D4RUNOFF

Data driven implementation of hybrid nature-based solutions for preventing and managing diffuse pollution from urban water runoff

D3.2. Multi-criteria decision analysis (MCDA) for selection and location of hybrid solutions

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D3.2. Multi-criteria decision analysis (MCDA) for selection and location of hybrid solutions	
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Deliverable lead	UC
Author(s)	Valerio Andrés (UC) Alejandro Roldán (UC) Sara García (UC) Jorge Rodríguez (UC) Pablo Pascual (UC) Daniel Castro (UC)
Contact	info@d4runoff.eu
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[a] **R**=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **OTHER**=other

[b] **PU**=Public, **SEN**=Sensitive, limited under the conditions of the GA

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Executive Summary

This deliverable 3.2 (D3.2) is the second one of the Work Package 3 (WP3) of the D4RUNOFF project. WP3 is divided in four tasks of six months each, with three deliverables in total. In this one, the work done during the third task is summarised in a public document open to comments and suggestions: a Multi-Criteria Decision Analysis (MCDA) for selection and location of hybrid solutions. This MCDA is mainly proposed for the selection of Nature-Based Solutions (NBS) used in urban drainage. The next deliverable (D3.3) will complete the WP3 adding the Geographical Information Systems (GIS) methodology with the final aim of selecting the best place for the NBS needed to improve the existing urban drainage conditions, resulting in hybrid systems.

The principal objective of the D3.2 is to develop a tool for the prioritization of NBS as alternatives to implement into the existing urban drainage systems, resulting in hybrid systems. Firstly, the D4RUNOFF researchers have reviewed the literature, highlighting the main criteria used for NBS comparison. With this information and the participation of the water utilities involved in the project, together with other partners, the selection of attributes and criteria was done. Four attributes or categories of criteria were defined, three of which are alligned with the pillars of the sustainable development (economy, environment and society) and the fourth represents the current feasibility of the NBS (expertise). Then, the criteria were weighted to finally propose three different methodologies. The first one was the Analytic Hierarchy Process (AHP) and the results of the survey sent to a selected group of experts was the same as that obtained in an informal consultation conducted on the social media of the project: the environmental criteria are the most important. However, with the objective methodology that was finally proposed, the Entropy Weight Method (EWM), a higher weight was assigned to the economic criteria. The third weighting method gives the option of direct weighting to the decision maker.

Afterwards, the definition of the indicators for each criterion was done considering mainly the D4RUNOFF Parametric Library (D3.1) but also other valuable references as the European Natural Water Retention Measures Platform. One of the main limitations of this MCDA is the quality and representativeness of the proposed indicators, that could be discussed and improved.

For the final ranking of alternatives, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was used, which provided different results depending on the weighting process. As conclusion, the two first positions correspond for both weighting methodologies to Wetlands and Green Roofs. This MCDA can be used openly thanks to the Excel spreadsheet developed for this purpose. From the results of this MCDA it can be stated that NBS can be prioritized according to different criteria, being possible and recommendable to combine them in order to offer a balanced, sustainable and realistic solution.

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1 Introduction

1.1 Aim of the MCDA for drainage solutions prioritization

The aim of this Multi-Criteria Decision Analysis (MCDA) for the selection and location of hybrid solutions is the prioritization of Nature-Based Solutions (NBS) to help practitioners and Decision Makers (DM) to find the most suitable NBS depending on a set of different criteria. The proposed MCDA methodology makes it possible not only to find the most suitable NBS according to the criteria considered, but also to establish a ranking of solutions according to their performance, in order to result in hybrid solutions for urban drainage (integrating NBS into the existing conventional drainage systems).

After the prioritization of the NBS, the requirements and restrictions for their location must be considered (see D3.1). This consideration will be implemented into the Geographical Information System (GIS) management of the hybrid drainage systems in the Task 3.4 (D3.3). Table 1 shows the list of NBS considered as alternatives and their main locations. Some changes and additional details have been considered in comparison with the D4RUNOFF Library (D3.1). In brackets the distinction is made between Infiltration (I) or Filtration (F) purposes, both in Bioretention Areas and Permeable Pavements. Sub-Surface variations (SS) of Detention and Infiltration Basins are also indicated.

Table 1. Alternatives considered and their main locations.

ALTERNATIVES	MAIN LOCATIONS
Bioretention Area (I)	Green Areas
Bioretention Area (F)	Green Areas
Detention Basin	Green Areas
Detention Basin (SS)	Green Areas
Filter Strip	Green Areas
Filter Strip (Lined)	Green Areas
Green Roof	Buildings
Green Wall	Buildings
Infiltration Basin	Green Areas
Infiltration Basin (SS)	Green Areas
Dry Well	Streets
Infiltration Trench	Streets
Permeable Pavement (I)	Streets
Permeable Pavement (F)	Streets
Retention Pond	Green Areas
Swale	Streets
Swale (Lined)	Streets
Filter Drain	Streets
Filter Drain (Lined)	Streets
Wetland FWS	Green Areas

1.2 Structure of the MCDA

The main steps for the definition of a MCDA are:

1. Selection of criteria and attributes: the attributes are the general categories of criteria that will be considered in the analysis and their definition is fundamental.
2. Criteria weighting: the relative importance of the attributes and criteria should be decided according to any of the different available methods.
3. Indicators of performance: quantitative or qualitative parameters must be selected to measure the performance of each alternative according to the selected criteria and attributes.
4. Ranking of alternatives: in this case, the different NBS are the alternatives, and their prioritization is done with the proposed method according with the previous criteria weighing and indicators of performance.

It is important to note that only NBS are considered in the MCDA. Additionally, some NBS categories defined in the D4RUNOFF Library (D3.1) were split here in various subcategories in order to consider specific design variations like the lining of some techniques (e.g., swales, filter drains, permeable pavements), which affect flood mitigation, or the possibility to develop sub-surface NBS (e.g., detention basins, infiltration basins) which affect land use optimization or aesthetic values respectively.

The structure proposed for the MCDA is presented in the flowchart in **Figure 1**.

Figure 1. Structure of the MCDA proposed for NBS selection.
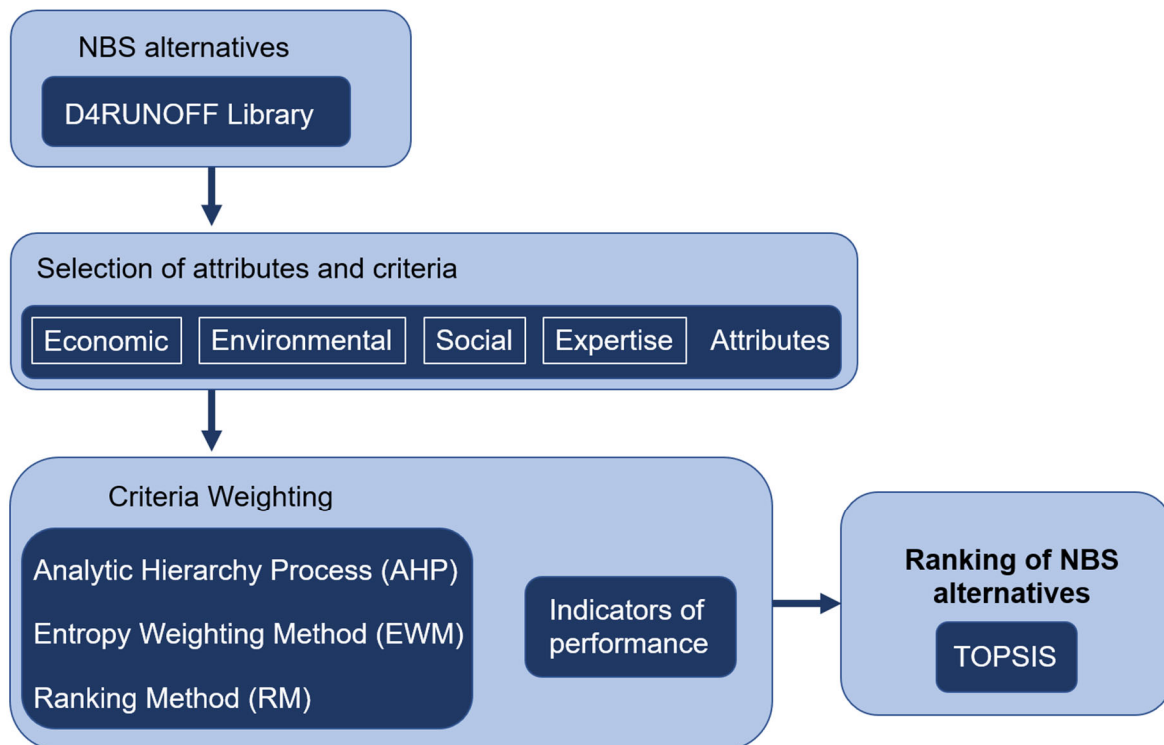
Additionally, to provide a flexible approach in the decision-making process, the MCDA has been developed allowing two types of analyses. On the one hand, a general ranking of alternatives has been provided based on available information retrieved from large datasets and a group of experts' opinions. On the other hand, a methodology has been developed to allow Decision-Makers (DM) to develop personalized ranking of alternatives according to site-specific constrains that can influence the decision-making process.

1.2.1 General ranking of alternatives

A general ranking of alternatives was developed based on the general information provided by the D4RUNOFF Library of drainage solutions developed in Task 3.1 (see D3.1). Two criteria weighting methods have been used to develop two prioritization lists of alternatives according to objective and subjective relative weights of criteria to allow flexibility in the NBS prioritization process. The user can find a suggested weight for each criterion according to two different methods: Analytic Hierarchy Process (AHP) and Entropy Weighting Method (EWM). Both methods are based on different principles: while AHP provides the relative importance of each criterion based on the subjective perception of a group of experts, EWM is based on the objective importance of each criterion according to the variability in the score of the alternatives in each criterion. On the other hand, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was used to rank the alternatives according to both criteria weighting methods and the results are provided in this document. As outcome, two general ranking lists of alternatives have been provided by using the TOPSIS method and the two previously described MCDA weighting methods, AHP and EWM, according to the scores of each alternative in each criterion.

1.2.2 Site Specific Ranking of alternatives

A spreadsheet in Excel has been programmed for this MCDA and included in this deliverable to allow Decision-Makers (DM) to establish personalized prioritization of alternatives according to their own preferences (MCDA spreadsheet). With this tool, the DM can consider site-specific situations, where the relative importance of the criteria may be different from the general proposed ones (e.g., in an intervention in a flood-prone area, the importance of flood mitigation would be probably higher than in a place where there is not such problematic). With this aim, the two weighting methods were included in the MCDA spreadsheet: AHP and EWM. Additionally, a third weighting method was included: the Ranking Method (RM), due to it is one of the easiest and less time-consuming subjective criteria weighting methods and can be useful in situations where there is a need of a quick result. More information about the weighting methods used can be found in Part 3 of this document.

In the MCDA spreadsheet, the scores of the alternatives (in the indicators of performance related to each criterion) are included and used to develop the prioritization lists included in this document. In order to set their own prioritization list, users should review the score of each alternative in each indicator. It should be noted that the score of each alternative listed in the MCDA spreadsheet is based on general information, mostly obtained from the parametric library developed in task 3.1 of the WP3 and the references considered therein (see D3.1). While there are some fixed scores based on large datasets, other indicators can be manually introduced by the user according to site specific considerations. For instance, the standard

score in construction costs of each alternative is based on the information gathered in the parametric library for general purposes, and based on international experiences, but the user can modify this value in order to consider site-specific situations. By using the MCDA spreadsheet, users will be able to obtain three ranking lists of alternatives based on the aggregated scores of each alternative according to the TOPSIS method, considering all the criteria and their relative weights according to the three weighting methods adopted: AHP, EWM and RM.

