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Comparative Analysis of Multicriteria Decision-Making Methods for Bus Washing Process Selection: A Case Study

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Abstract

Water is at the core of sustainable development, and its use for human activities, including vehicle washing, should be done in a sustainable way. There are several technical solutions for washing buses offering different performances, making it difficult to choose the one that best meets the requirements of each specific case. The literature on the topic hardly analyzes the choice of the best technical solution for washing buses and does not apply and compare the results of different multicriteria decision-making (MCDM) methods for the problem. The unique information available is from the different suppliers in the market. Whereby, this work intends to give a technical-scientific contribution to fulfill this gaps. Therefore, the main objectives of this work are (1) to select the best sustainable technical solutions for washing buses depending on the specific conditions for a case study and (2) to analyze how different multicriteria decision-making methods behave in the selection process. To achieve these objectives, the problem was approached as a case study in a public transport company in Portugal and the methodology followed the next steps: started with the identification of the different types of commercial technical solutions for washing buses; the company's experts selected four main criteria: water consumption, operating costs, quality of washing, and time spent; the criteria weights were determined using the fuzzy-AHP method; then four representative MCDM methods were selected, namely, AHP, ELECTRE, TOPSIS, and SMART; the ranks obtained for the four methods were compared; and a sensitivity analysis was performed. Considering the input data for the criteria and their weights, the results for all the methods showed that the best and the worst solution was the same, mobile portico with a brush and porticoes with three brushes, respectively. Furthermore, the results of the sensitivity analysis performed with disturbances for the weights of each criterion presented that the results are slightly affected and the similarity in rankings for the four MCDM methods was validated by Spearman's rank correlation coefficient (r_s) and Kendall's coefficient of concordance (W). Considering these results, the SMART method, the less complex one, showed no difference from the others. For that reason, simple methods, such as SMART, in line with other works in the literature perform well in most cases. As a final remark of this work, it can be said that the methodology employed in this project can also be deemed applicable to other similar companies seeking technical solutions for bus or truck washing. Furthermore, the application of the SMART method, the less complex one and the most understandable for people, showed no difference from the others, being able to be applied in similar situations.

1. Introduction

In a society whose concern with the environment is increasingly present, the use of alternative solutions that allow for the reduction of consumption of the planet's existing natural resources is a necessary condition. In addition, the negative implications for enterprises that do not look for better utilization of their resources are quite high. So, the way is to think/plan and act (not react) faster and beyond than the common in order to promote the desired resource utilization [1]. The study to be developed falls within this theme and deals more specifically with water resources.

Water is at the core of sustainable development and is essential for several aspects, including poverty reduction, economic growth, environmental sustainability, climate change, healthy ecosystems, and the survival of human beings (United Nations [2]). It is believed that, as the years go by, the world population will continue to increase. In fact, it is expected that in 2030, the population will reach 8.5 billion, in 2050 9.7 billion, and in 2100 11.2 billion (United Nations [2]). In the space of 70 years, we are talking about an increase of about 32%. Being aware of these data is important, insofar as, in this last century, the population tripled, and associated with this, the water consumption increased six times, putting this resource under threat [3]. Knowing that the population is growing at a constant rate, around 1% per year, and that this implies an increase in water consumption, it is estimated that in 2030, the world will be faced with a deficit of water resources in the order of 40% (United Nations [2]).

Great potential exists for using water more efficiently in agriculture, industries, and cities. Increasingly, investments in conservation, efficiency, reuse, and recycling can yield more useable water per unit cost than investments in new engineering projects to expand the freshwater supply [4] In fact, good measures and practices of governance and corporate governance should be developed in order to contribute to improve the sustainability in their three pillars: economic, environmental, and social [5]. For instance, some European countries began adopting policies that were aimed at restricting the consumption of drinking water (60–70 L per car) and/or imposing water recycling ratio (70–80%) in commercial vehicle washes [6].

This work addresses the problem of choosing the most suitable technical solutions to support bus washing. This is a multicriteria problem where the environmental criteria are quite important, but for the decision-makers, the economic, quality, and time spent criteria should also be considered. However, there are several technical solutions for washing buses offering different performances, making it difficult to choose the one that best meets the requirements of each specific case. Thus, selecting an optimal solution that can be used in the decision-making procedure to ensure that the criteria constraints are integrated without harming sustainability becomes a challenge for decision-makers [7].

