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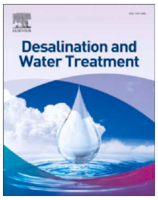

The selection of washing machine programs with fuzzy dematel and moora-ratio multi-criteria decision-making methods considering environmental and cost criteria☆

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ABSTRACT

The washing machine is the prevalent white household equipment in contemporary society. These machines provide consumers with a range of program options that encompass several variables, including temperature and detergent type. Nevertheless, the selection made by individual customers about the washing machine program they opt for carries substantial environmental consequences during the use stage of textile products. According to studies on the life cycle of clothes, it has been established that the use stage, following the extraction of raw materials, exerts the most substantial influence on environmental impacts. The objective of this research is to assess the washing machine programs provided by the manufacturer through the application of a comprehensive systematic approach for analysis. The evaluation of scenarios for washing machine programs was conducted using the MOORA-Ratio multi-criteria decision-making process. This evaluation considered various parameters, including environmental impact and cost. The life cycle assessment methodology was employed to quantify the environmental impact of the specified criteria. Based on the comprehensive study conducted by integrating criteria across numerous dimensions, it has been determined that the most favorable scenario wass scenario 1, which was developed for the Cotton 20 C program. The primary objective of this research endeavor is to fill a significant need in the current body of literature by undertaking a comprehensive review of washing machine programs that have not been previously recorded. This study employs a comprehensive methodology to investigate the environmental and economic implications linked to these activities, with the objective of delivering significant insights to producers and users.

1. Introduction

In contemporary times, washing machines have become a ubiquitous household device commonly found in the majority of residential dwellings. Despite the potential for enhanced convenience offered by these gadgets, there exists a concern regarding the widespread implementation of such technology and its potential adverse impact on the natural environment. Washing machines are not only widely prevalent, but the decisions made by individuals regarding their usage can potentially have substantial implications for the environment. The most recent iterations of washing machines are outfitted with a variety of distinct cleaning settings to optimize the outcomes for various types of fabrics. As an illustration, the washing program designated for synthetic garments entails a temperature of 40 ˚C and a duration of 2 h. Conversely, the program designated for woolen garments involves a temperature of 30 ˚C and a washing period of 45 min. The programs provided by machine producer have the potential to enhance customer pleasure; nevertheless, the selection of these programs is contingent upon user behaviors exclusively. For instance, it has been observed that consumers in China and Japan exhibit a preference for cold water, but customers in the United Kingdom and Germany tend to favor warm water [1]. Empirical evidence has demonstrated that the reduction of water temperature can lead to a significant decrease of approximately 28.5% in the ecological footprint associated with a pair of jeans in the United States [2]. Hence, it is vital to comprehend the sustainable thresholds of washing programs incorporated inside washing machines.

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In the literature, Stamminger et al. (2005) examined various types of washing machines and found that the utilization of energy-efficient older models can lead to a reduction in energy consumption [3]. Furthermore, the scholarly literature has also incorporated an examination of the impact of energy and water consumption associated with machines utilizing various technologies, such as impeller type, drum type, and mixer type [4]. The literature also contains studies on consumer behavior that have their origins in the sociocultural context. Two notable studies have been conducted in the field of consumer behavior related to washing and drying usage, as well as clothing consumer use behavior. Schmitz and Stamminger (2014) examined the behavior of European consumers in this regard, while Daystar et al. (2018) focused on measuring clothing consumer use behavior in six countries, namely Germany, China, Italy, Japan, the United Kingdom, and the United States [5,6].

According to Stamminger's (2011) study on washing machine programs, it was emphasized that the selection of washing options by consumers has the capacity to influence the total energy consumption of the laundry procedure by a factor of five [7]. However, the environmental effects of washing machine programs have yet to be examined using the life cycle assessment (LCA) methodology. Hence, the primary step in mitigating environmental consequences involves evaluating the environmental implications of washing machine programs and effectively disseminating this data to consumers. Furthermore, it is worth noting that there is currently a dearth of research in the existing body of literature that comprehensively investigates the environmental and cost implications of washing machine programs. The selection of a washing machine program plays a significant role in determining the environmental consequences associated with the washing process. However, customers also place considerable importance on the cost of the washing process when making their decisions. The preferences of users can be influenced by additional criteria such as the filling amount and residual moisture. The process of considering and evaluating each of these criteria represents a complex decision-making problem involving multiple criteria.

