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Supplementary material to the EU-CEM Handbook for CCAM
Preliminary version

Overview of methods for stakeholder identification and elicitation of preferences from stakeholders for prioritisation of criteria and comparison of CCAM alternatives

1. Introduction

1.1 Purpose of this document

This article provides supplementary material related to the European Common Evaluation Methodology for CCAM Handbook[1], hereafter referred to as EU-CEM Handbook. Similar to the EU-CEM Handbook, this article is intended for professionals planning and conducting evaluations for CCAM projects. The EU-CEM Handbook aims to provide guidelines and best practices for planning and conducting CCAM evaluations – especially impact assessments. The handbook can be applied in three types of activities:

1. Ex-ante impact assessments, where it can help to prepare for CCAM deployment and uptake, or to identify unintended outcomes that may require mitigation.
2. Ex-post evaluations, to assess the impacts of already implemented CCAM systems.
3. The design and deployment initiatives of CCAM systems, with an aim to maximise societal benefits.

As discussed in the EU-CEM Handbook, CCAM can have impacts on the level of **(a)** single vehicles and **(b)** humans, on **(c)** the transport system, and on **(d)** society overall. Furthermore, these impacts can be positive for some areas and negative in other. The present article aims to investigate this further by addressing the following questions (see section 1.4 for important definitions):

1. ***How can different CCAM options*[2] *be compared to each other?*** Different CCAM projects[2] might test distinct CCAM systems[2], considering different scenarios[2]. For each project, indicators related to different evaluation levels[2] and impact areas[2] may be collected and analysed. It might be the case that one scenario or project produces positive results in one but negative results in another. How can the results of different indicators for various scenarios (projects, or systems) be compared?

[1] For more information on the EU-CEM Handbook, see https://www.connectedautomateddriving.eu/methodology/common-evaluation-methodology/
[2] See section 1.4 for important definitions

2. ***Which stakeholders' preferences are relevant for the CCAM evaluation(s) in question?*** CCAM can have diverse impacts, including on users and non-users of a given CCAM system, as well as on the environment, land use, the economy, and society as a whole. Different groups may have different preferences regarding which criteria[2] they prefer or value most, and these could be in turn positively or negatively affected by CCAM implementations. Consequently, different stakeholders might have a higher or lower preference for various CCAM alternatives based on how well they perform on the criteria that the stakeholders value more highly. For comprehensive but also inclusive assessment of CCAM impacts, it is important to consider not only the values obtained for the different indicators[2] (associated with CCAM criteria) in the context of the CCAM alternatives being evaluated, but also how distinct stakeholder groups perceive the importance of each criterion.

1.2 Connection with EU-CEM Handbook

This article has a direct connection to the Sustainability section of the EU-CEM Handbook. As mentioned in the EU-CEM Handbook, the sustainability impact area constitutes an integrated evaluation of all impacts addressed within EU-CEM, providing the means to summarise indicator results from different impact areas and contextualise their implications for the sustainability of the transport system and society.

More specifically, the sustainability section of the EU-CEM Handbook suggests the use of a sustainability table[3] to display the outcomes of different indicators across different scenarios (CCAM systems, or CCAM projects). Such a table provides a visual representation of multiple impact areas for alternative societal scenarios, providing additional context for the evaluation of CCAM implementations. Moreover, the sustainability section explores the use of Multi-criteria analysis (MCA)[2] and SWOT[4] analysis as methods to further interpret and evaluate the sustainability impacts of CCAM, highlighting the impact that the selection of stakeholders can have on the results obtained from an MCA or SWOT.

In this context, this article further explores the use of Multi-criteria analysis to compare multiple indicators across various scenarios, offering a visual representation of these diverse impacts (see section 3.3.5 for a heatmap-style performance matrix). It also discusses the identification and engagement of diverse stakeholder groups beyond the project team (e.g., external experts, other relevant societal groups) to gain a broad perspective on how different groups perceive the importance of the CCAM impact areas (see chapter 2 for the identification of stakeholder groups and section 3.3.3 for the elicitation of preferences from stakeholders).

1.3 Structure of this document

This article is structured in six chapters. **Chapter 1** provides an introduction to the article, explaining its purpose and intended audience, how it is structure, how it relates to the EU-CEM Handbook, and some important definitions used throughout the document.

Chapter 2 explores stakeholder identification, providing a brief overview of approaches for participation in governmental policy-making and decision-making based on literature. Chapter 2 also includes guiding questions to help the CCAM project team identify relevant stakeholder groups to be involved for elicitation of preferences concerning CCAM impact areas. The guiding questions encourage the project team to consider key concepts like power, influence, authority, legitimacy,

[3] See section 4.4.6.2. Guidelines of the EU-CEM Handbook for details

[4] SWOT stands for Strengths, Weaknesses, Opportunities, and Threats. This method is not further discussed in this article. See section 4.4.6.2. Guidelines of the EU-CEM Handbook for more information.

justice, and control over essential resources (e.g., decision-making power, information, money, technology, knowledge), and how these factors might impact different stakeholders, which can support in identifying a diverse and comprehensive list of stakeholders. Chapter 2 ends with a brief discussion of stakeholder mapping methods, such as the Power-Interest Matrix and Salience Model, which can help the team not only develop a list of relevant stakeholders but also understand how they are positioned based on key concepts mentioned above. The expected outcome of chapter 2 would be relevant stakeholder groups identified, which include the CCAM project team itself, as well as, for instance, external experts, governmental organisations, private sector representatives, and representatives of vulnerable population groups, considering factors like gender, age, digital literacy, and geographical location, among others.

After identifying all relevant stakeholder groups, **chapter 3** explains how the project team can engage these stakeholders to elicit their preferences[2]. This process can be performed using various methods, and section 3.3.3 (together with Appendix 1) provides an overview of techniques identified in the literature for eliciting preferences from stakeholders and converting them into weights for multi-criteria analysis. Stakeholders can provide their input on different levels, either on the criteria or the indicators, or both, as discussed in section 3.3.3. Once the preferences have been collected, the corresponding individual weights can be aggregated into an overall set of weights for the criteria and indicators to compare different CCAM alternatives. This is further elaborated in section 3.3.4.

The final step in comparing CCAM options involves assessing the "best overall" CCAM alternative based on the aggregated weights provided by stakeholders and the measured performance of each option for each indicator. A linear additive model is often used in multi-criteria analysis to combine each option's performance across different criteria into a single overall value, identifying the "best" CCAM alternatives. Section 3.3.5 further discusses this. Chapter 3 concludes with a brief discussion on potential risks and limitations associated with using multi-criteria analysis, which should be considered by any project team interested in applying these methods in the context of CCAM assessments.

The remainder of the article consists of **chapter 4**, which offers overall conclusions to the document, **chapter 5**, which lists the references used in the article, and **chapter 6**, which includes appendices with additional information considered too technical or extensive for the main text

1.4 A note on terminology

Throughout this document, a number of concepts are used in the context of the EU-CEM Handbook and literature regarding stakeholder identification and engagement and multi-criteria analysis. The definition of each concept is provided below, and each concept is further discussed and contextualised as needed in the following chapters.

- **Multi-Criteria Analysis (MCA):** also referred to in literature by other names, including Multi-Criteria Decision-Making (MCDM), Multi-Criteria Decision Analysis (MCDA), Multi Actor Multi Criteria Analysis (MAMCA), among others. Includes a range of classes of tools, methods, and techniques (varying in complexity) that explicitly take into account multiple, frequently conflicting objectives as well as different metrics and criteria for making decisions (Dean, 2020). *[See chapter 3 for detailed discussions]*

- **Options**: in multi-criteria analysis, options (or alternatives) represent the different solutions being considered and compared against a set of criteria. Alternatives can take various forms, including site locations, policy options, and technological solutions, depending on the problem context (Macharis & Baudry, 2018). In the context of the EU-CEM Handbook, options can include different CCAM scenarios, CCAM systems, or CCAM projects, depending on the given case. *[See chapter 3 for detailed discussions]*

- **Criteria**: in multi-criteria analysis, criteria represent the measures of performance by which the options are judged. Each criterion must be measurable, at least qualitatively, to enable the assessment of how well a given option performs in relation to the criterion (Department for Communities and Local Government, 2009). In the context of the EU-CEM Handbook, criteria could be (a subset of) the distinct impact areas. *[See chapter 3 for further discussions]*

- **Indicator:** in multi-criteria analysis, indicators provide the means to assess the extent to which each alternative fulfils the identified criteria (Macharis & Baudry, 2018). In other words, they provide measures by which the performance of a given option against a given criterion can be assessed. If traffic safety is a criterion in a CCAM assessment, for example, the number of road injuries, number of accidents per vehicle kilometres travelled, among other indicators can be used to assess how each CCAM alternative perform regarding the traffic safety criterion. *[See chapter 3 for further discussions]*

- **Stakeholders**: represent groups of people, whether organised or unorganised, who share a common interest (or stake) in a particular issue or system, and can be at different levels, ranging from global, national, or regional, down to the household level (Grimble & Wellard, 1997). They are people or organisations that have a financial or other interest in the outcomes of any decision (Macharis & Baudry, 2018). *[See chapter 2 for further discussions]*

- **Elicitation of stakeholder preferences:** preference elicitation aims to determine the values of parameters related to preferences within decision support models (Expert Judgment Network, n.d.). In the context of multi-criteria analysis, a preference-related parameter can be the score (based on a given rating technique) given by a stakeholder to a criterion, which is later converted into the weight of that criterion in the perspective of that stakeholder. *[See chapter 3 for further discussions]*

- **CCAM project:** as defined in the EU-CEM Handbook, a CCAM project refers to a project that tests, evaluates or implements CCAM. This document is not intended to provide detailed discussions on CCAM projects – references to CCAM projects are included for illustrative purposes only. *[See EU-CEM Handbook for further discussions]*

- **CCAM system:** as defined in the EU-CEM Handbook, a CCAM system refers to a technology or service that enables Connected, Cooperative, and Automated Mobility. This document is not intended to provide detailed discussions on CCAM projects – references to CCAM projects are included for illustrative purposes only. *[See EU-CEM Handbook for further discussions]*

- **CCAM scenario:** as discussed in the EU-CEM Handbook, a scenario is defined as a structured depiction, specified by a set of pre-determined conditions and variables, representing actual or theoretical states, situations, or interactions. All evaluation and impact areas require scenario setting, though the scope and detail of scenarios may differ across areas. This document is not intended to provide detailed discussions on CCAM scenarios – references to CCAM scenarios are included for illustrative purposes only. *[See EU-CEM Handbook for further discussions]*

- **Evaluation level:** as discussed in the EU-CEM Handbook, evaluation level refers to the viewpoint of evaluation: (single) vehicle, (single) human, transport system, or society. *[See EU-CEM Handbook for further discussions]*

- **Impact area:** as discussed in the EU-CEM Handbook, impact area refers to field of study addressed under impact assessment activities. The EU-CEM Handbook provides 18 impact areas across four levels of evaluation. *[See EU-CEM Handbook for further discussions]*

2. Stakeholder identification

2.1 Introduction

This chapter addresses stakeholder identification in the context of CCAM implementation. It first discusses the importance of involving diverse stakeholders to develop more inclusive solutions that align with users' values and preferences. The chapter also presents different methods on how to involve stakeholders, depending on the intended goal of the involvement as identified in literature. A list of guiding questions is provided with an aim to encourage the project team to consider key concepts such as power, influence, authority, and legitimacy, among others, when thinking about relevant stakeholders. Lastly, the chapter suggests some potentially useful diagrams that a project team can use to not only list stakeholders but also visualise their positions in relation to important concepts such as power, legitimacy, urgency, and others. These visualisation tools can help the project team identify patterns, such as whether most stakeholders have high or low power or interest, which stakeholders might be significantly affected but have low influence on the decision, if there are stakeholders with high urgency, and if there are conflicts between stakeholders. These additional visual insights can aid in identifying a diverse and balanced group of stakeholders for involvement

2.2 The importance of involving diverse stakeholders in CCAM

Depending on which (and how) CCAM systems are implemented, a wide range of stakeholders might be affected. CCAM can lead to multiple impacts, on users, non-users, the environment, the economy and society as a whole, and these impacts can be positive or negative. Some impacts might be more direct or immediate, while others might be more indirect or take longer to develop. For instance, with automated vehicles (private or shared vehicles), possible direct impacts might be improved people mobility. But at the same time, a possible cascading effect could include changes in where people choose to live – potentially leading to more urban sprawl. Which groups may (disproportionally) benefit (or disbenefit) from a CCAM implementation? How might the quality of life in the studied area(s) be affected by CCAM implementation for distinct groups? Knowing the preferences of different stakeholder groups regarding relevant dimensions that can potentially be positively or negatively affected by CCAM implementations can allow a more holistic and inclusive assessment of CCAM impacts.

As discussed in deliverable “D3.2 – Evaluation of engagement and data collection strategies” from the Horizon Europe project SINFONICA, stakeholder engagement can help project teams to better understand public concerns, address specific needs, and ensure that the solutions developed are aligned with users’ values and expectations (SINFONICA Project, 2024c). By integrating diverse perspectives from users and stakeholders, such as citizens, researchers, public administrations, service providers, and representatives of civil society, the project team can identify CCAM implementations that are both technically advanced and socially inclusive, addressing the needs of various users. Furthermore, as mentioned in deliverable “D2.1 Engagement guidance for CCAM solutions” of the same SINFONICA project, stakeholder involvement supports the democratisation of innovation by including a broader range of participants in the process, which can empower communities by giving them a voice on solutions that can potentially impact their lives (SINFONICA Project, 2024b).

An important question that follows is then: which groups of people and/or organisations should be involved? There is ample literature available regarding stakeholder engagement and public participation for policy or decision-making contexts, and a thorough review of this is beyond the scope of this article, so an overview of some useful approaches, guiding questions and tools in the context of CCAM will be discussed in this section.

In an influential paper, Fung (2006) proposes a framework for understanding the range of institutional possibilities for public participation in governmental policy-making and decision-making. The author proposes three dimensions affecting public participation: **(1)** who participates; **(2)** how participants interact with each other and collectively make decisions; and **(3)** how discussions are then connected back to policy or public actions. For each of these dimensions, Fung (2006) proposes several methods or subcategories, which are summarised in Table 1.

