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A Novel Axial-Distance-Based Aggregated Measurement (ADAM) Method for the Evaluation of Agri-Food Circular-Economy-Based Business Models

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Abstract: Multicriteria decision making (MCDM) is a field that helps decision makers evaluate alternatives based on multiple criteria and encompasses scoring, distance-based, pairwise comparison, and outranking methods. Recent developments have aimed to solve specific problems and overcoming the limitations of previous methods. This paper proposes a new axial-distance-based aggregated measurement (ADAM) method, which is used in combination with the best-worst method (BWM) to evaluate agri-food circular economy (CE)-based business models (BMs) to create a more sustainable and efficient system for producing and consuming food. This paper proposes nine BMs, which were evaluated against eight criteria. The BWM method was used to obtain the criteria weights, while the ADAM method was used to obtain a final ranking of the BMs. The results indicate that a sustainable circular agri-food supply chain is a BM that can bring companies the most significant progress in business and strengthen their position in the market. We concluded that the ADAM method is effective for solving MCDM problems and that, overall, the model is an effective tool for solving the problem defined in this study. The main contributions are the development of a new MCDM method and a hybrid model, the establishment of the framework for evaluation and selection of CE-based BMs, and the identification of the most important ones.

Keywords: multicriteria decision-making (MCDM); axial distance-based aggregated measurement (ADAM); best-worst method (BWM); circular economy (CE); business model (BM); agri-food

MSC: 90B06; 90B50

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1. Introduction

Multicriteria decision-making (MCDM) is a field of study that aims to help decision makers evaluate and compare different alternatives based on multiple, often conflicting, criteria. The last few decades have seen an expansion in the development of new MCDM methods and models, each of them trying to eliminate some of the shortcomings of previous methods or to establish tools for solving specific types of problems. All relevant methods developed so far can be classified into one of four basic groups: scoring (additive), distance-based, pairwise comparison, and outranking methods.

Each of these groups, as well as the individual methods belonging to them, has advantages and disadvantages. Some overlap and are common to several methods or groups, while some are characteristic and specific for one method or group. The focus of this study was the development of a new MCDM method with the aim of eliminating some of the shortcomings identified in other methods, regardless of the group to which they belong. The result is a method that does not belong to any of the mentioned groups, but instead forms a group of its own. In recent years, there has been growing interest in the use of MCDM methods in various fields such as operations research, management science, engineering, and environmental studies. This study unites all these fields by applying the newly developed method, in combination with another method, in order to solve the problem of evaluating agri-food CE-based business models.

A business model (BM) refers to the way a company generates revenue and profits by creating, delivering, and capturing value. Over the past two decades, the concept of BMs has gained significant attention from scholars and practitioners in various fields, including management, strategy, economics, and information systems. One of the earliest and most influential frameworks for understanding BMs is the value proposition, which refers to the unique benefits or value that a company offers to its customers. A value proposition can be based on various factors, such as the product or service itself, the price or cost, the distribution channels, the customer experience, or the overall brand image. The strategic fit between a company's BM and its competitive environment is also important. A BM that is well-aligned with the competitive environment may enable a company to achieve a sustainable competitive advantage and superior performance. However, a misaligned BM may lead to suboptimal performance and vulnerability to disruption. Therefore, for the success of any business, one of the key decisions is the implementation of a BM which will enable the best performance of the company. BMs can also vary based on the type of industry or sector in which a company operates.

A CE is a system in which resources are used, reused, and recycled in a continuous loop. BMs that align with this concept prioritize the conservation of resources and minimize waste by designing products and services that can be easily repaired, reused, or recycled. Typical examples of CE-based BMs include product-as-a-service models, in which companies provide access to products rather than selling them outright, and closed-loop supply chains, in which waste materials are collected and used as inputs for new products. Other examples include product-life extension, product sharing, and rental models.

CE-based BMs in the agri-food sector aim to create a more sustainable and efficient system for producing and consuming food. They are mainly focused on the production and processing of products, their distribution, and the management of activities. These models emphasize the use of natural systems and practices to improve production and processing, closed-loop supply chains to bring waste materials back into production, and data and technology to optimize activities. These models not only reduce the environmental impact of the agri-food industry but also create new opportunities for growth, cost savings, and innovation.

The evaluation and ranking of BMs may help to shed light on the mechanisms and conditions under which they may be successful and how companies can adapt and innovate their BMs in response to changing market conditions. Therefore, another aim of this study was to rank the CE-based BMs that have the highest impact on the key players in the agri-food sector. Because there are multiple factors influencing the success of a certain BM, this is a multicriteria decision-making (MCDM) problem. To solve it, a novel hybrid MCDM model that combines best-worst method (BWM) and a newly developed axial-distance-based aggregated measurement (ADAM) method is proposed in this paper. The BWM method is used to obtain the criteria weights, while the ADAM method is used to rank the alternatives. The ADAM method was developed as a representative of a new group of MCDM methods, namely geometric methods. It is based on establishing alternatives ranked according to the comparisons of the complex polyhedral volumes corresponding to the defined alternatives.

As stated, the applicability of the method and the hybrid model is demonstrated by solving the problem of ranking CE-based BMs. The results indicate that the most significant BM is a sustainable circular agri-food supply chain, followed by entrepreneurship in the agri-food sector and agri-food reuse, remanufacturing, and recycling. Based on the results obtained, we concluded that the ADAM method is effective in solving MCDM problems and is competitive with other methods. We also concluded that an overall model is an effective tool for solving the defined problem and that the best ranked BM can significantly progress and strengthen companies' market position.

The main contributions of this study are the development of a new MCDM method and a hybrid model, the establishment of the sets of most promising CE-based BMs in the agri-food sector as well as the criteria for their evaluations, the development of a framework for the evaluation, selection, ranking, and identification of the most important CE-based BMs.

The rest of the paper is organized as follows: The next section provides an overview of the related body of literature from the areas covered by this study. The third section provides a detailed explanation of the newly developed ADAM method and hybrid MCDM model. A description of the problem on which the applicability of the method and the model is demonstration is presented in Section 4. The same section provides a validation of the results and the method as well as a sensitivity analysis. The discussion of the results, method, and the model, as well as limitations and implications of the study are presented in Section 5. The final section provides concluding remarks and future research directions.

2. Related Literature

In order to understand the context in which the novel ADAM method is defined and applied in combination with the BWM method to solve the problem of evaluating and ranking CE-based BMs in the agri-food sector, the following provides an overview of the related body of literature.

2.1. Multicriteria Decision Making

Operations research is a special field of mathematics that deals with the application of advanced analytical methods for decision making [1]. Operations research aims to find an optimal or near-optimal solution to complex decision-making problems. One of the most important and fastest-growing subfields of operations research is multicriteria decision making (MCDM). MCDM provides support for decision makers who are faced with a problem involving multiple criteria. It enables structuring and problem solving by finding the best acceptable solution in relation to the defined criteria [2]. Most practical problems in everyday life are affected by multiple noncommensurable and conflicting (competing) criteria and, most often, there is no single solution that satisfies all criteria at the same time [1]. In such situations, MCDM is used to differentiate between possible solutions based on the decision maker's preferences [2]. Decision making is considered to be the mental procedure that leads to the choice of a conviction or a direction to take from a range of feasible choices [3]. The development of MCDM as a scientific discipline that can be attributed to Benjamin Franklin, who developed, in the eighteenth century, a system of using a list of two entries with the assignment of the weights [4]. In his research, he used the word balance, which fully corresponds to the modern understanding of MCDM, which is finding a consensus, agreement, or compromise solution in relation to defined criteria. The development of MCDM as a modern scientific discipline, in the form in which it is studied today, is related to the second half of the twentieth century, i.e., the period after the Second World War [4].

The general methodology of applying MCDM methods involves three basic steps: (1) determination of sets of alternatives and criteria (or subcriteria) for their evaluation; (2) determining the weights of criteria (subcriteria) by assigning numerical values that indicate their importance; and (3) assigning numerical values to alternatives in relation to the criteria based on which it is possible to perform a final ranking of alternatives and choose the most favorable [5]. Alternatives should be available, comparable, real (not ideal), and practical (feasible); the criteria should be reasonable, mutually comparable, independent, quantifiable, and relevant to the alternatives [2]. Although they share a common concept, MCDM methods can significantly differ in terms of complexity and application procedures for obtaining the results. All methods can generally be divided into four basic groups [6]: scoring (additive), distance-based, pairwise comparison, and outranking methods. Some of the methods are more suitable for obtaining criteria weights [7] and some for obtaining the final rank of alternatives [8], but there are also methods that are suitable for both under certain conditions [9].

The scoring (additive) methods are the simplest MCDM methods that rank alternatives based on values obtained by simple arithmetic operations (addition, subtraction, multiplication, or division). Some of the typical representatives of this group of methods are simple additive weighting—SAW [10], weighted sum model—WSM [11], weighted product model—WPM [12], complex proportional assessment—COPRAS [13] and Additive Ratio assessment—ARAS [14]. In the literature, there are multiple examples of comparing the results obtained with these methods. Some of the most recent ones are in studies carried out by Goswami et al. [15], Hosseini Dehshiri and Zanjirchi [16], and Sahabuddin and Khan [17].

