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Optimizing Policies and Regulations for Zero Routine Gas Flaring and Net Zero

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Abstract

Global policy actions to reduce the environmental and social impacts of natural gas flaring are primarily derived from voluntary arrangements. This paper evaluates stakeholder preferences amongst competing policies and regulatory options, optimizing environmental governance to eliminate routine gas flaring by 2030 and achieve net-zero greenhouse emissions by 2050, whilst addressing questions of justice and fair implementation. Using a mixed-methods social scientific approach, incorporating literature and document review, interviews, expert surveys, Analytical Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (G-TOPSIS), we derive two competing perspectives on gas flaring policy strategy, with differences revealed through the AHP ranking process of individual criteria. All identified criteria and sub-criteria were integral to achieving the flaring and emissions targets, with "policy and targets" and "enabling framework" being the most important individual criteria. The "background and the role of reductions in meeting environmental and economic objectives" and ''nonmonetary penalties" were the key emergent sub-criteria. G-TOPSIS showed that fully implementing gas flaring policies and regulatory framework criteria to limit warming to 1.5 °C is the most effective policy alternative. Globally coordinated, uniform, and reciprocal legally binding agreements between countries to supplement national initiatives are imperative for improving the effectiveness of country-specific gas flaring policy strategies.

Keywords: climate change; CO_2; natural gas; venting; environmental policy and regulations; AHP; G-TOPSIS

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1. Introduction

Oil and natural gas development often involves flaring and venting during drilling, production, gathering, processing, and transportation operations. Gas flaring involves burning excess natural gas and oxygen at the wellhead during oil exploration and development, a technique used for emergency relief, overpressure, process upsets, startups, shutdowns, and other safety-related operational purposes [1–4]. Although posited as a routine industry practice, gas flaring is a major contributor to global climate change through the emission of CO_2, methane, and black carbon [5–7]. Gas flaring contributes an estimated 397.45 Mt of CO_2, which is about 1.07% of the world's total CO_2 emissions (37.15 Gt). In contrast, venting and other fugitive methane emissions from oil and gas operations total nearly 30 Mt of CH_4 per year, equivalent to roughly 780 Mt CO_2-equivalent (using a GWP of 26), or about 2.1% of global CO_2 emissions [8]. This share, while smaller than emissions from coal (41.0%), oil (32.0%), and natural gas (20.8%), still represents a significant and avoidable source of greenhouse gases. Flaring contributes CO_2 but also releases methane and black carbon, which have higher global warming potentials (GWPs) and direct climate impacts [9]. Addressing gas flaring is crucial for reducing these potent emissions and improving energy efficiency, as it represents a significant loss of natural gas that could otherwise contribute to the energy supply [10]. The World Bank estimates that over 400 million tons of CO_2 was emitted in 2021 from gas flaring alone, equivalent to the emissions produced by 9 trillion miles of car journeys. An estimated 10,000 gas flares are burning globally at any given time, with the wasted gas burned having the potential to power the whole of sub-Saharan Africa [10]. With natural gas prices at historic highs, gas flaring is an extraordinary waste of economic value, amounting to approximately USD 55 billion per year at USD 10 per million British thermal units (MBtu) [5].

Gas flaring releases sulfur dioxide, nitrogen oxides, and other acidic gases, driving terrestrial acidification and air pollution [7,11]. These emissions are linked to headaches, tremors, irregular heartbeats, respiratory and cardiovascular diseases, cancer, and liver and eye damage [6,12,13]. Contaminated water can also cause skin cancer and stomach ulcers [14,15]. Exposed communities, particularly in developing countries, face elevated exposure risks to air and groundwater pollution from living and working in proximity to oil and gas sites. These impacts can compound or exacerbate other co-risk factors, including (but not limited to) site worker safety, traffic collision, and other occupational health inequalities, making flaring a critical environmental justice concern [16–22]. Yet, despite the severity of the associated environmental impacts, the global gas flaring reduction policy has had a limited effect on total emissions. The World Bank/GGFR [23] estimated that 143 billion cubic meters (bcm) of natural gas was flared in 2020, with the top seven gas flaring countries, which produce 40% of the global oil and gas annually, accounting for 65% of the total. In 2021 alone, flaring activity directly released approximately 270 million tons of CO_2 and 8 million tons of methane (equivalent to 240 million tons of CO_2-eq) into the atmosphere, along with black soot and other greenhouse gases [5]. Action to reduce high volumes of atmospheric pollutants is primarily through voluntary policy programs and initiatives. Notable is the Zero Routine Flaring by 2030 (ZRF) initiative, a voluntary policy platform created by the World Bank and the United Nations in 2015. To date, 35 governments, 53 oil companies, and 12 development institutions have endorsed the ZRF initiative; however, enforcement remains dependent on domestic environmental regulations. The Global Gas Flaring Reduction Partnership (GGFR) is a voluntary program that provides technical support and guidance to countries to measure, report, and verify their gas flaring emissions and facilitate stakeholder cooperation to address environmental impacts. The GGFR also supports the ZRF initiative and projects that aim to capture and utilize methane from oil and gas operations, such as the Global Methane Hub [3,5,24,25]. Signatories to the Paris Agreement have also included strategies to minimize gas flaring as part of their Nationally Determined Contributions (NDCs), such as capturing associated gas, implementing regulations or fees, or promoting alternative energy sources.

A recent NDC synthesis report (2024) synthesized information from 168 of the latest available NDCs, representing 195 Parties to the Paris Agreement; it finds that current commitments would lead to an 8.3% increase in global GHG emissions by 2030 compared to 2010 levels [26]. Although gas flaring significantly contributes to methane, CO_2, and black carbon emissions, it represents only one component within a broader emissions landscape. Notably, however, is the projected 10.6% increase in total global greenhouse gas (GHG) emissions across all sectors. Achieving the 2050 net-zero target under current NDCs will therefore require additional, realistic measures and policies [27], including specific action on flaring. The updated NDC synthesis report and other research project emissions will increase temperatures to 1.5 °C if emissions are reduced by 45% by 2030 compared to 2019. Limiting warming to 2 °C by 2030 requires a 25% reduction in emissions, whereas a business-as-usual scenario sets the path for 2.7 °C warming by the end of the century [28–34]. Recent reductions in CO_2 emissions and gas flaring—5.8% and 5%, respectively [3,35]—highlight the gap between intended goals within Nationally Determined Contributions (NDCs) and actual outcomes [36,37]. In 2020, global CO_2 emissions fell by nearly two gigatons (2 Gt CO_2) due to lower energy demand. Yet atmospheric CO_2 levels rose to a record high of 412.5 parts per million, approximately 50% above pre-industrial levels. Similarly, gas flaring decreased by 5% in 2021, yet 144 billion cubic meters was still wasted globally at oil and gas facilities, emphasizing the persistent challenges in aligning emission targets with actionable reductions.

One of the key challenges to flaring reduction is that oil and gas companies and energy investors place relatively low importance on voluntary emission reduction programs compared to investment that conforms to mandated legislative and regulatory practices [38,39], particularly where profit is prioritized over emission reduction [40]. Without stronger global governance on flaring and its subsequent implementation in domestic regulatory practices, countries without oil and gas resources will likely continue to advocate for more stringent policies and effective regulatory frameworks in low-income, developing oil-producing nations [41]. Oil and gas firms often lobby to weaken flaring regulations, which undermines domestic compliance, monitoring, and reporting frameworks [42]. Experts disagree on the best remedy – some urge binding legislation that mandates flaring measurement and public reporting, while others argue that voluntary disclosure programs, backed by strategic regulation, can better motivate companies to adopt cleaner technologies [43]. Broader contextual factors, such as economic and technical feasibility, international aid, responsibility and equality, public participation and stakeholder engagement, international pressure, and domestic political negotiation among coalitions of interest, all influence the failure or success of flaring reduction [44].Thus, there is a need to combine policy action through multi-scalar initiatives that link international cooperation, national legislation, and local action [45,46].

Political, Institutional, and Regulatory Barriers to Gas Flaring Reduction

Efforts to reduce gas flaring face significant political and institutional barriers, with state and industry actors exerting a substantial influence on policy outcomes, environmental laws, and implementation measures [4]. The influence of fossil fuel lobbying leads to various institutional challenges, creating policy deficits that undermine the effectiveness of environmental protection [47,48]. These challenges (re)produce failures in institutional capability to achieve environmental protection goals [49–53]. Such deficits are particularly problematic in fossil fuel-rich developing nations, where rent-seeking behavior, the resource curse, and a lack of transparency weaken accountability within the industry and hinder the development of effective flaring abatement policies (e.g., [54–60]).

A major obstacle to policy action is the issue of infrastructural "lock-in" to carbon-intensive practices, i.e., entrenched dependence on fossil fuels for economic development outcomes. Lock-in can lead to flaring being tacitly endorsed as an economic measure [61–69], despite its adverse impacts on resource management, transboundary air pollution [70,71], and energy security risks. This problem is exacerbated by geopolitical shocks to energy markets, including the COVID-19 pandemic and Russia's invasion of Ukraine. The lack of coherent environmental policies and regulatory measures further hampers flaring reduction efforts, with failures in the design and implementation of gas flaring policies, incoherent legislative frameworks, and a lack of transparent reporting and statistical disclosure reduction [15,16,72–76]. Additionally, outdated legal provisions limit regulatory enforcement, with penalties often ineffective in deterring regulatory violations [1,49,53,69,76–79].

The environmental implications of gas flaring extend globally, resulting in greenhouse gas emissions and perpetuating local and international environmental injustices. Decisions surrounding economic development and flaring policies often result in transboundary pollution, impacting the environmental management efforts of other nations [80]. As a result, consistency in flaring policies among oil and gas producers and non-producers is crucial to achieving global environmental justice. However, current mitigation policies are typically approached on a national level, limiting their broader impact [20]. A multi-level governance approach that encourages international cooperation and solidarity is essential to fostering fair, shared emission reduction goals [81,82].

Although existing scholarship, consultations, and reports, e.g., [1,12,15,16,18,49,51,73,83–96], as well as interviews and expert surveys conducted in our previous research, have identified various policy and regulatory criteria to mitigate gas flaring, significant gaps remain in understanding the most critical gas flaring policy and regulatory framework criteria and sub-criteria for mitigating gas flaring effectively across scales. This empirical analysis aims to address the barriers to effective gas flaring reduction, focusing on issues of governance, energy justice, and implementation through empirical research with key stakeholders across the oil and gas policy and industry sectors. Selecting suitable gas flaring policies and regulatory framework criteria options to reduce the impact of climate change is complex. Hence, it necessitates an appropriate methodological approach for policy framing that can manage several alternatives. The Analytical Hierarchy Process (AHP) has been ranked among the top multi-criteria decision analyses, e.g., [97,98], and presents a suitable platform for decisions involving criteria and alternatives [99–101]. G-TOPSIS is also highly regarded for its ability to adapt to various situations and requirements. In uncertain decision-making, G-TOPSIS can enhance the precision of decision-making [102]. Combining the AHP and G-TOPSIS methods offers a robust and efficient model for conducting social science research on global gas flaring and energy.

2. Materials and Methods

Our research objective is to assess stakeholder preferences among policy and regulatory options, aiming to identify the most effective approach to eliminate routine gas flaring by 2030 and achieve net-zero emissions by 2050, while prioritizing principles of good governance, justice, and fair implementation. To address this objective, we employed a three-level hybrid methodology to identify, prioritize, and recommend solutions for gas flaring policy, regulatory criteria, and sub-criteria. We pose three research questions:

1. What are the key criteria and sub-criteria, and alternative gas flaring policies and regulatory frameworks, that can help meet the 2030 zero routine flaring target?
2. How can these criteria, sub-criteria, and alternative frameworks be prioritized, selected, and benchmarked to stimulate flaring reduction actions?
3. What are the optimal criteria and sub-criteria presenting the best alternative policy scenario to stimulate flaring reduction actions?

We employ a combination of the Analytic Hierarchy Process (AHP) and Grey Technique for Order of Preference by Similarity to Ideal Solution (G-TOPSIS) analysis to identify the most critical criteria and sub-criteria, as well as feasible alternative scenarios that meet these demands. The research involved three phases to address this (see Figure 1).

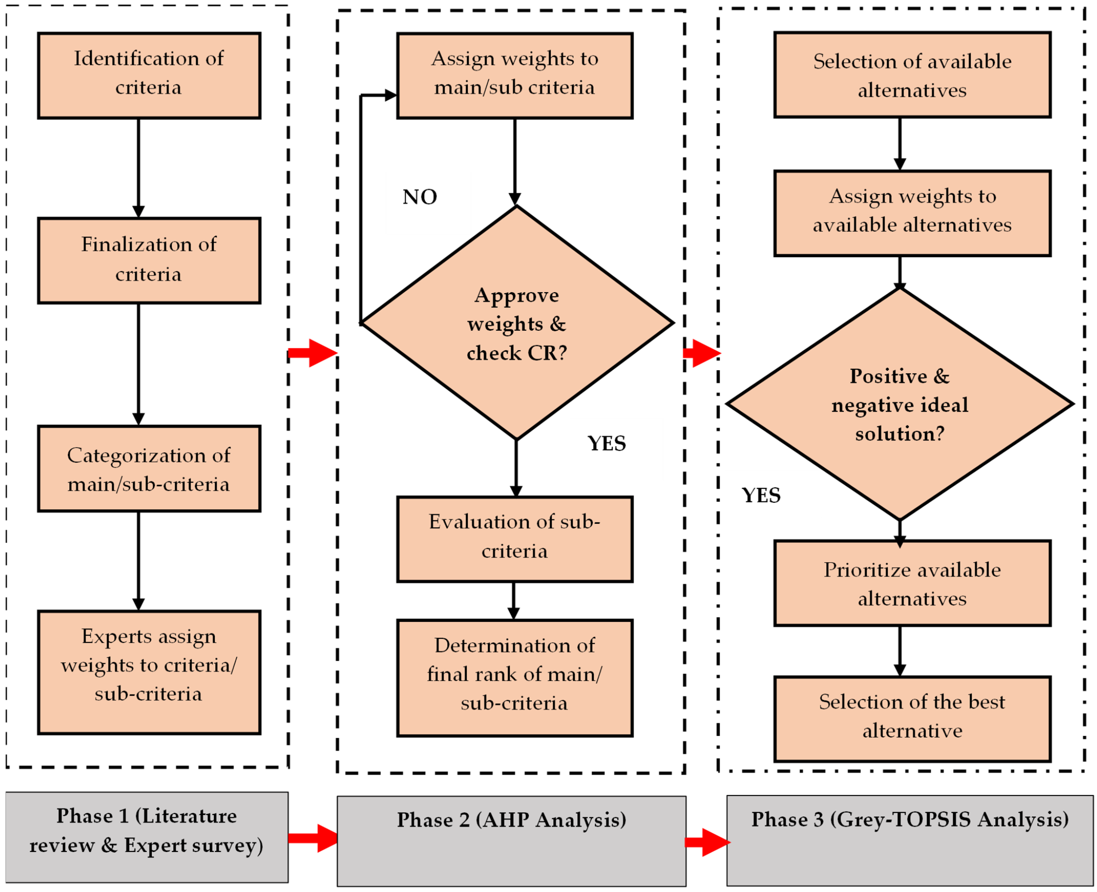

Figure 1. Process flow illustrating the various research phases involved in developing alternative policy and regulatory options. This flow chart outlines our three-phase methodology. In Phase 1 (Literature Review & Expert Elicitation), we identify, finalize, and categorize policy criteria and sub-criteria, then engage experts to assign preliminary weights. Phase 2 (AHP Analysis) uses the Analytic Hierarchy Process to refine these weights: Stakeholders review pairwise comparisons, consistency ratios (CRs) are checked, and only approved weight sets move forward to determine the final ranking of criteria and sub-criteria. Phase 3 (Grey-TOPSIS Analysis) selects and weights available policy alternatives, computes their closeness to the positive and negative ideal solutions, and produces a prioritized list of interventions. Red arrows indicate progression only when consistency thresholds are met, ensuring methodological rigor and decision-maker confidence.

- Phase 1—Identify Criteria and Sub-Criteria

The first phase focused on identifying gas flaring policy criteria and sub-criteria through a literature review, semi-structured interviews, and expert surveys. Feedback was collected from various stakeholders. Key criteria and sub-criteria were derived from eight objective reports and consultations by the Global Gas Flaring Reduction Partnership (GGFR) and the World Bank between 2002 and 2022.

