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## A MCDA MODEL FOR OLIVE OIL SUPPLIER SELECTION USING MACBETH

**Abstract:** *This work proposes a multi-criteria decision-making approach to select suppliers in the olive oil sector. Besides several performance criteria required to the supplier, olive oil characteristics such as colour, smell, and density, as well as organoleptic tests are used. Hence, the assessment and selection of suppliers assumes a major importance and needs to be done yearly. The process of finding a set of suppliers to choose from involves two sequential stages, namely identification and elimination. The identification stage consists of finding a set of potential suppliers. Then, in the elimination stage, suppliers that are not able to meet the thresholds associated with some technical indicators are disregarded. Thus, only a small set of very promising suppliers need to be assessed. The assessment was performed by resorting to the Macbeth approach, resulting in a ranking. The results obtained were validated through sensitivity and robustness analyses.*

**Keywords:** *Decision-making process; Multi-criteria; MCDA; Macbeth; Olive oil sector.*

### 1. Introduction

This work proposes a multi-criteria decision analysis (MCDA) methodology to evaluate and select suppliers for an olive oil distribution company.

Supplier selection (SS) is the process of inspecting and evaluating potential suppliers in order to select the one or ones to become part of the supply chain of an organization. Therefore, such selection is a strategic decision that significantly influences firms' competitive advantages (Rezaei et al., 2016; Wetzstein et al., 2016). Proper selection not only affects the purchasing costs and decision making but also the customers perception as product quality, product availability and reliability are supplier dependent, thus improving competitiveness and business performance. Hence, a reliable selection process needs to be established. In addition,

SS is not only beneficial for the company which is looking for a supplier, but also the companies that established themselves as potential suppliers. Potential suppliers by becoming aware of the essential and preferential requirements can be more focused, thus improving the efficiency and effectiveness of their activity (Ho et al., 2011). However, selecting the right supplier is a very difficult process (Liu & Hai, 2005) and it must consider several quantitative and qualitative criteria, which are to be defined and evaluated by the management (Ho et al., 2010), thus being multi-criteria in nature.

The SS problem has attracted the attention of many researchers and several solution methodologies have been proposed over the years, namely analytic hierarchy process (Chan & Kumar, 2007; Parthiban et al., 2012), analytic network process (Bayazit, 2006; Gencer & Gürpınar, 2007), MCDA best worst

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method (Rezaei et al., 2016), case-based reasoning (Choy and Lee, 2002; Choy et al., 2005), data envelopment analysis (Liu et al., 2000; Wu et al., 2007), fuzzy set theory (Chen et al., 2006; Banaeian et al., 2016), genetic algorithm (Ding et al., 2005), mathematical programming (Mustafi & Xavier, 1985; Mustafi & Chatterjee, 1989), and hybrid approaches (Dey et al., 2010; Oliveira et al., 2015). Concerning the olive oil context, as far as we are aware of, no works have been published, except for (Fontes et al., 2017). The work reported here builds upon that of Fontes et al. (2017). The main differences are the way in which DMs opinions are handled and the specific methodology used. In here, the three DMs involved act as one and a consensus evaluation is used; while in Fontes et al (2017) the value used was obtained as a weighted sum of the DMs individual opinions. Regarding the approach, in this work the MACBETH is used rather than the AHP, as in Fontes et al (2017). MACBETH has two main advantages: it is based on utility theory, which assigns a utility function to a decision maker through preference relations and the adherence to specific axioms and determines the numerical values for the pairwise comparisons by using six semantic categories on an ordinal scale within a linear programming, which means they “are not a priori fixed” (Bana e Costa and Vansnick, 1994).

Multi-Criteria Decision Analysis (MCDA) methodologies are particularly appropriated to address this type of problems (Rezaei et al., 2016) since in addition to involving several dimensions (here translated into criteria) on which the suppliers are to be evaluated, some of these dimensions are quantitative in nature, while others are qualitative and thus subjective (Ho et al., 2010). More often than not, these criteria are conflicting and hence their simultaneous optimization is not possible. Furthermore, the number of possible suppliers, here termed alternatives, is small and each has its own known characteristics. Therefore, the company needs to identify the top priorities for selecting the “best” supplier

based on its specific needs and the available information on suppliers (Agarwal et al., 2011).

The remainder of this document is organized as follows. Section 2 describes the MCDA methodology used in this work, namely the Macbeth. Section 3 reports on the application of the proposed methodology to a real-world decision-making problem in the olive oil distribution sector. Finally, Section 4 concludes the paper.