The distance-based methods are based on determining the distance of each alternative from some point, which can be an ideal, anti-ideal, or average solution, or any combination of the aforementioned distances. Some of the typical representatives of this group of methods are technique for order of preference by similarity to ideal solution—TOPSIS [18], višekriterijumska optimizacija i kompromisno rešenje—VIKOR [19], multiobjective optimization by ratio analysis—MOORA (plus the full multiplicative form—MULTI) [20,21], weighted aggregated sum product assessment—WASPAS [22], evaluation based on distance from average solution—EDAS [23], combinative distance-based assessment—CODAS [24], measurement of alternatives and ranking according to compromise solution—MARCOS [25], and comprehensive distance-based ranking—COBRA [26]. Some of the most recent studies in which these methods were compared are those of Dehshiri and Firoozabadi [27], Büşra and Abacioğlu [28], and Trung [29].

The pairwise comparison methods are based on the comparison of all pairs of criteria and alternatives, i.e., in determining the outperforming measures of each criterion/alternative in relation to every other. Some of the typical representatives of this group are analytic hierarchy process—AHP [30], analytical network process—ANP [31], stepwise weight assessment ratio analysis—SWARA [32], measuring attractiveness through a categorical-based evaluation technique—MACBETH [33], full consistency method—FUCOM [34], potentially all pairwise rankings of all possible alternatives—PAPRIKA [35], and best-worst method—BWM [36]. The most recent studies in which these methods were compared are the ones by Dagtekin et al. [37], Sharma et al. [38] and Alkan and Kahraman [39].

The outranking methods are based on the establishment of preference relationships in sets of criteria/alternatives, which indicate the degree of their dominance in relation to other criteria/alternatives. Some of the typical representatives of this group are élimination et choix traduisant la realité—ELECTRE [40], preference ranking organization method for enrichment of evaluations—PROMETHEE [41], factor relationship—FARE [42], indifference threshold-based attribute ratio analysis—ITARA [43], Kemeny median indicator ranks accordance—KEMIRA [44], and multiattributive border approximation area comparison—MABAC [45]. Some examples of recent studies that compared these methods were carried out by Biswas and Chaki [46], Bączkiewicz et al. [47], Wątróbski et al. [48].

The research gap that this study covers is the establishment of a novel MCDM based on the volumes of the complex polyhedra as the measures for ranking the alternatives. This method does not belong to any of the previously mentioned groups; instead, it represents a group in itself, called geometric MCDM. Although in the literature (e.g., [49,50]), some authors have already used the term geometric MCDM (or something similar), they are essentially not geometric. They are more methods that can be geometrically represented rather than being fundamentally based on geometric postulates and theorems, i.e., on geometry as a branch of mathematics. Accordingly, the method developed in this study represents a significant contribution to the field of MCDM because it not only expands the range of methods that can be used to solve numerous decision-making problems but also creates a completely new group of MCDM methods.

2.2. Circular-Economy-Based Business Models

The research on circular-economy-based BMs has provided valuable insights into the potential benefits and challenges of these models as well as the factors that influence their adoption and success. This research has implications for both practitioners and policy makers seeking to implement circular strategies and transition toward a more sustainable economy.

One notable trend in this research is the emphasis on the conceptual and theoretical foundations of circular economy business models, including their definitions, characteristics, and benefits. For example, many studies have examined the concept of a circular economy and its potential to create economic and environmental benefits (e.g., [51]) as well as the various business models that may be used to implement circular strategies (e.g., [52]).

Other studies have focused on specific types of circular economy business models, such as circular product–service systems (e.g., [53]), circular business models for small- and medium-sized enterprises (e.g., [54]) and platform-based models for facilitating the transition to circularity (e.g., [55]). There has also been research on the drivers and barriers to the adoption of circular economy business models, such as policy and regulatory frameworks (e.g., [56]), technological capabilities (e.g., [57]), and stakeholder perceptions (e.g., [58]).

In addition to the conceptual and theoretical research, there has also been a growing body of empirical research on CE-based BMs (e.g., [59]). These researchers have examined the performance and sustainability impacts of these models as well as the factors that influence their adoption and success. For example, some studies have analyzed case studies of specific companies or industries that have implemented CE-based BMs (e.g., [60]), while others have conducted surveys or experiments to investigate the impact of these models on various outcomes, such as resource efficiency, waste reduction, and economic performance (e.g., [61]).

Over the past decade, there has been a growing body of research on CE-based BMs in a variety of academic disciplines, including mostly management (e.g., [62]), marketing (e.g., [63]), engineering (e.g., [64]), and environmental science (e.g., [65]). However, to the best of our knowledge, there is no study dealing with CE-based BMs in the agri-food sector, which is one of the research gaps this study tried to cover.

Several researchers have proposed frameworks and tools for analyzing and evaluating business models. For example, the business model canvas, developed by Osterwalder and Pigneur [66], provides a structured approach for identifying and specifying the key elements of a business model. Other tools, such as the business model ontology [67], the business model pattern language [68], and the business model evaluation matrix [69], offer more detailed and comprehensive frameworks for the analysis and comparison of business models. One of the most appropriate tools for evaluating, ranking, or selecting BMs is the MCDM (e.g., [70]). However, there are only few studies using the MCDM methods to evaluate CE-based BMs. Husain et al. [71] used fuzzy TOPSIS to evaluate eleven BMs and selected the most important one for the implementation of the CE. Toker and Görener [72] used spherical fuzzy TOPSIS to evaluate CE-based BMs for small- and medium-sized enterprises. Accordingly, this study tried to fill this research gap and enrich the body of literature dealing with the application of MCDM methods to evaluate the CE-based BMs.

3. Methodology

The model implies the combination of two MCDM methods, one to establish the criteria weights and the second one to evaluate and obtain the final ranking of the alternatives. The general concept of the model is presented in the Figure 1.

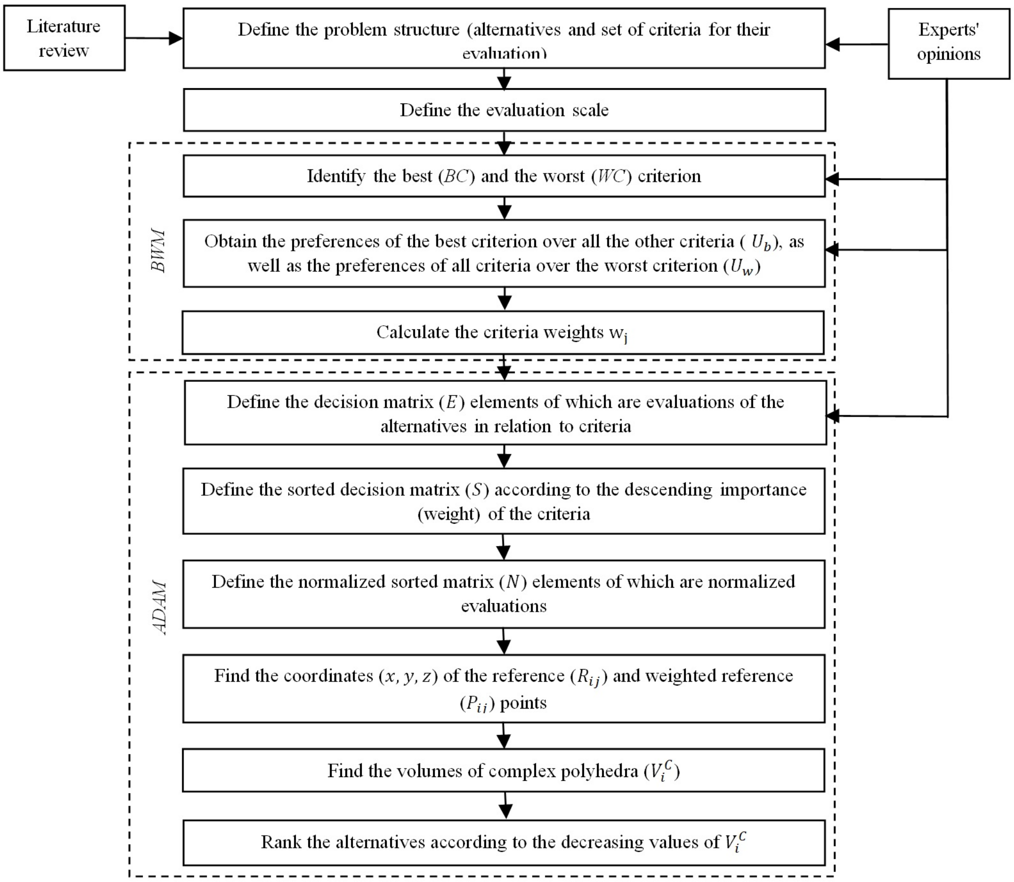

Figure 1. The general concept of the MCDM model.

Step 1: Define the structure of the problem, that is, sets of alternatives and criteria for their evaluation.

Step 2: Define an evaluation scale. In this study, a nine-point scale was used, which is presented in Table 1.

Table 1. Evaluation scale.

Linguistic Evaluation	Abbreviation	Numerical Value
None	N	1
Very Low	VL	2
Low	L	3
Fairly Low	FL	4
Medium	M	5
Fairly High	FH	6
High	H	7
Very High	VH	8
Extremely High	EH	9

Step 3: Obtain the criteria weights using the BWM method.

Step 4: Evaluate and rank the alternatives using the new ADAM method.

More detailed steps of applying BWM and ADAM methods are explained in the following subsections.

