SELECTION OF A VINEYARD FOR THE PRODUCTION OF HIGH-QUALITY WINE USING THE ANALYTIC HIERARCHY PROCESS (AHP)

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Abstract

In this paper the multicriteria decision making technique AHP (Analytic Hierarchy Process) is used to select a vineyard for the production of high-quality wine. The analysis was conducted with the help of an expert winemaker, who acted as the decision maker, and an AHP decision-making specialist team. The whole process includes: vineyard selection, criteria selection and analysis and criteria weighting process, ranking of the alternatives and final aggregated priorities. A sensitivity analysis of the results is also presented.

Keywords: *vineyard selection; Multicriteria Decision Making (MCDM); Analytic Hierarchy Process (AHP).*

1. Introduction and goals

The production of high-quality wine is a complex process that depends on many factors, such as type of soil, climate and the characteristics of the vineyard. When an investor wants to invest money in the production of high-quality wine he/she faces a complex decision-making problem.

The present work addresses the problem of vineyard selection to produce high-quality wine using the Analytic Hierarchy Process (AHP). The goal of the wine producer is to create a small-size winery for the production of high quality wine, with its own designation of origin (DO) or the label designation of Country Wine (Vino de la Tierra, VT), to be sold at a price higher than 60 € per bottle. The wine must also be an organic product. The project consists of the construction of a small new winery or the adaptation of an old building with a minimalist and functional design with the help of a renowned local architect and then hiring an experienced winemaker to produce the new wine brand. To achieve this goal it is essential to purchase an existing vineyard, the older the better, and equip the winery with the latest technology in winemaking and aging, including a bottling and bottle-aging cellar. The winery should be located in the vineyard or close to it. Therefore, the first problem is to find a vineyard that meets these requirements

The investor, hereinafter the Decision Maker (DM), decided to rely on a team of specialists in Multicriteria Decision Analysis of the Department of Engineering Design at the Polytechnic University of Valencia, hereinafter Analyst Team (AT). The role of the AT was to help the DM make a decision and develop a decision-making process that facilitated the systematic analysis of the problem and served to organize the information that the DM was generating during the process.

An important feature of the decision process was the inclusion of the personal dimension in the analysis: the DM expressed his intention to live near the Mediterranean Sea and his desire to take into account his personal expectations.

After conducting a comprehensive field work, five potential vineyards were found: two located in the province of Tarragona (in the municipalities of Capçanes and Bellmunt de Priorat), one in Valencia (municipality of Utiel), one in Alicante (municipality of Villena), and one in Mallorca (municipality of Felanitx).

2. Methodology

The Analytic Hierarchy Process (AHP) is a well-known multicriteria decision-making method, proposed by Saaty in 1980 (Saaty, 1980, 1996, 2001). According to the author, the method provides a theory of relative measurement of intangible criteria for decision analysis. The Analytic Hierarchy Process consists of the decomposition of the decision problem into simpler components or levels and the definition of a hierarchy framework by pairwise comparison between the levels. The top level of the hierarchy is the goal of the decision problem. The next level consists of the tangible and intangible criteria and sub-criteria used to assess the alternatives, which in turn, form the bottom level of the hierarchy. AHP uses pairwise comparisons to assign weights to the individual elements of each level, by measuring their relative importance using Saaty´s 1-9 scale, and then calculates the overall priority for the alternatives of the decision process (Saaty, 2008). The method also calculates a consistency ratio associated with each matrix of pairwise comparisons to verify the consistency of the DM. The mathematical foundations of the method can be found in Saaty (1994, 1996). Vaidya and Kumar (2006) analyzed 150 scientific articles on AHP applications published in prestigious scientific journals until 2006. AHP is being applied in many different areas: social, education, engineering, industry, politics, production, or resource allocation, among others.

The decision-making process involves the following stages and steps:
- Step 1. Structuring the problem into a hierarchy.

    - Step 1.1. Defining the overall goal of the decision problem.