In this study, the Multi-Attribute Decision Making (MDCM) methods were employed to ascertain the criteria weights and establish the ranking of washing machine programs. Initially, the fuzzy DEMATEL (Decision Making Experimentation and Evaluation Laboratory) method was employed to ascertain the weights of the criteria. Subsequently, the scenarios were ranked utilizing the MOORA (Multi-Objective Optimization by Ratio Analysis) method. The application of the DEMATEL approach has been utilized by the Geneva Research Center to tackle complex and comprehensive issues pertaining to decision-making [8,9]. The Dematel technique is a comprehensive approach utilized for the development and evaluation of a structural model that encompasses the causal relationships between intricate criteria and variables. However, it is crucial to recognize that individuals frequently face varying levels of uncertainty when making decisions in real-world scenarios. Zadeh (1965) introduced the theory of fuzzy logic as a means to tackle the difficulties arising from ambiguous or imprecise data [10]. The Fuzzy DEMATEL method is utilized to analyze the causal relationships among variables that contribute to decision-making under conditions of environmental uncertainty, employing Fuzzy linguistic variables The DEMATEL method has been utilized in various research studies, including supplier selection [11], choosing a truck for ground transportation [12] barriers to blockchain-based life cycle assessment in China [13], barriers to circular food supply chains in China [14], green supply chain [15,16], sustainable supply chain management [17], identifying critical success factors in emergency management [18], identification of influencing factors of college students' pro-environmental behavior [19]. The MOORA method, which was developed by Brauers and Zavadskas (2006), has been widely utilized in various applications in recent times [8]. This approach involves conducting a comprehensive analysis of all interactions between decision options and criteria and employing objective weighted values to generate weighted normalization. The MOORA method is a widely utilized approach in multi-criteria decision-making, which proves to be highly effective in selecting the most suitable alternative among a range of options. The rationale behind selecting MOORA as a decision-making method is grounded in several fundamental benefits. The MOORA ratio method is notable for its utilization of ratio analysis in the assessment of numerous criteria. This enables the assessment of the interactions and levels of significance of different criteria. When assessing the efficacy of washing machine programs, it is crucial to strike a harmonious equilibrium among various criteria, including environmental ramifications, financial implications, and load capacity. The MOORA ratio facilitates an impartial decision-making procedure by employing ratios among criteria to compute the equilibrium. Furthermore, the MOORA ratio provides a high degree of flexibility in the prioritization of the decision-making process. The relative significance of environmental criteria in relation to economic costs for washing machine programs is a plausible consideration. The MOORA ratio allows for the allocation of weights to criteria in order to establish a priority order. This affords decision-makers an opportunity to deliberate on priorities and preferences. Furthermore, the MOORA ratio framework effectively accounts for uncertainties that may arise during the decision-making process. In the assessment of washing machine program performance, uncertainties will inevitably arise. The utilization of the MOORA ratio enhances the reliability of the decision-making process by incorporating considerations for uncertainties. Ratio analysis is a method that effectively demonstrates the relative advantages or disadvantages of a specific alternative in comparison to others. Hence, the selection of the MOORA ratio is attributed to its inherent benefits, which encompass the achievement of equilibrium among diverse criteria, the ability to adaptively prioritize, and the capacity to effectively manage uncertainties. The application of MOORA method has been utilized to tackle various concerns raised within the research community. These concerns encompass the selection of steel sheet materials employed in the construction of automobiles, the selection of specialized education and rehabilitation centers, the determination of suitable locations for logistics centers, and the advancement of regional infrastructure in Lithuania [20–23].

This study offers a methodical approach to rank washing machine programs by utilizing decision-making theory, while considering various criteria such as environmental impact, cost, and other relevant criteria. The Fuzzy DEMATEL method was employed to ascertain the weights of the criteria that were identified for evaluating the washing machine programs. Additionally, the MOORA-Ratio technique was utilized to establish their ranking. The literature has addressed the influence of customers' washing machine usage habits on environmental outcomes [24]. However, none of these studies have comprehensively examined the environmental effects of current programs or conducted a holistic evaluation that considers criteria such as cost. It is imperative to underscore that the extant literature incorporates research that employ MCDM approaches. Nevertheless, the novelty of this study resides in the integration of MOORA-Ratio and Fuzzy DEMATEL methodologies, which have not been before applied in the context of this particular domain.

2. Materials and Methods

The study's research methodology is depicted in Fig. 1, offering a visual representation of the systematic technique employed to accomplish the research objectives. The diagram delineates the fundamental procedures and methodologies employed in the acquisition, examination, and comprehension of data, thereby providing a framework for the overall organization of the research.

2.1. Problem definition with scenarios

The primary aim of this study is to assess the performance of several washing machine programs using MCDM methodology. To achieve this objective, several evaluation scenarios have been developed. Hence, the study drew upon the various programs offered by a Turkish manufacturer of a washing machine with a 9-kilogram capacity and a

Fig. 1. Research Methodology.

Table 1
Scenarios (S: Scenario) proposed in the study.

Scenario	Filling Amount (kg)	Program Type
S1	9	Cotton 20 °C
S2	9	Cotton 40 °C
S3	9	Cotton 60 °C
S4	4.5	Cotton Eco 40 °C
S5	4.5	Cotton Eco 60 °C
S6	9	Cotton Eco 60 °C
S7	9	Cotton 90 °C
S8	4	Synthetic 40 °C
S9	4	Mix 40 °C
S10	2	Delicate/Silk 30 °C
S11	2	Wool 30 °C

rotational speed of 1200 revolutions per minute as the foundation for its potential findings [25]. Table 1 displays the programs that were selected for inclusion in the proposed scenarios, along with their corresponding capacity. As per the provisions outlined in regulation 2010/30/EU, scenarios S4, S5, and S6 encompass prescribed program parameters that are mandatory for energy labeling [[26,27]. It is postulated that the programs have been configured to deactivate the maximum velocity and automated dosage settings.

