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A critical review of multicriteria decision analysis practices in planning of urban green spaces and nature-based solutions

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ABSTRACT

Green spaces and nature-based solutions (NBS) are increasingly considered by land-use planning policies to respond to the multiple challenges related to sustainable development. The multiple benefits brought by NBS make the use of multicriteria decision analysis (MCDA) essential to optimally balance their use. MCDA offers a catalog of methods allowing to structure problems with multiple objectives and to help adopt the optimal solution. However, NBS planning is a recent discipline and research is still ongoing to make this practice more common. We carried out a critical literature review on MCDA-NBS tools and practices, following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method on the Web of Science database. We selected 124 papers on the subject between 2000 and 2022. We present a state-of-the-art MCDA approach for NBS and green space planning by looking at where these practices are applied, why and how this process is conducted, and who is involved in it. We found that studies are usually conducted in the global North on a single case study with the help of experts involved in the criteria weighting phase and the help of GIS MCDA tools often integrating a direct ranking method or the AHP method.

Key words: green spaces, MCDA, NBS, planning support

HIGHLIGHTS

- MCDA methods help to consider all NBS benefits and evaluate planning alternatives.
- Environmental and social criteria are more represented than economic and technical ones.
- Stakeholders are rarely involved throughout the entire MCDA process.
- MCDA tools for NBS planning are rarely accessible and adaptable to various contexts.
- MCDA processes are mainly conducted in countries of the Global North.

1. INTRODUCTION

1.1. Background

Green spaces play an important role in urban climate adaptation. Nature-based solutions (NBS) are explicitly designed to optimise climate adaptation potential and are increasingly considered as an innovative and more sustainable alternative to current urban stormwater management by gray infrastructures (Hamouz *et al.* 2020; Steis *et al.* 2020). They are engineered green systems such as rain gardens, green roofs and walls, ponds, swales, constructed wetlands, and urban forests which allow stormwater control at source by enhancing functions of infiltration, evapotranspiration, retention, conveyance, and water quality enhancement (Kuller *et al.* 2017). Some of the primary benefits include surface water quality protection, flood reduction, and resource recovery (e.g., water reuse).

Green spaces bring many co-benefits (Dagenais *et al.* 2017; Skrydstrup *et al.* 2020) such as improving esthetics, reducing the urban heat islands effect, and increasing biodiversity. The multifunctional potential of NBS highlights the need for careful spatial planning, considering the three pillars of sustainable development: environmental, social, and economic sustainability (Dorst *et al.* 2019; Monteiro *et al.* 2020; Brasil *et al.* 2021; Goodspeed *et al.* 2022). Most studies focus on environmental aspects (e.g., biodiversity, soil recovery) and stormwater management (Meerow 2020; Monteiro *et al.* 2020), and only consider a single benefit such as water quantity control (Meerow & Newell 2017; Meerow 2019). Moreover, opportunistic NBS planning leads to unintended results that do not maximize the potential of the multiple benefits of NBS (Kuller *et al.* 2018; Li *et al.* 2020; Meerow 2020). Multicriteria decision analysis (MCDA) is well suited to counter this issue by evaluating multiple objectives simultaneously, involving multiple stakeholders and preferences, as well as technical information.

The United Nations conference on Sustainable Development in Rio de Janeiro (Brazil) on 20–22 June 2013 sparked global interest in NBS and led to numerous studies about strategic urban planning, attempting to frame this new practice (Meerow 2020; Hanna & Comín 2021). NBS in urban climate adaptation plans are also referred to as green infrastructure (GI) or blue-green infrastructure (BGI) planning, low impact development (LID), best management practices (BMP), sustainable urban drainage systems (SUDS), water sensitive urban drainage (WSUD), or Sponge City, depending on the study location (Fletcher *et al.* 2015). The term ecosystem services (ES) is also widely used in this field and refers more broadly to environmental and socio-economic benefits that any type of green space (e.g., natural forests, wetlands, grassland, or engineered systems like the ones mentioned above) can provide to the urban environment (Dagenais *et al.* 2017; Billaud *et al.* 2020). In this paper, the term NBS will be used, as it is the term used by the United Nations since the Convention on Biological Diversity COP15 in Montreal in 2022. However, we will conduct our research by considering both purposefully designed (e.g., NBS, GI, BGI) and other (covered by the concept of ES) green urban spaces to address the broad palette of these spaces.

1.2. MCDA methods and tools

MCDA is a systematic approach to incorporate multiple objectives and combine subjective preferences with objective information in order to reach a rational decision. MCDA can help decision-makers analyze a complex decision problem that involves different stakeholders. It offers a rich collection of methodologies for structuring planning problems with conflicting objectives, allowing the design, evaluation, and prioritization of decision alternatives from a multicriteria model representing stakeholders' preferences (Ferretti & Montibeller 2016; Marttunen *et al.* 2017). Obtaining subjective preferences on a problematic situation, including objective weightings, is one of the main parts of MCDA (Aubert *et al.* 2020). A participatory (Schein 2017) and constructivist (Landry 1995) approach involving stakeholders is recommended by the scientific community (Belton & Pictet 1997), because it is expected to lead to the implementation of 80% of the decisions (Nutt 1999). By 'participatory', we refer to a collaborative process in which relevant stakeholders are involved in all steps of decision-making from objective definition to alternative development and preference elicitation. By 'constructivist', we refer to a process that consists of several steps that build towards a result.

