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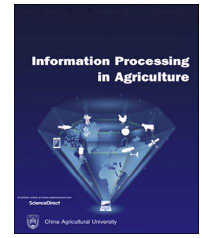

An integrated multi-criteria analysis for assessing sustainability of agricultural production at regional level

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ABSTRACT

Assessment of agricultural production sustainability is a multi-dimensional task that involves the quantification of various economic, social and environmental indicators at different scales and uncertainty levels. In this context, a particularly challenging approach is proposed involving the appropriate selection of the most representative criteria that ensure economic viability, eco-friendliness and social development, in order to overcome the limitations of other methodological approaches that are often vague and contradictory. In this study, a holistic methodology that integrates life cycle analysis (LCA), environmental risk assessment (ERA) along with on-site farm and regional surveys using the multi-criteria environment of the Analytical Hierarchy Process (AHP) is designed for the identification of the most sustainable agricultural management practices at regional level. Based on a set of 13 representative sub-criteria, the proposed approach was applied to *Pistacia vera L.* production in Aegina island, Greece, where narrow range of resources is available, groundwater supply is scarce and of poor quality. Overall, three alternative scenarios, i.e. Baseline scenario representing the current production (BL) as well as Composting (CO) and Biochar Use (BU) scenarios aiming at sustainability improvement were investigated. Results of multi-criteria and sensitivity analyses suggest that the optimal sustainable management scenario is CO, which involves on-site composting of organic solid waste, mainly produced at farm site, and subsequent application in the field. The proposed methodology shows significant potential as a valuable multi-criteria tool that can be easily adapted at regional level to assist decision makers such as farmers and their associations, policy makers, local and regional authorities to efficiently explore a range of alternative farm management practices and thus identify pathways toward sustainability.

1. Introduction

Over the last decades, there is a growing interest in assessing the sustainability of agricultural production systems, which is considered a key issue for the implementation of long term

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economically viable, ecologically sound and socially acceptable policies and practices at farm and regional level. However, the measurement of agricultural sustainability is a challenging task since it involves the dynamic and simultaneous balance among its pillars, i.e. environmental, economic and social, that in most cases are interlinked and often partially conflict with each other [1].

So far, a continuously growing number of sustainability frameworks, indicator-based assessment methodologies, protocols and regulations has emerged to evaluate agricultural sustainability. However, the application of existing and well-established sustainability assessment methods and tools such as SAFA [2], IDEA [3], MOTIFS [4], SMART [5], SAEMETH [6] and RISE [7] in most cases requires a complex set of indicators which makes data collection, processing and analysis, expensive and time-consuming.

Despite the large number of sustainability assessment studies for agricultural systems which are available in literature, the majority of the methods used lack integration and balance among the different dimensions of sustainability [8]. De Olde et al. [9] argue that measurement of agricultural sustainability based on the current assessment methods and tools is hindered by two main limitations. The first is that several key issues, such as GHG emissions and energy consumption are marginally considered, probably due to the use of simple assessment methods. As a result of this limitation, model-based indicators are preferred when sufficient and reliable data are available, since they create strong linkage between feasibility and relevance. The second limitation is due to the application of sustainability assessment tools which vary widely in terms of scoring methods used, context-specificity and assumptions considered [10,11].

To meet both challenges, several agricultural sustainability assessment approaches and methodological frameworks have been recently proposed by enabling the integration of well-established and comprehensive quantification methods such as life cycle assessment (LCA) and energy analysis on a multi-criteria analysis (MCA) environment [12,13]. However, previous studies have solely focused on assessing the environmental sustainability based on the associated environmental impacts at farm level rather than taking into account all three dimensions of sustainability. Furthermore, these studies do not consider the most negative pressures that occur and affect agricultural production at regional level [14,15]. As a result, the selection of the most suitable indicators is of high priority to provide a holistic picture of the system studied along with the need to maintain uncertainty at the lowest level.

