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A systematic review of the application of multi-criteria decision-making in evaluating Nationally Determined Contribution projects

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ABSTRACT

Analyses in the past decade and more recently, catastrophic events, including extreme temperatures, unpredictable weather patterns, floods, and wildfires caused by climate change, have become too common worldwide. There is overwhelming evidence that country commitments expressed in National Determined Contributions (NDCs) can contribute to stabilising or reversing the course of impacts of climate change. With the multiplicity of NDC measures, compounded by their complexities and limited resources, multi-criteria decision-making tools can be used in making informed decisions about their development. Furthermore, while many countries are blessed with an abundance of sustainable resources and technologies to feed into NDCs, a major challenge is prioritising them as part of the national and global climate change mitigation and adaptation agenda. Many multi-criteria decision-making (MCDM) methods and tools have been developed over the years. However, their implementation in practice for prioritising NDC measures is still not well-known despite their high acceptance in academic literature. This study adopts a systematic review of the peer-reviewed literature from the Web of Science and grey literature from the recently launched Technology Needs Assessment database to fully understand the MCDM tools used in evaluating NDC projects from academic versus practice perspectives. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method adopted, culminated in the identification of 464 peer-reviewed journal articles and 50 TNA reports used in the analysis. The results indicate amongst the many MCDM techniques in peer-reviewed literature, Analytic Hierarchy Process (AHP) is the most widely used in research, while simplified MCDM methods are the most used in practice.

1. Background

Globally, organisations or investors are interested in projects that meet their requirements. A typical project is shrouded with complex parts, processes, many parameters, and stakeholders with different level of experiences presenting huge decision-making challenges for investors. The need to limit climate change impacts has led governments to commit to National Determined Contribution (NDC) projects. NDCs are national climate plans highlighting climate actions, including climate-related targets and measures (e.g., projects, policies, organisations) governments plan to implement in response to climate change and as a contribution to global climate action. NDCs are at the heart of the Paris Agreement (Article 4, paragraph 2) where each country is required to outline and communicate their post-2020 climate actions. As of April 29th, 2022, according to the NDC Registry, 190 parties have submitted their updated NDCs while only 14 had submitted their second. Countries will need to include projects from different sectors that can easily help in meeting their NDCs commitments. Given that only few countries have submitted their revised NDCs, almost 7 years after the Paris Agreement, it is imperative for the remaining countries to choose eco-friendly projects that can help them achieve their climate change obligations. In addition to the fact that climate change mitigation measures contained in Intended Nationally Determined Contributions (INDCs) are difficult to compare [1], international obligations or client's requirements are so stringent that the need of a framework or a decision-making tool for choosing NDCs project is imperative. Like most environmental management fields, different multi-criteria decision-making (MCDM) techniques have been used in identifying the most performing projects. The Analytical Hierarchical Process (AHP) was employed to rank the various identified factors

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using inputs from 20 experts in Ghana's renewable sector [2]. An AHP-Technique for Order of Preference by Similarity to Ideal Solution (AHP-TOPSIS) has been used for identifying the best location for the implantation of large-scale photovoltaic plants [3]. Costa et al. [4] used a stochastic data envelopment analysis (DEA) as an alternative for estimating efficient costs, thus providing a much simpler alternative. Bertoncini et al. [5] applied the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) II method for the comparison of energy requalification strategies to design post-carbon cities. The trend in the literature including the aforementioned studies have hardly provided robust justifications and appropriateness for/of the MCDM chosen for their different studies. At best very weak rationales influenced by the authors background and knowledge of the chosen MCDM have often been advanced. This weakness has been corroborated by Guarini et al. [6] who revealed the lack of scholarly work about guidance for selecting the most appropriate MCDM for various projects. Despite the urgency to roll out the implementation of NDCs projects, there is limited evidence about the application of MCDM in prioritising different NDC projects.

Thus, the aim of this study is to investigate and develop an understanding of the applications of MCDM for the prioritisation of NDC projects. The following specific objectives are central to this aim:

- Identify the most used MCDM in prioritising NDCs
- Develop an understanding of the domains where MDCDM have been applied on NDC projects
- Develop a framework of how MCDM can be implemented in NDCs

Given the global nature of the impacts of climate change, the authors deliberately abstain from focusing on specific regional studies to avoid limiting the understanding of applications of MCDM on NDC projects. For the peer-reviewed literature used in this study was from any region in so far as it is about MCDM for NDC related projects. For the grey literature, most were drawn from international organisations' websites (e.g., NDC reports from The United Nations Framework Convention on Climate Change (UNFCCC and TNA reports from United Nations Environment Programme (UNEP)) that operates globally. The technology needs assessment reports are examples of grey literature that was used for this study. Perhaps partly because of the high vulnerability of developing countries especially African countries [7], most of the grey literature were from developing countries. Specifically grey literature were TNA reports of countries that have submitted only their 1st NDC reports which mostly covered African countries although some European (Georgia) and Asian (Indonesia) countries have been included.

To facilitate understanding, the remainder of this manuscript is divided into 5 sections. As noted in the preceding section, NDC measures are projects aimed at helping governments to achieve their climate change commitments. It is therefore imperative to examine the different project selection techniques to better inform MCDM applications on NDC projects. This is addressed in Section 2. The research methods used for this study are discussed in Section 3. In Section 4, the research findings are presented. The analysis and discussion of the research results are presented in Section 5 while the study concludes by a way of a summary in Section 6.

2. Project selection techniques

2.1. Overview of project selection techniques

Based on the literature, different methods have been used for selecting projects. The five most popular are single-criterion decision analysis [8], multi-criteria decision-making (MCDM) [9,10], cost–benefit analysis (CBA) [11], SWOT techniques [12], data envelopment analysis (DEA) [13]. Although, in the literature MCDM is used synonymously with multi-criteria analysis (MCA) and multi criteria decision analysis (MCDA), in this study MCDM will be used. In order to determine the most appropriate decision-making techniques for selecting NDCs projects, a comparative analysis of other project selection techniques versus MCDM was undertaken as in the ensuing paragraphs.

Single criterion versus MCDM: Decision-making techniques model complex preferences about projects, products, services, or anything that requires a choice to be made based on some criteria. The choice could be made on a single criterion, often called single-criterion decision analysis [8] or many criteria, called multi-criteria decision-making. In the latter case, it is possible the criteria on which to base judgments can be conflicting. For example, a client who wants a highly efficient photovoltaic system battery may be constrained by its high cost. These conflicting criteria upon which decisions are to be made are further exacerbated if many criteria are considered. Single-criterion decision-making is very limited in dealing with real-life problems [14] that have conflicting objectives. Furthermore, Janikowski et al. [14] argues that it is very necessary for real-life problems to be addressed from a multi-criteria perspective. That is why many multi-criteria techniques have gained significant interest from the research and the industrial community as a de-facto methodology for multi-criteria decision-making.

Cost–benefit analysis (CBA) versus MCDM: Cost benefit analysis (CBA) is a technique devised to evaluate the cost versus the benefits of a project proposal. The key in this method is determining a list of expenses of every project and what the benefits will be after successfully executing the project. Based on this, the return on investment (ROI), internal rate of return (IRR), net present value (NPV) and payback period can be computed. CBA based on a single metric — that of monetised value for comparing projects. CBA essentially totals all costs and benefits of a project over its lifetime and discounts future flows to calculate present values. A key strength is that it allows decision-makers to intuitively compare and rank diverse alternatives based on a single indicator [15]. However, most cost information especially in the preliminary stages of a project are often limited and many costs and benefits are difficult to monetise [16]. Some effects, such as construction costs, or travel time savings, are easier to express in monetary terms than others, such as nature, aesthetics, or social cohesion [17]. This is particularly difficult when governments possess limited resources for appraising large sets of small- and medium-sized projects [16].

