Sustainability assessment of olive groves in Andalusia: A methodological proposal

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Abstract

The olive industry in Andalusia, Spain, has recently undergone important changes due to the expansion and intensification of farming. This process is causing sustainability problems, not only in socio-economic terms (decrease in olive farmers' profits) but also from an environmental point of view (soil erosion, water pollution and biodiversity losses). The main objective of this study is to develop a methodology to analyse the sustainability of olive-growing farms in Andalusia. This methodology will allow us to take into account the three dimensions of sustainability (economic, socio-cultural and environmental), as well as to obtain a precise diagnosis of olive groves through a selection of indicators. A total of 27 indicators were selected, of which 7 analyse the economic dimension of sustainability, 9 analyse the socio-cultural dimension and 11 evaluate the environmental sustainability of olive groves in Andalusia. This set of indicators aims to help both decision-making processes and the implementation of public policies.

Key words: *sustainability, olive farming, Andalusia.*

Résumé

Le secteur oléicole a récemment subi des changements importants en Andalousie, en Espagne, à raison de l'expansion et de l'intensification de l'agriculture. Ce processus est à l'origine des problèmes de durabilité, non seulement à partir d'une dimension socio-économique (réduction du profit des oléiculteurs), mais aussi d'un point de vue environnemental (érosion des sols, pollution de l'eau ou perte de la biodiversité). L'objectif principal de cette étude est de développer une méthodologie pour analyser la viabilité des exploitations oléicoles en Andalousie. Cette méthode nous permettra de garder à l'esprit les trois dimensions du développement durable (économique, socioculturelle et environnementale), ainsi que d'obtenir un diagnostic précis des oliviers à travers une sélection d'un ensemble d'indicateurs. Un ensemble de 27 indicateurs ont été sélectionnés, dont 7 analysent la dimension économique de la durabilité, 9 analysent la dimension socioculturelle et 11 évaluent la durabilité de l'environnement de l'oliveraie en Andalousie. Cet ensemble d'indicateurs vise à aider à la fois les processus de décision et de mise en œuvre des politiques publiques.

Mots clés: durabilité, exploitation oléicole, Andalousie

1. Introduction

1.1. Olive groves as multifunctional agricultural systems

Andalusia is the world's leading olive-producing region. Olive groves cover an area of 1.5 million hectares in Andalusia (30% of the agricultural land in Andalusia, 59% of the olive-growing area in Spain, 30% of the olive-growing area in the EU and 19% worldwide). In macroeconomic terms, olive groves are the second most important agricultural sector in this region, behind horticulture, generating an income of 2,660 million Euro (M€) in 2007 (26% of agricultural production in Andalusia).

Olive groves are identified as a 'social crop' as this is one of the agricultural activities that creates most jobs per hectare. Indeed, the olive industry creates 32% of agricultural employment in Andalusia (91,327 direct jobs), more than other dynamic agricultural sectors (i.e., horticulture). In summary, olive grove production is an important socio-economic activity, which is particularly relevant in rural municipalities where olive farming is almost the only source of income for the population (CAP, 2008).

The environmental relevance of olive groves is also worth highlighting. Traditionally, olive groves in Andalusia were associated to high biodiversity, being an example of a 'high natural value' (HNV) agricultural system. This was possible due to low intensity olive farming (minimum use of agrochemicals), old olive trees with semi-natural herbaceous vegetation and their location in areas with different land uses (Beaufoy and Cooper, 2009). However, in recent times this ecological value has diminished due to the 'modernisation' of olive groves. This modernisation has been based on the expansion (new farms that have led to single-crop systems in large areas of Andalusia) and intensification of the crops (intensive use of fertilisers, pesticides and machinery and a large number of farms with uncovered soil). In spite of this modernisation process, many olive grove systems are still associated with natural ecosystems, and 138,536 hectares of olive groves (10% of the olive grove area in Andalusia) are included in Natura 2000.

In summary, olive grove systems provide a whole array of goods and services to the society in Andalusia. Some of these goods and services are 'commodity outputs', such as olive oil, as they are sold on the market. Alternatively, other goods and services are 'non-commodity outputs' or 'public goods' as they have no market to be sold on (e.g., the contribution of olive growing to maintaining high natural value agro-ecosystems or to supporting rural areas). Due to the lack of markets for public goods, olive growers do not receive any monetary compensation for providing them (OECD, 2001; Caron, et al., 2008; Kallas et al., 2008). The concurrence of production systems that provide both com-

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modities and non-commodities to the society and the possibility of 'market failure' (unsuitable supply of public goods due to the lack of incentives –remuneration - for a suitable supply) makes olive farming a perfect example of a multifunctional agricultural system (Viladomiu and Rosell, 2004; Arriaza et al., 2008).

1.2. Recent development of olive groves and sustainability problems in Andalusia

Spain's accession to the European Union (EU) and the implementation of Common Agricultural Policy (CAP) have encouraged the expansion and intensification of olive grove systems in Andalusia over the last two decades. However, this rapid expansion and intensification have caused several negative environmental impacts (Beaufoy and Pienkowski, 2000; Guzmán-Álvarez, 2005; García Brenes, 2007; Gómez Calero, 2009):