The literature on the topic hardly analyzes the choice of the best technical solution for washing buses and does not apply and compare the results of different multicriteria decision-making (MCDM) methods for the problem. The unique information available is from the different suppliers in the market. In this way, this work intends to give a technical-scientific contribution in the area since explicit analyses of the choice of the best technical solution for washing buses that consider the aforementioned criteria do not appear in the bibliography. To fulfill these gaps, the main objectives of this work are (1) to select the best sustainable technical solutions for washing buses depending on the specific conditions for a case study and (2) to analyze how different multicriteria decision-making methods behave in the selection process. To achieve the objectives, four representative multicriteria decision-making (MCDM) methods will be applied to a case study—a public transport company in Portugal, namely, water consumption, operating costs, quality of washing, and time spent.

According to Pazouki et al. [7], MCDM is a suitable approach for dealing with water resource management problems. The MCDM method integrates quantitative and qualitative criteria with the alternatives defined in new sustainable solutions with the mathematical approaches to facilitate managerial decision-making. In the field of water resource management, these techniques have received much attention over time, and various models have been developed in this regard [8]. Over the last few years, within the water sector, some of the last most important works that implemented MCDM methods are summarized in Table 1.

Table 1. Summary of the most recent important works applying MCDM methods in the water sector (adapted from [7]).

Author	Method (s)	Application
Minatour et al. [9]	Fuzzy-TOPSIS	Water supply management
Jozaghi et al. [10]	AHP and TOPSIS	Dam site selection
Golfam et al. [11]	AHP and TOPSIS	Evaluate alternatives for the management of the water supply system
Ebad et al. [12]	TOPSIS	Agricultural water supply
Ardestani et al. [13]	TOPSIS	Management and planning of water resources in drainage basins

Vishnupriyan et al. [14]	Fuzzy-TOPSIS	Optimal planning of desalination plant feasibility in different urban cities
Štirbanović et al. [15]	TOPSIS, VIKOR,	Selection of acid mine drainage (AMD)

Considering the works in Table 1, there are several MCDM methods applied in the water sector, but most of them used the AHP and TOPSIS, and in few cases, their combination with fuzzy logic is used to overcome the subjectivity of some criteria.

The rest of this paper is organized as follows: Section 2 identifies the main commercial and technical solutions for washing buses and their pros and cons. Section 3 presents the case study, including the problem, the quantification of the criteria and its weights, and the selection of the multicriteria decision-making methods to apply in the problem. Then, Section 4 presents the results and discussion. To finalize, some conclusions and future works are made in Section 5.

2. Commercial Technical Solutions for Washing Buses

Regarding works in the area that are associated with our objective, no study was found in databases such as Scopus or in the Web of Science. However, several technical solutions from manufacturers are available, such as Tammermatic [25], Morclean [26], Christ [27], Hydro-Chem Systems [28], NoviClean [29], InterClean [30], KKE Wash Systems [31], and Steamericas [32], and based on that information, this section summarizes and processes the information that was collected.

By technical washing solution is meant the process of carrying out the washing itself. The existing processes can carrying out the washing itself. The existing processes can be divided into two large groups: automatic washing and manual washing. By automatic washing, it is understood the case where it is a machine that performs the complete washing operation, without human intervention, and the manual one, despite being able to have the aid of machines, already requires human intervention.

There are basically three types of automatic washing systems: the porticoes with brushes (two, three, four, and five brushes; see Figure 1), high water pressure devices without brushes (see Figure 2), and high water pressure devices with brushes (see Figure 3).

Figure 1 Open in figure viewer | PowerPoint

Porticoes with five brushes—magnum 5 [27].

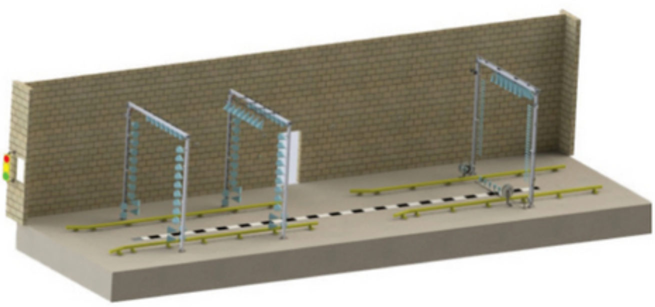

Figure 2 Open in figure viewer | PowerPoint

High water pressure device without brushes—bus wash system [28].

Figure 3 Open in figure viewer | PowerPoint

High water pressure device with brushes—bus wash system [29].

There are also basically three types of manual washing systems: the mobile portico with a brush (see Figure 4), washing with steam (see Figure 5), and manual high water pressure devices.