2.2. *Criteria determination*

The first step in the multiple-criteria decision-making process involves the identification of criteria. This study examined the environmental factors utilized in the selection of washing machine programs, namely Global warming potential (GWP) (kg CO_2 eq.), Human toxicity (HTP) (kg 1,4-DB eq.), and Acidification (AP) (kg SO_2 eq.). The selection of GWP, HTP, and AP was based on their significant environmental effects arising from their detergent usage as well as their consumption of energy and water resources. The utilization of LCA, widely regarded as the most dependable methodology presently accessible, was employed to quantify the environmental ramifications. The cost, measured in Turkish Liras (TL), is considered to be a highly significant factor in decision-making challenges [28,29]. As a result, the inclusion of washing program charges was implemented as a supplementary factor. The selection of the filling load (Kg) was based on its significance to consumers, as it directly affects both economic and environmental effects [24]. The residual moisture content (%) was chosen as the ultimate criterion for the same reasons [30]. The filling quantity and residual moisture levels are derived from the manufacturer's official manual for the washing machine. The provided criteria are given in Table 2.

2.2.1. *Environmental impact assessment with LCA*

The technique known as LCA has been standardized by ISO 14040 and ISO 14044 [31,32]. Its implementation follows a set of four fundamental stages in accordance with the accepted standard. The initial step encompasses the articulation of the research's objective and the delineation of the specific scope that will be examined in order to attain said target.

Table 2
Life Cycle Inventory Data.

Code of Criteria	Name of the Criteria	Unit
C1	Cost	TL
C2	Filling Load	kg
C3	Residual Moisture	%
C4	GWP	kg CO_2 eq.
C5	HTP	kg 1,4-DB eq.
C6	AP	kg SO_2 eq.

The objective of this LCA was to elucidate the environmental implications associated with the manufacturer-provided initiatives for a 9 kg, 1200 rpm washing machine manufactured in Turkey. The study utilized a functional unit of 9 kg of clothing that was washed in a washing machine. This choice of functional unit enabled all computations to be performed on a single output. The life cycle inventory (LCI) constitutes the subsequent phase within an LCA, wherein it procures pertinent input data required for the computation of environmental impacts. For this life cycle impact assessment (LCIA), data on the energy and water consumption, washing cycle time, and filling volume of the washing machine were gathered from the manufacturer's published manual [22]. To determine consumption estimates, the quantity of detergent suggested by the manufacturer of the selected powder detergent was utilized. The utilization of both primary and secondary data is crucial during the life cycle inventory (LCI) phase. The secondary data, namely detergent and electricity output, were acquired from the Ecoinvent Database for the purpose of this study. The study incorporates all life cycle inventory data within Table 3.

The consumption quantities for specific programs, as provided by the machine maker, have been categorized according to the filling load and sorted by functional unit. As an illustration, the consumption estimates for a quantity of 4.5 kilos were doubled due to the fact that the functional unit consisted of 9 kg of garments being laundered in a washing machine. Based on the information provided in the washing machine handbook, it is indicated that the average residual moisture content of clothing across all programs is 50%. Consequently, the quantity of wastewater can be determined by calculating 50% of the volume of water utilized.

LCIA phase, the quantification of environmental impacts is conducted by employing impact factors. During this phase, the selection of environmental effect categories for analysis and the choice of methodology for calculating these categories are made. The CML-IA methodology was employed during the LCIA phase of this study. The computations were performed using Simapro 9.2.02 software, specifically the PhD version [33]. The CML-IA approach allows for the calculation of various impact categories. However, for the purpose of this study, only effect categories directly associated with detergent use, water consumption, and energy consumption were considered. These categories include GWP (kg CO_2 eq.), HTP (kg 1,4-DB eq.), and AP (kg SO_2 eq.). The ultimate component of LCA entails the analysis and comprehension of findings, as well as the identification of areas of particular significance. The findings of this study were reported in the part entitled "Results and discussion."

2.2.2. Cost assessment

The cost factor is a fundamental criterion that buyers assess. This study aimed to ascertain the cost value of the designated functional unit. This study examines the many costs connected with operating a washing machine, specifically focusing on the expenses related to the cycle, such as the use of detergent, energy, and water. The pricing structure for electricity consumption among residential subscribers in Turkey is based on a price list that applies to usage levels up to 240 kilowatt. According to the tariff, the price of 1 kilowatt-hour (kWh) of electricity is 1.74 TL [34]. The water usage rates of the province of Kayseri were taken into account. In the specified province, the price of one cubic meter of water was 5.88 TL. The price of the detergent was obtained from a reputable online retail platform in Turkey and was determined to be 9.87 TL each cycle.