    - Step 1.2. Defining the decision criteria in the form of a hierarchy by identifying the main criteria and the sub-criteria under each main criterion. In this way each main criterion can be analyzed in detail considering the respective contribution of each sub-criterion.

    - Step 1.3. Defining the decision alternatives. The process for the identification of the alternatives varies depending on the type of decision problem.

- Step 2. Criteria prioritization. At this stage the local weights of the criteria are calculated by pairwise comparison among the criteria of each level and then the global weights are obtained.

- Step 3. Prioritization of alternatives. The priorities of the alternatives are obtained for each criterion.

- Step 4. Setting overall priorities associated with each alternative. At this stage, the global priorities of each alternative are aggregated to yield the overall priority of an alternative for a certain criterion.

3. Case study. Selection of a vineyard

The goals of the problem, outlined in the introduction, were defined in a first meeting between the DM and the AT. The interest expressed by the DM to live in the Mediterranean area was to influence the DM´s decision, which forced the AT to present two different decision analyses: one that takes into account the criteria and personal interests of the DM, and another that only takes into account business-related criteria. For the latter an expert winemaker was incorporated to the team. For this reason there were two different final hierarchies. The alternatives were evaluated from the point of view of the DM's personal interests and from the business point of view. Finally, the two ranks were analyzed together so that the DM could make his final decision based on the importance of his personal interests and of the business-related criteria.

The development of two different hierarchies allows for a greater independence of preference criteria and avoids influences between the personal and business-related criteria.

After two further meetings between the MD and the AT seven personal criteria and 26 business-related criteria were identified; the business-related criteria were grouped into 6 high-order criteria, which in turn were grouped into two clusters: one relative to socio-economic aspects, and the other to the quality of grapes and as a result to the quality of wine.
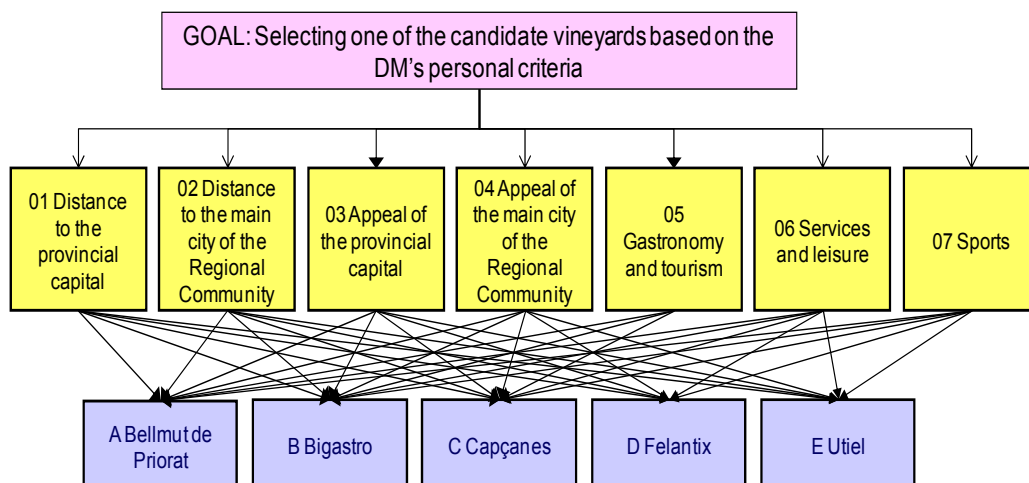
3.1 Hierarchy of the personal criteria

The main goal of this part of the problem is "selecting one of the candidate vineyards based on the DM's personal criteria". The personal criteria selected are described in Table 1. Figure 1 shows the resulting hierarchy.