Figure 4 Open in figure viewer | PowerPoint

Mobile portico with a brush—mobile wash system [30].

Figure 5 Open in figure viewer | PowerPoint

Washing with steam [32].

After analyzing all the technical solutions, a summary table was prepared where the main advantages and disadvantages of the types of automatic washing (Table 2) and the types of manual washing (Table 3) can be easily consulted.

Table 2. Summary of the advantages and disadvantages of the various types of automatic washing.

Pros	Cons
Porticoes with brushes	
(i) Fast (ii) Easy	(i) Aggressive chemicals (ii) The choice must be

(iii) Efficient (iv) Reasonable maintenance costs (v) The driver does not need to leave his vehicle (vi) Customizable (vii) Depending on the brand of equipment chosen, it may use recycled water	careful; if not, it could damage, for example, the bumpers and mirrors (iii) Preferably uniform vehicles (iv) The quality of service can be affected by the speed at which the driver passes the machine (v) Can damage the paint
High water pressure device *without brushes*	
(i) Easily adapts to irregular profiles	(i) It may not clean as well as when using brushes

Table 3. Summary of the advantages and disadvantages of the various types of manual washing.

Pros	Cons
Mobile portico with a brush	
(i) Efficient (ii) Easy to operate (iii) Consumes less water than an automatic wash or a fully manual wash (iv) It is a versatile piece of equipment (v) Good price-quality ratio	(i) It needs an operator (ii) Time-consuming

Washing with steam	(i) Reduces the use of chemicals (ii) Removes dirt effectively (iii) Can be used for cleaning the interior of the bus (iv) Disinfect surfaces (v) Does not damage vehicle paint	(i) It needs two operators (ii) High initial investment (iii) Time-consuming process, about 35 minutes

3. Case Study

3.1. The Problem and the Decision Criteria Identification

The case study was developed in an urban transport company in Portugal, in one of its collection centers for 60 regular passenger buses. Currently, the exterior washing process of the company's buses has two main stages: the manual prewash, which is done simultaneously with the interior wash, and the automatic wash. The automatic washing system is several years old and does not perform as intended, including many stops for maintenance and high water consumption, so the company intends to replace it.

Each bus is washed once a day, seven days a week, so the consumption associated with the automatic washing of the 60 buses was calculated and shows the following values:

(1) Total water consumption = 8 200 m^3/year.

(2) Average washing time = 9.8 minutes/bus.

With the aim of improving the daily washing process for the buses, namely, with greater water savings, the company proceeded to study the selection of the washing system that presents the best overall performance considering four sustainable criteria: water consumption, operating cost, quality of washing, and time spent.

3.2. Determination of the Criteria Weights

The criteria weights were calculated by the company's management based on the fuzzy analytical hierarchy process (FAHP) methodology. The FAHP methodology has the advantage over other similar techniques, such as AHP or ANP, because a linguistic scale is used for the criteria evaluation process, treating uncertainty present in the expert's decision in a much more convenient way [33].

One of the methods to derive weights from a pairwise comparison matrix in FAHP is the geometric mean method proposed by Buckley [34]. This method is particularly useful for handling fuzzy pairwise comparisons but can also be applied in the traditional AHP context. The steps to apply the geometric mean method are the following:

Table 4. Fuzzy scale of relative importance.

Fuzzy scale	Relative importance	Fuzzy number
1	Equal importance	(1, 1, 1)
3	Moderate importance	(2, 3, 4)
5	Strong importance	(4, 5, 6)
7	Very strong importance	(6, 7, 8)
9	Extreme importance	(9, 9, 9)

2, 4, 6, 8	Intermediate importance	(1, 2, 3) (2, 3, 4) (5, 6, 7) (7, 8, 9)

(1) Construct the pairwise comparison matrix:

Firstly, create the decision matrix A of dimension $m \times m$.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1m} \\ \vdots & \vdots & \vdots \\ a_{m1} & \cdots & a_{mm} \end{bmatrix}, \quad (1)$$

where each element a_{ij} represents the importance of criterion a_{ii} relative to the criterion, a_{jj} based on the decision-maker's judgments using the fuzzy scale of relative importance represented in Table 4.

Then, the fuzzied pairwise comparison matrix is calculated. Each a_{ij} corresponds to a A_{ij}, i, j = 1, …, m. A_{ij} is a fuzzy number (l, m, u). For reciprocal, if $i \neq j$ and , otherwise.