## 2. MCDA Methodology

MCDA deals with ill-structured problems and considers the vagueness of judgments of decision makers. This type of problems usually exhibits the following characteristics: multiple decision makers, multiple perspectives, several and conflicting criteria, intangible issues, and uncertainty (Mingers & Rosenhead, 2004).

The MCDA is a formal quantitative approach that allows for finding viable solutions in respect to a set of different criteria, which may have conflicting objectives (e.g., maximize quality vs. minimize costs). The main motivation underlying the development of this field of study relates to the recognition that human trials may be limited, distorted and prone to bias, especially when faced with problems that require processing and analysing large amounts of complex information (Dodgson et al., 2009). Thus, this approach is not intended to choose the “best” decision, but rather to help decision-makers to select one or more alternatives that are best suited to the identified needs and preferences and global understanding of the problem.

One of the challenges of using multi-criteria decision-making is the selection of a set of appropriate decision makers. Since several perspectives, e.g. technological and economical, should be taken into consideration it is important to include decision makers that represent different interest groups (Ongprasert & Todoroki, 2003).

The implementation of MCDA is a non-linear recurring process comprising several steps. The number of steps varies according to MCDA approach adopted, since each approach has its own characteristics. However, it is possible to outline the following three critical steps common to most MCDA approaches: structuring, evaluation, and recommendations. The structuring phase begins with a contextualization of the problem. Then, it moves onto the definition of the alternatives and criteria. Criteria are the important aspects on which the alternatives are to be evaluated. The evaluation phase includes two steps. On the one hand, each alternative needs to be evaluated on each of the defined criteria and on the other hand, the criteria relative importance needs to be determined. This phase ends with the model validation and computation of the overall performance of each alternative. Lastly, the recommendation phase starts with sensitivity and robustness analyses of the model created and ends with the identification of opportunities and recommendations that support improved performance (Oliveira et al., 2014, 2015).

In this paper, a MCDA is employed in order to rank suppliers of an olive oil distribution company. As usual, we begin with the identification of the company objectives concerning supplier selection. These objectives were divided into two groups: one more related to the overall objectives of the company (strategic) and another more related to the olive oil. The first group was used to determine requisites that potential suppliers need to satisfy and thus for each one of them a threshold value has been set. These objectives and corresponding threshold values were used in the elimination stage. Objectives in the second group, specifically related to the olive oil, were then used to determine the criteria on which suppliers are to be evaluated. Several meetings were held with the company where the study has been conducted. The first meeting had the sole purpose of identifying the decision makers, which in this case are the directors of the

domestic trade, foreign trade, and quality control departments. The following meeting allowed for the identification of the existence of two groups of objectives (as explained above). First, the strategic objectives and corresponding threshold values were set. Discussions on the criteria found in the supplier selection literature and on how to adapt them to the olive oil sector and to the specific needs of the company followed. Meanwhile, the company searched for suppliers of interest, asked them to supply information regarding the strategic objectives, and performed the elimination stage. In the meetings that followed, the DMs assessed the relative importance of the previously identified criteria and appraised each of the chosen suppliers in regards to their individual contribution to the criteria.

For support decision analysis, we use the MACBETH approach supported by the M-Macbeth tool due its wide application in MCDA context, its capacity to support DMs' point of view, especially in the agriculture context.

## 2.1. MACBETH

MACBETH stands for Measuring Attractiveness by a Categorical Based Evaluation Technique. It is a value measurement approach that uses non-numerical judgments about the difference of attractiveness in pairwise comparisons to obtain scores for the alternatives and weights for the criteria in MCDA (Bana e Costa and Vansnick, 1994). A range scale quantifying the difference of attractiveness between two alternatives is built by resorting to semantic judgments based on a semantic scale ("very weak", "weak", "moderate", "strong", "very strong", and "extreme"). The qualitative judgements of the decision maker are converted, by using linear programming, into numerical values, where a score of 0 is given to the least attractive option and a score of 100 to the most attractive option. A similar procedure is used to find the criteria weights. First, "good" and "neutral" reference levels

are determined for each criterion and then the DM ranks the criteria in order of importance regarding the improvement from neutral to good. Then, the DM judges the importance of an improvement from neutral to good with respect to the aforementioned semantic on two criteria at a time. The weights are calculated by applying linear program, as before, where 0 is the weight of the neutral

option and 100 the sum of weights. Consistency checks are performed for all pairwise comparisons. The overall score for each alternative is calculated using the additive aggregation model. Further details can be found in, e.g., Bana e Costa and Chagas (2004) and Bana e Costa et al. (2012). A summary of the steps involved in using MACBETH is given in Figure 1.