2 Selection of attributes and criteria

The first step for developing the MCDA was an extensive literature review looking for the main criteria used for selecting and prioritizing Nature Based Solution for stormwater management in previous works. The performed review was based on scientific publications collected from the main international databases (WoS and SCOPUS). In these databases, scientific papers were sought that included the following keywords (with the OR operator): SuDS, Sustainable Drainage, Nature Based Solutions, Green Infrastructure, Blue Infrastructure and Best Management Practices. This initial screening gave a set of 23402 search results. After this initial screening, the results were filtered by using the terms MCDA or Multicriteria, providing a set of 552 documents. Then, the list was furtherly refined by including the terms "Water Management" and "Stormwater", this giving a total set of 178 documents. Once the documents related to spatial MCDA were excluded (spatial considerations will be taken into account in the next deliverable of the WP3, D3.3), a set of 57 documents was finally selected.

The selected documents were analyzed by looking for the most used criteria in the technical literature related to the selection and prioritization of NBS. Moreover, during the D4RUNOFF General Assembly in Paris (M13), the main criteria used nowadays by the water utilities were discussed in the WP3 working session, with the aim of combining the literature review with the real practice of the companies. With this information an initial list of criteria was provided, which gathered 27 criteria included in 7 attributes. This initial list was sent to the water utilities involved in the D4RUNOFF project (AQUALIA, VCS and ACQUE), to other project partners (KLINK and ITG), and also to the representatives of the three demonstration municipalities of the project (Odense, Pontevedra and Santander), in order to receive their feedback about the importance of the selected criteria. With this aim, they were asked to score each criterion with 0, 1 and 2 depending on the importance given to each criteria (0: Not important, 1: Moderately Important and 2: Extremely Important). The results of this initial round are depicted in Figure 2.
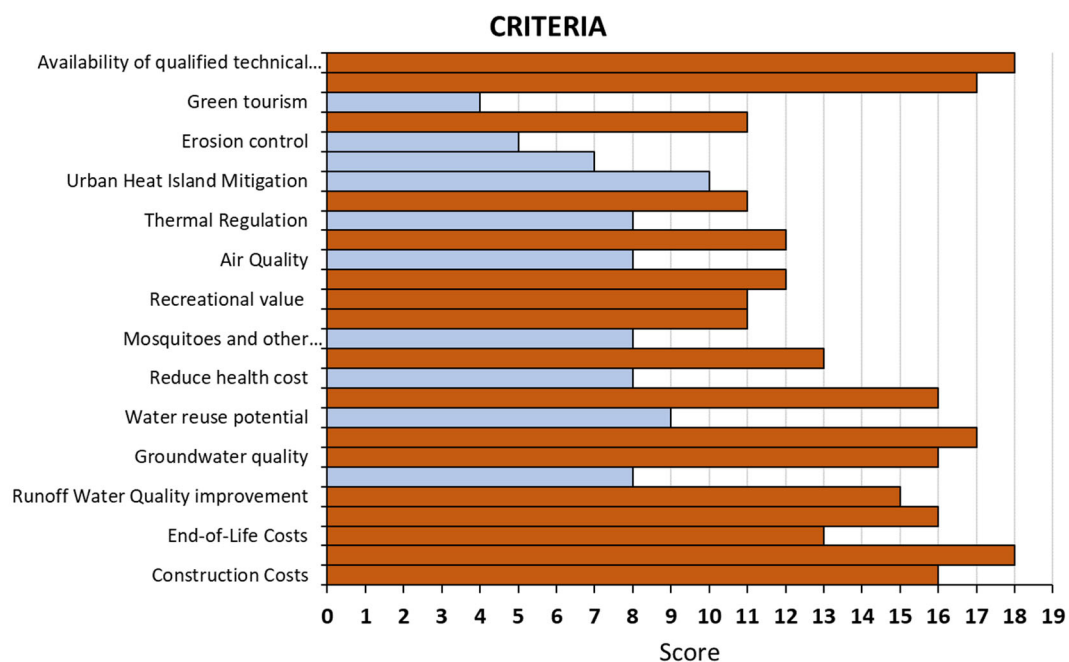
Figure 2. Initial List of criteria considered in the MCDA

After receiving their feedback on the importance of each criterion, the list was shortened to 15 criteria. Only those exceeding the median value of the importance given to all the considered criteria (this value was 11 in Figure 2) were selected. This list has been finally structured in 4 attributes (Economic, Environmental, Social and Expertise) where the selected criteria (Construction Costs, Flood Mitigation, etc.) were fitted, as it can be seen in Figure 3. It should be noted that the Expertise attribute was assessed directly, without criteria, as it is a standalone attribute that can be evaluated directly with its own indicator.
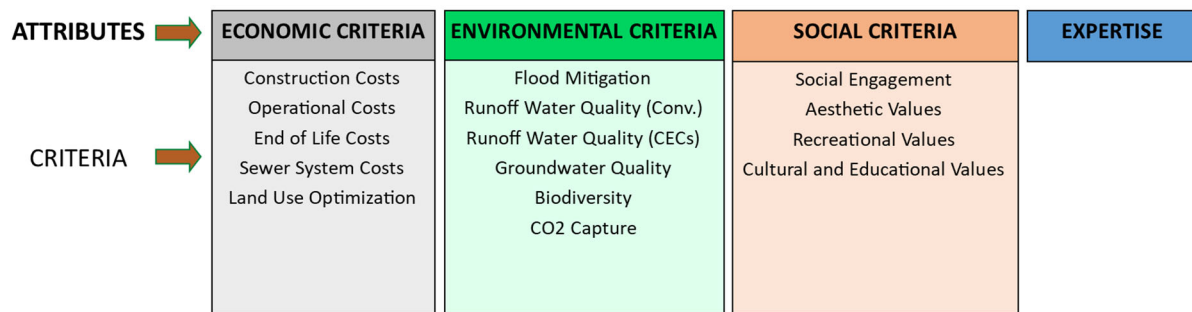
Figure 3. Final list of attributes and criteria considered in the MCDA

3 Criteria weighting

In most MCDA models, assigning weights to the selected criteria is probably the most important step. Considering the fact that the weights assigned to the criteria can significantly influence the results of the analysis, the selection of appropriate weighting methods is essential for ensuring the accuracy of MCDA.

Weighting methods can be grouped into three categories: subjective, objective and integrated (or combined weighting approaches). Subjective weight determination is based on expert opinion, and the analyst normally presents Decision Makers (DMs) a set of questions in the process, designed to elicit their subjective judgments. In objective weighting methods, the criteria weights are derived from information gathered for each criterion without any consideration of the decision maker's intervention. Finally, the integrated weighting approach is based on the combination of subjective and objective weighting methods.

There are a lot of MCDA models but only few of them have been widely used. The reasons for that are their simplicity (easy to implement), good performance and accurate outcomes. In Table 2 some of the most common and well-known MCDA methods for each of the categories are listed[1,2].

Table 2. Some Common and Well-Known MCDA weighting methods

Subjective Weighting Methods[1,2]	Objective Weighting Methods[1,2]	Integrated Weighting Methods[1,2]
Point Allocation	Entropy Method	Multiplication Synthesis
Direct Rating	CRITIC Method	Additive Synthesis
Ranking Method	Mean Weight	Optimal Weighting
Pairwise Comparisons	Standard Deviation	
Ratio Method	Statistic Variance Procedure	
SWING Method	IDEAL point method	
DELPHI Method		
Nominal Group Technique		
SMART Method		

Considering that each method can provide very different results, two types of weighting methods were selected: Subjective and objective weighting methods. This was done in order to provide a flexible approach for the decision-making problem, considering DMs preferences, and taking into account the influence of each criteria according to the variability in the performance of the alternatives. Two subjective weighting methods were selected: Pairwise Comparisons and the Ranking Method. Both methods consider only DM preferences without considering the alternatives or the score of the alternatives for the selected indicators of the performance for the considered criteria. As in pairwise comparison methods the number of comparisons to be made is very time-consuming, especially when the number of criteria and attributes is high, we decided to implement a second subjective weighting method that allows for fast calculations.

[1]Odu, G.O. (2019). Weighting methods for multi-criteria decision making technique. Journal of Applied Sciences and Environmental Management 23 (8), pp.1449-1457. (DOI: https://doi.org/10.4314/jasem.v23i8.7)
[2]Yusop, Z. B., Ahmed, K., Shirazi, S. M., & Zardari, N. H. (2015). Weighting methods and their effects on multi-criteria decision making model outcomes in water resources management. Springer. (DOI: https://doi.org/10.1007/978-3-319-12586-2)

Pairwise Comparison methods are based on the subjective judgement of a group of experts that is retrieved by performing successive pairwise comparison among the considered criteria in the decision-making process. There are several of these methods that are very well-known such as the Analytic Hierarchy Process (AHP)[3], the Best Worst Method (BWM)[4] or the Full Consistency Method (FUCOM)[5]. Considering that the AHP method is one of the most widely used MCDA methods[6], it was selected to perform pairwise comparisons among the selected criteria for NBS prioritization. As the AHP method only provides a fixed weight to each criterion according to the experts' judgement, a MCDA spreadsheet was developed in order to allow DMs to establish specific criteria weights according to AHP method and based on their own preferences.

Additionally, for the sake of flexibility, other subjective criteria weighting method were integrated into the spreadsheet to allow the users to establish their own preference for considering site-specific situations. With this aim, the Ranking Method (RM)[2] was selected as one of the simplest ways to assign weights to criteria, and the easiest procedure to consider DM preferences. Specifically, the Rank Order Centroid (ROC)[2,7] method was implemented to convert the ranking order established by the DM into weights. This method is less time-consuming than AHP, allowing for quick calculations that can be used for the initial stages of the analysis.

Finally, as a third method, an objective criteria weighting method was considered important to assess the relative importance of each criterion according to the scores of each alternative for each criterion. With this aim, the Entropy Weighting Method (EWM)[8] was also selected and applied for NBS prioritization. The EWM can computes unbiased relative criteria weights in a rather simple and straightforward manner that can be easily implemented in an Excel spreadsheet, being reliable in computing criteria weights appropriately, and permitting a quantitative assessment of efficiency and benefit/cost parameters[2].

3.1 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is one of the most popular and widely used and well-known MCDA methods[6]. AHP is a structured technique for organizing and solving complex decision-making problems based on a mathematical approach that considers DM psychology[9]. AHP provides a logical framework to quantify each decision-making element within a hierarchical structure. The method assigns weights to each criterion according to DM preferences based on pairwise comparisons. The alternatives are then evaluated based on the selected criteria. AHP follows the principles of reciprocal condition, homogeneity, dependency and expectations to prioritize each criterion[9].