(2) Calculate the weights using fuzzy geometric mean:

For each row in the matrix, calculate the geometric mean. The fuzzy geometric mean for the row is given by

(2)

where m is the number of elements (criteria) being compared.

(3) Normalize the fuzzy weights:

To derive the fuzzy weights from the geometric means, they are normalized so that their sum equals 1. The fuzzy weights for element are calculated as

(3)

where GM_k is the geometric mean of the k-th row.

(4) Calculate the center of area (COA) of fuzzy weights.

For each ,

(4)

(5) Normalize weights:

(5)

In this study, four evaluation criteria were considered: water consumption per year (C1), cost in 8 years (C2), quality of washing (C3), and time spent per bus (C4). The initial pairwise comparison matrix was performed by the company experts and is represented as

(6)

The weights of each criterion obtained by the geometric mean method are given in Table 5.

Table 5. Weights of each criterion obtained by the geometric mean method.

Criteria	**Weight**
Water consumption per year	0.43
Cost in 8 years	0.29
Quality of washing	0.17
Time spent per bus	0.11

3.3. Criteria Quantification for the Different Alternatives

The quantification of the criteria for the selection of the washing system was based on information from the proposals of the washing equipment manufacturers and the experts of the company under study. Taking into account the aforementioned factors, the following aspects were considered:

(1) To quantify the water consumption criterion, the consumption per wash defined by the manufacturer and the total number of washes that would be necessary for one year were considered

(2) To quantify the cost criterion, the investment costs were considered, which can be amortized over eight years, as well as the costs associated with energy consumption, equipment maintenance costs, and the cost of water consumed, all calculated for an eight-year period

(3) To quantify the quality of the washing criterion, a criterion of more subjective nature, the washing systems were rated using a scale of 1–5 by the company's experts

(4) To quantify the time spent criterion, the times provided by the manufacturers to carry out a wash were directly considered

Table 6 presents a summary of the quantification of the four criteria considered for all the washing system alternatives addressed in Section 2, except for cleaning with steam, because no information has been received from the suppliers.

Table 6. Data for technical solutions for washing alternatives.

Criteria		**Water consumption per year (m^3)**	**Cost in 8 years (€)**	**Quality of washing (scale 1–5)**	**(**
Technical solution for washing (alternatives)	Porticoes with two brushes	6 300	582 520	2	
	Porticoes with three brushes	20 895	691 806	3	
	Porticoes with four brushes	19 578	655 273	4	
	Porticoes with five brushes	16 170	608 481	5	
	High water pressure device	26 208	367 285	4	

WSI: without supplier information.

3.4. Selection of the Multicriteria Decision-Making Methods

MCDM problems are also known as discrete problems and concentrate on problems with explicitly known decision alternatives with finite numbers. It is an evaluation problem that chooses the best solution between a discrete number of alternatives. In these types of MCDM problems, goals, attributes (that are criteria), and alternatives are clear; however, the limitations are unclear, and the interaction level between decision-makers is limited [35].

In a mathematical form, a MCDM problem with m criteria (C_1, C_2, …, C_m) and n alternatives (A_1, A_2, …, A_n) can be expressed in a ($m \times n$) matrix. Equation (7) represents the decision matrix A in which element a_{ij} indicates the evaluation of the decision criterion C_i for the alternative A_j, and Equation (8) represents the weights' vector W—a set of normalized weights assigned to each criterion based on their importance [36].

(7)

(8)

With matrix A and the weights' vector , the basic inputs for the MCDM problems, a selected MCDM method scores the alternatives and orders them based on the best to the worst.

There are several methods to lead with MCDM problems, and Chai and Ngai [37] considered four distinctive categories: multiattribute utility methods, outranking methods, compromise methods, and other methods. For each of the four categories, the authors considered the following most important methods:

(i) Multiattribute utility methods: Assign a value to each alternative as a quantitative representation of people's preferences. The term "utility" is borrowed from economics, where human preference can be formulated by a utility (or value) function. The value of a utility function is comparable and is thus the proper measurement for ranking (choosing) alternatives [37]:

(1) AHP (Analytic Hierarchy Process)

(2) ANP (Analytic Network Process)

(ii) Outranking methods: Use binary relations to

(ii) Outranking methods: Use binary relations to compare alternatives through a weak preference, such as "as least as" and "as good as" [37]:

(1) ELECTRE (Elimination and Choice Expressing Reality)

(2) PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation)

(3) QUALIFLEX (Qualitative Flexible Multiple Criteria Method)