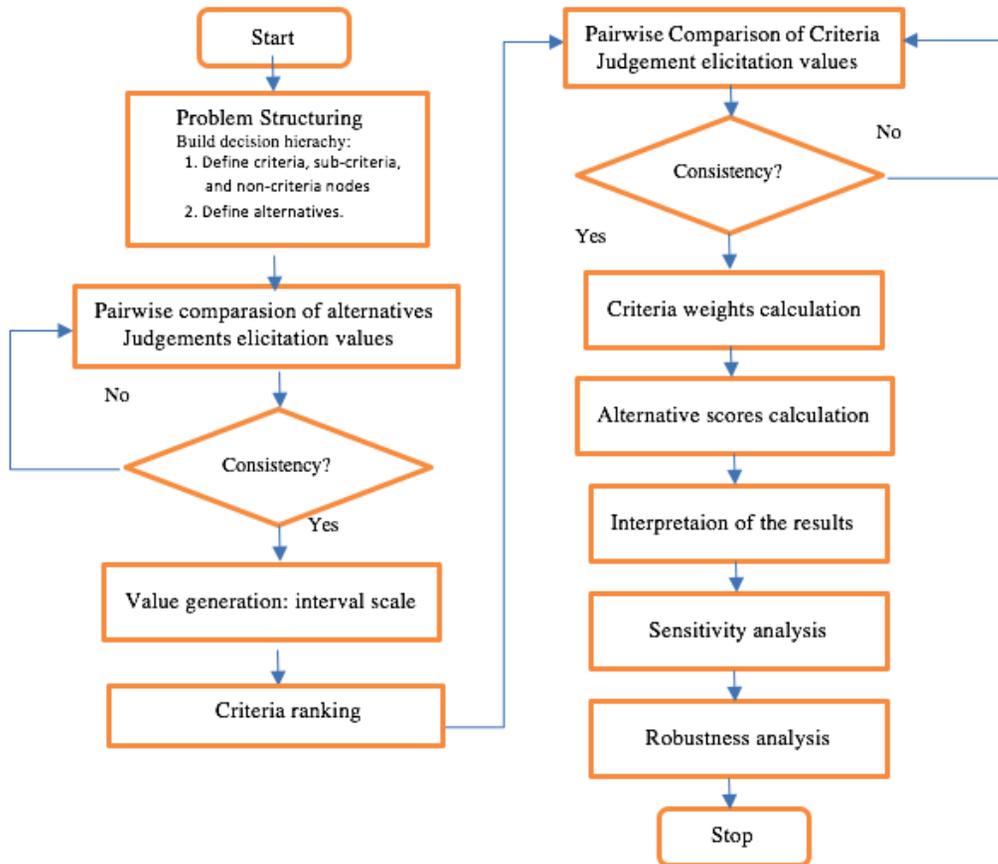


Figure 1. MACBETH approach

The MACBETH approach has been used in different contexts such as, development of scenarios and strategic plans for textile industry (Bana e Costa et al., 1999), and resource allocation in agriculture (Bana e Costa et al., 2013) education and career choice (Bana e Costa & Chagas, 2004), benefits and risk (Bana e Costa et al., 2008),

maintenance (Bana e Costa et al., 2012), among others.

### 3. Case Study

The case-study involves a small Portuguese company of olive oil distribution, which distributes exclusively Portuguese olive oils.

The portfolio of suppliers covers all areas of Portugal and features a range of olive oils of different varieties and qualities. The company works mainly with the domestic market; however, its international business is growing and currently it is present in six countries.

The company views the supplier selection process as a crucial decision and thus this process involves the directors of three departments, namely: domestic trade, foreign trade, and quality control. Three main reasons have led to the need to select new suppliers: i) replace one or more of the current suppliers; ii) looking for another variety of olive oil and/or increasing the amount of olive oil to buy; and iii) finding cheaper olive oils.

Olive oil is a protected agricultural product, by region and origin certificate:

- Protected Designation of Origin (PDO): identifies products that are produced, processed, and prepared in a specific geographical area, using the recognised know-how of local producers and ingredients from the region concerned. These are products whose characteristics are linked to their geographical origin. PDO products must adhere to a precise set of specifications to bear the logo.