SWOT techniques versus MCDM: The acronym SWOT stands for Strengths, Weaknesses, Opportunities and Threats. These are categories that are evaluated for strategic planning or analysis of a business, company, project, product or a person. A SWOT analysis identifies the internal and external attributes that can aid in making informed decisions about a given project, program and/or organisation. For example, SWOT has been used to critically analyse solar energy sources which culminated in the establishment of the state-of-the-art, identification of the potential and prospects for development of renewable energy in Romania [18]. Mahdavi et al. [19] argued that SWOT factors are too often imprecise, highly qualitative, and subjective. SWOT data collection and analysis entail a subjective process that reflects the bias of the individuals who collect the data and participate in the brainstorming session [20]. SWOT categorises factors into 4 individual lists of strengths, weaknesses, opportunities and threats. However, the tool provides no mechanism to rank the significance of one factor versus another within any list [20]. As a result, it is difficult to determine the amount of any one factor's true impact on the objective. SWOT analysis creates a one-dimensional model which categorises each problem attribute as a strength, weakness, opportunity or threat. As a result, each attribute appears to have only one influence on the problem being analysed. However, one factor might be both a strength and a weakness. For example, locating a chain of stores on well-travelled streets that grant easy access to customers might be reflected in increased sales. However, the costs of operating high-visibility facilities can make it difficult to compete on price without a large sales volume [20]. An MCDM overcomes the weaknesses of SWOT in the sense that it offers a way of prioritising or ranking various alternatives and uses many criteria in its decision analysis.

DEA versus MCDM

Developed by Charnes et al. [21], data envelopment analysis (DEA) is a nonparametric method in operations research and economics used for determining the productive efficiency of decision-making units (DMU). In very simple terms, DEA is usually measured as a ratio of the multiple inputs DMUs consumed over multiple outputs that they produce [21,22]. On the other hand, a MCDM method uses a common set of weights that expresses a decision maker's preferences [23]. In contrast, the DEA does not provide a common set of weights that could express the preferences of a decision-maker. Despite these differences, DEA could be used as a supplement for screening alternatives within MCDM [23]. The aforementioned difference is a high level one, and the details of other differences obviously depend on each MCDM techniques already examined by other researchers [22,24]. Hence, the detail differences between DEA and MCDM will not be explored further in this study.

As examined in the preceding paragraphs, MCDM is by far the best decision-making tool than others including, DEA, SWOT, CBA and single-criterion. MCDM considers so many different criteria or parameters consistent with real-life where individuals have to make decisions between choices that are in some instances conflicting with each other. Evidence based on experiences and research from other studies have proven MCDM to be an efficient and most appropriate technique than most decision-making tools [25]. The suitability and appropriateness of MCDM than most others for environmental decision problems has been argued by several authors [26–28]. Hermans and Erickson [26] and Hersh [27] argued that MCDM is appropriate than other techniques due to that fact that it can be used in diagnosing environmental decision problems, which typically involve multiple objectives, criteria, and decision-makers. This aligns with that of Kiker et al. [28] where they argued MCDM is more suitable because decision-making in environmental projects can be complex and seemingly intractable, principally because of the inherent trade-offs between socio-political, environmental, ecological, and economic factors. The selection of appropriate remedial and abatement strategies for contaminated sites, land use planning, and regulatory processes often involves multiple additional criteria such as the distribution of costs and benefits, environmental impacts for different populations, safety, ecological risk, or human values, making MCDM a better option than most decision-making tools [28].

The goal of NDCs is to help countries comply with their climate change obligations. Climate change mitigation measures are at the core of NDCs. Therefore, NDC measures are underpinned by environmental sustainability principles and hence MCDM is suitable for their analysis as argued by Hermans and Erickson [26] and Hersh [27]. Common NDC measures include projects, policies, organisations, etc, involving stakeholders at national and international levels. To make sure the measures meet their intended objectives, there must be appropriately chosen to comply with certain requirements that meet the different stakeholders' interests. The different stakeholders often have different conflicting criteria depending on their different interests. Therefore, MCDM can be used in making informed decisions about the various NDCs mitigation and adaptation measures for different countries.

2.2. Types of MCDM methods

There are several MCDM methods, although with each's own particularities, they share common characteristics of dealing with conflicting criteria, incomparable units, and difficulties in the selection of alternatives [29]. The most common methods are the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), The Analytic Hierarchy Process (AHP), ELimination Et Choix Traduisant la REalité or Elimination and Choice Translating REality (ELECTRE) and VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (meaning: Multicriteria Optimization and Compromise Solution). WSM (Weighted Sum Method), PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation), Multi-Attribute Utility Theory (MAUT).

As argued in Section 2.1, MCDM technique was/is the most appropriate for prioritising NDC projects. This is due to the inherent weaknesses with other decision-making tools and the suitability of MCDM for environmental decision problems — an important aspect of NDCs. Although the implementation process of the different MCDM techniques is largely similar, the underpinning mathematical principles slightly differ and can present challenges in practices during implementation in real-life problems. Thus, to gain insights into the applications of MCDM in practice, it is imperative to examine how the different methods have been implemented. To this end, MCDM applications on projects in general and specifically on NDCs have been examined. Before examining the MCDM applications on projects, the methods used in this study which helped in their identification will be discussed in the ensuing section.

3. Methods

A systematic literature review was conducted to achieve the aim and objectives of this study. The approach adopted is built on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [30] commonly used in academic scholarly works.

As presented in Fig. 1, peer-reviewed and grey literature were reviewed.

As can be seen on Fig. 1, two main categories of literature served as sources. The first was peer-reviewed literature from ScienceDirect database. The second was grey literature from NDC registry [31] and Technology Needs Assessment [32]. The peer-reviewed literature served two main purposes. Firstly, it was used to gain an in-depth understanding of the MCDM techniques and applications which informed the decision of which is/are suitable for NDC projects. Considering the goals of NDC projects in relation to climate change, a more systematic and focused approach to reviewing the literature was adopted. The search period was restricted to the range 1987 to 2022, and the focus was on journal outputs excluding review articles. The start date of 1987 was chosen because of its significance in climate change studies as it represents the year when the concept of Sustainable Development was popularised in the Brundtland report. The queries were conducted on the 18th of September 2022. Depending on the goals of each search term was formulated and used for the different queries in the ScienceDirect database (See Table 1). For example, if the goal was to determine articles that talk about AHP applications in NDCs, the term "AHP" and "Nationally Determined Contributions" was used. To ensure a maximum number of articles are identified, terms with equivalent meanings were used such as "AHP" and "Nationally Determined Contributions" and "Analytic Hierarchy Process" and "Nationally Determined Contributions" and "prioritization" and "Nationally Determined Contributions" and "prioritisation" and "Nationally Determined Contributions".