(iii) Compromise methods: Attempt to find the closest to the ideal solution. TOPSIS and VIKOR are the representative compromise methods, which apply aggregating functions to formulate the closeness to the ideal point [37]:

(1) TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)

(2) VIKOR (Multicriteria Optimization and Compromise Solution)

(iv) Other methods:

(1) SMART (Simple Multiattribute Rating Technique)

(2) DEMATEL (Decision-Making Trial and Evaluation Laboratory)

For each of the four categories, the selection of the most cited method according to the work of Taherdoost and Madanchian [35] was considered to simulate our case study. The study of Taherdoost and Madanchian [35] quantified the number of results (references), based on the "ScienceDirect" database, between 2012 and 2022, conducted on 21 April 2022. As a consequence, the selected methods are as follows:

(1) AHP to represent the multiattribute utility methods:

This is a pairwise comparison of hierarchical criteria considering different information [38]. AHP has been one of the most extensively used methods and has been extensively studied and refined since its appearance in the eighties [39, 40].

(2) ELECTRE to represent the outranking methods category: It consists on the elimination and choice translating reality [41], which is based on an outranking relation between the alternatives (i.e., considering two alternatives A_1 and A_2, A_1 outranks A_2 if there are strong enough reasons to state that A_1 is "at least as good as" A_2 and no enough reasons to state the contrary) and on the use of pseudocriteria.

(3) TOPSIS to represent the compromise methods category: This is a technique for order preference by similarity to ideal solution [42], in which the alternatives are ranked based on their distance from the defined ideal and negative-ideal solutions. According to Dharmalingam et al. [43], TOPSIS is the most effective and traditional method for solving MCDM in real-life application problems.

(4) SMART to represent the other methods category: This method weights the criteria based on their importance and evaluate each alternative against each criterion assigning directly a score [44]. One of the key advantages of SMART is its simplicity and ease of implementation. It does not require complex mathematical calculations or specialized software, making it accessible to a wide range of users. Additionally, SMART facilitates transparency and consensus building among stakeholders by providing a clear and structured methodology for decision-making.

All of these MCDM methods referred are quite explained in the literature, either by their authors or by the works where they are applied. For this reason, in this work further explanations are excused.

4. Results and Discussion

4.1. Ranking Using Different MCDM Methods

The best technical solution for washing buses was determined using the data in Table 6. The score and ranking of the alternatives were obtained by maximizing the washing quality and minimizing the other criteria. Among the eight possibilities for washing the buses, the alternatives with complete information were considered and are listed in Table 7. Note that there was no available information on the criterion steam cleaning. For this reason, it was not included in this study.

Table 7. List of alternatives with technical solution for washing.

Alternatives (A_i)	Technical solution for washing
A_1	Porticoes with two brushes
A_2	Porticoes with three brushes
A_3	Porticoes with four brushes
A_4	Porticoes with five brushes
A_5	High water pressure device without brushes
A_6	High water pressure device with a brush
A_7	Mobile portico with a brush

Initially, the order of alternatives was achieved considering the weights assigned to each criterion by the decision-maker. Thus, the criteria weights w_1 = 0.35, w_2 = w_3 = 0.25, and w_4 = 0.15 correspond to water consumption per year, cost in 8 years, quality of washing, and time spent per bus, respectively. Table 8 shows the ranks and spent per bus, respectively. Table 8 shows the ranks and scores of the alternatives obtained by the AHP, ELECTRE-III, TOPSIS, and SMART methods.

Table 8. Ranks and scores of the alternatives by the different MCDM methods.

Method	AHP		ELECTRE		TOPSIS		
Alternative	Score	Rank	Score	Rank	Score	Rank	Sc
A_1	1.160	3	2	3	0.657	2	6.
A_2	1.047	7	–5	7	0.208	7	6.
A_3	1.106	5	–3	6	0.278	5	6.
A_4	1.109	4	0	4	0.413	4	6.
A_5	1.086	6	–3	5	0.246	6	6.
A_6	1.200	2	3	2	0.629	3	6.
A_7	1.292	1	6	1	0.888	1	8.

4.2. Comparison of Rankings

The results in Table 5 show that the AHP, ELECTRE, TOPSIS, and SMART methods determined almost the same solution, i.e., only with differences in the middle of the ranking. The best alternative is *A*7 for the four methods, and the least interesting one is *A*2. However, the relative ranking of all the MCDM methods is compared by Spearman's rank correlation coefficient (r_s) and Kendall's coefficient of concordance (*W*) methods, according to (9) and (10), respectively. While the former does a pairwise comparison of ranks, the latter gives the concordance value altogether [19].

