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ARTICLES

A CIRCULAR FOOD ECONOMY MULTICRITERIA DECISION PROBLEM BASED ON THE FITRADEOFF METHOD

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ABSTRACT. The Circular Food Economy is a recent concept referred to co-creative food ecosystems where stakeholders from different echelons work together to improve the chain by using circular economy solutions for managing food loss and waste while increasing stakeholders' income and reducing the environmental affectation. There is a lack of quantitative information on what should be prioritized when designing circular options considering the actors' preferences. This study presents an application of the FITradeoff method within the Agri-Food Supply Chain in a multicriteria decision problem of ranking circular economy initiatives using six criteria (CO_2 generation, blue-water usage, land usage efficiency, social impact, income, and implementation) and nine hypothetical alternatives artificially created from available data. It explores information regarding preferable alternatives for householders. The results are considered a quantitative starting point for collecting consumers' preferences as a basis for further research to refine such circular initiatives into more beneficial and attractive ones.

Keywords: circular food economy, FITradeoff, agri-food supply chain, multicriteria decision.

1 INTRODUCTION

The Agri-Food Supply Chain (AFSC) (that is, farming, handling, food processing, distribution, and consumption) has unique characteristics and environmental issues related to the specificity of products (e.g., perishability), which demand conditions that, in contrast with other supply chains, the system is unable or hesitant to provide (Ciulli et al., 2020). The traditional market model of the food system is based on a linear supply that takes nonrenewable resources, produces

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recognized flaws, and disposes of food and non-edible products without taking advantage of their potential for reuse or recycling. This has generated economic growth, however, at the expense of a high food loss value (Jaroensathapornkul, 2021), increased waste, and negative environmental and social impacts around the world. Especially, food loss and waste (FLW) represent 1/3 of the global food production, generating about 3.6 gigatons equivalent of CO_2 (Food and Agriculture Organization of the United Nations, 2019).

Especially, under the current traditional linear supply system (that is, taking, making, and disposing of resources to supply food) the AFSC is wasteful and pollutes the environment. Annual FLW reaches 1/3 of the world's production, equaling to 1.4 billion tons, €16.000 million lost, and 15.3 million CO_2 equivalent tons generated (Ellen MacArthur Foundation, 2015). Moreover, decisions are made from both subjective and empirical viewpoints. This implies that the sustainability of the system is limited by the weak interaction between stakeholders (Food and Agriculture Organization of the United Nations, 2019) to make the chain smart, innovative, and sustainable.

In this context, this study uses the concept of Circular Food Economy (CFE) proposed by (Rico Lugo et al., 2022), understood as a co-creative food ecosystem where stakeholders from different echelons work together to improve the chain by implementing circular economy alternatives.

Achieving the objectives related to the FLW problem through the elements of the CFE depends on the commitment of the involved stakeholders and the understanding of their vision about the benefits of the solutions that can arise from FLW prevention actions. These benefits affect different goals that cannot be measured by a single metric; however, they must be integrated into a single assessment to compare actions. These characteristics are aligned with the definition of multicriteria decision problems proposed by Belton and Stewart (2002). Thus, the use of multicriteria decision analysis (MCDA) can help achieve a better understanding of stakeholder preferences and support their decision making on how to position themselves when facing the FLW problem.

Considering these aspects, the FITradeoff method for ranking (Frej et al., 2019), based on the FITradeoff method proposed by de Almeida et al. (2016), was selected to perform stakeholder preference analysis owing to its flexible elicitation process that allows the use of incomplete preferential information to provide a complete recommendation or incomplete but satisfactory, through a user-friendly, web-based decision support system (DSS) (available in http://www.fitradeoff.org). The method can better exploit statements provided by stakeholders through a process that requires less cognitive effort and is suitable for situations where the decision maker (DM) may not be able to provide accurate information owing to a limited understanding of the problem's specificity or limited availability of information. This feature is relevant for analyzing preferential information from AFSC stakeholders who have different levels of understanding and time availability. The user-friendly web-based DSS helps analysts interact with stakeholders, even when they are not at the same location, and the ranking version is suitable for prioritizing actions.

To provide a basis for future studies oriented to manage such challenges, this study aims to present an application of the FITradeoff method within the AFSC in a multicriteria decision problem related to the preference of stakeholders to join CFE alternatives. This study uses currently available information on the value function behavior of six criteria (CO_2 generation, blue water usage, land used in crops, social impact, financial benefit, and implementation factors) to generate a dataset on the consequences of nine hypothetical CFE alternatives. These values are presented to three householders, as representatives of the AFSC decision-maker echelon, to elicit their preferences about whether to join circular economy solutions and alternatives in their supply processes and obtain the rank of the most preferred CFE options.

This study seeks to obtain information about the CFE alternatives preferable from the perspective of consumers. Although comparisons between the ranks of alternatives obtained from decision makers are analyzed, this study does not intend to generalize knowledge. Instead, the results are considered a quantitative starting point of the tendency of consumers' preferences, which can be used as a basis for further research to refine CFE alternatives into more attractive options, for example, policymaking or R& D investment, and to develop more applications of the FITradeof method, including the use of empirical data and inclusion of stakeholders from other echelons.

The remainder of this paper is structured as follows. The theoretical bases of the FITradeoff method are explained in Section 2, and its application to current customers is described in Section 3. Section 4 presents a deeper discussion about the results of the application. Finally, the conclusions are presented in Section 5.

2 CIRCULAR FOOD ECONOMY

Specifically, CFE searches to prevent FLW, enhance food security, conserve biodiversity, and manage perishability by reusing, recycling, recovering, and reprocessing edible food and inedible parts into circular alternatives. It also seeks economic welfare in all echelons of the AFSC while maintaining environmental care (Rico Lugo et al., 2022). Figure 1 illustrates this definition.

The circular economy has presented advances in non-perishable products, while the agri-food system remains studied from isolated fields by mainly conceptual research. Some circular techniques have been studied in AFSC, usually from a qualitative viewpoint but the complexity of this sector and the limited availability of preferences information in accordance with variations in costs, revenues, and benefits of managing FLW have restricted the implementation of circular initiatives (Derqui et al., 2016) . Therefore, considering the preferences of stakeholders to join such initiatives is relevant when thinking about co-creativeness within the AFSC.