Using the specified terms led to an output of 1549 articles which was then filtered by considering only "peer-reviewed articles" (inclusion criteria) which led to 1155 articles. Given that synonyms were used in the search terms, e.g., "Prioritisation" and "Nationally Determined Contributions" and "Prioritization" and "Nationally Determined Contributions", the featuring of duplicates was eminent. A two-stage process was used to screen the 1155 articles to identify duplicates amongst all the search outputs. Firstly, the 1155 were imported into EndNote where duplicates were identified automatically and removed. Secondly, the remaining articles were manually checked to ensure there were no duplicates. The remaining 464 articles were identified and used for analysis. The analysis of the results from this search was conducted using VOSViewer and presented in Figs. 2 and 3. Also, depending

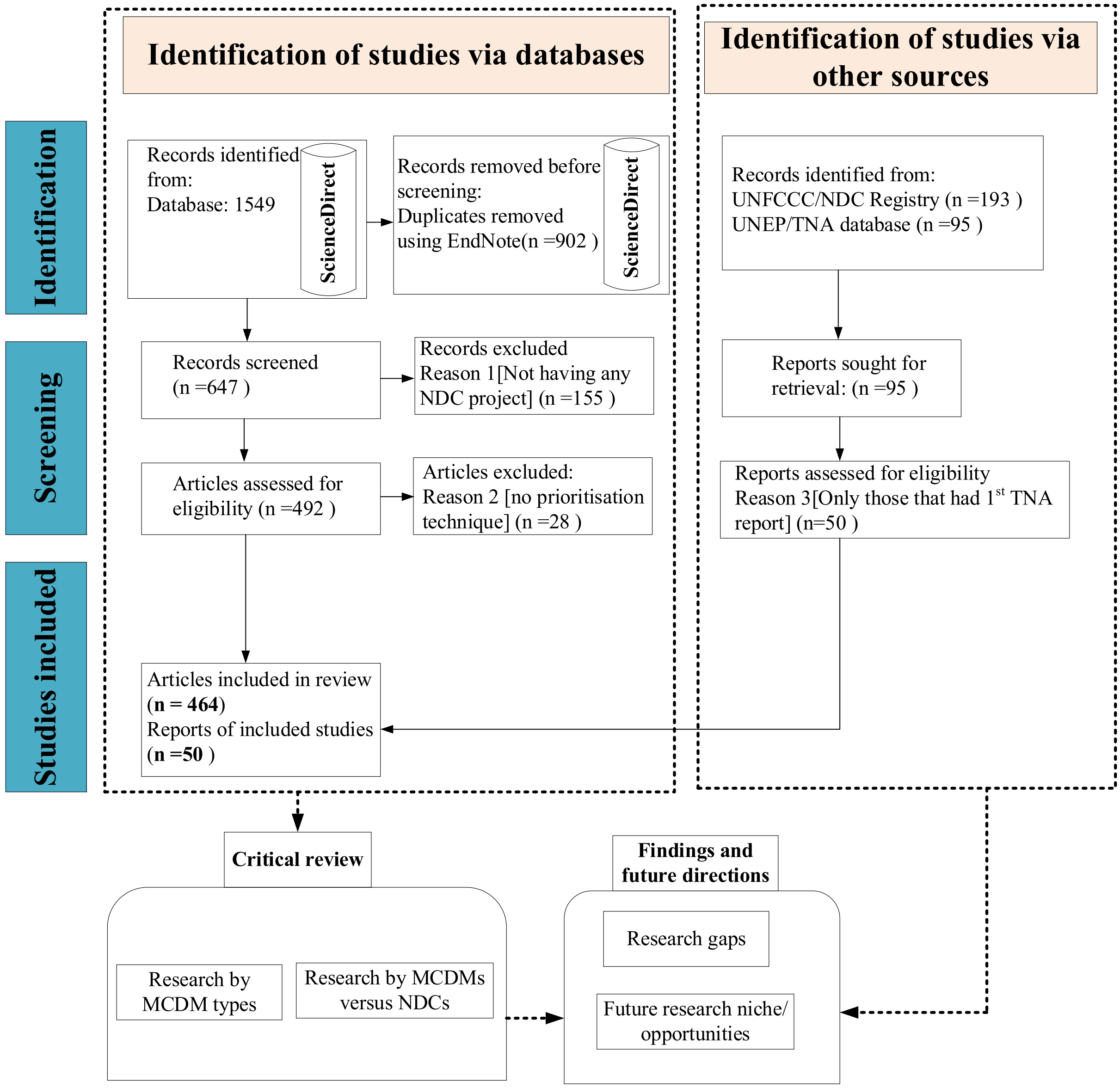

Fig. 1. Research method framework.
Source: Adapted PRISMA.

on the purpose of a systematic review study a scientometric and/or critical review should be implemented [33]. Based on Fig. 1, after the peer-reviewed literature a critical review was conducted to classify the content by themes such as research by MCDM types and research by MCDMs versus NDCs.

The second main type of literature is grey literature which was reviewed to identify the relevant NDC sectors, mitigation/adaptation measures/projects and indicators for project prioritisation. The literature from the NDC registry [31] and Technology Needs Assessment [32] websites were examined to identify the projects that can help countries meet their commitments. Through the NDC registry, countries that have submitted their first NDCs were identified while those that have undertaken a technology need assessment were identified through the TNA database [32]. Only countries that have submitted at least their 1st NDCs and conducted at least 1 TNA were considered. The process consisted of first identifying a country in the NDC registry before search for it in the TNA database. In total 50 countries were identified in TNA database and 1st TNA reports were considered for those that have submitted more than one and for others only the available TNA reports were considered if they had submitted just one report. In total, 50 reports were identified and reviewed. The analysis of the report has been presented in Section 4.2.

The examination of the two categories of studies, i.e., from peer-reviewed and grey sources led to the identification of knowledge gaps and served as the basis or foundation of this study. The findings of the study led to the identification of future research niche/opportunities. This is captured and presented in the lower part of Fig. 1.

4. Research findings

4.1. Findings from peer-reviewed literature: Evidence from research

4.1.1. Most applied MCDM in NDC

Fig. 2 is the result from the analysis of 464 articles about MCDM applications in NDCs.

Based on Fig. 2, it is evident that AHP is the most applied MCDM technique in NDCs. Although data envelopment analysis appears larger it occurs only once while AHP occurs in many instances (see green rectangles) and in other variants such as fuzzy-AHP (see blue rectangles). That notwithstanding, a further exploration of the various articles was

Table 1
Search terms for identification of articles in ScienceDirect.

Search term	1st output	2nd output	3rd output
“Multiple-Criteria Decision-Making” and “Nationally Determined Contributions”	6	5	
“MCDM” and “Nationally Determined Contributions”	44	34	
“Multi-criteria analysis” and “Nationally Determined Contributions”	45	35	
“MCA” and “nationally determined contributions”	27	17	
“Multiple-criteria decision analysis” and “Nationally Determined Contributions”	4	3	
“MCDA” and “nationally determined contributions”	41	28	
“Analytic Hierarchy Process” and “Nationally Determined Contributions”	77	55	
“AHP” and “Nationally Determined Contributions”	70	53	
“Technique for Order of Preference by Similarity to Ideal Solution” and “Nationally Determined Contributions”	13	12	
“TOPSIS” and “Nationally Determined Contributions”	40	32	
“ELimination Et Choix Traduisant la REalité or Elimination and Choice Translating REality” and “Nationally Determined Contributions”	0	0	
“ELECTRE” and “Nationally Determined Contributions”	21	14	464
“VIseKriterijumska Optimizacija I Kompromisno Resenje” and “Nationally Determined Contributions”	1	1	
“VIKOR” and “Nationally Determined Contributions”	13	10	
“Weighted Sum Method” and “Nationally Determined Contributions”	17	13	
“WSM” and “Nationally Determined Contributions”	11	10	
“Preference Ranking Organization Method for Enrichment Evaluation” and “Nationally Determined Contributions”	12	10	
“PROMETHEE” and “Nationally Determined Contributions”	22	13	
“Multi-Attribute Utility Theory” and “Nationally Determined Contributions”	9	5	
“MAUT” and “Nationally Determined Contributions”	9	6	
“Data Envelopment Analysis” and “Nationally Determined Contributions”	116	101	
“DEA” and “Nationally Determined Contributions”	138	114	
“Prioritization” and “Nationally Determined Contributions”	730	529	
“Prioritisation” and “Nationally Determined Contributions”	63	55	
	1549	*1155*	