Table 1: Description of the personal criteria

		Criteria	Description
Personal	C1	Distance to the provincial capital	Rate the time it takes to go from the winery to the provincial capital
	C2	Distance to the main city of the Regional Community	Rate the time it takes to go from the winery to the main city of the Regional Community
	C3	Appeal of the provincial capital	Rate the historical, cultural, socio-economic and weather appeal of the provincial capital
	C4	Appeal of the main city of the Regional Community	Rate the historical, cultural, socio-economic and weather appeal of the main city of the Regional Community
	C5	Gastronomy and tourism	Rate the gastronomic and tourist offer in an area that is one and a half hours away from the winery
	C6	Services and leisure	Rate the quality and variety of services and leisure offer. Distance to cinemas, theaters, shopping centers, markets, airports, marinas. Rate their relative importance.
	C7	Sports	Rate the available offer of your favourite sports: cycling and skiing, although you

In the next step the DM was asked to set priorities among the criteria, and then for each criterion, among the different alternatives. To do this, a simple questionnaire was designed in which the DM was responding to paired comparisons as defined in the AHP method. The results were obtained using Superdecisions software (www.superdecisions.com). For each pairwise comparison matrix we verified that the consistency index was acceptable, i.e. less than 0.1 (Saaty, 1994). Figure 2 graphically shows the priorities of the alternatives and Figure 3 graphically shows the weights of the criteria obtained from the DM's judgements.
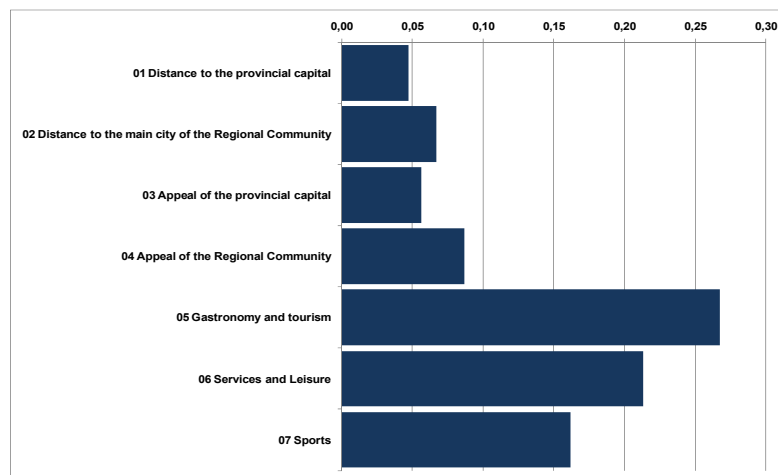
Figure 1: Hierarchy of the personal criteria

Figure 2: Ranking of the alternatives. Hierarchy of the personal criteria
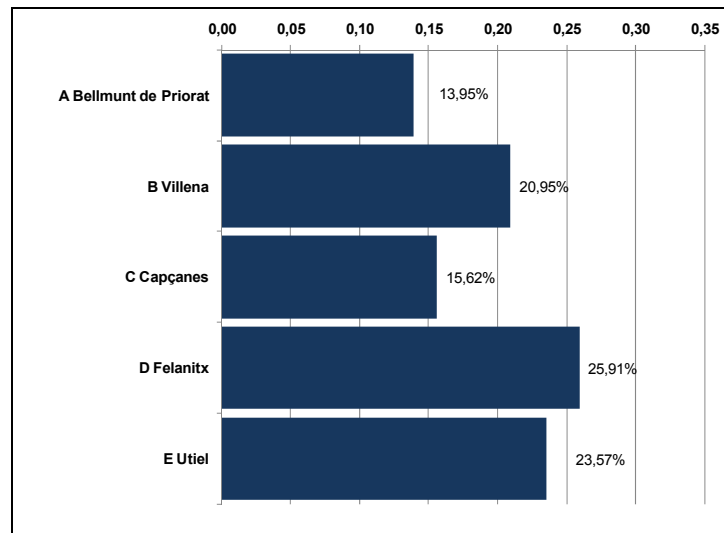
Figure 3: Ranking of the criteria. Hierarchy of the personal criteria

These results show that when the DM selects a vineyard location based on his personal criteria, he gives great importance to food and tourism, followed by services and leisure and the possibility of practicing sports. The top ranked alternatives for these criteria are those with higher overall priority rates (Felanitx, Utiel, & Villena).