(9)

where r_s is Spearman's rank correlation coefficient, D_i is the difference between the two ranks of each observation, and m is the no. of alternatives, and

(10)

where W is the concordance value, S_i is the sum of ranks of the same alternative in different methods, m is the no. of alternatives, and k is the no. of methods considered.

Table 9 presents Spearman's rank correlation coefficients for all possible pairwise combinations of the four MCDM methods. It can be observed that Spearman's rank correlation coefficient is varying from 0.929 to 0.991, indicating a very good correlation in ranking obtained by different methods [45]. For the combined category, the highest correlation was obtained between AHP and PROMETHEE and the worst one between TOPSIS and SMART methods.

Table 9. Spearman's rank correlation coefficients for all possible pairwise combinations of the different MCDM methods.

Methods combinations	AHP-ELECTRE	AHP-TOPSIS	AHP-SMART	ELECTRE-TOPSIS	ELECTI SMAF
r_s	0.991	0.964	0.964	0.955	0.92

The similarity in rankings obtained by these methods is also measured using Kendall's coefficient of concordance. Its value lies between 0 and 1, where a value of 1 results in a perfect match. In this case, the value of W is computed as 0.9687, which suggests that there is an almost perfect agreement between the considered methods [46].

4.3. Sensitivity Analysis

In the second phase, a sensitivity analysis was carried out to understand the influence of the weights on the solution. Sensitivity analysis was performed by creating a disturbance in one criterion at a time. For convenience, the criteria weights (w_i, i = 1, 2, 3, 4) were considered for the four methods (AHP, ELECTRE-III, TOPSIS, and SMART), with their sum equal to 1.

Let the criteria be w_j, j = 1, 2, 3, 4, and considering the disturbance $\alpha_j(\alpha_j \in]0, 1[)$ to be imposed on a criterion w_j, this is changed according to

(11)

When imposing a variation in the weight of a criterion, the remaining criteria must be recalculated, i.e., should be proportionally reduced as a criterion weight increased. For this purpose, the following equations are used:

(12)

(13)

In this study, the scheme imposes three perturbations, α = 0.10, 0.15, and 0.20, to the weights of each criterion for the four methods and obtains the alternatives score. The order of the technical solutions for washing according to the scores for the AHP, TOPSIS, and SMART methods, under the different unitary variation ratios for w_1, w_2, w_3, and w_4, are illustrated in Tables 10, 11, and 12, respectively. The bold values in these tables, for the columns w_1, w_2, w_3, and w_4, indicate the weights of the criteria that suffered the disturbance, and the bold ranks in the column "Ranks of the alternatives" indicates that the initial rank was maintained.

Table 10. Sensitivity analysis of the AHP method—ranks of the alternatives.

w_j		Criteria weights	Ranks the

						alternat
Variation	α	w_1	w_2	w_3	w_4	
w_1	0.10	**0.473**	0.268	0.157	0.102	**a**7 > **a** **a**1 > **a** **a**3 > **a** **a**2
	0.15	**0.495**	0.257	0.151	0.098	**a**7 > **a** **a**1 > **a** **a**3 > **a** **a**2
	0.20	**0.516**	0.246	0.144	0.093	**a**7 > **a** **a**1 > **a** **a**3 > **a** **a**2
w_2	0.10	0.412	**0.319**	0.163	0.106	*a*7 > *a* *a*1 > *a* *a*5 > *a* *a*2
	0.15	0.404	**0.334**	0.160	0.103	*a*7 > *a*

The bold values in these tables, for the columns w_1, w_2, w_3, and w_4, indicate the weights of the criteria that suffered the disturbance, and the bold ranks in the column "Ranks of the alternatives" indicates that the initial rank was maintained.

Table 11. Sensitivity analysis of the TOPSIS method—ranks of the alternatives.

w_j		Criteria weights				Ranks the alternat
Variation	α	w_1	w_2	w_3	w_4	
w_1	0.10	**0.473**	0.268	0.157	0.102	**a**7 > **a**

w_1	0.10	**0.473**	0.268	0.157	0.102	**a**7 > **a** **a**6 > **a** **a**3 > **a** **a**2
	0.15	**0.495**	0.257	0.151	0.098	*a*7 > *a* *a*6 > *a* *a*3 > *a* *a*5
	0.20	**0.516**	0.246	0.144	0.093	*a*7 > *a* *a*6 > *a* *a*3 > *a* *a*5
w_2	0.10	0.412	**0.319**	0.163	0.106	**a**7 > **a** **a**6 > **a** **a**3 > **a** **a**2
	0.15	0.404	**0.334**	0.160	0.103	*a*7 > *a*

The bold values in these tables, for the columns w_1, w_2, w_3, and w_4, indicate the weights of the criteria that suffered the disturbance, and the bold ranks in the column "Ranks of the alternatives" indicates that the initial rank was maintained.