The literature review examined journal articles, gas flaring and energy reports, official policy documents, and regulatory frameworks, using the keywords "gas flaring" AND "policies" OR "regulations" OR "barriers." Policy documents were sourced through Google, and academic articles were sourced through Scopus. Only English-language publications were included, with no restriction on publication year. Of 50 documents reviewed, 35 met the inclusion criteria. Contents that did not meet these requirements were excluded.

To complement this, we conducted interviews and surveys with stakeholders from the top 15 gas flaring countries, including academic and industry experts, oil and gas professionals, legal and regulatory authorities, government and NGO representatives, and citizen stakeholders. Drawing on these insights and the eight key GGFR/World Bank reports [12,84,87,103], we finalized and categorized the main criteria and sub-criteria for gas flaring policies and regulatory frameworks (see Tables 1 and A19 in the appendices for full details).

Table 1. Categorization of criteria in global gas flaring policies and regulations.

Main Criteria	Details of Each Criterion	Sub-Criteria	References
Policy and targets	Gas flaring and venting policies, abatement, and targets are set to avoid resource wastage and reduce local air pollution and GHG emissions. A bottom-up approach to setting sector-specific targets is necessary where no national flaring targets exist.	• Background and the role of reductions in meeting environmental and economic objectives • Targets and limits specified by the regulator	[1,12,15,16,49,51,73–76,84–96,103–106]
Legal, regulatory framework, and contractual rights	Gas flaring legal, regulatory framework, and contractual rights are usually anchored in national or local legislation governing the jurisdiction of the oil and gas sector and environmental management.	• Primary and secondary legislation and regulation • Legislative jurisdictions • Associated gas ownership	[1,12,15,16,49,51,73–76,84–96,103–106]
Regulatory governance and organization	Regulatory governance and organization criteria define which institutions have regulatory authority over the oil and gas industry—a factor essential to clearly define the institutions, along with the scope of their mandates and abatement strategies from the perspective of waste prevention.	• Regulatory authority • Regulatory mandates and responsibilities • Monitoring and enforcement • Development plans • Economic evaluation	[1,12,15,16,49,51,73–76,84–96,104]
Licensing and process approval	Regulations on gas flaring and venting depend on how associated gas is treated and oil development rights are granted in primary legislation. Approval can be granted through various permits and licenses. The state typically owns underground resources (Canada and the United States are notable exceptions) irrespective of the applicable fiscal regime.	• Flaring or venting without prior approval • Authorized flaring or venting	[1,12,15,16,49,51,73–76,84–96,103–106]
Measurement and reporting	Regulations that prescribe measurement and reporting standards and require companies to record and submit information help monitor compliance, track progress, compare performance, improve poorly performing assets, and identify those needing inspection.	• Measurement and reporting requirements • Measurement frequency and methods • Engineering estimates • Record keeping • Data compilation and publishing	[1,12,15,16,49,51,73–76,84–96,103–106]
Fines, penalties, and sanctions	Most jurisdictions, legislation, and contractual provisions impose sanctions, mandatory payments, or other enforcement measures for non-compliance with gas flaring regulations; under the "non-monetary penalties" sub-criterion, this also includes criminal sanctions (e.g., imprisonment or license revocation).	• Monetary penalties • Nonmonetary penalties	[1,12,15,16,49,51,73–76,84–96,103–106]
Enabling framework	The gas flaring enabling framework includes a range of economic instruments or flaring abatement programs that can be introduced to encourage producers and specifically target gas flaring and venting (e.g., fiscal or market-based incentives).	• Performance requirements • Fiscal and emission reduction incentives • Use of market-based principles • Negotiated agreements between the public and the private sector. • Interplay with midstream and downstream regulatory framework	[1,12,15,16,49,51,73–76,84–96,103–106]

We developed a corpus of policy materials that provide four optimal gas flaring policies and regulatory framework alternatives, considering both the Stated Policies Scenario

(STEPS), which considers only specific policies in place or those that have been announced by governments and the Announced Pledges Case (APC), which assumes that all announced national net-zero pledges are fulfilled fully and on schedule, regardless of whether they are supported by specific policies (See Appendix A Table A20). The alternatives in Appendix A Table A20 were derived from the following reports, forecasts, and scenarios, considering the following factors:

1. The current global CO_2 reduction trajectory of 5.8% [5,35].
2. The current global gas flaring reduction trajectory of 5% [24,107].
3. Remaining on course with the IEA (NZE by 2050) scenario necessitates eliminating all non-emergency flaring globally by 2030, translating into a 90% reduction [107].
4. Limiting temperature rises to 1.5 °C in model pathways with no or limited overshoot of 1.5 °C, with global net anthropogenic CO_2 emissions declining by about 45% from 2010 levels by 2030 [28–34].
5. Limiting global warming to below 2 °C by 2030, where emissions are projected to decline by about 25% by 2030 in most pathways [28–34].
6. The current IEA projections estimate that if annual CO_2 emissions trends continue to increase from 34 Gt in 2020 to 36 Gt in 2030 and remain on the same trajectory until 2050, the global average surface temperature is expected to rise by around 2.7 °C with the business-as-usual scenario [35,36,108].

- Phase 2: Evaluate, prioritize, and benchmark gas flaring policies and regulatory frameworks through Analytical Hierarchy Process analysis

The second phase calculated weights using the Analytic Hierarchy Process (AHP) to rank the criteria. Widely adopted for complex decision-making, the AHP structures problems hierarchically, allowing decision-makers to weight the significance of each criterion [109]. Its strengths lie in combining objective data with subjective judgments, making it adaptable to intricate problems. Using pairwise comparisons in AHP reveals logical inconsistencies, translating qualitative preferences into measurable values and leading to replicable, transparent, and policy-relevant social intelligence. The AHP presents a pairwise comparison matrix to compute the weights of the main and sub-criteria identified in phase 1. Further details on the method are presented in Section 3.1 below.

- Phase 3: Derive optimal gas flaring policy criteria and sub-criteria using G-TOPSIS

In the third phase, the Grey Technique for Order of Preference by Similarity to Ideal Solution (G-TOPSIS) approach prioritized solutions to overcome the identified barriers. G-TOPSIS ranks alternatives based on their relative importance and alignment with constraints. It involves basic calculations and short computation time, ranks the alternatives, incorporates both quantitative and qualitative criteria, and determines the relative importance of the alternatives and their compliance with the constraints. G-TOPSIS is valued for its local and experimental nature and is well-suited to various situations and requirements [105]. The G-TOPSIS method was employed to identify the optimal solution from four available alternatives (scenarios) that would meet the ZRF by 2030 and NZE by 2050 targets. These methods are detailed below and illustrated in Figure 1, following Refs. [100,110,111]. Further details on the methodological steps are presented in Section 3.2 below.

2.1. Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) is a well-established multi-criteria decision analysis technique that assigns weights to compare parameters or alternatives, providing a robust model for decision-making, rating, and prioritizing issues, thereby enabling management and formulation of a hierarchical model [112]. The AHP provides flexibility in integrating objective value evidence, subjective judgments, and expert knowledge [97]. It has been used either as a standalone or mixed-methods approach [113] on a range of environmental policy issues relevant to energy planning [97,114,115], and energy sustainability research [116–118].

Saaty [119] proposed the following stages, which were applied in the current study:

- **Stage 1. The development of the hierarchical pattern**—Decomposing the problem into a hierarchical tree [100] formed around classifications and specific criteria. Seven main criteria and twenty-four sub-criteria directly linked to global gas flaring policies and regulations were selected and categorized based on consultations held by Refs. [12,103] (Table 1; Appendix B Figure A1).
- **Stage 2. Assembling expert opinions**. The basic Saaty 1–9 AHP scale (Table 2) informed the development of a survey of expert participants to provide their opinions. From 120 survey links sent out, 17 people (14.2%) responded (Table 3). As there is no consensus among researchers on the number of respondents required for a reliable AHP analysis, the method can be applied to a wide range of respondents, from a single expert to multiple experts [119]. For example, Qureshi and Harrison's study [120] received 13 responses from farmers regarding riparian revegetation policy options. The 17 respondents from the top 15 gas flaring countries represented a highly informed group on global gas flaring policy and regulations. The selection of experts for the semi-structured interviews and expert surveys was based on the complexity of global gas flaring issues. During the interviews, respondents were asked specific questions about gas flaring governance, policies, processes, and management, though experts were also encouraged to share their broader perspectives on gas flaring. The interviewees were purposefully selected to represent a diverse range of stakeholders both directly and indirectly involved in gas flaring. This included ordinary citizens from gas flaring host communities, academics and professionals with expertise in environmental and related fields, non-affiliated citizens residing in those communities, regulatory and technical advisors, and legal and environmental consultants (see Table 3). These tables provide a detailed overview of the respondents by country, gender, focus area, and sector. Before the survey, experts were informed about the study's objective, and after providing consent in line with ethical procedures, data were collected through an online survey. The survey questionnaire focused on comparing the main criteria and the sub-criteria to obtain a vector of weights by applying the basic AHP scale (Table 2) to each criterion and sub-criterion.

Table 2. Saaty's scale of importance for pairwise comparison matrices.

Preference Scores	Definition	Explanation
1	Equally important	Both elements have equal priority.
3	Moderately important	One element is moderately favored over the other.
5	Strongly important	Experience and judgment strongly recommend preferring one element over the other.
7	Very strongly importance	An element is given a very strong preference over another, and its dominance is demonstrated in practice.
9	Extremely importance	There is the most decisive, practicable proof of facts to favor one operation over another.
2, 4, 6, 8	Intermediate weights	These intermediate weights represent a compromise between the preferences listed above.
Reciprocals		Reciprocals are used for inverse comparison.

Table 3. Information on consulted experts.

Country	Respondents (n = 17)
Angola/France/UK/Nigeria	3
Canada	1
Egypt	1
France	3
Germany	1
Iran	1
Mexico	1
Netherlands	1
Nigeria	9
Norway	1
Qatar	1
UAE/Oman/Nigeria	1
UK	3
USA	5
Gender	
Male	15
Female	2
Sector	
Academics/industry experts	4
Industry stakeholders/scientific	2
Oil and gas industry	9
Directors, law and regulatory, governmental, and NGO stakeholders	12
Energy consultancy	1
Ordinary citizen stakeholder	3
Others	3

Respondents were asked to engage in a pairwise comparison and rate the importance of each criterion on a scale of 1 to 9 for all 57 questions. Each question generated two sets of responses, labeled group A and group B, each containing a mix of respondents. An average response was calculated for each question in both groups' results. The consistency ratio (CR) of responses [100] was first checked using the CR equation (see the Calculation of Consistency Index section below). As the results would be inaccurate if CR $\geq$ 0.10, all CRs higher than 0.10 were adjusted, and the comparisons were recalculated. For example, when the CR of criteria or sub-criteria with a score of 4 exceeded 0.1, adjustments were implemented to maintain consistency by assigning a value of either 3 or 5 based on subjective judgment.

- **Stage 3. Pairwise comparison and calculation of the relative weights and consistency index (CI). The third stage involved four steps.**

Develop the pairwise comparison matrix. A pairwise comparison matrix was performed, and the values of the pairwise comparisons were determined using Equation (1). Given a matrix A for n = 5 criteria, we have:

$$A = \begin{matrix} a_{1\,1} & a_{1\,2} & \cdots & \cdots & a_{1\,n} \\ a_{2\,1} & a_{2\,2} & \cdots & \cdots & a_{2\,n} \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ a_{m\,1} & a_{m\,2} & \cdots & \cdots & a_{m\,n} \end{matrix} \quad (1)$$

Develop the normalized matrix A_1.

If operation i has a number assigned to it relative to z, then z has the same value as i. Hence, we calculated and obtained the eigenvalue and eigenvector, and the normalized comparison matrix (A_1), as follows:

$$A_{1\,1} = \begin{matrix} a_{1\,1} & a_{1\,2} & \cdots & \cdots & a_{1\,n} \\ a_{2\,1} & a_{2\,2} & \cdots & \cdots & a_{2\,n} \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ a_{m\,1} & a_{m\,2} & \cdots & \cdots & a_{m\,n} \end{matrix} \quad (2)$$

$$a_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \qquad for\ i,\ j = 1, 2, 3, \ldots\ldots n \quad (3)$$

where n = number of criteria.

$$w = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \text{ and } w' = Aw = \begin{bmatrix} w'_1 \\ w'_2 \\ \vdots \\ w'_n \end{bmatrix} \quad (4)$$

Calculation of eigenvalue and eigenvector.

The inputs in Table 1 were applied to produce the ratio scale consistency index as the output, built on the eigenvector. Defining X as the eigenvector, X_i as an eigenvalue of the given matrix, and λ_{max} as the largest eigenvalue of the pairwise comparison matrix, we calculated:

$$\lambda_{max} = \frac{1}{n}\left(\frac{X'_1}{X_1} + \frac{X'_2}{X_2} + \ldots \frac{X'_n}{X_n}\right) \quad (5)$$

Calculation of Consistency Index (CI).

The fourth step of the AHP analysis involved checking the CI calculation. A matrix (A_1) was formed to compare objectives and criteria in pairs. During the review of respondents' opinions, relative judgements (numbers allocated to criteria and sub-criteria) were combined and averaged to form a matrix of comparative judgments for opinions. Thus, the consistency of the pairwise comparison matrix was calculated as follows:

$$\text{CI} = \frac{\lambda_{max} - n}{n - 1} \quad (6)$$

Here, λ_{max} indicates the eigenvalue, and n represents the number of criteria. The consistency ratio (CR) is the ratio of the consistency index (CI) to the average random index (RI). The CR is thus given as:

$$\text{CR} = \left(\frac{\text{CI}}{\text{RI}}\right) \quad (7)$$

The value of the RI is based on the average consistency of square matrices of the number of observed criteria n with its corresponding assigned RI value, where RI indicates the random index (Table 4).

Table 4. Average random index (RI) based on matrix size.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

The CR should be within the threshold of 0.1 for the rankings to be consistent. If the CR ≥ 0.1, the results would be inaccurate, and the comparisons are recalculated. The weights of the key criteria and sub-criteria are provided using the AHP approach.

The overall global weight ranking of sub-criteria was calculated by multiplying the local weight of each sub-criterion by its corresponding main criterion. This was performed hierarchically, based on the obtained values, which helped us determine the overall importance of each sub-criterion.

2.2. Grey Numbers

The interval of the unknown and known values is known as the grey number, which comprises partial or incomplete system data. The grey number is expressed with the symbol $\otimes$. There are several types of grey numbers. Following Refs. [111,121], we introduce three types of grey numbers:

Type (1): If $\otimes B$ is a grey number whose lower bound can only be calculated, it is known as a grey number with only a lower bound and is denoted as. $\otimes B = [\ \underline{B}\ , \infty)$.

Type (2): If $\otimes B$ is a grey number whose upper bound can only be calculated, it is known as a grey number with only an upper bound and is denoted as. $\otimes B = (\ \infty\ ,\ \overline{B}]$.

Type (3): If If $\otimes B$ is a grey number whose lower and upper bounds can be calculated, it is referred to as an interval grey number and is denoted as $\otimes B = [\ \underline{B}\ ,\ \overline{B}]$.

If $\otimes B = [\ \underline{B}\ ,\ \overline{B}]$ and $\otimes C = [\ \underline{C}\ ,\ \overline{C}]$ are two grey numbers, then arithmetic operations can be written on them as Equations (8)–(11):

$$\otimes B + \otimes C = [\ \underline{B} + \underline{C}\ ,\ \overline{B} + \overline{C}\ ] \tag{8}$$

$$\otimes B - \otimes C = \otimes B + (- \otimes C) = [\underline{B} - \overline{C}\ ,\ \overline{B} - \underline{C}] \tag{9}$$

$$\otimes B \ \mathrm{x} \ \otimes C = [\ Min\ \{\ \underline{B}\,\underline{C}\ ,\ \overline{B}\,\overline{C}\ , \overline{B}\,\underline{C}\ ,\ \underline{B}\,\overline{C}\ \},\ Max\ \{\ \underline{B}\,\underline{C}\ ,\ \overline{B}\,\overline{C}\ , \overline{B}\,\underline{C}\ ,\ \underline{B}\,\overline{C}\ \}] \tag{10}$$

$$\frac{\otimes B}{\otimes C} = \otimes B \ \mathrm{x} \ \otimes C^{-1} = \left[Min \left\{ \frac{\underline{B}}{\underline{C}}, \frac{\underline{B}}{\overline{C}}, \frac{\overline{B}}{\underline{C}}, \frac{\overline{B}}{\overline{C}} \right\},\ Max \left\{ \frac{\underline{B}}{\underline{C}}, \frac{\underline{B}}{\overline{C}}, \frac{\overline{B}}{\underline{C}}, \frac{\overline{B}}{\overline{C}} \right\} \right] \tag{11}$$

$$L\ (\otimes B) = \overline{B} - \underline{B} \tag{12}$$

The length of the grey $\otimes B = [\ \underline{B} - \ \overline{B}\ ]$ was calculated from Equation (12).