3.2 Hierarchy of the business-related criteria

The hierarchy model consisted of five levels. The top level comprised the primary goal (Goal) that is, "selecting one of the candidate vineyards based on the business-related criteria". The second level included two first-order criteria that distinguish between the socioeconomic aspects and those related to the final product quality. At the third level there were six sets of criteria (clusters). In the fourth level 26 decision criteria were identified, and the fifth level comprised the alternatives. Table 2 shows the business-related criteria and their description. In this case, to help the DM in the weighting of criteria and evaluation of alternatives we counted with the participation of a winemaker who acted as an expert. The AT elaborated a questionnaire that identified the paired comparisons between the elements of each level and that was answered by the DM with the advice of the expert winemaker.

## Table 2: Hierarchy and description of the business-related criteria

Socioeconomic	Opportunity	C1	Reputation of the DO	Rate the reputation of the Designation of Origin of the new wine and its impact on the market
		C2	Financial aid for the production of organic wine	Rate the difficulty of implementing current standards for organic crops, and access to financial aid
		C3	Land	Rate the suitability of the land
		C4	Land price	Rate the price range of land, in € / Ha
		C5	Socioeconomic aspects, language	Rate the quality of the socioeconomic aspects for wine marketing including the languages used
	Exploitation cost	C6	Distance to distribution center	Rate the distance from the winery to a distribution center
		C7	Marketing cost	Rate the impact of the distribution and marketing channels on the final product cost
		C8	Harvest cost	Rate the difficulty and cost of grape harvest
	Facilities and infrastruc-tures	C9	Access	Rate whether the vineyards have access roads for trucks or should they be built
		C10	Power	Rate the availability of power supply, and otherwise, the distance to a possible power supply source. Note the difficulties relating to formalities and time arising from agreements with Hydroelectrica
		C11	Roads	Rate the conditions of the access roads from the wine cellar to distribution centres
		C12	Water	Rate the availability of potable water sources and / or the distance to a water supply network
		C13	Existing farm house	Rate the advantages of an existing old farm house to be converted into the new winery
		C14	Existing wine cellar	Rate the advantages of an existing wine cellar for the creation of the new cellar
Grape quality	Land features	C15	Soil composition	Rate the mineral composition and organic matter of the soil
		C16	Stratigraphy	Rate permeability, grain size, surface drainage and the existence of a bottom impervious layer to ensure humidity and force the plant to deepen its roots
		C17	Soil profile	Rate slope stability and the presence of terracettes in the area
		C18	Orientation	Rate the orientation of the vineyards with respect to the sun's path
		C19	Altitude	Rate the effects of altitude on the development of the vine and grape
	Weather conditions	C20	Temperature	Rate the influence of temperature pattern on grape quality
		C21	Rain	Rate the influence of rainfall pattern on grape quality
		C22	Sun hours	Rate the influence of sunshine hours on grape quality and maturation
		C23	Relative Humidity	Rate the impact of humidity on plant water balance

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	C24	Plant variety	Rate plant adaptation and soil type and give an extra bonus to the presence of local plant varieties
Grape vine characteristics	C25	Age of the grape vine	Rate the advantages of having old grape vines
	C26	Plant density	Rate the existing/required plant density ratio for the achievement of the expected quality standards

Figure 4 shows the hierarchy of the business-related criteria shown in Table 2. Figure 5 shows the weights of the criteria calculated with the help of Superdecisions software. Figure 6 shows the final prioritization of the alternatives.

Figure 5 shows that the 7 criteria highest rated by the DM account for 76.4% of his priorities. These criteria are: Altitude (23.2%), Orientation (16%), Age of the Grape vines (13.2%), Water (9.5%), Soil profile (5.6%), Stratigraphy (5.2%) and Reputation of DO (3.7%).