Table 1. Mechanism of public participation (Based on Fung (2006))

Dimension	Methods/subcategories	Details
Participant selection *Who is eligible to participate? How do individuals become participants?*	Open attendance	Participants self select from the general population.
	Selective recruitment	Underrepresented groups (such as low-income or minority communities) are targeted for participation (e.g., via community leaders or incentives to foster participation).
	Random selection of participants	Participants are randomly selected to discuss public issues. This approach can best ensure descriptive representativeness.
	Lay stakeholder engagement	Involvement of unpaid citizens that "have a deep interest in some public concern and thus are willing to invest substantial time and energy to represent and serve those who have similar interests or perspectives but choose not to participate" (Fung, 2006, p.68).
	Professional stakeholder involvement	Usually involves paid representatives of organised interests and public officials in regulatory negotiations – a process that brings representatives of affected interests together to reach consensus on the content and sometimes the language of a proposed rulemaking (Fiorino, 1988).
Communication and Decision *Interaction of participants within a public discussion or decision-making environment.*	Listen as spectator	When participants receive information about a subject without actively contributing (e.g., when attending a public hearing).
	Express preferences	Occurs for instance when individuals queue at a microphone to articulate their views during a community gathering.
	Develop preferences	When participants are encouraged to further learn about an issue and (possibly) alter their perspectives, typically via small group dialogues or informational sessions.
	Aggregate and bargain	When participants negotiate and combine their perspectives in order to arrive at a collective outcome (e.g., a town meeting where individuals vote on diverse issues).

Dimension	Methods/subcategories	Details
	Deliberate and negotiate	When individuals engage in reasoned discussions to form collective decisions, typically supported by preparatory materials and interactions.
	Deploy technical expertise	Typically do not include citizens but officials whose training and professional specialisation equip them to address specific issues (e.g., planners, regulators, social workers, researchers etc).
Authority and Power *How do the actions of participants or public authorities relate to what participants say?*	Personal benefits	Participants do not expect to have an impact on public decisions and engage primarily for their own learning or a sense of civic responsibility.
	Communicative influence	Public interest and sentiment indirectly affect policy or decision-makers (e.g., in the aftermath of tragedies that mobilise public opinion on an issue).
	Advise and consult	Involves officials maintaining their authority and power on a topic or issue while committing to collect input from participants.
	Co-governance	Individuals might collaborate with officials to create plans and formulate policies (e.g., local school councils consisting of parents, community members, educators, and school principals).
	Direct authority	Participatory groups have control over public decisions or resources

By taking into account the different dimensions (as stated in Table 1), decision-makers can compare and contrast methods in order to identify which one best suits their needs. For CCAM projects, the overall aim of a project can assist in determining which approach (in terms of dimensions and categories) of public participation is most suitable. For instance, if a project seeks to understand the general perception of citizens regarding CCAM, a public participation organised with a focus on open attendance, where participants can freely express themselves (i.e., without a predetermined format), could be beneficial, by allowing participants to voice their opinions in the manner they find most suitable. In such a case, using structured method to elicit the preferences of stakeholders to connect to a multi-criteria analysis (as discussed in chapter 3) likely will not be necessary, but the information collected from stakeholders might still be useful to the project team in different ways (e.g., by identifying most prevalent barriers to use CCAM, or biggest concerns specific population groups might have, or relevant needs from specific groups that CCAM can address, etc).

Alternatively, if a project aims to better investigate for example the impact of CCAM on accessibility and equity, it would likely be necessary to identify vulnerable or underrepresented groups. As an example, the SINFONICA focused on groups of people with mobility challenges, including elderly, people with cognitive disabilities, digitally non-connected people, women and people with gender-related challenges, and young people (SINFONICA Project, 2024a). Once identified, individuals (or their legitimate representatives) from these groups could be further involved to elicit their preferences. This could be done using e.g. an advise and consult approach, focusing on relevant criteria such as accessibility, liveability, economic opportunities, and mobility patterns that are likely to be impacted by CCAM implementations.

2.3 Guiding questions to support the identification of stakeholders

The three dimensions of participant selection, communication and decision, and authority and power, as proposed by Fung (2006), offer valuable insights into structuring public participation. However, identifying the relevant stakeholder groups to involve cans till remain challenging. To address this, the following list of questions, compiled from various literature fields, can offer additional support in identifying stakeholders. The list may include very similar questions more than once, but framed slightly differently. This approach can potentially prompt the project team to identify different stakeholder groups by examining the same topic from different perspectives

Table 2. Guiding questions for identifying stakeholders in CCAM projects

Suggested guiding questions for the identification of stakeholders in CCAM implementations
1. Which groups have demonstrated interest in the outcome of this project? [A] 2. Are there underrepresented or underserved populations that should be taken into account? [A] 3. Which communities, groups and individuals are most dependent on or have a stake in the policy or impact assessment processes? [B] 4. Are there groups that could be significantly impacted by the project? [A] 5. Which groups are likely to be impacted by the project? [A] 6. Which groups have an economic interest in the outcome of the project? [A] 7. Are there groups that might view the process or outcome as unfair if they are not involved in it? [A] 8. Which groups have access to and/or use the physical environment, public space, natural resources or others in areas that are likely to be affected by this project? [B] 9. Who uses (or can be expected to use) the CCAM system? [C] 10. Does the use of this CCAM system change (or can it be expected to change) depending on day of the week, period of the day, seasons of the year or other reasons that might be relevant when thinking about stakeholder groups? [B] 11. Which groups benefit from the this CCAM system? Which groups wish to benefit but are unable to do so? [C] 12. Are there groups that own property or conduct (business) activities at or around the location in which this CCAM system will be implemented? [A] 13. Who has rights and responsibilities over the implementation and use of this CCAM technology? [C] 14. Who would be affected by changing the current situation? [C] 15. Are there groups that have a legal right to be informed of any actions taken? [A] 16. Are there specific communities, groups or individuals who may be affected by this CCAM implementation? [B] 17. Are there local communities or non-profit organisations concerned with this issues? [B] 18. Are there legitimate representatives of these stakeholder groups? [B] 19. Are there business people or industries (across a wide range of sectors) that might be negatively affected by this CCAM implementation? [B]

20. Which official authorities or government agencies are officially responsible for the development, implementation and use of this CCAM technology? [B]
21. Which communities, groups or individuals are most knowledgeable about, and capable of providing input on this issue? [B]
22. Are there major trends (e.g., digitalisation, migration, population changes, climate change etc) that might affect this project and specific groups? [B]
23. Are there groups that have the ability to alter any decisions made? [A]
24. Which groups makes decisions that affect the implementation and use of this technology, and who does not? [C]
25. Are there groups calling for actions to be taken immediately? [A]
26. What might be unintended consequences of this proposed solution? [D]
27. Which stakeholders are we comfortable engaging now? And which stakeholders might we choose not to engage with and what might we miss by not involving them [D]
28. Who has an interest in or feels the consequences of the issues around which this project revolves? [F]
29. Who has formal/institutional position in policy-making matters related to this project? [F]
30. Who influences, directly or indirectly, relevant factors associated with this CCAM implementation? And who might be impacted by changes in these factors? [F]
31. Who has power or formal authority on these types of decisions and how can this influence the project's direction and outcomes? [F]
32. Are there stakeholders that control valuable resources for this project (e.g., decision power, information, money, technology, knowledge etc)? [F]
33. Are there groups directly affected by the outcomes and decisions at stake? Are they vulnerable to the consequences of this project? [E]
34. Are we engaging expert stakeholders from diverse domains (e.g., STEEP domains – Social, Technological, Economic, Environmental, and Political)? [E]

Notes:

[A] Based on Sharpe et al. (2021)

[B] Based on ICAT (2020)

[C] Based on Renard (2004)

[D] Based on Stroh (2015)

[E] Based on Jones and Van Ael (2022)

[F] Based on Enserink et al. (2022)

2.4 Suggestions of stakeholder mapping diagrams

In some situations, it may be important not only to have a list of stakeholder groups but also to understand how they (potentially) interact with each other or how they are visually positioned according to different scales (e.g., power, interest, influence, etc.). Potentially useful diagrams for this include the **Rainbow Diagram** (which maps the extent to which stakeholder groups are affected compared to their level of influence in a given project or policy), the **Salience Model** (which positions stakeholders based on their power, legitimacy, and urgency), the **Power-Interest Matrix** (which categorises stakeholders according to their level of power to influence a project and their interest in its outcomes), and the **Conflict (or Actors) Map** (which identifies the main groups involved in a topic or issue, as well as their relationships, and can help in identifying conflicts and understanding power dynamics). An in-depth discussion of such diagrams is beyond the scope of this article, but some examples identified in literature are provided below.

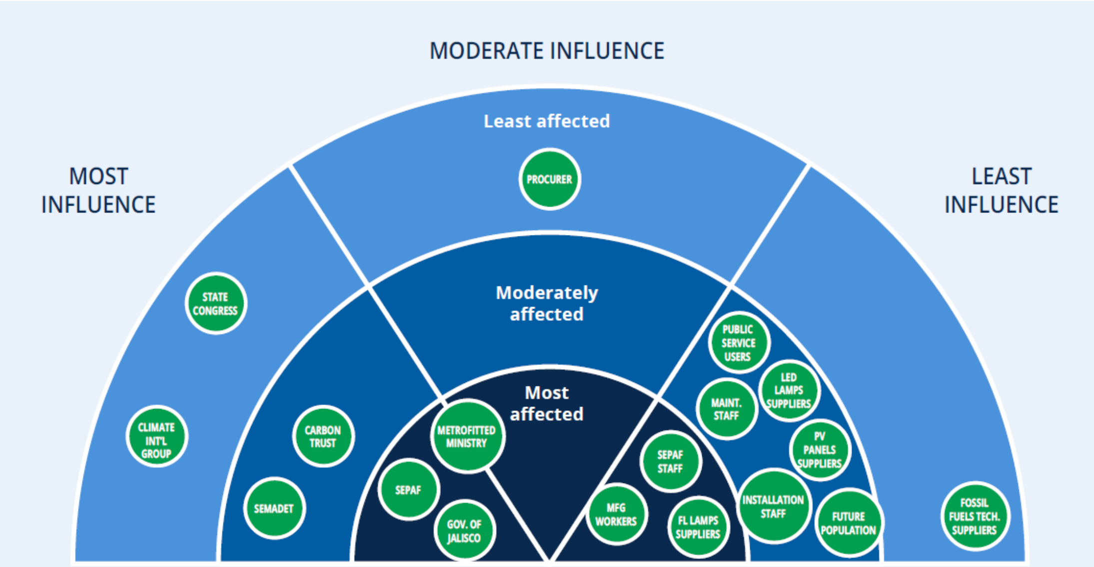

Figure 1. Example of Rainbow Diagram in the context of a sustainable development assessment in Mexico (Source: Initiative for Climate Action Transparency (2020))

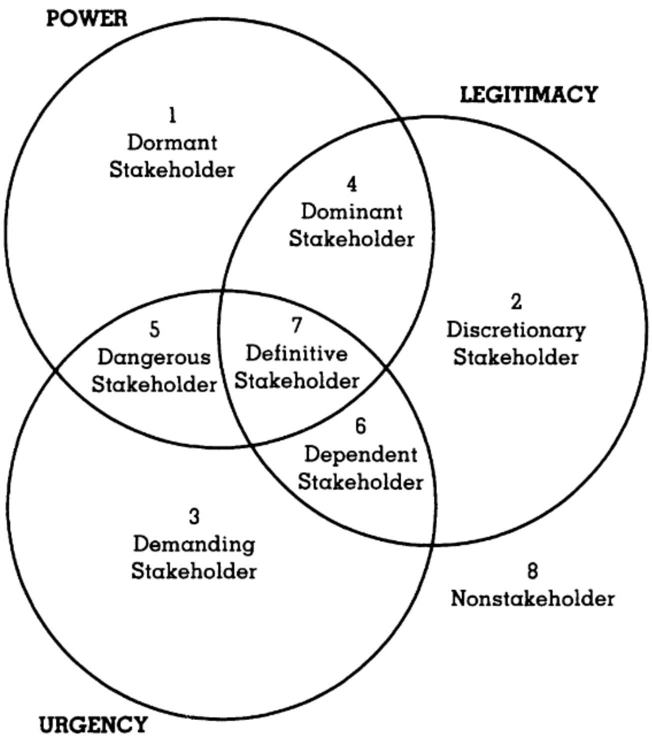

Figure 2. Salience Model (Source: Mitchell et al. (1997)). Power refers to a stakeholder's capacity to influence decisions or actions. Urgency refers to the extent to which stakeholder claims demand immediate attention. Legitimacy refers to the perceived appropriateness of a stakeholder's claims or actions.

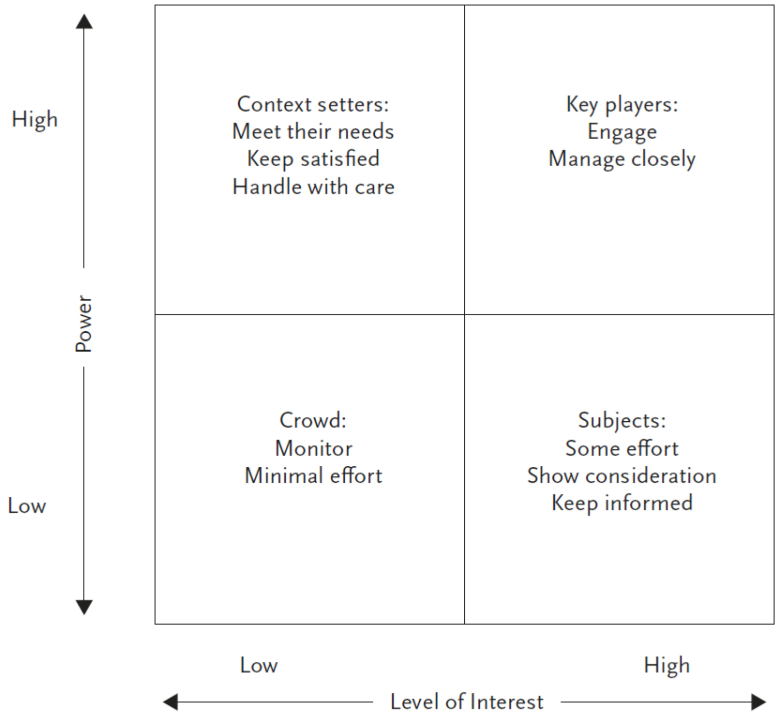

Figure 3. Power-Interest Matrix (Source: Enserink et al. (2022)). Power refers to a stakeholder's capacity to influence the outcomes of a project, policy or other. Interest refers to the degree to which a stakeholder is concerned about the outcomes of a project, policy or other.