Belton & Stewart (2002) classified MCDA methods into three categories based on the type of model used (Table 1). Some methods are at the intersection of these models (e.g., the MACBETH method) (Lavoie *et al.* 2016).

1.3. Existing literature reviews on MCDA for green space planning

The content of this section is based on 28 literature review papers we found during our research related to MCDA for NBS and green space planning (see section 2.1). We summarize the main results of this analysis here.

MCDA has been a relevant tool applied in a wide range of fields in the past years, proving its value, particularly in environmental projects where multiple stakeholders and tradeoffs are at play between the economic, environmental, and social spheres (Kiker *et al.* 2005).

Since 2000, five reviews focused on the application of MCDA for forest management planning (FMP) approaches, either on the integration of ES (Uhde *et al.* 2015; Blattert *et al.* 2017), of biodiversity objectives (Ezquerro *et al.* 2016), of multiple uses (Baskent 2018), or on forest economics of silviculture (Campos *et al.* 2017). Facing complex challenges, agricultural systems have also become a topic of interest for MCDA, either in agriculture models classification (Therond *et al.* 2017), in model-based scenarios for biodiversity changes (Chopin *et al.* 2019) or in sustainability assessment methods (Soulé *et al.* 2021). Previous reviews also focused on MCDA for ES, either on current research performed in cities (Haase *et al.* 2014a, 2014b), on emerging areas of interest and related key themes (Torres *et al.* 2021), or on a specific service like decision support tools for urban heat island mitigation (Qureshi & Rachid 2021) or flood risk management (Membele *et al.* 2022; Perosa *et al.* 2022). Tradeoffs in ES also received attention in a review by Deng *et al.* (2016) where analysis

Table 1 | MCDA categories by the type of model (value measurement, aspiration, outranking) based on Belton & Stewart (2002)

Type of model	Characteristics	Method examples
Value measurement models	Numerical preference scores are synthesized to perform aggregation into preference models.	Simple multi-attribute rating technique (SMART), swing, technique for order preferences by similarity to ideal solutions (TOPSIS), ordered weighted averaging (OWA)
Aspiration models	Criterion weights are obtained from pairwise comparisons between criteria, using an eigenvector technique. Weights are aggregated to obtain the global relative weights of the alternatives describing their global preference compared to the other alternatives.	Analytic hierarchy process (AHP)
Outranking models	Preferences are obtained by asking whether the advantages of one alternative over another are sufficient to overcome its disadvantages. The degree of dominance is calculated between the alternatives, describing whether an alternative is at least as good as another.	Preference Ranking Organization Method for Enrichment and Evaluation (PROMETHEE), Potentially All Pairwise Rankings of all possible alternatives (PAPRIKA), Elimination And Choice Translating Reality (ELECTRE)

tools and approaches across spatial and temporal scales were studied, and in a review by Smyth & Drake (2021) where tradeoffs within freshwater and marine ecosystems were classified. Chatzinikolaou *et al.* (2018) proposed a review of valuation methods and tools to assess the diversity of ES values in rural landscape management through the lens of MCDA. Natural resources management has been addressed in recent reviews, for example by Cook *et al.* (2019) for geothermal power projects or by Allain *et al.* (2017) for landscape management methods covering land-use planning, ecosystem conservation, water management, and forest management. Another predominant field of application of MCDA approaches is spatial modeling in land-use planning. Yang *et al.* (2007) reviewed GIS-MCDA-based evaluation models for land-use evaluation. Legesse Gebre *et al.* (2021) studied MCDA methods for land allocation problems covering papers from agricultural, forest, ecotourism, conservation, and protected area management. Gomes *et al.* (2021) reviewed land-use changes and their impact on ES provisioning. Some reviews have a broader scope, for example, Galychyn *et al.* (2020) reviewed the scientific literature on urban metabolism considering flows of materials, energy, resources, food, and people in cities, whereas some other studies focused on a specific context review, e.g., Escobar-Camacho *et al.* (2021) who studied the threats of the marine and terrestrial ecosystems of the Galapagos.

On stormwater management infrastructures specifically, Islam *et al.* (2021) focused on the review of LID approaches and their optimization, performance, and resilience to climate change. Kuller *et al.* (2017) reviewed existing planning support systems (PSS) for WSUD using GIS and MCDA, providing a comprehensive view of the purposes of those tools and their relevance. More recently, Wu *et al.* (2020) reviewed sustainable stormwater management (SSWM) concepts in the Global North comparing eight existing decision support tools. Jelokhani-Niaraki (2021) worked on reviewing and categorizing spatial multicriteria evaluation (SME), also called GIS-based multicriteria evaluation (GME) tools and approaches, operating in a collaborative context, according to either a parallel or sequential method, including all fields not necessarily for green spaces or NBS.

Although MCDA in NBS planning is increasingly recognized, no study was found that aimed to comprehensively review MCDA for NBS planning in terms of (i) method, (ii) involvement of stakeholders, (iii) criteria, and (iv) tools used in the studies. NBS and green space planning is a spatial problem and the use of geographic informatic systems (GIS) such as ArcGIS (Esri) or QGIS can assist the decision process. By coupling MCDA and GIS, we can transform and combine geographical data and value judgements expressed by the different criteria. GIS-MCDA applications are increasingly used in NBS and green space planning studies and are thus given special attention to support decision-makers and planners in their use.