Drawing on the aforementioned challenges, the present study aims to (i) develop a holistic multi-criteria methodology that integrates life cycle analysis (LCA), environmental risk assessment (ERA) and on-farm surveys in combination with the application of Analytical Hierarchy Process (AHP) to assess agricultural sustainability at regional level, (ii) explore its implementation by identifying and proposing the most suitable indicators to evaluate sustainability of the pistachio production in the island of Aegina, (iii) explore two alternative farm management scenarios, namely the Composting (CO) and the Biochar Use (BU) to improve long-term sustainability, and finally (iv) assess the reliability of the obtained results with respect to the variation of the criteria weights with the use of sensitivity analysis. To the best of our knowledge, no similar studies are available in literature, thus the proposed approach aims to fill an important gap with respect to model-based decision-making by farmers and other stakeholders, and propose optimal practices for sustainable improvement in other similar cultivations in the Mediterranean region.

2. Study area and methodology

2.1. Study area

The study area is the Aegina island which is located approximately 16.5 miles south of Piraeus, Greece, and is the second largest island of the Saronic Gulf covering a total area of 87 km^2 (Fig. 1). The island of Aegina is characterized by semi-arid Mediterranean climate, with annual rainfall of 435 mm and mean annual temperature of 19.7 °C for the year 2018 [16]. Almost 65% of annual rainfall is recorded in the winter period (November–February), while summers are usually dry. Aegina town has around 13,000 permanent residents but this number increases significantly in the summer to 60,000. Tourism and agriculture are the dominant activities in the island, followed by commerce and fishing. Pistachios are the main cultivated crops (63% of the total) mainly in the north part of the study area which has complex cultivation pattern according to Corine land cover [17], while less agricultural land is allocated to olive trees (20%), almonds (7%), lemon trees (4%), vineyards (2%) and others (4%) [18,19]. Twenty-five percent of the study area is defined as vulnerable to nitrates contamination, while the groundwater table usually fluctuates between 10 and 60 m depth [20].

2.2. Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) is a structured multi-criteria decision analysis (MCDA) method that deals with both qualitative and quantitative criteria and data with high degree of uncertainty [21,22]. Briefly, it involves: (i) structuring of assessment criteria/sub-criteria into a hierarchy of goals (problem decomposition), (ii) assessment of the relative importance of these criteria (weights) through the establishment of pair-wise comparison matrices that are converted into numbers (Table 1), (iii) comparison of the alternatives based on the judged importance of each one over another with respect to a common criterion, and finally, (iv) an overall ranking of the alternatives.

Practically, for each level, the calculation of the criteria weights by the AHP method is accomplished with the use of a pair-wise comparison matrix (A) obtained upon the decision maker's judgments a_{ij} for n elements as follows [21]:

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix}, \text{ where } a_{ji} = 1/a_{ij} \text{ for activities } i,j = 1,\cdots\cdots n \quad (1)$$