[3]Saaty, T. L. (1988). What is the analytic hierarchy process? (pp. 109-121). Springer Berlin Heidelberg.
[4]Rezaei J.Best-worst multi-criteria decision-making method (2015) Omega (United Kingdom), 53, pp. 49 – 57. DOI: 10.1016/j.omega.2014.11.009
[5]Pamučar D, Stević Ž, Sremac S. A New Model for Determining Weight Coefficients of Criteria in MCDM Models: Full Consistency Method (FUCOM). Symmetry. 2018; 10(9):393. https://doi.org/10.3390/sym10090393
[6]Kordana, S.; Słyś, D. (2020). Decision Criteria for the Development of Stormwater Management Systems in Poland. Resources, 9(2), 20. https://doi.org/10.3390/resources9020020
[7]Sureeyatanapas, P. (2016). Comparison of rank-based weighting methods for multi-criteria decision making. Engineering and Applied Science Research, 43, 376-379.
[8]Deng, H., Yeh, C. H., & Willis, R. J. (2000). Inter-company comparison using modified TOPSIS with objective weights. Computers and Operations Research, 27(10), 963–973.
[9]Tavana M., Soltanifar M., Santos-Arteaga F.J. Analytical hierarchy process: revolution and evolution (2023) Annals of Operations Research, 326 (2), pp. 879 – 907. DOI: 10.1007/s10479-021-04432-2

Since its conception, AHP has been a valuable tool for DM and researchers. Many outstanding works have been published based on AHP. Planning, alternatives selection, resources allocation, conflict resolution or optimization are among the applications of this methodology[10].

AHP can be easily implemented by following the next steps:

1. Creation of a hierarchical structure of the selected criteria. Initially, the main criteria defining the decision problem are determined, and then the problem is divided into target levels, criteria (and sub-criteria if it is needed). Each element of this hierarchy depends on its higher-level element, and this dependence continues linearly up to the highest level.

2. Definition of the pairwise comparison matrix where the elements of each level are compared in pairs. The number of comparisons can be determined by Eq. 1:

$$C_p = \frac{n \cdot (n-1)}{2} \tag{1}$$

Where C_p is the number of comparisons, and n are the number of attributes or criteria to be compared.

3. Determining the criteria weights based on pairwise comparisons takes three main steps.

- The first step is to develop the comparison matrix by comparing the criteria (Eq.2) where n is the number of criteria considered in the comparison.

$$\begin{pmatrix} X_{11} & \cdots & X_{1j} \\ \vdots & \ddots & \vdots \\ X_{i1} & \cdots & X_{ij} \end{pmatrix}; \ \forall i,j = 1 \dots n \tag{2}$$

Each column and row represent the relative importance of the criteria in relation to the rest of criteria, being the element X_{ij} the relative importance of the criterion i over the criterion j. Intensity values are used to complete the matrix (X_{ij}) on the basis of the original Saatys' absolute fundamental Scale[3] (Table 3).

Table 3. Saatys' Scale of Relative Importance

Intensity Value	Relative Importance
1	Equally preferred
2	Equally to moderate preferred
3	Moderately preferred
4	Moderately to Strongly preferred
5	Strongly preferred
6	Strongly to Very Strongly preferred
7	Very Strongly preferred
8	Very Strongly to Extremely preferred
9	Extremely preferred

The diagonal in the matrix is always 1 ($Xij = 1, \forall i = j$) and the lower left values are the inverse values of the upper right values: if criterion i has one of the above numbers assigned to it when compared to criterion j (X_{ij}), then criterion j has the reciprocal value when compared to i ($X_{ji} = 1/X_{ij}$). To fill in the lower triangular matrix, the reciprocal values of the upper diagonal are used.

[10]Omkarprasad S. Vaidya, Sushil Kumar, Analytic hierarchy process: An overview of applications, European Journal of Operational Research, Volume 169, Issue 1, 2006, Pages 1-29, https://doi.org/10.1016/j.ejor.2004.04.028.

- The second step is to calculate the priority value, also called the principal eigenvector or priority vector. To do this, the values in each column are added up, each element is divided by the column total ($N_{ij} = X_{ij}/\sum_{j=1}^{j=n} X_{ij}$), and the sum of the normalized scores in each row is divided by the number of criteria ($P_j = (\sum_{i=1}^{i=n} N_{ij})/n$; where n is the number of criteria.
- The third step is to estimate the consistency for sensitivity analysis, which is known as Consistency Ratio (CR). For this, it is necessary to calculate the weight vector ($W_i = \sum_{j=1}^{j=n}(X_{ij} \cdot P_j)$). Next, the consistency vector is calculated by dividing the elements of the weight vector coordinate-wise by those of the local priority vector. That is, each element of the consistency vector is obtained by dividing the corresponding element of the weighted sum vector by that of the local priority vector ($C_i = W_i/P_j$; $i = j$). Then, the largest Eigenvalue of the pairwise comparison matrix (λ_{max}) is calculated by averaging the elements of the consistency vector ($\lambda_{max} = \sum C_i/n$). Finally, the Consistency Index (CI) is calculated ($CI = (\lambda_{max} - n)/(n - 1)$, where n is the number of criteria), and the Consistency Ratio (CR) obtained by dividing the CI by the Random Index (RI), which represent the average CI expected in a random matrix where the judgements have been entered randomly (Table 4). If the CR is lower than 0.1, then the ratio indicates a reasonable level of consistency in the pairwise comparisons, but once the CR is high than 0.1, it shows that the pairwise comparisons are inconsistent in judgment and hence, cannot be considered for the weighting process.

Table 4. Random Index (RI)

Number of criteria (n)	3	4	5	6	7	8	9	10
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

To weight the criteria with the AHP method and carry out the subsequent selection of NBS, an anonymous survey was sent to a group of 50 experts in Sustainable Urban Drainage, including representatives from Academia (universities and research centers), companies (utilities and enterprises related with urban drainage), and public administrations (municipalities and regional/national/European institutions). The participants were kindly requested to share the survey with other experts among their contacts. The survey requested them to perform pairwise comparisons among the attributes and criteria summarized in Figure 1. First, they were asked to set the relative importance of each attribute in relation to the rest of attributes. In addition, they were asked to make a pairwise comparison between all criteria belonging to each attribute, according to the scale summarized in Table 2. Consequently, the survey was structured in 4 different parts, through which experts were asked to compare the importance of the Attributes (Part 1), and the Criteria belonging to those Attributes: Economic Criteria (Part 2), Environmental Criteria (Part 3) and Social Criteria (Part 4).

The survey was conducted online using the open source LimeSurvey and it is available for consultation in the following site till the end of the D4RUNOFF project: https://encuestas.unican.es/index.php/743877?lang=en.

The selected group of experts was asked to answer the survey between November 21th and December 11th of 2023. A total of 23 experts eventually answered the survey during that period of time, 5 of whom provided answers that were not consistent at all, and other 7 experts provided answers that, even including some parts that meet the consistency conditions, were still not fully consistent according to the CR values obtained for the pairwise comparisons (Table 5).

Table 5. Results the consistency check of the received surveys

Survey	Consistency Ratio (CR)				Consistency Check
	Attributes	Economic C.	Environmental C.	Social C.	
1	0,3439	0,0765	0,0425	0,4170	Partial
2	0,3262	0,6974	0,6707	0,1949	No
3	0,1680	0,1589	0,1395	0,0619	Partial
4	0,0437	0,1673	0,0689	0,1295	Partial
5	0,1249	0,0322	0,0466	0,1524	Partial
6	**0,0362**	**0,0030**	**0,0147**	**0,0038**	**Yes**
7	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**Yes**
8	0,0725	0,1376	0,4167	0,1815	Partial
9	**0,0393**	**0,0333**	**0,0464**	**0,0225**	**Yes**
10	**0,0303**	**0,0887**	**0,0213**	**0,0000**	**Yes**
11	0,1864	0,0537	0,0534	0,0076	Partial
12	0,6063	0,0094	0,0094	0,0029	Partial
13	**0,0225**	**0,0831**	**0,0373**	**0,0000**	**Yes**
14	**0,0525**	**0,0675**	**0,0634**	**0,0579**	**Yes**
15	**0,0454**	**0,0604**	**0,0528**	**0,0637**	**Yes**
16	0,2966	0,4882	0,1994	0,1499	No
17	0,5817	0,4671	1,1717	0,5427	No
18	0,1424	0,2918	0,2473	0,1452	No
19	0,6772	0,7504	0,2705	0,2796	No
20	**0,0476**	**0,0041**	**0,0321**	**0,0206**	**Yes**
21	**0,0743**	**0,0936**	**0,0950**	**0,0364**	**Yes**
22	**0,0787**	**0,0428**	**0,0373**	**0,0953**	**Yes**
23	**0,0532**	**0,0191**	**0,0232**	**0,0276**	**Yes**

Consequently, 11 survey responses were fully consistent and acceptable for performing the AHP weighting analysis. The Weighted Arithmetic Mean Method[11] was used for the aggregation of the individual priorities obtained from the surveys in one unique weight value for each criterion and attribute. The results obtained regarding the weight of each attribute and criteria considered for comparison are showed in Table 6. This table compares the results for the 11 fully valid surveys (surveys no.: 6, 7 ,9, 10, 13, 14, 15, 20, 21, 22, 23), the results for the 6 only partially valid surveys (surveys no.: 1, 3, 4, 5, 8, 11, 12), and the results for all the received surveys.

As it can be observed, the difference in the final weight of each criterion considering only totally consistent surveys is similar than the weight obtained by considering also partially consistent surveys (maximum difference is in the range of 2-3%) or all the received surveys (maximum

difference less than 5%). Still, in order to follow a rigorous scientific approach, and in accordance with the AHP method here defined, only fully consistent surveys were used to obtain the weight of the attributes and criteria considered.

Table 6. Weights of attributes and criteria according to the AHP method

Attribute *Criteria*	Fully Consistent	Partially Consistent	All Surveys
Economic Criteria	**27,45%**	**26,89%**	**23,23%**
Construction Costs	*4,66%*	*4,02%*	*3,70%*
Operational Costs	*7,27%*	*7,02%*	*5,99%*
End-of-Life Costs	*3,43%*	*3,10%*	*2,48%*
Sewer System Cost	*5,43%*	*5,57%*	*4,94%*
Land Use optimization	*6,67%*	*7,18%*	*6,12%*
Environmental Criteria	**39,33%**	**40,39%**	**42,01%**
Flood mitigation	*12,60%*	*13,13%*	*11,95%*
Runoff Water Quality (Conventional)	*7,89%*	*7,65%*	*6,95%*
Runoff Water Quality (Emerging Pollutants)	*6,59%*	*6,27%*	*7,63%*
Groundwater quality	*6,11%*	*7,01%*	*6,60%*
Biodiversity	*3,73%*	*3,96%*	*5,63%*
CO2 Capture	*2,41%*	*2,36%*	*3,25%*
Social Criteria	**17,06%**	**17,33%**	**15,41%**
Social Engagement	*6,12%*	*6,06%*	*4,98%*
Aesthetic Values	*3,84%*	*3,76%*	*3,26%*
Recreational value	*3,75%*	*3,83%*	*3,40%*
Cultural and educational Values	*3,35%*	*3,68%*	*3,77%*
Expertise	**16,16%**	**15,39%**	**19,35%**

Regarding the attributes, the most important is the Environmental, regardless of the surveys considered. Moreover, this same result was obtained in an informal consultation conducted in the social media of the D4RUNOFF project (thanks to the responsible partner, 3OC) by asking the general public about their opinion.

The most important economic criterion is the "Operational Cost", followed by the "Land Use Optimization". Among the environmental criteria, the "Flood mitigation" and the water quality considerations rank highest. Finally, in the group of social criteria, experts considered "Social Engagement" as clearly the most important one.

3.2 Entropy Weight Method (EWM)

The Entropy Weight Method (EWM) is an important information weighting model that has been extensively studied and practiced since 1947, when it was developed[12], and further refined in 1982. In the EWM method, the probability theory is used to compute uncertain information (Entropy). It determines the importance of every response, not including the preference of the DM. This method is used for assessing the weight in a given problem based on the information provided by the decision matrix or, in other words, the scores of the alternatives in the indicators of performance related to each criterion and/or attribute. The EWM works on the principle that the information from superior weight indicators is more constructive than that from lower indicator information.