1.4. Aims and objectives

NBS and green space planning remain underemphasized in planning policies (Langemeyer *et al.* 2016; Hanna & Comín 2021). Decision-making processes around policies and governance for NBS and green space planning leave room for improvement (Langemeyer *et al.* 2016). More specifically, decision-makers have expressed a need for knowledge, methods, and tools for planning and design of NBS (Ferreira & Santos 2021; Mubeen et al. 2021; Voskamp et al. 2021). They lack appropriate guidelines (Voskamp et al. 2021), as well as training and expertise in strategic urban NBS planning, resulting in the adoption of sub-optimal approaches (Albert et al. 2021; Voskamp et al. 2021). This systematic literature review thus aims to provide a comprehensive picture of MCDA practices for NBS and green space planning. The objectives are to analyze:

1. Where MCDA is applied, by looking at the case study location and the number of case studies conducted.
2. Why this process is conducted, by looking at the problem definition, the criteria selected, and the results obtained.
3. Who is involved in the process, by looking at the stakeholder type and engagement.
4. How this process is conducted, by looking at the MCDA methods and tools.

This work aims to provide knowledge on MCDA practices for NBS and green space planning and to give decision-makers tools and recommendations for their applications. The review will also highlight gaps and limitations in MCDA practices and will provide leads for future research.

First, the research approach is presented, followed by a presentation of the results, a discussion regarding the study's objectives and a section with recommendations for future work. In this paper, an NBS-MCDA 'tool' refers to any software, model, module, application, or method providing assistance with MCDA-based planning of NBS or green spaces.

2. RESEARCH APPROACH

2.1. Literature selection

We conducted this literature review following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method developed by Moher et al. (2009). This method consists of four main steps (Figure 1):

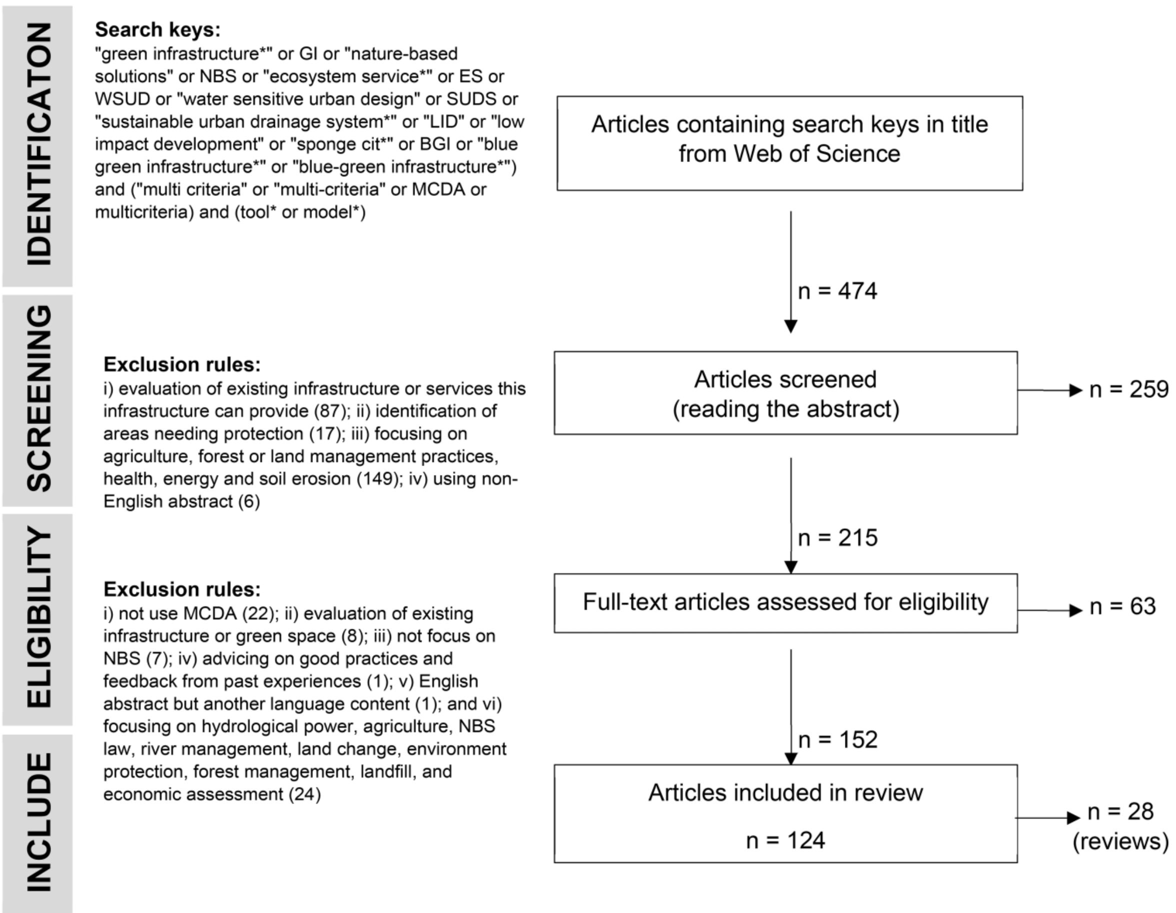

Figure 1 | Literature review method flow diagram, following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis; Moher et al. (2009)).