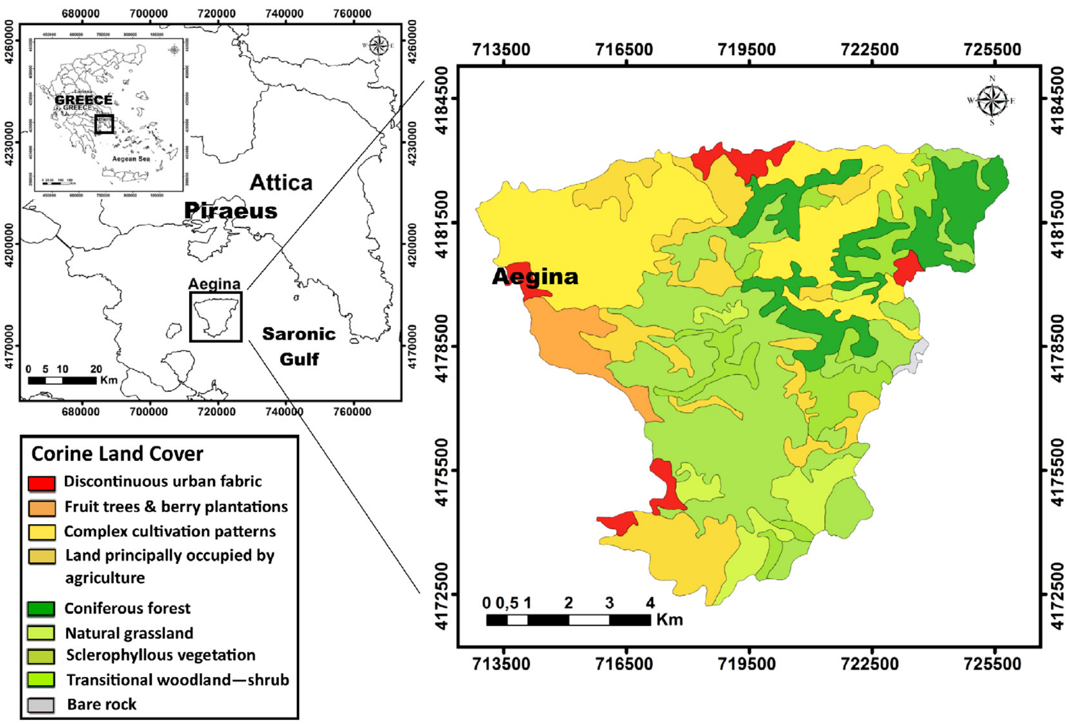

Fig. 1 – Location and Corine land cover map of the study area.

Table 1 – AHP 9-point fundamental scale [13].

Numerical scale	Definition
1	Two elements are equally important
3	One element is slightly more important than another
5	One element is strongly more important compared to another
7	One element is very strongly more important over another
9	Absolute dominance of one element over another
2, 4, 6, and 8	Intermediate values between two neighboring levels
Reciprocals (1/*x*)	A value attributed when activity *i* compared to activity *j* becomes the reciprocal when *j* is compared to *i*

As a result, the relative weights of matrix A are calculated from the following equation:

$$(A - \lambda_{max} \times I) \times w = 0 \quad (2)$$

where I is an identity matrix, 0 is a zero matrix and λ_{max} is the maximum eigenvalue of matrix A [23,24]. However, the sorting judgement of the order n of a pair-wise comparison is examined for consistency by two statistically important factors i.e. the Consistency Index (CI) and the Consistency Ratio (CR), defined respectively as follows:

$$CI = (\lambda_{max} - n) \times (n - 1) \quad (3)$$

$$CR = CI/RI \quad (4)$$

where n is the size of the matrix [25], and RI is a value that represents Saaty's calculated random index measures for various sizes of the matrix (n) [22]. The consistency of the comparison matrix can be considered acceptable when CR < 0. If larger values of CR are obtained, revision of the judgment of the decision makers is required.

2.3. *Development of the AHP model*

2.3.1. *Criteria selection*

Overall, a set of 13 representative sub-criteria was selected in order to fully cover the three pillars of sustainability (main criteria) i.e. environmental performance, economic development and social growth (Fig. 2) according to the main goal of assessing the sustainability of pistachio production in the study area.

The selection of the sub-criteria was based on their potential to thoroughly reflect the most important environmental and socioeconomic pressures that occur during pistachio production (on and upstream) in the study area. To this context, a detailed environmental risk assessment has been conducted to assess the environmental quality of the study area as well