- Protected Geographical Indication (PGI): identifies products whose quality or reputation is linked to the place or region where they are produced, processed, and prepared, although the ingredients used need not to be from that geographical area. All PGI products must adhere to a precise set of specifications to bear the logo.

- Traditional Speciality Guaranteed (TSG): identifies products of a traditional character, either in the composition or means of production, without a specific link to a particular geographical.

For more details see, e.g., Pérez y Pérez et al. (2013) and

[http://ec.europa.eu/agriculture/quality/index\\_en.htm](http://ec.europa.eu/agriculture/quality/index_en.htm). In Portugal there are six different PDO olive oil regions: PDO Trás-os-Montes; PDO Beira Interior; PDO Ribatejo; PDO

Alentejo Interior; PDO Norte Alentejano, and PDO Moura. This certification is supported by regional governmental entities for unique characteristics and organoleptic tests.

This case-study refers to the PDO region of Trás-os-Montes. The Association Inter-professional of Trás-os-Montes and Alto Douro olive producers (AIATAD) is the issuing body of the certification and it analyses several factors, such as 1) climate conditions, maturing, latitude and soil types; 2) dominant traditional varieties (“Verdeal”, “Madural”, “Cordovil”, “Cobrançosa” and “Negrinha do Freixo”); 3) olive oil extraction process and thermal conditions (cold or hot processes), treatment processes (other than washing, decantation, centrifugation, and filtration); and 4) chemical and organoleptic characteristics of the olive oil.

### 3.1. Criteria

The process of defining the criteria was conducted jointly with the directors (decision makers) of the domestic trade, foreign trade, and quality control departments. This collaboration took place through structured interviews and mediated by a questionnaire prepared in advance. The approach taken aimed at gathering the perspectives of each decision maker, to help define the criteria.

At the end of the first round of meetings we were able to decide on five criteria to be used to evaluate the suppliers: product quality, product cost, supplier's technical capacity, compliance with lead times, and product reliability, see Table 1. The value tree mapping our decision problem is illustrated in Figure 2.

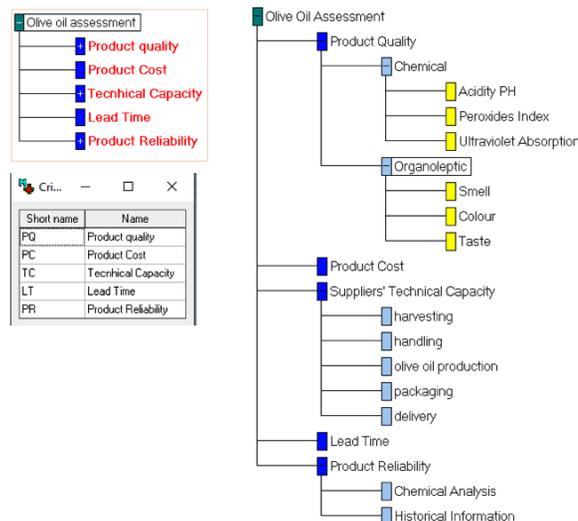
Recall that AIATAD is the institution responsible for evaluating the producers (suppliers of the distribution company) conditions, production processes, and olive oil. The DMs evaluation of the product quality (PQ) is based on the information supplied by the AIATAD regarding the latest olive oil campaign. The relevant information refers to the chemical and organoleptic tests.

Note that, the outcome of some these tests is mandatory information for retail trade. The information to assess product reliability is also received from the AIATAD. The price quoted by the potential suppliers is used as the product cost (PC). The supplier technical capacity (TC) is evaluated using the

information collected from visiting the potential suppliers and from companies they currently supply. Finally, the lead time information is collected from companies currently being supplied by the potential suppliers.

**Table 1.** Criteria definition and performance measures.

Criteria	Sub-criteria	issues	Indicators	Observation
Product Quality (PQ)	Chemical	Acidity ph.	An evaluation scale of 1 to 5 is used. 1-very weak, 2-weak, 3-Sufficient, 4-good, 5-very good.	Qualitative criteria.
		Peroxides Index		
		Ultraviolet Absorption		
	Organoleptic	Smell		
		Colour		
Product Cost (PC)			Cost: Price in euros per litre.	Quantitative criteria.
Suppliers technical capacity (TC)	harvesting		An evaluation scale of 1 to 5 is used. 1-very weak, 2-weak, 3-Sufficient, 4-good, 5-very good.	Perceived technical knowledge of the production process and of the in-place monitoring regarding the entire olive oil production path. This is a qualitative criterion
	handling			
	olive oil production			
	packaging			
	delivery			
Lead time (LT)			Average number of deliveries, out of ten, completed on time	This is a quantitative criterion (%) and it refers the time fulfilment of deliveries
Product Reliability (PR)			An evaluation scale of 1 to 5 is used. 1-very weak, 2-weak, 3-Sufficient, 4-good, 5-very good.	Suppliers ability to ensure small fluctuations, over time, of the olive oil quality (measured by chemical analysis during the production year). Although this is a qualitative criterion it is evaluated through the use of historical information since in every delivery the olive oil quality is assessed.