(i) defining and specifying the search key words and the parameters of the analysis, (ii) reading the abstract to select articles to be considered for the analysis and using inclusion and exclusion criteria, (iii) reading articles to refine the selection and extracting relevant information using predefined parameters, and (iv) synthesizing results for analysis. Using Web of Science, we conducted our literature search on 1 September 2022 and searched for papers published between 2000 and 2022.

We considered any type of urban green space and infrastructure, whether intentionally created to provide ES (e.g., LID, WSUD, NBS) or not (e.g., parks, forests, natural wetlands), using MCDA as the strategic planning tool. In order to cover this broad palette of green urban spaces, we included terminologies related to constructed green spaces with the purpose of climate adaptation (i.e., NBS, GI, WSUD, SUDS, LID, BGI) and other green spaces (covered by the search term ES). As supplementary material, we provided the research iterations, the final research formula, the 474 returned papers, the exclusion criteria for abstract screening and the exclusion rules for full-text screening. We analyzed literature reviews (28) separately (see section 1.3). The final number of articles included in this review is 124.

We performed an analysis of the 124 papers using a spreadsheet, following the framework on ecosystem service assessments and land-use planning developed by Langemeyer *et al.* (2016). We adopted this framework because it was specifically developed for MCDA approaches in the green space planning process instead of the framework of Belton & Stewart (2002) which focuses on the general MCDA process. The adopted framework specifies six key elements (problem definition, stakeholder analysis and engagement, alternative definition, criteria definition, criteria weighting, and alternative prioritization), each explained below, in section 2.2. We also collected statistics on the year of publication, and the geographical location of the authors and the case study.

2.2. Analysis

The framework by Langemeyer *et al.* (2016) helped to select the relevant data for the analysis and to classify them according to the six key elements (problem definition, stakeholder analysis and engagement, alternatives definition, criteria definition, criteria weighting, and alternative prioritization). We have slightly modified this guide by further developing the 'stakeholder analysis and engagement' element, combining the 'criteria weighting' and 'alternative prioritization' elements, and adding a 'results' analysis element. For a more in-depth analysis, we used the work of Sarabi *et al.* (2019) and Skrydstrup *et al.* (2020), which present an analysis of relevant stakeholders to consider for green space planning. Skrydstrup *et al.* (2020) also present an analysis of relevant criteria to consider for NBS and green space planning.

The first element, the problem definition, describes the scope (assessment, investment, selection, prioritization, etc.) and the scale. We classified scale into national (e.g., country), region, basin, local (e.g., city, municipality, metropolitan area) and site (e.g., lot).

The second element, stakeholder analysis and engagement, refers to the type of participation that stakeholders make during the process (workshop, interview, survey, etc.). In this element, we also specified how criteria were selected: (a) defined by the research team, (b) elicited by expert(s) or (c) elicited by stakeholders. We organized the processes of stakeholder engagement based on the moments of involvement: problem definition, alternative definition, criteria definition, criteria weighting, and alternative prioritization, based on the elements provided in Langemeyer *et al.* (2016).

The third element, alternatives definition, specifies whether a paper describes (a) an evaluation of alternative policies, infrastructures, or management practices or, (b) a selection of geographical sites (i.e., GIS application).

The fourth element, criteria definition, provides an analysis of the selected criteria in the studies. We used the framework presented by Skrydstrup *et al.* (2020; Figure 5), which classifies criteria following the United Nations' sustainability aspects (environmental, economic, social, and technical) similar to most papers evaluated in our literature review. While criteria classification is often based on the type of ES they provide (regulating, provisioning, cultural services), we opted to go for the above-mentioned framework for its understandability for lay people and the application to the reviewed literature. Besides the class of criteria, we also assessed the number of criteria considered in the studies.

The fifth element, criteria weighting, refers to the MCDA process, and includes both the aggregation rules used to calculate the performance of the alternatives to reach the objectives and the MCDA methods applied for preference elicitation, i.e., regarding the relative importance of the objectives. Those aggregation rules either come directly from the MCDA method (e.g., rank and prioritize one alternative with a pairwise comparison using the AHP method) or using aggregation methods, especially in the case of GIS-MCDA. Langemeyer *et al.* (2016) identified two different types of aggregation that are the most used in studies: linear or non-linear aggregation (i.e., the sum of all normalized values) and the ideal point approaches (i.e., the sum of normalized differences between the actual and an ideal performance on the criterion) (Langemeyer *et al.* 2016). Regarding MCDA methods, we used the three categories and the accompanying methods by Belton & Stewart (2002), provided in Section 1.2. We furthermore look at the method used to create value functions, used to compare criteria on a common scale.

We have added a sixth element that analyses the type of results obtained from the studies (e.g., scores, maps).