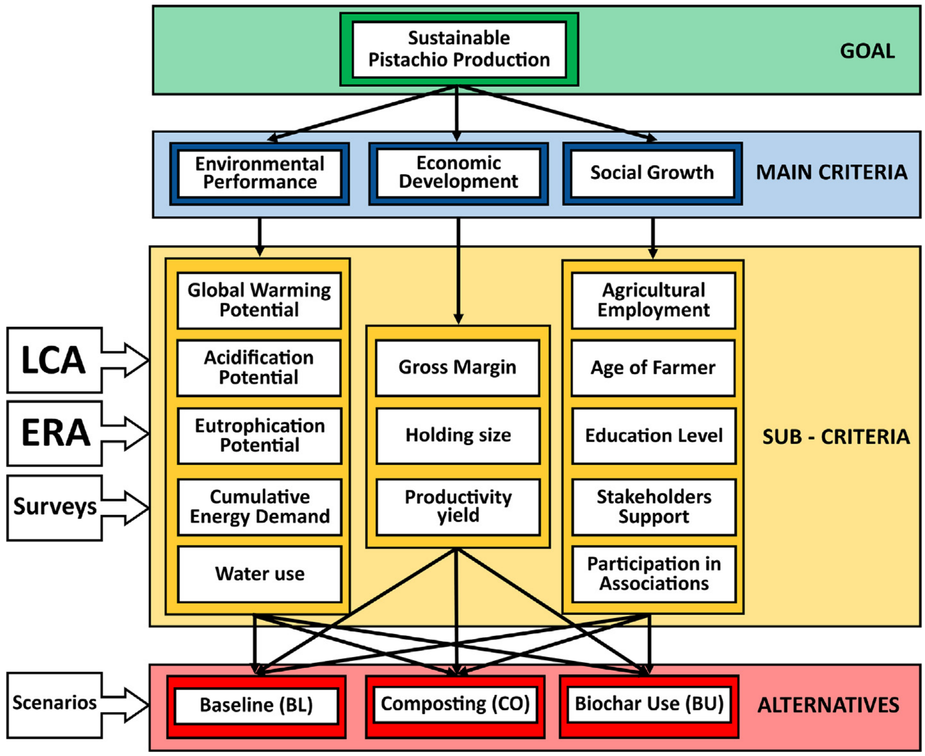

Fig. 2 – Overall structure of the two-stage AHP Model used in this study.

as its improvement due to the application of the developed in the frame of the AgroStrat project on-farm management strategies [26]. For that purpose, several environmental risk maps were created for the most important soil and water parameters i.e. soil pH, soil organic matter, soil salinity, heavy metals (manganese, copper and zinc) and irrigation water quality. Apart from that, a four-round survey campaign with very good response rate (>50%) has been performed using specific questionnaires for the farmers and the general public to identify their perspective towards socio-economic impacts that affect agricultural production in the study area. At last, numerical pairwise comparisons and criteria weights were calculated by combining the overall judgment received from a well-balanced group of experts (12 on total) from academia to agriculture as well as other stakeholders (municipalities, organizations and associations).

2.3.2. *Criteria definition*

2.3.2.1. *Environmental performance*. Environmental indicators are usually single sets of values derived from often poor quality data (e.g. farm inputs such as fertilizers and agrochemicals) which are characterized by rather high uncertainty since upstream impacts are not included [12]. To avoid such inconsistency, LCA outputs that holistically capture both resources usage and their associated environmental impacts were selected in the present study. More specifically, the impact categories of Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP) and Cumulative energy demand (CED) were estimated by applying the methodology presented by Bartzas and Komnitsas [18,27]. In brief, the consumption of raw materials i.e. fertilizers, pesticides, irrigation and processing water, energy and agricultural waste, as well as emissions of pollutants (CO_2, CH_4, VOCs, NOx, SO_2 etc.) to air, water and soil were taken into account based on the "cradle-to-gate" approach. More specifically, the following sub-criteria related to the environmental aspect of sustainability were selected:

(i) GWP: It is used to calculate the greenhouse effect and compare the potency of different greenhouse gases with that of CO_2 (in kg CO_2-eq).
(ii) AP: It refers to the increase in acidity of the soil and associated ecosystems due to chemical emissions derived from sulphur (S) and nitrogen (N) as NOx or ammonia (in kg SO_2-eq).
(iii) EP: It measures the excessive enrichment of waters and continental surfaces with nutrients and the associated adverse biological effects (in kg PO_4-eq).
(iv) CED: This impact was calculated based on the method proposed by Frischknecht et al. [28], in order to assess the energetic performance of pistachio production (in MJ kg^{-1}).
(v) Water use: refers to the amount of water used during different production steps in the life cycle chain (in m^3).

2.3.2.2. *Economic development*. Economic indicators are the most important factors reflecting the overall financial viability and profitability of farm families and agro-enterprises [29]. Three sub-criteria with respect to economic aspect of sustainability were selected:

(i) *Gross margin:* Gross margin is used to assess farm profitability. It is calculated as a difference between the farm revenue (price multiplied by yield) and variable costs. The sum of variable costs includes the costs for fertilizers and fuels as well as the cost of maintenance and labour.
(ii) *Holding size: The* holding size of the farm land (in ha) has positive effect on productivity and therefore its selection is considered of high importance for economic development.
(iii) *Agricultural productivity/Yield:* The agricultural productivity is one of the main factors that affects the economic performance of an orchard/farm. It is measured by the quantity of crop output produced (farm output/yield) per hectare during a given period (kg y^{-1} ha^{-1}).