In this sense, CFE, as a co-creative and innovative food ecosystem, is a key to enhancing the sustainability of nations in all its components: economic, social, and environmental. It is also important to consider that increasing the circularity in the agri-food context is directly aligned with the Sustainable Development Goals, especially SDG 12 Sustainable consumption and production (particularly in Target 12.3 Food loss and waste reduction), SDG 6 Water, and sanitation, SDG 8 Decent Work and Economic Growth, and SDG 13 Climate action. The support of CFE in

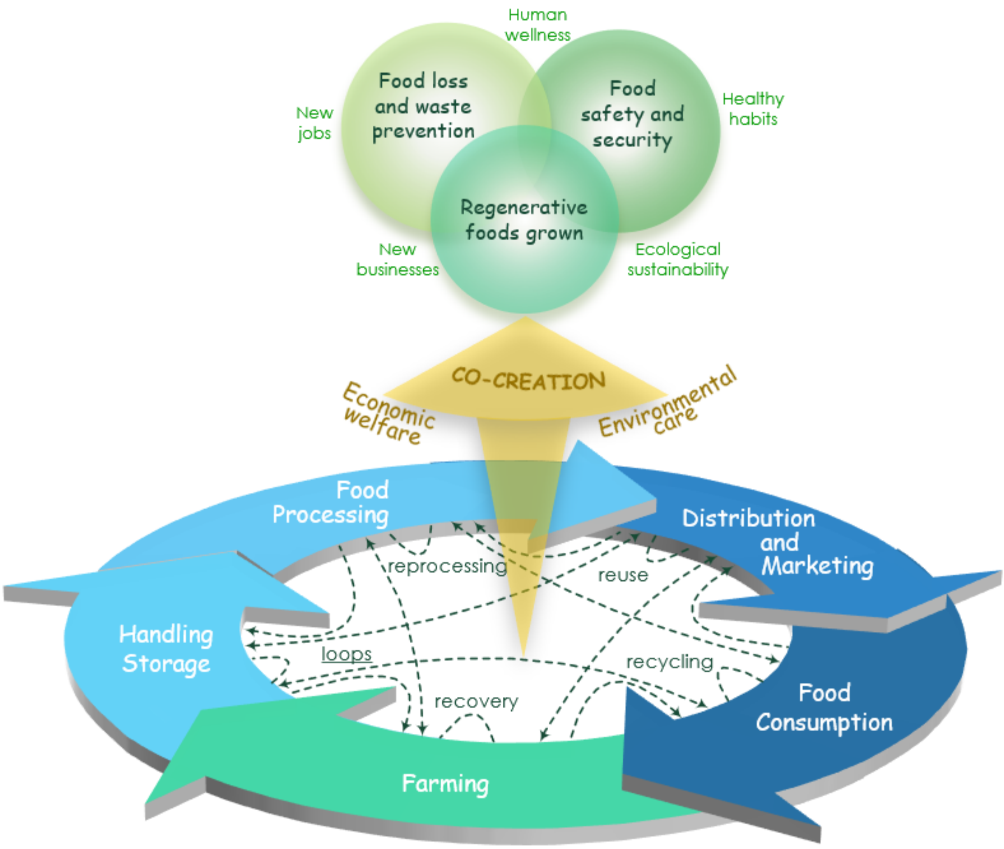


Figure 1 – Circular Food Economy (Rico Lugo et al., 2022).

reaching those SDGs is mainly based on the reduction in FLW generation and on the generation of new markets from the reuse of such wasted and lost food products.

Some previous studies have analyzed the selection of circular economy options in some echelons of the AFSC as a multicriteria decision problem. For instance, in terms of quantitative studies, a multi-objective mixed-integer linear model for sustainable fruit closed-loop supply chain network was studied by Jabarzadeh et al. (2020). A multiobjective sustainable hub location-scheduling decision problem for perishable AFSC was treated by Musavi and Bozorgi-Amiri (2017). Also, Khosroshahi et al., (2019) presented a game-theoretic approach for pricing decisions considering corporate social responsibility and a consumer satisfaction index using transparency-dependent demand. From the qualitative perspective, the characteristics and concepts associated with stakeholders' behavior and thoughts when considering circularity into the AFSC have been analyzed. Examples of that can be found in (Dhaoui et al., 2020; Donner et al., 2021; Trivellas et al., 2020).

However, such studies lack actual elicitation of the preferences of the stakeholders about CFE alternatives and usually are constructed based on simulation of preferences or similar assumptions. It means without interacting with current decision makers, especially householders, to quantitatively discover their preferred circular alternatives as a necessary starting point to apply decision methods. In contrast, this study deals with such issue by focusing on the application of the FITradeoff method to elicit preferences of AFSC real customers and assess CFE options.

3 FITRADEOFF METHODS

The FITradeoff method, proposed by de Almeida et al. (2016) addresses the problem of eliciting weights in decisions in which the additive model can be applied. One of the advantages of this method lies in its robust axiomatic basis derived from the tradeoff procedure for the additive model (Keeney et al., 1993).

The additive model considers a value function derived from the Multi-attribute Value Theory (MAVT) (Keeney et al., 1993), which obtains the value of alternatives through a weighted sum of intra-criteria values and weights, according to Equation 1.

$$v(a) = \sum_{j=1}^{n} w_j v_j(a_j)(1)$$

Where $v(a)$ is the value of alternative a, w_j is the weight of criterion j and $v_j(a_j)$ is the intra-criteria value of the performance of alternative a in criterion j.

It is important to note that in the additive model, preferential information not only considers the relative importance of the criteria but also scale information, which represents a tradeoff rate that the decision maker considers indifferent among the criteria. Although the most appropriate term for this parameter is the scale constant, for linguistic simplification, we will use the term weights, however, with the meaning of scale constants.

Another advantage of the FITradeoff method is the flexible and interactive process of elicitation, through its decision support system (DSS), which allows the decision maker to answer questions in which information based on strict preference relationships is sufficient to feed the decision model, as opposed to the tradeoff procedure, which requires statements of indifference that are more prone to inconsistency errors owing to the cognitive difficulty the decision maker faces in providing this information. Additionally, the decision maker is not required to answer a question if he/she has difficulty, and the method elaborates on another question that can be answered more easily.

Another important aspect is the reduced number of questions required to solve the problem, as the rank of the criteria is sufficient in some cases. According to de Almeida et al. (2016), the FITradeoff method does not require complete information because it performs an analysis on the weight subspace (Φ) delimited by the constraints generated by the information obtained, according to Equation 2, to verify if there is a convergence toward a well-defined recommendation.

$$\Phi = \left\{ \begin{array}{c} w_1, w_2, \ldots, w_j, \ldots, w_n \vee \sum_{j=1}^{n} w_j = 1; w_j \geq 0 \\ w_j v_j \left(x_j''\right) < w_{j+1} < w_j v_j \left(x_j'\right), j = 1, 2, \ldots, n-1 \end{array} \right\} \quad (2)$$

Where $v_j\left(x_j''\right)$ and $v_j\left(x_j'\right)$ are the intra-criteria performance values obtained from the elicitation process with the decision maker.

The FITradeoff method was initially developed to address the problem of choice, and other versions of the method were later proposed to address different decision problems. According to de Almeida et al. (2016), the FITradeoff for choice analyzes, in each interaction with the decision maker, whether all combinations of weights contained in Φ make the value of the same alternative the highest among all the set of alternatives in the problem. If this occurs, a recommendation is defined and provided to the decision maker. If different alternatives can have the highest value within the set of alternatives of the problem for different combinations of weights in Φ, the model elaborates an additional question to obtain more information in a new interaction with the decision maker, updating the constraints of the problem and reducing Φ.

Frej et al. (2019) proposed the FITradeoff method in a version suitable for ranking problems. In this version, the method searches for a weight subspace for which there is a strict preference or equivalence relationship defined for all pairs of alternatives in the problem set, for any combination of weights contained in Φ.

The FITradeoff method for sorting problems presented by Kang et al. (2020) divides the range of the value function of the additive model (0.1) into intervals that represent categories separated by boundaries. For each interaction with the decision maker, the method calculates the highest and lowest values that each alternative can reach through the combinations of weights in Φ. If for each alternative its maximum value is in the same category as its minimum value, the method ends with a recommendation of the found sorting. If there is an alternative whose highest value is in a different category than its lowest value, the model asks the decision-maker another question to try to reduce Φ.