We recorded the year of publication and compared the geographical location of the authors and the geographical location of the case study. We did not only consider the geographical location of the first author but all geographical locations represented by the authors, as there was a notable diversity in their location. We counted a location only once when an article was authored by several researchers from that location. We considered decision-aid tools, selecting MCDA tools specifically developed to assist the application of MCDA methods and other tools which integrate MCDA to generate alternatives (e.g., GIS tool with MCDA plug-in).

3. RESULTS

3.1. Date

While our search window spanned from 2000 to 2022, we found no papers dating before 2010. The number of publications increased recently, with 80% of papers published between 2016 and 2022. It shows that MCDA for NBS planning is a recent topic of interest to the scientific community (Figure 2).

3.2. Location

We evaluated the location of the authors and case studies separately, as we found no clear relation between them. For example, almost half (48%) of the studies are conducted by authors in Europe but only 30% of the case studies are in Europe (Figure 3). Moreover, most papers (84%) are based on a single case study, with only 16 papers considering multiple case studies.

The research is mainly conducted in Europe, followed by North America, Oceania, Asia, South America, and Africa. Most case studies were conducted in Europe, followed by North America, South America, Asia, Africa, and Oceania. Regarding countries, the USA itself counts 49 case studies representing 25%, followed by Italy (9%), Spain (8%), and China (6%).

3.3. Process

Statistics on the reviewed papers with respect to the six key elements of the Langemeyer *et al.* (2016) framework (section 2.2) are summarized in Tables 2 and 3.

We found that 52% of the papers use the term ES, ecosystem services. The terms GI, LID, NBS, SUDS, and SUDS are less present and articles do not usually specify the technologies considered (e.g., green roof, rain garden). There are an equal number of papers evaluating alternative policies, plans, or management practices

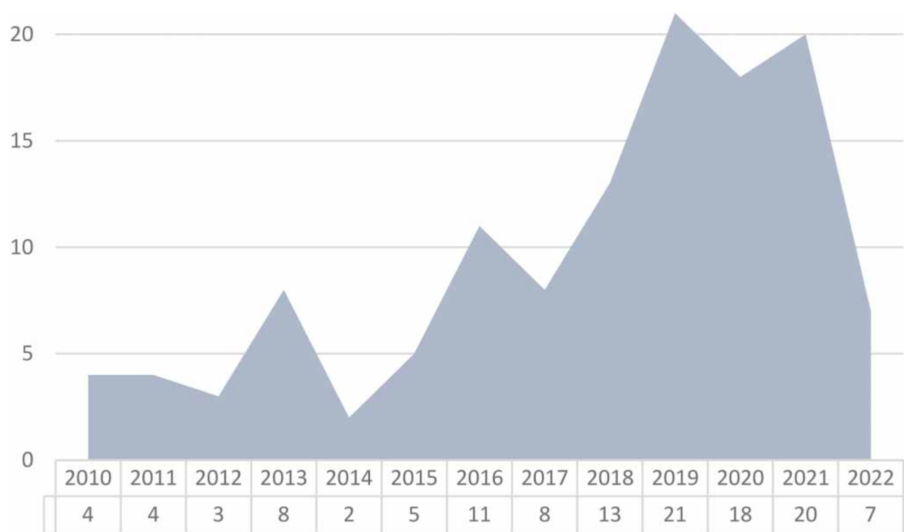

Figure 2 | Number of papers by year of publication.

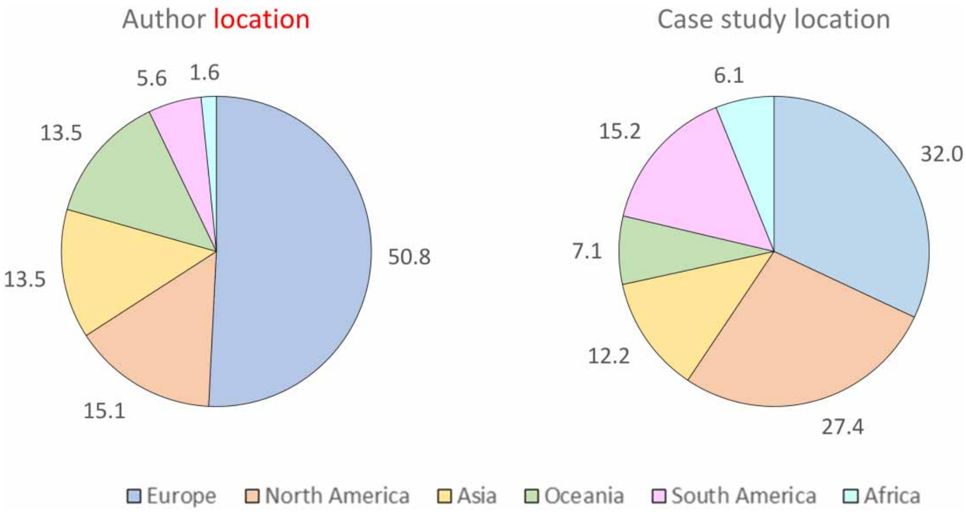

Figure 3 | Statistics regarding all authors' locations and case study location in the reviewed papers (% of papers).

for NBS and green space implementation (49%) on the one hand and selecting geographical sites suitable for NBS and green space implementation on the other (51%).