2.3.2.3. Social growth. Only over the last years, measurement of social growth has become a crucial topic for assessing agricultural sustainability [9]. In fact, the self-reliance of the farmers contributes to the retention of agricultural population in the countryside or other isolated regions such as islands and is the main pre-condition to achieve autonomy and sustainability [30]. To this context, the following five social sub-criteria were taken into account:

(i) *Age of farmer:* Age is a key indicator that is expected to influence farm management technology adoption by the farmer in any direction depending on its position in the life cycle chain, education level, managerial features, commitment to farming, size of farming operation and experience (in years).
(ii) *Education level*: The education level is directly related to farmers' skills to timely adopt sustainable management practices and successfully promote the use of modern technologies. It is measured using an ordinal scale 1 to 5 (1 – no primary education, 2 - primary education, 3 - secondary education, 4 - tertiary education, 5 - higher level in tertiary education).
(iii) *Agricultural employment*: Agricultural employment is an indicator that represents the level of employment along with its social implications in the agricultural sector through the provision and distribution of income. This indicator is a source of labour for the rural population that can be easily quantified in terms of hours of work per ha during the cultivation period.
(iv) *Stakeholders support:* It is crucial for the success of any change in the farm management practices adopted, creates awareness and defines the needs for training towards sustainable performance. This indicator is quantified as the total number of training programs/seminars followed by the farmer.
(v) *Participation in Associations:* Although participation in associations can be costly in terms of time and other resources, it is an easy way to access markets and increase social capital (in years of involvement).

2.3.3. Data collection and statistical analysis

To clearly grasp the needs of an integrated methodology approach, input data were obtained from different sources via several sampling methods, involving:

(a) primary data for the period 2012–2016 collected though an on-site survey of 16 pistachio orchards (from 0.2 to 4 ha) located in the study area and
(b) representative data obtained from questionnaires filled (58 on total) through personal interviews with experts, farmers and representatives of farmer associations. Both on-site and survey data were related to pistachio orchards with full productive mature trees and a 6-month irrigation period per year.

Statistical analysis was performed using IBM SPSS v.22 [31] to test the validity and reliability of the results obtained from the filled questionnaires. For that purpose, a $p < .05$ significance level was used while the reliability of scales was tested for consistency by Cronbach's alpha value. A detailed descriptive analysis of the both questionnaire data characteristics obtained in the present study is provided in the Supplementary material (S-1).

2.3.4. Development of alternative agricultural production scenarios

In order to verify the developed AHP model for pistachio production in Greece, three alternative scenarios (two currently used and one hypothetical) were investigated based on extrapolation of the survey data obtained in the 5 year period (2012–2016):

(i) Baseline scenario (BL). This scenario refers to actual current production and waste/by-product management practices that take place in the study area along with their socio-economic impact.
(ii) Composting scenario (CO). The CO scenario considers the partial shift to organic production with the use of local renewable resources; this scenario was implemented in two pilot fields selected in the frame of AGROSTRAT project [26]. Briefly, 50% (i.e. 250 kg ha^{-1} y^{-1}) of the currently used N/P/K chemical fertilizers is replaced by compost (20 t ha^{-1}) produced on-site (composting) from organic solid wastes generated within the same cultivation system, along with the addition of other available raw materials such as goat and sheep manure.
(iii) Biochar use scenario (BU). This hypothetical scenario includes the production of biochar from the produced agricultural wastes/by-products according to Komnitsas et al. [32] and its soil application to improve soil properties and promote carbon sequestration (CO), mitigation of non-CO_2 greenhouse gas emissions and reduction of nutrient leaching. More specifically, in the BU scenario, the production of biochar using 100% of the currently produced solid pistachio waste, i.e. 3573 kg ha^{-1} y^{-1}, is considered. It is believed that this

scenario may imply an eco-friendly and economic-growth-oriented vision; however, its long-term sustainability needs to be further evaluated. It is important to note that data concerning qualitative factors (social growth criterion) were taken from the CO scenario where needed, since both scenarios present identical options in respect to waste management and reuse.

2.3.5. *Sensitivity analysis*

Sensitivity analysis was carried out to address the uncertainty and subjectivity of the proposed AHP model by quantifying the influence of the criteria weights on the resulting decisions, i.e. alternative scenarios [23,27]. In this study, Expert choice® v.11 decision making software [33] was used by assigning different weight vectors to the main criteria/sub-criteria based on the following cases studied: (i) all criteria have an equal weight of 33.33% and (ii) the weight each main criterion given was 80% at a time, while the other two criteria were considered to be of the same importance (10%).

3. Results and discussion

3.1. *Results with respect to sustainability performance*

According to the AHP method employed in the first stage, the comparison matrix for determining the weights of the three criteria (environmental, economic and social) with respect to sustainability performance is presented in Table 2.