3. Weighing criteria with DEMATEL

The determination of the relative importance of different criteria for selecting washing machine programs is challenging due to its dependence on user preferences and opinions. Furthermore, the presence of a cause-effect relationship within the criterion poses challenges in assessing the relative significance. Therefore, the Fuzzy DEMATEL technique, which incorporates expert opinions to account for subjectivity and ambiguity, was employed to assess the interrelationships and relative significance of the criteria. The utilization of the Fuzzy DEMATEL method enhances the robustness of the decision-making process by enabling the incorporation of expert opinions. This method effectively manages uncertainty through the application of fuzzy set theory, which aids in the determination of criteria weights. Consequently, subjective judgments and imprecise information become applicable in decision-making scenarios, particularly those in which alterations in one criterion have an impact on others. The selection of this technique was based on its superior methodology in capturing the interdependence between criteria. It offers a full understanding of how these criteria might mutually influence one another. Additionally, this method is highly interpretable and facilitates comprehension through visual representations, such as influence matrices. This particular methodology is notable for its capacity to mitigate the influence of subjective bias and offer a structured yet adaptable framework for establishing the relative importance of criteria in decision-making scenarios. All detailed steps of the method are given below [35].

1. The first stage involved establishing a panel of experts or a decision-making committee, as well as determining the criteria that will be used for assessment. During this stage, a committee of eight specialists was established to offer their expert perspectives on pertinent matters.
2. In the second stage, direct fuzzy relationship matrices Z^k are obtained by experts comparing the criteria pairwise where Z^k is a $n \times n$ matrix where k is the number of experts. $Z^k = [z^k{}_{ij}]$ where Z is a $n \times n$ non-negative matrix; z_{ij} represents the direct impact of criteria i on criteria j; and, when $i = j$, the diagonal elements $z_{ij} = 0$.

To facilitate the assessment of the interdependencies among various criteria, a five-point fuzzy linguistic scale has been developed. This scale aims to assist specialists in their evaluation process. Experts were requested to utilize this scale to provide their linguistic assessments to construct a matrix that directly evaluates and relates various criteria. The positive TrFN was employed to examine and convert the linguistic information acquired from experts' opinions into fuzzy evaluations.

Table 3
Life Cycle Inventory Data.

Scenarios	Electricity (kWh)	Wastewater (m^3)	Detergent (kg)	Water (L)
S1	0.36	0.05	0.15	90.00
S2	1.20	0.05	0.15	90.00
S3	1.30	0.05	0.15	90.00
S4	0.88	0.05	0.30	92.00
S5	1.20	0.05	0.30	92.00
S6	0.90	0.03	0.15	57.00
S7	2.35	0.05	0.15	100.00
S8	1.76	0.07	0.34	137.25
S9	1.44	0.05	0.34	99.00
S10	0.95	0.08	0.68	153.00
S11	1.08	0.09	0.68	189.00

Table 4
Fuzzy linguistic scale used in the present research.

Linguistic Variables	Crisp equivalent	Equivalent Trapezoidal fuzzy numbers (TrFN)
Very Low Influence	1	(0, 0, 0.25, 0.25)
Low Influence	2	(0, 0, 0.25, 0.50)
Medium Influence	3	(0, 0, 0.50, 0.75)
High Influence	4	(0, 1, 0.75, 1)
Very High Influence	5	(1, 1, 1, 1)

Table 5
The Weights Of The Criteria.

Criteria	Weights
C1	0.18
C2	0.17
C3	0.16
C4	0.16
C5	0.16
C6	0.17

(Refer to Table 4). The TrFN can be represented as a quadruplet, (l_{ij},m_{ij},n_{ij},u_{ij}), where $l \leq m \leq n \leq u$. Direct fuzzy relationship matrices were given in Table S.1 in supplementary document.

3. In Stage 3, Normalize Fuzzy Direct Relationship Matrice "*D*" was created using formula (1). Normalize Fuzzy Direct Relationship Matrices are given in Table S.2. in supplementary document

$$D = \frac{Z^k}{\max\limits_{1 \leq i \leq n} \sum_{j=1}^{n} z_{ij}}, \; i, j = 1, 2, \; \ldots, n \tag{1}$$

4. In the fourth stage, the total relationship matrix *T* is obtained from the normalized direct relationship matrix using formula (2). The total relationship matrix is given in Table S.3. in the supplementary document.

$$T = D(I - D)^{-1} \tag{2}$$

5. The fuzzy values obtained in this step are defuzzified Using Centre of Area (COA) defuzzification technique [36]. The defuzzified total relationship matrix is given in Table S.4. in the supplementary document.
6. Once crips matrix T was constructed, the values of $r_i + c_j$ and r_i - c_j were computed. Row (r_i) and column (c_j) sums for each row *i* and column *j* from the *T* matrix, respectively, with Eqs. (3)–(5). The expression $r_i + c_j$ signifies the significance of component *I*, whereas r_i - c_j denotes the overall impact of criteria *i*. Affected and Influencer (Sender and Receiver) Groups values are given in Table S.5. in supplementary document.