Table 12. Sensitivity analysis of the SMART method—ranks of the alternatives.

w_j		Criteria weights				Ranks the alternat
Variation	α	w_1	w_2	w_3	w_4	
w_1	0.10	**0.473**	0.268	0.157	0.102	**a**7 > **a** **a**1 > **a** **a**5 > **a** **a**2

	0.15	**0.495**	0.257	0.151	0.098	$a7 > a6$ $a1 > a4$ $a3 > a5$ $a2$
	0.20	**0.516**	0.246	0.144	0.093	$a7 > a6$ $a1 > a4$ $a3 > a5$ $a2$
w_2	0.10	0.412	**0.319**	0.163	0.106	$a7 > a6$ $a1 > a4$ $a3 > a5$ $a2$
	0.15	0.404	**0.334**	0.160	0.103	$a7 > a6$

The bold values in these tables, for the columns w_1, w_2, w_3, and w_4, indicate the weights of the criteria that suffered the disturbance, and the bold ranks in the column "Ranks of the alternatives" indicates that the initial rank was maintained.

In the sensitivity analysis of the ELECTRE method, the adjustment of the weights followed the same scheme as the other methods. The concordance and discordance thresholds were not changed throughout the runs. Values are presented in Table 13.

Table 13. Indifference, preference, and veto thresholds considered in the ELECTRE method.

Thresholds\criteria	Water consumption per year (m^3)	Cost in 8 years (€)	Quality of washing (scale 1–5)	Time spent per bu (minute
Indifference	10	100	1	0.10

Preference	100	1000	2	0.3
Veto	101	1001	3	0.4

The results in Table 10 suggest that the initial rank, obtained with the weighting provided by the decision-maker, $a7 > a6 > a1 > a4 > a3 > a5 > a2$, of technical washing solutions, given by the AHP, is maintained only for W_1 for all the disturbance of α, i.e., $\alpha = 0.10$, 0.15, and 0.20 (values in bold in Table 10). For the rest of W, i.e., W_2, W_3, and W_4, the rank is changed. The alternatives in the fifth and sixth positions exchange between each other.

Table 11 shows the results for the TOPSIS method. In this method, the initial rank obtained with the weights established by the decision-maker is $a7 > a1 > a6 > a4 > a3 > a5 > a2$. This rank is verified for all of the disturbances in W_3 and W_4, and it is represented in bold in Table 11. However, there are four disturbances where the fifth, sixth, and seventh positions are exchanged.

The results in Table 12 suggest that the initial rank, obtained with the weighting provided by the decision-maker, $a7 > a6 > a1 > a4 > a5 > a3 > a2$, of technical washing solutions, given by the SMART, is maintained for the first disturbance in W_1 and for all the disturbances in W_3 and W_4 (values in bold in Table 10). For the rest of disturbances in W, the fifth and sixth positions exchange between them.

Table 14 shows the results for the ELECTRE method. In this method, the initial rank obtained with the weights established by the decision-maker is $a7 > a6 > a1 > a4 > a5 > a3 > a2$. This rank is verified for all of the disturbances in W_4 and for the two first in W_2 and W_3, and it is represented in bold in Table 14. For the rest of the disturbances, the alternatives in the fourth, fifth, and sixth positions exchange between each other.

Table 14. Sensitivity analysis of the ELECTRE method—ranks of the alternatives.

w_j		Criteria weights				Ranks the alternat
Variation	α	w_1	w_2	w_3	w_4	
w_1	0.10	**0.473**	0.268	0.157	0.102	*a*7 > *a*… *a*1 > *a*… *a*3 > *a*… *a*2
	0.15	**0.495**	0.257	0.151	0.098	*a*7 > *a*… *a*1 > *a*… *a*3 > *a*… *a*2
	0.20	**0.516**	0.246	0.144	0.093	*a*7 > *a*… *a*1 > *a*… *a*3 > *a*… *a*2
w_2	0.10	0.412	**0.319**	0.163	0.106	**a**7 > **a**… **a**1 > **a**… **a**5 = **a**… **a**2
	0.15	0.404	**0.334**	0.160	0.103	**a**7 > **a**…

The bold values in these tables, for the columns w_1, w_2, w_3, and w_4, indicate the weights of the criteria that suffered the disturbance, and the bold ranks in the column "Ranks of the alternatives" indicates that the initial rank was maintained.