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[12]*Shannon CE. A mathematical theory of communication. Bell Syst Tech J 1948;27(3):379e423.*

The EWM evaluates the values by measuring the degree of divergence. The higher the degree of divergence of the measured value the higher the degree of differentiation of the index, so the higher the weight that should be given to the index, and vice versa. Compared with various subjective weighting models, the biggest advantage of the EWM is that it avoids the interference of human factors on the weighting process, thus enhancing the objectivity of the comprehensive evaluation results. According to the literature, the results of the EWM are always reliable and effective[13, 14, 15]. Hence, it was selected as a suitable objective weighting method to prioritize NBS solutions. The application of the EWM is based on the score of the considered alternatives in the selected indicators of performance of the corresponding criteria. Considering a group of m criteria indicators of n alternatives, being the value of ith indicator for the jth alternative noted by X_{ij}, the first step is the standardization of the measured values for the indicators of the criteria ($P_{ij} = X_{ij}/\sum_{j=1}^{j=n} X_{ij}$). Next, the Entropy Value (E_i) for each criteria is calculated according to Eq. 3, and finally the weights of the criteria (W_i) are obtained through Eq. 4.

$$E_i = -\frac{\sum_{j=1}^{j=n} P_{ij} \cdot ln(P_{ij})}{ln(n)} \tag{3}$$

$$W_i = \frac{1 - E_i}{\sum_{i=1}^{i=m}(1 - E_i)} \tag{4}$$

Applying this method to the considered attributes and criteria (Figure 2), the weights obtained are showed in Table 7.

Table 7. Weights of attributes and criteria according to the EWM

Attribute	Criteria	Weight
Economic Criteria		**39,02%**
	Construction Costs	*13,44%*
	Operational Costs	*15,75%*
	End-of-Life Costs	*3,25%*
	Sewer System Cost	*4,70%*
	Land Use optimization	*1,88%*
Environmental Criteria		**21,71%**
	Flood mitigation	*2,98%*
	Runoff Water Quality (Conventional)	*3,03%*
	Runoff Water Quality (Emerging Pollutants)	*2,61%*
	Groundwater quality	*6,30%*
	Biodiversity	*3,85%*
	CO2 Capture	*2,95%*
Social Criteria		**16,91%**
	Social Engagement	*7,14%*
	Aesthetic Values	*2,74%*
	Recreational value	*4,50%*
	Cultural and educational Values	*2,52%*
Expertise		**22,36%**

[13]X. Lu, L. Y. Li, K. Lei, L. Wang, Y. Zhai, and M. Zhai, "Water quality assessment of Wei River, China using fuzzy synthetic evaluation," Environmental Earth Sciences, vol. 60, no. 8, pp. 1693–1699, 2010.

[14]Y. Zhou, Q. Zhang, K. Li, and X. Chen, "Hydrological effects of water reservoirs on hydrological processes in the East River (China) basin: complexity evaluations based on the multiscale entropy analysis," Hydrological Processes, vol. 26, no. 21, pp. 3253–3262, 2012.

[15]Yuxin Zhu, Dazuo Tian, Feng Yan, "Effectiveness of Entropy Weight Method in Decision-Making", Mathematical Problems in Engineering, vol. 2020, Article ID 3564835, 5 pages, 2020. https://doi.org/10.1155/2020/3564835

3.3 Ranking Method (RM)

Since DMs normally feel uncomfortable in assigning precise weights to criteria or they lack the adequate knowledge to do so, and since the AHP methodology is very time consuming, a more straightforward methodology simply based on establishing a priority order for the criteria would probably help to involve them in the decision making process. For this reason, the Ranking Method (RM) was also included in the Excel spreadsheet in order to allow DMs to establish their own criteria preference priority according to specific on-site situations.

Among the different Ranking Method weighting procedures, the Rank Order Centroid (ROC)[2,7] was selected because according to the literature it provides more accurate results than other ranking methods such as the Rank Sum, the Rank Exponent or the Rank Reciprocal[7,16]. As for the method implementation, the first step is to ask the DM to establish a prioritization or ranking of the criteria considered in the MCDA. Based on the priority order of the criteria assigned by the DM, the method assigns weights according to Eq. 5, where i is the number of criteria (i=1…N), and r_i denotes the rank of ith criterion in the ranking preference established by the DM.

$$W_i = \frac{1}{N} \cdot \sum_{i=1}^{i=N} \left(\frac{1}{r_i}\right)$$

(5)

4 Indicators of performance

Once the attributes and criteria have been selected and their weights assigned, the next step of the MCDA is to look for suitable indicators of the performance of each alternative (in this case, each NBS) according to each of the selected criteria. With this aim, the NBS parametric library developed in tasks 3.1 and 3.2 of this Project was selected as the main source of information together with the references used therein (see D3.1). The performance indicators selected for each criteria and attribute considered in this MCDA are summarized below.

4.1 Economic Criteria

In this attribute all the criteria related to economic issues were included. As there is a wide range of economic sides to be considered for the evaluation of each solution, a set of 5 economic criteria was selected for this MCDA. The indicator considered for each criterion used for analysing the performance of the different NBS considered as alternatives in relation to economic issues is described as follows:

- **Construction Costs (EC1)**: The performance indicator related to this criterion is the average unitary cost of construction per m² of land occupied by each solution (Eur/m²). This is estimated according to the information summarized in the D4RUNOFF Library presented in the deliverable D3.1 and the references used therein.

- **Operational Costs (EC2)**: As a performance indicator of a drainage solution in relation to operational costs, the average unitary yearly cost (Eur/m²·year) related to the maintenance and operation of a specific alternative according to the information summarized in the D3.1 was used. It is very important to take into account that, with a

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[16]Ahn BS, Park KS. Comparing methods for multiattribute decision making with ordinal weights. Computers & Operations Research 2008;35(5):1660- 1670.

- proper maintenance and operational budget, the life span of a NBS could be as long as desired. Consequently, this category adds up all replacement costs, including capital costs for necessary partial replacements.

- **End-of-Life Costs (EC3)**: The end-of-life of a NBS can be due to lack of maintenance, extraordinary events that can cause fatal damages, or simply changes on the land use that motivates the elimination of a NBS. For assessing the end-of-life costs (mainly due to disposal of the used materials) a qualitative indicator was developed based on the construction materials required to build an NBS. Depending on the used materials, three categories were established on the basis that the end-of-life costs are directly related to the used construction materials that need to be managed after the end of the service life:
    - o 1 represents the techniques with lower end-of-life costs. It has been assigned to all the techniques that only use soil, sand and aggregates with little or no need of building materials.
    - o 2 includes those techniques with medium end-of-life costs that require the use of some building materials like concrete or liner membranes.
    - o 3 accounts for those techniques with higher end-of-life costs that require more intensive use of building materials such as geomembranes, plastics, steel or asphalt to be landfilled after the end of their service life.

- **Sewer System Costs (EC4):** To evaluate the performance of NBS in relation to this criterion, it was necessary to develop a new qualitative indicator, which is based on the capacity of a system to avoid the entrance of the stormwater into the sewerage network (saving money to the water utility). NBS were classified in 4 categories according to their capacity to reduce runoff volumes and infiltrate the captured runoff:
    - o 1-No reduction: This category was used for all the NBS that do not promote reduction in runoff volumes, so even if they can slow down, laminate and treat the runoff, they are not capable of reducing the runoff volumes that will finally enter the sewerage system.
    - o 2-Low Reduction: This category was used for those NBS that allow some degree of runoff volume reduction by infiltration and/or evapotranspiration, so that they provide some reduction in runoff volumes that enter the sewerage system.
    - o 3-Medium Reduction: This category was used to categorize those NBS that provide a moderate runoff volume reduction, allowing infiltration or evapotranspiration in a higher degree than previous ones.
    - o 4-High Reduction: This category corresponds to all the techniques that are specifically designed and conceived to reduce runoff volumes mainly through infiltration.

- **Land Use Optimization (EC5)**: To consider this criterion, a dummy indicator was created based on the information summarized in the parametric library (D3.1) previously developed in WP3. The indicator can have two different values: 1, if the technique does not allow other land uses together with the use as a drainage solution; and 2, if the used space can be additionally used for secondary purposes. It should be noted that sub-surface variations of NBS are catalogued with a 2 even if the general

information of the D3.1 establishes a monofunctional use of the system. Thus, in these cases the surface is available for secondary uses.

The estimated global scores of each alternative for the indicators of the economic criteria are showed in the following Table (Table 8).

Table 8. Scores of alternatives in Economic Criteria

ALTERNATIVES	Economic Criteria				
	EC1	EC2	EC3	EC4	EC5
Bioretention Area (I)	275,00	14,4375	1	3	1
Bioretention Area (F)	275,00	14,4375	1	1	1
Detention Basin	29,75	2,7500	1	1	1
Detention Basin (SS)	29,75	2,7500	3	1	2
Filter Strip	3,50	0,2750	1	3	2
Filter Strip (Lined)	3,50	0,2750	2	1	2
Green Roof	137,50	1,7500	3	3	2
Green Wall	450,00	8,6500	3	3	2
Infiltration Basin	26,25	2,8250	1	4	2
Infiltration Basin (SS)	26,25	2,8250	3	4	2
Dry Well	66,40	5,0000	2	4	1
Infiltration Trench	40,00	2,1250	2	4	1
Permeable Pavement (I)	170,00	3,0000	3	4	2
Permeable Pavement (F)	170,00	3,0000	3	1	2
Retention Pond	14,60	3,0000	1	1	1
Swale	190,00	1,2500	1	2	1
Swale (Lined)	190,00	1,2500	2	1	1
Filter Drain	190,00	1,2500	2	2	1
Filter Drain (Lined)	190,00	1,2500	3	1	1
Wetland FWS	50,00	0,0300	1	2	1

4.2 Environmental Criteria

The environmental attribute aims to collect and summarize the criteria that needs to be considered for the prioritization of NBS alternatives based on the main environmental parameters related to urban drainage. The criteria considered and the performance indicators of the alternatives in relation to this attribute are summarized below:

- **Flood Mitigation (EnC1)**: The indicator used to categorize the ability of a solution to mitigate flooding risks was obtained from the European Natural Water Retention Measures (NWRM) platform (http://nwrm.eu/) and the factsheets of NBS collected therein. According to these factsheets, the "Flood risk reduction" capacity of a NBS is categorized as: None, None to Low, Low, Low to Medium, Medium, Medium to High, or High. For this MCDA, a numeric value was assigned to each category:
  - o 1,0: None
  - o 1,5: None to Low
  - o 2,0: Low

- 2,5: Low to Medium
- 3,0: Medium
- 3,5: Medium to high
- 4,0: High

- **Runoff Water Quality (EnC2)**: The indicator used to assess the capacity of NBS to improve runoff water quality is their capacity to filter runoff pollutants summarized in the parametric library (D3.1) developed in the previous tasks of the WP3. Only techniques that do not allow full infiltration of the received water are considered to have an effect on the runoff water quality. The value assigned to each NBS is the average value of the runoff treatment capacity of the NBS regarding the 6 different conventional pollutants summarized in the parametric library (D3.1), and is based on the following values for their treatment capacity of each pollutant:
  - 1,00: No treatment
  - 2,00: Low Treatment
  - 3,00: Medium Treatment
  - 4,00: High Treatment

- **Runoff Water Quality-CECs (EnC3)**: To evaluate the performance of drainage solutions in relation to CECs treatment, a new indicator was developed based on the efficiency in treating emerging pollutants in a scale between 0 and 7. The number of pollutant families treated by the system was considered according to the information summarized in the parametric library (D3.1).