Figure 4: Hierarchy of the business-related criteria
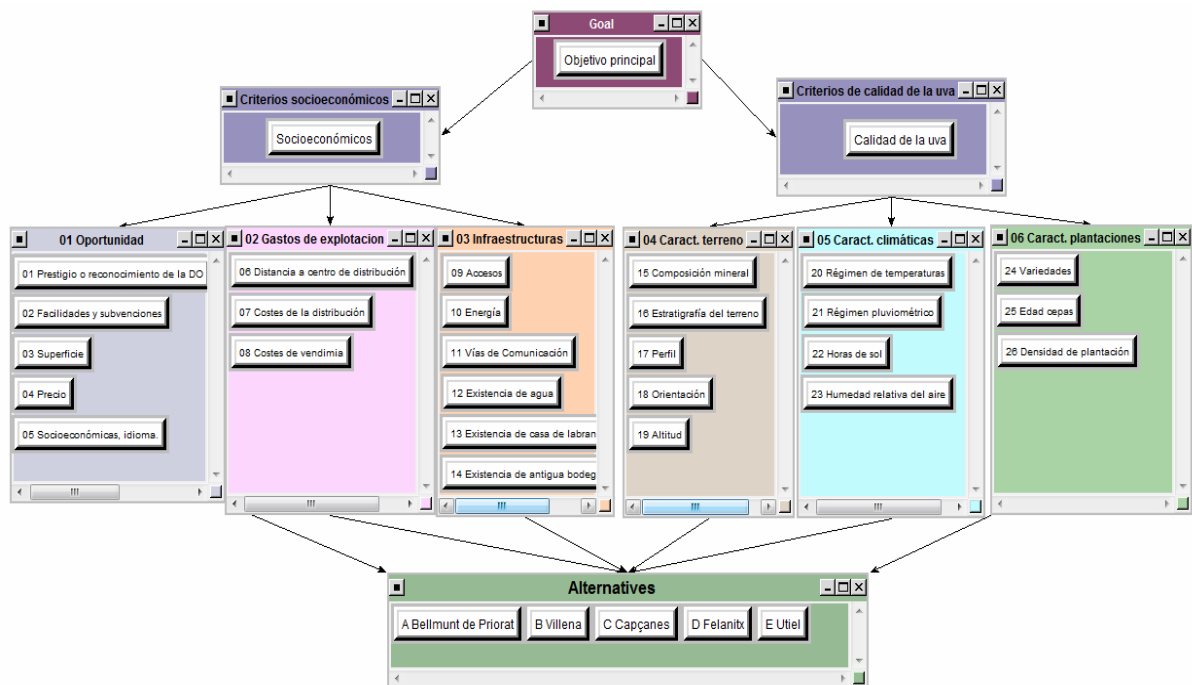
Figure 5: Weights. Hierarchy of the business-related criteria
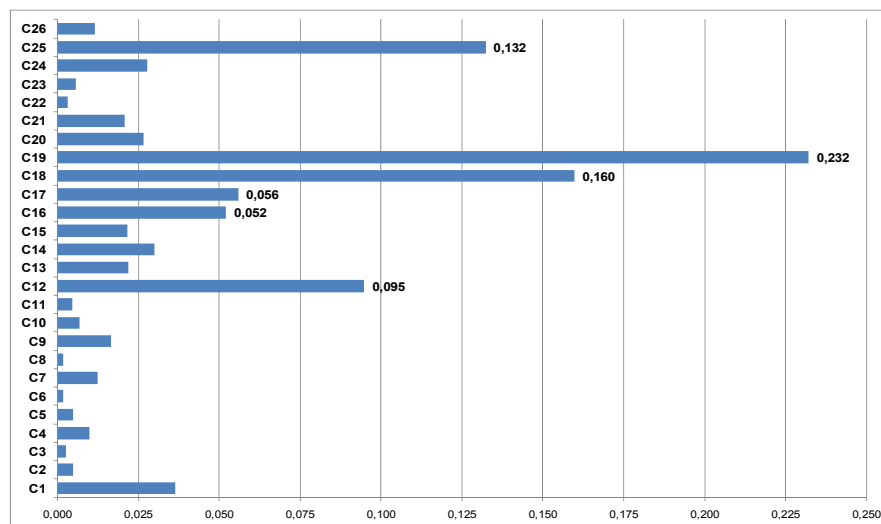
Figure 6: Total score of the alternatives. Hierarchy of the business-related criteria
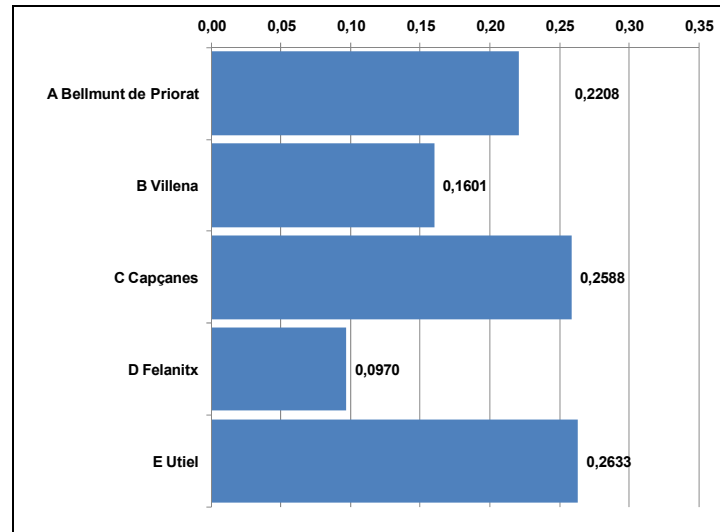