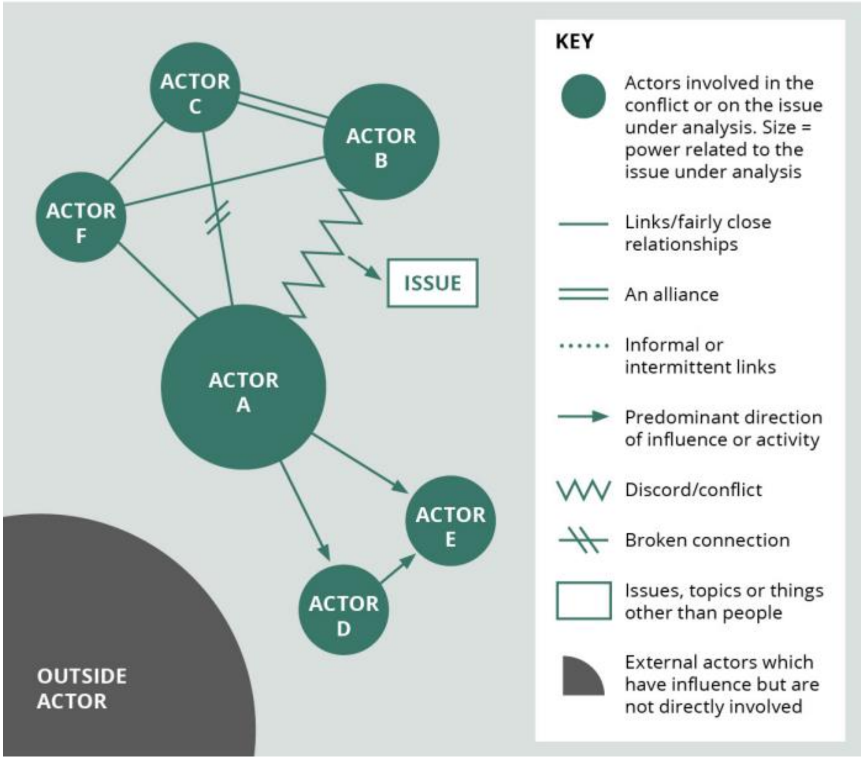

Figure 4. Conflict (or Actors) Map (Source: Herbert (2017))

It is important to emphasise that, as mentioned by Jones and Van Ael (2022), stakeholder selection processes have inherent biases, and the most effective way to address these biases is to make them explicit; to use rules that achieve a purposeful outcome and are perceived as fair. Therefore, the guiding questions provided do not offer a definitive answer to who should be involved, but they can assist the project team in considering relevant groups from multiple perspectives, such as power, influence, secondary effects, vulnerable groups, among others. The final definition of the stakeholders to be involved remains a decision by the project team, and factors such as the project schedule, budget, and the team's expertise in stakeholder engagement may impose limitations on the list of stakeholders that can be included.

3. Elicitation of stakeholder preferences, prioritisation of criteria and comparison of CCAM alternatives

3.1 Introduction

This chapter addresses three topics: elicitation of stakeholder preferences, prioritisation of CCAM criteria, and comparison of CCAM alternatives. It is structured to progressively build the discussion on MCA and CCAM. Initially, a brief overview of MCA is provided to contextualise relevant concepts necessary for further discussions. The chapter then explores different methods identified in literature to elicit preferences from stakeholders and apply them to EU-CEM CCAM criteria. Different stakeholder groups might be involved, as discussed in the previous chapter, or simply the project team itself, depending on the project's purpose and scope. Following this, the chapter discusses how to aggregate the input of multiple stakeholders into an overall set of weights for the different criteria being evaluated. Finally, it explains how to compare CCAM alternatives using a performance matrix, the aggregate weights of the criteria, and a linear additive model to compute a final score for each CCAM alternative. The chapter concludes with a brief discussion on the limitations associated with multi-criteria analysis, which should be considered by any project team interested in exploring the approaches discussed in this chapter.

3.2 Overview of multi-criteria analysis

This section provides a brief overview of multi-criteria analysis. This article does not aim to provide a thorough discussion on MCA methods, but instead to provide an overview of most important elements in multi-criteria analysis, some of which are further discussed in the context of the EU-CEM Handbook in later sections of this document.

3.2.1 Contextualisation of Multi-Criteria Analysis

Multi-criteria analysis is not a single approach or method, but rather an umbrella term encompassing various techniques and tools for comparing distinct alternatives (or options) against multiple, and potentially conflicting, criteria (Dean, 2020). Multi-criteria analysis therefore describes any structured approach used to determine overall preferences among alternative options, where the options achieve multiple objectives (Department for Communities and Local Government, 2009). In literature, multi-criteria analysis is also referred to by names such as multiple-criteria decision-making (MCDM), multiple-criteria decision analysis (MCDA), multi-objective decision analysis (MODA), multiple-attribute decision-making (MADM), and multi-dimensional decision-making (MDDM) (Dean, 2020).

Multi-criteria analysis methods differ from mono-criteria analysis methods like Cost-Benefit Analysis (CBA) by incorporating multiple dimensions of interest into the evaluation. As Dean (2020) discusses, while CBA assesses an initiative based on its economic feasibility, typically using the Net Present Value over the considered time horizon, MCA methods enable a systematic comparison of alternatives against a broad range of criteria, which can be physical, monetary, or qualitative in nature (Van Ierland, de Bruin, & Watkiss, 2013).

3.2.2 Main components of Multi-Criteria Analysis

3.2.2.1 Alternatives (or options)

Alternatives refer to the alternative course of actions proposed in order to address an identified issue and accomplish a primary objective (Dean, 2020). Options therefore represent the different solutions being considered and compared against a set of criteria. Options in the context of the EU-CEM Handbook are discussed in section 3.3.1.

3.2.2.2 Objectives

Objectives represent goals against which any proposed option is evaluated and are typically grouped into various broad assessment categories, including economic, environmental, and social dimensions (Dean, 2020). Objectives are often described using strategic or higher-level dimensions, such as economic growth, social cohesion, or sustainable development, which then options that may contribute to the achievement of these objectives can be identified (Department for Communities and Local Government, 2009). A discussion on the objective level is not the focus of this article, but a possible overarching objective in the context of CCAM assessment, as stated in the EU-CEM Handbook, could be to "maximise societal benefits of CCAM and improve the usefulness of the evaluation results for decision-making in both public and private sectors".

3.2.2.3 Criteria

In Multi-Criteria Analysis (MCA) literature, criteria are usually referred to as the performance measures used to evaluate the alternatives (Department for Communities and Local Government, 2009). This means the criteria should be operational, i.e., it should be clear how well each option performs against each criterion. Criteria therefore represent the "intermediate points to which the information provided by indicators can be integrated" (Macoun & Prabhu, 1999, p.12). A given criterion may have multiple indicators to evaluate how well an option performs against it, or it could be represented by a single indicator, depending on the purpose and scope of the analysis. Criteria in the context of the EU-CEM Handbook are discussed in section 3.3.2.

3.2.2.4 Indicators (or measures)

As mentioned above, criteria should be operational in MCA. Operationalising the criteria involves developing quantitative or qualitative indicators that communicate how well an option (or alternative) meets each criterion (Macharis & Baudry, 2018). Depending on the source, measures is also a term often used to refer to what provides the evidence base for scoring the criterion (Infrastructure Australia, 2021). Indicators in the context of the EU-CEM Handbook are discussed in section 3.3.2.

3.2.2.5 Performance score

A performance score indicates how well an option performs against a specific criterion (Dean, 2020). The performance score of an option for a given indicator therefore represent how well that option performs against that indicator. In MCA, since the criteria often encompass very different dimensions (e.g., costs, time, sizes, distances, etc.), the scores typically need to be normalised to enable comparison between criteria for the available options. A common method used is min-max normalisation, which rescales the data in each criterion so that all values fall within the range of 0 to 1. Section 3.3.5.1 discusses this further.

3.2.2.6 Weights

A criterion weight represents the level of importance of that criterion in the context of that multi-criteria analysis (Dean, 2020). There are various approaches to defining the weights of criteria in literature, which are further discussed in section 3.3.3. The process of determining the weights typically involves eliciting preferences from stakeholders regarding the available criteria, using methods such as pairwise comparison, AHP, ranking of criteria, or others (see section 3.3.3). Once the weights for each criterion are established, if multiple stakeholders are involved, an aggregated weight representing the collective preferences of the stakeholders can be calculated (see section 3.3.4).

3.2.2.7 Aggregation of scores and ranking of options

The aggregation of scores involve combining the performance of each option on each criterion of an overall score of an option. There are different methods to perform this, such as the Linear Additive Model, Outranking methods (e.g., ELECTRE, PROMETHEE, and TOPSIS), Non-linear aggregation methods (e.g., Ordered Weighted Averaging (OWA), Choquet integral), among others. The simplest and most straightforward approach to addressing multi-criteria decision problems is to use the simple additive weighting (SAW) or weighted sum method (WSM) (Effatpanah et al., 2022), also known simply as the linear additive model to calculate a final score for each option under evaluation, as further discussed in section 3.3.5. Other methods are beyond the scope of this article and are mentioned for reference purposes, with more detailed discussion being available e.g., in Effatpanah et al. (2022).

3.2.2.8 Overview of benefits and limitations of multi-criteria analysis

Some of the benefits and limitations of multi-criteria analysis, as identified in literature are mentioned below.

Benefits:

- **Comprehensiveness**: by explicitly considering multiple objectives and criteria, multi-criteria analysis (MCA) techniques can provide deeper insights into the problem at hand compared to single-criterion methods like cost-benefit analysis (CBA) (Dean, 2020).
- **Flexibility**: Multi-criteria analysis (MCA) methods allow the investigation of different types of problems and supports different types of data (quantitative or qualitative) (Dean, 2020).
- **Transparency**: by presenting the structure of objectives, criteria, indicators, weights, and scores through tables, matrices, or graphics, multi-criteria analysis methods offer a clearer and more transparent approach for appraising options (Dean, 2020).
- **Structural clarity:** by providing a structured way to compare options and how they achieve stated objectives, it allows stakeholders and decision-makers to more easily see how option recommendations have been formulated (Infrastructure Australia, 2021). Additionally, the structure of MCA methods allow for the combination of multiple indicators into one score (FAME ,2025).
- **Stakeholder involvement**: Multi-criteria methods (e.g., Multi Actor Multi Criteria Analysis (MAMCA)) can be designed to explicitly consider the objectives and goals of multiple stakeholders, effectively integrating them into the decision-making process (Macharis et al., 2012).

Limitations:

- **Demand for expertise and training**: even though Multi-criteria analysis is well-structured, flexible, and transparent, it can be more challenging and demand expertise to successfully implement compared to other techniques like Cost-Benefit Analysis, which often relies on market values or pre-existing valuations of non-market quantities (Department for Communities and Local Government, 2009).
- **Subjectivity**: a key feature of multi-criteria analysis is its emphasis on the judgement of stakeholders (and the project team) regarding elements such as criteria, indicators, weights, and aggregations, which can be a matter of concern (Department for Communities and Local Government, 2009). Additionally, MCA may create an illusion of precision, as numerical scores and weightings might not fully capture complexities of the real-world (FAME ,2025).
- **Challenges in involving multiple stakeholders**: when considering major projects or decisions with potentially far-reaching consequences, identifying all potential stakeholders and their perspectives can be challenging, especially due to time and budget constraints. Practitioners using MCA may implicitly adopt the client's perspective (e.g., Minister, Department, Organisation funding the assessment) or the views of organised and powerful stakeholder groups, potentially neglecting the interests of other affected parties (Dean, 2020).

- **Low intuitive meaning of results:** final results result may be hard to interpret and communicate to the public (Dean, 2020; FAME, 2025).

Section 3.4 further develops on some risks and limitations associated with the methods discussed in the next sections.

3.3 Illustrative example of a multi-criteria analysis process

3.3.1 Define options to be evaluated

In the context of CCAM implementations, options can include different scenarios tested within a CCAM project, distinct CCAM systems assessed within or between CCAM projects, or entirely separate CCAM projects, as illustrated in Table 3. Options can be evaluated independently or a reference alternative may be included to serve as a benchmark for comparison (i.e., options are compared against this baseline), usually a business as usual (BAU) or baseline reference (Macharis & Baudry, 2018). The EU-CEM Handbook also highlights the importance of a baseline reference, which represents the situation before the introduction of a CCAM system or when it is not in use (see Guideline 3.27 of EU-CEM Handbook for details). This contrasts with a treatment condition, which represents the situation when a CCAM system is introduced or in use. Please refer to the EU-CEM Handbook for a more detailed discussion on how CCAM scenarios should be developed.

Table 3. Illustrative examples of options for evaluation in a CCAM multi-criteria analysis

CCAM project X (Comparison of scenarios) [1]
Societal scenario 1
Societal scenario 2
Societal scenario 3
…

CCAM project Y (Comparison of CCAM systems)
CCAM system A (e.g., robotaxi)
CCAM system B (e.g., automated shuttle services)
CCAM system C
…

Comparison of CCAM projects
CCAM project 1
CCAM project 2
CCAM project 3
…

[1] As mentioned in the EU-CEM Handbook sustainability chapter, sustainability impact assessment mainly concerns the societal scenarios level, although impacts may also be analysed at the transport system level using traffic scenarios to identify the conditions under which benefits are maximised and disbenefits minimised (please refer to the EU-CEM Handbook Chapter 3.3 for an in-depth discussion on the scenario levels).

3.3.2 Define criteria and indicators for comparing different options

In the context of the EU-CEM Handbook, the criteria may consist of (a subset of) the impact areas, depending on the specific CCAM project, its objectives, and data availability for the indicators. The indicators used to evaluate how well the various CCAM options meet the criteria would then be taken from the list of indicators suggested for each evaluation area in the EU-CEM Handbook. In certain CCAM projects, it may be the case that not all proposed indicators in a specific evaluation area are collected due to data unavailability, technical challenges, or other constraints. Alternatively, some projects might have produced additional indicators beyond the recommended ones in the EU-CEM Handbook. In such cases, it might be challenging to ensure that the options remain comparable, as indicators (and potentially criteria) might not be the same between the CCAM alternatives being evaluated, which would require the project team to carefully evaluate the best way to address such cases (e.g., by focusing on the indicators that are consistently available across all projects to maintain a uniform set of indicators).