**Figure 2.** Problem structuring: value tree and criteria short name

### 3.2. Alternatives

As explained before, only potential suppliers capable of satisfying the required threshold value for a set of technical indicators are considered. The indicators established include PDO, PGI and TSG certificates, among others not discussed here. Given this elimination process, the number of suppliers was reduced to three: S1, S2, and S3.

Table 2 summarised the DM's elicitations, based on the available information for each supplier in each criterion, according to the scales defined in Table 1.

**Table 2.** DMs elicitation for each alternative in each criterion

	PQ	PC	TC	LT	PR
S1	3	€3.5	4	8	5
S2	3	€2.5	3	9	3
S3	5	€4.0	5	6	4

The values shown in Table 2 are consensus values that were reached the DMs after discussion. We have employed a three stages procedure to obtain such values:

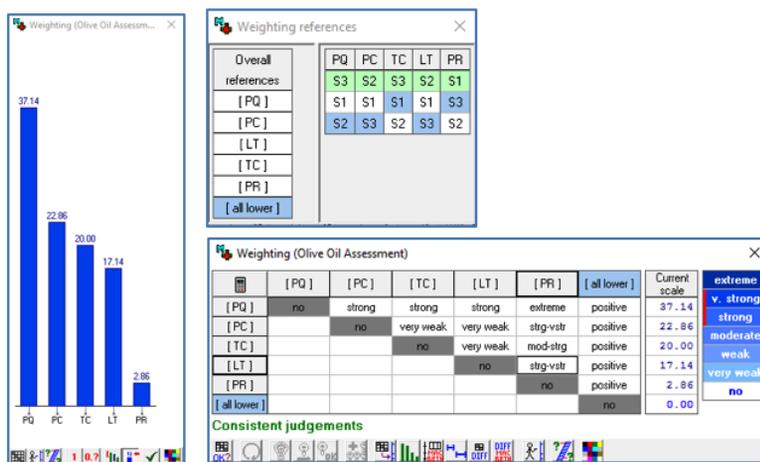
- Preference elicitation stage age 1: individual elicitations are expressed by the DMs;
- Information exchange stage: DMs present, explains, and clarify their own point of view

- Negotiation stage: the DMs discuss differences and look for their cause to negotiate in order to reach an agreement.

The advantage of this procedure over additive aggregation of individual elicitations is that it fosters problem discussion thus providing a better understanding of the problem, criteria, and alternatives.

### 3.3. Elicitation of the criteria weights

After structuring the decision problem, the DMs were asked to assess the relative importance of the identified criteria. Here we also used the three stages procedure explained in Section 3.2 to obtain a consensus value. The DMs performed pairwise comparisons using Macbeth's semantic six-point intensity scale to judge the differences in attractiveness. Then, and according to the procedure described in Section 2.1, the weights were obtained. The DMs may adjust these values and need to validate them. The weights are independent of the measurement units of the criteria and non-negative. The convention is that higher weights reflect higher importance. The pairwise comparison results and the criteria weights are reported in Figure 3.



**Figure 3.** Swing weighting procedure for criteria weighting

### 3.4 DMs judgments elicitation of each alternative on each criterion

The DMs were then asked to judge the difference of attractiveness between every pair of alternatives (suppliers) regarding each criterion, again following the three stages procedure previously mentioned. A consistency check takes part simultaneously and if inconsistency is detected, judgements

need to be revised. Figure 4 shows the results of the pairwise comparisons for all criteria, regarding the semantic scale values and the corresponding numerical values. The qualitative judgements are then used to generate values on an interval scale, which are proposed by M-MACBETH and need to be validated by the DMs. Note that, if needed the DMs may perform some adjustments to the proposed values.