Figure 6 shows that the highest rated alternative is Utiel (26.3%), closely followed by Capçanes (25.9%) and by Bellmut de Priorat (22.10%) at a greater distance. Note that in this ranking list Felanitx is in the last place, while in the ranking of personal criteria it occupies the second place, close to the first place.

3.3 Combination of hierarchies

In order to obtain the final prioritization of the alternatives, the personal and business-related criteria were combined on the basis of the weights assigned in each hierarchy and calculated with the following expression:

$$V(A) = wP * VP(A)+(1- wP) * VN(A)$$

where:

wP is the weight of the personal expectations on the final decision.

VN(A) is the total score of each alternative for the business-related criteria.

VP(A) is the total score of each alternative for the personal criteria.

Table 3 shows the resulting data according to the weight assigned to the DM's personal preferences. In Figure 7 the relative weight of the DM's personal expectations on the final decision is represented on the horizontal axis, and the prioritization of the alternatives on the vertical axis.

Table 3: Final rating of the alternatives depending on the type of criteria used: personal or business-related

	$V_N(X)$										
A	22,10%	21,69%	21,29%	20,88%	20,47%	20,06%	19,66%	19,25%	18,84%	18,43%	18,03%
B	16,00%	16,25%	16,50%	16,74%	16,99%	17,24%	17,49%	17,73%	17,98%	18,23%	18,48%
C	25,00%	24,53%	24,06%	23,59%	23,12%	22,66%	22,19%	21,72%	21,25%	20,78%	20,31%
D	9,70%	10,51%	11,32%	12,13%	12,94%	13,75%	14,56%	15,37%	16,18%	16,99%	17,81%
E	26,30%	26,16%	26,03%	25,89%	25,75%	25,62%	25,48%	25,34%	25,21%	25,07%	24,94%
w_P	0,00%	5,00%	10,00%	15,00%	20,00%	25,00%	30,00%	35,00%	40,00%	45,00%	50,00%