Table 4. Examples of criteria and indicators (limited selection based on EU-CEM Handbook – for illustrative purposes only)

Criteria (from EU-CEM Handbook Impact areas)	Indicator	Unit
Technical functioning of vehicle	Frequency of system failures	# system failures per km driven
	Disengagement rate	# Disengagements per km driven
User	Willingness of users to adopt and continue using the CCAM system in the future	Measure on a relevant scale
	User experience with the system	Measure on a relevant scale
	Non-user experience (views and experiences of non-users affected by the system)	Measure on a relevant scale
People mobility	Amount of travel an individual does in total within a specific time (e.g., year)	# trips; # kms; # hours
	Value of travel time (Perceived costs of travel time)	€/time unit
Traffic safety	Accident risk	# per exposure unit (e.g., # of accidents per vehicle km driven; # of accidents per hours driven…)
	Accident severity	% (Probability of a given accident severity level (fatal, serious, slight) once an accident has occurred)
Energy and environment	CO2 emissions	g/VKT/vehicle category; g/pax-km; g/tonne-km
	Pollutant emissions	g/VKT/vehicle category; g/pax-km; g/tonne-km
	Air quality exposure	µg/m3; # of inhabitants exposed to concentration levels exceeding legal limits or defined thresholds.
	Noise exposure	Db(A); # of inhabitants exposed to noise levels exceeding legal limits or defined thresholds.
Accessibility	Reachable activities	# of activities of a given category reachable within a defined travel time

Criteria (from EU-CEM Handbook Impact areas)	Indicator	Unit
	Mobility options	# of mobility options available within a specified distance for trips from home to destination
	Understandability of mobility options	% of users who struggle to use a specific mobility option
	Affordability	Average share of household budget spent on mobility
…	…	…

3.3.3 Eliciting preferences from stakeholders

Once options and the criteria for comparing the different CCAM options are established, the relevant identified stakeholder groups can be involved for the elicitation of preferences. As mentioned earlier, preference elicitation aims to determine the values of parameters related to preferences within decision support models. In the context of multi-criteria analysis, a preference-related parameter can be the score (based on a given rating technique) given by a stakeholder to a criterion, which is later converted into the weight of that criterion in the perspective of that stakeholder.

Different stakeholders can be involved for the elicitation of preferences. One group that will likely always be present is the project team itself, but it might also be relevant to include a more diverse group of stakeholders to gain a broader and more comprehensive understanding of the significance of different criteria for the assessed group, as discussed in chapter 2.

3.3.3.1 Level at which stakeholders will provide input

The first decision that the project team has to make refers to whether stakeholders will provide their input at the level of criteria or indicators. External stakeholders (i.e., beyond the project team) are most likely to offer their preferences at the criteria level (e.g., traffic safety, accessibility, energy and environment, etc), unless they are comfortable and capable of providing input at the indicator level within each criterion (e.g., accident risk, accident severity, mobility options, affordability, reachable activities). A discussion on the operational level regarding the process in which the elicitation of preferences from stakeholders takes place is beyond the scope of this article, but it is likely that educational or contextualisation materials on the diverse impacts of CCAM across the EU-CEM impact areas, along with examples of potential impacts, would be necessary as preparatory materials before stakeholders can provide their preferences regarding the available criteria.. Additionally, workshops, focus groups, interviews, or surveys can be utilised to gather the necessary input, and online platforms can support the process by offering questionnaire or whiteboard functionalities relevant for data collection purposes.

The project team is expected to provide input on the importance of each indicator within a criterion, given their familiarity with CCAM assessments and the specifics of the measured indicators within the available criteria. However, the project team can also contribute input regarding the available criteria, which would then be combined with input from other stakeholders to derive the aggregated weights of each criterion and indicator (see section 3.3.4 for details).

Figure 5 provides an illustrative example from the Australian Government's Guide to Multi-Criteria Analysis, showcasing the weights of various criteria within an objective and different measures (or indicators) within a criterion. The specific numerical values of the weights (e.g., 50%, 30%) at the indicator or criteria level can be derived from the methods discussed in the next section.

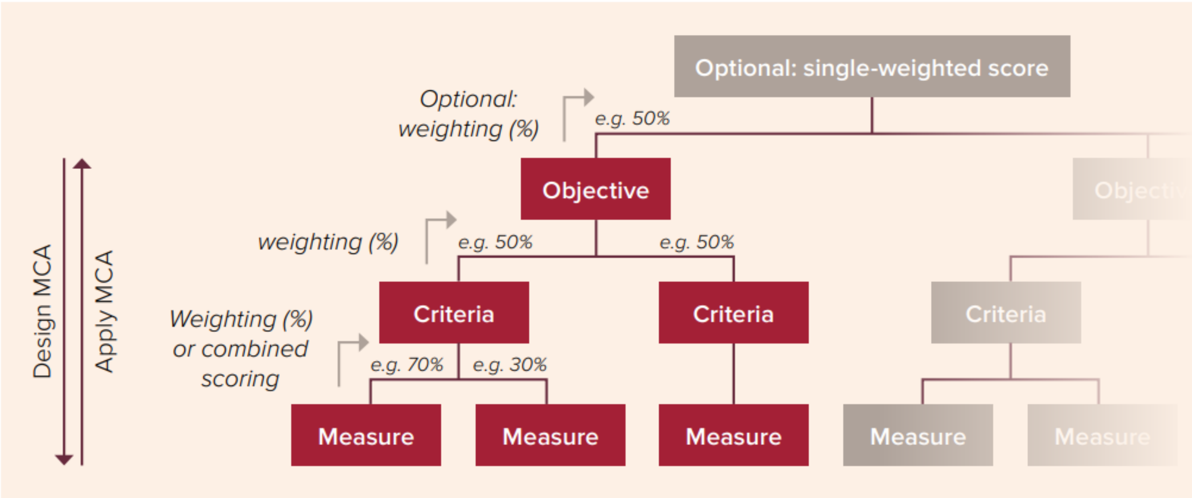

Figure 5. Example of a MCA hierarchical structure with corresponding weights for indicators (measures) and criteria (Source: (Infrastructure Australia, 2021))

3.3.3.2 Method used to elicit preferences from stakeholders

The second decision refers to the method by which stakeholders will provide their input. There are various techniques available in the literature, typically categorised into two groups:

1. **Ratio Assignment Techniques (RAT).** These techniques involve eliciting stakeholder preferences by asking them to assign scores (or points) to each criterion, from which the corresponding weights are then calculated (Ezell et al., 2021). There are multiple ratio assignment techniques, such as Direct Assignment Technique (DAT), Simple Multi Attribute Rating Technique (SMART), Swing Weight Technique (SWING), and Simple Pairwise Comparison (PW) (Ezell et al., 2021).
2. **Approximate techniques (AT).** These methods determine weights mainly through the ordinal ranking of criteria based on their relative importance. Stakeholders provide their preferences (i.e., ranking) for the available criteria, but do not offer quantitative details on the extent of importance of one criterion over another (Ezell et al., 2021). Examples include Equal Weighting (EW), Rank Ordered Centroid Technique (ROCT), Rank Summed Weighting Technique (RSWT), and Rank Reciprocal Technique (RRT).

A thorough discussion on all the ratio assignment and approximate techniques is beyond the scope of this article, but a detailed discussion can be found in Ezell et al. (2021). Appendix 1 provides an overview of the techniques mentioned above. The decision on which method to use for eliciting preferences from stakeholders ultimately rests with the project team. They must consider factors such as project constraints (e.g., time and budget), the team's familiarity with various methodologies, the complexity of the method for stakeholder groups (i.e., will they be able to provide input at the expected level?), the type of input required from stakeholders (e.g., is a ranking of criteria sufficient, or must stakeholders also specify the intensity of their preferences?), the number of stakeholder groups involved, among others.

For illustration purposes, the Direct Assignment Technique (DAT) and Rank Ordered Centroid Technique (ROCT) methods are applied below in an illustrative example where a stakeholder is asked to provide his preferences regarding the following criteria:

- (Impact on) Traffic safety
- (Impact on) Energy and environment
- (Impact on) Accessibility
- (Impact on) Employment
- (Impact on) Liveability

Note: all examples mentioned bellow are for illustrative purposes only and do not represent actual results from the elicitation of preferences from stakeholders.

Direct Assignment Technique (DAT)

The stakeholder provides his input following a "fixed pot of points" approach with a total of 1000 points to be allocated.

Table 5. Illustrative example of the application of the Direct Assignment Technique (DAT)

Criteria	**Score** (A)	**Total Score** ((B) = ∑ (A))	**Weight** (C = (A) / (B))	**Sum of weights** ((D) = ∑ (C))
Energy and environment	400	1,000	0.40	1.00
Traffic safety	270		0.27	
Accessibility	120		0.12	
Liveability	110		0.11	
Employment	100		0.10	

Rank Ordered Centroid Technique (ROCT)

The stakeholder offers his input solely by ranking the available criteria according to his preferences, without providing any additional information on the extent to which he prefers one criterion over another. Consider the same stakeholder as above is asked to rank the criteria according to his preferences, which would lead to:

1st criterion: Energy and environment
2nd criterion: Traffic safety
3rd criterion: Accessibility
4th criterion: Liveability
5th criterion: Employment

Once the ranking of the criteria has been stablished, the weights of the criteria (w_i) can be calculated using the following formula, as discussed by Ezell et al. (2021):

$$w_i = \frac{1}{N} \times \sum_{K=i}^{N} \frac{1}{K}$$

In which:

- w_i represents the weight of criterion i
- N represents the number of criteria

- K represents the rank of each item starting from the rank of the criterion being weighted (i) up to the total number of criteria (N)

The ROC method transforms a list of items ranked by importance into weights. It does this by examining each item's position in the ranking and considering all the positions below it. The weights are then averaged so that the total weight sums to 1. The weight of each of the criteria is then calculated as:

$$w_{\text{Energy and environment}} = \frac{1}{5} \times \left(1 + \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \frac{1}{5}\right) = 0.46$$

$$w_{\text{Traffic safety}} = \frac{1}{5} \times \left(\frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \frac{1}{5}\right) = 0.26$$

$$w_{\text{Accessibility}} = \frac{1}{5} \times \left(\frac{1}{3} + \frac{1}{4} + \frac{1}{5}\right) = 0.16$$

$$w_{\text{Liveability}} = \frac{1}{5} \times \left(\frac{1}{4} + \frac{1}{5}\right) = 0.09$$

$$w_{\text{Employment}} = \frac{1}{5} \times \left(\frac{1}{5}\right) = 0.04$$

Table 6 summarises the results obtained for the weights of each criterion by using the techniques Direct Assignment Technique (DAT) and the Rank Ordered Centroid Technique (ROCT). It is interesting to notice that for some criteria (e.g., Liveability, and particularly Traffic Safety), the weights obtained using both techniques were quite similar. However, for other criteria (e.g., Employment), the weights differed significantly, highlighting one of the limitations of techniques like ROCT. This difference underscores the contrast between knowing only the order of preference a stakeholder has for the criteria versus understanding the intensity of preference for each criterion.

Table 6. Summary of results for the weights of criteria using the Direct Assignment Technique (DAT) and the Rank Ordered Centroid Technique (ROCT)

Criteria	Weight (DAT)	Weight (ROCT)
Energy and environment	0.40	0.46
Traffic safety	0.27	0.26
Accessibility	0.12	0.16
Liveability	0.11	0.09
employment	0.10	0.04
TOTAL	**1.00**	**1.00**

Appendix 1 provides illustrative examples of how the weights of each criterion are calculated using the other methods mentioned in section 3.3.3.2.

3.3.4 Aggregate input from stakeholder groups

The examples provided in section 3.3.3.2 consider the case in which one stakeholder provides input regarding the priority of the available criteria. In real life CCAM projects, it is likely that the project team will want to involve a number of stakeholders in order to obtain a more diverse a comprehensive understanding of the importance of the different criteria.

Consider a situation in which 4 stakeholders provide their preferences regarding the criteria stated in the previous section using the Direct Assignment Technique (DAT). Table 7 presents an illustrative example with the scores provided by each stakeholder and the final weights for each of them.

Table 7. Summary of scores and weights for each criterion and stakeholder (illustrative data)

Stakeholder	Stakeholder 1		Stakeholder 2		Stakeholder 3		Stakeholder 4	
Criteria	**Score**	**Weight**	**Score**	**Weight**	**Score**	**Weight**	**Score**	**Weight**
Energy and environment	470	0.47	95	0.10	110	0.11	110	0.11
Traffic safety	95	0.10	135	0.14	215	0.22	515	0.52
Accessibility	100	0.10	90	0.09	485	0.49	50	0.05
Liveability	135	0.14	115	0.12	90	0.09	275	0.28
Employment	200	0.20	565	0.57	100	0.10	50	0.05
TOTAL	1000	1.00	1000	1.00	1000	1.00	1000	1.00

The Aggregation of Individual Priorities (AIP) approach can be used to aggregate the individual priorities (in blue in Table 7) into a single final priority. The most common approach for performing this is by using the arithmetic mean or the geometric mean. According to Forman and Peniwati (1998), while both the arithmetic and geometric mean can be used for AIP, the geometric mean aligns more closely with the meaning of judgments and priorities in AHP. If for some reason a given stakeholder is given a higher level of importance to their opinion by the project team (e.g., they represent a vulnerable population group or a group that is likely to have to bear more negative impacts of a CCAM system), the Aggregation of Individual Priorities (AIP) method can also be modified to take this into account.

Appendix 2 provides a more in-depth discussion of the example provided in Table 7 considering aggregation of priorities using both the arithmetic mean and the geometric mean, as well as with equal and unequal levels of importance among each stakeholder individual priority.

3.3.5 Compare options based on results of indicators and input from stakeholder groups

The steps taken thus far enable the project team to gain a comprehensive view of how various stakeholder groups perceive the importance of relevant criteria in the context of CCAM implementations. Beyond the individual priorities of the stakeholders, a consolidated perspective can also be achieved. If the project team aims to better understand which criteria are most valued by stakeholders in a broader sense when considering CCAM projects and systems, the results obtained up to this point can already offer valuable insights.