3.1. BWM Method

The main concept of the BWM is to evaluate and compare a set of alternatives based on multiple criteria. It is a variant of the MCDM belonging to a group of pairwise comparison methods, which is a systematic process for evaluating and ranking alternatives based on multiple, often conflicting, criteria. In this method, a decision maker is asked to evaluate each alternative with respect to each criterion and to select the best and worst alternative for each criterion. The decision maker then assigns a weight to each criterion based on its relative importance. The scores for each alternative are then calculated by multiplying the weight of each criterion by the corresponding score assigned by the decision maker. The alternative with the highest overall score is then selected as the best option.

The BWM method is subject to subjective judgments, limited to binary evaluations and decisions and requires the pairwise comparisons, which usually lead to more resource-demanding decision making [34]. However, in comparison with some other pairwise methods, most popular of which are AHP and ANP, it is very flexible, is suitable for the consideration of a large number of criteria because it requires less data (pairwise comparisons), and is very simple and easy to use [36]. The BWM method is more consistent, provides more accurate results, reduces violations, reduces total deviation, minimizes duplication, and has a higher level of compliance compared with other MCDM methods [73]. Due to these advantages, it was selected to obtain criteria weights in this study. Some of the most recent applications of the BWM method proving its effectiveness are for risk assessment [74], evaluation of healthcare waste treatment facilities [75], assessment of groundwater vulnerability conditions [76], the ranking of the best stocks for portfolio inclusion in the banking sector [77], and the identification of energy distribution strategies [78].

The main steps of the method applications are as follows [36]:

Step 3.1: Identify the best (BC) and the worst (WC) criteria.

Step 3.2: Obtain the preferences of the best criterion over all the other criteria as well as the preferences of all criteria over the worst criterion using the scale presented in Table 1. In this way, two vectors are obtained, $U_b = (u_{b1}, u_{b2}, \ldots, u_{bm})$ and $U_w = (u_{1w}, u_{2w}, \ldots, u_{mw})$, in which u_{bj} implies the preference of the best criterion BC over criterion j ($j = 1, \ldots, m$), and u_{jw} implies the preference of the criterion j ($j = 1, \ldots, m$) over the worst criterion WC.

Step 3.3: Calculate the criteria weights w_j as:

$$\min \xi \tag{1}$$

subject to:

$$|w_b - u_{bj} w_j| \leq \xi,\ \forall j = 1, \ldots, m \tag{2}$$

$$|w_j - u_{jw} w_w| \leq \xi,\ \forall j = 1, \ldots, m \tag{3}$$

$$\sum_{j=1}^{m} w_j = 1 \tag{4}$$

$$w_j \geq 0,\ \forall j = 1, \ldots, m \tag{5}$$

The value of ξ indicates the consistency of the comparison, i.e., the closer the value to zero, the higher the consistency.

3.2. Axial-Distance-Based Aggregated Measurement (ADAM) Method

The ADAM method represents entirely new group of MCDM methods, namely geometric MCDM. The process of ranking alternatives in this method is based on determining the volumes (aggregated measurement) of complex polyhedra that are defined by points (vertices) in a three-dimensional coordinate system. Each of the points belongs to one of three types: coordinate origin (O), reference points (R), and weighted reference points (P). The coordinate origin is a point with coordinates $(0, 0, 0)$. Reference points are points with coordinates $(x, y, 0)$ that define the value of the alternative according to some criterion as the axial distance of the point from the coordinate origin in the x–y plane. The weighted reference points have coordinates (x, y, z), where the coordinate z is used to obtain the axial distance of the weighted reference point from the x–y plane. These distances correspond to the weights of the criteria. A simple example of a complex polyhedron obtained for the problem of evaluating an alternative in relation to the three criteria is shown in Figure 2.

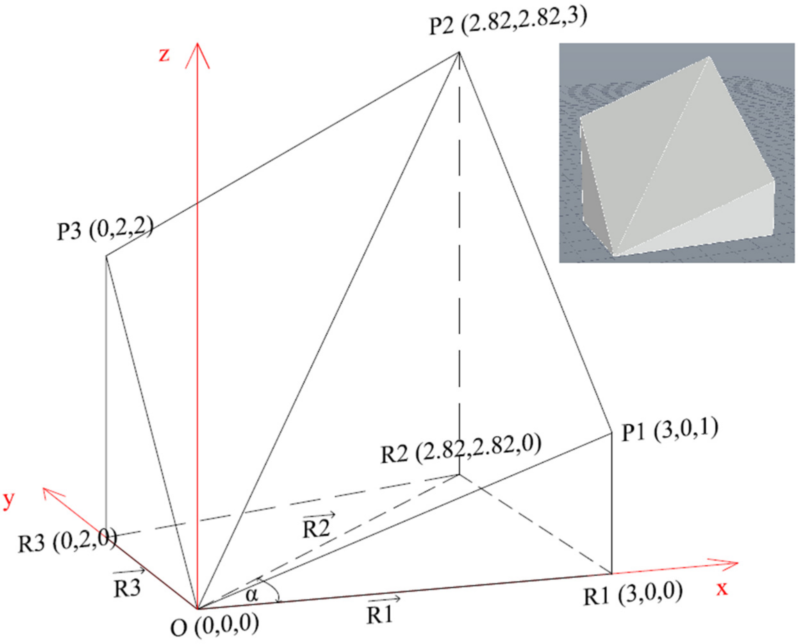

Figure 2. An example of a complex polyhedron for evaluating an alternative against three criteria.

The complex polyhedron shown in Figure 2 is defined by seven points, of which O indicates the coordinate origin; points R_1, R_2, and R_3 indicate the reference points and points P_1, P_2 and P_3 indicate weighted reference points. The coordinates of the reference points R_1, R_2, and R_3 are obtained on the basis of a vector that defines the value of the alternative according to some criterion. A vector is defined by course, direction, and magnitude. The course of the vector that defines the value of the alternative is defined by the angle α in relation to the x axis. The vector is always directed away from the coordinate origin. The magnitude of the vector is defined by its length, which corresponds to the value of the alternative according to that criterion.

In the example in Figure 2, the coordinates of the reference point Q for the first criterion are obtained by defining the vector $\overrightarrow{R_1}$, whose course is defined by an angle of 0° in relation to the x axis, starting from the coordinate origin and ending at a distance of 3 from the coordinate origin. Accordingly, it is clear that point R_1 has coordinates (3,0,0). In a similar way, the coordinates of the reference point R_2 for the second criterion are obtained through the vector $\overrightarrow{R_2}$, whose course is defined by an angle of 45° with respect to the x axis, starting from the coordinate origin and ending at a distance of 4 from the coordinate origin. Accordingly, it is clear that point R_2 has coordinates (2.82,2.82,0). The coordinates of the reference point R_3 for the third criterion are obtained through the vector $\overrightarrow{R_3}$, whose course is defined by an angle of 90° in relation to the x axis, starting from the coordinate origin and ending at a distance of 2 from the coordinate origin. Accordingly, it is clear that point R_3 has coordinates (0,2,0).

The coordinates of the weighted reference points P_1, P_2, and P_3 are obtained by adding a third dimension to the projections of the points R_1, R_2 and R_3 from the x–y plane; that is, the coordinate z, instead of a value of 0, takes the value of the weight of the observed criterion. Accordingly, if the first criterion has a weight of 1, the coordinates of the point P_1 are (3,0,1); if the second criterion has a weight of 3, the coordinates of the point P_2 are (2.82,2.82,3); and if the third criterion has a weight of 2, the coordinates of point P_3 are (0,2,2).

By defining all the points that define a complex polyhedron, it is possible to calculate its volume as the sum of the volumes of k polyhedra ($k = 1, \ldots, n-1$), which are, in this case, irregular pyramids. Each polyhedron consists of sides formed by a coordinate origin with reference and weighted reference points of two consecutive criteria. The final order of alternatives is obtained according to the decreasing values of the obtained volumes of complex polyhedra. A detailed description of the steps of applying the method is shown below:

Step 4.1: Define the decision matrix E elements, which are evaluations e_{ij} of the alternatives i in relation to criteria j, i.e., vector magnitudes that correspond to the evaluations of the alternatives in relation to the criterion:

$$E = \left[e_{ij}\right]_{m \times n} \tag{6}$$

where m is the total number of alternatives, and n is the total number of criteria.

Step 4.2: Define the sorted decision matrix S elements, which are s_{ij}, indicating the sorted evaluations e_{ij} in descending order according to the importance (weight) of the criterion:

$$S = \left[s_{ij}\right]_{m \times n} \tag{7}$$

Step 4.3: Define the normalized sorted matrix N elements, which are normalized evaluations n_{ij} obtained as:

$$n_{ij} = \begin{cases} \frac{s_{ij}}{\max\limits_{i} s_{ij}}, & for j \in B \\ \frac{\min\limits_{i} s_{ij}}{s_{ij}}, & for j \in C \end{cases} \tag{8}$$

where B is the set of benefit, and C is the set of cost criteria.