Frej et al. (2021) presented a version of FITradeoff that incorporates a cost-benefit analysis to address portfolio problems. This method uses a procedure to identify the best alternatives to compose the portfolio through incomplete preferential information, considering the ratio between the value that the alternatives can obtain with the weights in Φ and their consumption in the constraint cost function of the problem. All FITrade-off methods can be applied via DSS and are available at http://www.fitradeoff.org.

Mendes et al. (2020) presented an analysis of the performance of the FITradeoff method for choice, developed through simulated cases, considering different scenarios, such as weight distributions, number of criteria, and number of alternatives. According to the authors, only with the rank of the criteria, the FITradeoff method for the choice problem manages to obtain a unique solution in 5% of cases, and in 97% substantially eliminates the number of alternatives in the problem because they are defined by the method as dominated. Considering the cases in which information beyond the rank of the criteria is necessary, in most cases, the method manages to obtain a unique solution with up to three (n-1) questions to the decision maker after ranking the criteria.

To make the FITradeoff method more efficient, de Almeida et al. (2021) incorporated a holistic evaluation procedure for choice and rank versions into the FITradeoff method. Holistic evaluation does not necessarily eliminate the original evaluation procedures of FITradeoff, which act by decomposition, however, it allows the decision maker to provide additional information by comparing the real alternatives of the problem. For example, it can eliminate an alternative in the problem of choice or establish a preference relationship between a pair of alternatives for the ranking problem. This combined procedure tends to speed up the elicitation, as the holistic assessment acts directly on several criteria simultaneously, in addition to reducing the set of solutions.

Some studies related to FITradeoff are dedicated to the exploration of neuroscience to assess cognitive aspects and find ways to improve the DSSs that incorporate this method. Roselli et al. (2019) presented a neuroscience study applied to FITradeoff to find ways to improve the graphical visualization of the DSS using eye-tracking equipment in undergraduate and graduate students.

Roselli et al. (2020) presented an analysis of 52 production engineering students, using electroencephalogram equipment combined with eye-tracking, to identify behavioral aspects and cognitive difficulties that could lead them to provide inconsistent statements when using the FITradeoff DSS.

Da Silva et al. (2021) used an electroencephalogram and eye-tracking equipment to analyze the steps of the DSS FITradeoff and the types of problems that are more difficult for the decision maker, considering aspects such as cognitive effort, response time, and pupil dilatation. The results revealed that problems that combine qualitative and quantitative criteria tend to be more challenging, and that the first and third stages of the model are the ones that the decision maker has the most difficulty, which allows the analyst to identify the moments when providing support to decision makers is more critical and expands the possibilities for DSS improvements.

Roselli and de Almeida (2021) evaluated through neuroscience experiments, the use of holistic assessment incorporated into the DSS FITradeoff to identify success-based decision rules so that analysts can identify opportunities to successfully use the procedure and explore options to improve visualization of the DSS.

Several studies have investigated the applications of FITradeoff methods in various areas such as IT/IS (Henriques de Gusmao and Pereira Medeiros, 2016), energy (Kang et al., 2018), infrastructure (Martins et al., 2020), health (Camilo et al., 2020), industry, (de Morais Correia et al., 2021) and water resources (Monte and Morais, 2019).

3.1 FITradeoff for ranking

The FITradeoff method for ranking proposed by (Frej et al., 2019) aims to find a pre-order of alternatives through the interactive and flexible elicitation procedure proposed by de Almeida et al. (2016). Thus, the method performs pairwise comparisons between the alternatives of the problem to identify whether, with the partial information obtained, it is possible to establish a preference relationship.

The steps of the FITradeoff DSS for ranking, originally proposed by Frej et al. (2019) are presented in Figure 2.

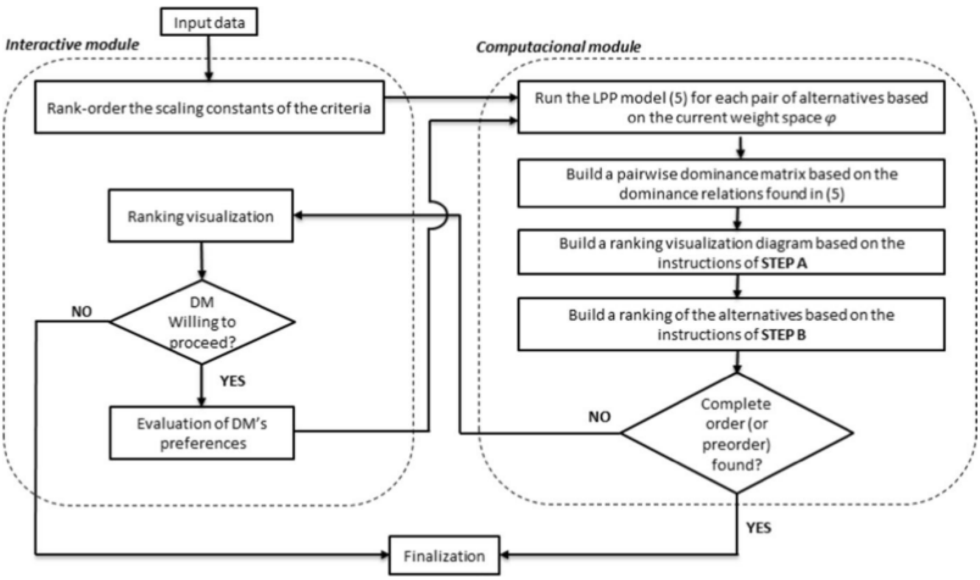


Figure 2 – DSS FITradeoff para ranking (Frej et al., 2019).

Let $a_i, a_k \in A$ be alternatives of the decision problem, such that $i \neq k$. FITradeoff for ranking aims to identify whether there is a preference relationship for each pair of alternatives (a_i, a_k) through linear programming problems (LPP) represented by equations 3 to 7, according to Frej et al. (2019).

$$MaxD(a_i, a_k) = \sum_{j=1}^{n} w_j v_j(a_{ij}) - \sum_{j=1}^{n} w_j v_j(a_{kj}) \, (3)$$

$$s.t. w_j v_j\left(x_j^{''}\right) < w_{j+1} j = 1, 2, \ldots, n-1 \, (4)$$

$$w_j v_j\left(x_j^{'}\right) > w_{j+1} j = 1, 2, \ldots, n-1 \, (5)$$

$$\sum_{j=1}^{n} w_j = 1 \, (6)$$

$$w_j \geq 0 j = 1, 2, \ldots, n-1 (7)$$

Equation 3 represents the objective function of the LPP that maximizes the difference between the value of a_i and that of a_k, calculated according to Equation 1. Equations 4 and 5 represent the constraints of the weight space (Φ) obtained through DSS interaction with the decision maker in the flexible elicitation procedure through decomposition. Equation 6 normalizes the weights, and the nonnegativity of the weights is guaranteed using Equation 7.

Let D^*_{ik} be the optimal solution of the LPP and ε an equivalence threshold that represents a possible difference in value that is considered irrelevant.