However, if the project team aims to identify which options perform "best"— based on how different stakeholder groups prioritise the available criteria — in order to identify the most suitable CCAM options for a given situation, it is necessary to refer back to the actual results obtained for each option and indicator. This section provides an illustrative example of how this can be done.

3.3.5.1 Illustrative comparison of CCAM projects

Consider an illustrative example in which different projects develop and test CCAM services, and the project team wishes to compare the services considering both indicators results from these projects and input from stakeholders.

Note: all examples mentioned bellow are for illustrative purposes only and do not represent actual weights obtained from elicitation of preferences from stakeholders or measured indicators from CCAM assessments.

1. Collecting input from stakeholders for illustrative case

Consider that four stakeholder groups were involved in providing their input regarding the criteria of Energy and Environment, Traffic Safety, Accessibility, Liveability, and Employment. Each stakeholder used the Direct Assignment Technique, following a "fixed pot of points" approach with a total of 1000 points to be allocated among all criteria. After prioritisation by the stakeholders and the calculation of the corresponding weights, all individual stakeholder weights were aggregated into a final priority weight (column in blue in Table 8) using the geometric mean method, with all stakeholders having equal importance (see Appendix 2 for details).

Table 8. Summary of stakeholders' priorities and final aggregated criteria weights

Stakeholder	Stakeholder 1		Stakeholder 2		Stakeholder 3		Stakeholder 4		Final aggregated weights (geometric mean)	
Criteria	**Score**	**Weight**	**Score**	**Weight**	**Score**	**Weight**	**Score**	**Weight**	**Not normalised**	**Normalised**
Energy and environment	470	0.47	95	0.10	110	0.11	110	0.11	0.15	0.20
Traffic safety	95	0.10	135	0.14	215	0.22	515	0.515	0.19	0.25
Accessibility	100	0.10	90	0.09	485	0.49	50	0.05	0.12	0.16
Liveability	135	0.14	115	0.12	90	0.09	275	0.275	0.14	0.18
Employment	200	0.20	565	0.57	100	0.10	50	0.05	0.15	0.20
TOTAL	1000	1.00	1000	1.00	1000	1.00	1000	1.00	0.76	1.00

2. Definition of criteria and indicators for illustrative case

For this illustrative case, assume the following indicators within each criterion were selected from the suggested list of indicators on EU-CEM Handbook. The weight (within each criterion) is assumed to be allocated based on expert consultations (i.e., provided by the project team via one of the methods discussed in Appendix 1) and will be used alongside input from various stakeholder groups (at the criteria level) to compare different projects.

The total weight of all indicators within the same criterion always equals one. Each indicator can have either a positive or negative polarity. An indicator with positive polarity means that higher values are more desirable (e.g., happiness), whereas an indicator with negative polarity indicates that lower values are more desirable (e.g., depression). The weighted contribution of each indicator can then be calculated by multiplying the weight of that indicator (in this case provided by experts) with the final weight of the criterion to which the indicator belongs (aggregated based on input from all stakeholders involved – provided by column in blue in Table 8).

Table 9 summarises the results. Only a limited number of indicators were selected for illustrative purposes (see the EU-CEM Handbook for a full list of recommended indicators for each impact area).

Table 9. Summary of criteria, indicators and weights for illustrative case

Criteria	Indicator	Polarity	Weight (within criterion)	Cumulative weight of criteria	Weighted contribution of indicator	Cumulative global weight

			(considered to have been assigned by expert consultation with project team for each criterion on first column)	*(cumulative weight of each criterion is always equal to one and represents the sum of all weights within criterion)*	*(= weight (within criterion) × final aggregated weight of criterion (normalised weights from Table 8))*	*(= SUM of all weights in column Weighted contribution of indicator)*
Energy and environment	CO2 emissions	Negative (i.e., lower values are preferred)	0.50	1	0.50 × 0.20 = **0.10**	= 0.10 + 0.06 + 0.04 + 0.13 + 0.13 + 0.05 + 0.05 + 0.06 + 0.18 + 0.20 = **1.00**
	Air quality exposure	Negative (i.e., lower values are preferred)	0.30		0.30 × 0.20 = **0.06**	
	Noise exposure	Negative (i.e., lower values are preferred)	0.20		0.20 × 0.20 = **0.04**	
Traffic safety	Road injuries or injury accidents	Negative (i.e., lower values are preferred)	0.50	1	0.50 × 0.25 = **0.13**	
	Accident risk	Negative (i.e., lower values are preferred)	0.50		0.50 × 0.25 = **0.13**	
Accessibility	Reachable activities	Positive (i.e., higher values are preferred)	0.30	1	0.30 × 0.16 = **0.05**	
	Reachable people, households or businesses	Positive (i.e., higher values are preferred)	0.30		0.30 × 0.16 = **0.05**	
	Affordability	Negative (i.e., lower values are preferred)	0.40		0.40 × 0.16 = **0.06**	
Liveability	Community cohesion	Positive (i.e., higher values are preferred)	1.00	1	1.00 × 0.18 = **0.18**	
Employment	Number of jobs	Positive (i.e., higher values are preferred)	1.00	1	1.00 × 0.20 = **0.20**	

3. Visualising indicator results of CCAM projects

By linking back to the various CCAM projects under evaluation in this illustrative case and their illustrative results for the selected indicators, a situation similar to the one depicted in Figure 6 can be obtained. For instance, CCAM Project 1 scores positively on indicators such as road injuries, accident risk, and affordability, but negatively on reachable households and community cohesion. Similarly, CCAM Project 3 performs well on indicators of CO2 emissions and air quality, while it scores poorly on indicators related to road injuries and reachable activities.

Even though the actual results of each scenario can be presented (as measured) in a performance matrix as depicted in Figure 6, the EU-CEM sustainability chapter advises that the evaluation of whether CCAM is more or less sustainable than the current transport system for the defined societal scenarios should be performed in comparison to a baseline scenario (see EU-CEM Handbook for details).

Legend:

- **Positive polarity** — Refers to an indicator in which **the higher the value, the better.**
- **Negative polarity** — Refers to an indicator in which **the lower the value, the better.**

↓ Indicators

	CO2 emissions [g/VKT/vehicle category]	Air quality exposure [Number of inhabitants exposed to concentration levels exceeding legal limits or defined thresholds - in thousands]	Noise exposure [Number of inhabitants exposed to noise levels exceeding legal limits or defined thresholds - in thousands]	Road injuries or injury accidents [number of accidents - in thousands]	Accident risk [number of accidents per vehicle km driven - in thousands]	Reachable activities [number of activities of a given category reachable within a defined travel time - in thousands]	Reachable people, households or businesses [Number of households that can be reached from an activity centre within a defined travel time - in thousands]	Affordability [Average share of household budget spent on mobility]	Community cohesion [Composite score representing the social bonds and collective identity within a community (scale -100)]	Number of jobs [number of jobs - in thousands]
Weighted contribution of indicator →	0.10	0.06	0.04	0.13	0.13	0.05	0.05	0.06	0.18	0.20
Cumulative global weight →	0.10 + 0.06 + 0.04 + 0.13 + 0.13 + 0.05 + 0.05 + 0.06 + 0.18 + 0.20 = 1.00									
Polarity of indicator →	Negative	Negative	Negative	Negative	Negative	Positive	Positive	Negative	Positive	Positive
↓ CCAM Projects										
CCAM project 1	33.00	25.00	50.40	9.00	51.44	45.75	72.10	0.46	10.00	40.17
CCAM project 2	67.00	87.00	35.00	35.00	244.06	34.86	96.58	0.51	93.00	15.94
CCAM project 3	27.82	22.50	83.90	76.30	191.40	7.38	99.37	0.56	15.00	13.44
CCAM project 4	65.00	38.00	57.60	38.00	78.91	68.77	146.45	0.88	23.00	38.65
CCAM project 5	36.00	57.00	86.00	30.00	105.84	56.44	167.90	0.67	12.00	53.81

← **Worse outcomes** (compared to available options) — **Better outcomes** (compared to available options) →

Figure 6. Heatmap-style visualisation of the performance of each indicator for each CCAM project. A diverging colour gradient was used to visually represent the CCAM projects that perform better (darker green) or worse (darker red) for each indicator, depending on its polarity (**illustrative data**).

In order to obtain an overall picture of the different CCAM projects (i.e., the alternatives) across all indicators under evaluation, the preferences of the stakeholders, in the form of the final weights of the indicators, can be incorporated into a “score” calculated for each CCAM project. A common approach in multi-criteria analysis is to use a linear additive model to compute a final score for each option under evaluation. The linear additive model demonstrates how the values of an option across different criteria can be combined into a single overall value by multiplying the value score of each criterion by its respective weight and then summing all these weighted scores into a final overall score (Department for Communities and Local Government, 2009). In the context of the illustrative CCAM assessment, the final score of each CCAM project is calculated by multiplying the score obtained by each project for each indicator by the weight of that indicator, and then summing these weighted scores across all indicators.

This linear additive method is performed using the following equation.

$$S_i = \sum_{j=1}^{n} w_j x_{ij}$$

In which:

- S_i: refers to the final score of option i (from a set of m options – from CCAM project 1 to CCAM project 5 in the illustrative case)
- w_j: refers to the weight of each indicator (i.e., the weighted contribution of each indicator), in which $\sum_{j=1}^{n} w_j = 1$
- x_{ij}: refers to the score of option i on indicator j (i.e., the actual result of indicator j for option i). These values usually have to be normalised due to the fact that they potentially refer to very different types of indicators and units of measure (e.g., grams of CO2 per kilometre, thousands of people exposed to noise levels, percentage of household income, etc).

As mentioned above, given that different criteria often have different units or scales, the values have to be normalised in order to make them comparable. Without normalising, criteria with large numeric ranges (e.g., thousands of people) would dominate the final score, even if stakeholders to not give these criteria higher weights. There are different normalisation methods, and the most suitable one should be investigated by the project team based on the purpose of the analysis and how the corresponding data is distributed. A common method is the Min-Max normalisation, but the Z-score, Distance to a reference point, and others can also be useful (see OECD (2008) for an in-depth discussion on normalisation methods).

For the purpose of the illustrative case at hand, the Min-Max normalisation will be used, which is also the method used by the OECD Better Life Index[5]. For each indicator, the normalisation method below is performed:

$$x_{ij_{normalised}} = \begin{cases} \dfrac{x_{ij} - x_{min}}{x_{max} - x_{min}}, if\ positive\ polarity \\ 1 - \dfrac{x_{ij} - x_{min}}{x_{max} - x_{min}}, if\ negative\ polarity \end{cases}$$

[5] See OECD Better Life Index for more information

Where x_{ij} represents the actual observed value for a given indicator in a given option (i.e., the coloured cells in Figure 6), x_{min} represents the minimum value for that given indicator across all considered alternatives, and x_{max} represents the maximum value for that given indicator across all considered options. The application of the Min-Max normalisation to the illustrative results depicted in lead to the following results, in which for each indicator the actual observed values are converted to normalised values varying in a range between 0 (for the worst observed outcome) and 1 (for the best observed outcome).

The final score of each CCAM project can then be computed using the linear additive model as described. Figure 7 shows the normalised indicator values corresponding to the performance matrix depicted in Figure 6 and Figure 8 shows the final score of each CCAM option (project) after performing the linear aggregation.

Figure 8 shows that based on the results of each CCAM project for each indicator and the aggregated weight of the indicators (derived from stakeholder preferences regarding the criteria and the allocation of weights to the indicators within each criterion by the project team), CCAM Project 1 emerges as the option with the highest final score (0.67) in this illustrative example, followed by CCAM Project 5 (0.61) and CCAM Project 4 (0.47).

It is important to emphasise that what the final score does is a mathematical abstraction used to compare the different alternatives on the same scale (a score from 0-1). If the weights of the indicators were different (e.g., a higher importance of indicators on reachable households and community cohesion, and a lower importance of indicators on road injuries and accident risk), other CCAM projects could yield a higher final scores than CCAM project 1.

4. Special case: one or more indicators exceed acceptable thresholds

The method illustrated in the previous subsections can be further expanded to consider additional cases. One important example to consider is when one or more indicators exceed a given acceptable threshold (higher or lower than acceptable limit). Thresholds values can be set for instance in compliance with policy targets and legal instruments, scientific criteria, among other reasons decisions (Dean, 2020). An indicator would exceed an acceptable threshold if it depicts higher values than what is acceptable (in case of a negative polarity indicator, such as an air pollution indicator), or if it depicts lower values than what is acceptable (in case of a positive polarity indicator, such as an indicator on minimum desired levels of mobility options).

For such situations, the final score of each options depicted in Figure 8 can be adjusted in order to penalise alternatives that violate (higher or lower) acceptable threshold. To operationalise this, in case one or more indicators have an acceptable threshold, this information would be considered when calculating the final score of each scenario. A auxiliary variable can be set to 1 if none of the indicators in a given alternative violate acceptable thresholds. In that case, the final score of each option would remain the same (as a number $n \times 1 = n$). In contrast, if a given alternative depicts a value for one or more indicators that violate acceptable thresholds, this auxiliary variable can be set to 0 (or -1), effectively bringing the final score of that alternative to zero or negative numbers. Once the final score of the available alternatives are ranked from highest to lowest, the final score of these scenarios would be sent to the bottom of the list, which could also be filtered to remove such cases from further consideration.