Step 4.4: Find the coordinates $(x,\ y,\ z)$ of the reference (R_{ij}) and weighted reference (P_{ij}) points that define the complex polyhedron in the following way:

$$x_{ij} = n_{ij} \times \sin \alpha_j,\ \forall j = 1, \ldots, n;\ \forall i = 1, \ldots, m \tag{9}$$

$$y_{ij} = n_{ij} \times \cos \alpha_j,\ \forall j = 1, \ldots, n;\ \forall i = 1, \ldots, m \tag{10}$$

$$z_{ij} = \begin{cases} 0,\ for R_{ij} \\ w_j,\ for P_{ij} \end{cases},\ \forall j = 1, \ldots, n;\ \forall i = 1, \ldots, m \tag{11}$$

where α_j is the angle that determines the direction of the vector that defines the value of the alternative, which is obtained as:

$$\alpha_j = (j-1)\frac{90^\circ}{n-1},\ \forall j = 1, \ldots, n \tag{12}$$

Step 4.5: Find the volumes of complex polyhedra V_i^C as the sum of the volumes of the pyramids of which it is composed using the following equation:

$$V_i^C = \sum_{k=1}^{n-1} V_k,\ \forall i = 1, \ldots, m \tag{13}$$

where V_k is the volume of the pyramid obtained by applying the following equation:

$$V_k = \frac{1}{3} B_k \times h_k,\ \forall k = 1, \ldots, n-1 \tag{14}$$

where B_k is the surface of the base of the pyramid defined by the reference and weighted reference points of two consecutive criteria and is obtained by applying the following equation:

$$B_k = c_k \times a_k + \frac{a_k \times (b_k - c_k)}{2} \tag{15}$$

where a_k is the Euclidean distance between the reference points of two consecutive criteria, which is obtained by applying the following equation:

$$a_k = \sqrt{\left(x_{j+1} - x_j\right)^2 + \left(y_{j+1} - y_j\right)^2} \tag{16}$$

b_k and c_k are the magnitudes of the vectors corresponding to the weights of two consecutive criteria, that is:

$$b_k = z_j \tag{17}$$

$$c_k = z_{j+1} \tag{18}$$

h is the height of the pyramid from the defined base to the top of the pyramid located in the coordinate origin (O) and is obtained by applying the following equation:

$$h_k = \frac{2\sqrt{s_k(s_k - a_k)(s_k - d_k)(s_k - e_k)}}{a_k} \tag{19}$$

where s_k is the semicircumference of the triangle defined by the x and y coordinates of two consecutive criteria and the coordinate origin and is obtained as:

$$s_k = \frac{a_k + d_k + e_k}{2} \tag{20}$$

where d_k and e_k are the Euclidean distances of the reference points of two consecutive criteria from the coordinate origin and are obtained as:

$$d_k = \sqrt{x_j^2 + y_j^2} \tag{21}$$

$$e_k = \sqrt{x_{j+1}^2 + y_{j+1}^2} \tag{22}$$

Step 4.6: Rank the alternatives according to the decreasing values of the volumes of complex polyhedra V_i^C $(i = 1, \ldots, m)$. The best alternative is the one with the highest volume value.

4. Agri-Food Circular-Economy-Based Business Model Evaluation

A BM is a plan or framework that outlines how a company will generate revenue and make a profit. It defines the products or services that the company will offer, the target market it will serve, and the channels it will use to reach and sell to customers. There are many different types of BMs, and a company may use a combination of different models to achieve its goals. The choice of BM depends on the nature of the company's products or services, its target market, and its overall goals and objectives. Because the aim of this study was to investigate BMs based on CE in the agri-food sector, the following describes some of the most promising ones. The BMs were obtained through a literature review and from focus groups of experts from the fields of logistics, supply chain, and agri-food.

4.1. Agri-Food Circular-Economy-Based Business Models

CE-based BMs appear as alternatives in this study. They were identified based on a literature review in the field and adapted to the specific needs of the problem being solved in this study, that is, adapted to the needs of the companies belonging to the agri-food sector. Nine business models were defined.

BM1: Sustainable agri-food production. This BM is based on agricultural production aimed at creating sustainable food products able to become part of circular supply chains. The ultimate goal is to achieve global self-sustainability through the redistribution of arable land; the cultivation of high-yield crops the realization of agricultural activities through high standards in terms of environmental protection, precision, and efficiency focusing on integrated and organic production and the development of agroecological and conservative agricultural systems. [79]. To achieve this goal, new sensing, smart, and sustainable technologies must be introduced such as intelligent hydroponic greenhouses, sun-trackers for multiple purposes, quadrotors or drones (unmanned aerial vehicles), and agricultural hexapod robots. [80]. The success of this BM largely depends on the responsible management of production in terms of the rational usage of water, pesticides, and fertilizers/nutrients, as well as the establishment of socially responsible and globally accepted supply chains [79].

BM2: Agri-food collaborative organization. A BM based on horizontal and vertical cooperation is very well-recognized as a way of improving the sustainability of agri-food supply chains [81]. Cooperation is seen as one of the most important factors for encouraging participants to take more responsibility, which will ensure the achievement of social, economic, and environmental goals and thus reduce conflicts in agri-food supply chains [82]. Today's agri-food supply chains are characterized by a high degree of dynamism, nonstationarity, stochasticity, and discontinuity. This forces operators and other supply chain participants to develop new skills, capabilities, methods, tools, and approaches to meet these challenges. BMs that are capable of forming complex collaborative approaches provide significant support for the planning and management of sustainable circular agri-food supply chains [82].

BM3: Sustainable circular agri-food supply chain. New strategies for managing agri-food supply chains based on the principles of sustainability and open cooperation between multiple participants enable circularity and reduce the complexity of agri-food distribution networks and thus distribution-related externalities. BMs based on sustainable circular supply chains in the agri-food sector aim to reduce food loss and waste, identify adequate packaging methods, and apply alternative modes of transport that reduce all negative environmental effects (greenhouse gases, noise, particles, and emissions) and improve food security [79]. They also strive to improve transparency not only for hygienic reasons but also as a way to apply ethical principles and effectively manage costs, quality, reliability, flexibility, transparency, social responsibility, innovation, and collaboration [83]. All these goals lead to one comprehensive goal, which is the achievement of a circular sustainable supply chain with the triple bottom line principle, i.e., the achievement of the social, economic, and environmental sustainability of the system.

BM4: Ownership and capital structure in the agri-food sector. A business model based on ownership and capital structure in the agri-food sector would involve the ownership of agricultural land and food production facilities by a combination of shareholders, investors, and the company's management team [84]. The capital structure of the business would involve a mix of debt and equity financing, with the goal of maximizing the return on investment for shareholders, while ensuring the company has adequate funding for operations and growth [85]. In this model, the agri-food company would produce and distribute a range of agricultural and food products, such as crops, livestock, dairy products, and processed foods. The company would have a network of suppliers for raw materials and distribution channels for its finished products, including wholesale distributors, retailers, and food service providers. To generate revenue, the company would sell its products at a profit, either directly to consumers or through intermediaries. It may also generate income from services such as contract farming, storage and logistics, and food processing. The company could also invest in research and development to improve its production processes and develop new products. To manage its operations and growth, the company can have a board of directors and a management team responsible for making strategic decisions and allocating resources. The board would be responsible for overseeing the company's performance and ensuring that it complies with laws and regulations. The management team would be responsible for implementing the board's decisions and running the day-to-day operations of the business. Overall, a business model based on ownership and capital structure in the agri-food sector would involve a combination of production, distribution, and sales activities, with a focus on maximizing shareholder value while providing a range of products and services to customers.

BM5: Agri-food product life extension. A business model based on agri-food product life extension involves developing and implementing strategies to extend the shelf life or usability of food products in order to reduce waste and increase efficiency. This type of business model can be based on a variety of approaches, including physical, chemical, and biological methods [86]. One example of a business model based on agri-food product life extension is the use of innovative packaging technologies, such as modified atmosphere, i.e., vacuum packaging [87] or active packaging [88], to extend the shelf life of fresh products. These technologies can help to preserve the quality and nutritional value of the food by inhibiting the growth of microorganisms and slowing down the processes of oxidation and respiration. Another approach to agri-food product life extension is the use of natural or chemical preservatives, such as vinegar or sodium benzoate [89], to extend the shelf life of processed foods, such as sauces, pickling, and condiments. These preservatives can help to inhibit the growth of microorganisms and prevent spoilage. A third approach to agri-food product life extension is the use of innovative technologies, such as high-pressure processing or pulsed electric fields [90], to inactivate microorganisms and extend the shelf life of fresh or minimally processed foods. These technologies can help to preserve the quality and nutritional value of the food while maintaining its natural appearance and taste. Overall, a business model based on agri-food product life extension can offer a range of benefits, including reduced waste, increased efficiency, and improved sustainability. By developing and implementing strategies to extend the shelf life or usability of food products, companies can help to reduce the environmental and economic impacts of food waste and contribute to the development of a more sustainable food system.

BM6: Agri-food sharing platforms. A business model based on agri-food sharing platforms involves creating an online platform or marketplace where farmers, producers, and consumers can exchange or share food products, resources, and knowledge [91]. This type of business model can be based on a variety of approaches, depending on the specific goals and target market of the platform. One example of a business model based on agri-food sharing platforms is the creation of a community-supported agriculture (CSA) platform [92], where consumers can purchase a share of a farmer's produce in advance and receive a weekly delivery of fresh, locally grown produce. This model can help to support small-scale farmers and promote sustainable agriculture practices while providing consumers with access to high-quality, locally sourced food. Another approach to agri-food sharing platforms is the creation of a food waste reduction platform [93], where consumers can purchase or donate surplus or surplus food from producers, retailers, or restaurants. This model can help to reduce both food waste and the environmental and economic impacts of food waste. A third approach to agri-food sharing platforms is the creation of a knowledge-sharing platform [94], where farmers and producers can share information, resources, and expertise with each other and with consumers. This model can help to facilitate the exchange of information and ideas as well as promote collaboration and innovation within the agri-food sector. Overall, a business model based on agri-food sharing platforms can offer a range of benefits, including increased sustainability, reduced waste, and improved access to high-quality, locally sourced food. By creating a platform or marketplace for the exchange of food products, resources, and knowledge, companies can help to support small-scale farmers and promote the development of a more sustainable food system.