Table 7
Normalization Matrix with MOORA-Ratio Method.

Criteria/ Scenario	C1	C2	C3	C4	C5	C6
S1	0.129	0.408	0.318	0.141	0.152	0.135
S2	0.200	0.408	0.318	0.162	0.200	0.154
S3	0.208	0.408	0.318	0.164	0.205	0.157
S4	0.246	0.204	0.318	0.251	0.248	0.251
S5	0.273	0.204	0.318	0.259	0.266	0.259
S6	0.165	0.408	0.318	0.141	0.158	0.139
S7	0.300	0.408	0.318	0.194	0.272	0.183
S8	0.351	0.182	0.240	0.315	0.347	0.309
S9	0.314	0.182	0.360	0.292	0.301	0.292
S10	0.450	0.091	0.180	0.518	0.458	0.528
S11	0.472	0.091	0.270	0.536	0.493	0.540

$$T = [t_{ij}]_{nxn} \text{i, j} = 1, 2, \ldots\text{n} \tag{3}$$

$$r_i = \sum_{1 \leq j \leq n}^{n} t_{ij\,\forall_i} \tag{4}$$

$$c_i = \sum_{1 \leq j \leq n}^{n} t_{ij\,\forall_i} \tag{5}$$

7. The cause-effect diagram was constructed subsequent to the acquisition of the horizontal axis ($r_i + c_j$) and the vertical axis (r_i - c_j). The term ($r_i + c_j$) denotes the magnitude of influence between criteria, whereas (r_i - c_j) represents the relationship of influence between criteria. The cause-effect diagram is given in Table S.7 and Figure S.1 in supplementary document.

As a result of fuzzy DEMATEL method the weights of the criteria were determined and given in Table 5.

4. MOORA-ratio method

In this study, the MOORA-ratio method is the MCDM technique examined. The following steps describe the application of the MOORA-ratio approach to the problem defined in this study [37].

Step 1 Creating the decision matrix: In this step, the criteria included in the decision problem and their weights are determined in the decision matrix (X) in formula (6). The utilization of the MOORA approach necessitates the inclusion of quantitative data. The rows of the decision matrix contain many decision scenarios, while the columns represent the criteria. In the decision matrix, X_{ij} shows the value of the *ith* scenario in the *jth* criteria.

Table 6
Decision Matrix for MOORA-Ratio Method.

Criteria	C1	C2	C3	C4	C5	C6
Criteria Weight	0.18	0.17	0.16	0.16	0.16	0.17
S1	2.645	9	53	3.434	0.746	0.019
S2	4.107	9	53	3.938	0.979	0.021
S3	4.281	9	53	3.998	1.007	0.022
S4	5.051	4.5	53	6.122	1.215	0.035
S5	5.608	4.5	53	6.314	1.304	0.036
S6	3.391	9	53	3.442	0.776	0.019
S7	6.167	9	53	4.724	1.336	0.025
S8	7.212	4	40	7.669	1.703	0.043
S9	6.439	4	60	7.114	1.476	0.040
S10	9.247	2	30	12.636	2.249	0.073
S11	9.694	2	54	13.061	2.418	0.075

Table 8
Weighted Matrix with MOORA-Ratio Method.

Criteria/ Scenario	C1	C2	C3	C4	C5	C6	y_i*	Rank
S1	0.023	0.069	0.050	0.023	0.025	0.023	-0.074	**1**
S2	0.036	0.069	0.050	0.026	0.033	0.026	-0.101	**3**
S3	0.038	0.069	0.050	0.026	0.033	0.026	-0.104	**4**
S4	0.045	0.035	0.050	0.040	0.040	0.042	-0.183	**6**
S5	0.050	0.035	0.050	0.042	0.043	0.043	-0.193	**7**
S6	0.030	0.069	0.050	0.023	0.026	0.023	-0.082	**2**
S7	0.055	0.069	0.050	0.031	0.044	0.031	-0.141	**5**
S8	0.064	0.031	0.037	0.051	0.057	0.052	-0.230	**9**
S9	0.057	0.031	0.056	0.047	0.049	0.049	-0.227	**8**
S10	0.082	0.015	0.028	0.083	0.075	0.089	-0.341	**10**
S11	0.086	0.015	0.042	0.086	0.080	0.091	-0.370	**11**

Table 9
Life Cycle Impact Assessment Results.

Scenario	GWP (kg CO_2 eq.)	HTP (kg 1,4-DB eq.)	AP (kg SO_2 eq.)
S1	3.434	0.746	0.019
S2	3.938	0.979	0.021
S3	3.998	1.007	0.022
S4	6.122	1.215	0.035
S5	6.314	1.304	0.036
S6	3.442	0.776	0.019
S7	4.724	1.336	0.025
S8	7.669	1.703	0.043
S9	7.114	1.476	0.040
S10	12.636	2.249	0.073
S11	13.061	2.418	0.075

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & \vdots & \vdots \\ x_{n1} & \cdots & x_{nm} \end{bmatrix} \tag{6}$$

According to the scenario, criteria and criteria weight, the decision matrix was produced for the MOORA-Ratio Method and is shown in Table 6.