If the two grey numbers $\otimes B = [\ \underline{B}\ ,\ \overline{B}]$ and $\otimes C = [\ \underline{C}\ ,\ \overline{C}]$ are represented, the degree of greyness between these two numbers is obtained using Equation (13) [122]. For this study, we employed grey linguistic variables based on grey numbers to assess the impact of the alternatives presented in Table A21 in the Appendix A.

Accordingly,

$$p\ \{\otimes B\ \leq\ \ \otimes C\ \} = \frac{Max\ \{0\ ,\ L^{*} - Max\ (\ 0\ ,\ \ \overline{B} - \underline{C}\ )\}}{L^{*}} \tag{13}$$

where $L^{*} = L\ (\otimes B) + L\ (\otimes C)$

2.3. Grey Group TOPSIS (G-TOPSIS) Method

In 1981, Yoon and Hwang developed the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method [123]. The Grey TOPSIS method assesses n alternatives using m parameters. The method determines the optimal positive and negative solutions among several alternatives. The least distance from the optimal positive solution and the highest distance from the optimal negative solution is referred to as an optimal alternative. Following Ref. [121]'s recommendation, we established the following stages of the G-TOPSIS method. (See Appendix B for the complete Grey Group TOPSIS (G-TOPSIS) Method equations).

3. Results

3.1. Results of AHP

The overall weight and ranking of the main criteria and sub-criteria, as ranked by respondents in groups A and B, are presented in Tables A17 and A18. The estimated weights of the seven main criteria (at the parent level) are shown in Figure 2.

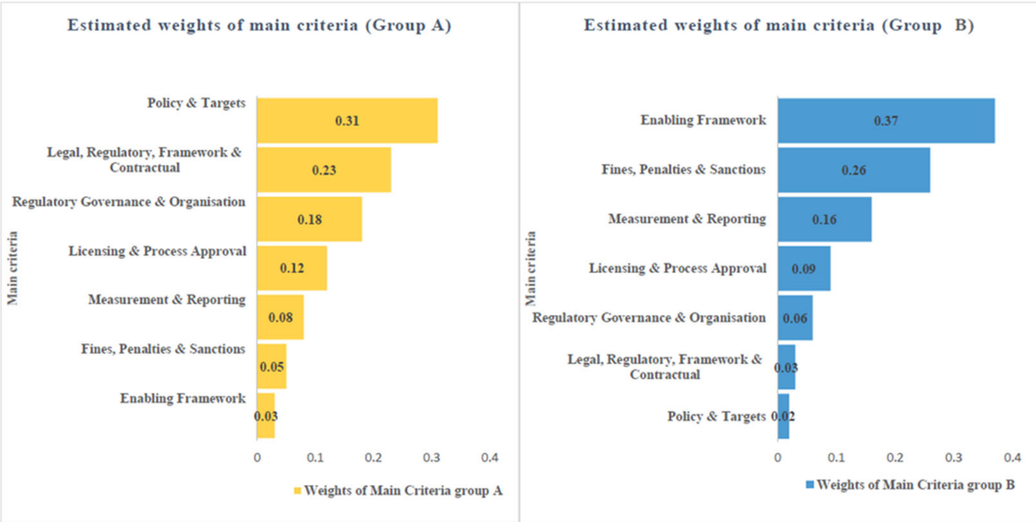

Figure 2. Estimated weights of the seven main criteria from group A and B respondents.

The seventeen experts in groups A and B, purposively selected from the top 15 gas flaring countries to capture both depth and diversity of insight, span a range of legal traditions (common law in Nigeria and the UK; civil law in France, Germany, and Egypt; and hybrid systems elsewhere) that may shape governance priorities. Their backgrounds (see Table 3) include ordinary community stakeholders, academics and environmental professionals, non-affiliated residents, regulatory and technical advisors, and legal/environmental consultants. After briefing and informed consent, all respondents completed the 57-question online AHP survey (Table 3), applying the basic AHP scale to each main criterion and sub-criterion to generate comparative weight vectors. Although participants were assigned to fixed groups A and B, throughout the survey their answers and, in some cases, their group labels, interchanged, reflecting fluid boundaries in how responses mapped to each group. The concentration of experts from Nigeria and the UK reflects both the policy importance and expert accessibility in those flaring-intensive contexts while differing national enforcement cultures may have influenced sub-criterion rankings.

"Policy and Targets" and "enabling framework" criteria were estimated as having the highest importance, with a weight of 0.31 for group A and 0.37 for group B. Although some respondents in both groups also estimated "enabling framework" for group A as low, with weights of 0.03, and "policy and targets" for group B as low, with weights of 0.02, overall, the results indicate that these were estimated as the most important criteria among the main criteria in both groups. The remaining main criteria were ranked as follows: "legal, regulatory framework, and contractual rights" (group A = 0.23, group B = 0.03), "regulatory governance and organization" (group A = 0.18, group B = 0.06), "licensing and process approval" (group A = 0.12, group B = 0.09), "measurement and reporting" (group A = 0.08, group B = 0.16), and "fines, penalties, and sanctions" (group A = 0.05, group B = 0.26). Results from the calculation of the weights of each criterion are presented in Tables A17 and A18, Figure 2, and Appendix A Tables A1 and A2.

3.2. Results of AHP Local Priority Weights

Appendix A Tables A3–A16 presents the pairwise comparison matrix for each sub-criterion. Figure 3 displays the local priority weight of the sub-criteria for both groups of respondents.

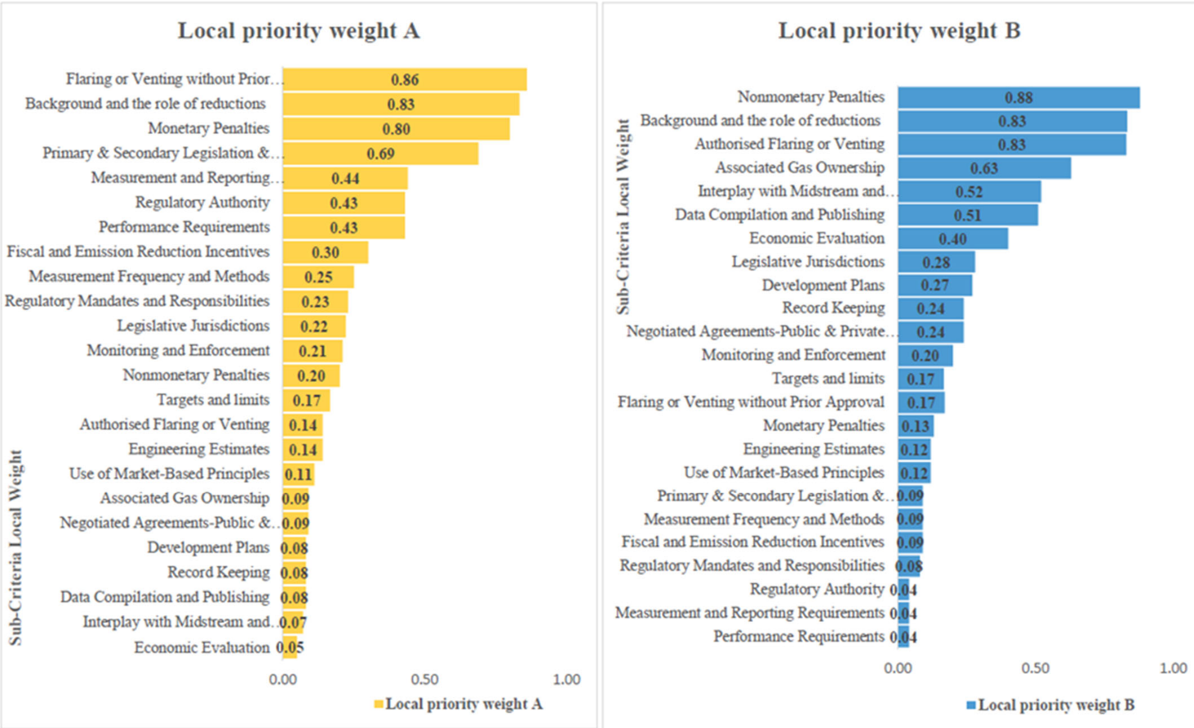

Figure 3. Local weights of sub-criteria (group A and B stakeholders).

The analysis of sub-criteria revealed distinct priorities and practical trade-offs across stakeholder groups. Within the policy and targets dimension, "background and role of reductions" received the highest weight for stakeholder group A (A = 0.83) because it underpins both environmental and economic goal setting, whereas stakeholder group B (B = 0.17) cautioned that without clear, measurable targets, such narratives risk becoming empty commitments. Conversely, "targets and limits" ranked highest for stakeholder group B (B = 0.83), reflecting a preference for firm caps that provide regulatory certainty, while for stakeholder group A (A = 0.17), it was warned that excessively rigid limits may prove politically infeasible or provoke non-compliance.

Under legal, regulatory, and contractual rights, "legislative jurisdictions" mattered to both groups (A = 0.22; B = 0.28), as clear legal authority enables enforcement, although overlapping mandates can still create loopholes. "Associated gas ownership" scored low among stakeholder group A (A = 0.09) but was critical for stakeholder group B (B = 0.63), as secure property rights incentivize companies to capture and sell gas. Stakeholder group A also flagged the risk that privatization without strong oversight could leave communities undercompensated.

In the regulatory governance and organization category, "regulatory authority" emerged as the top priority for stakeholder group A (A = 0.43; B = 0.04) as the key determinant of any oversight framework, but limited capacity and budget constraints risk rendering authorities toothless. "Regulatory mandates and responsibilities" clarified roles (A = 0.23; B = 0.08) yet carried the danger of procedural gridlock, while "monitoring and enforcement" was seen as essential by both stakeholder groups (A = 0.21; B = 0.20) despite the high costs and logistical challenges of on-site inspections. "Development plans"

(A = 0.08; B = 0.27) helped align infrastructure expansion with emissions goals but risked becoming mere rubber stamps, and "economic evaluation" (A = 0.05; B = 0.40) was valued by stakeholder group B as a persuasive tool, though stakeholder group A cautioned that cost–benefit analyses often understate social and health externalities.

Within licensing and process approval, absolute prohibition of flaring or venting without prior approval carried overwhelming weight for stakeholder group A (A = 0.86; B = 0.17), underscoring its potential for immediate emissions cuts. However, stakeholder group B stressed that enforcement depends on robust, real-time monitoring technologies. By contrast, "authorized flaring/venting" resonated with stakeholder group B (A = 0.14; B = 0.83) for its clarity and flexibility, even as stakeholder group A warned that generous allowances could institutionalize routine emissions if not regularly revisited.

Measurement and reporting sub-criteria showed that stringent "requirements" (A = 0.44; B = 0.04) and higher "measurement frequency and methods" (A = 0.25; B = 0.09) were championed by stakeholder group A to ensure accountability, while stakeholder group B pointed to the high costs of deploying advanced monitoring equipment. "Engineering estimates" (A = 0.14; B = 0.12) provided an affordable way to fill data gaps, albeit with acknowledged uncertainty; "record keeping" (A = 0.08; B = 0.24) supported traceability, though manual logs remain prone to error; and "data compilation and publishing" (A = 0.08; B = 0.51) was seen by stakeholder group B as essential for transparency, even as stakeholder group A cautioned that without standardized protocols, published figures may lack comparability.

For fines, penalties and sanctions, "monetary penalties" ranked highest for stakeholder group A (A = 0.80; B = 0.13) as a direct deterrent, though stakeholder group B warned that firms might simply budget fines as a cost of doing business. "Non-monetary penalties" were preferred by stakeholder group B (A = 0.20; B = 0.88), with measures such as permit suspensions or public disclosures carrying reputational weight, provided, as stakeholder group A noted, that solid legal backing ensures enforceability.

Finally, the enabling framework highlighted that "performance requirements" (A = 0.43; B = 0.04) and "fiscal and emission reduction incentives" (A = 0.30; B = 0.09) serve as effective incentives and penalties according to stakeholder group A, yet stakeholder group B cautioned that poorly designed incentives can drain public coffers without yielding real emissions benefits. "Market-based principles" (A = 0.11; B = 0.12) and "negotiated agreements" (A = 0.09; B = 0.24) offered flexibility and the potential to spur innovation, though both groups warned of transparency risks and the possibility that large incumbents might disproportionately benefit. "Interplay with midstream and downstream frameworks" (A = 0.07; B = 0.52) gained support from stakeholder group B for holistic gas capture, while stakeholder group A highlighted the coordination challenges inherent in working across multiple regulatory bodies.

Figure 4 shows that "flaring or venting without prior approval" in the licensing and process approval component (group A = 0.86) and "non-monetary penalties" in the fines, penalties and sanctions component (group B = 0.88) carry the greatest weight among all sub-criteria and emerged as the most important by their respective stakeholder groups. They are closely followed by "background and role of reductions in meeting environmental and economic objectives" in policy and targets (A = 0.83; B = 0.83). Within fines, penalties and sanctions, "monetary penalties" (A = 0.80), and in licensing and process approval, "authorized flaring or venting" (B = 0.83), also rank highly for both groups. In the legal, regulatory and contractual rights category, "primary and secondary legislation and regulation" (A = 0.69) and "associated gas ownership" (B = 0.63) emerge as key factors, while "measurement and reporting requirements" (A = 0.44) and "interplay with midstream and downstream frameworks" (B = 0.52) are the top priorities in measurement and reporting and the enabling framework, respectively. Consistency ratios for all pairwise comparison matrices (Tables A17 and A18) remain well within acceptable bounds, confirming the reliability of these rankings.

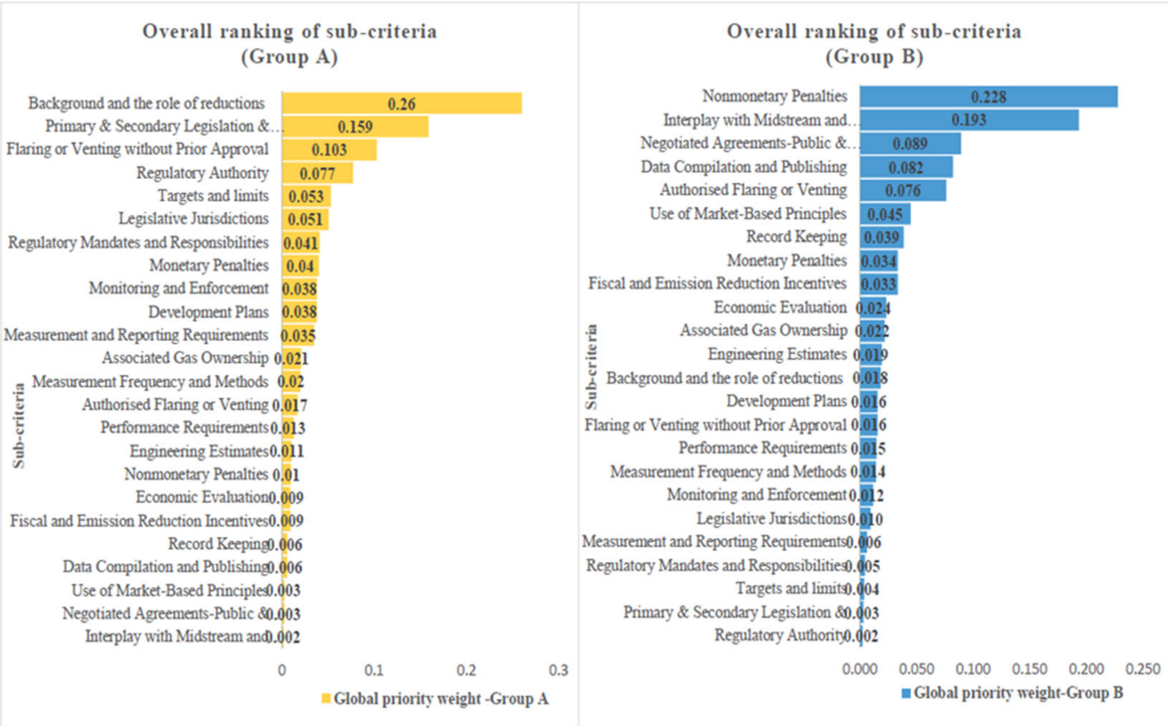

Figure 4. Overall global ranking of sub-criteria (groups A and B).