BM7: Entrepreneurship in the agri-food sector. The development of entrepreneurship in the agri-food sector represents a BM that can play a key role in establishing circular supply chains. By educating entrepreneurs in this area, positive attitudes and public opinions are formed, and the support of the state through various programs enables this attitude to be expanded and accepted by other participants in the sector. In this way, the ultimate goal is achieved: the adoption of CE as a key concept that enables the flourishing of the agri-food sector. The entrepreneurial spirit is formed in the contact of entrepreneurs with other business actors. Therefore, the success of entrepreneurship primarily depends on the attitudes and social cognitive abilities of the entrepreneurs themselves [95]. In fact, failure often happens due to the failure to recognize good ideas or the insufficient engagement of entrepreneurs in their development and implementation. Therefore, it is very important to adequately educate future and current entrepreneurs so that they can be knowledgeable in the key success factors [96]. In addition, the government must support the development of entrepreneurial intention, e.g., through the opening of national, regional, or local centers that promote and support entrepreneurial activities and support capacity building and the development of skills that help participants in the agri-food sector to establish market-oriented businesses [97].

BM8: Agri-food reuse, remanufacturing, and recycling. A business model based on agri-food reuse, remanufacturing, and recycling involves developing and implementing strategies to extend the lifespan of food products and reduce waste by reusing, repairing, or recycling materials and resources. This type of business model can be based on a variety of approaches, depending on the specific goals and target market of the company. One approach to agri-food reuse, remanufacturing, and recycling is the creation of a circular product–service system, where a company offers repair, refurbishment, or maintenance services for its food products, rather than selling them as new products. This model can help to extend the lifespan of the products and reduce waste while generating additional revenue streams for the company. Another model involves remanufacturing in the agri-food industry, i.e., fixing or repairing packaged products that are damaged, faulty, misshaped, incorrectly weighed, or broken, in order to restore them to their original, intended specifications [98]. The agri-food industry generates a large amount of waste on farms and during processing, which can cause significant social and environmental issues. However, this waste can be used as raw materials to produce valuable chemicals that have various industrial applications, such as food ingredients, nutraceuticals, bio-derived fine chemicals, and biofuels. To extract and transform these phytochemicals from agriculture and food waste, which can be prone to microbial spoilage and are complex in nature, it is necessary to use fast pretreatment and integrate various processes [99]. Overall, a business model based on agri-food reuse, remanufacturing, and recycling can offer a range of benefits, including reduced waste, increased efficiency, and improved sustainability. By developing and implementing strategies to extend the lifespan of food products and reduce waste, companies can help to create a more circular and sustainable food system.

BM9: Smart agri-food. The development of the CE concept, in any sector, even in the agri-food one, largely depends on the degree of digitization and application of modern information and communication technologies [100]. This BM, which implies the development of a smart agri-food sector based on three basic pillars: smart farming, smart food production, and smart services, represents one of the success factors of CE in this sector. Smart farming is often equated with the term agri-tech and implies the application of modern technological solutions with the aim of improving the efficiency of agricultural production [101]. With the development of the Industry 4.0 concept, smart farming has taken on a new dimension and implies the introduction of various technologies such as the Internet of Things, cloud computing, artificial intelligence, virtual reality, augmented reality, and advanced robotics in farming [102,103]. The greater demand for specialized (e.g., innovative texture-building foods) and personalized (e.g., required concentration of fat, sugar, and micronutrients) food products, on one hand, and the limited availability of ingredients and services, on the other, require the application of Industry 4.0 technologies in production processes, thus creating smart food manufacturing [104]. Industry 4.0 technologies could also be applied to develop smart services in the agri-food sector, primarily for performing various activities in the circular supply chain [98].

4.2. Criteria for BM Evaluation

The described BMs can be evaluated and ranked according to a number of criteria. The criteria were defined based on a literature review and the opinions of experts in the field who considered the potential criteria in the discussion groups and selected the following as representative:

C1. Partnerships. Partnerships are essential for the success of any business model [105]. Partnerships can be established between participants belonging to the same or different interest groups, such as public and private companies and authorities. The results of the formation of partnerships are the creation of a better business climate, better conditions for investment, creation of new jobs, savings in investment and operating costs, better quality of products and services, and risk sharing. [106]. Business models that provide better opportunities and prerequisites for forming partnerships are more favorable.

C2. Resources. Savings in human, financial, energy, material, and other resources should be the priority in any sustainable business model (e.g., [107,108]). Savings in human resources can be achieved through a more rational organization of work; of finances through optimization of processes and activities; of energy through the use of alternative energy sources and a more rational consumption of primary ones; and of materials through the processes of reuse, remanufacturing, recycling, and refurbishing. Business models that enable greater savings of the mentioned resources are more favorable.

C3. Costs. The implementation of different business models requires different investment costs in the initial stages of implementation (e.g., [109,110]). These costs are most often generated by the processes of research and development, selection and procurement of technology, employment and training of staff, or the establishment of distribution channels. Business models that are less costly are more favorable.

C4. Values. The processes within the R9 concept—refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover—reduce the introduction of new (virgin) materials into the production processes and thus the reduction of waste and the preservation of the environment [111]. In addition to these, one of the main benefits of these processes is value preservation, creation, transfer, and capture through the use of the same materials over and over again [107]. Business models that enable or support the R9 concept are more favorable.

C5. Profitability. Profitability is achieved by increasing revenues and savings. Revenues in business models that support circularity can be increased through state incentives in the form of subsidies aimed at reducing the introduction of virgin materials and waste. In addition, circularity enables savings in supply processes, insurance, delivery delays, margins, and taxes. (e.g., [112,113]). Business models that enable more revenues and savings, i.e., that enable more profitable operations, are more favorable.

C6. Channels. The marketing channel represents a series of participants between producers and consumers (e.g., wholesalers and retailers) who perform certain actions in order to fulfill the marketing task, that is, to sell products in such a way that the interests of all participants are satisfied. The physical channel represents a series of activities of transportation, transshipment, storage, inventory, consolidation, and deconsolidation, which aim to physically move the goods from the producer to the consumer. Together, they form distribution channels. Business models that enable greater efficiency in the implementation of distribution channels are more favorable [114,115].

C7. Relationships. The relationships between different players, such as administrations, institutions, producers, and consumers, have to be powerful and able to ensure the highest performance of the business models (e.g., [116,117]). For this purpose, working groups, public discussions, and consultations are organized by various associations, organizations, and chambers of commerce,. The purpose is to inform, exchange ideas, identify requirements, and make decisions. Business models that enable the development of extraordinary relationships among all players are more favorable.

C8. Ethics. Business ethics means defining values and norms that have developed over time and that have been agreed upon by a group of participants. These values and norms become an integral part of the culture of organizations and are further transferred to all new participants. However, they are also dependent on new participants who join the organization. One of the most important business ethical norms concerns social responsibility [118]. Business models based on actions or decisions that do not have a negative impact on or even promote the protection of social and environmental principles are considered socially responsible and are therefore more favorable [119].

4.3. Results

In order to solve the defined problem by applying the developed MCDM model, it was necessary to first define a focus group. The focus group consisted of 36 experts with varying degrees of experience from the management, agri-food, and circular economy sectors. The structure of experts is shown in Table 2.

Table 2. Focus group structure.

Sector	Number of Experts	Experience (Years)
Management	5	<5
	4	5–15
	8	>15
Agri-food	3	<5
	5	5–15
	4	>15
Circular economy	1	<5
	3	5–15
	3	>15

The experts were asked to evaluate the criteria and alternatives using the linguistic expressions given in Table 1. Their evaluations were statistically combined, using a probability distribution. The ratings with the highest frequency in the population, that is, the answers with the highest probability, were chosen as the representative ratings for the entire focus group. In this way, the best and worst criteria were first defined and then the evaluations of the other criteria in relation to them. The grades were converted into numerical values by applying the relationships from Table 1; then, by solving the linear programming problem (1)–(5) the weights of the criteria were obtained. The representative evaluations of the focus group as well as the obtained criteria weights are shown in Table 3.

Table 3. Representative evaluations of the focus group and the final criteria weights.

Criterion	Best/Worst	Best over Other	u_{bj}	Other over Worst	u_{jw}	w_j
C1		FL	4	L	3	0.077
C2		L	3	FL	4	0.103
C3		VL	2	M	5	0.155
C4		N	1	FH	6	0.241
C5	BC	/	/	H	7	0.275
C6		FH	6	N	1	0.052
C7		M	5	VL	2	0.062
C8	WC	H	7	/	/	0.034

The representative evaluations of alternatives according to the criteria, obtained by applying the previously described procedure, are shown in Table 4. The evaluations were then converted into numerical values by applying the relationships given in Table 1; thus, matrix E was formed as in (6).

Table 4. Representative evaluations of alternatives in relation to criteria.

	BM1	BM2	BM3	BM4	BM5	BM6	BM7	BM8	BM9
C5	H	FH	EH	VH	L	H	EH	FH	FH
C4	EH	L	VH	VL	EH	FH	FH	EH	VH
C3	FL	M	H	VH	H	H	EH	M	VL
C2	EH	H	H	VL	EH	FL	FL	EH	FH
C1	M	EH	FH	H	VL	EH	M	FL	L
C7	FL	EH	EH	VH	VL	EH	VH	L	L
C6	M	VH	EH	M	FL	EH	VH	L	FL
C8	EH	H	EH	VL	FH	L	L	EH	H

Afterwards, using Equations (7) and (8), the sorted decision matrix S and normalized sorted matrix N were obtained. Using Equations (9)–(12), the coordinates of the reference (R_{ij}) and weighted reference (P_{ij}) points were obtained. These coordinates are presented in Tables 5 and 6, respectively.