The MCDA process is often performed by the research team (80%) and rarely involves stakeholders (18%) who are mainly solicited during the weighting phase. Moreover, when a group of stakeholders takes part in the MCDA process, their expertise is rarely specified. The research team involved was often mentioned as expert stakeholders, but other potential stakeholders (Skrydstrup *et al.* 2020, Figure 4) are usually not mentioned or described in sufficient detail.

Regarding the criteria elicitation process, 60% of the studies include a maximum of 10 criteria and rarely more than 20 criteria (83%). The criteria considered most often cover social aspects (90%) and environmental aspects (84%). During the weighting phase of the MCDA process, linear aggregation rules such as the simple additive weighting (SAW) method are used in half of the studies. We also found that 35% of the studies follow the AHP method. The first MCDA method category by Belton & Stewart (2002) is predominant and concerns 65% of the studies, with almost half of the studies not relying on a specific method and using a direct ranking process. Notably, some case studies used more than one method. When applying MCDA methods, an important decision concerns the value function, i.e., the conversion of the criteria's attribute data scales into a common and numerical scale. We found various types of value functions being used, and most frequently a scale between 0 and 1, which appears in 33% of the reviewed papers. Finally, for the prioritization of alternatives, linear aggregation is used in 56% of the case studies. However, this information is not often given.

3.4. Tools

GIS tools are used in 56% of the case studies, but references on the tools are usually lacking or the tools are not available in open source (13% not available). Tools are generally developed for specific cases, using a specific MCDA method and the model based on the selected MCDA method.

MCDA tools developed to facilitate MCDA method application are only mentioned in 13% of the studies. 26% of the studies do not use any tool or provide no mention of a tool (Table 4).

4. DISCUSSION

4.1. Case study objectives

MCDA methods are often used for landscape management integrating environmental, economic, and social issues (Allain *et al.* 2017). The MCDA process for NBS and green space planning is applied to rank alternative policies, plans, or management practices for NBS and green space implementation or to select geographical sites suitable for NBS and green space implementation. It aims to combine objectives that are measured using different types of information, both qualitative as well as quantitative data. This facilitates the use of social criteria (90% of papers) which are often expressed qualitatively (e.g., esthetics). Indeed, the literature review of Haase *et al.* (2014a, 2014b) on ES assessment found that studies often focused on biophysical aspects and undervalued

Table 2 | Statistics (number and % of reviewed papers) for the first, second, and third key elements of the Langemeyer *et al.* (2016) framework (problem definition, stakeholder analysis and engagement, alternative definition)

(i) Problem definition		
Scope	**Number**	**%**
ES	64	52
GI	19	15
LID	14	11
NBS	8	6
SUDS	4	3
WSUD	5	4
Other	10	8
Scale	**Number**	**%**
Global	9	7
Region	22	18
Basin	22	18
Local	50	40
Site	17	14
(ii) Stakeholder analysis and engagement		
Type		
Research team	99	80
Expert(s)	12	10
Stakeholders (group)	22	18
No information	7	6
Involvement phase	**Number**	**%**
Problem definition	15	12
Alternative definition	23	19
Criteria definition	25	20
Criteria weighting	85	69
No involvement	36	29
Involvement type	**Number**	**%**
Survey	26	21
Interview	19	15
Workshop	40	32
Individual exercise	16	13
None/no information	23	19
(iii) Alternative definition		
Alternative type	**Number**	**%**
Selection of suitable geographical sites	63	51
Evaluation of alternative policies, plans or management practices	69	49

Note: ES, ecosystem services; GI: green infrastructures; LID, low impact development; NBS, nature-based solutions; SUDS, sustainable urban drainage systems; WSUD, water sensitive urban design.

social aspects because they are subjective and difficult to quantify. This trend is also reflected in tools for NBS and green space planning which often integrate biophysical factors only (Kuller *et al.* 2017). However, technical and economic data are less present in the studies, possibly reflecting a lack of knowledge of the design and the cost of NBS. Indeed, research on NBS is recent (no paper found before 2010) but other studies may have been carried out under a different name, without appearing in our research.

Table 3 | Statistics (number and % of reviewed papers) for the fourth, fifth, and sixth key elements of the Langemeyer *et al.* (2016) framework (criteria definition, criteria weighting, results)

(iv) Criteria definition

Number of criteria	Number	%
x ≤ 10	74	60
10 < x ≤ 20	29	29
20 < x ≤ 30	10	8
Above 30	4	3
No information	2	2

Criteria type		Number	%
SOC.	Esthetics	35	28
	Recreation	42	33
	Mobility	13	10
	Health	60	48
	Safety and security	58	46
	Connectedness	22	18
	Education	22	18
	Occupation	32	26
ENV.	Water quality	49	39
	Resources	62	26
	Nature	80	64
ECO.	Business development	31	25
	Low cost	42	34
TEC.	Integration with existing infrastructures	22	18
	Flexibility	11	9
	Simple & transparent	16	13
	Supply safety	34	27

(v) Criteria weighting

Aggregation method	Number	%
Linear aggregation	64	52
AHP	44	35
PWC	51	41
Ideal point	9	7

MCDA method		Number	%
First	Direct ranking	57	46
	TOPSIS	11	9
	MAVT	4	3
	SMART	3	2
	SWING	1	1
Second	AHP	44	35
Third	PROMETHEE	4	3
	ELECTRE	2	2
Other	NAIADE	5	4
	DELPHI	3	2
	VIKOR	2	2
	MACBETH	1	1