Step 2 Normalization of the decision matrix: While creating the normalized decision matrix (N), the following formulation is used regardless of the minimum or maximum objective in the criteria.

$$x_{ij}^{*}\frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^{2}}},\ i = 1,\ 2,\ \ldots, nj = 1,\ 2,\ \ldots, m \tag{7}$$

The values obtained as a consequence of normalizing the choice matrix are shown in Table 7 as the outcomes of this operation.

Step 3 Performance calculation of decision scenarios: The sum of the performance values for the minimization direction is subtracted from the sum of the normalized performance values for maximization. The performance of each decision **scenario** is determined according to the criteria defined by the equation below (8). Here, *g* and *n-g* represent the number of measures to maximize and minimize, respectively. The y_i*, denotes the normalized values of the decision scenarios *i* (*i* = 1,2,., n) according to all criteria**.**

$$y_i^{*} = \sum_{j=1}^{g} x_{ij}^{*} - \sum_{j=g+1}^{n} x_{ij}^{*},\ i = 1,\ 2, \ldots, n \tag{8}$$

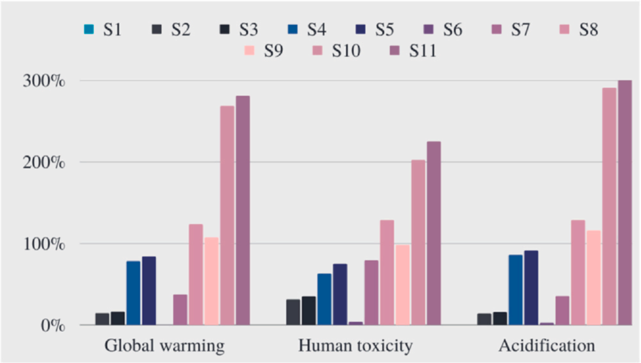

Fig. 2. The Variation Ratio of the Scenarios Environmental Impacts Results (Since S1 had the lowest values, it was chosen as the reference scenario, and its value was set to zero; it was therefore omitted from the figure. Since the percentage change of S6 was 0, it was not depicted on the figure).

Table 8 presents the results of the calculations used to rank the different scenarios, including the Weighted Matrix with the MOORA-Ratio Method.

Step 4: Ranking the scenarios: The $\boldsymbol{y_i}$* values are ordered from largest to smallest to get final ranking of the scenarios. The 1st in this ranking is selected as the most suitable **scenario**. The rankings of the scenarios examined in this study are given in Results and Discussion Section.

5. Results and discussion

5.1. LCA results

LCA was used to assess the environmental impacts of 11 washing program scenarios given by the washing machine manufacturer. Table 9 displays the findings for the researched environmental effect categories GWP, HTP, and AP.

According to the results, the scenario S1 that was the Cotton 20 °C program had the lowest GWP. This was followed by the Cotton Eco 60 °C in S6 with a GWP of 3442 kg CO_2 eq., which the manufacturer also referred to as the eco program. S2 and S3 have GWP values of 3.938 kg CO_2 eq. and 3.998 kg CO_2 eq., respectively, placing them third and fourth for lowest GWP. With a value of 4724 kg CO_2 eq., S7 was the scenario with the fifth-lowest GWP effect. Despite being labeled "eco" by the machine maker, the S4 and S5 had a greater GWP than the aforementioned scenarios due to their smaller fill volumes. With the Wool 30 °C program, S11 had the highest GWP value. The environmental impact of doing laundry as often as a functioning unit is substantial. This is owing to the fact that the amount of filling in S11 is rather modest, at about 2 kg.

With a value of 0.746 kg Eqs. 1,4-DB, S1 in the Cotton 20 °C program had the lowest potential for HTP impact. Cotton Eco 60 °C in S6 ranked second with a 0.776 kg 1,4-DB equivalent weight. S3 was the cotton 40 program implementation scenario with the third-lowest HTP value. S10 and S11 had the highest quantities of HTP, with 2.249 and 2.418 kg 1,4-DB eq., respectively.

S1 and S6 both had a value of 0.19 kg SO_2 eq., indicating they had the least impact on AP. The next two cases, S2 and S3, showed respective values of 0.021 kg SO_2 eq. and 0.022 kg SO_2 eq. S10 and S11 had the greatest APs, which are 0.073 kg SO_2 eq. and 0.075 kg SO_2 eq., respectively. Fig. 2 depicts the variation of the scenarios environmental impacts results.