Table 5. Coordinates of the reference points.

	R_{i1}	R_{i2}	R_{i3}	R_{i4}	R_{i5}	R_{i6}	R_{i7}	R_{i8}
R_{1j}	(0,0.7,0)	(0.2,0.9,0)	(0.2,0.3,0)	(0.6,0.7,0)	(0.3,0.3,0)	(0.3,0.1,0)	(0.4,0.1,0)	(1,0,0)
R_{2j}	(0,0.6,0)	(0,0.2,0)	(0.2,0.5,0)	(0.4,0.5,0)	(0.7,0.6,0)	(0.9,0.4,0)	(0.8,0.2,0)	(0.7,0,0)
R_{3j}	(0,1,0)	(0.2,0.8,0)	(0.3,0.7,0)	(0.4,0.5,0)	(0.4,0.3,0)	(0.8,0.4,0)	(1,0.2,0)	(0.9,0,0)
R_{4j}	(0,0.8,0)	(0,0.1,0)	(0.4,0.8,0)	(0.1,0.1,0)	(0.5,0.4,0)	(0.7,0.3,0)	(0.4,0.1,0)	(0.1,0,0)
R_{5j}	(0,0.2,0)	(0.2,1,0)	(0.3,0.7,0)	(0.6,0.7,0)	(0.1,0.1,0)	(0.1,0,0)	(0.3,0.1,0)	(0.6,0,0)
R_{6j}	(0,0.7,0)	(0.1,0.5,0)	(0.3,0.7,0)	(0.2,0.3,0)	(0.8,0.6,0)	(0.8,0.4,0)	(0.9,0.2,0)	(0.2,0,0)
R_{7j}	(0,1,0)	(0.1,0.5,0)	(0.4,0.9,0)	(0.2,0.3,0)	(0.3,0.3,0)	(0.7,0.3,0)	(0.8,0.2,0)	(0.2,0,0)
R_{8j}	(0,0.6,0)	(0.2,1,0)	(0.2,0.5,0)	(0.6,0.8,0)	(0.3,0.2,0)	(0.2,0.1,0)	(0.2,0,0)	(0.9,0,0)
R_{9j}	(0,0.6,0)	(0.2,0.8,0)	(0.1,0.1,0)	(0.3,0.4,0)	(0.2,0.1,0)	(0.2,0.1,0)	(0.3,0.1,0)	(0.7,0,0)

Table 6. Coordinates of the weighted reference points.

	P_{i1}	P_{i2}	P_{i3}	P_{i4}	P_{i5}	P_{i6}	P_{i7}	P_{i8}
P_{1j}	(0,0.7,0.3)	(0.2,0.9,0.2)	(0.2,0.3,0.2)	(0.6,0.7,0.1)	(0.3,0.3,0.1)	(0.3,0.1,0.1)	(0.4,0.1,0.1)	(1,0,0)
P_{2j}	(0,0.6,0.3)	(0,0.2,0.2)	(0.2,0.5,0.2)	(0.4,0.5,0.1)	(0.7,0.6,0.1)	(0.9,0.4,0.1)	(0.8,0.2,0.1)	(0.7,0,0)
P_{3j}	(0,1,0.3)	(0.2,0.8,0.2)	(0.3,0.7,0.2)	(0.4,0.5,0.1)	(0.4,0.3,0.1)	(0.8,0.4,0.1)	(1,0.2,0.1)	(0.9,0,0)
P_{4j}	(0,0.8,0.3)	(0,0.1,0.2)	(0.4,0.8,0.2)	(0.1,0.1,0.1)	(0.5,0.4,0.1)	(0.7,0.3,0.1)	(0.4,0.1,0.1)	(0.1,0,0)
P_{5j}	(0,0.2,0.3)	(0.2,1,0.2)	(0.3,0.7,0.2)	(0.6,0.7,0.1)	(0.1,0.1,0.1)	(0.1,0,0.1)	(0.3,0.1,0.1)	(0.6,0,0)
P_{6j}	(0,0.7,0.3)	(0.1,0.5,0.2)	(0.3,0.7,0.2)	(0.2,0.3,0.1)	(0.8,0.6,0.1)	(0.8,0.4,0.1)	(0.9,0.2,0.1)	(0.2,0,0)
P_{7j}	(0,1,0.3)	(0.1,0.5,0.2)	(0.4,0.9,0.2)	(0.2,0.3,0.1)	(0.3,0.3,0.1)	(0.7,0.3,0.1)	(0.8,0.2,0.1)	(0.2,0,0)
P_{8j}	(0,0.6,0.3)	(0.2,1,0.2)	(0.2,0.5,0.2)	(0.6,0.8,0.1)	(0.3,0.2,0.1)	(0.2,0.1,0.1)	(0.2,0,0.1)	(0.9,0,0)
P_{9j}	(0,0.6,0.3)	(0.2,0.8,0.2)	(0.1,0.1,0.2)	(0.3,0.4,0.1)	(0.2,0.1,0.1)	(0.2,0.1,0.1)	(0.3,0.1,0.1)	(0.7,0,0)

The complex polyhedra defined by the reference and weighted reference points are presented in Figure 3. Their volumes were then obtained using Equations (13)–(22). The alternatives were finally ranked by arranging them in the descending order by the values of the corresponding polyhedron volumes. The obtained volumes are presented in Table 7. As can be seen from the results, the best ranked one was BM3.

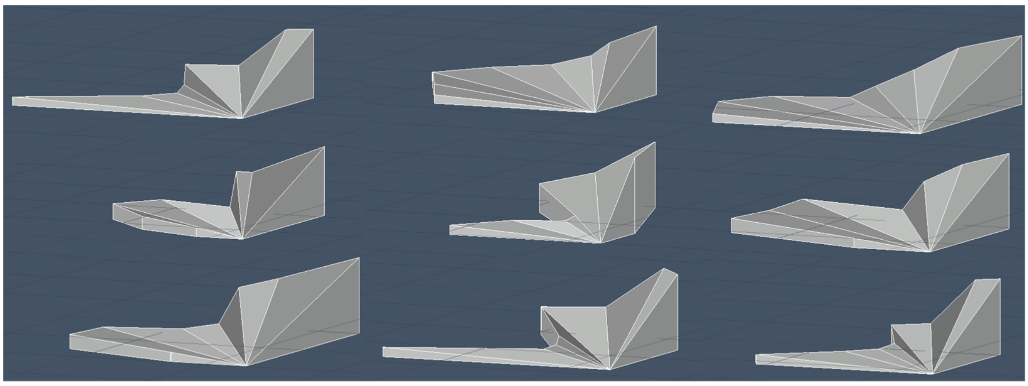

Figure 3. Complex polyhedra for the defined alternatives.

Table 7. Volumes of the complex polyhedra and ranking of the alternatives.

	BM1	BM2	BM3	BM4	BM5	BM6	BM7	BM8	BM9
Volumes	0.025	0.021	0.04	0.009	0.023	0.026	0.028	0.026	0.012
Rank	5	7	1	9	6	3	2	4	8

The problem could also be solved using the ADAM software package that we developed, which is available online http://adam-mcdm.com/ [120], accessed on 6 February 2023 (See Supplementary Materials).

4.4. Validation

In order to validate the ADAM method and the obtained results, the same problem with the same input data was solved using other MCDM methods. From each of the four groups of MCDM methods, the two most popular methods (i.e., the most widely used in the literature to date) were selected. From the group of the scoring (additive) methods, SAW and COPRAS were selected; from the group of the distance-based methods, TOPSIS and VIKOR were selected; from the group of the pairwise comparison methods, AHP and SWARA were selected; and from the group of the outranking methods, PROMETHEE and ELECTRE were selected. The obtained rankings are presented in Table 8, and their comparison is shown in Figure 4.

Table 8. Ranking comparison by various MCDM methods.

	BM1	BM2	BM3	BM4	BM5	BM6	BM7	BM8	BM9
ADAM	5	7	1	9	6	3	2	4	8
TOPSIS	3	9	1	8	6	5	2	4	7
VIKOR	3	7	1	8	9	4	2	5	6
SAW	5	7	1	8	6	4	2	3	9
COPRAS	5	7	1	8	6	4	2	3	9
AHP	4	8	1	6	5	7	2	3	9
SWARA	2	4	1	6	8	3	5	7	9
PROMETHEE	3	6	1	8	7	4	2	5	9
ELECTRE	3	9	1	8	6	4	2	5	7

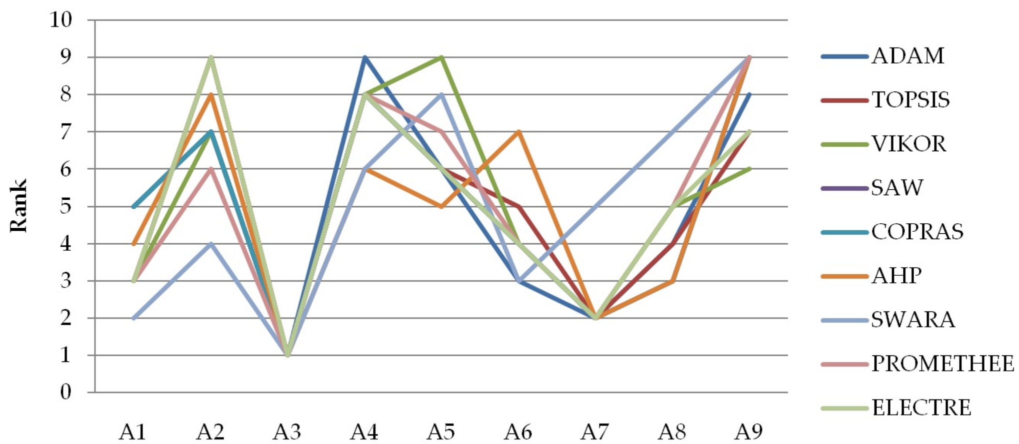

Figure 4. Comparisons of rankings by various MCDM methods.