Legend:

Positive polarity (↑)
Refers to an indicator in which **the higher the value, the better.**

Negative polarity (↓)
Refers to an indicator in which **the lower the value, the better.**

↓ **Indicators**

	CO2 emissions *[g/VKT/vehicle category]*	Air quality exposure *[Number of inhabitants exposed to concentration levels exceeding legal limits or defined thresholds - in thousands]*	Noise exposure *[Number of inhabitants exposed to noise levels exceeding legal limits or defined thresholds - in thousands]*	Road injuries or injury accidents *[number of accidents - in thousands]*	Accident risk *[number of accidents per vehicle km driven - in thousands]*	Reachable activities *[number of activities of a given category reachable within a defined travel time - in thousands]*	Reachable people, households or businesses *[Number of households that can be reached from an activity centre within a defined travel time - in thousands]*	Affordability *[Average share of household budget spent on mobility]*	Community cohesion *[Composite score representing the social bonds and collective identity within a community (scale -100)]*	Number of jobs *[number of jobs - in thousands]*
Weighted contribution of indicator →	0.10	0.06	0.04	0.13	0.13	0.05	0.05	0.06	0.18	0.20
Cumulative global weight →	0.10 + 0.06 + 0.04 + 0.13 + 0.13 + 0.05 + 0.05 + 0.06 + 0.18 + 0.20 = 1.00									
Polarity of indicator →	↓	↓	↓	↓	↓	↑	↑	↓	↑	↑
↓ CCAM Projects										
CCAM project 1	1.00	0.96	0.70	1.00	1.00	0.63	0.00	1.00	0.00	0.66
CCAM project 2	0.00	0.00	1.00	0.61	0.00	0.45	0.26	0.88	1.00	0.06
CCAM project 3	1.00	1.00	0.04	0.00	0.27	0.00	0.28	0.76	0.06	0.00
CCAM project 4	0.05	0.76	0.56	0.57	0.86	1.00	0.78	0.00	0.16	0.62
CCAM project 5	0.79	0.47	0.00	0.69	0.72	0.80	1.00	0.50	0.02	1.00

Lower values (closer or equal to 0) ← → **Higher values** (closer or equal to 1)

Figure 7. Heatmap-style visualisation of normalised performance of each indicator for each CCAM project. A diverging colour gradient was used to visually represent the CCAM projects that perform better (darker green) or worse (darker red) for each indicator (illustrative data).

Legend:

↑ **Positive polarity**
Refers to an indicator in which **the higher the value, the better.**

↓ **Negative polarity**
Refers to an indicator in which **the lower the value, the better.**

↓ Indicators

	CO2 emissions [g/VKT/vehicle category]	Air quality exposure [Number of inhabitants exposed to concentration levels exceeding legal limits or defined thresholds - in thousands]	Noise exposure [Number of inhabitants exposed to noise levels exceeding legal limits or defined thresholds - in thousands]	Road injuries or injury accidents [number of accidents - in thousands]	Accident risk [number of accidents per vehicle km driven - in thousands]	Reachable activities [number of activities of a given category reachable within a defined travel time - in thousands]	Reachable people, households or businesses [Number of households that can be reached from an activity centre within a defined travel time - in thousands]	Affordability [Average share of household budget spent on mobility]	Community cohesion [Composite score representing the social bonds and collective identity within a community (scale 1-100)]	Number of jobs [number of jobs - in thousands]
Weighted contribution of indicator →	0.10	0.06	0.04	0.13	0.13	0.05	0.05	0.06	0.18	0.20
Cumulative global weight →	0.10 + 0.06 + 0.04 + 0.13 + 0.13 + 0.05 + 0.05 + 0.06 + 0.18 + 0.20 = 1.00									
Polarity of indicator →	↓	↓	↓	↓	↓	↑	↑	↓	↑	↑
↓ CCAM Projects										
CCAM project 1	1.00	0.96	0.70	1.00	1.00	0.63	0.00	1.00	0.00	0.66
Final score of project 1	(1.00 × 0.10) + (0.96 × 0.06) + (0.70 × 0.04) + (1.00 × 0.13) + (1.00 × 0.13) + (0.63 × 0.05) + (0.00 × 0.05) + (1.00 × 0.06) + (0.00 × 0.18) + (0.66 × 0.20) = **0.67**									
CCAM project 2	0.00	0.00	1.00	0.61	0.00	0.45	0.26	0.88	1.00	0.06
Final score of project 2	(0.00 × 0.10) + (0.00 × 0.06) + (1.00 × 0.04) + (0.61 × 0.13) + (0.00 × 0.13) + (0.45 × 0.05) + (0.26 × 0.05) + (0.88 × 0.06) + (1.00 × 0.18) + (0.06 × 0.20) = **0.40**									
CCAM project 3	1.00	1.00	0.04	0.00	0.27	0.00	0.28	0.76	0.06	0.00
Final score of project 3	(1.00 × 0.10) + (1.00 × 0.06) + (0.04 × 0.04) + (0.00 × 0.13) + (0.27 × 0.13) + (0.00 × 0.05) + (0.28 × 0.05) + (0.76 × 0.06) + (0.06 × 0.18) + (0.00 × 0.20) = **0.27**									
CCAM project 4	0.05	0.76	0.56	0.57	0.86	1.00	0.78	0.00	0.16	0.62
Final score of project 4	(0.05 × 0.10) + (0.76 × 0.06) + (0.56 × 0.04) + (0.57 × 0.13) + (0.86 × 0.13) + (1.00 × 0.05) + (0.78 × 0.05) + (0.00 × 0.06) + (0.16 × 0.18) + (0.62 × 0.20) = **0.49**									
CCAM project 5	0.79	0.47	0.00	0.69	0.72	0.80	1.00	0.50	0.02	1.00
Final score of project 5	(0.79 × 0.10) + (0.47 × 0.06) + (0.00 × 0.04) + (0.69 × 0.13) + (0.72 × 0.13) + (0.80 × 0.05) + (1.00 × 0.05) + (0.50 × 0.06) + (0.02 × 0.18) + (1.00 × 0.20) = **0.61**									

Lower values (closer or equal to 0) ← → **Higher values** (closer or equal to 1)

Figure 8. Calculation of the final score of each CCAM project

3.4 Risks and limitations of the discussed methodology

The methods discussed in this article regarding computing weights for different criteria and aggregating the results into a final score for each alternative (via the linear additive method) have some important risks and limitations that should be taken into account by the project team interested in exploring such methods:

1. **Double counting effects in multi-criteria analysis.**

   As mentioned in the Multi-criteria analysis manual for making government policy, double counting "should not be allowed in MCA, since double counted effects are likely to be given more weight in the final overall decision than they deserve." (Department for Communities and Local Government, 2009, p.37). Double counting may lead to an inflated or deflated ranking of options (Chief Minister, Treasury and Economic Development, n.d.). Some general recommendations include a careful evaluation by the project team of the available criteria and indicators to ensure that the same benefit or effect is not being double counted and if other methods such as CBA are also being conducted, then the project team should be careful not to include evaluation criteria that may be assessed through the CBA, so as not to double-count benefits (Chief Minister, Treasury and Economic Development, n.d.). If necessary, the project team should involve subject matter experts in multi-criteria analysis for a more thorough assessment.

2. **Comparing CCAM alternatives using a linear additive model**

   The process described in section 3.3.5.1 of computing a final score of each alternative under evaluation using a linear additive model has an important limitation. The primary condition for justifying the use of the additive form is mutual preferential independence (MPI) of the criteria; if this cannot be assured, more complex models should be employed (Antov, 2018). In strict terms, MPI implies that the trade-off between any two criteria remains unaffected by the performance level of any third criterion (An Introductory Guide to Multi-Criteria Decision Analysis (MCDA) – Government Analysis Function, n.d.).

   In an additive model where there is mutual preferential independence of the criteria, each criterion independently contributes to the final score of each alternative. This means that **a stakeholder's preferences regarding one criterion do not depend on the performance of the other criteria**. However, the issue is that preferences "are not always mutually independent. For example, the enjoyment a person gets from consuming a trifle may not be the sum of the amount of jelly, custard, sponge, etc. it contains, but be related in some way to the proportions in which they are combined. If this is the case, a simple weighted sum of the amounts of jelly, custard and so forth contained in a set of option trifles will not in general reproduce the preference ranking that the individual has for the trifles." (Department for Communities and Local Government, 2009, p.36).

   In practical situations, interactions between criteria may occur, indicating that the assumption of additivity does not always hold true (Liang et al., 2022). Moreover, this assumption is often not examined to confirm whether preference independence is applicable to a specific composite indicator (Munda & Nardo, 2008). In the context of the assessment of CCAM implementations, if stakeholders "are reluctant to offer preference judgements on the grounds that 'it depends' on another criterion" (An Introductory Guide to Multi-Criteria Decision Analysis (MCDA) – Government Analysis Function, n.d.), it is likely that the criteria do not have mutual preferential independence. In such cases, the project team might investigate whether it is possible to review the criteria to ensure MPI, might decide not to perform a linear additive aggregation of the criteria and scores (and investigate the suitability of different methods for such cases, such as ELECTRE, PROMETHEE, or Choquet Integral Models), or use the final score of a CCAM option as one additional source of information in assessing CCAM impacts, but not the sole factor, while also highlighting that the final scores might not entirely accurately represent how stakeholders perceive those criteria.

3. **Comparing alternatives with different scale scenarios**

   When comparing alternatives, it might be the case that one or more alternative involves lower-level scenarios. According to the EU-CEM guidelines, scaling up is necessary when estimating impacts on the societal level based on results from lower-level scenarios. Therefore, even if the same criteria and indicators are being considered, if some of the alternatives include lower-level scenarios (e.g., on a particular road section or within a limited area or based on a limited group of participants), while others consider societal scenarios (e.g., covering entire networks and all trips made in them, including non-automated vehicles and non-motorised travel) the project team might need to estimate the impacts over broader regions and longer periods compared (scaling up) before a comparison with other alternatives can be performed (see Guideline 3.14. from the EU-CEM for a more in-depth discussion on scaling up results).

4. Conclusions

This article aimed to provide an overview of methods for identifying and eliciting stakeholder preferences to prioritise criteria and compare CCAM alternatives. It serves as a supplementary material for the EU-CEM Handbook, and, similar to the handbook, it is intended for professionals involved in planning and evaluating CCAM projects. The article is structured around two guiding questions: **(1)** how can different CCAM alternatives be compared, and **(2)** which stakeholders' preferences are relevant for this comparison? As CCAM can have impacts on single vehicles, humans, the transport system, and society overall, as discussed in the EU-CEM Handbook, this article argues that for a comprehensive and inclusive assessment of CCAM impacts, it is important to consider both the values obtained for different indicators and how distinct stakeholder groups perceive the importance of each criterion.

The article was organised in two main chapters, one for the stakeholder identification (chapter 2), and one for the elicitation of stakeholder preferences and comparison of CCAM alternatives (chapter 3), with the remaining of the chapter providing an introduction (chapter 1), conclusion (chapter 4), references (chapter 5), and appendices (chapter 6).

Chapter 2 provided a brief overview of approaches for participation in governmental policy-making and decision-making based on identified literature. It includes guiding questions that can assist the CCAM project team in identifying relevant stakeholder groups for eliciting preferences concerning CCAM impact areas. These questions can support the project team to consider key concepts such as power, influence, authority, and legitimacy, as well as how these factors might affect different stakeholders, supporting the project team in identifying relevant stakeholders by not only developing a list of stakeholders, but also considering how relevant concepts such as power, interest or legitimacy might affect them differently.

Chapter 3 addressed how the project team can engage stakeholders to elicit their preferences and converting them into weights for multi-criteria analysis using different methods. The chapter also offers a brief overview of multi-criteria analysis to set the stage for further discussions. When multiple stakeholders are involved, as addressed in Chapter 2, chapter 3 discusses two methods for aggregating individual stakeholder priorities into a consolidated set of weights for different criteria – the arithmetic mean and the geometric mean. Once stakeholder preferences have been elicited and converted into weights, and the relevant CCAM alternatives identified, chapter 3 discusses how to combine the performance score of each alternative in each criterion with the weight of each indicator using a linear additive model to obtain a final score for each CCAM alternative. If any alternatives have performance scores for one or more indicators that exceed threshold values (e.g., higher or lower than acceptable levels), the chapter briefly discusses a proposed straightforward method to adjust the final score of each CCAM option. This involves using auxiliary variables (e.g., 0 or -1) that can be multiplied by the final score of each alternative that violates thresholds, making them more clearly identifiable (and possibly deemed unsuitable for consideration).

Chapter 3 concludes with an overview of key risks and limitations associated with using multi-criteria analysis to assess CCAM impacts. Firstly, it highlights the risk of double counting effects or benefits through indicators or criteria that measure essentially the same aspects. Secondly, it discusses the necessity of mutual preferential independence (MPI) for the linear additive model to be valid. MPI means that a stakeholder's preference for one criterion is independent of the performance of other criteria. If MPI does not hold, each criterion does not independently contribute to the final score, meaning that other more sophisticated methods beyond the linear additive model should be used. The chapter also addresses the issue of alternatives involving different scale scenarios. Some alternatives may include lower-level scenarios, such as specific road sections or limited areas, while others may consider broader societal scenarios, encompassing entire networks and all trips, including non-automated vehicles and non-motorised travel. In such cases, the project team may need to scale up scenarios (as discussed in the EU-CEM Handbook) before making comparisons between alternatives.

It is important to emphasise that this supplementary material does not replace the EU-CEM Handbook in any way. References to key concepts from the EU-CEM Handbook (e.g., CCAM scenarios, CCAM systems, etc) are made in this article for illustrative purposes, to provide examples connected to the EU-CEM Handbook content. Readers should refer back to the EU-CEM Handbook for proper definitions, contextualisation, and discussions. Multiple references to the EU-CEM Handbook have been added to this article whenever relevant. Finally, it is important for the project team to critically assess the suitability of the methods proposed in this article, considering the specific projects at hand, their purpose and scope, as well as factors like project budget and schedule, and the team's familiarity with stakeholder identification, preference elicitation, and multi-criteria analysis. For more nuanced or complex situations, such as involving risk of double counting and to ensure mutual preferential independence (MPI) of the criteria (in case the linear additive model is to be used), it is recommended to involve subject matter experts in multi-criteria analysis and stakeholder engagement.

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6. Appendices

6.1 Appendix 1 – Overview of techniques for the elicitation of preferences from stakeholders

This section presents an overview of the following techniques for the elicitation of preferences from stakeholders:

4. **Ratio Assignment Techniques (RAT).** These techniques involve eliciting stakeholder preferences by asking them to assign scores (or points) to each criterion, from which the corresponding weights are then calculated (Ezell et al., 2021). There are multiple ratio assignment techniques, such as Direct Assignment Technique (DAT), Simple Multi Attribute Rating Technique (SMART), Swing Weight Technique (SWING), and Simple Pairwise Comparison (PW) (Ezell et al., 2021).
5. **Approximate techniques (AT).** These methods determine weights mainly through the ordinal ranking of criteria based on their relative importance. Stakeholders provide their preferences (i.e., ranking) for the available criteria, but do not offer quantitative details on the extent of importance of one criterion over another (Ezell et al., 2021). Examples include Equal Weighting (EW), Rank Ordered Centroid Technique (ROCT), Rank Summed Weighting Technique (RSWT), and Rank Reciprocal Technique (RRT).