If $D^*_{ik} < 0$, then a_kPa_i(a_k is preferable to a_i, since there is no combination of weights on Φ such that $v(a_i) \geq v(a_k)$.

If $D^*_{ik} < \varepsilon$ and $D^*_{ki} < \varepsilon$, then a_iIa_k (a_i and a_k are indifferent), since there is no combination of weights on Φ that makes one of the alternatives have a relevant advantage over the other.

If $D^*_{ik} > \varepsilon$ and $D^*_{ki} > \varepsilon$, then a_i and a_k are not defined with the level of information that defines the weight subspace Φ, since each of the two alternatives can take a relevant advantage over the other for at least one combination of weights in Φ.

It is relevant to emphasize that the MAVT axioms, including those from the tradeoff procedure, do not allow incomparability relations. For FITradeoff, it is considered that the structure of the decision maker's preferences and axioms of the method remain the same as in the tradeoff procedure. That is, the decision maker has well-defined weights for which all alternatives can be evaluated and ordered only through relations of strict preference or indifference. In this way, the not defined relations do not derive from the structure of the decision maker's preferences nor from the MAVT axioms, but from the absence of sufficient information about the weights to define the relations more clearly because the decision maker does not want or cannot give more precise information.

Similarly, FITradeoff assumes that the decision maker's weights get a complete pre-order. The absence of complete preferential information, however, leads to undefined relations and, consequently, to undefined positions in the ranking, which generates a partial pre-order, not due to incomparability relationships, but due to the different complete pre-orders that can be obtained for different viable weight vectors.

Initially, the FITradeoff method obtains the problem data through the DSS, which proceeds with the steps of intra-criteria evaluation and ranking of weights. Once the weights have been ranked, FITradeoff will find the optimal solution of the LPP represented by equations 3-7, for each pair of alternatives (a_i, a_k) considering initially $v_j\left(x''_j\right) = 0$ and $v_j\left(x'_j\right) = 1$, for all $j = 1, 2, \ldots, n-1$.

If there are at least two alternatives with no defined relation to the available information, the DSS offers the decision maker partial information obtained so far and gives the options to continue the elicitation process and provide more information to the model or end the process with partial information. If the decision maker opts to continue the elicitation process, the DSS requests more information to reduce the viable weight subspace and retest the pairwise relationships of the alternatives through the LPP with the updated constraints.

In the FITradeoff version proposed by Frej et al. (2019), the elicitation process continues through a decomposition procedure, where the decision maker can select from two fictitious consequences, whose values calculated by Equation 1 are equivalent to w_{j+1} and $w_j v_j\left(x_j^{-}\right)$, where $w_j v_j\left(x_j^{'}\right) > w_j v_j\left(x_j^{-}\right) > w_j v_j\left(x_j^{''}\right)$. The decomposition procedure seeks to obtain more information by exploring the relationship between the adjacent criteria. An exception is made to the first question of the decomposition procedure, which explores the relationship between the first and last criteria to obtain information about the distribution of weights.

De Almeida et al. (2021) incorporated the holistic assessment procedure into FITradeoff to offer the decision maker a new way of providing information that can accelerate the elicitation process. Thus, after ordering the weights, the decision maker can select whether to provide information through the decomposition procedure or whether to carry out a holistic assessment. The holistic evaluation procedure comprises establishing a direct preference relationship of the decision maker between two alternatives that are considered incomparable with the partial information provided so far. At each holistic assessment, where the decision maker establishes a relation $a_k P a_i$, a new constraint is added to the LPP, according to Equation 8.

$$\sum_{j=1}^{n} w_j v_j\left(a_{kj}\right) > \sum_{j=1}^{n} w_j v_j\left(a_{ij}\right) \quad (8)$$

One of the advantages of holistic evaluation is that in addition to directly defining the preference relationship between a pair of alternatives, it also reduces the weight subspace by eliminating all combinations of weights that violate the constraint imposed by Equation 8, which can help define other preference relationships that have not yet been identified.

At each interaction, DSS FITradeoff provides information about the preference relations defined thus far and the partial ranking obtained, giving the decision maker the option of continuing the procedure and providing more information or ending with incomplete information. The DSS ends the procedure when complete information is obtained, that is, a complete pre-order, or when the decision maker declares that he is satisfied with the partial pre-order information.

4 APPLICATION

4.1 Decision problem description

The circular economy has been recognized by citizens and other stakeholders as an innovative way to satisfy consumer needs by providing sustainable products and services. Therefore, several circular alternatives have been implemented in most markets. However, within the AFSC, such an implementation faces various obstacles. First, there is a lack of information about the CFE options that are more attractive for actors because, for instance, everyone has their own preference across different criteria and factors. Thus, more research is required to elicit such preferences using quantitative methods.

Especially, consumers do not have a clear understanding of the meaning of a circular economy or how they can benefit from one circular option or another. Although there are studies that analyze their tendencies in acquiring sustainable food products, most of them used qualitative approaches without evaluating what is more interesting for the final decision maker considering different criteria.

Therefore, by providing quantitative data about the consequences of CFE alternatives which certain customers may or may not join clarification about preferences can be obtained. To achieve this, considering FLW in Japan was around 5.7 million tons in 2018 (most recent data), of which 46% was generated in households (Consumer Affairs Agency, 2021), this study was conducted within the context of Japanese consumers presenting hypothetical CFE alternatives and their consequences (potential benefits) across the most treated criteria published in literature. Sets of questions were presented to each decision maker using the FITradeoff for Ranking Decision Support System (available at http://cdsid.org.br/fitradeoff/) to obtain initial information about the order of CFE alternatives that they preferred. Thus, this is a multicriteria decision ranking problem (see Section Circular Food Economy). Throughout the experiment for preference elicitation, one of the authors as decision analyst accompanied each householder. The model was built through an adaptation of the framework presented by de Almeida (2013) and described in Figure 3.

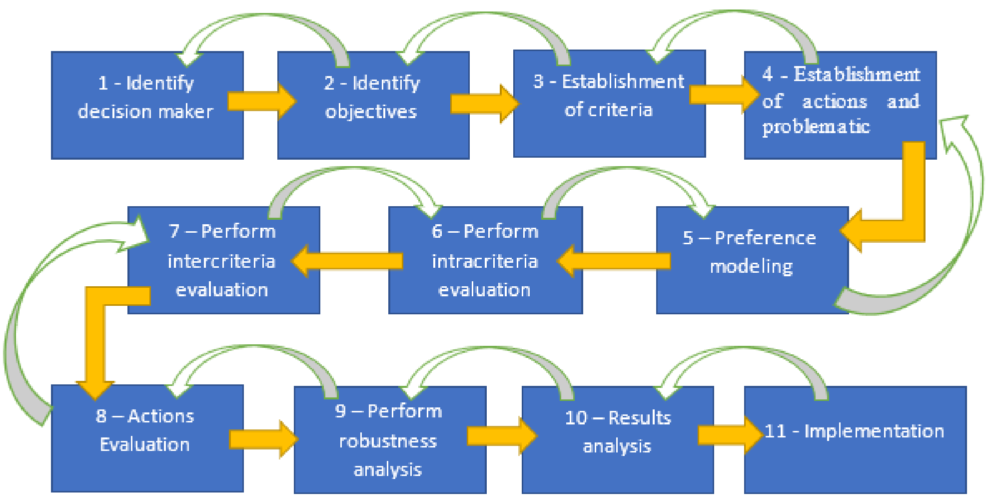


Figure 3 – Framework of the application model, adapted from de Almeida (2013).