3.3. Overall Global Weight Ranking of Sub-Criteria

Table A17 (group A stakeholders) and Table A18 (group B stakeholders), as well as Figure 4, show the final global weighting of the sub-criteria.

Figure 4 shows the final overall ranking results of the sub-criteria after calculating global weights. From Table A17 and Figure 4, it is evident that background and the role of reductions in meeting environmental and economic objectives obtained the highest priority global weight of 0.260 among all sub-criteria, followed by primary and secondary legislation and regulation, with a global priority weight of 0.159. The third and fourth positions among all sub-criteria have respective global priority weights of 0.103 and 0.077 for group A stakeholders.

The global ranking of gas flaring policies and regulatory framework sub-criteria by group B stakeholders is shown in Table A18 and Figure 4. It is evident from this that nonmonetary penalties and interplay with midstream and downstream regulatory frameworks were given the highest global weights of 0.228 and 0.193, respectively.

3.4. G-TOPSIS Analysis for Policy Development on Gas Flaring

The findings of the G-TOPSIS analysis (Table 5) show that alternative A1 (full implementation of gas flaring policies and regulatory framework criteria), with a weight of 1, is the best solution. This requires a 100% decrease in CO_2 emissions, accompanied by a corresponding reduction in gas flaring, to limit temperature rises below the 1.5 °C warming target. The second-best alternative is A2 (significant implementation of gas flaring policies and regulatory framework criteria), with a weight of 0.60715. This requires a 45% decrease in CO_2 emissions and a corresponding 90% reduction in gas flaring to limit temperature rise to a 1.5 °C target. The partial implementation of gas flaring policies and regulatory framework criteria (A3), which require a 25% decrease in CO_2 emissions and a 50% reduction in gas flaring, translating to a 2 °C temperature rise, is ranked third, with a weight of 0.3474. Business as usual (BAU), which maintains the status quo and the current CO_2 and flaring reduction trajectories of 5.8% and 5%, respectively, is the least important alternative, with a weight of 0. Table 5 presents the results of the positive grey ideal solution and negative ideal solution obtained through the G-TOPSIS analysis.

Table 5. G-TOPSIS final ranking for available alternatives of gas flaring policies and regulatory framework.

Code	Alternative	S_i^+	S_i^-	p_i	Rank
A1	Full implementation of gas flaring policies and regulatory framework main criteria	0	0.30767	1	1
A2	Significant implementation of gas flaring policies and regulatory framework main criteria	0.13532	0.20914	0.60715	2
A3	Partial implementation of gas flaring policies and regulatory framework main criteria	0.21028	0.11194	0.34740	3
A4	Business as usual (BAU) or do nothing	0.30767	0	0	4

The greyness degree between ideal solutions and alternatives, including the ideal solutions and alternatives, was measured as shown below:

$$P1(S1 \leq S^{max}) = 1$$

$$P2(S2 \leq S^{max}) = 0.60715$$

$$P3(S3 \leq S^{max}) = 0.34740$$

$$P4(S4 \leq S^{max}) = 0$$

The ranking of alternatives is based on the feasible degree of greyness presented below:

$$P1 > P2 > P3 > P4$$

4. Discussion

To abate gas flaring on a global scale requires the implementation of collaborative and consistent national and international policies and regulatory frameworks. The ranking of the main criteria used in this study has recognized policy and targets (with weights of 0.31 for group A stakeholders and 0.02 for group B stakeholders) and an enabling framework (with weights of 0.37 for group A stakeholders and 0.03 for group B stakeholders) as the most important elements in reducing global gas flaring. Gas flaring and venting abatement policies and targets are set to avoid resource wastage and reduce local air pollution and GHG emissions, while an enabling framework includes a range of economic instruments or flaring abatement programs that can be introduced to encourage producers and specifically target gas flaring (e.g., fiscal or market-based incentives).

A lack of appropriate policies and targets in gas flaring remains a key challenge in global flaring reduction, particularly where the political lobbying of oil and gas companies limits effective domestic implementation [73]. Although several studies [15,16,73–76,96], have also identified these criteria as some of the barriers to achieving global flaring reduction, our study's ranking underscores the urgent need for a more extensive global initiative to prioritize the implementation of these top two criteria. While our study highlights the urgent need for a more comprehensive global effort to implement these top two criteria, the entire ranking can serve as a global benchmark for policymakers and gas flaring nations to consider in setting future targets.

Economic benefits, commonly prioritized by oil- and gas-rich nations over climate change concerns, are the main barriers to functional policy implementation [49,65]. Various studies (including those by Refs. [49,53,73–77,79,124–128]), have identified the need for an enabling framework including fiscal incentives and emission reduction incentives for investments and a weak natural gas market and tax reductions to reduce flaring. However, the extent to which this criterion hinders flaring reduction globally has not been sufficiently researched. Accordingly, results from group B stakeholders ranked the "enabling flaring framework" criteria as one of the essential ways to reduce flaring globally. While some gas flaring nations have passed flare abatement laws and instituted fiscal incentives, these country-specific laws and measures have not yielded the desired outcome due to a lack of political will to end gas flaring and provide economically viable gas markets through operational policies and regulations [50,67,68,129]. This includes the fossil fuel industry, its influence over policy, and the overall economic benefits of oil companies and oil-rich nations. Gas flaring regulations vary globally, making it challenging for oil companies to follow all applicable laws. This inconsistency can result in some companies flaring gas in countries with weaker regulations. As this research proposes uniform global policies and regulations to mitigate global gas flaring, it would ensure a fairer playing field, simplify compliance, reduce ambiguity, and lower the cost of reducing gas flaring through a standardized approach.

For group A stakeholders, legal and regulatory frameworks and contractual rights carry a weight of 0.23, whereas for group B, this weight is 0.03. These frameworks are typically anchored in national or local legislation that governs the industry and environmental management at the national or local level. Sanctions and penalties for non-compliance with gas flaring regulations are also important considerations. Regarding fines, penalties, and sanctions, a weight of 0.26 was assigned by group B stakeholders, while group A stakeholders assigned a weight of 0.05. In most jurisdictions, legislation and contractual provisions impose fines, penalties, sanctions, mandatory payments, or other enforcement mechanisms for non-compliance with gas flaring regulations. However, regulatory failures in designing and implementing gas flaring policies and ineffective penalty systems lead to inconsistencies. Such inconsistency is largely attributed to ambiguous and incoherent legislative and regulatory frameworks, non-transparent reporting, and poor disclosure of gas-flaring statistical data. These factors are also linked with the fundamental reasons why investment in associated gas recovery and processing facilities may be lacking. Addressing these criteria and sub-criteria should form an integral part of the global approach to deterring flaring offenders and achieving the Zero Routine Flaring by 2030 goal. Based on the rankings from the two stakeholder groups, it is crucial to have effective and comprehensive policies and targets for reducing gas flaring to achieve the overall environmental and economic goals. While it is crucial to have measures within the legal and regulatory frameworks and contractual rights, rather than relying exclusively on fines, penalties, and sanctions, these measures are still not as important as having strong and transparent gas flaring policies and targets that create an enabling framework.

The regulatory governance and organization criteria determine which institutions have the authority to regulate the oil and gas industry. Adequate and effective measurement and reporting are also crucial criteria, with national or local regulations mandating companies to record, process, and submit the information specified by the regulator. However, our analysis reveals that current administrative frameworks may not be suitable for implementing current legal and regulatory provisions and new policies independently and in a timely manner. As a result, group A stakeholders weighted the regulatory governance and organization criteria as 0.18, while group B stakeholders weighted it 0.06. Similarly, measurement and reporting were weighted 0.16 for group B stakeholders and 0.08 for group A stakeholders. These rankings further indicate regulatory failure in designing and implementing gas flaring policies, an incoherent legislative and regulatory framework, a lack of monitoring and enforcement capacity, and non-transparent reporting of gas flaring data in most jurisdictions. Furthermore, although strengthening institutions involved in flaring management is essential, the two stakeholder groups have ranked this criterion as third in importance, considering the implementation of appropriate policies and targets, and establishing a suitable enabling framework, as more significant in achieving flaring reduction targets. Although regulatory governance, organization, measurement, and reporting criteria are essential to the overall goal, results show that they are not as crucial as having strong and transparent policies and targets, an enabling framework that supports these goals, and legal and regulatory frameworks that protect contractual rights.

Group A and B stakeholders ranked licensing and process approval as the least important criteria, with weights of 0.12 and 0.09, respectively. Although ranked as the least important criterion, it is crucial to achieving an overall global flaring reduction. Few studies have identified this criterion as a barrier to meeting the ZRF target. However, gas flaring and venting regulations depend on how the associated gas is treated, the oil development rights granted in primary legislation, and the application and approval procedures for gas flaring and venting. The right to flare and vent can be obtained through a flaring and venting permit, a field development plan for a license or contract, or an environmental license. Based on these factors, this criterion may not be as significant as the others. While it is worth addressing, the impact on the overall decision-making process in gas flaring policies and regulatory frameworks to abate flaring may be less significant.

In situations where decision-making is uncertain, G-TOPSIS can enhance the precision of decision-making. Despite slow rates of global CO_2 and gas flaring reductions, the G-TOPSIS analysis revealed relatively optimistic scenarios, identifying four critical conceptual pathways representing different interpretations and consequences. Depending on the chosen pathway, all scenarios must implement the AHP results as a foundational benchmark at different levels.

The best solution identified was alternative A1, which has a weight of 1 and requires full implementation of the AHP results to stay on course and ensure that emission reduction goals are achieved. This suggests that all the criteria must be implemented, with particular emphasis on those that are ranked highly. Additionally, it requires a 100% decrease in CO_2 emissions and a corresponding decrease in gas flaring to limit the temperature rise to below the 1.5 °C warming target. As global warming is likely to reach 1.5 °C between 2030 and 2052 if emissions continue to increase at the current rate, the alternative A1 option would be the appropriate target to avoid long-term climate change. While the global warming rate is projected to exceed 1.5 °C, countries' pledges to reduce emissions are currently not on track to limit global warming to 1.5 °C. This implies that climate-related risks to health, livelihoods, and other risks will increase [108]. Though the alternative A1 conceptual framework advocates stabilizing global temperature to just below 1.5 °C, it is crucial to take action to limit global warming to avoid the consequences of climate-related risks.

The most viable alternative to reducing greenhouse gas emissions is A2, which emphasizes the significant implementation of gas flaring policies and regulatory frameworks. A2 weighs 0.60715 and aims to decrease global net anthropogenic CO_2 emissions by 45% from 2010 levels by 2030. Additionally, it involves a 90% reduction in all non-emergency gas flaring to limit temperature rises to 1.5 °C. Alternative A2 appears more feasible, considering the current carbon lock-in conditions in industrial nations [61,62,65,130,131]. This approach is compatible with IPCC projections and aligns with stabilizing the global temperature rise at 1.5 °C. However, achieving this goal will require significant reductions in emissions of methane and black carbon by 35% or more by 2050 relative to 2010 [108]. Additionally, the choice of the measure of global temperature affects the estimated remaining carbon budget, as limiting the total cumulative global anthropogenic CO_2 emissions since the pre-industrial period is crucial. Anthropogenic CO_2 emissions since the pre-industrial period have depleted the remaining budget by 2200 ± 320 $GtCO_2$. Current emissions of 42 ± 3 $GtCO_2$ per year since 2017 underscore the urgency of implementing this alternative.

The third alternative (A3), with a weighting of 0.3474, involves the partial implementation of gas flaring policies and regulatory framework criteria, aiming to reduce CO_2 emissions by 25% and gas flaring by 50%, thereby achieving a warming target of 2 °C or below. This conceptual pathway also requires significant reductions in CO_2 emissions and gas flaring, like those in pathways limiting warming to 1.5 °C. While the 2018 IPCC report acknowledges the possibility of a temporary global temperature exceedance of 1.5 °C, this projected scenario would significantly increase the risk of irreversible climate impacts, such as the collapse of polar ice shelves and accelerated sea level rise. Limiting warming to 1.5 °C or below, rather than to 2 °C, can help reduce these risks, but the specific greenhouse gas emissions pathway adopted will determine the impacts the world will experience.

An inimical option for dealing with global gas flaring and climate change is to adhere to the current status quo, known as business as usual (BAU). This implies maintaining the current levels of CO_2 and flaring reduction trajectories (as projected by the IEA, GGFR, and the World Bank) at 5.8% and 5%, respectively [3,5,35,107]. This option is the least favorable, with a weight of 0, as it would result in an annual increase in energy-related and industrial process CO_2 emissions from 34 Gt in 2020 to 36 Gt by 2030, with no significant reduction, thereafter remaining at this level until 2050. This trajectory, if continued, would lead to a projected 2.7 °C rise in global average surface temperature by 2100, along with a similar increase in non-energy-related GHG emissions [103]. To avoid this, it is crucial that the stated policies scenario (STEPS) and announced pledges case (APC) be fully implemented and achieved on time, regardless of whether the current country-specific policies support them.

While the presented scenarios are consistent with previous projections, the findings provide additional insight into the required global policies and regulatory framework for achieving ZRF and supporting the various scenarios. The most effective solution for global gas flaring and CO_2 emissions is alternative A1. However, there is no easy solution to the problem of global gas flaring and climate change. The novelty of this research lies in the findings indicating that alternative A2 is the most feasible option for reducing gas flaring and CO_2 emissions, suggesting that significant progress can be achieved without a complete overhaul of the economy. Nevertheless, this alternative still requires significant reductions in global gas flaring and CO_2 emissions, and its political feasibility remains uncertain. Alternative A4, which entails maintaining the current status quo, is the least favorable option for addressing global gas flaring and climate change. If this trajectory continues, the global average surface temperature is projected to rise by 2.7 °C by 2100.

5. Conclusions and Policy Implications

This study aimed to prioritize and develop alternative policies and regulations to stimulate zero routine flaring by 2030 and achieve net-zero emissions by 2050, while addressing issues of good governance, justice, and fair implementation. By understanding these criteria, sub-criteria, and the available alternatives, industry, environmental policymakers, and the IOCs can plan better for and successfully implement and execute global gas flaring policies and regulatory frameworks.

Four conclusions are derived from our multi-criteria analysis. First, despite some divergence between group A and group B rankings, all identified criteria and sub-criteria, as evidenced by the successive GGFR/World Bank consultations and multiple scholarly publications on the topic, are critical to reaching the 2030 zero routine flaring goal. Second, policy, targets, and enabling frameworks were the most significant criteria, followed by the legal and regulatory framework; contractual rights; fines, penalties, and sanctions; regulatory governance and organization; measurement and reporting; and licensing and process approval. Third, the background and role of reductions in meeting environmental and economic objectives, as well as non-monetary penalties, are the most crucial sub-criteria for abating global gas flaring. Fourth, application of the G-TOPSIS result confirms that full implementation of all criteria (alternative A1) has the greatest potential to cut CO_2 emissions by 80–100%, aligning with a $\leq$ 1.5 °C warming trajectory. Alternative A2, representing significant implementation of all flaring policies and regulatory criteria, would drive a 45% reduction in CO_2 emissions and a corresponding 90% cut in routine flaring, enough to meet a 1.5 °C warming limit under A3, which entails only partial implementation of 25% CO_2 emissions and 50% reduction in routine flaring, translating to a temperature rise warming target of 2 °C. In contrast, the business-as-usual (BAU) scenario maintains the current CO_2 and flaring reduction trajectories of 5.8% and 5%, respectively.

Finally, we argue that our findings underscore the importance of policy coherence, consistency, and fairness in developing transnational policies and regulatory frameworks for reducing gas flaring, accompanied by a reciprocal, legally binding set of policies and agreements between countries to prevent ineffective, country-specific abatement efforts.

These findings have implications for global gas flaring policy strategies. Firstly, the consensus on policy criteria and sub-criteria established through GGFR/World Bank consultations, supported by extensive scholarly literature, underscores the essential nature of each identified element in achieving the 2030 target of zero routine flaring. Despite variations in priorities and rankings between stakeholder groups A and B, both groups ultimately recognize the importance of a comprehensive regulatory and policy framework for effective flaring mitigation.

The differing perspectives across stakeholder groups also elucidate distinct challenges and incentives within the policy landscape, highlighting the need for a nuanced approach. For instance, while respondents in both groups prioritized economic incentives, some also stressed the importance of strict enforcement mechanisms. This diversity of viewpoints enables a more holistic understanding of stakeholder preferences, allowing for the development of balanced, inclusive policies that account for the diverse motivations and needs inherent in flaring reduction.