a) *Soil erosion.* This environmental impact has been exacerbated in recent years due to the expansion of olive groves towards soils with unfavourable conditions for agricultural production (steep slopes, lands particularly sensitive to erosion or with frequent torrential rain). These adverse conditions and the poor management of soil by farmers have damaged natural vegetation cover (farms with uncovered soil). The Regional Government in Andalusia (CAP, 2008) reported that 29.7% of olive farms had moderate soil erosion problems (12-50 t/ha·year), 11.8% suffered high soil erosion (50-100 t/ha·year) and 11.2% very high soil erosion (more than 100 t/ha·year).
b) *Overexploitation of water resources*. Before the 1980s, most olive trees in Andalusia were rain-fed, but the intensification of the crop has seen the emergence of more than 400,000 hectares of irrigated olive groves. Although olive trees have low water requirements and are usually irrigated using highly efficient irrigation systems (water extractions vary between 1,500 and 2,000 m^3/ha·year), the pressure on water resources is high. Increasing water extraction causes not only the overexploitation of water resources, but also jeopardises the satisfaction of other water demands.
c) *Non-point source water pollution*. Olive grove systems have contributed to a decrease in water quality due to the use of agrochemical products (mainly herbicides and fertilisers). Non-point source water pollution in rivers, dams and aquifers has sparked several sanitary alarms in the last few years in Andalusia, such as the prohibition of drinking water from dams surrounded by olive trees.
d) *Biodiversity loss*. One of the main characteristics of olive groves in the 1980s (traditional farming) was the high biodiversity associated with the crop. However, the intensification of olive farms has changed this situation (disappearance of vegetable cover, water pollution, high insecticide use and soil erosion) and diminished both the number and diversity of animal species in olive grove systems.
e) *Damage to traditional agricultural landscapes*. Olive grove systems coexisted in the past with other crops such as pastures, vineyards or cereals. However the intensification of olive grove systems has seen this diversity disappear and olive groves are now often the only crop on farms.

1.3. Objective

Olive farming sustainability in Andalusia should be revisited due to the impacts caused by the expansion and intensification of this crop. This study aims to develop a theoretical framework and a methodology to evaluate the sustainability of olive farms. All three dimensions of sustainability (economic, social and environmental) are considered in the analysis and a set of indicators was selected in order to obtain a precise diagnosis of olive farms in this region.

The methodology developed in this study could be applied in the future to contribute to improving both decision-making processes and the implementation of public policies in the olive industry (e.g. policy reforms regarding agricultural revenues, agri-environmental schemes or agricultural management systems and rural development).

2. Theoretical framework

2.1 Conceptualisation of 'sustainable agriculture'

There is a broad consensus that agricultural sustainability meets the following requirements (Raman, 2006): a) enhance food security, b) protect natural resources and prevent environmental degradation, c) be economically viable and d) be socially acceptable. Taking these requirements into consideration, agricultural sustainability can be defined by the *'mosaic' approach*, as a concept that encompasses three main dimensions (Yunlong and Smit, 1994; Hansen, 1996; Raman, 2006):

- *Environmental sustainability*. Sustaining the preservation of biological productivity and ecosystem services is basic to achieve sustainable agriculture. Indeed, agricultural sustainability can be defined as the ability to ensure greater agricultural productivity while simultaneously conserving natural resources and preventing the depreciation of ecosystems.
- *Economic sustainability*. In order to be sustainable, agriculture must be economically viable, ensuring not only adequate profitability for farmers (microeconomic approach), but also a positive contribution to national/regional income (macroeconomic approach).
- *Socio-cultural sustainability*. Agriculture must be socially and culturally relevant, i.e. it should ensure food security and equitable income distribution, as well as contributing to the viability of rural communities.

Analysing agricultural sustainability requires some geographic bounds. Like most related works in the literature, farms (Andalusian olive farms in our case) are considered the basic unit for this analysis of agricultural sustainability. This option has been taken because farms are the targets of the policies focused on the governance of the agricultural industry (van der Werf and Petit, 2002; Poeta and Marta-Costa, 2006; van Passel et al., 2007).

2.2. Empirical evaluation of agricultural sustainability through a set of indicators

Agricultural sustainability has been measured using four methodological frameworks: a) analysis of sustainability indicators (Bell and Morse, 2008), b) analysis of seasonal patterns of productivity (Lynam and Herdt, 1989; Byerlee and Murgai,

2001) , c) resilience and sensitivity analysis of agricultural systems (Blaikie and Brookfield, 1987), and d) simulation techniques (Hansen and Jones, 1996). After evaluating the pros and cons of each methodological approach, there is widespread scientific agreement that constructing and calculating sustainability indicators is the most adequate approach to analysing agricultural sustainability (Smith and McDonald, 1998; Ness et al., 2007). This study employs that methodological framework to evaluate the sustainability of olive farms in Andalusia.

The methodology approach followed to evaluate sustainability is based on two main criteria: reliability and applicability. *Reliability* demands both a selection of indicators based on the characteristics of olive groves in Andalusia, as well as a suitable questionnaire design to collect primary data at farm level and later to calculate the indicators. *Applicability* requires an easy, fast and inexpensive *methodology*, as all of these requirements facilitate the empirical implementation of an approach to guide the design of agricultural policies. Reliability and applicability cannot be achieved simultaneously, but a balance between the two criteria must be preserved when analysing sustainability. An interesting example of a both reliable and applicable empirical approach to assessing olive farm sustainability in Tunisia with sustainability indicators can be found in Laajimi and Ben Nasr (2009).

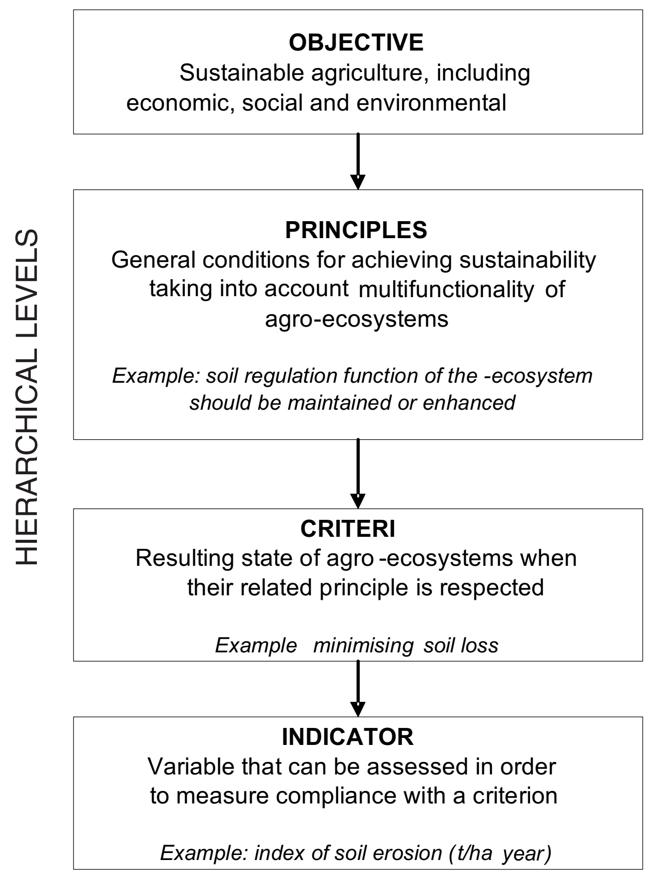
2.3. Theoretical framework to analyse agricultural sustainability through a set of indicators