In the first step, the decision maker is identified within the context that is analyzed, corresponding to who has the power to implement choices and allocate resources, and whose preferences should be analyzed. Considering the objectives of this study, we define final consumers as decision-makers, since they have a strong impact on the behavior of other actors in the CFE. Therefore, the preferences of three householders are analyzed regarding objectives related to the treatment of problems associated with FLW and how each one prioritizes different initiatives. It is important to emphasize that this study seeks to analyze each individual separately and not treat the problem as a group decision, which may be the scope of future studies.

The second step seeks to identify the objectives to be achieved with the decision. These objectives may not be easily evaluated and may be related to long-term and strategic goals. Lower objectives can be defined as means of achieving higher or strategic objectives for the problem. The third stage, in contrast, aims to establish metrics through criteria for evaluating the impacts of actions on objectives.

A key step in a multicriteria decision problem is to define the objectives and related criteria because they influence the subsequent steps to elicit stakeholder preferences. Based on the literature review, the expertise of the authors, and the AFSC experts' consultations, the objectives identified are illustrated in Figure 4. The arrow in each block on the right of the figure represents the direction of the objective of each criterion (i.e., maximize or minimize). Under the premise that customers desire to contribute to reduce FLW, the decrease in the environmental impact of the AFSC activities, increment of social benefits to stakeholders across the chain, and increase in the implementation of CFE alternatives are explored.

Subsequently, the environmental side was divided into the increment in the possibility of reducing CO_2 emissions, blue water waste, inefficient use of land for food growth, and FLW disposal. The social benefit for AFSC stakeholders was translated into an increment of contribution to improve the Multidimensional Poverty (MPI) index and increase the income of actors across the chain. Finally, the ease of implementation of CFE alternatives into the chain, considering that there are barriers such as low level of IT usage and interaction between stakeholders, contributes to making a smarter chain.

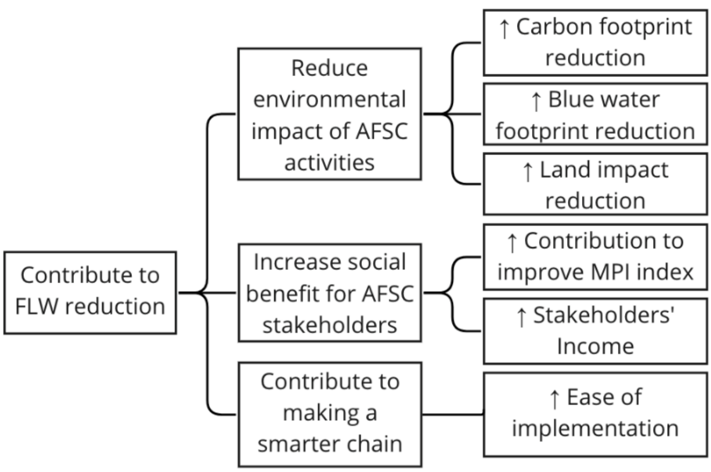


Figure 4 – Objectives and criteria identification.

Each criterion is an evaluation factor of the consequences and affects the stakeholders' final decisions. Specifically, CO_2, H_2O, and land impacts are three general factors that are directly caused by food waste and loss. According to the data provided by the Food and Agriculture Organization of the United Nations (Food and Agriculture Organization of the United Nations, 2019), 1 ton of food lost can cause 2.5 tons of CO_2, 157.9 m^3 of blue water, and pollute 3.1

hectares of land in eastern and south-eastern Asia. We assume that each alternative can alleviate the CO_2, blue water, and land impacts to some extent. Specifically, the criterion CO_2 impact refers to the reduction in carbon dioxide[FF0C?]H_2O impact indicates the amount of blue water that can be improved, and land impact represents hectares of land that can be saved from burying food garbage. The MPI impact shows the decreased number or rate of deprived people in a certain country. The income impact determines the monetary amount that can be saved by recycling or reusing the FLW. The last criterion implies the ease of implementing CFE alternatives.

Step 4 consists of delimiting the space of actions to be studied and defining the decision problematic. The actions considered in this study were simulated in order to obtain different profiles of contributions in relation to the objectives so that it was possible to analyze how the householders would position themselves in relation to the actions and consequently accept lower levels of performance in some criteria to achieve better performances in other criteria. The procedure for generating the alternatives and the parameters used are described in sections 4.2 and 4.3. Regarding the decision problem, it is considered that ranking is better suited to the objectives of this study since it allows analyzing the position of each action in the ranking. It allows a better understanding of the established preference relations and, subsequently, how the decision maker prioritizes each profile of action.

Step 5 seeks to understand aspects related to the preference structure that will be used as a basis for evaluating the available options for the decision. The importance of this step lies in the information modeling that will define which preference relationships will be admitted, in addition to choosing the most appropriate decision support method. Thus, a structure that allows the relations of strict preference (P) and indifference (I) was considered. It was also considered compensatory rationality of decision makers. As consumers may have little knowledge of decision support methods and specialized issues in CFE and FLW, an approach that allows obtaining preference relationships and ranking without the need to provide complete preferential information was chosen. In this way, the FITradeoff method for ranking was selected since its flexible structure allows reaching a ranking with incomplete information and analyzing which statements the decision maker feels more apt to provide, making the procedure cognitively easier.

Steps 6 performs the intracriteria evaluation. For simplicity, we assume that the value functions of these criteria are linear and positively affect decision makers' choices by a compensatory rationality. In the FITradeoff algorithm, this assumption implies that the value of the consequence for decision makers changes linearly as the value of the criterion changes. When the value of the criterion increases, the value of the consequence also increases, meaning that decision makers are more likely to choose this consequence. However, the value attributes differ for each criterion: we assume that the CO_2, H_2O, land, and income impacts are continuous, as they are represented by units. The MPI and implementation impacts are assumed to be discrete, as they are measured by Likert scales, implying the degree of the effect.

Since it was planned to select householders in Japan to conduct the FITradeoff experiment, the effect of each criterion caused by a one-year FLW in Japan was calculated. According to the Customer Affairs Agency, Government of Japan (Consumer Affairs Agency, 2021), the one-year

FLW in Japan was six million tons in 2018. Using the impact index of eastern and southeastern Asia provided by the United Nations, we discovered that Japan generates 15 million tons of CO_2, 947.4 million cubic meters of blue water, and wastes 18.6 million hectares of land. It is assumed that alternatives may reduce the pollution for each criterion to a certain degree.

Therefore, the possible ranges of alternatives to achieve in one year in terms of CO_2, H_2O, and land impacts are from 0.1 million tons to 1 million tons, 10 million m^3 to 100 million m^3, and 0.1 million hectares to 1 million hectares, respectively. However, the income impact is difficult to calculate because it includes many parts, and this research assumes that the range for income impact is from 10 million dollars to 100 million dollars a year. For MPI and implementation impacts, Likert scales were set from one to five.

The next steps of the framework will be presented in an integrated way with the application of the FITradeoff method for ranking in Sections 4.4 and 5.