- **Groundwater Quality (EnC4):** The indicator used to assess the capacity of NBS to improve groundwater quality is their capacity to filter runoff pollutants according to the information summarized in the parametric library (D3.1). Only techniques that allow for water infiltration of the received water are considered to have an effect on groundwater quality. The value assigned to each NBS is the average value of the treatment capacity of the NBS regarding the 6 different conventional pollutants summarized in the parametric library, and is based on the following values for their treatment capacity of each pollutant:
  - 1,00: No treatment
  - 2,00: Low Treatment
  - 3,00: Medium Treatment
  - 4,00: High Treatment

- **Biodiversity enhancement (EnC5)**: The indicator used to categorize the ability of a solution to promote biodiversity was obtained from the European Natural Water Retention Measures (NWRM) platform (http://nwrm.eu/) and the factsheets of NBS collected therein. According to these factsheets, the "biodiversity preservation" capacity of NBS is categorized as: None, None to Low, Low, Low to Medium, Medium, Medium to High, or High. It is important to note that sub-surface variations of NBS have been scored 1, as they are not directly suitable for biodiversity preservation. For this MCDA a numeric value was assigned to each category:
  - 1,0: None
  - 1,5: None to Low

o 2,0: Low
o 2,5: Low to Medium
o 3,0: Medium
o 3,5: Medium to high
o 4,0: High

- **CO2 Capture (EnC6)**: The indicator used to categorize the ability of a solution to promote CO2 capture was obtained from the European Natural Water Retention Measures (NWRM) platform (http://nwrm.eu/) and the factsheets of NBS collected therein. According to these factsheets, the "CO2 capture" capacity of NBS is categorized as: None, None to Low, Low, Low to Medium, Medium, Medium to High, or High. It is important to note that sub-surface variations of NBS have been scored with 1 as they are not suitable for CO2 capture. For this MCDA a numeric value was assigned to each category:
  o 1,0: None
  o 1,5: None to Low
  o 2,0: Low
  o 2,5: Low to Medium
  o 3,0: Medium
  o 3,5: Medium to high
  o 4,0: High

The estimated global scores of each alternative in relation to Environmental Criteria are showed in the following Table.

Table 9. Scores of alternatives in Environmental Criteria

ALTERNATIVES	Environmental Criteria					
	EnC1	EnC2	EnC3	EnC4	EnC5	EnC6
Bioretention Area (I)	4,0	1,00	6,0	3,83	3,0	2,5
Bioretention Area (F)	4,0	3,83	6,0	1,00	3,0	2,5
Detention Basin	4,0	3,00	5,0	1,00	3,0	2,5
Detention Basin (SS)	4,0	3,00	5,0	1,00	1,0	1,0
Filter Strip	2,0	2,50	3,0	2,50	2,5	2,0
Filter Strip (Lined)	2,0	2,50	3,0	1,00	2,5	2,0
Green Roof	3,0	2,00	3,0	1,00	2,0	2,0
Green Wall	3,0	2,00	3,0	1,00	2,0	2,0
Infiltration Basin	4,0	1,00	2,0	3,66	3,0	2,5
Infiltration Basin (SS)	4,0	1,00	2,0	3,66	1,0	1,0
Dry Well	4,0	1,00	2,0	2,33	1,0	1,0
Infiltration Trench	4,0	1,00	2,0	3,83	1,0	1,0
Permeable Pavement (I)	3,0	1,00	3,0	3,50	1,0	1,0
Permeable Pavement (F)	3,0	3,50	3,0	1,00	1,0	1,0
Retention Pond	4,0	3,33	6,0	1,00	4,0	2,5
Swale	3,0	2,83	3,0	2,83	2,5	2,0
Swale (Lined)	3,0	2,83	3,0	1,00	2,5	2,0
Filter Drain	3,0	2,83	3,0	2,83	1,0	1,0
Filter Drain (Lined)	3,0	2,83	3,0	1,00	1,0	1,0
Wetland FWS	3,0	3,33	7,0	1,00	4,0	4,0

4.3 Social Criteria

The social attribute aims to collect and summarize the main factors regarding the social perspective that should be considered for the selection and prioritization of NBSs. Four criteria are considered under this attribute, all of them assessed by qualitative indicators, which are briefly described below:

- **Social Engagement (SC1)**: The indicator used to assess the performance of each NBS for this criterion is the participatory planning score of each NBS according to the parametric Library developed in WP3 (D3.1). The indicator gives a score between 1 and 6 to each NBS according to the following categories:
    - 1: No effect
    - 2: Low engagement
    - 3: Medium engagement
    - 4: High engagement
    - 5: Very high engagement
    - 6: Extreme engagement

- **Aesthetic Values (SC2)**: The indicator used to categorize the ability of a solution to provide aesthetic values was obtained from the European Natural Water Retention Measures (NWRM) platform (http://nwrm.eu/) and the factsheets of NBS collected therein. According to these factsheets, the Aesthetic value of NBS is categorized as: None, None to Low, Low, Low to Medium, Medium, Medium to High, or High. It is important to note that the sub-surface variations of NBS were catalogued with None aesthetic values (Score: 1). For this MCDA a numeric value was assigned to each category:
    - 1,0: None
    - 1,5: None to Low
    - 2,0: Low
    - 2,5: Low to Medium
    - 3,0: Medium
    - 3,5: Medium to high
    - 4,0: High

- **Recreational Values (SC3)**: The indicator used to categorize the ability of a solution to provide Recreational Values was obtained from the European Natural Water Retention Measures (NWRM) platform (http://nwrm.eu/) and the factsheets of NBS collected therein. According to these factsheets, the Recreational Opportunities provided by NBS are categorized as: None, None to Low, Low, Low to Medium, Medium, Medium to High, or High. As with the previous social criterion, sub-surface variations of NBS were scored 1. For this MCDA a numeric value was assigned to each category:
    - 1,0: None
    - 1,5: None to Low
    - 2,0: Low
    - 2,5: Low to Medium

- o   3,0: Medium
- o   3,5: Medium to high
- o   4,0: High

- **Cultural and Educational Values (SC4)**: The indicator used to categorize the ability of a solution to provide cultural values was obtained from the European Natural Water Retention Measures (NWRM) platform (http://nwrm.eu/) and the factsheets of NBS collected therein. According to these factsheets, the Cultural Value of NBS is categorized as: None, None to Low, Low, Low to Medium, Medium, Medium to High, or High. As with the previous social criterion, sub-surface variations of NBS were scored 1. For this MCDA a numeric value was assigned to each category:
  - o   1,0: None
  - o   1,5: None to Low
  - o   2,0: Low
  - o   2,5: Low to Medium
  - o   3,0: Medium
  - o   3,5: Medium to high
  - o   4,0: High

The estimated global scores of each alternative in relation to Social Criteria are showed in the following Table.

Table 10. Score of alternatives in Social Criteria

ALTERNATIVES	Social Criteria			
	SC1	SC2	SC3	SC4
Bioretention Area (I)	4	3,0	3,0	3,0
Bioretention Area (F)	4	3,0	3,0	3,0
Detention Basin	1	3,0	3,0	3,0
Detention Basin (SS)	1	1,0	1,0	1,0
Filter Strip	1	2,5	1,0	2,5
Filter Strip (Lined)	1	2,5	1,0	2,5
Green Roof	1	3,0	2,0	3,0
Green Wall	1	3,0	2,0	3,0
Infiltration Basin	1	3,0	3,0	3,0
Infiltration Basin (SS)	1	1,0	1,0	1,0
Dry Well	1	1,0	1,0	1,0
Infiltration Trench	1	2,0	1,0	2,0
Permeable Pavement (I)	1	1,0	1,0	1,0
Permeable Pavement (F)	1	1,0	1,0	1,0
Retention Pond	1	4,0	3,0	4,0
Swale	1	2,5	1,0	2,5
Swale (Lined)	1	2,5	1,0	2,5
Filter Drain	1	2,0	1,0	2,0
Filter Drain (Lined)	1	2,0	1,0	2,0
Wetland FWS	1	3,0	3,0	3,0

4.4 Expertise

The expertise attribute is based on the assessment of the available information regarding previous experience with a specific NBS, assuming that greater previous experience leads to both, a higher know-how about a solution and a higher availability of qualified technical personnel. Such expertise reduces risks in the implementation of a specific NBS and ultimately favors its application by the DM. This attribute was assessed directly, without sub-criteria as it is a standalone parameter to be considered. To assess the performance of drainage solutions in relation to this criterion, an indicator was developed based on the number of published works in Scopus, one of the main scientific databases. The results of the score of each alternative in this criterion according to the selected performance indicator can be seen in Table 11. The higher the number of research works, the larger the international experience with this solution and hence, the higher the score assigned to this criterion (in this case, the score is directly the number of publications in Scopus). Of course, other databases can be used to refine the consideration of this attribute.

Table 11. Scores of alternatives in Expertise Criteria

ALTERNATIVES	Expertise (number of publications in Scopus)
Bioretention Area (I)	758
Bioretention Area (I)	758
Detention Basin	948
Detention Basin (SS)	948
Filter Strip	963
Filter Strip (Lined)	963
Green Roof	4422
Green Wall	1010
Infiltration Basin	574
Infiltration Basin (SS)	574
Dry Well	496
Infiltration Trench	334
Permeable Pavement (I)	1296
Permeable Pavement (F)	1296
Retention Pond	688
Swale	2176
Swale (Lined)	2176
Filter Drain	88
Filter Drain (Lined)	88
Wetland FWS	12589

5 Performance Evaluation of alternatives

To assess the performance of the NBS in relation to the considered criteria and based on the weights obtained after applying the previously described methodologies, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)[17] was used. This is a distance-based method that ranks the alternatives based on their geometric distance to ideal and anti-ideal solutions. The logic behind this method is very close to the way people choose, as the best alternatives are those close to the Positive Ideal Solution (PIS) but also far from the Negative Ideal Solution (NIS). Mathematically speaking, the method is based on the concept that the preferred alternative should have the shortest geometric distance to the PIS and the largest geometrical distance from the NIS as it is shown in Figure 4.
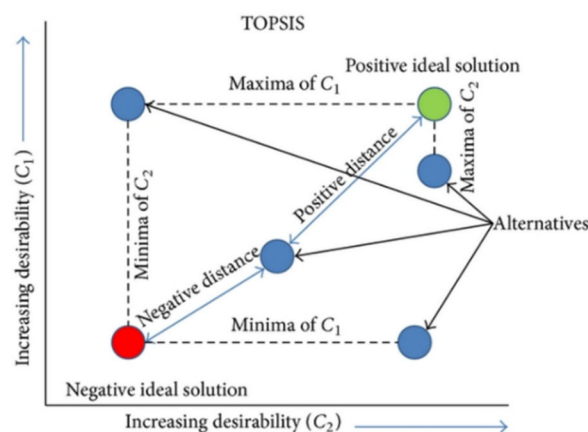
Figure 4. Scheme of TOPSIS performance evaluation

(Source (CC-BY): https://doi.org/10.1155/2014/793074)

In terms of implementation, TOPSIS is a compensatory aggregation method that compares a set of alternatives, normalizes scores for each criterion considered in the MCDA, and calculates the geometric distance between each alternative and the ideal alternative. The ideal solution maximizes the benefit criteria and minimizes the cost criteria, whereas the anti-ideal solution maximizes the cost criteria and minimizes the benefit criteria (e.g., in the case of Economic Criteria, the ideal solution will be the alternative with the lowest score, i.e., the cheapest alternative; in the case of flood mitigation, the ideal solution will be the alternative with the highest score, i.e., the one that mitigates the flood risk the most). TOPSIS makes full use of attribute information, provides a cardinal ranking of alternatives, and does not require attribute preferences to be independent. It also helps DM to organize the problems to be solved and carry out analysis, comparisons and rankings of the alternatives. Accordingly, the selection of a suitable alternative can be made.