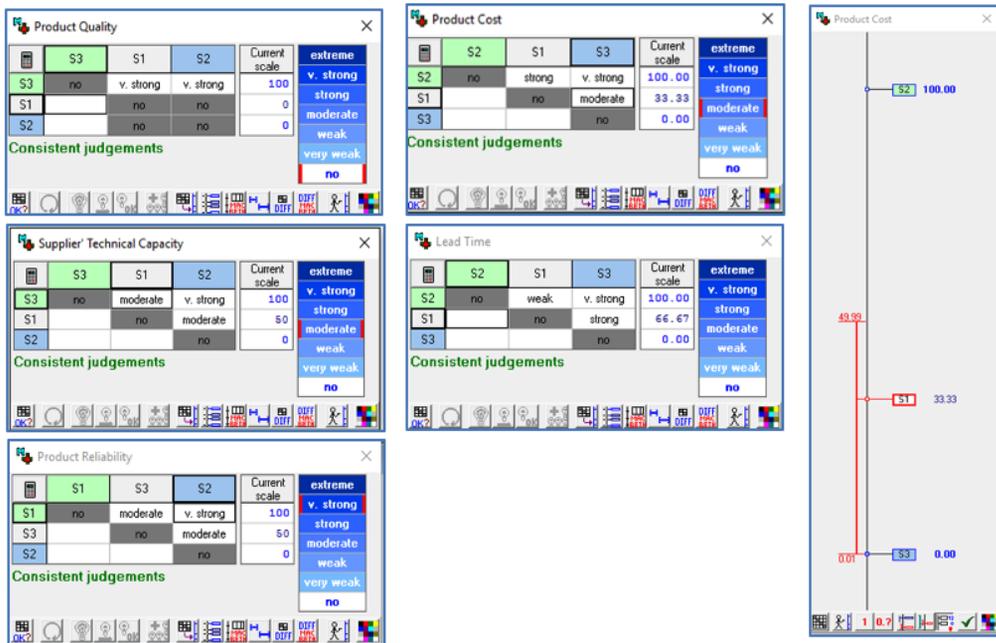


Figure 4. Pairwise comparison matrices for criteria qualitative judgements

### 3.5. Supplier ranking

As said before, the output of the whole procedure a ranking of the suppliers considered. In order to do so, we need find a global score for each supplier. This global score is obtained by an additive aggregation model that calculates for each supplier the weighted sum of the scores obtained in each criterion. This global score is then used to rank the suppliers.

Figure 5 shows for each supplier the global score and the scores obtained in each criterion, as well as criteria weights. As it can be seen, supplier 3 had the largest global score, followed by supplier 2, and supplier 1 has the smallest score. Note that, supplier 3 although the best regarding product quality and technical capacity, it is most expensive one and the one that misses the most the deadlines. Nevertheless, according to the global scores obtained the suppliers are ranked in the following order: supplier 3, supplier 2, and supplier 1.

Options	Overall	PQ	PC	TC	LT	PR
S1	31.91	0.00	33.33	50.00	66.67	100.00
S2	40.00	0.00	100.00	0.00	100.00	0.00
S3	58.57	100.00	0.00	100.00	0.00	50.00
[ all upper ]	100.00	100.00	100.00	100.00	100.00	100.00
[ all lower ]	0.00	0.00	0.00	0.00	0.00	0.00
Weights :		0.3714	0.2286	0.2000	0.1714	0.0286

Figure 5. Suppliers global score

### 3.6. Sensitivity analysis on weight

Since some steps of the MCDA process can be permeated by subjectivity and uncertainty, thus the model and corresponding results need to be validated. Sensitivity analysis enables such validation, since it shows the

impact of a change in the weight of a criterion. More specifically, it allows to obtain for each criterion the value it would have to have in order to change the final ranking. The results obtained can be seen in the graphs in Figure 6.