4.2 Alternatives

An alternative represents a circular food economy that can reuse wasted and lost food to generate a new food supply chain process and products. Each alternative provides a possible solution for reducing FLW. It means that alternatives are hypothetical because they do not directly correspond to an actual developed CFE solution already available in the market. Alternatives and their consequences values were artificially created considering the current Japanese data related to FLW. Especially, an alternative is evaluated from four aspects: environmental, social, financial, and implementation. Each aspect included a different criterion. For instance, the environmental aspect covers carbon, blue water, and land impacts. The social aspect includes MPI and income impacts. The implementation aspect only covers the impact of implementation in this case. We assume that each alternative can solve FLW to different degrees corresponding to different criteria; stakeholders such as householders rank alternatives based on their preferences toward contributions of the alternative and specific problems solved by the alternative.

Nine alternatives were provided in the experiment to determine how each player ranked them. They are labeled from A1 to A9, and each alternative derives certain achievement for each criterion. Specifically, alternatives A1 to A6 provide the most desirable results in terms of carbon, blue water, land, MPI, income, and implementation impacts, respectively. A7 provides a better result for the combination of carbon and MPI impacts. A8 can achieve a better result for a combination of blue water and income impacts. Similarly, a better result can be acquired by A9, which is a combination of land and implementation impacts. The experiment using the FITradeoff algorithm helps to define the stakeholders' preferences to implement correct policies to reduce FLW.

4.3 Generation for Consequence Space

After defining the criteria and alternatives, the consequence matrix is generated, as described in this subsection. This figure illustrates the specific results that can be achieved by each alternative.

Table 1 – Consequence matrix.

Criteria	Alternatives								
	A1	A2	A3	A4	A5	A6	A7	A8	A9
Carbon	1.00	0.34	0.27	0.28	0.04	0.25	0.80	0.19	0.07
Blue Water	26.63	100	24.62	26.21	29.12	32.25	37.46	80.00	26.68
Land	0.22	0.27	1.00	0.16	0.17	0.24	0.06	0.22	0.80
MPI	3	1	1	5	2	3	4	2	2
Income	3.60	1.78	2.73	3.67	10.00	2.19	4.49	8.00	2.53
Implementation	1	1	1	3	4	5	2	3	4

For instance, alternative A1 generates 1 million tons reduction of CO_2 as it is assumed that it gives the most desirable results of carbon impact. The carbon and income impacts are set of A7 to 0.8 million tons and 8 million dollars, respectively, since this generates better results of a combination of carbon and income impacts.

It is supposed that 0.8 million tons and 8 million dollars are relatively high numbers in their ranges. The consequence indexes of carbon impact for other alternatives were randomly taken from a normal distribution *N(0.2, 0.1)*. Moreover, the normal distributions of insignificant consequences for other criteria were set as follows: blue water *N(30, 10)*; land *N(0.2, 0.1)*; MPI *(2, 1)*; Income *N(3, 1.5)*; Implementation *N(2, 1)*. Table 1 lists the results of the consequence matrix.

4.4 Application Using FITradeoff Method

This subsection introduces the process of the experiment, which is essentially separated into two parts: the first part defines the preference of decision makers for each criterion, and the second part derives the weights that affect the decision maker's valuations of consequences for each criterion. Three decision makers participated in the experiment, and their identities were not disclosed for personal data protection policies. All are Japanese householders who are currently engaged in the AFSC as consumers of food products and services. Before starting the application, the AFSC and CFE characteristics, decision problem context, and their roles within the experiment were explained in detail.

For the intra-criteria evaluation and the ranking of weights (see Section FITradeoff for ranking), in the first part of the experiment, decision makers compare two consequences based on their preferences and the effect of each criterion corresponding to each consequence. Figure 5 demonstrates the screen displayed to decision makers, which is mainly divided into three sections: consequence, preference, and operation. The consequence section demonstrates the two consequences each time. Each consequence displays the effect of each criterion, and the length demonstrates the degree of the effect; the longer the length, the better the result. Decision makers only compare consequences with a simple criterion in this section. After making the decision, the decision makers select a preferable consequence in the operation section. Based on their decisions, the rank of the criterion is simultaneously revealed in the preference section.

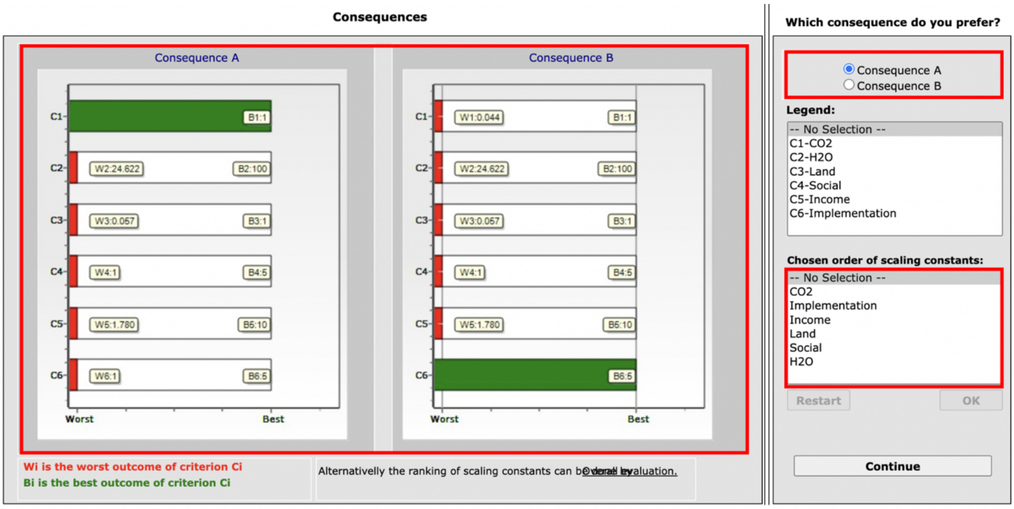


Figure 5 – Experimental process for part 1.

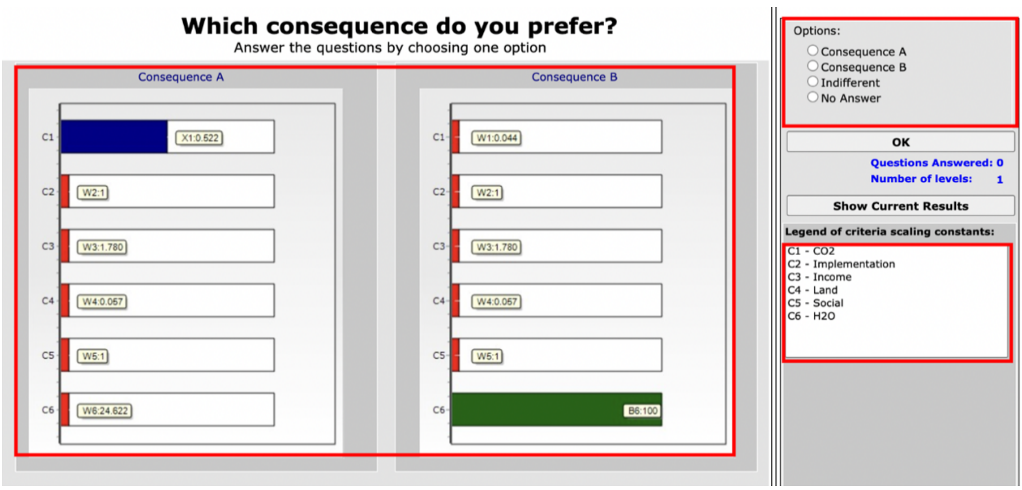


Figure 6 – Experimental process for part 2.