Beyond technical and legal measures, our findings underscore the importance of social dimensions in policy design. Stakeholder information asymmetries, place protective actions such as organized protest or direct action against facility proposals, and varying levels of public trust in oil and gas companies and policy institutions can significantly affect local acceptance of flaring-reduction measures. For example, transparent data-sharing and the development of effective community engagement platforms can mitigate localized community resistance by ensuring procedural environmental justice through shared decision-making and demonstrating actions that generate tangible health and economic co-benefits. Conversely, exclusion of vulnerable groups from decision-making risks entrenching procedural environmental injustice. Integrating these social considerations into national and transnational frameworks can enhance policy coherence, legitimacy, and enforcement.

Achieving zero routine flaring and net-zero emissions demands a multi-level governance approach that integrates local and international perspectives. In this context, incorporating diverse stakeholder insights promotes a governance framework that addresses national, regional, and global concerns while aligning with global objectives for equitable and sustainable emission reductions. As emphasized by Refs. [81,132], such a collaborative approach fosters international cohesion, enhancing policy effectiveness and adaptability across different regulatory contexts.

6. Limitations

The seven main criteria and twenty-four sub-criteria identified in this study are not the only criteria and sub-criteria in gas flaring policies and regulations. There are others, including governments developing policies specifying the role of flaring and venting reduction; regulatory procedures; adequately staffed and financed regulators; definitions and boundaries; regulatory approaches; adopting a prescriptive approach, adopting a performance-based approach, or adopting a hybrid approach; autonomy and accountability; regulator independence; participation and predictability; and third-party access (TPA) to gas infrastructure (access to upstream/midstream gas infrastructure). Although these criteria and sub-criteria were identified from various articles and reports, they were consolidated into seven main criteria and twenty-four sub-criteria in the 2022 GGFR/The World Bank consultation. Hence, they were not listed separately to prevent redundancy and repetition.

While the criteria, sub-criteria, and alternatives identified, prioritized, and selected in this study can serve as a global benchmark to abate gas flaring and CO_2 emissions, generalizations are limited by the non-random sample of respondents. Further testing of policy options through surveys sampling a larger, demographically representative subset of the global population would be beneficial. Additionally, the projections analyze a specific period in gas flaring and CO_2 emissions, reflecting historical trends that may shift with changes in global energy and environmental policies. Given the dynamic nature of these scenarios, trajectories, projections, and forecasts may evolve as economic, technological, and social contexts change. Future research could enhance understanding by analyzing current projections and trajectories for gas flaring and CO_2 emissions to capture updated dynamics. Moreover, applying this framework to other sectoral policies would provide valuable insights into the effectiveness of different approaches to emission reduction, supporting broader climate and sustainability goals.

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Abbreviations

The following abbreviations are used in this manuscript:

Abbreviation	**Definition**
AHP	Analytical Hierarchy Process
APC	Announced Pledges Case
BAU	Business as Usual
CI	Consistency Index
CO_2	Carbon Dioxide
CO_2-eq	Carbon Dioxide Equivalent
CR	Consistency Ratio
G-TOPSIS	Grey Technique for Order of Preference by Similarity to Ideal Solution
GGFR	Global Gas Flaring Reduction Partnership
GHG	Greenhouse Gas
Gt CO_2	Gigatons of Carbon Dioxide
GWP	Global Warming Potentials
IPCC	Intergovernmental Panel on Climate Change
IOCs	International Oil Companies
Mt	Megaton
NDC	Nationally Determined Contribution
RI	Regulatory Instruments
STEPS	Stated Policies Scenario
ZRF	Zero Routine Flaring

Appendix A. Normalized Tables

Table A1. Main criteria group A.

	Policy and Targets	Legal, Regulatory Framework, and Contractual Rights	Regulatory Governance and Organization	Licensing and Process Approval	Measurement and Reporting	Fines, Penalties, and Sanctions	Enabling Framework	Priority	Rank
Policy and targets	1.00	2.00	3.00	4.00	3.00	4.00	6.00	31%	1
Legal, regulatory framework, and contractual rights	0.50	1.00	2.00	4.00	3.00	4.00	4.00	23%	2
Regulatory governance and organization	0.33	0.50	1.00	3.00	4.00	3.00	5.00	18%	3
Licensing and process approval	0.25	0.25	0.33	1.00	3.00	4.00	4.00	12%	4
Measurement and reporting	0.33	0.33	0.25	0.33	1.00	3.00	4.00	8%	5
Fines, penalties, and sanctions	0.25	0.25	0.33	0.25	0.33	1.00	4.00	5%	6
Enabling framework	0.17	0.25	0.20	0.25	0.25	0.25	1.00	3%	7
	0.31	0.23	0.18	0.12	0.08	0.05	0.03		

Table A2. Main criteria group B.

	Policy and Targets	Legal, Regulatory Framework, and Contractual Rights	Regulatory Governance and Organization	Licensing and Process Approval	Measurement and Reporting	Fines, Penalties, and Sanctions	Enabling Framework	Priority	Rank
Policy and targets	1	0.33	0.25	0.17	0.17	0.14	0.11	2%	7
Legal, regulatory framework, and contractual rights	3	1	0.33	0.25	0.17	0.14	0.17	3%	6
Regulatory governance and organization	4	3	1	0.33	0.2	0.2	0.25	6%	5
Licensing and process approval	6	4	3	1	0.33	0.2	0.2	9%	4
Measurement and reporting	6	6	5	3	1	0.33	0.25	16%	3
Fines, penalties, and sanctions	7	7	5	5	3	1	0.33	26%	2
Enabling framework	9	6	4	5	4	3	1	37%	1
	0.02	0.03	0.06	0.09	0.16	0.26	0.37		

Table A3. Policy and targets group A.

	Background and the Role of Reductions	Targets and Limits	Priority	Rank
Background and the role of reductions	1.00	5.00	83%	1
Targets and limits	0.20	1.00	17%	2
	0.83	0.17		

Table A4. Policy and targets group B.

	Background and the Role of Reductions	Targets and Limits	Priority	Rank
Background and the role of reductions	1.00	0.20	17%	2
Targets and limits	5.00	1.00	83%	1
	0.17	0.83		

Table A5. Legal, regulatory framework, and contractual rights group A.

	Primary and Secondary Legislation and Regulation	Legislative Jurisdictions	Associated Gas Ownership	Priority	Rank
Primary and secondary legislation and regulation	1.00	4.00	6.00	69%	1
Legislative jurisdictions	0.25	1.00	3.00	22%	2
Associated gas ownership	0.17	0.33	1.00	9%	3
	0.690951	0.217648	0.091401		

Table A6. Legal, regulatory framework, and contractual rights group B.

	Primary and Secondary Legislation and Regulation	Legislative Jurisdictions	Associated Gas Ownership	Priority	Rank
Primary and secondary legislation and regulation	1.00	0.25	0.20	9%	3
Legislative jurisdictions	4.00	1.00	0.33	28%	2
Associated gas ownership	5.00	3.00	1.00	63%	1
	0.09	0.28	0.63		

Table A7. Regulatory governance and organization group A.

	Regulatory Authority	Regulatory Mandates and Responsibilities	Monitoring and Enforcement	Development Plans	Economic Evaluation	Priority	Rank
Regulatory authority	1.00	3.00	3.00	4.00	5.00	43%	1
Regulatory mandates and responsibilities	0.33	1.00	2.00	3.00	4.00	23%	2
Monitoring and enforcement	0.33	0.50	1.00	5.00	5.00	21%	3
Development plans	0.25	0.33	0.20	1.00	3.00	8%	4
Economic evaluation	0.20	0.25	0.20	0.33	1.00	5%	5
	0.43	0.23	0.21	0.08	0.05		

Table A8. Regulatory governance and organization group B.

	Regulatory Authority	Regulatory Mandates and Responsibilities	Monitoring and Enforcement	Development Plans	Economic Evaluation	Priority	Rank
Regulatory authority	1.00	0.25	0.20	0.25	0.17	4%	5
Regulatory mandates and responsibilities	4.00	1.00	0.20	0.20	0.25	8%	4
Monitoring and enforcement	5.00	5.00	1.00	0.50	0.33	20%	3
Development plans	4.00	5.00	2.00	1.00	0.50	27%	2
Economic evaluation	6.00	4.00	3.00	2.00	1.00	40%	1
	0.04	0.08	0.20	0.27	0.40		

Table A9. Licensing and process approval group A.

	Flaring or Venting Without Prior Approval	Authorized Flaring or Venting	Priority	Rank
Flaring or venting without prior approval	1.00	6.00	86%	1
Authorized flaring or venting	0.17	1.00	14%	2
	0.86	0.14		

Table A10. Licensing and process approval group B.

	Flaring or Venting Without Prior Approval	Authorized Flaring or Venting	Priority	Rank
Flaring or venting without prior approval	1.00	0.20	17%	2
Authorized flaring or venting	5.00	1.00	83%	1
	0.17	0.83		

Table A11. Measurement and reporting group A.

	Measurement and Reporting Requirements	Measurement Frequency and Methods	Engineering Estimates	Record Keeping	Data Compilation and Publishing	Priority	Rank
Measurement and reporting requirements	1.00	3.00	4.00	3.00	4.00	44%	1
Measurement frequency and methods	0.30	1.00	3.00	3.00	3.00	25%	2
Engineering estimates	0.25	0.33	1.00	3.00	2.00	14%	3
Record keeping	0.33	0.33	0.33	1.00	1.00	8%	4
Data compilation and publishing	0.25	0.33	0.50	1.00	1.00	8%	5
	0.44	0.25	0.14	0.08	0.08		

Table A12. Measurement and reporting group B.

	Measurement and Reporting Requirements	Measurement Frequency and Methods	Engineering Estimates	Record Keeping	Data Compilation and Publishing	Priority	Rank
Measurement and reporting requirements	1.00	0.25	0.33	0.20	0.13	4%	5
Measurement frequency and methods	4.00	1.00	0.50	0.25	0.25	9%	4
Engineering estimates	3.00	2.00	1.00	0.33	0.33	12%	3
Record keeping	5.00	4.00	3.00	1.00	0.20	24%	2
Data compilation and publishing	8.00	4.00	3.00	5.00	1.00	51%	1
	0.04	0.09	0.12	0.24	0.51		

Table A13. Fines, penalties, and sanctions group A.

	Monetary Penalties	Nonmonetary Penalties	Priority	Rank
Monetary penalties	1	4	80%	1
Nonmonetary penalties	0.25	1	20%	2
	0.8	0.2		

Table A14. Fines, penalties, and sanctions group B.

	Monetary Penalties	Nonmonetary Penalties	Priority	Rank
Monetary penalties	1.00	0.14	13%	2
Nonmonetary penalties	7.00	1.00	88%	1
	0.13	0.88		

Table A15. Enabling framework group A.

	Performance Requirements	Fiscal and Emission Reduction Incentives	Use of Market-Based Principles	Negotiated Agreements—Public and Private Sector	Interplay with Midstream and Downstream RF	Priority	Rank
Performance requirements	1	3	4	4	3	43%	1
Fiscal and emission reduction incentives	0.3	1	4	4	5	30%	2
Use of market-based principles	0.3	0.3	1	2	2	11%	3
Negotiated agreements—public and private sector	0.3	0.3	0.5	1	2	9%	4
Interplay with midstream and downstream RF	0.3	0.2	0.5	0.5	1	7%	5
	0.43	0.30	0.11	0.09	0.07		

Table A16. Enabling framework group B.

	Performance Requirements	Fiscal and Emission Reduction Incentives	Use of Market-Based Principles	Negotiated Agreements--Public and Private Sector	Interplay with Midstream and Downstream RF	Priority	Rank
Performance requirements	1.00	0.25	0.25	0.20	0.11	4%	5
Fiscal and emission reduction incentives	4.00	1.00	0.50	0.20	0.25	9%	4
Use of market-based principles	4.00	2.00	1.00	0.33	0.25	12%	3
Negotiated agreements—public and private sector	5.00	5.00	3.00	1.00	0.20	24%	2
Interplay with midstream and downstream RF	9.00	4.00	4.00	5.00	1.00	52%	1
	0.04	0.09	0.12	0.24	0.52		

Table A17. The overall weight and ranking of the main criteria and sub-criteria (group A stakeholders).

Main Criteria	Weights of Main Criteria	Main Criteria Ranking	Main Criteria CR	Sub-Criteria	Sub-Criteria CR	Local Priority Weight	Local Rank	Global Priority Weight	Overall Rank
Policy and targets	0.31	1	9.7%	Background and the role of reductions	0.0%	0.83	1	0.26	1st
				Targets and limits	0.0%	0.17	2	0.053	5th
Legal, regulatory framework, and contractual rights	0.23	2	9.7%	Primary and secondary legislation and regulation	5.6%	0.69	1	0.159	2nd
				Legislative jurisdictions	5.6%	0.22	2	0.051	6th
Regulatory governance and organization	0.18	3	9.7%	Associated gas ownership	5.6%	0.09	3	0.021	12th
				Regulatory authority	9.0%	0.43	1	0.077	4th
Licensing and process approval	0.12	4	9.7%	Regulatory mandates and responsibilities	9.0%	0.23	2	0.041	7th

Table A17. *Cont.*

Main Criteria	Weights of Main Criteria	Main Criteria Ranking	Main Criteria CR	Sub-Criteria	Sub-Criteria CR	Local Priority Weight	Local Rank	Global Priority Weight	Overall Rank
				Monitoring and enforcement	9.0%	0.21	3	0.038	9th
Measurement and reporting	0.08	5	9.7%	Development plans	9.0%	0.08	4	0.038	10th
				Economic evaluation	9.0%	0.05	5	0.009	18th
Fines, penalties, and sanctions	0.05	6	9.7%	Flaring or venting without prior approval	0.0%	0.86	1	0.103	3rd
				Authorized flaring or venting	0.0%	0.14	2	0.017	14th
Enabling framework	0.03	7	9.7%	Measurement and reporting requirements	6.3%	0.44	1	0.035	11th
				Measurement frequency and methods	6.3%	0.25	2	0.02	13th
				Engineering estimates	6.3%	0.14	3	0.011	16th
				Record keeping	6.3%	0.08	4	0.006	20th
				Data compilation and publishing	6.3%	0.08	5	0.006	21st
				Monetary penalties	0.0%	0.8	1	0.04	8th
				Nonmonetary penalties	0.0%	0.2	2	0.01	17th
				Performance requirements	8.20%	0.43	1	0.013	15th
				Fiscal and emission reduction incentives	8.20%	0.3	2	0.009	19th
				Use of market-based principles	8.20%	0.11	3	0.003	22nd
				Negotiated agreements—public and private sector	8.20%	0.09	4	0.003	23rd
				Interplay with midstream and downstream RF	8.20%	0.07	5	0.002	24th

Table A18. The overall weight and ranking of the main criteria and sub-criteria (group B stakeholders).

Main Criteria	Weights of Main Criteria	Main Criteria Ranking	Main Criteria CR	Sub-Criteria	Sub-Criteria CR	Local Priority Weight	Local Ranking	Global Priority Weight	Overall Ranking
Enabling framework	0.37	1	9.6%	Nonmonetary penalties	0.0%	0.88	1	0.228	1st
Fines, penalties, and sanctions	0.26	2	9.6%	Interplay with midstream and downstream RF	9.8%	0.52	5	0.193	2nd
Measurement and reporting	0.16	3	9.6%	Negotiated agreements—public and private sector	9.8%	0.24	11	0.089	3rd
Licensing and process approval	0.09	4	9.6%	Data compilation and publishing	9.3%	0.51	6	0.082	4th
Regulatory governance and organization	0.06	5	9.6%	Authorized flaring or venting	0.0%	0.83	3	0.076	5th
Legal, regulatory framework, and contractual rights	0.03	6	9.6%	Use of market-based principles	9.8%	0.12	17	0.045	6th
Policy and targets	0.02	7	9.6%	Record keeping	9.3%	0.24	10	0.039	7th
				Monetary penalties	0.0%	0.13	15	0.034	8th
				Fiscal and emission reduction incentives	9.8%	0.09	20	0.033	9th
				Economic evaluation	9.6%	0.40	7	0.024	10th
				Associated gas ownership	8.9%	0.63	4	0.022	11th
				Engineering estimates	9.3%	0.12	16	0.019	12th
				Background and the role of reductions	0.0%	0.83	2	0.018	13th
				Development plans	9.6%	0.27	9	0.016	14th
				Flaring or venting without prior approval	0.0%	0.17	14	0.016	15th
				Performance requirements	9.8%	0.04	24	0.015	16th
				Measurement frequency and methods	9.3%	0.09	19	0.014	17th
				Monitoring and enforcement	9.6%	0.20	12	0.012	18th
				Legislative jurisdictions	8.9%	0.28	8	0.010	19th
				Measurement and reporting requirements	9.3%	0.04	23	0.006	20th
				Regulatory mandates and responsibilities	9.6%	0.08	21	0.005	21st
				Targets and limits	0.0%	0.17	13	0.004	22nd
				Primary and secondary legislation and regulation	8.9%	0.09	18	0.003	23rd
				Regulatory authority	9.6%	0.04	22	0.002	24th

Table A19. Categorization of criteria in global gas flaring policies and regulations.