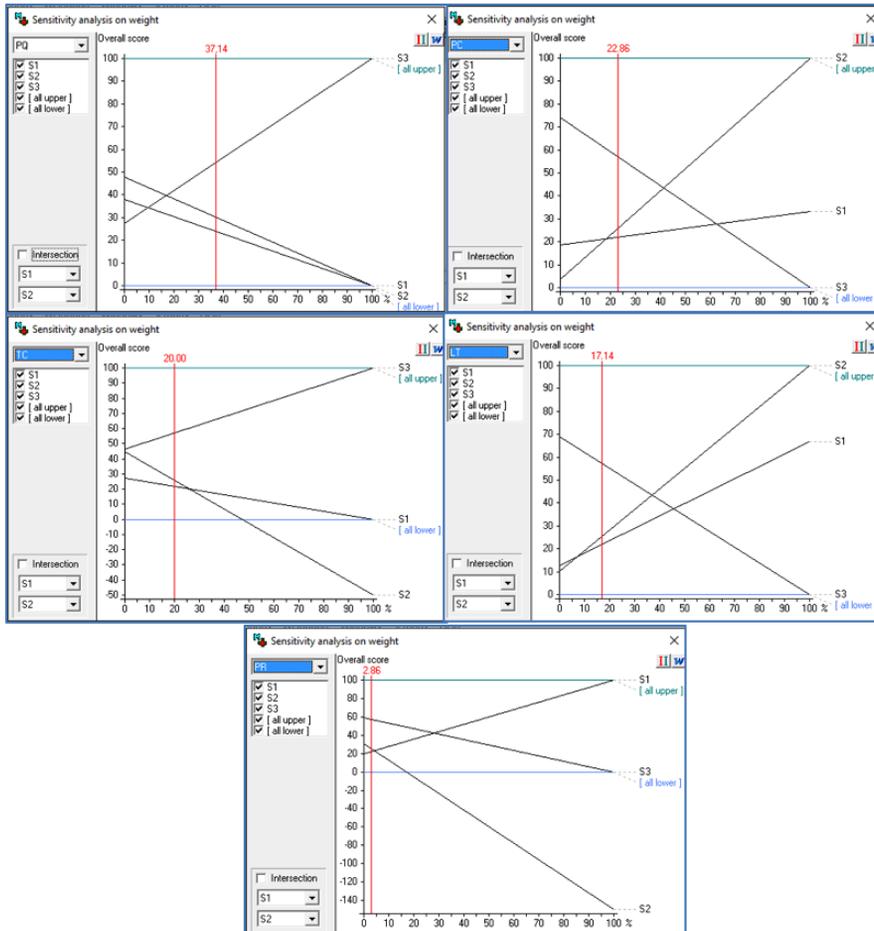


Figure 6. Sensitivity analysis on criteria weights -impact in the suppliers ranking

Product Quality (PQ) is the most important criteria and has a 37,17% weight. Changes in its value only have impact in the ranking if it drops dramatically to about 15%, in which case supplier 1 would be ranked first. Product Cost (PC) has been found to be the second most important criteria. For supplier 3 to lose the top position, the weight of PC would have to increase by about 20%, from its current value (around 23%), in which case supplier 2 would have the largest global score. Changes in the Technical Capacity (TC) weight would not lead to any changes in the ranking regardless of the magnitude. The lead time (LT) has a weight of about 17% and only for values of about 40% or more it would have any consequences regarding the suppliers ranking. Finally, regarding product reliability (PR), the first ranked supplier would only change if its value goes up from less than 3% to almost 30%.

### 3.7. Robustness analysis

The robustness analysis is also helpful as uncertainty plays a role in the decision-making process. Through it, one can determine whether the result of the best alternative changes with a variation of up to a predefined percentage on each criterion scale and on criteria weights (in our case 5% in both). Furthermore, the M-MACBETH robustness analysis provides pictorial information regarding dominance (red triangle), additive dominance (green plus), and lack of dominance (question mark). The results obtained can be seen in Figure 7 (Appendix).

As it can be seen from Figure 7a, no dominance is found between suppliers; however, by including rank order variation on the weights, supplier 3 additively dominates supplier 2, see Figure 7b. Note that, this dominance can be observed both on the left-hand side shown by the “green plus” and on the right-hand side since the overall value differences of the suppliers has a minimum of 0.3 and a maximum of 99.87. As both are positive supplier 3 dominates supplier 2.

Allowing changes in the judgments about difference in attractiveness inputted in M-MACBETH leads to no new additive dominances (see Figure 7c). Finally, the impact of cardinal changes is provided in Figure 7d. Allowing for a local variation (score of each supplier on each criterion) of  $\pm 5\%$  and a global variation (criteria weights) of  $\pm 3\%$  leads to the dominance of supplier 3 over the other two suppliers.

## 4. Conclusions

This work proposes the use of MACBETH, a multi-criteria decision analysis approach, to address the supplier selection problem of an olive oil distribution company. The use of multi-criteria decision analysis methods encourages discussion and deeper analysis of the problem within various departments. In this work, the reflection and discuss of the problem was strengthened as we used a three stages procedure to look for consensus decisions and evaluations. The main reasons behind the choice of MACBETH were the use of utility theory, a flexible and dynamically determined ordinal scale, and the automatic consistency checks.