Calculated weights based on expert responses indicate that the main environmental criterion is the most important sustainability factor (0.540), followed by the economic (0.297) and social (0.163) main criteria, respectively. This suggests that the main environmental criterion may generate larger impact towards the sustainable production of pistachios. As shown in the footnote of Table 2, the maximum eigenvalue of the comparison matrix (λ_{max}) and the consistency index (CI) are 3.009 and 0.005, respectively, while the CR that represents the consistency ratio is 0.008. Since the CR value falls within the acceptable value of <10% [34], the comparison matrix is checked for its consistency. Similarly, the local and global weights for sub-criteria calculated based on their comparison matrices using the AHP method are shown in Table 3. The local weights represent the relative scores of the criteria/sub-criteria in a group, e.g. environmental, while their global weights are obtained by multiplying the local weights with the global score of their corresponding group.

Regarding the environmental criterion, both Acidification Potential and Eutrophication Potential are the most important sub-criteria presenting the same local weight of 0.279, i.e. 27.9% importance among sub-criteria group in the main criterion. Among the remaining sub-criteria related to environmental performance, Water Use ranks third, with a local weight of 0.169 followed by Cumulative Energy Demand (0.148), and Global Warming Potential (0.125).

Based on the calculated weights assigned to economical criterion, Productivity Yield is ranked as the most important sub-criterion, with a local weight 0.484. A less important criterion is Gross Margin (0.348), since this is strictly related to yield, followed by Holding Size (0.168).

Among the Social growth sub-criteria, the most important is Agricultural employment, with a local weight of 0.328 followed by Education Level (0.277). Quite similar weights were calculated for the sub-criteria of Age of Farmer (0.139), Stakeholders Support (0.128) and Participation in Associations (0.128), respectively.

3.2. *Alternative agricultural production scenarios*

In the second stage, the results obtained by the aforementioned criteria weights against the alternative scenarios are presented in Table 4. As shown, Composting and Biochar use Scenarios were identified, with a negligible difference, as the most sustainable options for the pistachio production in Aegina based on the sustainability criteria and global weights considered in this study. More specifically, CO is the best ranked scenario, with priority of 37.9%, followed by the BU with priority of 35.7%. On the other hand, BL was the worst ranked scenario, with priority of 26.4%, as a result of its low performance with respect to environmental (23.5%) and social (24.3%) criteria, respectively. It is noteworthy that the criteria of AP and EP presented both the least importance (11.1%) in relation to the environmental dimension of the BL scenario, while cumulative energy demand and water use attained the highest importance i.e. 54.0% and 50.0%, respectively. Only regarding economic performance, all alternatives exhibited quite the same priority values (~33.0%). This is because the economic criterion is highly dependent on the yield obtained and slight differences for all alternative scenarios were observed in the production period investigated.

Considering the normalized scores obtained by the sub-criteria, it is observed that the proposed alternative production scenarios i.e. CO and BU have a considerable positive impact on the environment with priorities of 40.5% and 36.0%, respectively because of their lower acidification potential and eutrophication potential impacts compared to BL scenario, thus exhibited equal performance (44.4%) in both cases. The anticipated environmental benefits can be attributed to

Table 2 – Comparison matrix[a] and weights of main criteria with respect to sustainability performance.

Criteria	Environmental	Economic	Social	Weights
Environmental	1	2	3	0.540
Economic	1/2	1	2	0.297
Social	1/3	1/2	1	0.163

a λ_{max} = 3.009, CI = 0.005, CR = 0.008 < 0.1.

Table 3 – Local and Global weights for sub-criteria.

Main Criteria	Weights	Sub-criteria	Local weights	Global Weights	Ranking
Environmental	**0.540**				
		Global Warming Potential	0.125	0.068	5th
		Acidification Potential	0.279	0.151	1st–2nd
		Eutrophication Potential	0.279	0.151	1st–2nd
		Cumulative Energy Demand	0.148	0.080	4th
		Water use	0.169	0.090	3rd
Economic	**0.297**				
		Gross Margin	0.348	0.103	2nd
		Holding Size	0.168	0.050	3rd
		Productivity Yield	0.484	0.144	1st
Social	**0.163**				
		Agricultural Employment	0.328	0.054	1st
		Age of Farmer	0.139	0.023	3rd
		Education Level	0.277	0.045	2nd
		Stakeholders Support	0.128	0.021	4th–5th
		Participation in Associations	0.128	0.021	4th–5th

Table 4 – Normalized performance of the alternative scenarios against the sustainable criteria/sub-criteria adopted in this AHP study.