Within the potential analytical frameworks to evaluate agricultural sustainability based on indicators, it is worth highlighting the SAFE (*Sustainability Assessment of Farming and the Environment Framework*) alternative (Sauvenier et al., 2006; van Cauwenbergh et al., 2007). The general aim of this framework is to evaluate agricultural sustainability following a hierarchical structure based on the PC&I theory by defining different levels sequentially. In this sense, three levels were distinguished: a) principles, b) criteria and c) indicators:

- *Principles*. This first hierarchical level is related to the multiple functions of the agro-ecosystem and consequently includes the three pillars of sustainability: the economic, environmental and social dimensions. Principles are general conditions for achieving sustainability and they must be considered universally applicable to any agricultural system.
- *Criteria*. A criterion is the resulting state of agricultural systems when its related principle is respected. The use of criteria transfers principles to agro-ecosystems (olive farms in this particular case). Indeed, criteria are more specific than principles and therefore easier to link indicators to.
- *Indicators*. An indicator is a variable of any type that can be assessed in order to measure compliance with a criterion. Indicators should produce a representative picture of the sustainability of any agricultural system in all its aspects (economic, social and environmental).

This study follows the SAFE analytical framework in order to develop a methodology to assess the sustainability of olive grove systems in Andalusia. Principles, criteria and indicators are presented in the following sections.

Fig. 1. *SAFE Hierarchical Framework.*



3. Methodology

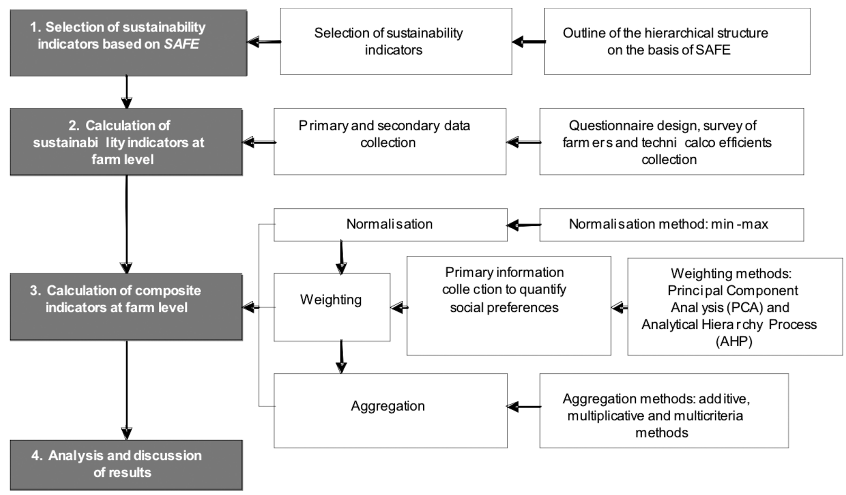
3.1. Outline of the methodology

Fig. 2 is a flow chart that summarises the methodology followed in this study. Four steps were identified in order to analyse agricultural sustainability:

1. *Selection of basic indicators*. Using SAFE as a methodological framework, we defined a number of principles and criteria regarding the agricultural sustainability of olive groves in Andalusia (see Section 3.2). Taking these specific principles and criteria into account, we identified some sustainability indicators on the basis of an extensive literature review (see Section 4). As a result, a hierarchical structure for our case study was established including 6 principles, 22 criteria and 27 sustainability indicators.
2. *Calculation of sustainability indicators at farm level*. Once information is gathered, the value of sustainability indicators is calculated at farm level. This step will be carried out in future research through primary (survey of farmers) and secondary (technical coefficients) data collection.
3. *Calculation of sustainability composite indicators at farm level*. Nardo et al. (2005a and 2005b), and OECD and JRC (2008) identified ten steps that analysts should follow in order to build composite indicators.
4. *Analysis, discussion and dissemination of results*. Carrying

out steps 2 and 3 will enable us to perform a comparative and critical analysis of results in future research. The conclusions derived from this analysis must improve the governance of agricultural management in the case study (olive groves in Andalusia).

Figure 2. Methodology outline.



This study is focused on the development of step 1, while the empirical application (steps 2 to 4) is postponed for future research.

3.2. Selection of principles, criteria and indicators

According to the SAFE analytical framework, the first step is to build the structure of the hierarchical framework including principles, criteria and indicators. As analysing agricultural sustainability requires not only a multidisciplinary approach, but also the participation of stakeholders (Raman, 2006; Purvis et al., 2009), this research was supported by a panel of 18 experts constituted *ad hoc*. This panel comprised 8 scientific experts in different fields, such as agricultural economics, sociology and rural development, ecology and environmental management and olive agronomy, as well as 10 experts from the olive growing sector (2 experts from the Regional Ministry of Agriculture and the Environment, 2 experts from agricultural organisations, 3 technical managers, 1 representative from the Spanish Association of Olive Municipalities and 2 olive farmers).

First, authors developed a draft document on principles and criteria regarding the sustainability of olive farms in Andalusia based on an extensive review of agricultural sustainability literature. This document was discussed with the panel of experts during a full-day meeting. The suitability of the approach to assess the sustainability of Andalusian olive farms was confirmed and the experts also agreed the hierarchy of principles and criteria to be used in the empirical analysis (see principles and criteria in Table 1).