Main Criteria	Sub-Criteria	Details of Each Criterion
Policy and targets	• Background and the role of reductions in meeting environmental and economic objectives • Targets and limits specified by the regulator	Gas flaring and venting policies, abatement, and targets are set to avoid resource wastage and reduce local air pollution and GHG emissions. While national targets are common and sufficient if there is a national carbon price, they can also be set at the sectoral level. However, a bottom-up approach to setting sector-specific targets is necessary where no national flaring targets exist. These targets are crucial to avoiding resource wastage, reducing local and transboundary air pollution and GHG emissions, and promoting the development of a midstream gas sector while expanding access to electricity.
Legal, regulatory framework, and contractual rights	• Primary and secondary legislation and regulation • Legislative jurisdictions • Associated gas ownership	Gas flaring, legal, regulatory framework, and contractual rights are usually anchored in national or local legislation governing the jurisdiction of the oil and gas sector and environmental management. Issues such as authority over oil and gas, ownership, allocation of permits, contractual rights and obligations, the right to commercialize associated gas, fiscal regimes, sector institutional organizations, and the regulator's role and functions usually fall within primary-sector legislation. However, many jurisdictions have laws that prescribe natural resource management functions and environmental policies but do not explicitly mention gas flaring and venting, thereby creating legal and regulatory frameworks that can lead to ambiguity in contractual rights.
Regulatory governance and organization	• Regulatory authority • Regulatory mandates and responsibilities • Monitoring and enforcement • Development plans • Economic evaluation	Gas flaring regulatory governance and organization criteria define which institutions have regulatory authority over the oil and gas industry—a factor essential to clearly defining the institutions, along with the scope of their mandates and abatement strategies from the perspective of waste prevention. There is currently no generally established practice for determining which government agencies and ministries are solely responsible for managing oil and gas. However, the final institutional arrangements depend on the type of resource ownership (federal, subnational, or non-state) and the regulations in place (including oil and gas development and production, environmental, and fiscal regulations).
Licensing and process approval	• Flaring or venting without prior approval • Authorized flaring or venting	Gas flaring and venting regulations depend on how associated gas is treated and oil development rights are granted in primary legislation. The application and approval procedures for gas flaring and venting, as well as the right to flare and vent, can be granted through a flaring and venting permit, a field development plan for a license or contract, and an environmental license. Ambiguity over the ownership of associated gas and laws that consider it waste, along with the right to commercialize flared gas, are considerable barriers to its economic use. The state typically owns underground resources (Canada and the United States are notable exceptions) irrespective of the applicable fiscal regime.
Measurement and reporting	• Measurement and reporting requirements • Measurement frequency and methods • Engineering estimates • Record keeping • Data compilation and publishing	National or local regulations are considered adequate and effective when they prescribe measurement and reporting standards and procedures that mandate companies to record, process, and submit the information specified by the regulator. Such data facilitate monitoring operators' compliance with approved objectives and targets, tracking progress toward achieving the set objectives and targets, comparing the performance of similar kinds of assets, enabling operators of poorly performing assets to improve their performance, and identifying assets requiring site inspections.

Table A19. *Cont.*

Main Criteria	Sub-Criteria	Details of Each Criterion
Fines, penalties, and sanctions	• Monetary penalties • Nonmonetary penalties	Most jurisdictions, legislation, and contractual provisions impose sanctions, mandatory payments, or other means of enforcement for noncompliance with gas flaring regulations.
Enabling framework	• Performance requirements • Fiscal and emission reduction incentives • Use of market-based principles • Negotiated agreements between the public and the private sector • Interplay with midstream and downstream regulatory framework	The gas flaring enabling framework includes a range of economic instruments or flaring abatement programs that can be introduced to encourage producers and specifically target gas flaring and venting (e.g., fiscal or market-based incentives). Under the fiscal framework, the fiscal burden is reduced by lowering taxes or eliminating royalties for capturing, using, or marketing associated gas, rather than flaring or venting it. Alternatively, the fiscal burden of flaring and venting can be increased by imposing royalties on gas flared or vented without the regulator's prior approval and imposing carbon taxes on all GHG emissions. For example, when producers reduce flaring or venting, they may be able to sell carbon credits through emission trading systems and offset credit schemes, green investment funds, and financial grants for specific emission abatement investments.

Table A20. Scenarios ranked by G-TOPSIS for gas flaring policy and regulatory framework alternatives.

Code	Alternative	Gas Flaring Reduction Target (%)	Description	Benefit
A1	Full implementation of gas flaring policies and regulatory framework main criteria	100% zero routine flaring (ZRF)	If CO_2 emissions are decreased by 100% and a 100% reduction in gas flaring	Limit temperature to below 1.5 °C warming target
A2	Significant implementation of gas flaring policies and regulatory framework main criteria	90% reduction	If CO_2 emissions are decreased by 45% and a 90% reduction in gas flaring	Limit temperature to 1.5 °C warming target
A3	Partial implementation of gas flaring policies and regulatory framework main criteria	50% reduction	If CO_2 emissions are decreased by 25% and a 50% reduction in gas flaring	Temperature rises to 2 °C warming target
A4	BAU or do nothing	5% reduction	Business as usual (BAU), a 5.8% reduction in CO_2	Temperature rises to 2.7 °C warming target

Table A21. The intensity of importance in linguistic variables adapted from the fundamental AHP scale of 1–9.

No.	Linguistic Variables	Equivalent Grey Numbers	Gas Flaring Reduction Target (%)	Description	Benefit
1	Full implementation of gas flaring policies and regulatory framework criteria	(6.9)	100% reduction—zero routine flaring (ZRF)	If CO_2 emissions are decreased by 100% and a 100% reduction in gas flaring	Limit temperature to below 1.5 °C warming target
2	Significant implementation of gas flaring policies and regulatory framework criteria	(3.5)	90% reduction	If CO_2 emissions are decreased by 45% and a 90% reduction in gas flaring	Limit temperature to 1.5 °C warming target
3	Partial implementation of gas flaring policies and regulatory framework criteria	(1.3)	50% reduction	If CO_2 emissions are decreased by 25% and a 50% reduction in gas flaring	Temperature rises to 2 °C warming target
4	BAU, maintaining the current status quo or doing nothing	(0.1)	5% reduction	Business as usual (BAU) or maintaining the current status quo, with a 5.8% reduction in CO_2	Temperature rises to 2.7 °C warming target

Note: Implementation of flaring policies and regulatory framework main criteria and sub-criteria with the equivalent grey numbers (full = [6–9], significant = [3–5], partial = [1–3], BAU = [0–1]).

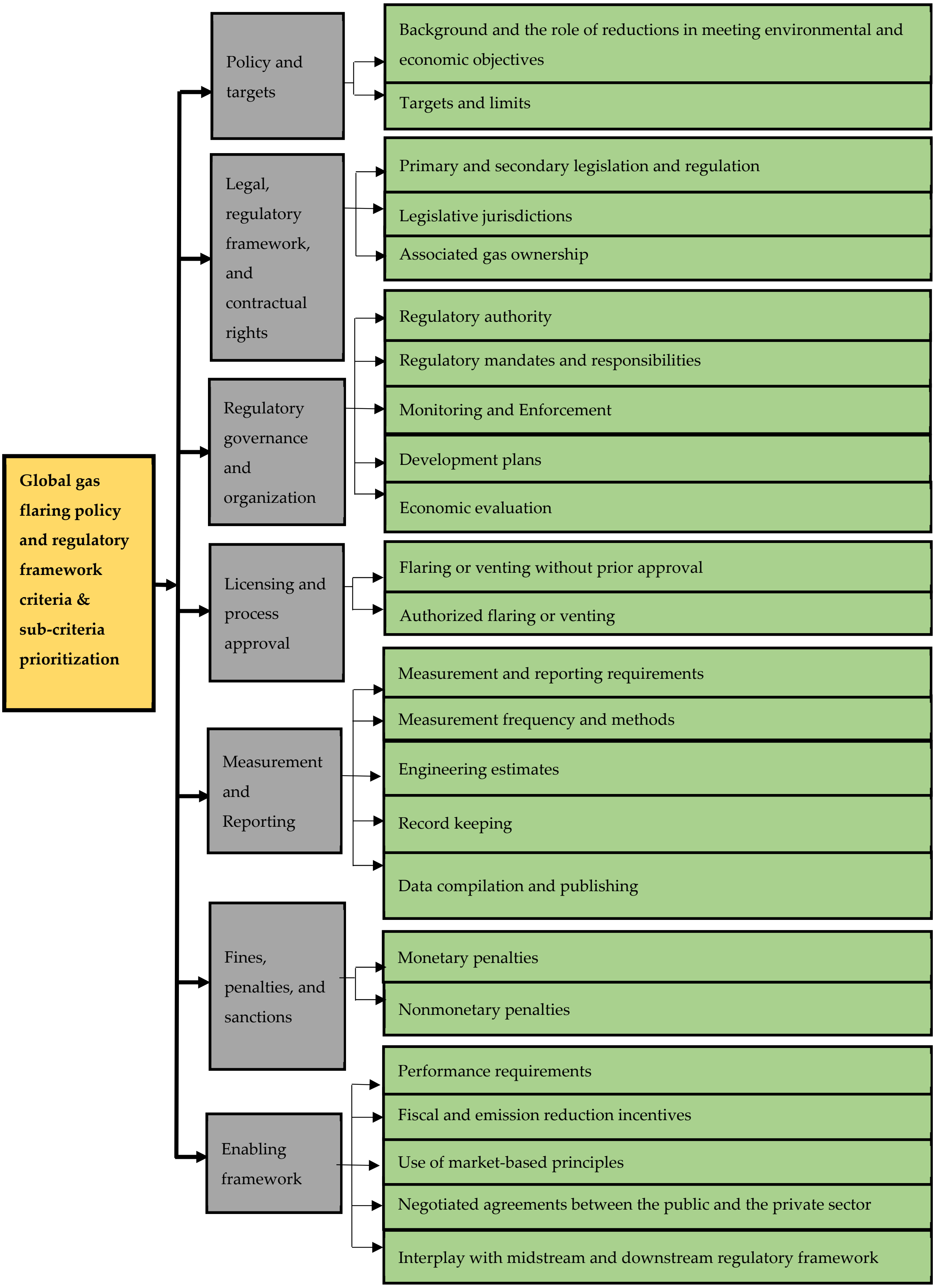

Figure A1. The hierarchical structure of criteria and sub-criteria ranking of global gas flaring policies and regulatory framework.

Figure A1—The hierarchical structure of the criteria and sub-criteria ranking of global gas flaring policies and the regulatory framework. The gold box defines and represents the AHP objective. The grey boxes indicate the seven main criteria, while the green boxes denote the twenty-four sub-criteria, illustrating their relationship with each main criterion.

Appendix B. Grey Group TOPSIS (G-TOPSIS) Method

Stage 1: First, we calculated the weights of each criterion based on expert opinion by using the grey linguistic variables in Table A21. Assuming that the number of decision-makers is k, we calculated the criterion j weight of alternatives using Equation (A1).

$$\otimes wj = \frac{1}{k}\left[\otimes w_j^1 + \otimes w_j^2 + \cdots + \otimes w_j^k\right] \tag{A1}$$

Stage 2: The linguistic variables were utilized to assess the significance of each research alternative in the criteria. Assuming that the number of decision-makers is k in criterion j, then the value of alternative i was calculated as follows (Equation (A2)):

$$\otimes G_{ij} = \frac{1}{k}\left[\otimes G_{ij}^1 + \otimes G_{ij}^2 + \cdots + \otimes G_{ij}^k\right] \tag{A2}$$

Stage 3: The grey decision matrix was denoted as follows in Equation (A3):

$$D = \begin{matrix} \otimes G_{1\,1} & \otimes G_{1\,2} & \cdots & \otimes G_{1\,n} \\ \otimes G_{2\,1} & \otimes G_{2\,2} & \cdots & \otimes G_{2\,n} \\ \vdots & \vdots & \vdots & \vdots \\ \otimes G_{m\,1} & \otimes G_{m\,2} & \cdots & \otimes G_{m\,n} \end{matrix} \tag{A3}$$

where $\otimes G_{ij}$ represents the significance of alternative i in criterion j.

In Stage 4, we represented a standardized matrix of grey decisions, as shown in Equation (A4):

$$D^* = \begin{matrix} \otimes G^*_{1\,1} & \otimes G^*_{1\,2} & \cdots & \otimes G^*_{1\,n} \\ \otimes G^*_{2\,1} & \otimes G^*_{2\,2} & \cdots & \otimes G^*_{2\,n} \\ \vdots & \vdots & \vdots & \vdots \\ \otimes G^*_{m\,1} & \otimes G^*_{m\,2} & \cdots & \otimes G^*_{m\,n} \end{matrix} \tag{A4}$$

where the criteria were benefit attributes, such as the temperature limit, where a low warming target is beneficial. Then, Equation (A5) was utilized for normalization:

$$G^*_{ij} = \left[\frac{\underline{G}_{ij}}{G_j^{max}}, \frac{\overline{G}_{ij}}{G_j^{max}}\right] where\ G_j^{max} = \max_{1\le j\le m}\left\{\overline{G}_{ij}\right\} \tag{A5}$$

Also, where the cost attributes were based on reduction targets for CO_2 and gas flaring, and high percentage reductions were beneficial, Equation (A6) was utilized for normalization purposes.

$$G^*_{ij} = \left[\frac{\underline{G}_j^{min}}{G_j^{min}}, \frac{G_{ij}^{min}}{G_j^{min}}\right] where\ G_j^{min} = \min_{1\le j\le m}\left\{\overline{G}_{ij}\right\} \tag{A6}$$

In Stage 5, we developed a grey-weighted normalized decision matrix, as shown in Equation (A7):

$$V = \begin{matrix} \otimes V_{1\,1} & \otimes V_{1\,2} & \cdots & \otimes V_{1\,n} \\ \otimes V_{2\,1} & \otimes V_{2\,2} & \cdots & \otimes V_{2\,n} \\ \vdots & \vdots & \vdots & \vdots \\ \otimes V_{m\,1} & \otimes V_{m\,2} & \cdots & \otimes V_{m\,n} \end{matrix} \quad where \otimes V_{ij} = \otimes G^{*}_{ij} \, x \otimes w_j \tag{A7}$$

Stage 6: The optimal positive and negative solutions were calculated using Equations (A8) and (A9), respectively:

$$S^{max} = \{[\max_{1 \le j \le m} \underline{V}_{i1}, \max_{1 \le j \le m} \overline{V}_{i1}], [\max_{1 \le j \le m} \underline{V}_{i2}, \max_{1 \le j \le m} \overline{V}_{i2}], \ldots, [\max_{1 \le j \le m} \underline{V}_{i\,n}, \max_{1 \le j \le m} \overline{V}_{i\,n}]\} \tag{A8}$$

$$S^{min} = \{[\min_{1 \le j \le m} \underline{V}_{i1}, \min_{1 \le j \le m} \overline{V}_{i1}], [\min_{1 \le j \le m} \underline{V}_{i2}, \min_{1 \le j \le m} \overline{V}_{i2}], \ldots, [\min_{1 \le j \le m} \underline{V}_{i\,n}, \min_{1 \le j \le m} \overline{V}_{i\,n}]\} \tag{A9}$$

Stage 7: The potential greyness degree between optimal positive and negative alternatives was calculated using Equation (A10):

$$p\{s_i \le S^{max}\} = \frac{1}{n}\sum_{j=1}^{n} p\left\{\otimes V_{ij} \le \otimes G^{max}_{j}\right\} \tag{A10}$$

Stage 8: Alternatives were arranged in descending order, corresponding to the values obtained in Stage 7. Higher priority was given to the alternative with the highest degree of greyness.