Table 10 below presents a summary of each technique, as well as their strengths and limitations, as identified in literature. Some illustrative example beyond the ones mentioned in section 3.3.3 Eliciting preferences from stakeholders are also provided.

Table 10. Overview MCA prioritisation techniques

Technique	Description	Strengths and limitations
Ratio Assignment Techniques (RAT)		
Direct Assignment Technique (DAT)	Participants assign a direct score to criteria, which could be a number based on a set of available points (“fixed pot of points”, e.g., 100 points in total to be distributed among the criteria), or based on a defined scale (“allocation of absolute points”, e.g., 0 – 5, 0 – 100). The resulting weights are then calculated by taking the ratio of individual scores to the total score among all criteria (Ezell et al., 2021). For the “allocation of absolute points” approach, participants may or may not be allowed to assign the same value to different criteria (e.g., giving a value of 5 on a scale from 0 to 5 to two or more criteria). The OECD Better Life Index[5] is an example of an index where users (i.e., visitors on the website) assign a score from 0 to 5 to the various topics within the index (users can assign the same value to two or more topics).	**Strengths**: • Straightforward implementation with stakeholders (Ezell et al., 2021). • Effort to apply this technique increases linearly with the number of criteria, as the number of questions required to assign weights using the direct assignment technique is equal to the number of criteria (Ezell et al., 2021). **Limitations**: • Weights determined using the "divide the pot" approach must be recalculated if new attributes are added or old ones are removed (Ezell et al., 2021). • A well-defined constructed scale indicating what different scoring levels mean needs to be provided to users to avoid situations where participants use different reference points. (Ezell et al., 2021). This could happen if, for example, on a 0 - 100 scale, one participant might view a score of "35" as "poor" and "100" as "perfection", while another sees 35 as "below average" and 100 as "of utmost importance".

Technique	Description	Strengths and limitations
Simple Multi Attribute Rating Technique (SMART)	Weights are determined indirectly through systematic comparison of criteria against the one considered to be the **least important**. Participants are asked to (1) rank the criteria from the least preferred to the most preferred, and (2) evaluate how much more important the remaining criteria are in relation to the reference (Ezell et al., 2021). For example, if 1,000 points are available for allocation to the different criteria, and there are four criteria (A, B, C, D), with criterion C being considered the least important by a given stakeholder. Criterion C could then be assigned a reference score of 50 points, while the other criteria would be allocated a higher number of points based on how much more important the stakeholder perceives them in comparison to the reference criterion.	**Strengths**: • This technique does not need to be repeated if old criteria are removed or new are added, unless the criterion being removed is the least important one, or if a newly added criterion becomes the least important (Ezell et al., 2021). • Effort to apply this technique increases linearly with the number of criteria, as the number of questions required to assign weights using the direct assignment technique is equal to the number of criteria minus one (Ezell et al., 2021). **Limitations**: • The choice of scores for the least or most important attributes can affect the resulting weights if other scores are not adjusted based on relative importance (e.g., if the least important criterion is assigned a value of 10 and another criterion is given a value of 30, the latter should be increased to 60 if the baseline score changes to 20 – if participant changes their mind for example) (Ezell et al., 2021).
Swing Weight Technique (SWING)	Similar to the Simple Multi Attribute Rating Technique (SMART), but criteria are systematic compared against the one considered to be the **most important** criterion (Ezell et al., 2021).	**Strengths**: • Same as for the Similar to the Simple Multi Attribute Rating Technique (SMART) **Limitations**: • Same as for the Similar to the Simple Multi Attribute Rating Technique (SMART)

Technique	Description	Strengths and limitations
Simple Pairwise Comparison (PW)	This method systematically assesses all pairs of criteria to determine which is more important, awarding a point to the criterion judged more important for each pairwise comparison. Criteria weights are then computed by dividing the number of points assigned to each criterion by the total number of points distributed across all criteria (Ezell et al., 2021). In this method, the process involves (1) pairwise ranking of the criteria by stakeholders, and (2) calculating weights by normalising each criterion score against the total score among all criteria.	**Strengths**: • Provides a simpler and more straightforward application process compared to other techniques, as it requires stakeholders to repeatedly indicate their preference between pairs of criteria (e.g., Criterion A vs Criterion B; Criterion A vs Criterion C; Criterion B vs Criterion C…) (Ezell et al., 2021). **Limitations**: • This approach does not inherently include checks for internal consistency (i.e., transitivity). For instance, if A > B (i.e., A is preferred to B), and B > C, then logically A > C. However, the technique by itself does not validate if preferences are consistent, being that left to the users (Ezell et al., 2021). Alternatively, expert software would need to be used to ensure consistency of preferences.
Analytic Hierarchy Process (AHP)	Can be considered a special case of Pairwise Comparison. The Analytic Hierarchy Process (AHP) was developed by Thomas L. Saaty in the 1970s and is a widely known and used multi-criteria decision making method. With the AHP method, stakeholders can score options according to their "relative strength of preferences and feelings" (Saaty, 1987, p.161). Criteria are assessed following a pairwise comparison scale from 1–9 , as proposed by Saaty (1987): • **1 – Options have equal importance (i → j).** Two options are perceived to contribute equally to the objective • **3 – Moderate importance of one over another (i → j).** Judgment moderately favour one option over another • **5 – Strong importance of one over another (i → j).** Judgment strongly favour one option over another • **7 – Very strong importance of one over another (i → j).** Judgment very strongly favour one option over another	**Strengths**: • Ease of explanation, simplicity in facilitating a group through the process, and the availability of user-friendly software to implement the AHP process (Ezell et al., 2021). • Pairwise comparisons are typically well-accepted in practice as a method for determining the relative importance of criteria and the relative performance of options (Department for Communities and Local Government, 2009). • Suitable for situations where judgements are the primary form of input information, as opposed to performance measurements (Department for Communities and Local Government, 2009). **Limitations**:

Technique	Description	Strengths and limitations
	• **9 – Extreme importance of one over another (i → j).** The preference for one of the options against the other is of the of the highest possible order of affirmation • **2,4,6,8 – Intermediate values between the two adjacent odd scales.** Used when compromise is needed (odd scale from 1-9 is usually preferred) • **Reciprocals –** If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	• Potential for Inconsistency Between Judgment and Ranking Criteria and for rank reversal • The total number of comparisons and the demands on the decision maker can become overwhelming as the number of criteria and hierarchical levels increase Ishizaka (2012). As the total number of pairwise comparisons needed is equal to (N × (N-1)) / 2, the number of necessary pairwise comparisons can become quickly too large.
Approximate techniques (AT)		
Equal Weighting (EW)	This technique assumes that no additional information is known about the relative importance of the different criteria. Therefore, all criteria receive the same priority, and consequently, the same weight – simply given by $w_i = \frac{1}{N}$. As mentioned by Ezell et al (2021), one of the reasons one might chose the equal weights approach is to adopt maximum entropy arguments. This implies that if nothing is known about a distribution except that it belongs to a certain class (typically defined by specific properties or measures), then the distribution with the highest entropy should be selected (Wikipedia contributors, 2025a). The Human Development Index (HDI) is an example of index in which an equal weigh is given to its subcomponents.	**Strengths**: • Simplest form of weighing technique • Can be useful as a starting point for analysis, in which no priority is given to any of the criteria ("balanced perspective") • Can be performed without formal stakeholder involvement, which can be viewed as either a strength or a limitation, depending on the context. **Limitations**: • Does not account for the varying importance of different criteria, potentially leading to oversimplification of complex decisions • Can be performed without formal stakeholder involvement, which can be viewed as either a strength or a limitation, depending on the context.
Rank Ordered Centroid Technique (ROCT)	This approach assumes knowledge of the ordinal ranking of preference attributes with no additional supporting quantitative information on how much more important one criterion is compared to the others. Participants provide	**Strengths**: • Capable of generating meaningful weights based on ordinal rankings of attributes (Ezell et al., 2021), making it useful for situations where decision-

Technique	Description	Strengths and limitations
	the ranking of the criteria according to how they perceive them, and the weights are then computed based on their ranks.	makers can easily rank items by importance but find it challenging to assign precise weights. • Can be easily implemented using standard spreadsheet tools (Ezell et al., 2021). **Limitations**: • Operates under the principle of applying a uniform distribution across the range of possible weights that a criterion can assume based on its importance rank (Ezell et al., 2021), which might not align with how stakeholders perceive the importance of the available criteria.
Rank Summed Weighting Technique (RSWT)	Operates similarly to the Rank Ordered Centroid Technique (ROCT), where participants rank the available criteria based on their perceptions, and the weights are then calculated according to the ranking. However, the method of computing the weights follows a different mathematical formulation than the Rank Ordered Centroid Technique (ROCT).	**Strengths**: • Same as for the Rank Ordered Centroid Technique (ROCT) **Limitations**: • Principle underlying the Rank Summed Weighting Technique (RSWT) technique is the weighting of each criterion in proportion to its rank order in terms of importance (Ezell et al., 2021), which might not align with how stakeholders perceive the importance of the available criteria.
Rank Reciprocal Technique (RRT)	Operates similarly to the Rank Ordered Centroid Technique (ROCT), where participants rank the available criteria based on their perceptions, and the weights are then calculated according to the ranking. However, the method of computing the weights follows a different mathematical formulation than the Rank Ordered Centroid Technique (ROCT).	**Strengths**: • Same as for the Rank Ordered Centroid Technique (ROCT) **Limitations**: • The use of a ratio assignment technique is advised when more precise weighting is possible, as Rank Reciprocal Technique (RRT) is most suitable when only an ordering of attributes is feasible (Ezell et al., 2021).

For all examples below, consider an illustrative case in which a stakeholder is asked to provide their preferences regarding the following criteria:

- (Impact on) Traffic safety
- (Impact on) Energy and environment
- (Impact on) Accessibility
- (Impact on) Employment
- (Impact on) Liveability

6.1.1 Ratio Assignment Techniques (RAT)

6.1.1.1 Direct Assignment Technique (DAT):

Example provided in section 3.3.3.2

6.1.1.2 Simple Multi Attribute Rating Technique (SMART):

The SMART technique follows the following steps, as described by Ezell et al. (2021): (1) rank order attributes, (2) establish the reference attribute, (3) estimate the importance of other attributes with respect to the reference attribute, and (4) calculate weights.

In this method, the least important attribute typically receives a default score, and the stakeholder assigns higher or equal scores (but not lower) to the other attributes based on their perceived importance relative to the reference attribute. In the illustrative example, "Liveability" is considered the least important criterion and is given a default value of 50.

Table 11. Illustrative example of the application of the Simple Multi Attribute Rating Technique (SMART)

Criteria	Rank	Score (A)	Total Score ((B) = ∑ (A))	Weight ((C) = (A) / (B))	Sum of weights ((D) = ∑ (C))
Energy and environment	1	400	1,000	0.40	1.00
Traffic safety	2	350		0.35	
Accessibility	3	125		0.13	
Employment	4	75		0.08	
Liveability *(least important)*	5	50		0.05	

6.1.1.3 Swing Weight Technique (SWING)

This technique follows the same overall process as the Simple Multi Attribute Rating Technique (SMART). However, in the SWING technique, the stakeholder ranks the criteria and then assign a reference score to the most important criteria. From that, the other criteria receive lower or equal (but not higher) scores based on their perceived importance relative to the reference attribute. In the illustrative example, "Energy and environment" is considered the most important criterion and is given a default value of 100.

Table 12. Illustrative example of the application of the Swing Weight Technique (SWING)

Criteria	Rank	Score (A)	Total Score ((B) = ∑ (A))	Weight ((C) = (A) / (B))	Sum of weights ((D) = ∑ (C))
Energy and environment *(most important)*	1	100	283	0.35	1.00
Traffic safety	2	85		0.30	
Accessibility	3	60		0.21	
Employment	4	25		0.09	
Liveability	5	12.5		0.04	

6.1.1.4 Simple Pairwise Comparison (PW)

Ezell et al. (2021) describe the pairwise comparison method for assigning weights as a process of systematically evaluating all pairs of criteria to identify which one the stakeholder considers more important. During each comparison, a point is awarded to the criterion deemed more significant by the stakeholder. Once all comparisons are completed, the weights of the criteria are calculated by dividing the points allocated to each criterion by the total points distributed among all criteria.

To perform the pairwise comparisons of N criteria, it is necessary to perform $N(N-1)/2$ comparisons. Therefore, for the illustrative example, a stakeholder would need to perform $5(5-1)/2 = 10$ comparisons. Consider that a given stakeholder performed the pairwise comparisons as depicted below.

Table 13. Illustrative example of Pairwise comparisons of criteria

Point	Comparison			Point
✓	Energy and environment	vs	Traffic safety	
✓	Energy and environment	vs	Accessibility	
	Energy and environment	vs	Employment	✓
✓	Energy and environment	vs	Liveability	
✓	Traffic safety	vs	Accessibility	
	Traffic safety	vs	Employment	✓
	Traffic safety	vs	Liveability	✓
	Accessibility	vs	Employment	✓
✓	Accessibility	vs	Liveability	
✓	Employment	vs	Liveability	

The above comparisons would lead to the following results.

Table 14. Illustrative example of the application of the Simple Pairwise Comparison (PW)

Criteria	Points	Weight
Energy and environment	3	0.30
Traffic safety	1	0.10
Accessibility	1	0.10
Employment	4	0.40
Liveability	1	0.10
TOTAL	**10**	**1.00**

6.1.1.5 Analytic Hierarchical Process (AHP)

As discussed by Ezell et al. (2021), AHP can be seen as a special case of the Simple Pairwise Comparison (PW) technique, and its popularity made it one of the more widely applied MCA methods (Department for Communities and Local Government, 2009). With the AHP method, stakeholders can score options according to their "relative strength of preferences and feelings" (Saaty, 1987, p.161) . Criteria are assessed by means of pairwise comparisons using a scale from 1–9 , as depicted below.