As a summary, comparing all the solutions of the four methods, it can be stated that the most attractive washing technique is number 7, mobile portico with a brush, and the one that least contributes to achieving the objectives the one that least contributes to achieving the objectives is number 2, porticoes with three brushes; the results are little affected by the sensitivity analysis; there exists similarity in rankings for the four MCDM methods; SMART method, the less complex one, showed no difference from the others.

Comparing the results of our study with similar works, regarding the two main objectives of this research, the following can be considered:

(1) The ranking of the alternatives cannot be compared with others because according to available information, this is the first work with the MCDM approach in the area of assessment of washing solutions for buses.

(2) Considering the similarity in the ranks for the four MCDM methods, the results are in line with the works of Janssen [47] and the work of Hajkowicz and Higgins [48]. The first one concluded that "The main methodological challenge is not in the development of more sophisticated MCDM methods. Simple methods, such as weighted summation, perform well in most cases. More important is the support of problem definition and design." The second study also found strong agreement between different MCDM techniques used for six different water resource problems, concluding that "so long as ordinal and cardinal data are handled appropriately, the ranking of decision options is unlikely to change markedly by using a different MCDM technique."

5. Conclusion

This work addresses the problem of choosing the most suitable technical solutions to support bus washing. This is a challenging topic because water is considered to be at the core of sustainable development and its use for bus washing should be done in a sustainable way. Several technical solutions exist for washing buses, each offering varying levels of performance. This diversity can make it challenging to select the solution that best fits the unique needs of each company or case. Cumulatively, there also exist some MCDM methods and the most feasible one without high effort in its application should be chosen.

Despite the extensive research, no explicit analyses were found in the literature regarding the selection of the optimal technical solution for bus washing. Therefore, this work aims to fill this gap by providing a technical and scientific contribution to aid in the decision-making process of choosing bus washing solutions. Therefore, the main objectives of this work were (1) to select the best sustainable technical solutions for washing buses depending on the specific conditions for a case study and (2) to analyze how different multicriteria decision-making methods behave in the selection process.

In order to select the best sustainable technical solutions for washing buses for a specific case study, a public transport company in Portugal was chosen. Four criteria were considered by the company's experts: water consumption, operating costs, quality of washing, and time spent. It should be emphasized that the chosen criteria encompass environmental concerns, leading to the creation of a set of criteria referred to as sustainable criteria. Then, the criteria weights were calculated by fuzzy-AHP method, obtaining the data of 0.43, 0.29, 0.17, and 0.11, respectively. After that, four MCDM representative methods were applied, AHP, ELECTRE, TOPSIS, and SMART, their ranking results were compared, and the results with the sensitivity analysis were evaluated.

Considering the input company data for the criteria and its weights, for the four MCDM methods applied, AHP, ELECTRE, TOPSIS, and SMART, the results showed that the best and the worst solution was the same, mobile portico with a brush and porticoes with three brushes, respectively. Furthermore, the results of the sensitivity analysis performed with disturbances for the weights of each criterion showed that the results are slightly affected, and the similarity in rankings for the four MCDM methods was validated by Spearman's rank correlation coefficient (r_s) and Kendall's coefficient of concordance (W). Considering these results, the SMART method, the less complex one, showed no difference from the others. For that reason, simple methods, such as SMART, in line with other works in the literature, perform well in most cases. In the context of company environments, the SMART method could be applied in other similar cases, without the fear of the results and with less effort to perform the assessment of the alternatives.

To give continuity to this work and overcome the work limitations, further research will be performed to evaluate the waste water treatment solutions originating from the bus wash. This study will allow evaluating the washing system incorporated with the water treatment solution as a whole solution. For sure, this will bring different approaches and eventually different results for the problem.

As a final remark of this work, it can be said that the methodology employed in this project can also be deemed applicable to other similar companies seeking technical solutions for bus or truck washing. Furthermore, the application of the SMART method, the less complex one and the most understandable for people, showed no difference from the others, being able to be applied in similar situations.

Conflicts of Interest

The authors declare there are no conflicts of interest.

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Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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