References

1. Buzcu-Guven, B.; Harriss, R. Extent, impacts and remedies of global gas flaring and venting. *Carbon Manag.* **2014**, *3*, 95–108. [CrossRef]
2. Elvidge, C.D.; Baugh, K.; Tuttle, B.; Ziskin, D.; Ghosh, T.; Zhizhin, M. Improving Satellite Data Estimation of Gas Flaring Volumes Year Two Final Report to the GGFR. 2009. Available online: http://www.mdpi.com/1996-1073/2/3/595 (accessed on 17 August 2019).
3. GGFR/The World Bank. Global Gas Flaring Data: Global Gas Flaring Tracker Report, March 2023. Global Gas Flaring Reduction Partnership (GGFR)-Gas Flaring Dropped by 5 Percent. Available online: https://www.worldbank.org/en/programs/gasflaringreduction/global-flaring-data (accessed on 29 April 2023).
4. Willyard, K.A. An historical political economy analysis and review of Texas oil and gas well flaring laws and policy. *Energy Policy* **2019**, *128*, 639–647. [CrossRef]
5. IEA. Flaring Emissions Must Drop Rapidly to Get on Track with the IEA's Net Zero Emissions by 2050 Scenario. Gas. Available online: https://www.iea.org/fuels-and-technologies/gas (accessed on 17 August 2019).
6. Johnston, J.E.; Chau, K.; Franklin, M.; Cushing, L. Environmental Justice Dimensions of Oil and Gas Flaring in South Texas: Disproportionate Exposure among Hispanic communities. *Environ. Sci. Technol.* **2020**, *54*, 6289–6298. [CrossRef]
7. Motte, J.; Alvarenga, R.A.F.; Thybaut, J.W.; Dewulf, J. Quantification of the global and regional impacts of gas flaring on human health via spatial differentiation. *Environ. Pollut.* **2021**, *291*, 118213. [CrossRef] [PubMed]
8. IEA. Understanding Methane Emissions—Global Methane Tracker 2024—Analysis. Available online: https://www.iea.org/reports/global-methane-tracker-2024/understanding-methane-emissions?utm_source=chatgpt.com (accessed on 14 May 2024).
9. Chen, C.; McCabe, D.C.; Fleischman, L.E.; Cohan, D.S. Black Carbon Emissions and Associated Health Impacts of Gas Flaring in the United States. *Atmosphere* **2022**, *13*, 385. [CrossRef]
10. Ourworldindata.org. CO_2 Emissions by Fuel Type—Our World in Data. Available online: https://ourworldindata.org/grapher/co2-by-source?stackMode=absolute (accessed on 14 May 2024).
11. Dung, E.J.; Bombom, L.S.; Agusomu, T.D. The effects of gas flaring on crops in the Niger Delta, Nigeria. *GeoJournal* **2008**, *73*, 297–305. [CrossRef]

12. GGFR/The World Bank. Global Flaring and Venting Regulations: 28 Case Studies from Around the World. Washington DC, May 2022. Available online: https://thedocs.worldbank.org/en/doc/fd5b55e045a373821f2e67d81e2c53b1-0400072022/related/Global-Flaring-and-Venting-Regulations-28-Case-Studies-from-Around-the-World.pdf (accessed on 14 May 2024).
13. Blundell, W.; Kokoza, A. Natural gas flaring, respiratory health, and distributional effects. *J. Public Econ.* **2022**, *104601*, 208. [CrossRef]
14. Ite, A.E.; Ibok, U.J. Gas Flaring and Venting Associated with Petroleum Exploration and Production in the Nigeria's Niger Delta. *Am. J. Environ. Prot.* **2013**, *1*, 70–77. [CrossRef]
15. Soltanieh, M.; Zohrabian, A.; Gholipour, M.J.; Kalnay, E. A review of global gas flaring and venting and impact on the environment: Case study of Iran. *Int. J. Greenh. Gas Control.* **2016**, *49*, 488–509. [CrossRef]
16. Ialongo, I.; Stepanova, N.; Hakkarainen, J.; Virta, H.; Gritsenko, D. Satellite-based estimates of nitrogen oxide and methane emissions from gas flaring and oil production activities in Sakha Republic, Russia. *Atmos. Environ.* **2021**, *X*, 11. [CrossRef]
17. Lee, J.; Sorensen, C.; Lemery, J.; Workman, C.F.; Linstadt, H.; Bazilian, M.D. Managing upstream oil and gas emissions: A public health oriented approach. *J. Environ. Manag.* **2022**, *310*, 114766. [CrossRef] [PubMed]
18. Babalola, A.A.; Olawuyi, D.S. Overcoming Regulatory Failure in the Design and Implementation of Gas Flaring Policies: The Potential and Promise of an Energy Justice Approach. *Sustainability* **2022**, *14*, 6800. Available online: https://ideas.repec.org/a/gam/jsusta/v14y2022i11p6800-d830194.html (accessed on 14 May 2024). [CrossRef]
19. Facchinelli, F.; Pappalardo, S.E.; Della Fera, G.; Crescini, E.; Codato, D.; Diantini, A.; Jimenez, D.R.M.; Mendoza, P.E.F.; Bignante, E.; De Marchi, M. Extreme citizens science for climate justice: Linking pixel to people for mapping gas flaring in Amazon rainforest. *Environ. Res. Lett.* **2022**, *17*, 2022. [CrossRef]
20. Aigbe, G.O.; Cotton, M.; Stringer, L.C. Global gas flaring and energy justice: An empirical ethics analysis of stakeholder perspectives. *Energy Res. Soc. Sci.* **2023**, *99*, 103064. [CrossRef]
21. Izarali, M.R. Human Rights and State-Corporate Crimes in the Practice of Gas Flaring in the Niger Delta Nigeria. *Crit. Criminol.* **2016**, *24*, 391–412. [CrossRef]
22. Nwosisi, M.C.; Oguntoke, O.; Taiwo, A.M.; Agbozu, I.E.; Noragbon, E.J. Spatial patterns of gas flaring stations and the risk to the respiratory and dermal health of residents of the Niger Delta, Nigeria. *Sci. Afr.* **2021**, *12*, e00762. [CrossRef]
23. The World Bank/GGFR. Global Gas Flaring Tracker Report. Washington, DC 20006, April 2021. Available online: https://documents.vsemirnyjbank.org/ru/publication/documents-reports/documentdetail/607721619582621535/global-gas-flaring-tracker-report-april-2021 (accessed on 14 May 2024).
24. GGFR/The World Bank. 2022 Global Gas Flaring Tracker Report. 2022 Global Gas Flaring Tracker Report. Available online: https://www.worldbank.org (accessed on 29 June 2023).
25. IEA. Net Zero by 2050: A Roadmap for the Global Energy Sector. Available online: https://www.iea.org/reports/net-zero-by-2050 (accessed on 14 May 2024).
26. UNFCCC. 2024 NDC Synthesis Report | UNFCCC. 2024 NDC Synthesis Report. Available online: https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/2024-ndc-synthesis-report (accessed on 14 May 2024).
27. Den Elzen, M.; Kuramochi, T.; Höhne, N.; Cantzler, J.; Esmeijer, K.; Fekete, H.; Fransen, T.; Keramidas, K.; Roelfsema, M.; Sha, F.; et al. Are the G20 economies making enough progress to meet their NDC targets? *Energy Policy* **2019**, *126*, 238–250. [CrossRef]
28. UNFCCC. Updated NDC Synthesis Report: Worrying Trends Confirmed. Updated NDC Synthesis Report. Available online: https://unfccc.int/news/updated-ndc-synthesis-report-worrying-trends-confirmed (accessed on 14 May 2024).
29. Ma, X.; Zhao, C.; Yan, W.; Zhao, X. Influences of 1.5 °C and 2.0 °C global warming scenarios on water use efficiency dynamics in the sandy areas of northern China. *Sci. Total Environ.* **2019**, *664*, 161–174. [CrossRef]
30. Patra, A.; Min, S.K.; Kumar, P.; Wang, X.L. Changes in extreme ocean wave heights under 1.5 °C, 2 °C, and 3 °C global warming. *Weather. Clim. Extrem.* **2021**, *33*, 100358. [CrossRef]
31. Tian, C.; Yue, X.; Zhou, H.; Lei, Y.; Ma, Y.; Cao, Y. Projections of changes in ecosystem productivity under 1.5 °C and 2 °C global warming. *Glob. Planet Chang.* **2021**, *205*, 103588. [CrossRef]
32. Yin, S.Y.; Wang, T.; Hua, W.; Miao, J.-P.; Gao, Y.-Q.; Fu, Y.-H.; Tyrlis, E.; Chen, D. Mid-summer surface air temperature and its internal variability over China at 1.5 °C and 2 °C global warming. *Adv. Clim. Chang. Res.* **2020**, *11*, 185–197. [CrossRef]
33. Qin, P. More than six billion people encountering more exposure to extremes with 1.5 °C and 2.0 °C warming. *Atmos. Res.* **2022**, *273*, 106165. [CrossRef]
34. Ma, X.; Zhao, C.; Tao, H.; Zhu, J.; Kundzewicz, Z.W. Projections of actual evapotranspiration under the 1.5 °C and 2.0 °C global warming scenarios in sandy areas in northern China. *Sci. Total Environ.* **2018**, *645*, 1496–1508. [CrossRef] [PubMed]
35. IEA. CO_2 Emissions—Global Energy Review 2021—Analysis—IEA. CO_2 Emissions. Available online: https://www.iea.org/reports/global-energy-review-2021/co2-emissions (accessed on 14 May 2024).
36. Kharbach, M.; Chfadi, T. Economic growth and challenges in achieving NDC targets: A Moroccan perspective. *Energy Rep.* **2022**, *8*, 7010–7015. [CrossRef]

37. Teng, F. Ambitious and credible pledges. *Nat. Clim. Chang.* **2022**, *12*, 779–780. [CrossRef]
38. Lutsey, N.; Sperling, D. Canada's voluntary agreement on vehicle greenhouse gas emissions: When the details matter. *Transp. Res. D Transp. Environ.* **2007**, *12*, 474–487. [CrossRef]
39. Alsaifi, K.; Elnahass, M.; Salama, A. Market responses to firms' voluntary carbon disclosure: Empirical evidence from the United Kingdom. *J. Clean. Prod.* **2020**, *262*, 121377. [CrossRef]
40. Friedman, M. *The Social Responsibility of Business Is to Increase Its Profits in Corporate Ethics and Corporate Governance*; Zimmerli, W.C., Holzinger, M., Richter, K., Eds.; Springer: Berlin/Heidelberg, Germany, 2007. [CrossRef]
41. Jost, F.; Dale, A.; Schwebel, S. How positive is 'change' in climate change? A sentiment analysis. *Environ. Sci Policy* **2019**, *96*, 27–36. [CrossRef]
42. Rezessy, S.; Bertoldi, P. Voluntary agreements in the field of energy efficiency and emission reduction: Review and analysis of experiences in the European Union. *Energy Policy* **2011**, *39*, 7121–7129. [CrossRef]
43. Li, Y. Voluntary disclosure and investment in environmental technology. *J. Econ. Behav. Organ.* **2017**, *133*, 331–341. [CrossRef]
44. Zheng, X.; Guo, K.; Luo, H.; Pan, X.; Hertwich, E.; Jin, L.; Wang, C. Individualism and nationally determined contributions to climate change. *Sci. Total Environ.* **2021**, *777*, 146076. [CrossRef] [PubMed]
45. Siriwardana, M.; Nong, D. Nationally Determined Contributions (NDCs) to decarbonise the world: A transitional impact evaluation. *Energy Econ.* **2021**, *97*, 105184. [CrossRef]
46. Aigbe, G.O.; Stringer, L.C.; Cotton, M. Gas Flaring in Nigeria: A Multi-level Governance and Policy Coherence Analysis. *Anthr. Sci.* **2023**, *1*, 1–17. [CrossRef]
47. Scheren, P.A.G.M.; Ibe, A.C. 22 Environmental pollution in the Gulf of Guinea: A regional approach. *Large Mar. Ecosyst.* **2002**, *11*, 299–320. [CrossRef]
48. Giwa, S.O.; Nwaokocha, C.N.; Odufuwa, B.O. Mitigating gas flare and emission footprints via the implementation of natural gas vehicles in Nigeria. *Energy Policy* **2017**, *111*, 193–203. [CrossRef]
49. Korppoo, A. Russian associated petroleum gas flaring limits: Interplay of formal and informal institutions. *Energy Policy* **2018**, *116*, 232–241. [CrossRef]
50. Olujobi, O.J.; Yebisi, T.E.; Patrick, O.P.; Ariremako, A.I. The Legal Framework for Combating Gas Flaring in Nigeria's Oil and Gas Industry: Can It Promote Sustainable Energy Security? *Sustainability* **2022**, *14*, 7626. [CrossRef]
51. Hassan, A.; Kouhy, R. Gas flaring in Nigeria: Analysis of changes in its consequent carbon emission and reporting. *Account. Forum* **2013**, *37*, 124–134. [CrossRef]
52. Nelson, E.; Udok, U.; Enobong; Akpan, B. Gas Flaring in Nigeria: Problems and Prospects Cite This Paper Gas Flaring in Nigeria: Problems and Prospects. *Glob. J. Politics Law Res.* **2017**, *5*, 16–28. Available online: https://www.academia.edu/39867037/AN_APPRAISAL_OF_THE_LEGAL_AND_INSTITUTIONAL_FRAMEWORK_FOR_THE_CONTROL_OF_GAS_FLARING_IN_NIGERIA (accessed on 2 December 2022).
53. Nelson, N. National Energy Policy and Gas Flaring in Nigeria. *J. Environ. Earth Sci.* **2015**, *5*, 14. Available online: www.iiste.org (accessed on 2 December 2022).
54. Watts, M. Resource curse? Governmentality, oil and power in the Niger Delta, Nigeria. *Geopolitics* **2004**, *9*, 50–80. [CrossRef]
55. Idemudia, U. The resource curse and the decentralization of oil revenue: The case of Nigeria. *J. Clean Prod.* **2012**, *35*, 183–193. [CrossRef]
56. Goumandakoye, H. Oil in Niger: A foundation for promise or a new resource curse? *Extr. Ind. Society* **2016**, *3*, 361–366. [CrossRef]
57. Apergis, N.; Katsaiti, M.S. Poverty and the resource curse: Evidence from a global panel of countries. *Res. Econ.* **2018**, *72*, 211–223. [CrossRef]
58. Oduyemi, G.O.; Owoeye, T.; Adekoya, O.B. Health outcomes and the resource curse paradox: The experience of African oil-rich countries. *Resour. Policy* **2021**, *73*, 102201. [CrossRef]
59. Ackah-Baidoo, A. Enclave development and 'offshore corporate social responsibility': Implications for oil-rich sub-Saharan Africa. *Resour. Policy* **2012**, *37*, 152–159. [CrossRef]
60. Symons, K. Transnational spaces, hybrid governance and civil society contestation in Mozambique's gas boom. *Extr. Ind. Soc.* **2016**, *3*, 149–159. [CrossRef]
61. Mattauch, L.; Creutzig, F.; Edenhofer, O. Avoiding carbon lock-in: Policy options for advancing structural change. *Econ. Model* **2015**, *50*, 49–63. [CrossRef]
62. Unruh, G.C. Understanding carbon lock-in. *Energy Policy* **2000**, *28*, 817–830. [CrossRef]
63. Unruh, G.C. The Real Stranded Assets of Carbon Lock-In. *One Earth* **2019**, *1*, 399–401. [CrossRef]
64. Unruh, G.C.; Carrillo-Hermosilla, J. Globalizing carbon lock-in. *Energy Policy* **2006**, *34*, 1185–1197. [CrossRef]
65. Ylä-Anttila, T.; Gronow, A.; Stoddart, M.C.J.; Broadbent, J.; Schneider, V.; Tindall, D.B. Climate change policy networks: Why and how to compare them across countries. *Energy Res. Soc. Sci.* **2018**, *45*, 258–265. [CrossRef]
66. Akinola, A.O. Resource Misgovernance and the Contradictions of Gas Flaring in Nigeria: A Theoretical Conversation. *J. Asian Afr. Stud.* **2018**, *53*, 749–763. [CrossRef]