Once the order of scale constants of the criteria was obtained, the second part of the experiment focused on obtaining the rank of the CFE alternatives. In this process, the screen is divided into three parts, as described in previous processes. However, these parts had some changes compared with the previous processes (Figure 6). In the consequence process, the length implying the degree of the effect of the criterion becomes flexible, and decision makers should make choices with various amounts of criteria. Decision makers' choices under the flexibility of the degree of the effect is the key process in evaluating the weight of each criterion for decision makers.

Moreover, more options are provided in the operation process. For instance, decision-makers can select the indifference between two consequences or even opt not to make a comparison. The preference section reveals the decision-makers' preference lists for each criterion, which is defined in the first part. Furthermore, decision makers can select the holistic evaluation method to compare two alternatives directly, from the beginning of the second part or even answering many questions, however, the rank of the alternatives is still ambiguous. Finally, the experiment ended when the answer was sufficient to rank alternatives for decision makers.

5 DISCUSSION OF RESULTS

The results analysis section is divided into two parts in accordance with the FITradeoff process: ranking of weights (scale constants) of the criteria and final ranking of CFE alternatives. The former provides insights into which criterion is more relevant from the viewpoint of each consumer, while the latter supplies information about the type of alternatives that better capture the interests of the participants.

5.1 Scale constants

The performance of the weights varies from one decision-maker to another because each decision-maker (DM) has specific preferences between the evaluated criteria. Table 2 presents the correspondence between the criteria names and their rank ID for the householders.

Table 2 – Ranking of weights.

ID	DM 1	DM 2	DM 3
C1	Implementation	CO_2	Income
C2	CO_2	MPI	Implementation
C3	Land	Land	CO_2
C4	H_2O	Implementation	Land
C5	MPI	Income	MPI
C6	Income	H_2O	H_2O

Although direct comparisons of scale constants cannot be done because this experiment is an initial recognition of the preferences of AFSC consumers within a small sample selected by convenience for simplification, there are some initial insights about what draws more attention from such actors. For instance, CO_2 reduction has received great attention and was in the first place, while the blue water impact decrease was not seen as largely relevant. By contrast, income demonstrates a strong difference in ranking weights. For two householders, it was not a relevant criterion to join CFE initiatives, whereas it was the most important factor for one householder.

Specifically, the values of the scale constants for each criterion for each decision maker are illustrated in Figure 7. The maximum and minimum values were found. Overall, there are some stabilities in the five criteria (carbon, water, and land footprints, MPI, and implementation), while the scale constant of income is strongly different for householder 3, resulting in the variation in

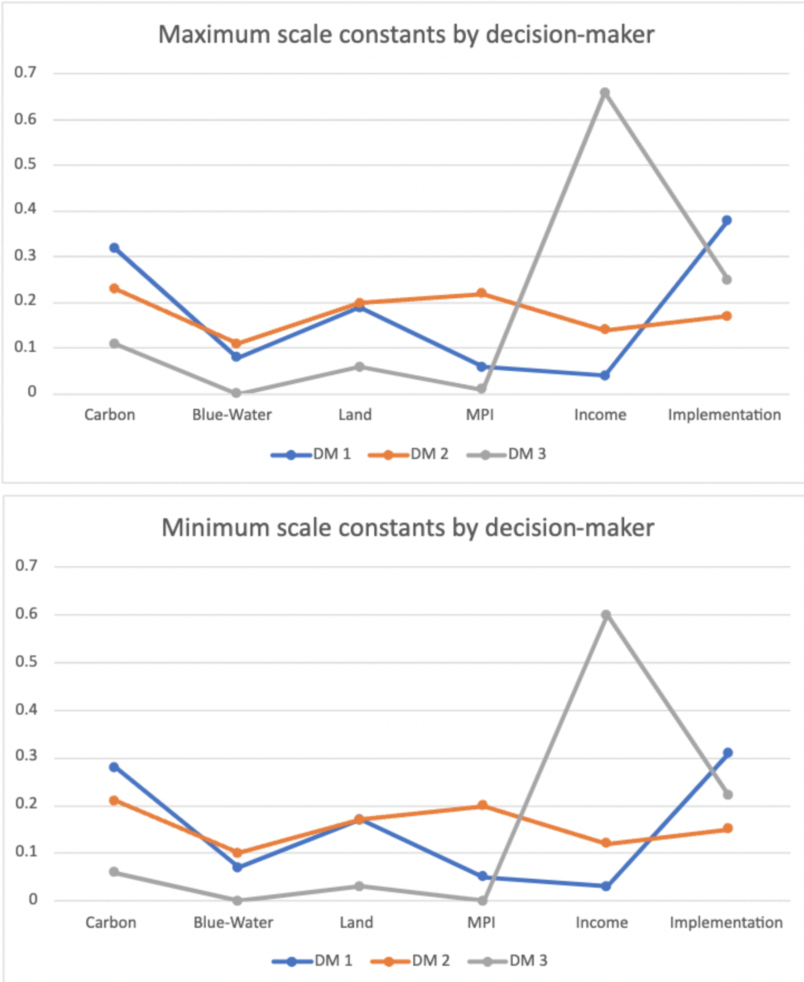
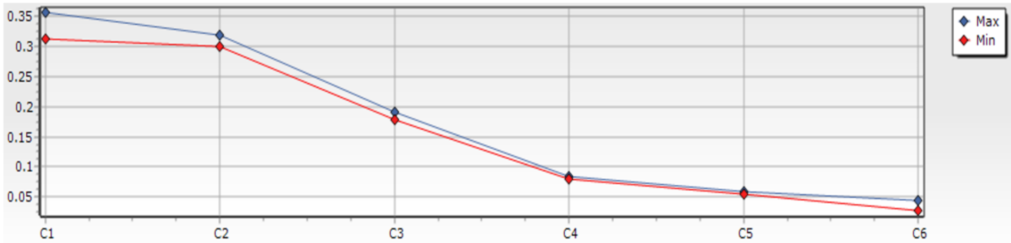


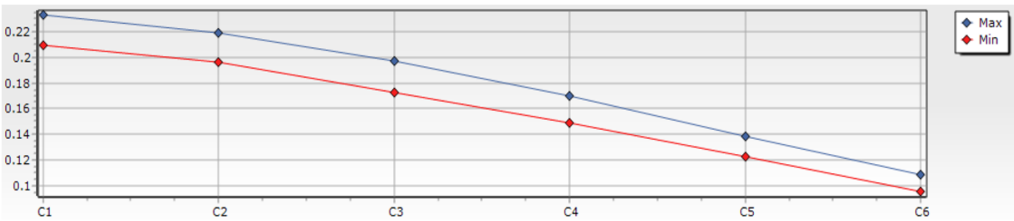
Figure 7 – Scale constants for all householders.

the rank of its corresponding weight. This demonstrates a strong divergence in how householders identify the tradeoff between the financial and non-financial aspects related to FLW. Furthermore, the maximum and minimum scales demonstrate the same trend, concluding that the decision makers make decisions consistently, and their preferences toward the six criteria seem steady.