The method provides four major advantages: (i) a sound logic that represents the rationale of human choice; (ii) a scalar value as an outcome that simultaneously accounts for both the best and worst alternatives; (iii) a simple computation process that can be easily programmed in a spreadsheet; and (iv) the fact that the performance measures of all alternatives on attributes and criteria can be visualized in a polyhedron, at least for any two dimensions.

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17. C. Hawng, K. Yoon, "Multiple Attribute Decision Making: Methods and Applications," A State of the Art Survey 1. Berlin Heidelberg Springer, 1981.

These advantages make TOPSIS a major performance evaluation technique as compared to other related techniques. In recent years, TOPSIS has been successfully applied in the fields of human resources management, transportation, product design, manufacturing, energy, medicine, engineering, water management, quality control, and location analysis[18,19].

The TOPSIS method consists of several steps. Considering a MCDA problem with m alternatives and n criteria, the procedure is as follows:

1. Build the normalized decision matrix by dividing the scores of each alternative in the indicators of the performance for each criterion by the square root of the sum of squares of the score of each alternative, that is:

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum (X_{ij})^2}}; \ \forall i = 1 \dots m; j = 1 \dots n \tag{6}$$

2. Build the weighted normalized decision matrix by multiplying the normalized scores of each alternative in the j criterion by the weight of each criterion:

$$V_{ij} = W_j \cdot r_{ij} \tag{7}$$

3. Determine the ideal solution (A^+) and the anti-ideal solution (A^-) for each criterion:

$$A^+ = \{V_1 \dots V_n\}, where: V_j = \{Max(V_{ij}) \ for \ Benefits; Min \ (V_{ij}) \ for \ Costs\}$$
$$A^- = \{V_1 \dots V_n\}, where: V_j = \{Min(V_{ij}) \ for \ Benefits; Max \ (V_{ij}) \ for \ Costs\} \tag{8}$$

4. Calculate the separation measures for each alternative in each criterion:

$$S_i^+ = \left[\sum (V_j - V_{ij})^2 \right]^{1/2}; \ \forall V_j \in A^+$$
$$S_i^- = \left[\sum (V_j - V_{ij})^2 \right]^{1/2}; \ \forall V_j \in A^- \tag{9}$$

5. Calculate the relative closeness to the ideal solution for each alternative:

$$C_i = \frac{S_i^-}{(S_i^+ + S_i^-)} \tag{10}$$

6. Rank the alternatives according to their relative closeness to the ideal solution (C_i)

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[18]Majid Behzadian, S. Khanmohammadi Otaghsara, Morteza Yazdani, Joshua Ignatius. (2012). A state-of the-art survey of TOPSIS applications, Expert Systems with Applications 39(7), 13051-13069, https://doi.org/10.1016/j.eswa.2012.05.056
[19]Zulqarnain, R.M., Saeed, M., Ahmad, N., Dayan, F., & Ahmad, B. (2020). Application of TOPSIS Method for Decision Making. International Journal of Scientific Research in Mathematical and Statistical Sciences 7(2), 76-81

6 Ranking of alternatives

6.1 General Ranking of alternatives

The final ranking of NBS according to two of the selected weighting methods (AHP and EWM), based on the scores of the alternatives summarized above, considering the judgements of the experts consulted and using the TOPSIS performance evaluation method, are shown in Table 12.

Table 12. Ranking of alternatives according to the TOPSIS method

AHP Weights+TOPSIS			EWM Weights+TOPSIS		
NbS	Ranking	Score	NbS	Ranking	Score
Wetland FWS	1	0,8147	Wetland FWS	1	0,8621
Green Roof	2	0,4016	Green Roof	2	0,4682
Swale	3	0,3001	Filter Strip	3	0,3949
Swale (Lined)	4	0,2912	Filter Strip (Lined)	4	0,3922
Filter Strip	5	0,2878	Swale	5	0,3758
Retention Pond	6	0,2843	Swale (Lined)	6	0,3725
Filter Strip (Lined)	7	0,2789	Detention Basin	7	0,3635
Detention Basin	8	0,2785	Retention Pond	8	0,3606
Infiltration Basin	9	0,2770	Infiltration Basin	9	0,3600
Detention Basin (SS)	10	0,2700	Detention Basin (SS)	10	0,3594
Infiltration Basin (SS)	11	0,2652	Infiltration Basin (SS)	11	0,3560
Infiltration Trench	12	0,2640	Infiltration Trench	12	0,3558
Permeable Pavement (I)	13	0,2568	Permeable Pavement (I)	13	0,3328
Permeable Pavement (F)	14	0,2476	Permeable Pavement (F)	14	0,3272
Filter Drain	15	0,2404	Filter Drain	15	0,3234
Bioretention Area (Inf)	16	0,2355	Filter Drain (Lined)	16	0,3207
Filter Drain (Lined)	17	0,2326	Dry Well	17	0,3173
Dry Well	18	0,2303	Bioretention Area (Inf)	18	0,1933
Bioretention Area (Fil)	19	0,2262	Bioretention Area (Fil)	19	0,1831
Green Wall	20	0,1621	Green Wall	20	0,1675

As it can be observed in Table 12, Wetlands and Green Roofs are the two preferred NBS following both methodologies. On the other hand, Green Walls and Bioretention Areas are the last NBS in the rankings provided by those methods. When analyzing the results of each NBS for each of the considered attributes, it can be seen that their performance changes depending on the set of criteria considered. Tables 13 to 15 show the ranking of alternatives considering each attribute independently.

Thus, in Table 13 the ranking of alternatives according to Economic Criteria are presented. As it can be observed, when considering only the economic criteria, Filter Strips are the preferred options as they are the cheapest NBS in relation to the indicators of Construction, Operational and End-of-Life Costs. On the other hand, Bioretention areas are the most expensive system in terms of Construction and Operational Costs, so it makes sense that they are ranked as the last alternative when only economic criteria are taken into account. This bad performance in

terms of cost considerations is the reason behind the relatively low score of the Bioretention Areas in the general ranking of alternatives showed in Table 11.

Table 13. Ranking of alternatives according to Economic Criteria

Ranking according to Economic Criteria					
AHP Weights+TOPSIS			EWM Weights+TOPSIS		
NbS	Ranking	Score	NbS	Ranking	Score
1	Filter Strip	0,9179	1	Filter Strip	0,9655
2	Infiltration Basin	0,8473	2	Wetland FWS	0,9086
3	Infiltration Basin (SS)	0,8071	3	Filter Strip (Lined)	0,9052
4	Infiltration Trench	0,7916	4	Infiltration Trench	0,8737
5	Wetland FWS	0,7852	5	Infiltration Basin	0,8519
6	Filter Strip (Lined)	0,7809	6	Infiltration Basin (SS)	0,8435
7	Green Roof	0,7757	7	Detention Basin	0,8278
8	Permeable Pavement (I)	0,7327	8	Retention Pond	0,8227
9	Detention Basin (SS)	0,7145	9	Detention Basin (SS)	0,8220
10	Swale	0,7071	10	Green Roof	0,7849
11	Filter Drain	0,7008	11	Swale	0,7370
12	Detention Basin	0,6989	12	Filter Drain	0,7357
13	Retention Pond	0,6956	13	Swale (Lined)	0,7292
14	Dry Well	0,6800	14	Dry Well	0,7277
15	Swale (Lined)	0,6695	15	Filter Drain (Lined)	0,7264
16	Filter Drain (Lined)	0,6594	16	Permeable Pavement (I)	0,7159
17	Permeable Pavement (F)	0,6561	17	Permeable Pavement (F)	0,7028
18	Green Wall	0,3634	18	Green Wall	0,2850
19	Bioretention Area (Inf)	0,2505	19	Bioretention Area (Inf)	0,2361
20	Bioretention Area (Fil)	0,2069	20	Bioretention Area (Fil)	0,2294

Lined systems fall behind their unlined counterparts due to their lower capacity to reduce sewer system costs, as they are not able to avoid runoff volumes to enter in the sewerage. Similarly, infiltration subcategories of NBS are ranked better than their non-infiltration counterparts for the same reason. Finally, Sub-surface sub-categories of NBS are ranked below the surface version of the NBS because, even if they allow for multifunctional uses of the occupied land area, they also require the use of plastic materials that increases their End-of-Life costs.

Table 14 shows the NBS prioritization according to both AHP and EWM methods, attending only to environmental indicators. As it can be observed, the ranking for the environmental attribute showed big differences depending on the weight method used. Considering the weights obtained with AHP, Retention Ponds, Wetlands and Bioretention Areas are the preferred options as they have the biggest potential to treat runoff pollutants, mitigate flooding risks and increase biodiversity. But when the weights obtained with EWM are considered instead, also Infiltration Basins and Swales are included in the top 4 of alternatives due to the different weights given to the criteria considered in the Environmental attribute. On the other hand, Green Roofs, Green Walls and lined Filter Drains are the less preferred alternatives according to both weighting methodologies, as they have little or no effect in water quality and flood mitigation. Similar than for the Economic Criteria, lined options are less preferred than non-lined ones, as lined NBS have less potential to mitigate flooding risks and have no effect in groundwater quality. Similarly, sub-surface systems are less preferred than surface systems

as they have no effect on biodiversity and CO2 capture, so they are ranked below their counterparts at the surface level.

Table 14. Ranking of alternatives according to Environmental criteria

Ranking according to Environmental Criteria					
AHP Weights+TOPSIS			EWM Weights+TOPSIS		
NbS	Ranking	Score	NbS	Ranking	Score
1	Retention Pond	0,6279	1	Bioretention Area (Inf)	0,6752
2	Wetland FWS	0,6069	2	Infiltration Basin	0,6052
3	Bioretention Area (Inf)	0,5834	3	Swale	0,5273
4	Bioretention Area (Fil)	0,5808	4	Wetland FWS	0,5066
5	Detention Basin	0,5674	5	Infiltration Trench	0,4921
6	Detention Basin (SS)	0,5145	6	Infiltration Basin (SS)	0,4770
7	Swale	0,4906	7	Permeable Pavement (I)	0,4621
8	Infiltration Basin	0,4699	8	Retention Pond	0,4609
9	Filter Drain	0,4482	9	Filter Strip	0,4560
10	Infiltration Trench	0,4405	10	Bioretention Area (Fil)	0,4182
11	Infiltration Basin (SS)	0,4332	11	Filter Drain	0,4164
12	Swale (Lined)	0,3944	12	Detention Basin	0,3914
13	Dry Well	0,3733	13	Dry Well	0,3071
14	Permeable Pavement (I)	0,3710	14	Swale (Lined)	0,2938
15	Filter Strip	0,3654	15	Filter Strip (Lined)	0,2709
16	Permeable Pavement (F)	0,3647	16	Detention Basin (SS)	0,2594
17	Filter Drain (Lined)	0,3594	17	Permeable Pavement (F)	0,2245
18	Green Roof	0,3043	18	Green Roof	0,2238
19	Filter Strip (Lined)	0,2929	19	Green Wall	0,2119
20	Green Wall	0,2207	20	Filter Drain (Lined)	0,1892

Finally, Table 15 shows the prioritization of NBS when only Social Criteria are considered. As it can be observed, there are not major differences between the results from both weighting methods, EWM and AHP, the priorization list being the same. Bioretention Areas, Retention Ponds and Detention Basins are on top of the ranking due to their high input in the considered social indicators. On the other hand, Permeable Pavements, Dry Wells and sub-surface versions of Detention and Infiltration Basins are the last ranked with no score for this attribute as they have no effect on any of the performance indicators used.