Table 15. Scales and rational for pairwise comparison in AHP (source: (Saaty, 1987))

Intensity of importance (absolute scale)	Definition	Explanation
1	Options have equal importance (i → j)	Two options are perceived to contribute equally to the objective
3	Moderate importance of one over another (i → j)	Judgment moderately favour one option over another
5	Strong importance of one over another (i → j)	Judgment strongly favour one option over another

7	Very strong importance of one over another (i → j)	Judgment very strongly favour one option over another
9	Extreme importance of one over another (i → j)	The preference for one of the options against the other is of the of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent odd scales	Used when compromise is needed (odd scale from 1-9 is usually preferred)
Reciprocals	If activity **i** has one of the above numbers assigned to it when compared with activity **j**, then **j** has the reciprocal value when compared with **i**	

Using the illustrative example, a stakeholder would conduct pairwise comparisons of the various criteria, answering the question for each pair (***X***, ***Y***), "How important is ***X*** relative to ***Y***?" with the proposed scale (1 – 9) or its reciprocals (1/9 – 1). An illustrative result of such pairwise comparison is depicted below.

Table 16. Illustrative matrix of pairwise comparisons of criteria using the AHP technique

Criteria	Energy and environment	Traffic safety	Accessibility	Employment	Liveability
Energy and environment	**1**	1/7	1/5	1/3	1/5
Traffic safety	7	**1**	2	3	3
Accessibility	5	1/2	**1**	3	1
Employment	3	1/3	1/3	**1**	5
Liveability	5	1/3	1	1/5	**1**
Total (collumn sum)	21.00	2.31	4.53	7.53	10.20

To achieve the preferences mentioned above, the stakeholder would conduct pairwise comparisons of the various criteria. Since this is a symmetrical matrix, only the upper section (i.e., above the main diagonal, in blue) needs to be completed. In a pairwise comparison matrix like the one shown, the main diagonal (in grey) is always equal to 1 (as it compares the same element with itself), and the lower section of the matrix (i.e., below the main diagonal, in green) automatically receives the reciprocal of the values provided in the upper section.

Once a matrix of pairwise comparisons is developed, in order to obtain the weights of each criteria, one has to solve for the principal eigenvector of the matrix and then normalise the results[6] . When exact calculations are required, expert software (or packages in programming languages such as Python) that perform AHP analyses are usually used. An approximation method to obtain the weights of each criteria is to normalise the elements in each column of the matrix of pairwise comparisons and then compute the average for each row, which is presented below.

[6] As discussed in Saaty, R. (1987, p.170), "The solution is obtained by raising the matrix to a sufficiently large power then summing over the rows and normalizing to obtain the priority vector w = (w_1,..., w_n). The process is stopped when the difference between components of the priority vector obtained at the k^{th} power and at the $(k + 1)^{th}$ power is less than some predetermined small value."

Table 17. Illustrative example of Eigenvector calculation for criteria

Criteria	Energy and environment	Traffic safety	Accessibility	Employment	Liveability	Approximate weight of criteria (average of row)*
Energy and environment	0.0476	0.0619	0.0441	0.0442	0.0196	0.043
Traffic safety	0.3333	0.4330	0.4412	0.3982	0.2941	0.380
Accessibility	0.2381	0.2165	0.2206	0.3982	0.0980	0.234
Employment	0.1429	0.1443	0.0735	0.1327	0.4902	0.197
Liveability	0.2381	0.1443	0.2206	0.0265	0.0980	0.146
Total (collumn sum)	1.0000	1.0000	1.0000	1.0000	1.0000	1.000

**Calculated using an approximate method by taking the arithmetic mean of all criteria (for precise Eigenvector calculations, specialised software is typically used)*

The values in the last column determine the criterion's participation (or weight) in relation to the goal's overall result. In the example above, Traffic safety has a weight of 38%, followed by Accessibility (23.4%), Employment (19.7%), Liveability (14.6%), and finally Energy and environment (4.3%). The sum of all rows in a given column result in one for all of the columns, and the sum of all the weights in the last column result in one.

To assess the consistency of pairwise comparisons and determine if a stakeholder's judgments are logically coherent, the AHP method suggests calculating the Consistency Ratio (CR). This involves comparing the consistency index (CI) of the pairwise comparison matrix with the consistency index of a random-like matrix (RI) (Mu & Pereyra-Rojas, 2016). A detailed discussion on this subject is outside the scope of this article, but further information on the Consistency Ratio and the thresholds suggested in literature can be found in sources such as Mu and Pereyra-Rojas (2016) and Saaty (1987).

6.1.2 Approximate techniques (AT)

6.1.2.1 Equal Weighting (EW)

This method presumes that there is no knowledge regarding the relative importance of the various criteria, or that the information necessary to differentiate between the criteria is unreliable (Ezell et al., 2021). In such situations, a conservative approach is to assume that the actual weights of the different criteria follow a uniform distribution[7]. One classic example of Equal Weights is the Human Development Index (HDI) by the United Nations Development Programme (UNDP).

In the Equal Weighting (EW) technique, all criteria receive the same weight, which is given by:

$$w_i = \frac{1}{N}$$

In which:

- w_i represents the weight of criterion i
- N represents the number of criteria

Table 18 shows the results of the criteria weights in the illustrative example using the Equal Weighting (EW) technique.

[7] This concept is rooted in entropy from information theory. Entropy relates to the degree of uncertainty or information linked to a variable's potential states or outcomes (Wikipedia contributors, 2025b). Consequently, if there is uncertainty about the weights of the available criteria, one might opt to minimise assumptions about the distribution of the weights, thereby maximising entropy (Ezell et al., 2021). This is accomplished by employing the Uniform Distribution, where uncertainty is at its peak when all possible events are equally likely (Wikipedia contributors, 2025b))

Table 18. Illustrative example of the application of the Equal Weighting (EW)

Criteria	Weight
Energy and environment	1/N = 0.2
Traffic safety	0.2
Accessibility	0.2
Employment	0.2
Liveability	0.2
TOTAL	**1.00**

6.1.2.2 Rank Ordered Centroid Technique (ROCT)

Example provided in section 3.3.3.2

6.1.2.3 Rank Summed Weighting Technique (RSWT)

Similar to the ROCT technique, in the Rank Summed Weighting Technique (RSWT), the stakeholder offers his input solely by ranking the available criteria according to his priorities and preferences, without providing any additional information on the extent to which he prefers one criterion over another. Consider a given stakeholder has the following rank of preferences regarding the available criteria.

1st criterion: Energy and environment
2nd criterion: Traffic safety
3rd criterion: Accessibility
4th criterion: Liveability
5th criterion: Employment

The weights of the criteria (w_i) in RSWT can be calculated using the following formula, as discussed by Ezell et al. (2021):

$$w_i = \frac{(\mathrm{N} - i + 1)}{(\sum_{K=1}^{N} N - k + 1)}$$

In which:

- w_i represents the weight of criterion i
- N represents the number of criteria
- i represents the rank of criterion being weighted (i)
- K represents each element in the set of available criteria (1 – N)

The weights of the criteria can then be computed.

$$w_{\text{Energy and environment}} = \frac{(5-1+1)}{(5-1+1)+(5-2+1)+(5-3+1)+(5-4+1)+(5-5+1)} = 0.333$$

$$w_{\text{Traffic safety}} = \frac{(5-2+1)}{(5-1+1)+(5-2+1)+(5-3+1)+(5-4+1)+(5-5+1)} = 0.267$$

$$w_{\text{Accessibility}} = \frac{(5-3+1)}{(5-1+1)+(5-2+1)+(5-3+1)+(5-4+1)+(5-5+1)} = 0.200$$

$$w_{\text{Liveability}} = \frac{(5-4+1)}{(5-1+1)+(5-2+1)+(5-3+1)+(5-4+1)+(5-5+1)} = 0.133$$

$$w_{\text{Employment}} = \frac{(5-5+1)}{(5-1+1)+(5-2+1)+(5-3+1)+(5-4+1)+(5-5+1)} = 0.067$$

6.1.2.4 Rank Reciprocal Technique (RRT)

Similar to the ROCT technique, in the Rank Reciprocal Technique (RRT), the stakeholder offers her input solely by ranking the available criteria according to her priorities and preferences, without providing any additional information on the extent to which she prefers one criterion over another. Consider a given stakeholder has the following rank of preferences regarding the available criteria.

1st criterion: Energy and environment
2nd criterion: Traffic safety
3rd criterion: Accessibility
4th criterion: Liveability
5th criterion: Employment

The weights of the criteria (w_i) in RRT can be calculated using the following formula, as discussed by Ezell et al. (2021):

$$w_i = \frac{(1/i)}{(\sum_{K=1}^{N} 1/k)}$$

In which:

- w_i represents the weight of criterion i
- N represents the number of criteria
- i represents the rank of criterion being weighted (i)
- K represents each element in the set of available criteria (1 – N)

The weights of the criteria can then be computed.

$$w_{\text{Energy and environment}} = \frac{(1/1)}{(1/1+1/2+1/3+1/4+1/5)} = 0.333$$

$$w_{\text{Traffic safety}} = \frac{(1/2)}{(1/1+1/2+1/3+1/4+1/5)} = 0.219$$

$$w_{\text{Accessibility}} = \frac{(1/3)}{(1/1+1/2+1/3+1/4+1/5)} = 0.146$$

$$w_{\text{Liveability}} = \frac{(1/4)}{(1/1+1/2+1/3+1/4+1/5)} = 0.109$$

$$w_{\text{Employment}} = \frac{(^1/_5)}{(^1/_1 + ^1/_2 + ^1/_3 + ^1/_4 + ^1/_5)} = 0.088$$

6.2 Appendix 2 – Overview of aggregation of individual priorities methods

This section presents an overview of the geometric and arithmetic methods for aggregating individual priorities.

Consider a situation in which 4 stakeholders provide their preferences regarding the criteria stated in the previous section using the Direct Assignment Technique (DAT). Table 7 presents an illustrative example with the scores provided by each stakeholder and the final weights for each of them.

Stakeholder	Stakeholder 1		Stakeholder 2		Stakeholder 3		Stakeholder 4	
Criteria	**Score**	**Weight**	**Score**	**Weight**	**Score**	**Weight**	**Score**	**Weight**
Energy and environment	470	0.47	95	0.10	110	0.11	110	0.11
Traffic safety	95	0.10	135	0.14	215	0.22	515	0.52
Accessibility	100	0.10	90	0.09	485	0.49	50	0.05
Liveability	135	0.14	115	0.12	90	0.09	275	0.28
Employment	200	0.20	565	0.57	100	0.10	50	0.05
TOTAL	1000	1.00	1000	1.00	1000	1.00	1000	1.00

The Aggregation of Individual Priorities (AIP) approach then refers to aggregating the individual priorities (in blue in Table 7) into a single final priority. The most common approach for performing this is by using the arithmetic mean or the geometric mean. According to Forman and Peniwati (1998), while both the arithmetic and geometric mean can be used for AIP, the geometric mean aligns more closely with the meaning of judgments and priorities in AHP. If for some reason a given stakeholder is given a higher level of importance to their opinion by the project team (e.g., they represent a vulnerable population group or a group that is likely to have to bear more negative impacts of a CCAM system), the Aggregation of Individual Priorities (AIP) method can also be modified to take this into account, as presented below.

Aggregation via the (weighted) arithmetic mean:

$$P_g(C_j)_{arithmetic} = \frac{\sum_{i=1}^{n} r_i \, P_i(C_j)}{\sum_{i=1}^{n} r_i}$$

Aggregation via the (weighted) geometric mean:

$$P_g(C_j)_{geometric} = \left(\prod_{i=1}^{n} P_i(C_j)^{r_i}\right)^{\frac{1}{\sum_{i=1}^{n} r_i}}$$

In which:

- $P_g(C_j)$ refers to the group priority of criterion j;
- $P_i(C_j)$ refers to the individual i's priority of criterion j;
- r_i refers to the relevance (i.e., importance of opinion) of individual i

For both the $P_g(C_j)_{arithmetic}$ and $P_g(C_j)_{geometric}$ cases, if all stakeholders have equal importance, the weighted arithmetic and geometric means become the simple unweighted versions.

If all stakeholders have equal relevance concerning their individual priorities (i.e., all priorities have the same importance), the aggregated weights of the criteria would be:

$$P_g(Energy\ and\ environment)_{arithmetic} = \frac{(0.47 + 0.10 + 0.11 + 0.11)}{4} = 0.196$$

$$P_g(Energy\ and\ environment)_{geometric} = \sqrt[4]{(0.47 \times 0.10 \times 0.11 \times 0.11)} = 0.152$$

If stakeholders have different importance regarding their priorities (e.g., $(r_1, r_2, r_3, r_4) = (1,3,5,2)$), then the aggregated weights of the criteria would be:

$$P_g(Energy\ and\ environment)_{arithmetic} = \frac{((0.47 \times 1) + (0.10 \times 3) + (0.11 \times 5) + (0.11 \times 2))}{(1 + 3 + 5 + 2)} = 0.139$$

$$P_g(Energy\ and\ environment)_{geometric} = \sqrt[(1+3+5+2)]{(0.47^1 \times 0.10^3 \times 0.11^5 \times 0.11^2)} = 0.121$$

When using the geometric mean, the components of the final priority vector may not sum to one, requiring further normalisation to achieve this (De Souza Carmo et al., 2013). shows a summary of the results obtained for the final priority vector based the weights presented for each criterion in Table 7 using both the arithmetic and geometric means.

Table 19. Summary of final criteria weights for both the arithmetic and geometric aggregation methods (based on results from Table 7)

Criteria	Arith. mean unwtd. [A]	Arith. mean wtd [B]	Geom. mean unwtd [C]	Geom. mean unwtd_norm. [D]	Geom. mean wtd [E]	Geom. mean wtd_norm. [F]
Energy and environment	0.196	0.139	0.152	0.199	0.121	0.156
Traffic safety	0.240	0.237	0.194	0.255	0.206	0.265
Accessibility	0.181	0.263	0.122	0.160	0.176	0.227
Community cohesion	0.154	0.135	0.140	0.184	0.122	0.157
Employment	0.229	0.227	0.154	0.202	0.151	0.195
TOTAL	1.000	1.000	0.762	1.000	0.776	1.000

Notes:

[A] Unweighted arithmetic mean

[B] Weighted arithmetic mean (assumes importance factors of 1, 3, 5, and 2 for stakeholders 1, 2, 3, and 4, respectively)

[C] Unweighted geometric mean

[D] Normalised Unweighted geometric mean (in order to have the sum of factors being equal to 1)

[E] Weighted geometric mean (assumes importance factors of 1, 3, 5, and 2 for stakeholders 1, 2, 3, and 4, respectively)

[F] Normalised Weighted geometric mean (in order to have the sum of factors being equal to 1)