To assess the strength and direction of the monotonic relationship between the obtained ranks, the Spearman correlation coefficient (SCC) was calculated for each pair of methods. The Spearman correlation is a statistical measure often used to evaluate the degree to which one variable is related to another in a nonlinear relationship. It can range from -1 to 1, with values closer to 1 indicating a stronger relationship. The SCC values of the method comparisons are presented in Table 9.

Table 9. SCC values of method comparisons.

	ADAM	TOPSIS	VIKOR	SAW	COPRAS	AHP	SWARA	PROMETHEE	ELECTRE
ADAM	1	0.883	0.883	0.967	0.967	0.75	0.583	0.917	0.9
TOPSIS	0.883	1	0.867	0.883	0.883	0.867	0.5	0.867	0.983
VIKOR	0.883	0.867	1	0.783	0.783	0.633	0.683	0.883	0.883
SAW	0.967	0.883	0.783	1	1	0.867	0.567	0.917	0.867
COPRAS	0.967	0.883	0.783	1	1	0.867	0.567	0.917	0.867
AHP	0.75	0.867	0.633	0.867	0.867	1	0.417	0.783	0.8
SWARA	0.583	0.5	0.683	0.567	0.567	0.417	1	0.8	0.567
PROMETHEE	0.917	0.867	0.883	0.917	0.917	0.783	0.8	1	0.883
ELECTRE	0.9	0.983	0.883	0.867	0.867	0.8	0.567	0.883	1

The ADAM method showed significant statistical correlation to all the selected methods. The average SCC value of the ADAM method was 0.872, which was greater than that of most of the selected methods. The lowest average SCC value achieved was that of the SWARA method, 0.631. The only three methods that had somewhat greater or equal average SCCs as that of the ADAM method were PROMETHEE, SAW, and COPRAS, with values 0.885, 0.872, and 0.872, respectively. This indicated a very high degree of conformity of the ADAM method with some of the most prominent MCDM methods in the literature.

4.5. Sensitivity Analysis

In order to check the stability of the obtained solution, 21 scenarios were defined, in which the weights of the three most important criteria were varied. In the first seven scenarios, the weight of the most important criterion (C5) was reduced by 15%, 30%, 45%, 60%, 75%, 90%, and 100%, respectively. At the same time, the weights of all other criteria were proportionally scaled to give a sum of 1 as follows:

$$w_j^* = (1 - w^{r*}) \frac{w_j}{(1 - w^r)} \tag{23}$$

where w^r is the weight of the criterion to be reduced before the reduction; w_j is the weight of any criterion j, except for a criterion whose weight is reduced; w^{r*} is the new criterion weight after reduction; and w_j^* is the new scaled weight value of any criterion j, except for a criterion whose weight is reduced. The remaining 14 scenarios were formed in the same way, by reducing the weights of the second and third most important criteria (C4 and C3, respectively) and scaling the remaining ones. The criteria weights obtained in this way in all 21 scenarios are shown in Table 10.

Table 10. Criteria weights in sensitivity analysis scenarios.

	C1	C2	C3	C4	C5	C6	C7	C8
Sc.1	0.082	0.109	0.164	0.255	0.234	0.055	0.065	0.036
Sc.2	0.086	0.115	0.173	0.268	0.193	0.058	0.069	0.038
Sc.3	0.091	0.121	0.181	0.282	0.151	0.06	0.073	0.04
Sc.4	0.095	0.127	0.19	0.296	0.11	0.063	0.076	0.042
Sc.5	0.1	0.133	0.199	0.31	0.069	0.066	0.08	0.044
Sc.6	0.104	0.139	0.208	0.323	0.028	0.069	0.083	0.046
Sc.7	0.107	0.143	0.214	0.333	0	0.071	0.086	0.048
Sc.8	0.081	0.108	0.162	0.205	0.289	0.054	0.065	0.036
Sc.9	0.085	0.113	0.17	0.169	0.302	0.057	0.068	0.038
Sc.10	0.089	0.118	0.177	0.133	0.315	0.059	0.071	0.039

Table 10. *Cont.*

	C1	C2	C3	C4	C5	C6	C7	C8
Sc.11	0.092	0.123	0.184	0.096	0.328	0.061	0.074	0.041
Sc.12	0.096	0.128	0.192	0.06	0.341	0.064	0.077	0.043
Sc.13	0.1	0.133	0.199	0.024	0.354	0.066	0.08	0.044
Sc.14	0.102	0.136	0.204	0	0.363	0.068	0.082	0.045
Sc.15	0.08	0.106	0.132	0.248	0.283	0.053	0.064	0.035
Sc.16	0.082	0.109	0.108	0.254	0.291	0.054	0.065	0.036
Sc.17	0.084	0.112	0.085	0.261	0.298	0.056	0.067	0.037
Sc.18	0.086	0.115	0.062	0.267	0.306	0.057	0.069	0.038
Sc.19	0.088	0.117	0.039	0.274	0.313	0.059	0.07	0.039
Sc.20	0.09	0.12	0.015	0.281	0.321	0.06	0.072	0.04
Sc.21	0.092	0.122	0	0.285	0.326	0.061	0.073	0.041

For the weights from each scenario, the MCDM model was applied, and the results obtained (final ranking of alternatives) are shown in Table 11. Additionally, a comparative view of the results is given in Figure 5.

Table 11. Ranking results obtained in the scenarios.

	BS1	BS2	BS3	BS4	BS5	BS6	BS7	BS8	BS9	SCC
Sc.0	5	7	1	9	6	3	2	4	8	/
Sc.1	5	7	1	9	6	3	2	4	8	1.000
Sc.2	5	7	1	9	6	3	2	4	8	1.000
Sc.3	5	6	1	9	7	2	3	4	8	0.967
Sc.4	5	6	1	9	7	2	3	4	8	0.967
Sc.5	5	6	1	9	7	3	2	4	8	0.983
Sc.6	5	7	1	9	6	3	2	4	8	1.000
Sc.7	5	7	1	9	6	3	2	4	8	1.000
Sc.8	5	7	1	9	6	3	2	4	8	1.000
Sc.9	5	7	1	9	6	3	2	4	8	1.000
Sc.10	5	6	1	9	7	3	2	4	8	0.983
Sc.11	5	6	1	9	7	3	2	4	8	0.983
Sc.12	5	6	1	9	7	3	2	4	8	0.983
Sc.13	5	7	1	9	6	3	2	4	8	1.000
Sc.14	5	7	1	9	6	3	2	4	8	1.000
Sc.15	5	7	1	9	6	3	2	4	8	1.000
Sc.16	5	7	1	9	6	3	2	4	8	1.000
Sc.17	5	7	1	9	6	3	2	4	8	1.000
Sc.18	5	7	1	9	6	3	2	4	8	1.000
Sc.19	5	7	1	9	6	4	2	3	8	0.983
Sc.20	5	7	1	9	6	4	2	3	8	0.983
Sc.21	5	7	1	9	6	4	2	3	8	0.983

Based on the results of the sensitivity analysis, it can be seen that in all scenarios, the ranking of BS3 (ranked first), BS1 (ranked fifth), BS9 (ranked eighth) and BS4 (ranked ninth) were unchanged. Other BSs slightly changed their rank throughout the scenarios. BS7 ranked second in all scenarios except in Sc.3 and Sc.4. BS6 ranked third in most scenarios. It changed rank to second in Sc.3 and Sc.4 and to fourth in Sc.19–21. BS8 ranked fourth in all but the last three scenarios. BS5 and BS2 alternately changed ranks between being sixth and seventh. In order to check how statistically significant the changes in the ranking of the alternatives in the scenarios were, SCC values were calculated for each scenario in comparison with the initial one (Table 11). In all scenarios, the values ranged between 0.967 and 1, and the average value for all scenarios was 0.991. These results proved that the obtained solution was very stable and could be adopted as the final one.