Main Criteria/Sub-criteria	Baseline Scenario (BL)	Composting Scenario (CO)	Biochar Use Scenario (BU)
Environmental	**0.235**	**0.405**	**0.360**
Global Warming Potential	0.163	0.540	0.297
Acidification Potential	0.111	0.444	0.444
Eutrophication Potential	0.111	0.444	0.444
Cumulative Energy Demand	0.540	0.297	0.163
Water use	0.500	0.250	0.250
Economic	**0.334**	**0.321**	**0.345**
Gross Margin	0.122	0.320	0.558
Holding Size	0.240	0.550	0.210
Productivity Yield	0.500	0.250	0.250
Social	**0.243**	**0.390**	**0.367**
Agricultural Employment	0.260	0.327	0.413
Age of Farmer	0.413	0.260	0.327
Education Level	0.196	0.493	0.311
Stakeholders support	0.124	0.517	0.359
Participation in Associations	0.200	0.400	0.400
Overall score (Rank)	***0.264 (3rd)***	***0.379 (1st)***	***0.357 (2nd)***

lower SO_2 and NO_x emissions as result of carbon sequestration achieved due to composting of the organic material (CO scenario) and by the biochar application to soil (BU) instead of dumping of pistachio waste on the field. However, it is underlined that the benefits of the two alternative scenarios will become more visible after a longer period of time, since they mainly aim to improve soil quality.

3.3. *Sensitivity analysis*

The main results of the sensitivity analysis conducted for four different cases are shown in Fig. 3. Performance of each alternative scenario (priorities) is presented as coloured lines and numerical values (right column) while the impact of varied weights with respect to sustainable pistachio production (objective) in each case investigated are presented as vertical bars (left column).

As can be seen from Fig. 3a, when all sustainability criteria have equal weight of (33.33%), no significant changes are observed in the performance of the three scenarios in contrast to their original values obtained by the AHP model, thus indicating that reliable results were obtained using multi-criteria analysis. In this context, sensitivity results demonstrate that the composting scenario (CO) is the optimal alternative with respect to sustainability in the cases when the environmental (Fig. 3b) or the social (Fig. 3d) criteria are assigned a global weight of 80% at a time and the remaining 20% is equally assigned to the other criteria. The reason for this result lies in the lower GHG emissions along with the high pistachio waste reduction achieved in the CO. However,