In a second step, draft sets of indicators for each criterion were identified based on the literature review performed, taking into account the following criteria (Sauvenier et al., 2006; Bell y Morse, 2008): 1) solid analytical grounds, 2) measurability, 3) relevance for the sustainability of the agricultural system, 4) clarity, 5) policy relevance, 6) time and scale dependence and 7) adaptation. In addition to these criteria, and according to Pannell and Glenn's (2000) guidelines, only the indicators that can be calculated at a reasonable cost and in reasonable time were selected. All these indicators were also discussed with the panel of experts in a second full-day meeting, allowing a wide consensus on the 27 indicators finally chosen to assess the sustainability of olive farms in Andalusia.

4. Sustainability indicators

4.1. Economic sustainability indicators

According to the panel of experts, olive grove economic sustainability encompasses two principles: a) farmers' economic sustainability (i.e., the economic viability of olive farms) and b) public economic sustainability (i.e., food security and wealth creation in the society as a whole).

Table 2 shows that farmers' economic sustainability needs to meet three criteria: a1) the achievement of adequate income; a2) income stability, and a3) a guarantee that farmers can cope with changes. In addition, public economic sustainability addresses the following four criteria: b1) maximisation of production values, b2) achievement of stability in production values, b3) maximisation of the contribution to the regional economy, and b4) minimisation of dependence on subsidies. In order to quantify the achievement of these economic criteria, 7 indicators were selected (Table 2).

4.1.1. Olive farmers' profits (PROFITOLIV)

Net profit is defined as gross income less total expenses in a given period, including depreciation on capital goods (PROFITOLIV in €/ha·year). Only those olive farms that record positive PROFITOLIV scores will be sustainable in the long run. By contrast, negative scores would imply a gradual loss of farm assets which might lead farmers to abandon agricultural activity. The sustainability of olive farms would increase as PROFITOLIV records higher positive values.

4.1.2. Variation in farmers' profits (PROFITVAR)

The variation in farmers' profits over a period of time may be quantified through measures of dispersion from time series of annual profits. This variation was calculated by a coefficient of variation of the indicator PROFITOLIV over the last 8 years. Farmers are more efficient in input use and show high willingness to invest in their farms when facing a low risk scenario, i.e., when their income is yearly stable (Moschini and Hennessy, 2001). Farmer income stability over a period of time (low values of PROFITVAR) would result in olive farms being more economically sustainable.

4.1.1. Adaptation index (ADAPTIND)

Olive farm viability depends not only on income and costs (profits and their stability over time), but also on how they adapt to changes in technology, policy reforms, changes in agricultur-

Table. 1. *Principles and criteria to analyse the sustainability of olive groves.*

SUSTAINABILITY DIMENSIONS	PRINCIPLES	CRITERIA
ECONOMIC SUSTAINABILITY	Farmer's economic sustainability. Economic viability of olive farms.	Adequate farmer income
		Stability of farmer income
		Guaranteeing adaptation capacity
	Public economic sustainability. Food security and wealth creation	Maximising production value
		Stable production value
		Maximising the contribution to the regional economy
		Minimising dependence on subsidies
SOCIO-CULTURAL SUSTAINABILITY	Social sustainability. Contribution to rural development	Maximising job creation
		Guaranteeing the capacity to remunerate jobs
		Guaranteeing the intergenerational transfer of farms
		Adequate population density in rural areas
	Cultural sustainability. Conservation of cultural heritage	Guaranteeing the supply of high quality food
		Enhancing or protecting the visual quality of the landscape
		Protecting cultural and landscaping values
ENVIRONMENTAL SUSTAINABILITY	Biodiversity protection	Guaranteeing olive grove genetic diversity
		Enhancing or protecting biological diversity
		Enhancing or protecting habitat diversity (ecosystem)
	Protection of natural resources (soil and water)	Minimising soil erosion
		Enhancing or protecting soil fertility
		Enhancing or protecting soil and water quality
		Minimising water extraction from ecosystems
		Optimising energy balance

al outputs or inputs, market or environmental changes (climate change). It is quite difficult to calculate how well farms adapt to changes as this variable is non-observable and can be considered intangible (dimensionless). As regards coping with these difficulties, an *ad hoc* index is developed as a *proxy* to quantify a farmers' ability to cope with changes. The indicator ADAPTIND is defined as a mathematical function of a set of variables such as a) average slope of the land as a shaping factor of the technologies applied on the farm, b) irrigation water availability as a factor needed for a potential irrigation transformation of the farm, c) farmers' age, as young farmers are usually more willing to confront changes, and d) farmers' education, as educated farmers are usually more willing to confront changes. Therefore, ADAPTIND is expressed as a weighted sum of this set of variables:

$$ADAPTING = W_{slope}\ SLOPE + W_{water}\ WATER + W_{age} AGE + W_{education}\ EDUCATION \quad [1]$$

where w_i represents the importance of each variable in the indicator, *ADAPTIND* is the adaptation index (dimensionless); *SLOPE* shows land's slope (dimensionless); *WATER* shows irrigation water availability (dimensionless): No=0, Yes=1; *AGE* is a normalised (dimensionless) variable that shows a farmer's age and *EDUCATION* is a normalised (dimensionless) variable that shows a farmer's education.

The weights of each variable, w_i, were obtained from the panel expert valuation through the implementation of the Analytical Hierarchy Process (AHP) introduced in Saaty (1980). Each expert made pair-wise comparisons between all four variables, thereby obtaining the weights. In order to perform these pairwise comparisons, a 1-9 scale is used. The scores from these comparisons were used to build Saaty matrices, which were employed to determine the vector of priorities or weights $(w_1,...w_k,...w_n)$. The geometric mean method was applied to aggregate individual priorities. The resulting weights were: w_{slope}=37.1%; w_{water}=18.8%; w_{age}=23.0% and $w_{education}$=21.1%.