67. Iornumbe, G.Y. The State, Lack of Political Will and Persistent Gas Flaring in the Niger Delta by. *Int. J. Socail Sci.* **2019**, *13*, 114–126.
68. Benson, A. Social and Environmental Drivers of Climate Change Vulnerability in the Niger Delta region, Nigeria. *Eur. J. Environ. Earth Sci.* **2020**, *1*, 1–10. [CrossRef]
69. Olujobi, O.J. Analysis of the Legal Framework Governing Gas Flaring in Nigeria's Upstream Petroleum Sector and the Need for Overhauling. *Soc. Sci.* **2020**, *9*, 132. [CrossRef]
70. Varkkey, H. Transboundary Pollution. *Political Science. Preprints* **2019**. [CrossRef]
71. La Torre, D.; Liuzzi, D.; Marsiglio, S. Transboundary pollution externalities: Think globally, act locally? *J. Math. Econ.* **2021**, *96*, 102511. [CrossRef]
72. Altamirano-Cabrera, J.C.; Wangler, L.; Weikard, H.P.; Kroll, S. Political Economy of International Environmental Agreements. *Encycl. Energy Nat. Resour. Environ. Econ.* **2013**, *3*, 300–305. [CrossRef]
73. Loe, J.S.P.; Ladehaug, O. Reducing gas flaring in Russia: Gloomy outlook in times of economic insecurity. *Energy Policy* **2012**, *50*, 507–517. [CrossRef]
74. Rodrigues, A.C.C. Decreasing natural gas flaring in Brazilian oil and gas industry. *Resour. Policy* **2022**, *77*, 102776. [CrossRef]
75. Shahab-Deljoo, M.; Medi, B.; Kazi, M.K.; Jafari, M. A techno-economic review of gas flaring in Iran and its human and environmental impacts. *Process Saf. Environ. Prot.* **2023**, *173*, 642–665. [CrossRef]
76. Wen, Y.; Xiao, J.; Peng, J. The effects of the 'Zero Routine Flaring by 2030' initiative: International comparisons based on generalized synthetic control method. *Environ. Impact Assess Rev.* **2023**, *100*, 107095. [CrossRef]
77. Olujobi, O.J.; Olusola-Olujobi, T. Comparative appraisals of legal and institutional framework governing gas flaring in Nigeria's upstream petroleum sector: How satisfactory? *Environ. Qual. Manag.* **2020**, *33*, 487. [CrossRef]
78. Radhakrishnan, A.; DiCarlo, D.; Orbach, R.L. Discrepancies in the current capabilities in measuring upstream flare volumes in the Permian Basin. *Upstream Oil Gas Technol.* **2023**, *10*, 100084. [CrossRef]
79. Branco, D.A.C.; Szklo, A.S.; Schaeffer, R. Co_2e emissions abatement costs of reducing natural gas flaring in Brazil by investing in offshore GTL plants producing premium diesel. *Energy* **2010**, *35*, 158–167. [CrossRef]
80. Millimet, D.L. Empirical Methods for Political Economy Analyses of Environmental Policy. *Encycl. Energy Nat. Resour. Environ. Econ.* **2013**, *3*, 250–260. [CrossRef]
81. Nabernegg, S.; Bednar-Friedl, B.; Muñoz, P.; Titz, M.; Vogel, J. National Policies for Global Emission Reductions: Effectiveness of Carbon Emission Reductions in International Supply Chains. *Ecol. Econ.* **2019**, *158*, 146–157. [CrossRef]
82. IPCC. The Evidence Is Clear: The Time for Action Is Now. We Can Halve Emissions by 2030. IPCC. Available online: https://www.ipcc.ch/2022/04/04/ipcc-ar6-wgiii-pressrelease/ (accessed on 14 May 2024).
83. GGFR/The World Bank. Global Flaring and Venting Regulations: A Comparative Review of Policies. 2022. Available online: https://www.worldbank.org (accessed on 14 May 2024).
84. GGFR/The World Bank. Gas Flaring Reduction Initiative: Report on Consultations with Stakeholders and the Kyoto Mechanisms for Flaring Reductions. Oslo, Norway, April. 2002. Available online: https://documents1.worldbank.org/curated/en/297051468762607776/pdf/272750global1g1tiative0Report0no-01.pdf (accessed on 14 May 2024).
85. GGFR/The World Bank. Guidance on Upstream Flaring and Venting: Policy and Regulation. Washington, DC, March 2009. Available online: https://documents1.worldbank.org/curated/en/200701468344636937/pdf/826120WP0polic00Box379864B00PUBLIC0.pdf (accessed on 14 May 2024).
86. GGFR/The World Bank. Regulation of Associated Gas Flaring and Venting: A Global Overview and Lessons from International Experience. Washington, DC, 2004. Available online: https://documents1.worldbank.org/curated/en/590561468765565919/pdf/295540Regulati1aring0no10301public1.pdf (accessed on 14 May 2024).
87. GGFR/The World Bank. Global Gas Flaring Reduction Public-Private Partnership-Expanded Update October 2004. October 2004. Available online: https://documents1.worldbank.org/curated/en/342761468780614074/pdf/295550GGF0a0pu1ship10no10401public1.pdf (accessed on 14 May 2024).
88. GGFR/The World Bank. Flaring Report on Global Flaring Reduction Initiative: Report on consultations with stake-holders. Norway, April 2002. Available online: https://archivesholdings.worldbank.org/global-gas-flaring-reduction-ggfr-initiative-conference-oslo-april-15-16-2002-bent-svensson-committee-records-volume-2 (accessed on 14 May 2024).
89. GGFR/The World Bank. A Voluntary Standard for Global Gas Flaring and Venting Reduction. May 2004. Available online: https://documents1.worldbank.org/curated/en/342761468780614074/pdf/A-voluntary-standard-for-global-gas-flaring-and-venting-reduction.pdf (accessed on 14 May 2024).
90. Gerner, F.; Svensson, B.; Djumena, S. Gas Flaring and Venting: A Regulatory Framework and Incentives for Gas Utilization. World Bank, Washington, DC, 2004. Available online: https://openknowledge.worldbank.org/handle/10986/11253 (accessed on 14 May 2024).
91. Osuoha, C.A.; Fakutiju, M.A. Gas Flaring in Niger Delta Region of Nigeria: Cost, Ecological and Human Health Implications. *Environ. Manag. Sustain. Dev.* **2017**, *6*, 2017. [CrossRef]

92. Aghalino, S.O. Gas Flaring, Environmental Pollution and Abatement Measures in Nigeria, 1969–2001. *J. Sustain. Dev. Afr.* **2009**, *11*, 219–238.
93. Elvidge, C.D.; Bazilian, M.D.; Zhizhin, M.; Ghosh, T.; Baugh, K.; Hsu, F.C. The potential role of natural gas flaring in meeting greenhouse gas mitigation targets. *Energy Strategy Rev.* **2018**, *20*, 156–162. [CrossRef]
94. Hassan, A. Dealing with vulnerability to carbon emission from gas flaring: The roles of transparency and utilisation policies in Nigeria. *OPEC Energy Rev.* **2020**, *44*, 369–403. [CrossRef]
95. Okafor, J.C.; Aniche, E.T. Nigeria and World Bank Global Gas Flaring Reduction (GGFR) Partnership: The Tragedy of the Commons. *Dev. Ctry. Stud.* **2016**, *6*, 12. Available online: https://www.iiste.org (accessed on 14 May 2024).
96. Sedlar, D.K.; Vulin, D.; Jukić, L.; Smajla, I. Possibility of decreasing CO_2 emissions from flaring on a mature oil field. *J. Pet. Sci. Eng.* **2018**, *171*, 1302–1308. [CrossRef]
97. Pohekar, S.D.; Ramachandran, M. Application of multi-criteria decision making to sustainable energy planning—A review. *Renew. Sustain. Energy Rev.* **2004**, *8*, 365–381. [CrossRef]
98. Kumar, A.; Sah, B.; Singh, A.R.; Deng, Y.; He, X.; Kumar, P.; Bansal, R.C. A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. *Renew. Sustain. Energy Rev.* **2017**, *69*, 596–609. [CrossRef]
99. Saaty, T.; Vargas, L. *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process, Second*; Springer: New York, NY, USA, 2012. [CrossRef]
100. Saaty, T.L. How to Make a Decision: The Analytic Hierarchy Process. *Inf. J. Appl. Anal.* **1994**, *24*, 19–43. [CrossRef]
101. Buckley, J.J. Fuzzy Hierarchical Analysis*. *Fuzzy Sets Syst.* **1985**, *17*, 233–247. [CrossRef]
102. Arabameri, A.; Blaschke, T.; Pradhan, B.; Pourghasemi, H.R.; Tiefenbacher, J.P.; Bui, D.T. Evaluation of Recent Advanced Soft Computing Techniques for Gully Erosion Susceptibility Mapping: A Comparative Study. *Sensors* **2020**, *20*, 335. [CrossRef]
103. World Bank Group. Global Gas Flaring Reduction: A Public-Private Partnership World Bank Group Regulation of Associated Gas Flaring and Venting: A Global Overview and Lessons. World, 2004. Available online: https://www.worldbank.org/ggfr (accessed on 5 July 2019).
104. Agbonifo, P.E. Risk Management and Regulatory Failure in the Oil and Gas Industry in Nigeria: Reflections on the Impact of Environmental Degradation in the Niger Delta Region. *J. Sustain. Dev.* **2016**, *9*, 126–131. [CrossRef]
105. GGFR/The World Bank. Global Gas Flaring Reduction Partnership (GGFR) Guidance on Upstream Flaring and Venting Policy and Regulation. 2009. Available online: https://documents.worldbank.org/pt/publication/documents-reports/documentdetail/188931641222323127/announcement-of-qatar-first-gulf-country-joins-world-bank-led-effort-to-reduce-greenhouse-emissions-from-gas-flaring-on-january-25-2009 (accessed on 30 April 2023).
106. PFC Energy/The World Bank. Using Russia's Associated Gas Prepared for the Global Gas Flaring Reduction Partnership and the World Bank 71382 v1. 2007. Available online: https://www.pfcenergy.com (accessed on 30 April 2023).
107. IEA. Net Zero by 2050—Analysis—IEA. Available online: https://www.iea.org/reports/net-zero-by-2050 (accessed on 14 May 2024).
108. IPCC. IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. 2018. Available online: https://www.researchgate.net/publication/329841417_Global_warming_of_15C_An_IPCC_Special_Report_on_the_impacts_of_global_warming_of_15C_above_pre-industrial_levels_and_related_global_greenhouse_gas_emission_pathways_in_the_context_of_strengthening_the (accessed on 30 April 2023).
109. Saaty, T.L. Making and validating complex decisions with the AHP/ANP. *J. Syst. Sci. Syst. Eng.* **2005**, *14*, 1–36. [CrossRef]
110. Saaty, R.W. The analytic hierarchy process—What it is and how it is used. *Math. Model.* **1987**, *9*, 161–176. [CrossRef]
111. Liu, S.; Yang, Y.; Forrest, J. Grey Data Analysis. In *Computational Risk Management*; Springer: Singapore, 2017. [CrossRef]
112. Balubaid, M.; Alamoudi, R.; Balubaid, M.; Alamoudi, R. Application of the Analytical Hierarchy Process (AHP) to Multi-Criteria Analysis for Contractor Selection. *Am. J. Ind. Bus. Manag.* **2015**, *5*, 581–589. [CrossRef]
113. Solangi, Y.A.; Longsheng, C.; Shah, S.A.A. Assessing and overcoming the renewable energy barriers for sustainable development in Pakistan: An integrated AHP and fuzzy TOPSIS approach. *Renew. Energy* **2021**, *173*, 209–222. [CrossRef]
114. Mateo, J.R.S.C. Multi-Criteria Analysis. *Green Energy Technol.* **2012**, *83*, 7–10. [CrossRef]
115. Taha, R.A.; Dain, T. Multi-criteria applications in renewable energy analysis, a literature review. *Res. Technol. Manag. Electr. Ind.* **2013**, 17–30. Available online: https://www.scopus.com/record/display.uri?eid=2-s2.0-84924238463&origin=inward&featureToggles=FEATURE_NEW_DOC_DETAILS_EXPORT:1 (accessed on 14 May 2024).
116. Wang, J.J.; Jing, Y.Y.; Zhang, C.F.; Zhao, J.H. Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renew. Sustain. Energy Rev.* **2009**, *13*, 2263–2278. [CrossRef]
117. Robles, C.; Polo, A.; Ospino, A. An AHP-based approach for evaluating renewable energy sources. *Int. J. Energy Econ. Policy* **2017**, *7*, 38–47. Available online: https://www.scopus.com/record/display.uri?eid=2-s2.0-85049238958&origin=inward&featureToggles=FEATURE_NEW_DOC_DETAILS_EXPORT:1 (accessed on 14 May 2024).

118. Chanchawee, R.; Usapein, P. Ranking of renewable energy for the national electricity plan in Thailand Using an Analytical Hierarchy Process (AHP). *Int. J. Renew. Energy Res.* **2018**, *8*, 1553–1562. [CrossRef]
119. Ghimire, L.P.; Kim, Y. An analysis on barriers to renewable energy development in the context of Nepal using AHP. *Renew. Energy* **2018**, *129*, 446–456. [CrossRef]
120. Qureshi, M.E.; Harrison, S.R. Application of the analytic hierarchy process to riparian revegetation policy options. *Small-Scale For. Econ. Manag. Policy* **2003**, *2*, 441–458. [CrossRef]
121. Zare, A.; Feylizadeh, M.R.; Mahmoudi, A.; Liu, S. Suitable computerized maintenance management system selection using grey group TOPSIS and fuzzy group VIKOR: A case study. *Canada. Decis. Sci. Lett.* **2018**, *7*, 341–358. [CrossRef]
122. Bakar, A.S.A.; Khalif, K.M.N.K.; Yaakob, A.M.; Gegov, A.; Amin, A.Z.M. Grey Number Based Methodology for Non-homogeneous Preference Elicitation in Fuzzy Risk Analysis Management. In *Applying Fuzzy Logic for the Digital Economy and Society. Fuzzy Management Methods*; Meier, A., Pedrycz, W., Portmann, E., Eds.; Springer: Cham, Switzerland, 2019; pp. 135–148. [CrossRef]
123. Yoon, K.; Hwang, C.L. Manufacturing plant location analysis by multiple attribute decision making: Part I—Single-plant strategy. *Int. J. Prod. Res.* **2007**, *23*, 345–359. [CrossRef]
124. Mrabure, K.O.; Ohimor, B.O. Unabated gas flaring menace in Nigeria. The need for proper gas utilization and strict enforcement of applicable laws. *Commonw. Law Bull.* **2020**, *46*, 753–779. [CrossRef]
125. Svensson, B. Gas Flaring Reduction—A Global Perspective Background of Global Flaring. 2005. Available online: https://19january2021snapshot.epa.gov/sites/static/files/2017-06/documents/svensson_2005aiw.pdf (accessed on 14 May 2024).
126. Zhizhin, M.; Matveev, A.; Ghosh, T.; Hsu, F.C.; Howells, M.; Elvidge, C. Measuring gas flaring in Russia with mul-tispectral VIIRS nightfire. *Remote Sens.* **2021**, *13*, 3078. [CrossRef]
127. Bello, F. Towards a Legal Framework for Deploying Carbon Technologies to Address the Environmental Impacts of Gas flaring in Nigeria. *J. Sustain. Dev. Law Policy* **2023**, *13*, 102–124. Available online: https://www.ajol.info/index.php/jsdlp/article/view/243195 (accessed on 14 May 2024).
128. Fawole, O.G.; Cai, X.M.; Mackenzie, A.R. Gas flaring and resultant air pollution: A review focusing on black carbon. *Environ. Pollut.* **2016**, *216*, 182–197. [CrossRef]
129. Akinola, A.O.; Wissink, H. Public Sector Performance in the Nigerian Downstream Oil Sector: A Critical Reflection. *J. Asian Afr. Stud.* **2018**, *53*, 476–490. [CrossRef]
130. Kinnon, M.A.M.; Brouwer, J.; Samuelsen, S. The role of natural gas and its infrastructure in mitigating greenhouse gas emissions, improving regional air quality, and renewable resource integration. *Prog. Energy Combust. Sci.* **2018**, *64*, 62–92. [CrossRef]
131. Janipour, Z.; de Nooij, R.; Scholten, P.; Huijbregts, M.A.J.; de Coninck, H. What are sources of carbon lock-in in energy-intensive industry? A case study into Dutch chemicals production. *Energy Res. Soc. Sci.* **2020**, *60*, 101320. [CrossRef]
132. IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability | Climate Change 2022: Impacts, Adaptation and Vulnerability. Available online: https://www.ipcc.ch/report/ar6/wg2/ (accessed on 14 May 2024).