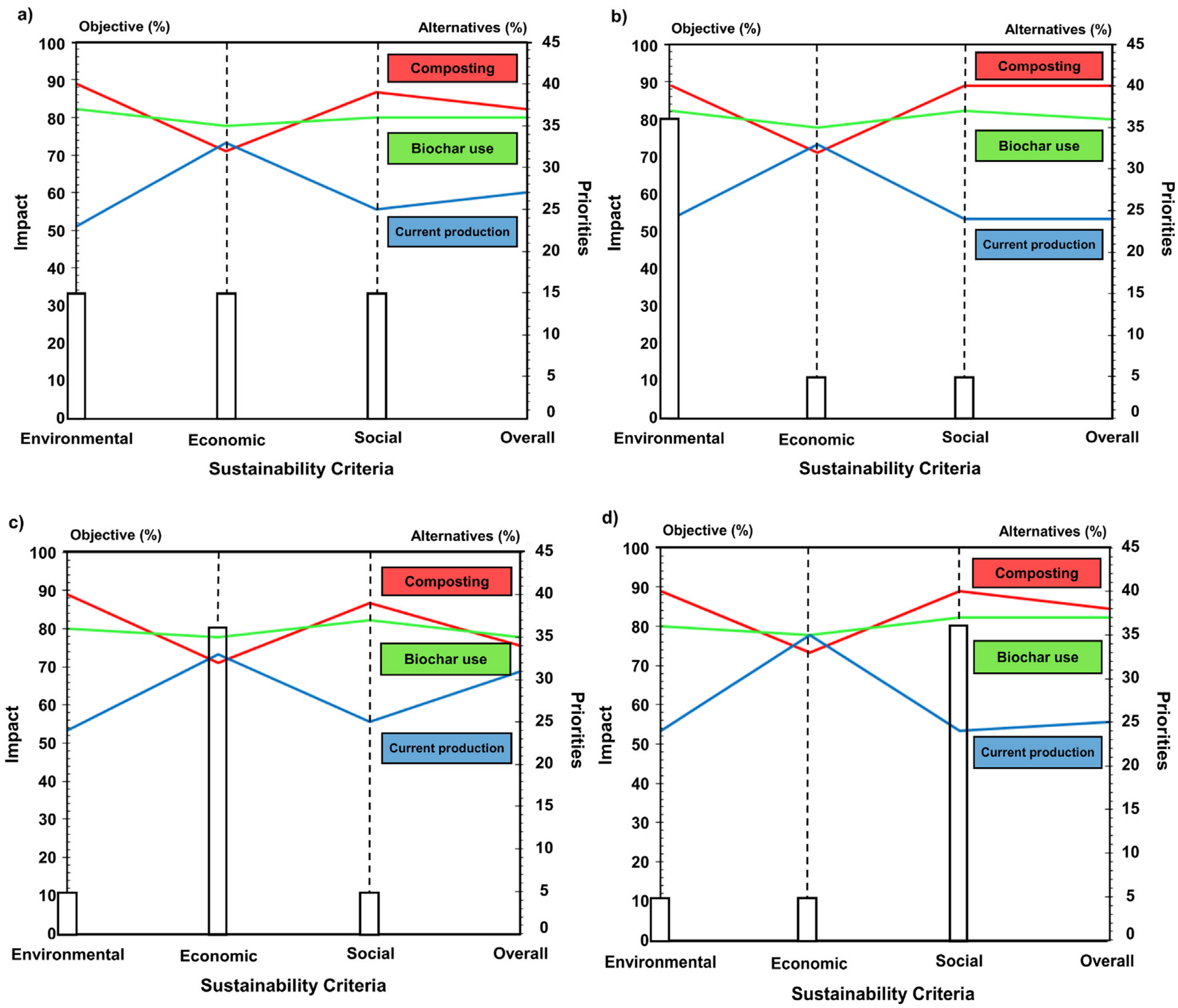

Fig. 3 – Performance sensitivity of the results using the Expert choice software.

in the case (Fig. 3c) when economic criterion received a weight of 80%, the BU was ranked first with priority ranking of 34.9%, followed by CO (0.338) and BL (0.313). The main reason behind this is that the cost of composting is in most cases almost double compared to biochar production; this may differ though since it depends on the technology used in each case [35].

In most cases investigated, BL corresponding to current pistachio production practices is ranked last, thus suggesting that the current farm practices are unsustainable, due to the high amount and sole use of chemical fertilizers, which are produced from non-renewable resources that in most cases are imported and therefore economically unaffordable.

4. Conclusion

In the present study, a holistic decision making methodology that integrates life cycle analysis (LCA), environmental risk assessment along with on-site-farm and regional surveys and the application of Analytical Hierarchy Process (AHP) is developed. The integrated method was then applied to assess the sustainability of pistachio production in Aegina, Greece and identify/propose the most sustainable management practices at regional level.

To this context, three alternative scenarios, i.e. baseline scenario representing the current cultivation operations as well as Composting and Biochar Use scenarios aiming at sustainability improvement via GHG mitigation, waste reduction, irrigation water needs minimization and soil improvement were investigated. In total, a set of 13 representative sub-criteria were evaluated and the importance of their weights were identified in the developed hierarchy. Results of AHP analysis demonstrated that CO is the best sustainable management scenario investigated, mostly based on its environmental pillar as a consequence of the associated benefits gained by on-site composting of the currently produced organic solid waste and their reuse in the field to improve soil properties. Furthermore, the obtained results using sensitivity analysis also proved the robust performance of the composting scenario among others when tested under several variations of the weights assigned in the AHP model.

Consequently, the proposed methodology can be easily adapted to other similar crops and areas in the Mediterranean region and thus help various decision makers and stakeholders to prioritize farm management practices and identify efficient adoption ways in achieving sustainable agricultural production at a regional level.

Declaration of Competing Interest

The authors declare that there is no conflicts of interest.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.inpa.2019.09.005.

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