Value function scale	Number	%
0 < x ≤ 1	41	33
1 < x ≤ 9	11	9
1 < x ≤ 5	10	8

(*Continued.*)

Table 3 | Continued

Value function scale	Number	%
$1 < x \leq 100$	9	7
$0 < x \leq 5$	5	4
$0 < x \leq 10$	2	2
$0 < x \leq 1,000$	1	1
No information	45	36
(vi) Results		
Output	**Number**	**%**
Numerical score	124	100
Maps	73	59
Graphs & figures	66	53
Result	**Number**	**%**
Ranking of alternative	81	65
Master plan	29	23
Equitable alternatives	16	13

Note: AHP, analytic hierarchy process; PWC, pairwise comparison; TOPSIS, Technique for Order Preferences by Similarity to Ideal Solutions; MAVT, Multi-Attribute Value Theory; PROMETHEE, Preference Ranking Organization Method for Enrichment and Evaluation; ELECTRE, Elimination And Choice Translating Reality; NAIADE, Novel Approach to Imprecise Assessment and Decision Environments; MACBETH, Measuring Attractiveness through a Categorical-Based Evaluation TecHnique.

Table 4 | Statistics on tools used for MCDA application

Tools		Number	%
MCDA	Logical/Super decision	3	2
	PROMETHEE II	2	2
	NAIADE	2	2
	HUGIN	1	1
	D-sigh	1	1
	PEST	1	1
	Vector MCDA	1	1
	Optamos	1	1
	DPSIR	1	1
Spatial	GIS-based	53	43
	LIAM/LISAM/SUSAM (GIS plug-in)	5	4
	GIPS (GIS plug-in)	3	2
	ILWIS (GIS plug-in)	3	2
	IDRISI (GIS plug-in)	2	2
	GISM (GIS plug-in)	1	1
	SSANTO (GIS plug-in)	1	1
	ARIES (GIS plug-in)	1	1
	UrbanBEATS	2	2
Other	InVest	8	6
	No tool/No information	32	26

Most studies (60%) are limited to 10 criteria which is consistent with the recommendations of the field of multi-criteria decision science (Liquete *et al.* 2016) as too many criteria would reduce their individual impact on the multicriteria model and lead to less obvious results.

4.2. Case study and location

Almost all papers included in this literature review (120) are built around case studies. However, the adaptation of the MCDA methods to a different context (cultural, geographical, climate, politics) has not been really explored yet as most of the papers (104) only evaluate them in single case studies which means that the research remains context-specific and not global.

The studies are mainly conducted in the Global North with 57% of them made in Europe and North America. The other continents are underrepresented, which may reflect a lack of resources and capacity available for research and implementation in Africa and South America. Indeed, Kuller *et al.* (2022) found that studies for NBS implementation in the Global South are hampered by the lack of relevant institutional capacity and stakeholder involvement in planning processes, available data, and government policies. These results can be biased by the fact that NBS and associated terms are European and North American and the research focused on articles in English only. Furthermore, there could be a general lack of knowledge and research about NBS and the potential of MCDA to support their strategic planning. Nevertheless, NBS and green spaces in general are sustainable alternatives to traditional planning that have the potential to mitigate the impacts of climate change and environmental degradation due to urbanization and are worth to be studied globally.

Moreover, the author and study case locations are not always linked, which leads to situations where studies from the Global North are sometimes conducted in the Global South (Africa, South America, and parts of Asia), providing a possibly incomplete perspective. Indeed, local actors have a better knowledge of the issues, policies, and culture of their territory, which probably leads to more appropriate results. Working with local partners when a research group is based on a case study abroad could lead to a better acceptance and application of the results. There may also be more interest in using NBS and MCDA than can be reported from the peer-reviewed literature consulted in this review. Indeed, much of the work may remain hidden in design reports and technical documentation.

4.3. Stakeholders

MCDA is intended to be a participative process. However, 29% of the reviewed studies did not integrate stakeholders at all. This is still more common than in the literature review of Chatzinikolaou *et al.* (2018) which concluded that 60% of the studies for ES assessment do not involve stakeholders. Moreover, stakeholders are often only solicited during the criteria weighting phase (69% of papers) and very little during the other stages which reflects a lack of knowledge and experience in conducting an MCDA process. Indeed, Jelokhani-Niaraki (2021) found that the participatory steps are often limited to the determination of weights in 46% of the case studies. It would be relevant to integrate an expert in MCDA in order to be able to lead the MCDA process and guide the stakeholders through each step.

The value of the MCDA participatory process is that it brings together stakeholders with different fields of expertise. In the papers, this aspect is never developed, and the stakeholders presented usually have an academic background, posing fundamental problems regarding representativeness. Most studies involve one to five experts who carry out the criteria weighting exercises and sometimes help in the choice of criteria. Allain *et al.* (2017) also found in their literature review that the process of stakeholder selection is not often formally addressed. Furthermore, 80% of the studies use the expertise of the research team to carry out the MCDA process partially or fully. It is important to bring together stakeholders with different expertise in order to bring knowledge on all aspects of sustainable development through the implementation of NBS and obtain a relevant multicriteria model. This is also reflected in the way stakeholder opinion is collected with only 24% of the studies organizing workshop sessions, 44% of the studies not even describing the process and the remaining studies using surveys, interviews, or individual exercises. This contradicts the intention for MCDA to be deliberate processes that lead to collective as opposed to individual decision-making. Allain *et al.* (2017) showed that workshops are the best way to interact with stakeholders when doing a participative and collaborative study. However, the literature review is essentially based on scientific publications, certainly from the academic field, and remains limited to that.