ADAPTIND values were bounded between 0 and 1. While zero implies a null adaptation to changes, a value of 1 denotes optimum adaptation to changes. The farms that recorded high scores for this indicator are viable in the long run and more sustainable from an economic perspective.

Table. 2. *Criteria and indicators of economic sustainability of olive groves.*

PRINCIPLES	CRITERIA	SUSTAINABILITY INDICATORS (*acronym*) [measurement unit]
Farmers' economic sustainability. Economic viability of olive farms.	Adequate farmer income	Olive farmer profit (*PROFITOLIV*) [€/ha·year]
	Stability of farmer income	Variation in farm profit (*PROFITVAR*) [dimensionless]
	Warranted capacity to face changes.	Adaptation index (*ADAPTIND*) [dimensionless]
Public economic sustainability. Food security and wealth creation	Maximising production values	Production values (*PRODVAL*) [€/ha·year]
	Stability in production values	Sales variation (*SALESVAR*) [dimensionless]
	Maximising the contribution to the regional economy	Contribution to Agricultural Value Added (*CONTRAAV*) [€/ha·year]
	Minimising subsidy dependence	Percentage of income from subsidies (*PERCSUBV*) [dimensionless]

4.1.4. Production value (PRODVAL)

The contribution of olive farms to food security can be approached by the value of olive production (€/ha·year). While a zero value of this indicator means farmer crop abandonment, the higher the value of this indicator, the greater the economic sustainability of the olive farm.

4.1.5. Changes in farm sales (SALESVAR)

Changes in farm sales over a period of time may be quantified through measures of dispersion. These changes were calculated using a coefficient of variation of the indicator PRODVAL over the last 8 years. Changes in the value of olive production (PRODVAL) due to changes in yields or prices imply a reduction in agricultural sustainability. Public economic sustainability requires stability in agricultural production every year. Production stability implies a steady olive oil supply chain, as it minimises the risk of olive supply being insufficient to meet demand. Therefore, the higher the SALESVAR score, the less economically sustainable the olive farm.

4.1.6. Contribution to Agricultural Added Value (CONTRAAV)

The contribution of olive farms to regional wealth can be assessed through gross value added (GVA). GVA is defined as income from output sales less expenses due to intermediate consumption goods. This indicator is a *proxy* to quantify olive farms' contribution to regional gross domestic product (GDP), as it shows the value added in the olive oil supply chain by olive farms. A negative score in this indicator denotes a loss of wealth in the regional society (i.e. low economic sustainability of olive farms from a public perspective). By contrast, positive values of CONTRAAV imply a positive contribution to regional wealth (i.e., high economic sustainability of olive farms from a public perspective).

4.1.7. Percentage of income from subsidies (PERCSUBV)

The economic viability of olive farms, excluding subsidies received by farmers, helps to achieve acceptable levels of economic sustainability from a public perspective. A zero value of the indicator PERCSUBV means the highest sustainability, as olive farm viability does not depend on public support (i.e., public subsidies). By contrast, higher values of this indicator represent lower economic sustainability.

4.2. Socio-cultural sustainability indicators

The socio-cultural sustainability of olive farms is based on two principles: a) social sustainability due to the contribution of olive farms to rural development, and b) cultural sustainability as olive farms contribute to the conservation of cultural heritage (Table 3). According to the panel of experts, social sustainability must address four criteria: a1) maximisation of job creation, a2) guarantee the ability of the olive industry to remunerate workers properly, a3) guarantee of the intergenerational transfer of olive farms, and a4) maintenance of adequate population density in rural areas. In addition, cultural sustainability must take into account three criteria: b1) guarantee of a quality food supply, b2) enhancement or protection of the visual quality of landscape and b3) preservation of cultural and landscape values. In order to quantify the achievement of each criterion, 9 indicators have been selected (Table 3).

4.2.1. Total labour (TOTLAB)

Job creation in rural areas is one of the most important social roles of agriculture. Total labour in olive farms was selected as an indicator to quantify the social implications of olive farms in rural areas (TOTLAB). A zero value in this indicator implies farmer crop abandonment. Higher values of TOTLAB show labour-demanding olive farms and thus more sustainable farms from a social perspective.

4.2.2. Apparent labour productivity (PRODLAB)

Fulfilling a social role requires not only creating jobs but also generating income to guarantee proper remuneration of jobs. Apparent labour productivity (PRODLAB) is considered as an indicator to quantify the capacity of olive farms to remunerate jobs. Apparent labour productivity is defined as value added per person employed. The higher the value of PRODLAB, the more sustainable farms are from a social perspective, because olive farms help job creation in the long run.

4.2.3. Risk of agricultural and rural abandonment (ABANDON)

Agricultural and rural abandonment is a consequence of a number of factors, such as low profitability of agriculture in less favoured areas (i.e. presence of environmental handicaps), perceived lack of opportunities for young people in rural areas and well-paid jobs in neighbouring territories. For our case study, agricultural and rural abandonment risk (ABANDON) is quantified considering farmers' responses to the question 'To what extent do you think that farm transfer to the next generation is guaranteed after your retirement?' Responses varied between 100% when the farm transfer is guaranteed and 0% when nobody manages the farm after the farmer's retirement. The higher the values of ABANDON, the higher the social sustainability of olive farms.

4.2.4. Percentage of family and permanent labour (FAMPERLAB)

Olive farming shows seasonal employment as labour is mainly demanded during harvesting (around 45% to 60% of total labour in olive farms is required during harvesting). Seasonal employment neither increases population density in rural areas nor contributes to rural development in olive grove systems. The indicator FAMPERLAB quantifies the percentage of family and permanent labour of total labour in olive farms. This indicator is bounded between 0 and 1. A value of zero means that labour demand is totally satisfied by part-time seasonal workers, while a value of one implies that labour demand is satisfied by family members or permanent workers. As family and permanent workers usually live close to the farm, values of FAMPERLAB close to 1 imply more socially sustainable olive farms.