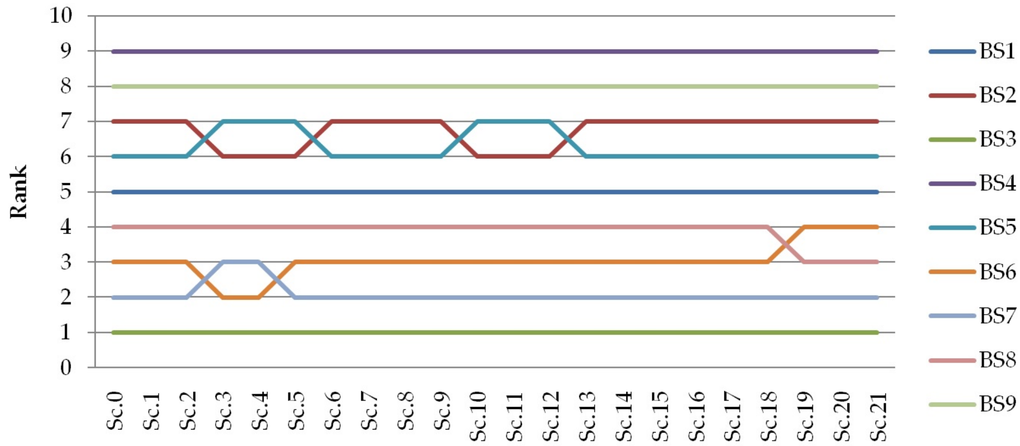

Figure 5. Sensitivity analysis.

5. Discussion

The significance of the developed method and model, the established framework, and the results obtained are discussed through their contributions, limitations and implications in the following.

5.1. Contributions

The main contribution of this study is the development of a novel ADAM MCDM method. The reason and motive for developing a new method and the establishment of a new group of geometric MCDM methods were the certain disadvantages of the existing MCDM methods. Every MCDM method has its own disadvantages, but the most important ones can be attributed to the whole group or may even be common for multiple groups.

Some potential disadvantages related to distance-based methods are the sensitivity to the choice of the distance function, difficulty in handling qualitative criteria, and inability to independently calculate the criteria weights [121]. The results of the analysis can be highly dependent on the specific distance function used. and different distance functions can lead to different rankings of alternatives. These methods are typically designed to handle quantitative criteria and may not be well-suited for dealing with qualitative criteria. They require direct input of criteria weights, usually calculated using some other types of MCDM methods.

The most prominent disadvantages of the pairwise methods are reliance on pairwise comparisons, bias in pairwise comparisons, limited ability to handle complex preferences, and limited ability to handle missing data [122]. These methods rely on pairwise comparisons, which can make it difficult to handle trade-offs between multiple criteria and may not fully capture the complex relationships between criteria. They can also be influenced by human bias in the pairwise comparisons that are used to rank alternatives. They require comparisons of all pairs of decision-making elements, which can significantly increase the overall dimensions of the problem and thus the required resources. Finally, the evaluation is based on information on the relationships between all pairs of decision-making elements; therefore, these methods may struggle to handle situations where data are missing or incomplete, which can lead to inaccurate or unreliable results.

Outranking multicriteria decision-making methods have several potential disadvantages, including the assumption that the criteria are independent as well as the complexity and limited ability to handle qualitative criteria [123]. The ranking obtained with these methods can be distorted if the criteria are dependent on each other. Outranking methods can be computationally complex, and they require a lot of data, which can be difficult to obtain. These methods are typically designed to handle quantitative criteria and may not be well-suited for dealing with qualitative criteria. Outranking methods also share some disadvantages with distance-based methods, such as difficulties in the interpretation of results and handling complex preferences [124]. They have difficulties in interpreting the overall score; therefore, it can be hard to understand what the resulting score means. Additionally, these methods may not be able to fully capture complex or nonlinear preferences, which can result in suboptimal solutions.

One of the main disadvantages of the scoring (additive) methods is also the assumption that the criteria are independent. In addition, there is one disadvantage that this group of methods shares with distance-based methods: they both have limited ability to handle trade-offs [125]. They do not always provide a clear way to handle trade-offs between different criteria, which can make it difficult to identify the overall best alternative.

The main advantages of the ADAM method in comparison with the aforementioned ones are that it is simple, easily understandable, user friendly, insensitive to the increase in the number of criteria, very intuitive, and has very low risk of rank reversal. The simplicity of the method is reflected in the use of simple calculations of the volumes of geometric bodies, i.e., polyhedra. Although these polyhedra are called complex, the calculation of their volume is actually very simple and requires a basic knowledge of geometry. Accordingly, the method is very simple to apply, and the calculation of final values for alternative ranking does not become more complex with an increase in the number of criteria. As the method is based on the volumes of geometric bodies that can be easily represented graphically, it is very easy to interpret the results and reach a conclusion about the final ranking of the alternatives. In most cases, this can be performed even visually, which makes the method very intuitive. The tests of the method proved that the obtained solutions are very stable and that changes in the criteria weights only insignificantly change the results, i.e., the risk of a change in the ranking of alternatives is very low.

Another contribution of the study is the establishment of a hybrid MCDM model that combines the ADAM method with the BWM method, thus creating a universal tool for making decisions in any field.

The other contributions of the study concern the problem considered. One of the contributions is the definition of a wide set of potentially applicable CE-based BMs in the agri-food sector. The other one is the establishment of the set of criteria and a framework for their evaluation. Lastly, an important contribution is the identification of the most promising BMs. Until now, there has been some research in the literature dealing with the definition of CE-based BMs (e.g., [59–61]) as well as their evaluation and selection (e.g., [71,72]). However, to the best of our knowledge, there are no studies in which multiple CE-based BMs have been developed, evaluated, and ranked in the agri-food sector.

5.2. Limitations

The limitations of the entire model are derived from the limitations of the methods that form it. The newly developed ADAM method has certain limitations: It requires the direct input of criteria weights. Therefore, when more complex interrelations are used between criteria, it cannot independently derive the weights. In these cases, it should be used in combination with some other methods. In our case, it is the BWM method that has some limitations as well. It heavily relies on expert opinions and subjective assessments, which may not always be reliable. Therefore, the BWM method can be subject to bias, as the decision maker's personal preferences and subjective views can influence the results. It is also not suitable for a large number of criteria as it becomes time-consuming and difficult for decision makers to make comparisons.

The limitations of the framework and the problem discussed in the study concern the defined business models and a set of criteria for their evaluation. It is certainly possible to identify or define some BMs that have not been considered. It is also possible to define some other criteria concerning the defined set of alternatives that would contribute to easier decision making. Another limitation is that the demands and goals of different stakeholders were not specifically considered in the decision-making process.

5.3. Implications

The basic theoretical implications of the work concern the expansion of the body of literature in the areas of MCDM theory, sustainability, and the agri-food sector. The new MCDM method, as well as the entire hybrid model, developed in this study can be used in research in any field. Of course, it would be necessary to implement certain adjustments and adaptations to the specific problem being solved in terms of criteria, interest groups, and rating scale. However, the nature of the method and the model is such that nothing restricts them from being used to solve any MCDM problem. The problem discussed in this paper can initiate new studies in which business models based on the circular economy are defined and analyzed as one of the current main trends supporting sustainable development. In addition, research in the agri-food sector could use the results of this study and build upon them to create some new business models or investigate the effects of applying the best ranked ones.

As for the practical (managerial) implications, the developed method and model could be used as a tool to help decision makers, managers, planners and designers, and strategy and policy makers at different levels when making decisions that include a large number of alternatives and criteria, in any field. The ADAM method, which enables the graphical presentation of solutions, is particularly suitable for managers due to the possibility of effectively presenting the results. The developed ADAM software also significantly facilitates the application of the method. The results obtained in this study point to the CE-based BMs to which managers should pay special attention in order to more easily make a decision on their adoption and application in their business, i.e., in companies in the agri-food sector. This is another significant practical implication that would result in improvements in business efficiency, sustainable growth of the company, company image, and positioning in the market.

6. Conclusions

There has been an expansion in the development of new MCDM methods in recent decades. These methods can be classified into four groups: scoring, distance-based, pairwise comparison, and outranking methods. Each group and its methods have both advantages and disadvantages. Therefore, a new MCDM method was developed in this study to overcome the shortcomings of existing methods, forming a group of its own. MCDM methods have gained popularity in various fields such as operations research, management science, engineering, and environmental studies. We applied the newly developed method in combination with another method to evaluate agri-food CE-based BMs. The ranking of BMs can reveal success factors and how companies can adapt and innovate in response to changing market conditions.

Based on the results, we concluded that the ADAM method is effective for solving MCDM problems and is more than competitive than other methods. We also concluded that an overall model is an effective tool for solving the problem defined in this study. As for the problem itself, we concluded that the sustainable circular agri-food supply chain is a BM that can bring companies the most significant progress in their business and strengthen their position on the market.

The study contributes to several research fields. The main contribution of the study to the field of operations research, and MCDM in particular, is the development of a new ADAM method and a hybrid model that combines it with the BWM method. The study contributes to the fields of management, agri-food, and sustainability by establishing sets of the most promising CE-based BMs in the agri-food sector, the criteria for their evaluations, and the framework for the identification of the most important ones. The results of this study can help managers in the agri-food sector to prioritize and adopt CE-based BM as a strategy that can improve business efficiency, sustainable growth, image, and market positioning. Adopting these models can also help professionals reduce waste, conserve resources, and mitigate the environmental impact of the agri-food sector.

Future research may deal with the further development of the ADAM method as well as the creation of new hybrid models that combine it with some other methods. The possibilities of extending the method to the environment of interval sets (fuzzy, gray, and rough) can also be explored. In future research, the method and model can be applied to solve other problems in the areas covered by this study and in other areas. Regarding the problem discussed in this study, future research can identify or define new CE-based BMs and consider additional criteria for their evaluation. An important direction of future research would be the inclusion of interest groups in the decision-making process and the identification of the most favorable solutions for each of them as well as a compromise solution.

Supplementary Materials: ADAM software can be downloaded at: http://adam-mcdm.com/, accessed on 6 February 2023.

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