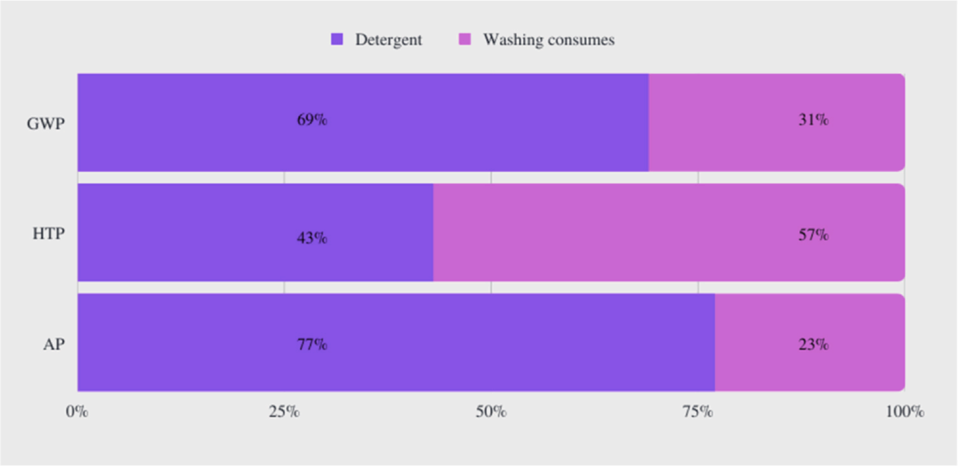

Fig. 3. Input contribution to the LCA Results for S1.

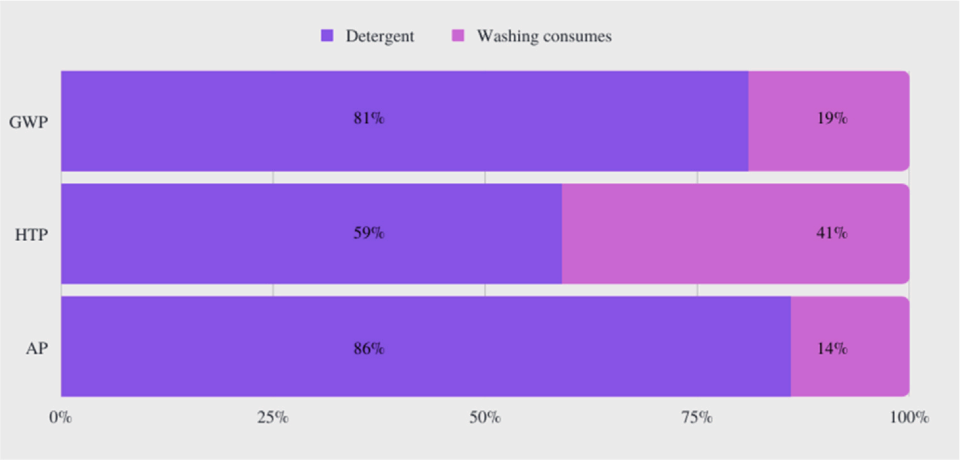

Fig. 4. Input contribution to the LCA Results for S11.

In Figure 2 S1 was used as the baseline scenario, and the percentage increase of environmental impacts for the other scenarios were calculated. The effect category with the greatest change between washing machine programs was the HTP category, with a variance of 290% in S11. It was the second category with the greatest rise in S11 within the GWP category, with a 280% increase. Lastly, the HTP category grew dramatically by 224%.

The Cottons 20 °C program, designed for cottons with the lowest washing temperature in S1, was the program with the lowest environmental impact across all categories considered. This results demonstrated the significance of washing temperature selection in terms of environmental effects. Fig. 3 shows the input contribution to the LCA Results for S1. The figure indicated that detergent consumption contributed the most to the GWP and AP categories, with 69% and 77%, respectively. 57% of the HTP category was comprised of washing consumes, which includes electricity and water consumption.

Fig. 4 depicts the contribution of the S11 inputs with the largest environmental consequences to the LCA results. According to the results, the input with the greatest impact across all categories was detergent. The input with the smallest influence was wash consumes, which accounts for 19% of GWP and 14% of AP. The most important reason for this results was that more detergent was needed to wash 9 kg of clothes due to the low washing capacity of this program prepared for woolens.

5.2. Cost results

The expenses of the selected functional unit were incorporated into the computations. Taking into account of the filling load, Cost value was determined in TL that provided 9 kg of washed clothing. The costs of each scenario were derived by summing the separate costs calculated for the energy, water, and detergent inputs. Table 10 offers a summary of the observed findings.

S1 was the scenario with the lowest overall cost, at 2.65 TL. Following this situation come S6 with 3.39 TL. The next two situations, S2 and S3, had 4.11 TL and 4.28 TL, respectively. S11 was the most expensive scenario with a cost of 9.69 TL. Fig. 5 depicts cost results of the scenarios.

5.3. MOORA-ratio results

MOORA-Ratio Results were acquired according to the $y_i{}^*$ values. Results of MOORA-Ratio Method are given in Table 11.