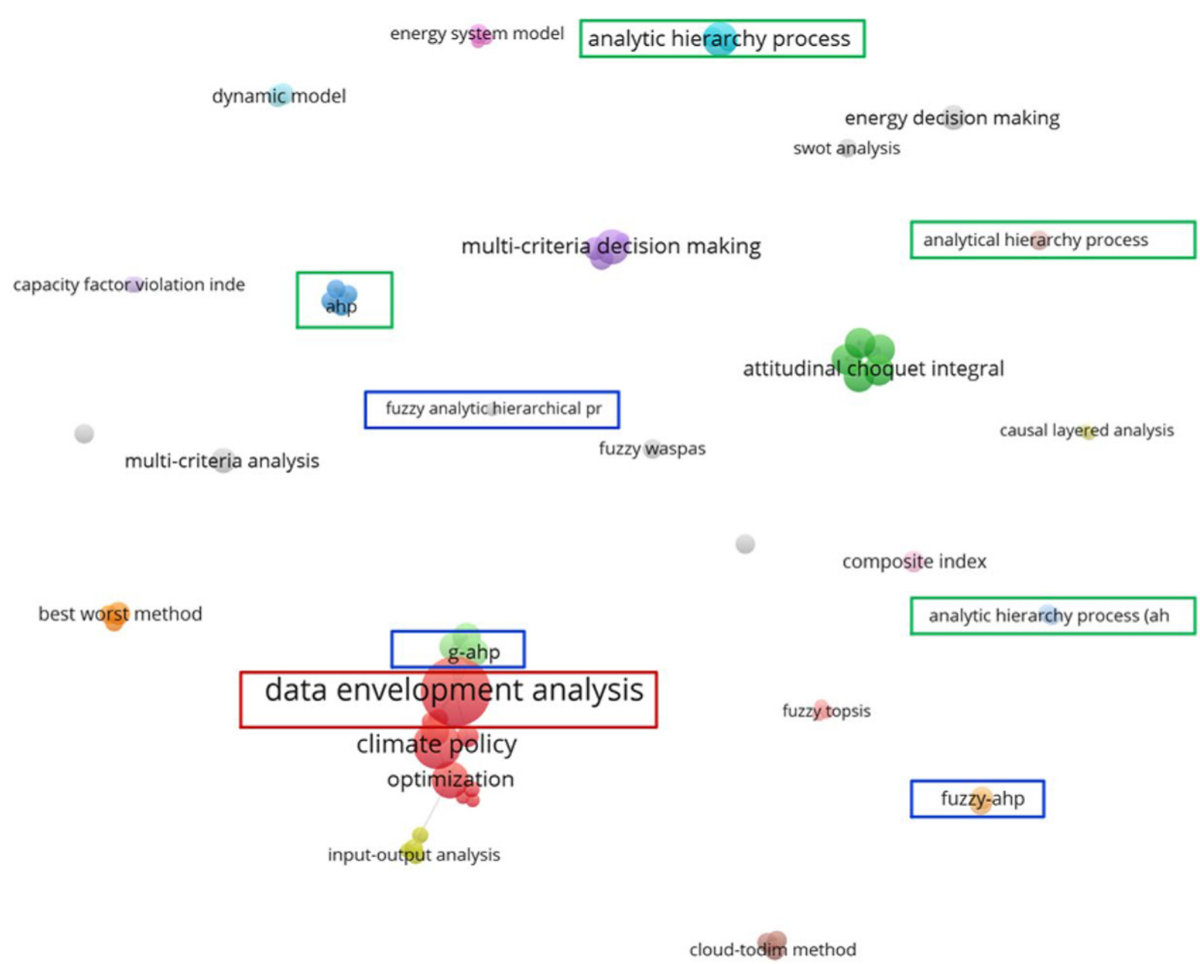

Fig. 2. MCDM techniques. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

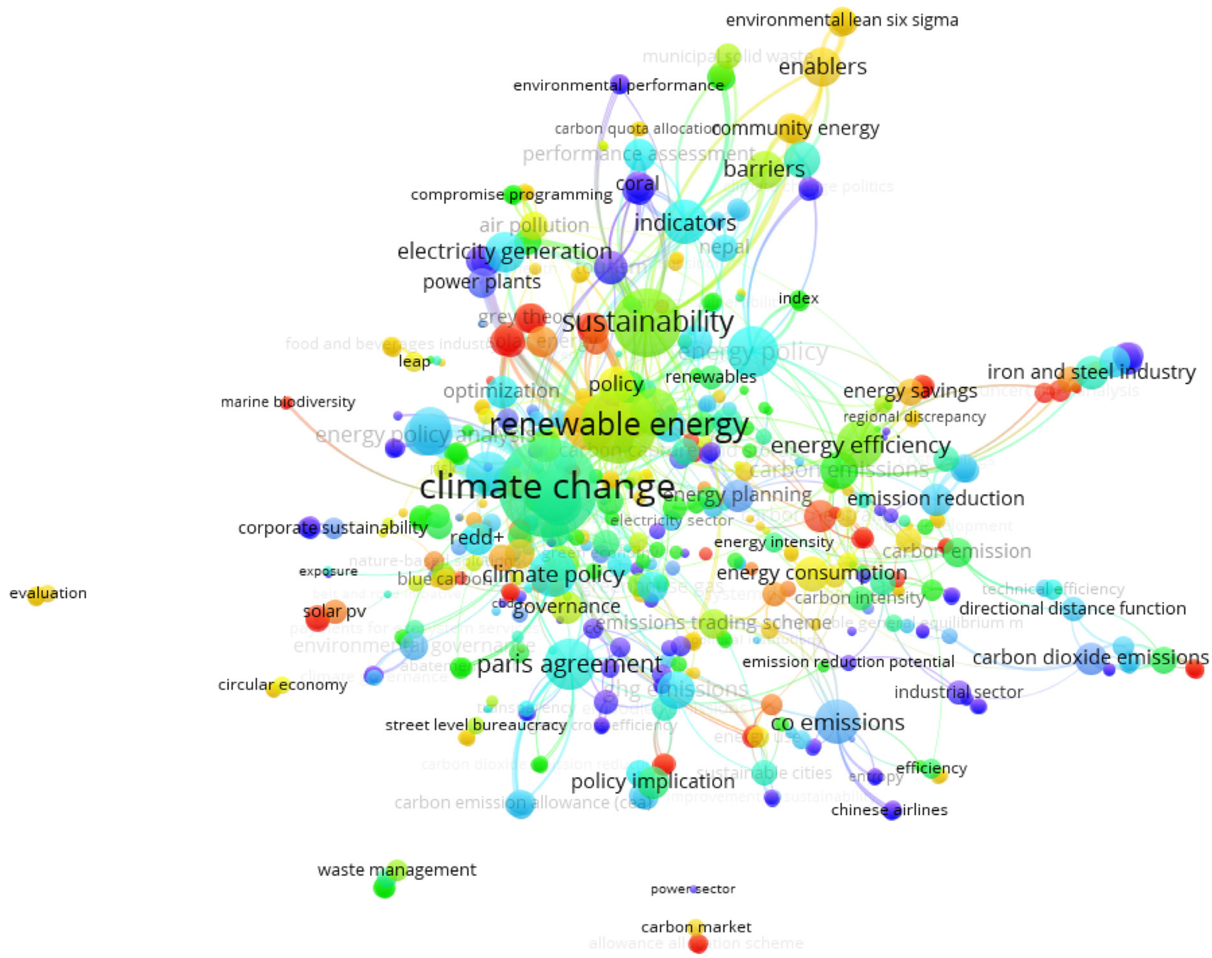

Fig. 3. Domain of applications of MCDM. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

undertaken to understand the applications of the various MCDM on climate change related projects and/or NDCs. A summary of the review is presented in Table 2.

4.1.2. NDC domains where MCDM have been applied

On processing the 464 datasets in VOSViewer and filtering the results by NDCs domains where MCDM have been applied, Fig. 3 is obtained.