4.2.5. Denomination of origin membership (ORIGIN)

Agriculture must provide high quality food. Olive oil quality is assessed using two indicators, classification under a Denomination of Origin (DO) and the percentage of olive oil produced by the farm that qualifies as 'extra virgin'. First, we analyse whether the olive oil produced by the farm is included in one of the 12 protected DOs recognised in Andalusia. The indicator ORIGIN varies between 1 if the olive farm is a member of a DO and zero if not. A value of one denotes the highest cultural sustainability of an olive farm.

4.2.6. Percentage of olive oil classified as extra virgin olive oil (VIRGINOIL)

Another indicator that contributes to quantifying food quality is the percentage of extra virgin olive oil produced by farms (VIRGINOIL). Extra virgin olive oil satisfies the high quality criteria on olive oil production. As the indicator VIRGINOIL is a percentage, it is bounded between 0 and 1. Values close to 1 show that most of the olive oil produced on the farm is extra virgin and consequently the sustainability of the olive farm is higher.

4.2.7. Percentage of farm planted with crops other than olive trees (OTHERCROP)

One of the cultural sustainability criteria is to protect the visual quality of agricultural landscape. Two indicators are considered in this analysis to meet this criterion, the percentage of the farm with crops other than olive trees and soil cover. The first indicator (OTHERCROP) is defined as the percentage of land covered by crops other than olive trees. As the visual quality of olive grove landscapes in Andalusia includes contrasting colours and textures due to a mixture of olive trees and other crops (Arriaza et al., 2004), breaking single-crop farming contributes to enhancing the visual quality of the landscape. The indicator OTHERCROP ranges from 0 to 1. A value of zero means a farm

Table. 3. *Criteria and indicators of socio-cultural sustainability of olive groves.*

PRINCIPLES	CRITERIA	SUSTAINABILITY INDICATORS (*acronym*) [measurement unit]
Social sustainability. Contribution to rural development	Maximising job creation	Total labour (*TOTLAB*) [labour_unit/ha·year]
	Warranted capacity to remunerate jobs	Apparent labour productivity (*PRODLAB*) [€/labour_unit]
	Warranted intergenerational transfer of farms	Risk of agricultural abandonment (*ABANDON*) [%]
	Adequate population density in rural areas.	Percentage of family and permanent labour supply (*FAMPERLAB*) [%]
Cultural sustainability. Conservation of cultural heritage	Warranted supply of quality food	Guarantee of origin membership (*ORIGIN*) [dimensionless qualitative: 0,1]
		Percentage of olive oil classified as extra virgin olive oil (*VIRGINOIL*) [%]
	Enhancing or protecting the visual quality of the landscape	Percentage of land with crops other than olive groves (*OTHERCROP*) [%]
		Soil cover (*COVER*) [%]
	Protecting cultural and landscaping values	Index of protection of olive heritage (*HERITAGE*) [dimensionless] bounded [0,1]

solely consisting of olive trees, which does not enhance the visual quality of the landscape (lowest cultural sustainability), whereas a value of 1 indicates a multiple-crop farm with higher quality agricultural landscape (highest cultural sustainability).

4.2.8. Soil cover (COVER)

As soil cover contributes to enhancing landscape valuation (Arriaza et al., 2004), soil cover has also been selected as an indicator to quantify the visual quality of agricultural landscape. This indicator is actually defined as the percentage of days during the year in which vegetation covers the soil. In this case a value of zero implies uncovered soil and low-valued olive grove landscape, whereas soils with vegetation denote high-valued landscape (higher sustainability).

4.2.9. Index of protection of olive heritage (HERITAGE)

Agricultural landscape includes the protection of a number of anthropogenic elements such as one hundred-year-old olive trees, ranches (*haciendas*), old olive oil mills, stone walls, hedges, etc. The protection of olive heritage is considered an intangible factor and consequently an *ad hoc* index was built to quantify this heritage (HERITAGE). The indicator HERITAGE is defined as a mathematical function of a set of variables such as the presence of the above-mentioned elements. Thus, this indicator is calculated as the weighted sum of these variables:

$$HERITAGE = W_{hund\_oliv} HUND\_OLIV + W_{ranch\_mill} RANCH\_MILL + W_{hedges} HEDGES + W_{tourism} TOURISM \quad [2]$$

where *HERITAGE* is the index of protection of olive heritage (dimensionless); *HUND_OLIV* shows the presence of one hundred-year-old olive trees on the farm (dimensionless: No=0, Yes=1); *RANCH_MILL* shows the presence of ranches or old mills for making olive oil on the farm (dimensionless: No=0, Yes=1); *HEDGES* denotes the presence of stone walls, terraces, hedges or similar heritage elements on the farm (dimensionless: No=0, Yes=1); and *TOURISM* captures the presence of rural tourism activities (rural houses, guide tours, etc.) on the farm (dimensionless: No=0, Yes=1).

Weights, w_i, were obtained from a valuation exercise implemented by the panel of experts using the AHP methodology: w_{hund_oliv}=10.8%; w_{ranch_mill}=27.8%; w_{hedges}=16.4% and $w_{tourism}$=44.9%.

The indicator HERITAGE is bounded between 0 and 1. A value of zero indicates the lowest sustainable olive farm as no heritage elements were present on the farm. The higher the values of this indicator, the higher the socio-cultural sustainability of olive farms.

4.3. Environmental sustainability indicators

The environmental sustainability of olive groves addresses two principles regarding biodiversity and protection of natural resources (Table 4). According to the SAFE analytical framework, these principles are connected to a number of criteria. The panel of experts agreed that biodiversity protection is concerned with three criteria: a1) guarantee of olive grove genetic diversity, a2) protection of biological diversity and a3) protection of habitat diversity (ecosystem). In addition, the panel of experts also agreed that natural resource protection will be achieved when b1) soil erosion is minimised, b2) soil fertility is protected or enhanced, b3) soil and water quality are protected or enhanced, b4) water extraction is minimised and b5) the agricultural energy balance is optimised. In order to quantify the achievement of each criterion, 11 indicators were selected (Table 4).