According to the MOORA-ratio methods results, S1 which contained the Cotton 20 °C programs was optimal. The second-best scenario was S6, which included the Cotton Eco 60 °C program, which the machine maker also defines as eco-friendly. According to the manufacturer, Cotton Eco 40 °C and Cotton Eco 60 °C programs in S4 and S5 were ranked sixth and seventh, respectively. These results were due to the programs' washing capacity. Despite their lower consumption, they required twice as many applications to produce the same amount of clean laundry as the functional unit of this study. S2 (Cotton 40 °C), S3 (Cotton 60 °C), and S7 (Cotton 90 °C) were, in order, the third, fourth, and fifth best scenarios in the ranking list. This series of scenarios illustrated the relationship between washing temperature and environmental impact and expenses. Mix 40 °C ranked eighth in S9, following

Table 10
Cost Assessment Results (TL)

Scenario	Electricity	Water	Detergent	Total
S1	0.63	0.53	1.49	2.65
S2	2.09	0.53	1.49	4.11
S3	2.26	0.53	1.49	4.28
S4	1.53	0.54	2.98	5.05
S5	2.09	0.54	2.98	5.61
S6	1.57	0.34	1.49	3.39
S7	4.09	0.59	1.49	6.17
S8	3.05	0.81	3.35	7.21
S9	2.51	0.58	3.35	6.44
S10	1.64	0.90	6.70	9.25
S11	1.88	1.11	6.70	9.69

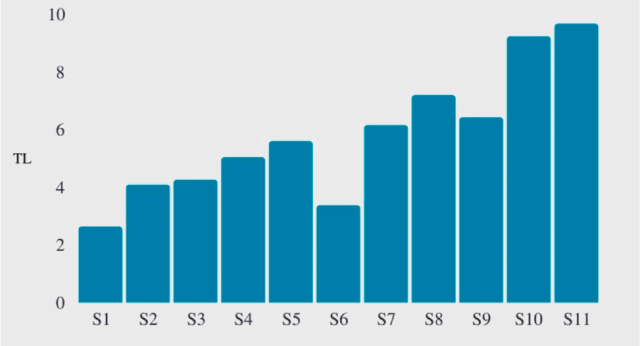

Fig. 5. Cost Results of the Scenarios.

Table 11
Results of MOORA-Ratio Method.

Scenario	Program	Rank
S1	Cotton 20 °C	1
S6	Cotton Eco 60 °C	2
S2	Cotton 40 °C	3
S3	Cotton 60 °C	4
S7	Cotton 90 °C	5
S4	Cotton Eco 40 °C	6
S5	Cotton Eco 60 °C	7
S9	Mix 40 °C	8
S8	Synthetic 40 °C	9
S10	Delicate/Silk 30 °C	10
S11	Wool 30 °C	11

cotton programs. Despite its low temperature, this program lagged in the global review due to its insufficient filling. The S8, which contains Synthetic 40 °C, rated ninth. The worst-ranked scenarios were S10 and S11 including Delicate/Silk 30 °C and Wool 30 °C, respectively. The most significant aspect in these results was the filling load. Regardless of washing temperature, synthetic and wool-specific washing machine plans have a greater environmental impact and expense than cotton-specific washing machine programs.

6. Conclusions

This study aimed to assess washing machine programs using the MOORA-ratio method, considering six criteria including environmental impacts, costs, residual moisture, and load size. Using the LCA method, the environmental impact categories GWP, AP, and HTPs were calculated. For the cost criterion, calculations were made using information from the washing machine manufacturer.

Based on the findings of the study, the most suitable scenario was S1, which includes the Cottons 20 °C program. The S6, which featured the eco-friendly Cotton Eco 60 °C program, ranked second. The manufacturer's eco-friendly initiatives remained ranked sixth and seventh, respectively. In addition, the study revealed that the washing temperature has a significant effect on environmental impacts and costs. In addition, the cost or environmental impact of eco-designated programs with limited washing capacity was not as low as anticipated. Regardless of washing temperature, washing machine programs designed for synthetics and wool have a larger environmental impact and cost more than those designed for cotton.

This study has a limitation in that it considers a limited number of criteria when focusing on washing machine programs. Due to the difficulty in determining additional preferences, such as fabric type or fabric softener usage by the user, other criteria that would cause emissions and economic impacts were not taken into account. In addition, because the study focuses on the washing programs of a particular brand, the consumption of various washing machine brands may also vary. Finally, the data is derived from the machine manufacturer's manual, and actual consumption may vary. Expanding the evaluation criteria; measuring actual consumption values during use to improve data quality; applying fuzzy multi-criteria decision-making methods to reduce uncertainty could be the focus of future research on this topic.

This study provided a comprehensive review of washing machine programs, taking environmental consequences, cost, and load criteria into consideration. It has brought substantial insights to both machine manufacturers and customers, significantly influencing their selections. In future research, new washing machine brands and softener consumption data could be also included to the analysis.

Declaration of Competing Interest

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

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NA.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.dwt.2024.100005.

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