Fig. 3 shows that the NDC domain where MCDM have been applied the most is climate change followed by renewable energy. It is important to note that climate change is a very generic and high-level concept which implies any green project can be considered a climate change project. Consequently, renewable energy, followed by sustainability and energy efficiency were considered the most common domains where MCDM has been applied instead of climate change as a domain. However, the diagram does not provide a context of application. Thus, some selected articles from the 464 were analysed to gain an in-depth understanding of the context of applications with regards to the NDC measures. Although the 464 articles covered the period 1987 to 2022, only selected articles from 2015 (this is chosen to coincide with the year NDCs were instituted) were examined to identify their applications as shown in Table 2.

Based on Table 2, the literature revealed a paucity of research that explicitly stated it was exploring MCDM applications on NDC projects. Only research by Mahapatra et al. [34], Fang et al. [35], Bolaños et al. [36] and Barbosa et al. [37] explicitly stated their application of MCDM on NDC projects or measures. Although most other articles did not explicitly mention NDCs they did investigate how MCDM methods can be applied to eco-friendly or climate change-related projects. Inspite of this, they were projects that if implemented can lead to a reduction in greenhouse gases or any other environmental impact. The articles were classified under the section “other projects in Table 2”. On examining the different studies, it emerged that, the strengths, and weaknesses of each MCDM are partly related to the domain of application. Ghaleb et al. [58] have corroborated this where on applying AHP, TOPSIS and VIKOR on manufacturing process, the TOPSIS and VIKOR approaches were better suitable to the problems of manufacturing process selection than AHP. Lamelas et al. [59] proved AHP was far better than other MCDM techniques for land-use management of Zaragoza city in Spain. AHP is one of the most preferred MCDM techniques used in planning energy projects [60]. Several studies demonstrate the relevance of this method in energy planning projects with renewable energies. In Hernández et al. [61], a hierarchical methodology for the integral net energy design was developed; and in Ahmad and Tahar [62] AHP was used to select renewable energy sources.

Mahapatra et al. [63] used a fuzzy analytic hierarchy process (FAHP) to evaluate the contribution of freight transportation towards India’s Nationally Determined Contributions (NDCs). Wei [64] used an integrated MCDM method combining benefits, opportunities, costs, risks (BOCR) theory, AHP, interval type-2 fuzzy numbers (IT2FNs), and TOPSIS to evaluate the sustainability of Photovoltaic poverty alleviation project in order to improve the poverty alleviation performance and efficiency.

Wang et al. [65] used a multi-criteria decision-making (MCDM) model, fuzzy-AHP (FAHP), and weighted aggregated sum product assessment (WASPAS) in evaluating potential wave energy stations at the Vietnamese coastline. Yanar and Demir [66] used MCDM methods to evaluate the carbon dioxide reduction methods in the global automotive industry.

Table 2
MCDM methods application on NDC and other projects.

Application area	Considered problem/Decision context	MCDM methods	Reference
Transport	Contribution of freight transportation towards India's NDCs [India]	Fuzzy AHP	Mahapatra et al. [34]
Carbon emission	Assessment of carbon emission allowance allocation to help China meets its China's INDCs [China]	DEA	Fang et al. [35]
Forestry	Prioritisation tool for climate change adaptation measures in the forestry sector [Nicaragua]	AHP	Bolaños et al. [36]
Sugar-energy	The study integrates SWOT with surveys (Delphi) and AHP to identify challenges, opportunities, and the most adequate strategies and public policies for the main companies in the sugar-energy sector.	SWOT, AHP	Barbosa et al. [37]
	Other projects		
	Prioritisation of NAMAs	MCDM, no specific MCDM mentioned	Sharma et al. [38]
Power generation	Analysed the predominant factors related to coal-based power generation in Bangladesh.	AHP	Zaman et al. [39]
Sustainable construction management	Choose the best option for sustainable construction management	AHP	Erdogan et al. [40]
Green building	Green building material selection	AHP	Khoshnava et al. [41]
Sustainable investment	Selection of sustainable investment	TOPSIS	Escrig-Olmedo et al. [42]
Wind power	Offshore wind power station site selection	PROMETHEE	Wu et al. [43]
Solar power	Optimal site selection for parabolic trough concentrating solar power plant	PROMETHEE	Wu et al. [44]
Solar power	Evaluation of solar power plant location alternatives	Fuzzy AHP-PROMETHEE II	Funda and Zeki [45]
Agriculture Forestry	Classification of agricultural crops Prioritisation of watershed reforestation	VIKOR Fuzzy VIKOR	Deepa and Ganesan [46] Sunarsih et al. [47]
Hydro power	Selection of best location for small hydro power project using AHP, WPM and TOPSIS	AHP, Weighted product method, TOPSIS	Rana and Patel [48]
	Select the best and sustainable methods among the existing technologies at various stages in the production process of non-centrifugal sugar (NCS)	fuzzy AHP, ELECTRE I	Srinivas et al. [49]
Solar power	Determination of suitable areas for solar power installation in Vietnam	DEA, Grey AHP (G-AHP), Grey TOPSIS (G-TOPSIS)	Wang et al. [50]
Waste-to-energy	Select a satisfactory site for waste-to-energy (WtE) project to make a win-win situation under a low-carbon perspective has become the concern of many researchers.	AHP, fuzzy linguistic term set (HFLTS)	Gao et al. [51]
Solar energy	Evaluation of solar farms locations in Morocco	AHP	Mensour et al. [52]
Waste-to-energy	Selection of appropriate WtE technology considering both subjective perspective of decision-maker and objective evaluation of the actual performance metrics of each alternative	Fuzzy-AHP, Fuzzy-Entropy and Fuzzy-Multi-Objective Optimisation	Alao et al. [53]
Biomethane in the transport sector	The study uses SWOT-AHP to analyse the strengths, weaknesses, opportunities and threats (SWOT) of biomethane in the transport sector.	SWOT, AHP	D'Adamo et al. [54]
Solar PV and CSP	The AHP and Weighted Sum Average approaches have been applied in the ArcGIS Pro environment to estimate solar Photovoltaics (PV) and Concentrated Solar Power (CSP) systems potentials at the national and regional levels in Ghana.	AHP	Mary [55]
Thermal, gas, nuclear, solar, wind, biomass, and hydro energy	Fuzzy AHP method is applied to prioritise sustainable energy alternatives (thermal, gas, nuclear, solar, wind, biomass, and hydro energy).	Fuzzy AHP	Saraswat and Digalwar [56]
Green infrastructure	The evaluation and prioritisation of alternative solution strategies for green infrastructure development through AHP and Fuzzy Weighted Aggregated Sum Product Assessment (WASPAS) concludes the strategy of green infrastructure (GI) in urban areas as the best strategy to develop GI in China	AHP and Fuzzy WASPAS	Wang [57]

Tscheikner-Gratl et al. [67] compared five available MCDM methods (ELECTRE, AHP, WSM, TOPSIS, and PROMETHEE) for the application in an integrated rehabilitation management scheme for a real-world case study and analysed them with respect to their suitability to be used in integrated asset management of water systems. The result revealed that simple methods such as the AHP gave results like the ones obtained with the complex outranking method PROMETHEE. Obviously, the main advantage of the AHP is its simplicity and ease of understanding by people who are not familiar with the multi-criteria decision support methods [59]. As argued by Algarín et al. [60], the AHP is a flexible and intuitive method for decision makers, which also calculates the consistency of the judgments of the experts. Based on simplicity and

Table 3
Common MCDM tools used on NDC projects.

