal regions, J. Clean. Prod. 161 (2017) 1143–1152, https://doi.org/10.1016/j.jclepro.2017.05.030.

[45] S. Hashemkhani Zolfani, N. Rezaeiniya, E. Kazimieras Zavadskas, Z. Turskis, Forest Roads Locating Based on AHP and COPRAS-G Methods: an Empirical Study Based on Iran, 2011.

[46] H. Hasheminasab, M. Kharrazi, Y. Gholipour, D. Streimikiene, Chapter 2: a sustainability assessment framework for petroleum refinery projects with multi-criteria decision-making techniques, Sustainability Modeling in Engineering (2019) 27–71.

[47] L.A. Zadeh, Fuzzy sets, Inf. Control 8 (3) (1965) 338–353.

[48] P.T. Chang, L.C. Huang, H.J. Lin, The fuzzy Delphi method via fuzzy statistics and membership function fitting and an application to the human resources, Fuzzy Set Syst. 112 (3) (2000) 511–520.

[49] S. Hashemkhani Zolfani, R. Maknoon, E.K. Zavadskas, An introduction to prospective multiple attribute decision making (PMADM), Technol. Econ. Dev. Econ. 22 (2) (2016) 309–326, https://doi.org/10.3846/20294913.2016.1150363.

[50] A. Siddiqi, F. Ereiqat, L.D. Anadon, Formulating expectations for future water availability through infrastructure development decisions in arid regions, Syst. Eng. 19 (2) (2016) 101–110, https://doi.org/10.1002/sys.21337.

[51] S. Hashemkhani Zolfani, R. Maknoon, E.K. Zavadskas, Multiple attribute decision making (MADM) based scenarios, Int. J. Strat. Property Manag. 20 (1) (2016) 101–111, https://doi.org/10.3846/1648715X.2015.1132487.

[52] S. Humphrey-Murto, L. Varpio, C. Gonsalves, T.J. Wood, Using consensus group methods such as Delphi and Nominal Group in medical education research, Med. Teach. 39 (1) (2017) 14–19.

[53] A. Sourani, M. Sohail, The Delphi method: review and use in construction management research, J. Construct. Educ. 11 (1) (2015) 54–76.

[54] S. Hashemkhani Zolfani, R. Masaeli, From past to present and into the sustainable future; PMADM approach in shaping regulatory policies of the medical device industry in the new sanction period, in: P. Chatterjee, M. Yazdani, S. Chakraborty (Eds.), Sustainability Modeling in Engineering; A Multi-Criteria Perspective, Word Scientific, Singapore, 2019.

[55] J.J. Jassbi, R.A. Ribeiro, L.R. Varela, Dynamic MCDM with future knowledge for supplier selection, J. Decis. Syst. 23 (3) (2014) 232–248, https://doi.org/10.1080/12460125.2014.886850.

[56] J. Ondrus, T. Bui, Y. Pigneur, A foresight support system using MCDM methods, Group Decis. Negot. 24 (2) (2015) 333–358, https://doi.org/10.1007/s10726-014-9392-8.

[57] Y. Gholipour, H. Hasheminasab, M. Kharrazi, J. Streimikis, Sustainability Criteria Assessment for Life-Cycle Phases of Petroleum Refinery Projects by Madm Technique, 2018.