										$V_P(X)$
A	17,62%	17,21%	16,80%	16,40%	15,99%	15,58%	15,17%	14,77%	14,36%	13,95%
B	18,72%	18,97%	19,22%	19,47%	19,71%	19,96%	20,21%	20,46%	20,70%	20,95%
C	19,84%	19,37%	18,90%	18,43%	17,97%	17,50%	17,03%	16,56%	16,09%	15,62%
D	18,62%	19,43%	20,24%	21,05%	21,86%	22,67%	23,48%	24,29%	25,10%	25,91%
E	24,80%	24,66%	24,53%	24,39%	24,25%	24,12%	23,98%	23,84%	23,71%	23,57%
w_p	55,00%	60,00%	65,00%	70,00%	75,00%	80,00%	85,00%	90,00%	95,00%	100,00%

Figure 7: Final rating of the alternatives depending on the type of criteria used: personal or business-related
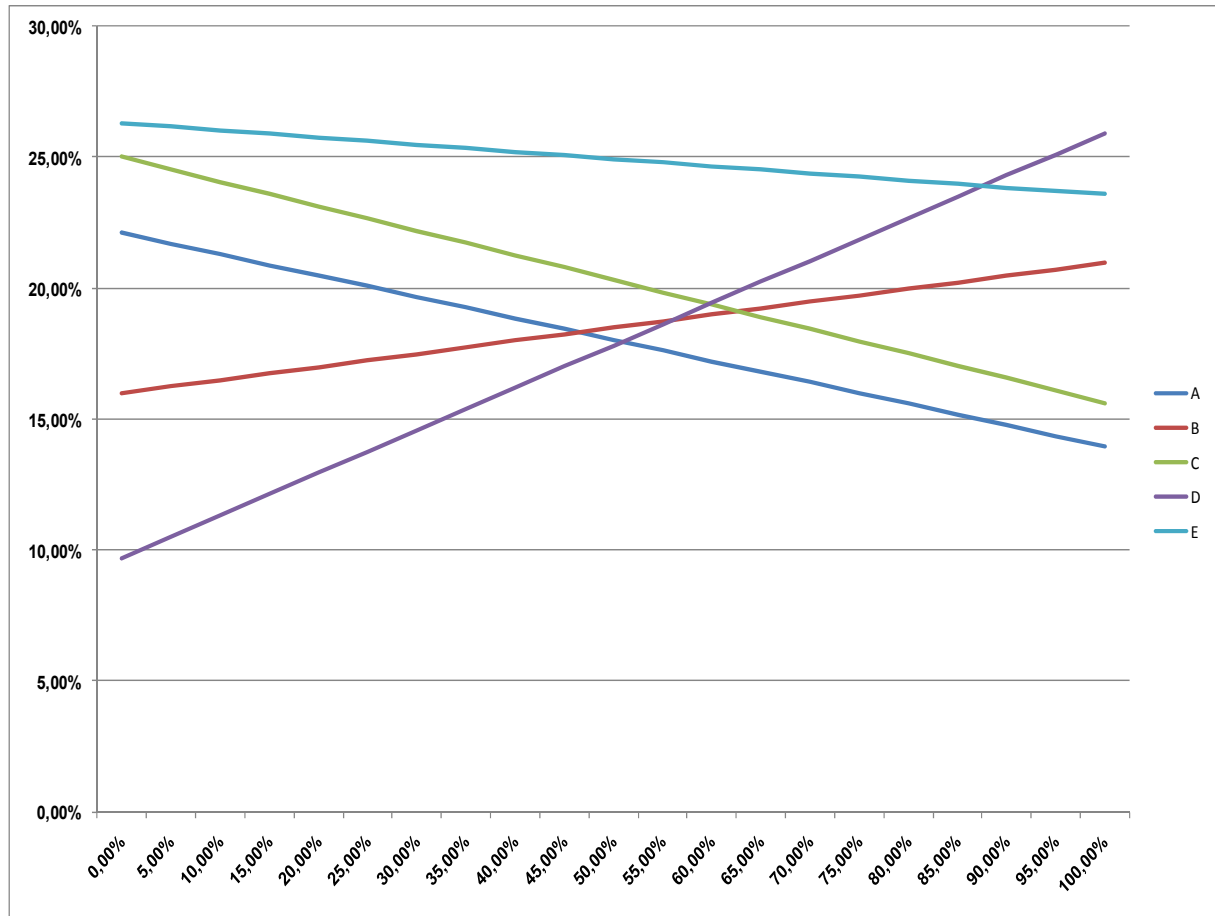