Country	Adaptation or Mitigation	Year	Sensitivity analysis or not (Yes = Y, No = N)
Benin	Mitigation	2020	Y
Burkina Faso	Mitigation	2018	N
Burundi	Mitigation	2018	Y
Central African Republic	Mitigation	2020	Y
Chad	Adaptation	2021	Y
Côte d'Ivoire	Mitigation	2013	Y
Djibouti	Mitigation	2020	Y
Eswatini	Adaptation	2016	Y
Ghana	Adaptation	2012	Y
Guinea	Adaptation	2019	Y
Kenya	Mitigation	2013	N
Liberia	Adaptation	2019	Y
Madagascar	Adaptation	2020	Y
Malawi	Mitigation	2020	Y
Mali	Mitigation	2012	N
Mauritius	Mitigation	2012	Y
Morocco	Adaptation	2012	Y
Niger	Mitigation	2020	Y
Rwanda	Adaptation	2012	N
Rwanda	Mitigation	2012	N
Senegal	Adaptation	2012	Y
Seychelles	Adaptation	2017	Y
Sudan	Mitigation	2013	N
Tanzania	Adaptation	2016	N
Togo	Mitigation	2016	N
Tunisia	Adaptation	2015	Y
Uganda	Adaptation	2020	N
Zambia	Mitigation	2013	N
Bhutan	Adaptation	2013	N
Fiji	Adaptation	2020	Y
Georgia	Mitigation	2012	N
Indonesia	Adaptation	2012	N
Jordan	Mitigation	2016	Y
Laos	Mitigation	2013	Y
Lebanon	Adaptation	2012	Y
Myanmar	Mitigation	2020	Y
Nepal	Mitigation	2021	Y
Pakistan	Adaptation	2016	N
Sri Lanka	Adaptation	2011	Y
Thailand	Mitigation	2012	Y
Vanuatu	Mitigation	2020	Y
Vietnam	Adaptation	2012	Y
Cook Islands	Mitigation	2020	N
Ukraine	Adaptation	2019	Y
Moldova	Mitigation	2012	Y
Grenada	Mitigation	2018	N
Belize	Adaptation	2017	N
Guyana	Adaptation	2016	Y
Trinidad and Tobago	Mitigation	2021	N
Haiti	Mitigation	2020	Y

the fact that the application of AHP on environmental problems has yielded similar results like other complex methods like PROMETHEE, these authors further undertook a detailed study of its application on NDC projects.

4.2. Findings from grey literature: Evidence from practice

The output from reviewing the TNA database is presented in Table 3.

The 50 countries with first TNA reports are in the first column. The TNA database is designed to allow for easy filtration of its content to classify the reports into mitigation or adaptation. The search function was used to filter and classify the reports and after that the authors browsed the reports to confirm whether it was a mitigation or adaption report. The output is in the 2nd column. The years of publications of the reports is shown in the 3rd column. Of the 50 countries, only 32 (64%) did conduct sensitivity analysis on the agreed prioritisation criteria. Furthermore, the review of TNA reports revealed that decision-makers were using simplified MCDM tools instead of more sophisticated and more elaborate and proven scientific ones. In fact, all the 50 countries used simplified MCDM and so it was not necessary to dedicate a column for this. The simplified MCDM was a kind of midway between the more established approaches, e.g., AHP and the very low level MCDM often referred to as intuitive decision-making tools [68].

4.3. Framework for the implementation of MCDM tools in NDCs

4.3.1. Critical appraisal of AHP in prioritising NDC projects

From an academic perspective, Fig. 2 suggests AHP is the most widely used MCDM applications on NDCs. Therefore, a detail exploration on how AHP can be used in prioritising NDC projects will be examined in this section. AHP is one of the main mathematical models currently available to support decision theory. To maintain simplicity, the underpinning mathematical models and details of the method will not be examined here. That notwithstanding, the goal of this section is to present, discuss, and apply the principles and techniques of AHP in the prioritisation and selection of NDCs measures. To ensure proper implementation and participation of stakeholders with little or no experience in the method, areas where they can contribute will be emphasised.

Like most MCDM methods, one of the most important steps of AHP is the development of a hierarchical structure. This is a structure with the goal at the top level, the attributes/criteria at the second level and the alternatives at the third level. The three layered (goal, criteria, alternatives) structure can be adapted or tailored to meet a particular problem domain. Concerning NDC projects, a sector or sectors should be prioritised in the first instance followed by the prioritisation of projects. This means two goals should be set. The first is to identify the most important sector(s) and the second is to identify the most important project (s). This means corresponding double set of criteria and double set of alternatives will have to be included in the hierarchical structure. Taking these into account, the AHP framework proposed by Saaty [69] is modified for NDCs and presented in Fig. 4.

The focus group, in-depth interviews and AHP are combined as the components of the NDC selection framework. The focus group and in-depth interviews are used for obtaining strategic information about the future development of NDC projects from a group of experts and policy-makers with knowledge of climate change projects and policies of the given country. The AHP is used for evaluating the impacts of NDCs on any country's strategic objectives with regards to climate change adaptation and mitigation. Given climate change mitigation is about limiting emissions and adaptation is about coping with impacts, the criteria are different in some instances. For example, the criteria for adaptation are likely to be about vulnerability compared to those of mitigation. Ideally, the application of AHP in NDCs should be divided into 2 – adaption and mitigation to consider the different criteria. However, variables will be used to represent the criteria, only one generic framework for the implementation of AHP on climate change mitigation/adaptation NDC projects will be examined.

4.3.1.1. Selection and prioritisation of NDCs mitigation/adaptation sectors. This is about the activities related with the NDC adaptation sectors captured in the lower part of Fig. 4 ("selection/prioritisation of sectors"). The activities for the identification and selection of sectors are examined in the ensuing paragraphs.

Step 1. Identification of the decision problem: Decision makers must completely be aware of the decision problem. It is important to identify, understand and define the problem before deciding. In other words, it is important to identify the context in which a particular adaptation decision needs to occur. Based on an understanding of the context the main stakeholders that need to be involved; the outputs of the AHP process and their use; and the different constraints, legal requirements, champions, synergies with existing priorities or plans that need to be considered must be established. Common literature sources such as national and international policy documents can be a good point to