Table. 4. *Criteria and indicators of environmental sustainability of olive groves.*

PRINCIPLES	CRITERIA	SUSTAINABILITY INDICATORS (*acronym*) [measurement unit]
Biodiversity protection	Warranted olive grove genetic diversity	Number of olive grove varieties (*NUMVAR*) [olive grove varieties] number
	Enhancing or protecting biological diversity	Index of biological diversity (*DIVERSIND*) [dimensionless] bounded [0,1]
		Pesticide risk (*PESTRISK*) [kg rat/ha· year]
	Enhancing or protecting habitat diversity (ecosystem)	Percentage of land with crops other than olive grove (*OTHERCROP*) [%]
		Percentage of non-cultivated land (river flows, hedges, etc.) (*NONCULTIV*) [%]
Protection of natural resources (soil and water)	Minimising soil erosion	Soil erosion (*EROSION*) [t/ha· year]
	Enhancing or protecting soil fertility	Soil organic matter (*ORGMAT*) [dimensionless] bounded [0,1]
	Enhancing or protecting soil and water quality	Nitrogen balance (*NITROGENBAL*) [N kg/ha· year]
		Residual herbicide use (*RESHERB*) [kg active matter/ha· year]
	Minimising water extraction from ecosystem	Irrigation water use (*WATERUSE*) [m^3/ha· year]
	Optimising energy balance	Energy balance (*ENERGYBAL*) [kcal/ha· year]

4.3.1. Number of olive grove varieties (NUMVAR)

The genetic diversity of olive groves is a natural heritage that should be protected for future generations. However, the latest olive farming practices tend to homogenise olive grove varieties. A new indicator is included in the analysis to quantify the contribution of olive farms to the protection of the phylogenetic resources of olive farms. This indicator (NUMVAR) calculates the number of olive grove varieties on the farm. The minimum value of NUMVAR is 1, denoting the least sustainable olive farm (e.g. one olive grove variety on the farm).

4.3.1. Index of biological diversity (DIVERSIND)

Biological diversity in the ecosystems of olive groves includes several living beings. Quantifying species at farm level goes beyond the scope of this research, but an *ad hoc* indicator has been built to analyse biological diversity on olive farms (DIVERSIND). According to the panel of experts and on the basis of an extensive literature review on olive grove biodiversity (Duarte et al., 2009), the indicator DIVERSIND is defined as a mathematical function of a number of variables: a) presence of vegetation cover (flora and fauna protection), b) weed control through grazing (the least harmful soil management method), c) placement of branches from pruning into piles on the borders of the farm (refuge areas for some species), d) olives left on olive trees after harvesting (olives for fauna feeding), and e) removal of fertigation or subsurface drip irrigation (minimising animal poisoning):

$$DIVERSING = W_{cover}COVER + W_{graze}GRAZE + W_{piled}\,PILED + W_{olive}OLIVE + W_{irrig}IRRIG \quad [3]$$

where *DIVERSIND* is the biological diversity index (dimensionless); *COVER* shows the presence of vegetation cover (dimensionless: No=0, Yes=1); *GRAZE* represents weed control through grazing (dimensionless: No=0, Yes=1); *PILED* denotes the presence of piles of branches on the borders of the olive farm (dimensionless: No=0, Yes=1); *OLIVE*: the presence of olives on olive trees after harvesting (dimensionless: No=0, Yes=1); *IRRIG*: the removal of fertigation or subsurface drip irrigation (dimensionless: No=0, Yes=1).

Not all biological diversity variables can be calculated for every olive farm, as the last one (IRRIG) only refers to irrigated olive farms. In order to cope with this circumstance, the panel of experts estimated two sets of weights also implementing the AHP technique, one for irrigated farms (including five variables) and another for non-irrigated farms (including four variables). Weights for irrigated olive farms were: w_{cover}= 56.6%; w_{graze}= 9.6%; w_{piled}= 13.0%; w_{olive}= 9.8% and w_{irrig}=11.0%. Weights for non-irrigated olive farms were: w_{cover} = 63.6%; w_{graze} = 10.8%; %; w_{piled} = 14.6% and w_{olive} =11.0%.

The indicator DIVERSIND is bounded between 0 and 1. A value of 1 indicates optimum biodiversity on the farm and the highest environmental sustainability. By contrast, a value of zero shows that none of the practices mentioned above have been implemented to protect or enhance biological diversity on the olive farm.

4.3.3. Pesticide risk (PESTRISK)

Besides the previous indicator, biodiversity in the ecosystems of olive groves also depends on pesticide use. Pesticides help control pests but may also reduce the population of non-target species. A specific indicator is included to quantify the biocide activity of the active matters included in pesticides (PESTRISK):

$$PESTRISK = \sum_{m=1}^{m=M}\sum_{n=1}^{n=N}\frac{QPC_m \times CMA_{mn}}{DL50_n} \quad [4]$$

where *PESTRISK* is pesticide risk, measured as the potential biocide capacity of pesticides (rat kg/ha·year); QPC_m is the commercial product *m* used (kg of product *m*/ha·year); CMA_{mn} is the content of active matter *n* in the product *m* (g active matter *n*/kg of product *m*); $DL50_n$ is a lethal dose of 50% of the active matter *n* (g active matter *n*/rat kg).

The lowest value of this indicator is zero, denoting organic olive farms. These production systems are the most sustainable from an environmental perspective because they have the highest value of biodiversity protection. High values of PESTRISK indicate a reduction in both the biodiversity and environmental sustainability of olive farms.

4.3.4. Percentage of land with crops other than olive groves (OTHERCROP)

This indicator achieves two criteria as it contributes to the visual quality of agricultural landscape (see Section 4.2.7) and biodiversity, i.e. as a *proxy* of heterogeneity of land use and diversity of the ecosystem. A value of zero of OTHERCROP means a farm is devoted solely to olive farming without any other variety of ecosystems (i.e. lowest environmental sustainability). However, high values of the indicator represent the presence of several crops or land uses on the olive farm and thus the existence of several ecosystems and higher environmental sustainability.