The ranking obtained reflects the relative quality of the compromise reached by each alternative (possible supplier) in relation to set of criteria defined by the decision makers. The best-ranked supplier had a score significantly larger than the other two. Furthermore, sensitivity and robustness analyses have shown the ranking to be robust. On the one hand, the sensitivity analysis showed the ranking to remain the same unless dramatic changes (at least 15%) occur in the criteria weights. On the other hand, the robustness analysis showed that for reasonable variations, up to 5% both in individual suppliers evaluation and criteria evaluations, the chosen supplier would always be the same one, as it dominates the other two.

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Appendix

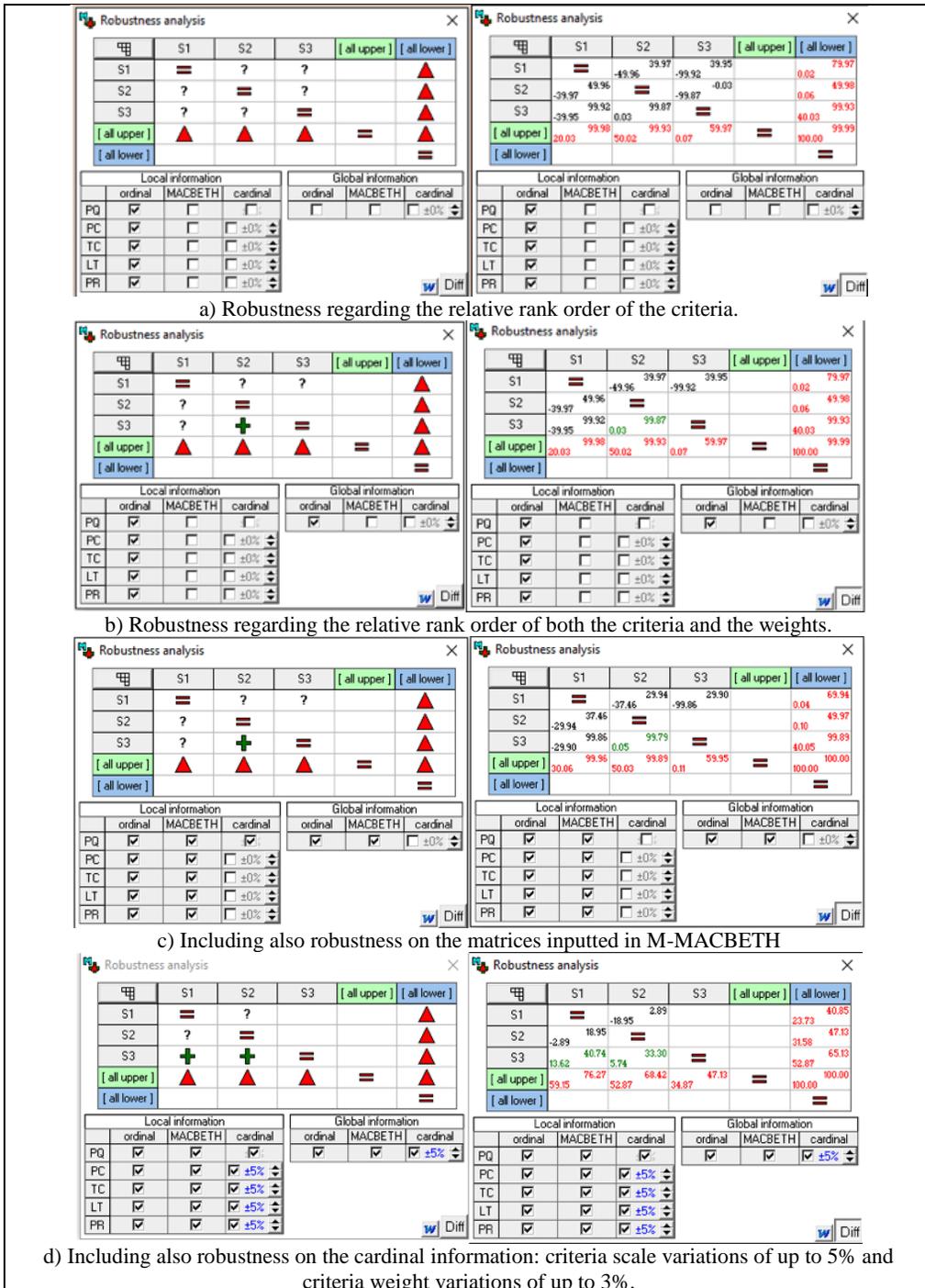


Figure 7. Robustness analysis (criteria scales and criteria weights)