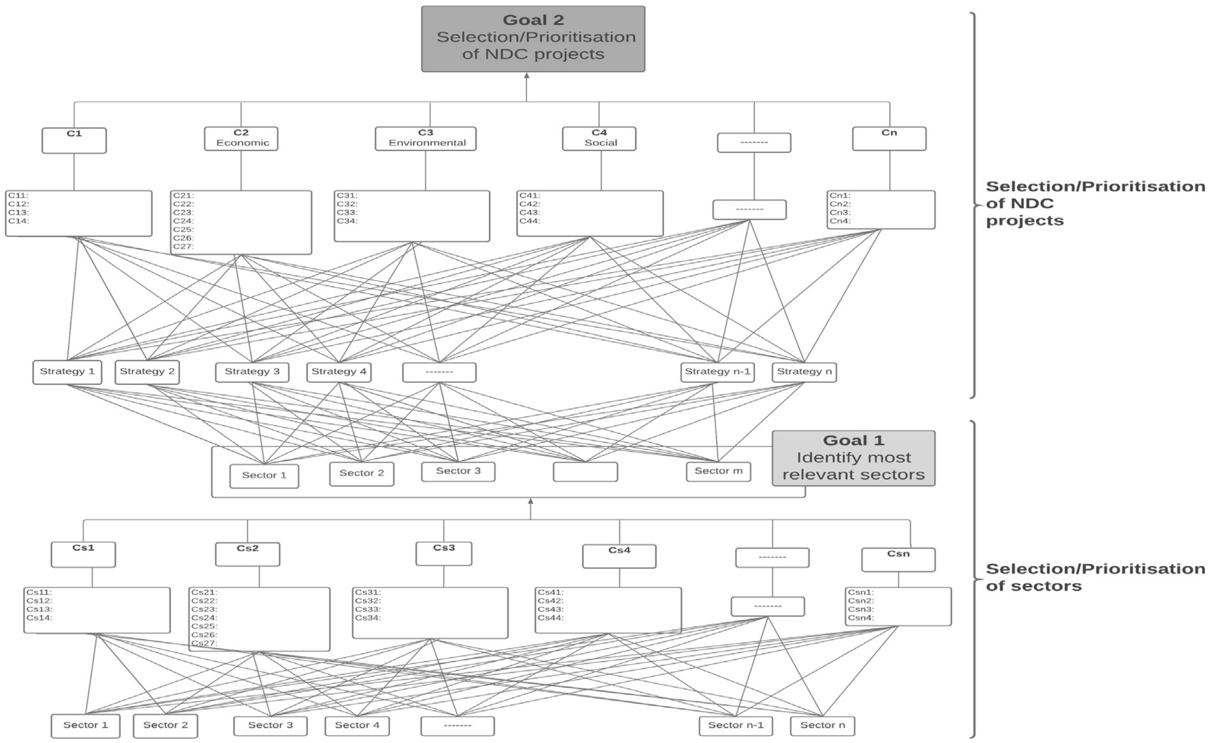

Fig. 4. Modified AHP method framework for selecting NDCs.

commence from to understand the context. Some examples are Agenda 2063, Intergovernmental Panel on Climate Change reports, The Paris Agreement, Sustainable Development Goals, etc.

Step 2: Sector prioritisation: Based on AHP captured in Fig. 4, three main activities should be undertaken here. These are goal setting, criteria identification, the identification, and prioritisation of the sector(s).

Sector identification: It is important to have a clear picture what is the intended target or what should be achieved at the end of the AHP process. The aim is to identify and select the most important sectors that can help countries achieve their NDCs and other sustainable development goals. In most cases, the goal(s) already exist in government policy documents, national and international strategic reports, INDCs, etc. Nonetheless, the stakeholders involved in the NDC should brainstorm and agree on the most important strategic objective(s) of the country. For example, the government of Gabon stated in its NDC that one of it aims to achieve at least 50% reduction in emissions compared to the business-as-usual scenario in 2025 [70]. Based on this, a preliminary list of sectors that can aid in the achievement of this reduction target is drawn. The drawn up list should contain sectors identified as Sector 1, sector 2, sector 3, Sector 4,…… Sector n as shown in Fig. 4. With limited resources and conflicting interest, it is important to establish a list of criteria for selecting and prioritising the various sectors.

Selection of criteria for prioritisation of sectors: It is important to establish criteria for prioritisation of the sectors that can contribute to NDC adaptation/mitigation measures. This is due to the limited resources and the criticality of some sectors concerning NDC climate change adaptation. A good starting point is to conduct a bibliographic review related to the different sectors. Key government strategic documents should be consulted to identify policies vis-à-vis the different sectors. Some of these documents can provide clues about the criteria that can be used in prioritising the different sectors. Based on this a preliminary list of sub-criteria is prepared and grouped into categories. To establish the final sub-criteria, a group of experts from different strata of the community (Academics: Researchers, university professors. Regulators, Non-governmental organisations: environmental protection organisations and community organisations belonging to rural communities) should be consulted. Various techniques including surveys and focus groups discussions should be used to engage the different stakeholders. The different criteria agreed on by the different stakeholders are identified as Cs1, Cs2, Cs3,….Csn. Other established criteria for analysing adaptation have been examined in Dixit and McGray [71] and Weiland and Tröltzsch [72]. The sub-criteria for the various sectors are also determined. For example the sub-criteria for main criteria Cs1 are Cs11, Cs12, Cs13…. Cs1n. Through any of the survey methods (e.g., in-depth interviews) weights are attributed to the different sub-criteria. Once the weights are determined, the whole AHP process can now be implemented which will lead to the ranking of the different sectors (Sector 1, Sector 2, Sector 3,…. Sector m) enabling us to achieve the set goal — identification of the most relevant sector, captured as **Goal setting (Goal 1)** on Fig. 4. It is important to note that $m \leq n$, where both m and n are positive integers which means that the number of sectors (denoted by m) agreed on by stakeholders involved could be less than or equal to the number of sectors (denoted n) that they started off with.

In most cases, the sectors for adaptation/mitigation are well-known, and therefore a detailed AHP technique may not be needed for their prioritisation. This means the sector (s) are chosen based on well-known information or through other means such as brainstorming with various stakeholders.

4.3.1.2. Selection and prioritisation of NDC mitigation/adaptation measures or projects. This is about the activities related with the NDC adaptation measures captured in the upper part of Fig. 4 ("selection/prioritisation of NDC projects"). The activities for the identification and selection of NDC projects are examined in the ensuing paragraphs.

Step 1. Identification of the decision problem: Decision-makers must completely be aware of the decision problem. It is important to identify, understand and define the problem before deciding. This process must be able to identify the root causes by carefully limiting assumptions. For the problem to be well-defined and the root causes clearly identified,

Table 4
Comparison scale of analytic hierarchy process.

Numerical rating	Definition
1	i is equally important to k
3	i is slightly more important than k
5	i is strongly more important than k
7	i is very strongly more important than k
9	i is extremely more important than k
2,4,6,8	Intermediate
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity k, then

the main stakeholders need be involved. In the case of adaptation some examples of decision-makers are experts from the civil societies, government officials and vulnerable people or those likely to be impacted by climate change should no mitigation measures be put in place. In most cases, national and international organisations already have some information that can inform the identification of the decision problem. For example, the national vision for Nigeria's urban sectors that all its cities should reduce their carbon footprint by 50% by 2050 and move towards becoming carbon-neutral and climate-resilient at the end of the century [73].

Step 2. Establishing the problem hierarchy: Based on the decision problem, the main goal and the objectives should be defined. The goal is located at the top-level; at the second level are the criteria, which can be divided into sub-criteria according to the level of detail required. The criteria are defined as a set of attributes that allow the decision maker to set preferences. All the alternatives are in the last level, which are the possible solutions to make the final decision. In relation to Fig. 4, the goal is Goal 2, the main criteria (C_1, C_2, C_3,…Cn), the sub-criteria are for example C_{11}, C_{12}, C_{13}… that belong to the main criteria C_1. The alternatives are the strategies (Strategy 1, Strategy 2,…… Strategy n). These strategies are the NDCs adaptation actions or measures.

Step 3. Weightings of criteria, sub-criteria and indicators: The weights of the criteria are assigned accordingly and a pairwise comparison is then implemented. A numerical value must be assigned to all criteria according to the preferences of the decision maker. In Saaty [74], the scale presented in Table 4 was proposed, and its effectiveness has been validated by numerous researchers with a theoretical support related to the best scale to compare homogeneous elements.

With the scale proposed by Saaty, the decision maker must perform the paired comparison, set priorities, and assign relative weights. A matrix A of paired comparisons must be developed where the terms a_{ik} ($w_{\mathrm{i}}/w_{\mathrm{k}}$) are the result of the comparison between the elements i and k. The opposite values of the comparisons are placed in the a_{ki} position of A as can be seen in Eq. (1).

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix} \tag{1}$$

These pair-wise comparisons result in a (NxN) positive reciprocal matrix A, where the leading diagonal $a_{ik} = 1$ and reciprocal property $a_{ki} = (1/a_{ik})$, i, $k = 1 \ldots n$ assuming: if indicator i is 'p-times' the importance of indicator k, then, necessarily, indicator k is '$1/p$-times' the importance of indicator i. The normalised weight of each indicator is determined by dividing the indicator's relative weight by the sum of relative weights in ith column, and then averaging the values across the corresponding kth rows (i representing the criteria of an object k); this average in the column is the normalised weight vector W containing weights (W_{ji}) of the selected indicators.