Table 15. Ranking of alternatives according to Social criteria.

Ranking according to Social Criteria					
	AHP Weights+TOPSIS			**EWM Weights+TOPSIS**	
NbS	**Ranking**	**Score**	**NbS**	**Ranking**	**Score**
1	Bioretention Area (Inf)	0,8618	1	Bioretention Area (Inf)	0,9063
2	Bioretention Area (Fil)	0,8618	2	Bioretention Area (Fil)	0,9063
3	Retention Pond	0,3874	3	Retention Pond	0,3249
4	Detention Basin	0,3256	4	Detention Basin	0,2901
5	Infiltration Basin	0,3256	5	Infiltration Basin	0,2901
6	Wetland FWS	0,3256	6	Wetland FWS	0,2901
7	Green Roof	0,2771	7	Green Roof	0,2167
7	Green Wall	0,2771	8	Green Wall	0,2167
9	Filter Strip	0,1975	9	Filter Strip	0,1354
10	Filter Strip (Lined)	0,1975	10	Filter Strip (Lined)	0,1354
11	Swale	0,1975	11	Swale	0,1354
12	Swale (Lined)	0,1975	12	Swale (Lined)	0,1354
13	Infiltration Trench	0,1382	13	Infiltration Trench	0,0937
14	Filter Drain	0,1382	14	Filter Drain	0,0937
15	Filter Drain (Lined)	0,1382	15	Filter Drain (Lined)	0,0937
16	Detention Basin (SS)	0,0000	16	Detention Basin (SS)	0,0000
17	Infiltration Basin (SS)	0,0000	17	Infiltration Basin (SS)	0,0000
18	Dry Well	0,0000	18	Dry Well	0,0000
19	Permeable Pavement (I)	0,0000	19	Permeable Pavement (I)	0,0000
20	Permeable Pavement (F)	0,0000	20	Permeable Pavement (F)	0,0000

6.2 Site-Specific Ranking of alternatives

To obtain a site-specific ranking of alternatives, the MCDA has been programmed in an Excel Spreadsheet to be easily used. The results of the MCDA based on the different weighting methods here considered and the score of each NBS in each performance indicator, regarding each criterion considered in the analysis, are summarized in this document and integrated in the MCDA spreadsheet. End users will be able to develop the same analysis performed here but adapting the weights and the scores of alternatives to their own conditions. For this, users will find three editable worksheets in the Excel spreadsheet (with the worksheet name highlighted in green), four non-editable worksheets where the results of the analyses are summarized (with the worksheet name highlighted in orange), and finally five non-editable calculation sheets (with the worksheet name highlighted in red). Additionally, a how to use worksheet was also integrated in the spreadsheet to provide the main instructions required to perform the analysis. However, if any user has difficulties in using the spreadsheet or any doubt can contact us at the e-mail: info@d4runoff.eu.

6.2.1 How to use worksheet

In the first worksheet of the EXCEL, called "How to Use" and highlighted in blue, the user will find the main instructions related to the application of the different MCDA methods implemented in the spreadsheet, indicating also the steps that needs to be performed in order to obtain the criteria weights and NBS alternatives rankings. A screenshot of this worksheet is showed in Figure 5.

HOW TO USE THIS SPREADSHEET		
The user will find 9 worksheets in this spreadsheet. **Green-labeled worksheets** are editables, so the users can modify some of the values of the worksheet in order to fit the MCDA to their specific situation. **Red-labeled worksheets** are used for calculation purposes and hence arer non-editable worksheets. **Orange-Labeled worksheets** are those worksheets that provide the outputs of the MCDA, and hence are also non-editable worksheets. Finally, the only **blue-labeled worksheet** is this worksheet where the user can find how to use the		
To develop a MCDA analysis with this spreadsheet the user should follow the following steps:		
1		The first step to use this worksheet is selecting the weighting method for criteria and attributes. The user can also use all the weighting methods available in the spreadsheet but needs to fill all the information required for each method independently. It is important to note that the Entropy Weight Method, is an objective weighting method based only on the information gathered from the performance values for the NBS alternatives, and hence, the weights of criteria and the ranking of alternatives will only change if the user change the performance values in the corresponding worksheet.
	Ranking Weighting Method	For the method implementation, the user should go to the worksheet called "RM_Input Data" and establish a prioritization or ranking of the criteria considered in the MCDA. There are 4 different ranking lists that have to be fullfilled by the user: The first comparing attributes, and the rest comparing Economic Criteria, Environmental Criteria and Social Criteria (respectively). Based on the priority order of the criteria assigned by the DM in the four ranking lists, the method assigns weights to these criteria. **To rank the criteria, it should be taken into account that the criterion ranked number 1 is the most important and as the ranking number increases the importance decreases**. The numbers for ranking criteria and attributes should be consecutive, so if there are 4 criteria to be ranked, the user should prioritize them using the values: 1, 2, 3, 4, assigning each value to one (and only one) criteria of the specific ranking list according to the preference of the DM. In this method it is not possible to establish equal importance of criteria or attributes. Once all the criteria have a priority order (number) assigned, the weight process is finished and the weights of criteria and attributes can be seen in the worksheet called "WEIGHTS Summary", under the column called "WEIGHTS (RM)"
	Analytic hierarchy Process Weighting Method	The method assigns weights to each criterion according to DM preferences based on pairwise comparisons. In the worksheet "AHP_Input data" **the user is asked to perform pairwise comparisons** among attributes and criteria. The user will find 4 independent groups of pairwise comparisons, one for comparing the attributes, and the others to compare Economic, Environmental and Social criteria (respectively). The user should assign a relative importance coefficient in each pairwise comparison based on his/her own preferences (or those assigned by the group which is representing). **The relative importance coefficient in each pairwise comparison is a value between 1 and 9 that represent the preference of the DM and can be assigned by simply putting an "x" in the corresponding box of the pairwise comparisons table of the "AHP_Input Data" worksheet**. It should be noted that, numerically, **the relative importance value associated to each comparison represents how many times one criterion is more important than the other criterion**, so if the user put a value of "1: Equally important" when comparing criterion A and criterion B, it means that both criteria have the same importance, while if the user put a value of "3: Moderately prefered" of criterion A in relation to criterion B, means that the criterion A is three times more important than criterion B. It is also important to highlight that only one box should be marked in each row not to corrupt the system calculations. Once the user have finished all the pairwises comparisons **the user should check the Consistency Check verification boxes placed below the pairwise comparison tables to ensure that the performed pairwise comparisons are consistent**. This verification assess if the relative importance values assigned to each pairwise comparison meet aritmetic consistency (e.g. If the user consider the criterion A equally important than criterion B and 2 times more important than another criterion, called criterion C, hence the criterion B should be also 2 times more important than criterion C). If the Consistency Ratio (CR) of some pariwise comparison table is lower than 0.1, the assigned values of relative importance can be considered consistent and the message "Consistency Check Passed" will appear in the corresponding table highlighted in green. If any consistency check fails (CR higher than 0.1), the message "Consistency Check Fail" will appear highlighted in red indicating the inconsistency. To solve this inconsistency, the user can go to the Consistency Check Column, and review the comparisons where inconsistencies are detected (those highlighted with a red or yellow icon depending on the level of inconsistency) and adjust the scores until the CR value eventually falls behind the value of 0.1. Once the user has assigned scores to each comparison and the consistency has been ensured, the process is finished and the new

Figure 5. Screenshot of the "How to use" implemented in the spreadsheet.

6.2.2 RM Weighting worksheets

There are two worksheet related to this method. The first one, labeled in green and called "RM_Input Data" is used to ask the user to rank criteria and attributes according to their importance. To rank the criteria, it should be taken into account that the criterion ranked number 1 is the most important and as the ranking number increases the importance decreases (Figure 6a). The numbers for ranking criteria and attributes should be consecutive and the method does not support for equally important criteria. Once all the criteria have a number assigned the weight process is finished and the weights of criteria and attributes can be seen in the worksheet called "RM_Weights" (the third worksheet, labeled in organge, Figure 6b) and also summarized in the worksheet called "WEIGHTS Summary", under the column called "WEIGHTS (RM)".

(a)

ATTRIBUTES	RANKING OF IMPORTANCE
Economic	1
Environmental	2
Social	3
Expertise	4

ECONOMIC CRITERIA	RANKING OF IMPORTANCE
Construction Costs	1
Operational Costs	2
End-of-Life Costs	3
Sewer System Cost	4
Land Use optimization	5

ENVIRONMENTAL CRITERIA	RANKING OF IMPORTANCE
Flood mitigation	1
Runoff Water Quality (Conventional)	2
Runoff Water Quality (Emerging Pollutants)	3
Groundwater quality	4
Biodiversity	5
CO2 Capture	6

SOCIAL CRITERIA	RANKING OF IMPORTANCE
Social Engagement	1
Aesthetic Values	2
Recreational value	3
Cultural and educational Values	4

(b)

CRITERIA	WEIGHT (RM)
Economic Criteria	**52,08%**
Construction Costs	23,78%
Operational Costs	13,37%
End-of-Life Costs	8,16%
Sewer System Cost	4,69%
Land Use optimization	2,08%
Environmental Criteria	**27,08%**
Flood mitigation	11,06%
Runoff Water Quality (Conventional)	6,55%
Runoff Water Quality (Emerging Pollutants)	4,29%
Groundwater quality	2,78%
Biodiversity	1,66%
CO2 Capture	0,75%
Social Criteria	**14,58%**
Social Engagement	7,60%
Aesthetic Values	3,95%
Recreational value	2,13%
Cultural and educational Values	0,91%
Expertise	**6,25%**

Figure 6. RM weighting: (a) RM_Input Data worksheet and (b) RM_Weights worksheet

6.2.3 AHP Weighting Method worksheets

There are two worksheets related to this method. The first one is called "AHP_Input Data". In this worksheet the user should fill in the relative importance of each attribute in relation to the rest of attributes, and the relative importance of each criterion within each attribute with the rest of criteria within the same attribute in order to perform the AHP weighting procedure. To do this, the user must score each pairwise comparison between 1 and 9 by simply putting an "x" in the corresponding box and depending on the preferred attribute or criterion between the two compared, as showed in Figure 7. It should be noted that the number associated to each comparison represents how many times one criterion is more important than the other criterion. It is also important to highlight that only one box should be marked in each row not to corrupt the system calculations.