Figure 7 shows that Alternative E (Utiel) is the highest rated until the weight of personal criteria reaches approximately 87%. From this value, that is if the personal criteria weigh more than 87% (approximately) then the highest rated alternative is Alternative D (Felanitx). However, Alternative D is the last choice in the range of personal criteria weighting between 0 and 51%; i.e. if the business-related criteria were taken into consideration this alternative would not be selected. From this weight value Felanitx gains positions and stands the second in the weight range between 60% and 87% approximately. Alternative C (Capçanes) is the second best rated alternative up to a weight value of approximately 60%. From this weight value it moves down to the third place.

3.4 Sensitivity analysis

A sensitivity analysis was conducted to observe any changes in the ranking of the alternatives when the criteria weights are modified. This analysis was conducted on the two hierarchies of the case study. The procedure followed was to gradually change the weights of the criteria, one by one (in several successive steps), keeping the other weights constant and verifying the effects on the ranking of the alternatives.

Superdecisions software performs the calculations in a systematic way: it can change the weight of each criterion from an initial value to an end value in several steps, set by the AT, and graphically represent the evolution in the ranking of the alternatives.

As an illustration, Figure 8 shows the graph resulting from modifying the weight of the socio-economic criteria in the hierarchy of business-related criteria. Note that it presents a very stable ranking. The same can be said for the other criteria in the two hierarchies. The variations observed occurred when the weight values were substantially modified.

Figure 8: An illustration of the sensitivity analysis
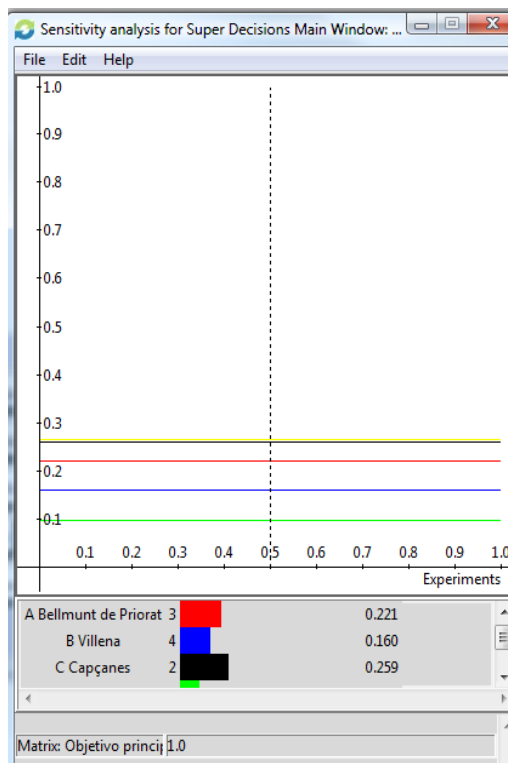
4. Conclusions

In this paper the AHP method is used to help an investor to select the location of a vineyard for the production of high-quality wine. The method has the advantage of being able to systematically and reliably analyze multiple criteria. The problem relating to the case study is of great conceptual complexity due to the large number of criteria which had to be taken into account by the DM, aided by an expert winemaker. Business-related as well as personal criteria were analyzed and aggregated in the decision analysis.

Note that the alternative Utiel is first in both rankings. This alternative would be the best solution, unless the weight of the personal criteria was less than 87%. Capçanes is also a good option, provided the weight of the personal criteria does not exceed 60%.

The DM found the method very useful because it allowed him to sort out a large amount of information. Additionally, the process forced him to deeply reflect on the problem in a simple and easy manner, as the questions in the questionnaire were easy to answer.

In future research the ANP method will be applied to the case study analyzed, as the ANP technique takes into account the influences among the different elements of the problem.

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