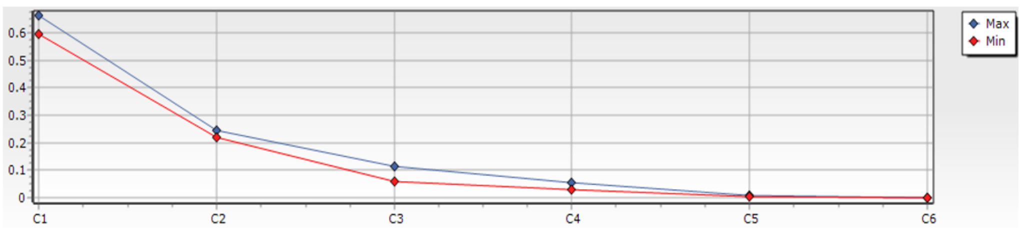
The notations of IDs described in Table 2 are used in Figure 8 to illustrate the maximum and minimum values of the scale constants found by the FITradeoff method for each decision maker separately. The criteria are illustrated from the most relevant (C1 on the left side of the figure) to the least important (C6 on the right side) for each householder. DM 1 and 2 demonstrated a similar scale constant for their most preferred criterion (0.38 and 0.23), while the value for householder 3 was 0.66. This may mean that decision makers have strong preferences and well-defined priorities in terms of what to expect from the contribution of CFE alternatives. In comparison,



(a) DM 1



(b) DM 2



(c) DM 3

Figure 8 – Scale constants for all decision-makers (generated by FITradeoff DSS).

DM 2 maintained a relatively stable decrement of weight values across criteria (Figure 8b), indicating that he/she had no strong (or unclear) preferences between the criteria presented in this experiment. The least preferred criterion has a scale constant of less than 0.1 in all cases.

5.2 Alternatives rank

In terms of the alternatives rank, owing to the variation in the scale constants of each participant, the rank of the CFE alternatives also varies. The results are presented in Table 3.

As explained in Section Scale constants, a direct comparison could not be performed using this experiment. However, an interesting fact is that A2 was ranked as the least preferred alternative. Since this alternative was focused on the reduction of the blue water footprint, this experimental application resulted in this effect not being more relevant for consumers than any of the other evaluated factors. Similarly, A3 was the next-lowest ranked alternative. Thus, a decrease in the inefficient use of land related to FLW is not a priority from the viewpoint of the final stakeholder of the AFSC.

Table 3 – Ranking of alternatives.

Ranking	Householder		
	1	2	3
1	A6	A7	A5
2	A9	A4	A8
3	A7	A1	A7
4	A1	A8	A4, A6
5	A8	A6	A9
6	A4	A9	A1
7	A5	A5	A3
8	A3	A3	A2
9	A2	A2	-

Moreover, there is no homogeneity for the first place of rank, which is mainly influenced by the differences in the scale constants. However, it can be said that A7 is interesting for decision makers. A7 offers a better result of a combination of carbon and MPI impact reductions and a combination of environmental and social factors. In the case of householder 3, indifference between A4 (focused on MPI index reduction) and A6 (focused on ease of implementation) was found. This indicates that CFE alternatives that offer benefits in the MPI impact, while being easy to adapt to the AFSC, could be equally interesting for that decision maker. Nevertheless, the crucial factor in deciding whether to join a CFE alternative for that decision maker is the income impact, as A5 and A8 both generate high-income impacts. Overall, the experimental results clearly show that decision makers feel confident about their preferences because the scale constants do not vary.

Therefore, there are several benefits to using the FITradeoff method to define decision makers' preferences about alternatives to solve FLW issues by implementing CFE options.Furthermore, the FITradeoff method helps to solve FLW issues by increasing social value and environmental and economic impacts, considering the cost of each alternative from the perspective of each stakeholder.First, FITradeoff can provide a clear vision of decision makers' preference consistency. For instance, the scale constant (see Figure 7) shows a clear trend of how decision makers' preferences of each criterion change during the process. As a result, decision makers with a high non-consistency level may eliminated to derive a more effective and valid result. Second, the FITradeoff method analyzes both preference rank and the magnitude of each criterion. By collecting all decision makers' choices, some interesting results can appear. For example, although most people preferer criterion A, criterion B may have the highest priority because some people may hold extremely large-scale constants for criterion B. Therefore, observing the normal preference rank rather than using the FITradeoff method would not derive the most effective and accurate outcome. Third, the FITradeoff method can provide alternatives automatically, saving time and effort to generate options for decision makers. If most decision makers prefer the same alternative, it provides a lead to develop solutions for decreasing FLW by considering different combinations of criteria.

Although the experimental data from the three decision makers may not be strong enough, especially in terms of the number of decision makers, to make a conclusion or make a direct comparison between the results, it can be said that the application proved that using the FITradeoff algorithm allows finding an optimal CFE alternative within the context of the experiment and provides relevant insights about the behavior of decision maker preferences.

For instance, circular alternatives strongly related to blue water footprint reduction are not highly valorized by householders, while options concerning carbon footprint decrease, income increment, and other social aspects, such as contribution to reducing the MPI index, are more attractive for them. Alternatively, the utilization of the DSS was easily understood by all decision makers in the experiment, and the convenience of the holistic evaluation feature was demonstrated for the case where some alternatives had already been ranked, while the decomposition procedure was more suitable during the first part of the experiment.

Finally, further studies may include eliciting preferences based on the FITradeoff method using empirical data of actual CFE alternatives, extending the scope of stakeholders to other AFSC echelons, and including a sensitivity analysis of the values of the consequence matrix. Further research is needed to explore the design of CFE alternatives that fit the preferences of AFSC stakeholders, and how to capture their interests in joining such options.

Therefore, in an upcoming study, we plan to obtain more information about the AFSC decision makers from other echelons of the chain (that is, farming, handling, food processing, and distribution), and develop a deep elicitation process with householders and food service providers with the aim of better understanding their desires. The plan includes the utilization of empirical data and analysis of actual CFE alternatives within a quantitative and co-creative model to implement circular alternatives within the chain.

6 CONCLUSIONS

The results obtained with the FITradeoff method applied within the context of CFE by an experiment with actual householders have demonstrated relevant initial insights about the preference behavior across the selected criteria.

This study serves as a basis to reduce the lack of information on the CFE options that are more attractive to decision makers. For example, the values of the scale constants revealed that decision makers' preferences were consistent because the maximum and minimum values obtained presented the same trend and similar magnitudes.

The application revealed that the FITradeoff DSS is a suitable tool for use within the AFSC to elicit criteria weights and rank alternatives. All the decision makers expressed that they felt confident while answering the questions and remarked that their participation in the experiment expanded their knowledge of the circular economy and their perception of FLW issues.

A future research proposal is disclosed, and further studies are suggested based on the FITradeoff results of the preference elicitation process. There are several ways to analyze CFE and the corresponding decision-making processes; thus, we encourage researchers from various areas of knowledge to work on the actual implementation of a circular economy within the AFSC to reduce food waste and other environmental and socioeconomic impacts.

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