Table 5
RI.

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

RI: Random consistency index.
In addition, Saaty defines the consistency ratio (CR) = CI/RI. If CR ≤ 0.1, then the results are consistent. When RC > 0.1, the data are inconsistent and therefore the decision maker judgments must be reviewed.

Step 4: Definition of priorities (ranking): Based on the input from criteria weights and scores of criteria, the global weight for the criteria, sub-criteria and alternatives is obtained from the multiplication of the local weight (w_{i}) by the global weight of the immediately superior criterion. The sum of the global weights of the alternatives in relation to each criterion is the mechanism to obtain the evaluation of all possible alternatives. After the evaluations, a decision-making tool can be applied to rank the alternatives or allowing choosing a more promising alternative from a set of defined alternatives.

Step 5: Sensitivity Analysis: An advantage of the AHP is it allows confirming the consistency of the judgments through a sensitive analysis. In the case of problems of consistency with the decision maker, a matrix R is generated by performing a perturbation in the matrix A in such a way that: R*w = λmax*w; where w is the auto-vector of the comparison matrix and λmax is the dominant auto-value of the same matrix.

Consistency index (CI) is used to measure consistency, which is mathematically defined as CI = (λmax − n)/(n − 1). To verify the CI values, a comparison is made with the random consistency index (RI). This parameter is defined as an average of the CIs of a large set of matrices with random inputs [75] Table 5.

4.3.2. Simplified MCDM for NDC projects

Upon, review of grey literature, it emerged that a simplified MCDM is being used to prioritise various NDC measures. This is presented in the ensuing sections. Given the simplistic nature of MCDM, in its presentations, areas that can be strengthened to ensure it captures enough data for the prioritisation process have been highlighted.

Step 1: Identification of Sectors and technologies: This step made it possible to identify and select the technologies to be evaluated on the basis of an examination of the existing planning documents, relying on the methodological guides for the Evaluation of Technological Needs, the database of descriptive sheets of the technologies and other sources such as Climate Techwiki, and the Climate Technology Center and Network (CTCN). This step led to the preparation of a list of technologies for each sub-sector and technical sheets to be shared with the participants.

Step 2: Establish the prioritisation criteria: This step aims to identify criteria which are performance measures by which technologies are evaluated. The identification of criteria is a procedure requiring brainstorming or other research methods on possible criteria. A crucial point to note is the fact that in this step points of views of interest groups are considered or taken into account while ensuring that the number of criteria is as low as is compatible with taking a well-founded decision. This procedure requires the grouping of criteria into categories and sub-categories for evaluating the performance of the different technologies.

Step 3: Establish the weights of the various prioritisation criteria: Once the criteria are defined, reorganised and validated by the participants (see step 2), the criteria are weighted. The allocation of weights was based on the importance given by the participants to the different criteria. This importance is determined by development and climate change priorities at national and sectoral levels. After verification, the assigned weights are validated by all the participants. The weights can be on a scale of 0 to 1 or 1 to 100 or any other agreed scale.

Step 4: Scoring technologies according to the different criteria: This step aims to score the technologies on an agreed scale. The members of each group that should have been constituted from the different interest groups come to a consensus around a particular score for each technology on the respective criterion. The scoring of each technology against each criterion is often done on a scale of 0 to 100, with 0 being the least preferred technology and 100 being the most preferred technology.

Step 5: Combining Weights and Scores by Multiplication: The weights and scores are combined by multiplying each score with the weight of the respective criterion.

Step 6: Presents the aggregated total score results for each technology: This step aims to rank the technologies in order of priority according to their score in relation to the criteria and the weight assigned to each criterion according to the participatory process described above. Technologies are ranked from most preferred (the one with the highest weighted relative total score) to least preferred (the one with the lowest weighted relative total score).

Step 7: Sensitivity analysis: Sensitivity analysis is conducted to determine how target variables, i.e., ranking of the technologies (from Step 6) are affected based on changes in other variables known as input variables in this case (scores for the different technologies). Based on Table 3, only 32 (64%) of the TNA reports had conducted sensitivity analysis on the agreed prioritisation criteria.

5. Analysis and discussions

This study was driven by the fact that despite many MCDM techniques reported and recommended by researchers, there is a limited understanding of how they have been used in practice especially in NDC projects. To gain an in-depth understanding of MCDM in prioritising NDC projects, the research uncovered 3 main findings.

Firstly, this study suggests that while so many MCDM have been published in the literature they are hardly used in practice especially on prioritising NDC measures. Amongst, the MCDM, the most widely discussed in academic research is AHP while simplified MCDM is commonly used in practice. The former was the most discussed in peer-reviewed literature (Fig. 2) while the latter was common in TNA reports (See Table 3). These opposing views may be due to decision makers or practitioners doubting the usefulness of more comprehensive MCDM. In Ishizaka and Siraj [68], it was argued that many decision makers still question the usefulness of multi-criteria decision-making methods and prefer to rely on intuitive decisions.

Secondly, although MCDM techniques have been applied on so many areas. The leading areas are renewable energy, sustainability, and energy efficiency (See Fig. 3). In practice, the fact NDCs are designed to align with economic and climate change priorities of countries, means MCDM applications are likely to be more in certain domains than others. However, from an academic perspective it is imperative to expand research in MCDM applications to other areas than renewable energy, sustainability, and energy efficiency. This has the potential to inform countries that wants to implement MCDM to their specific areas of interests to meet their NDCs goals.

Thirdly, due to the complexity of NDC projects and their respective sectors, a clear framework for prioritisation of the technologies for the NDC projects is lacking. This was developed and proposed in Fig. 4. The Figure highlighted the two goals-the identification and prioritisation of sector and NDC project/measures for different countries. The framework was based on AHP and how to implement it on NDC was discussed. A simplified MCDM was also presented, and its weaknesses discussed.

6. Conclusions and recommendations

The premise of this study is that NDC projects are becoming more and more complex and yet, despite the avalanche of MCDM tools in academic literature there is little evidence of their use in practice. The complexities of the projects are exacerbated by the too many criteria which at times are conflicting upon which professionals need to exploit in making informed decisions. Building on this, a comparative analysis of single criterion and MCDM was conducted. This was followed by a review of the different MCDM and their applications on NDCs. It emerged that the most frequently applied MCDM in academic literature is AHP while simple MCDM was applied in practical NDC projects. The two methods were detailed through a framework to facilitate understanding. The first was the AHP which was modified to consider the two stage goals aimed at identifying sectors and then NDC measures (See Fig. 4). As part of the framework the implementation of the modified AHP and simplified MCDM were examined in Sections 4.3.1 and 4.3.2 respectively. The study revealed most MCDM applications were in the renewable energy sector, sustainability and energy efficiency with fewer published literature about other sectors such as forestry, land use, livestock, etc. A weakness of this study is to fact that framework consisting of two MCDM models lie at both extremes — AHP (heavy and mostly used by academics) on one extreme and the simplified MCDM (light and mostly used by professionals) on the other. Our first recommendation for future studies for researchers and practitioners is to find a balance between complex AHP in academic literature and simplified MCDM techniques that is limited in rigour and produce a more unified method for prioritising NDC projects. This will be a kind of middle ground (moderated MCDM) between academics and professionals with the potential impacts of more uptake and implementation of the moderated MCDM in practice. The study revealed sensitivity analysis was used in 64% of the simplified MCDM technique. This implies 36% may not have captured the significance or importance or weights of the different criteria in the prioritisation of NDCs Hence, our second recommendation is that organisations, governments should propose a policy explicitly stating the need to conduct a sensitivity analysis in the prioritisation of NDC measures.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

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

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