4.4. MCDA methods and tools

A direct ranking method, following an SAW aggregation rule, is used in 46% of the papers which is confirmed by the research of Allain *et al.* (2017). The analytic hierarchy process (AHP) combined with pairwise comparison is the second most used MCDA method (35% of the papers) even though it is highly criticized by the MCDA community for its important bias risks (Belton & Pictet 1997). Unlike the MACBETH method or the PROMETHEE method, the AHP method does not come with a tool to facilitate its application and the consistency of judgements. In addition, this method offers little transparency in the justification of the final results, which may confuse stakeholders. Other advanced methods (third category of Belton & Stewart 2002) are rarely used, which may reflect a lack of knowledge and expertise in the application and selection of MCDA methods. As mentioned in section 4.3, it would be relevant to include an expert in MCDA in the research team for the choice of the method and its application.

MCDA tools are not (yet) commonly used for NBS and green space planning (13% of the papers reviewed) and GIS-MCDA tools are common (43% of the papers). This is consistent with Ezquerro *et al.* (2016) who found that 50% of the studies explicitly include GIS data or software. The main issue is that there is not one particular GIS-MCDA tool that gets preference in the field which leads to the development of tools that are built for a particular study context and are not developed in view of its transfer to another context. Moreover, we found that 56% of papers rely on linear aggregation which is the most often used decision rule for GIS-MCDA tools (Jelokhani-Niaraki 2021) for its simplicity in collaborative spatial decision-making. The MCDA for NBS and green space planning research is still in its infancy with a predominance of water management and spatial tools which is in line with the literature review of Lerer *et al.* (2015) and does not represent all the social, and environmental, technical, and economic aspects of a situation.

4.5. Recommendations and future work

It would be interesting to study in more detail the impact of the case study context on the MCDA process for the implementation of NBS or green spaces by applying it to several case studies, in different geographical locations and exposed to different issues. There is a need to develop more studies outside of Europe and North-America to gain insight into the context of the Global South and the good practices to adopt in that context.

The technical knowledge of NBS and the return on investment of these new infrastructures seems to be missing in the literature. More research on the subject could help in the development of new indicators or understand why they are underrepresented in studies.

In order to better represent the different visions of the spatial planning issue for NBS and green spaces, it would be relevant to conduct case studies involving several types of stakeholders in the MCDA process through participatory workshops (Belton & Pictet 1997; Nutt 1999; Skrydstrup *et al.* 2020). Indeed, none of the studies mention the presence of municipal or citizen representatives nor do they include private sector professionals. Furthermore, for a good application of the MCDA process, it is recommended to involve stakeholders at each step, leading to better ownership of the results and transferability of the method in the future (Nutt 1999).

Advanced methods (i.e., third category and others as MACBETH) have been rarely explored in the studies, although they have shown good results in other spatial planning studies (Lavoie *et al.* 2016). The impact of the MCDA method itself (SMART, AHP, MACBETH, and PROMETHEE) on the results of the same case study for NBS and green space implementation has not been studied in current literature. This could provide new knowledge on the strengths and limitations of each method and allow a more informed choice of the MCDA method for practitioners. This research could help determine the best method to use in NBS or green space planning.

Finally, various GIS-MCDA tools have been developed for a specific context but their adaptation to other contexts has rarely been explored. Rather than creating new tools, resources may be better spent on adapting and improving existing and available tools. Moreover, no tools for NBS or green space implementation exist that integrate different MCDA methods and could help evaluate the impact of the chosen method on the results obtained. This research could also help determine the best method to use in NBS or green space planning and would simplify the development and improvement of existing tools.

Another point researchers and practitioners need to be aware of concerns the use of the term ecosystem services (ES). It is ambivalent as it designates services (i.e., benefits, criteria) and a green space (which can also be a technology, designated as NBS).

5. CONCLUSION

This literature review includes 124 papers published between 2000 and 2022 related to the use of the MCDA process for NBS and green space planning. Those studies are usually conducted in Europe and North America on a single case study and a specific context. Stakeholders are not systematically integrated into the MCDA process and when they are, it is usually a few experts from academia who are called upon for the criteria weighting phase and are not involved in the whole process, as recommended. The criteria considered for the evaluation of alternatives are environmental or social, but only a few are technical or economic. One of the most used

MCDA methods in the studies is the AHP method despite its high risk of bias. Generally, studies apply a direct ranking method following SAW rules. Mapping results are produced using GIS tools that integrate the algorithms of the relevant MCDA method.

Research opportunities arise for testing NBS and green space planning approaches and advanced MCDA methods to various contexts, integrating a group of stakeholders with profiles covering all the relevant fields for NBS and green space planning, and developing existing tools for better flexibility and adaptation to a wide variety of contexts.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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