Figure 7 — AHP_Input Data worksheet

PAIRWISE COMPARISONS

ATTRIBUTES

Attribute A	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Attribute B	CONSISTENCY CHECK
Economic	x (left, ~2)	Expertise	✓
Environmental	x (left, ~4)	Expertise	✓
Social	x (left/right, ~1)	Expertise	✓
Economic	x (far left, 9)		✓
Environmental	x (left, ~7)		✓
Economic	x (center, ~1)		✓

Consistency Check Passed — CR= 0,053

> Consistency Check: OK.
> The values introduced are consistent

ECONOMIC CRITERIA

Criterion A	9 8 7 6 5 4 3 2 1 2 3 4 5 6	Criterion B	CONSISTENCY CHECK
Construction Costs	x (left, ~5)		✗
Operational Costs	x (right, ~6)		⚠
End-of-Life Costs			✓
Sewer System Cost	x (right, ~2)	Sewer System Cost	⚠
Construction Costs	x (right, ~3)	Sewer System Cost	⚠
Operational Costs	x (right, ~3)	Sewer System Cost	✓
End-of-Life Costs	x (right, ~5)		✓
Construction Costs	x (left, ~5)		✗
Operational Costs	x (left, ~2)		✓
Construction Costs	x (left, ~2)		✗

Consistency Check Fail — CR= 0,220

> The user should review the score given to these comparisons firstly the ones marked with a red icon, and, if the inconsistency persist, the ones with a yellow icon.

> Consistency Check fails.
> The values introduced are not consistent.

ENVIRONMENTAL CRITERIA

Criterion A	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Criterion B	CONSISTENCY CHECK
Flood mitigation	x (far left, 9)	CO2 Capture	✓
Runoff Water Quality (Conventional)	x (left, ~8)	CO2 Capture	✓
Runoff Water Quality (Emerging Pollutants)	x (left, ~8)	CO2 Capture	✓
Groundwater quality	x (left, ~5)	CO2 Capture	✓
Biodiversity	x (left, ~4)	CO2 Capture	✓
Flood mitigation	x (left, ~7)	Biodiversity	✓
Runoff Water Quality (Conventional)	x (left, ~4)	Biodiversity	✓
Runoff Water Quality (Emerging Pollutants)	x (left, ~4)	Biodiversity	✓
Groundwater quality	x (left, ~2)	Biodiversity	✓
Flood mitigation	x (left, ~6)	Groundwater quality	✓
Runoff Water Quality (Conventional)	x (left, ~3)		✓
Runoff Water Quality (Emerging Pollutants)	x (left, ~3)		✓
Flood mitigation	x (left, ~4)		✓
Runoff Water Quality (Conventional)	x (left, ~2)		✓
Flood mitigation	x (center-left, ~1)		✓

Consistency Check Passed — CR= 0,041

> Having Groundwater Quality a relative importance of 2 in relation to Biodiversity means that Groundwater Quality is 2 times more important than Biodiversity

SOCIAL CRITERIA

Criterion A	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Criterion B	CONSISTENCY CHECK
Social Engagement	x (center, ~1)	Cultural and educational Values	✓
Aesthetic Values	x (left, ~3)	Cultural and educational Values	✓
Recreational value	x (left, ~3)	Cultural and educational Values	✓
Social Engagement	x (right, ~4)	Recreational value	✓
Aesthetic Values	x (center, ~1)	Recreational value	✓
Social Engagement	x (right, ~1)	Aesthetic Values	✓

Consistency Check Passed — CR= 0,064

Figure 7. AHP_Input Data worksheet screenshot.

Once that is done, the user should check the Consistency Check verification boxes below each table to ensure that the performed pairwise comparisons are consistent. If the Consistency Ratio (CR) is lower than 0.1, the assigned values of relative importance in the performed pairwise comparisons can be considered consistent and therefore, the check-box of CR will be highlighted in green and the message "Consistency Check Passed" will appear highlighted in green. If any Consistency Check fails (CR higher than 0.1), the check-box of CR will be highlighted in red indicating the inconsistency and the message "Consistency Check Fails" will appear highlighted in red. To solve the inconsistency, the user can go to the Consistency Check column, review the comparisons where inconsistencies are detected (those highlighted with a red or yellow icon) and adjust the scores until the CR value eventually falls behind the value of 0.1 and the message "Consistency Check Passed" appears in the corresponding cell.

Once the user has assigned scores to each comparison and the consistency has been ensured the process is finished and the new weights of criteria and attributes will be showed in the next worksheet, called "AHP_Weights" and summarized in the worksheet called "Weights Summary", under the column called "WEIGHTS (AHP)".

6.2.4 Entropy Weighting Method (EWM) worksheet

The worksheet of the spreadsheet called "EWM Calculations" apply the EWM to the performance values summarized in the "Performance Values" worksheet and is a non-editable worksheet. It is due to the fact that EWM assigns weights only considering the performance scores of the alternatives. In this worksheet only the calculations used by this methodology to assign weights to attributes and criteria based on the performance values summarized in the "Performance Values" worksheet are integrated. Therefore, in order to obtain different criteria or attribute weights accordint to the EWM, the user should change the performance values in the "Performance Values" worksheet of the spreadsheet. When this is done, the EWM will be automatically re-calculated and the results for the weights of attributes and criteria will be presented in the "WEIGHTS Summary" worksheet, under the column called "WEIGHTS (EWM)".

6.2.5 Performance Values worksheet

The worksheet of the spreadsheet called "Performance Values" is a fully-editable worksheet. It summarizes the scores of each alternative for the indicators selected to assess the performance of alternatives in each criterion and attribute. Even if the values summarized in this worksheet are based on large datasets, mainly obtained from the parametric library developed in previous tasks of the WP3, the user can modify these values in order to consider site-specific situations or self-developed studies with more detailed information about the performance of the alternatives in relation to the selected performance indicators. It should be noted that if a user would like to modify the values of this worksheet, all the values in the same column should be in the same units and scale. If the performance values of the alternatives were modified, the ranking of alternatives according to the weights assigned to each criterion and attribute would also be modified.

On the other hand, by modifying the values of this worksheet, also the relative weights of attributes and criteria according to the EWM will be modified as this method assigns weights on the basis of the scores of the alternatives in the performance indicators.

6.2.6 Weights Summary worksheet

The worksheet called "WEIGHTS Summary" summarizes the weights of attributes and criteria according to the three previously described methods (AHP, EWM and RM), as shown in Figure 8. This worksheet provides users with the criteria weights that are going to be used for prioritizing alternatives. The information showed in this worksheet can provide the user with a range of acceptable weights for the different criteria.

CRITERIA	WEIGHTS (AHP)	WEIGHT (EWM)	WEIGHT (RM)
Economic Criteria	**47,10%**	**41,25%**	**52,08%**
Construction Costs	9,42%	14,21%	23,78%
Operational Costs	3,79%	16,65%	13,37%
End-of-Life Costs	1,72%	3,43%	8,16%
Sewer System Cost	9,42%	4,97%	4,69%
Land Use optimization	22,75%	1,99%	2,08%
Environmental Criteria	**36,05%**	**19,74%**	**27,08%**
Flood mitigation	9,51%	0,97%	11,06%
Runoff Water Quality (Conventional)	12,47%	3,20%	6,55%
Runoff Water Quality (Emerging Pollutants)	7,82%	2,76%	4,29%
Groundwater quality	3,18%	5,63%	2,78%
Biodiversity	2,10%	4,07%	1,66%
CO_2 Capture	0,97%	3,11%	0,75%
Social Criteria	**4,64%**	**15,38%**	**14,58%**
Social Engagement	0,22%	5,56%	7,60%
Aesthetic Values	1,83%	2,67%	3,95%
Recreational value	1,83%	4,49%	2,13%
Cultural and educational Values	0,76%	2,67%	0,91%
Expertise	**12,21%**	**23,64%**	**6,25%**

Figure 8. Weights summary according to the three used weighting methods.

6.2.7 NBS Ranking worksheet

Finally, this worksheet presents the ranking of alternatives obtained by applying the TOPSIS methodology and according to the three weighting methods described above. As it can be seen in Figure 9, for each alternative there is a column "Score" where its score is provided on a scale between 0 and 1, and another column "ranking" where the alternatives are ranked by an ordinal number between 1 and 20 based on the score obtained. The best alternative is the one ranked 1 and corresponds to the alternative with the highest score, and the rest of alternatives are ranked in increasing order according to the score obtained. By using the results showed in this worksheet the user can prioritize interventions according to the ranking given to each NBS alternative.

NbS	AHP+TOPSIS Ranking	AHP+TOPSIS Punctuation	EWM+TOPSIS Ranking	EWM+TOPSIS Punctuation	RM+TOPSIS Ranking	RM+TOPSIS Punctuation
Bioretention Area (I)	20	0,24433786	18	0,17640562	18	0,35107961
Bioretention Area (F)	18	0,25431083	19	0,16822253	19	0,35082435
Detention Basin	9	0,3611009	7	0,36480532	5	0,69392538
Detention Basin (SS)	4	0,39912688	9	0,3609275	7	0,68153924
Filter Strip	3	0,4071063	3	0,39627947	2	0,71317315
Filter Strip (Lined)	6	0,3938651	4	0,39396258	3	0,70603605
Green Roof	2	0,46962631	2	0,47147917	10	0,6370524
Green Wall	19	0,2525806	20	0,16805943	20	0,17752461
Infiltration Basin	5	0,39412613	10	0,36031703	6	0,68711455
Infiltration Basin (SS)	7	0,39163787	11	0,35647106	9	0,67509515
Dry Well	13	0,33031342	17	0,3182036	11	0,63473187
Infiltration Trench	12	0,34551033	12	0,35606529	8	0,67664392
Permeable Pavement (I)	10	0,35658945	13	0,33332474	14	0,55852195
Permeable Pavement (F)	11	0,34876181	14	0,32889126	15	0,55645588
Retention Pond	8	0,37069706	8	0,36186675	4	0,69822837
Swale	14	0,31641317	5	0,37711298	12	0,57297222
Swale (Lined)	15	0,30714728	6	0,37447286	13	0,56680183
Filter Drain	16	0,26836066	15	0,32410811	16	0,55209439
Filter Drain (Lined)	17	0,26027524	16	0,32197902	17	0,54558735
Wetland FWS	1	0,76140492	1	0,88753507	1	0,80739698

Figure 9. NBS Ranking Summary according to the three weighting methods considered.

7 Final Remarks

This Multi-Criteria Decision Analysis (MCDA) is a useful tool for raking NBS alternatives according to the 4 selected attributes and based on the parametric library developed in task 3.1 (D3.1), as a synthesis of the available knowledge onstormwater management systems in urban areas, mainly focused on Nature-Based Solutions (NBS) for urban drainage. This MCDA is only a step forward and needs to be combined with the information available in Geographical Information Systems (GIS) in order to eventually provide a prioritization of solutions based on the specific situations that can arise in the different urban areas. This will be the final objective of the last task of WP3, and will be summarized in the next deliverable (D3.3).

From the results of this MCDA it can be stated that NBS can be prioritized according to different criteria, being possible and recommendable to combine them to offer a balanced, sustainable and realistic solution. The consideration of economic criteria or environmental alone is no longer an option. Decision makers must base their judgement on more indicators than the traditional ones, and from now on they can count on this MCDA proposal for the selection and location of NBS, resulting in hybrid drainage systems.

8 Acronyms

Table 16. Acronyms

Acronyms	Name
AHP	Analytic Hierarchy Process
BWM	Best Worst Method
CECs	Contaminants of Emerging Concern
CI	Consistency Index
CR	Consistency Ratio
D	Deliverable
DM	Decision Makers
EWM	Entropy Weighting Method
FUCOM	Full Consistency Method
GIS	Geographical Information System
IIRM	Inconsistency Index of a Random Matrix
MCDA	Multi-criteria decision analysis
NBS	Nature-based Solutions
NIS	Negative Ideal Solution
NWRM	European Natural Water Retention Measures
RM	Ranking Method
PIS	Positive Ideal Solution
ROC	Rank Order Centroid
SuDS	Sustainable Drainage Systems
SS	Sub-surface
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
WP	Work package