4.3.5. Percentage of non-cultivated land (NONCULTIV)

This indicator assesses the value of non-agricultural ecosystems in olive farms such as river flows, rocky outcrops, etc. Considering these ecosystems allows us to account for the habitat of some species that do not live in olive grove systems, but rather in their surroundings. The lowest value of this indicator is zero, which would be the most unfavourable situation in terms of environmental sustainability. The higher the value of NONCULTIV, the more environmentally sustainable the olive grove is.

4.3.6. Soil erosion (EROSION)

Soil erosion is one of the main environmental problems in olive grove systems. Due to its importance, an indicator is included to estimate soil loss (EROSION) taking into account edafo-climatic conditions and crop management. This indicator is defined using the revised universal soil loss equation (RUSLE) (Gómez Calero and Giráldez, 2009):

$$EROSION = R \times K \times LS \times C \times P \quad [5]$$

where *EROSION* is the soil eroded (t/ha·year); *R* is the rainfall-runoff erosivity factor and depends on the amount of rainfall and peak intensity sustained over a period (dimensionless); *K* is the soil erodibility factor and depends on soil structures (dimensionless); *LS* is the slope length factor L computing for the effect of slope length on erosion and the slope steepness factor S computing for the effect of slope steepness on erosion (dimensionless); *C* is the cover-management factor showing the effect of cropping and management practices on erosion rates and P is the support practice factor representing the impact of support practices on the average annual erosion rate (dimensionless).

High values for the indicator EROSION (high soil loss) denote olive farms with a limited capacity to protect soil and which are consequently less sustainable from an environmental perspective.

4.3.7. Soil organic matter (ORGMAT)

Soil quality and quantity must be protected. Soil stock variations are quantified by the indicator EROSION, but soil quality also needs to be assessed through another indicator. As one of the main determinants of soil quality is soil organic matter, an *ad hoc* indicator was built to analyse the soil organic matter of olive farms (ORGMAT). The panel of experts agreed to define the indicator ORGMAT using the following mathematical function:

$$ORGMAT = W_{tillage}TILLAGE + W_{cover}COVER + W_{pruning\_rest}PRUNING\_REST \quad [6]$$

where *ORGMAT* is the index of soil organic matter (dimensionless); *TILLAGE* is tillage activities to maintain vegetation cover (dimensionless: more than one tillage activity per year=0, one or no tillage activity=1); *COVER* represents the vegetation cover (dimensionless: No=0, Yes=1); and *PRUNING_REST* is the milling of pruning rests into the soil (dimensionless: No=0, Yes=1).

The panel of experts estimated the weights (w_i) of equation [6] following the AHP method. Results were: w_{tilage}=7.7%; w_{cover}=49.3% and $w_{pruning\_rest}$=43.0%.

The indicator ORGMAT is bounded between 0 and 1. The highest value of the indicator (1) shows the most sustainable olive farms in terms of maintaining soil fertility.

4.3.8. Nitrogen balance (NITROGENBAL)

Nitrogen is an essential nutrient (macronutrient) for olive groves. However, an excess amount of nitrogen in soils may cause severe environmental damage. Excess nitrogen leaches into water bodies through rainfall or irrigation, generating nonpoint source water pollution (eutrophication). In addition, excess amounts of nitrogen may speed soil bacteria denitrification, emitting nitrogen oxides into the atmosphere, which causes the greenhouse effect (300 times more than the effect of CO_2). Due to both negative externalities, we include an indicator to quantify the impacts of nitrogen use. Nitrogen balance (NITROGENBAL) is defined as the physical difference (excess/shortage) between the nitrogen content of inputs (fertilisers) and outputs (harvesting). The difference between both quantities is the nitrogen liberated into the environment. This indicator is not bounded. Lower values of NITROGENBAL mean that nitrogen emissions into the environment are also lower (higher environmental sustainability).

4.3.9. Residual herbicide use (RESHERB)

Conservation tillage systems in olive groves lead to a greater use of herbicides. Agrochemicals are harmful to the environment and human health through aquifer and reservoir pollution. An indicator is defined to quantify the impact of agrochemicals on the environment. This indicator measures the active matter content of residual herbicides used in olive farming (RESHERB). The lowest value of this indicator is 0 indicating that no residual herbicides are used on the farm. This value suggests organic olive farming and consequently no damage is caused to the environment. Any increase in RESHERB should be considered a negative environmental impact.

4.3.10. Irrigation water use (WATERUSE)

Irrigated olive farms account for 47% of irrigated land in Andalusia (CHG, 2008). This consumption may involve problems of over-extraction and environmental damage. Consequently, an indicator measuring the water actually extracted from the ecosystems (irrigation) was chosen. The indicator WATERUSE takes a value of zero in non-irrigated olive farms. These farms are the most environmentally sustainable as water is not used for irrigation purposes. By contrast, higher values of the indicator mean greater water use for irrigation and potential negative impacts on aquatic ecosystems (i.e., lower environmental sustainability).

4.3.11. Energy balance (ENERGYBAL)

Agriculture is a substantial producer of greenhouse gases (GHG) due to farm mechanisation (fuel consumption) and biological processes such as microbial degradation of soil organic matter, bacteria denitrification, etc. In addition, agriculture is also considered a drain for GHG due to the photosynthetic activity of crops. Improving agricultural practices may play a role in mitigating climate change (Lal, 2008; Smith et al., 2008).

An indicator to compute the energy balance (ENERGYBAL) of olive farms is included in the analysis (Guzmán and Alonso, 2008). This balance is defined as the difference between the energy contained in the output (agricultural production) and the energy contained in agricultural inputs (input use and tillage practices). Positive values of ENERGYBAL mean that olive farms are using less energy than is produced in photosynthesis. The higher the positive values of this indicator, the higher the environmental sustainability. By contrast, negative values of ENERGYBAL suggest less sustainable olive farms from an environmental perspective (energy consumption is higher than energy production).

5. Conclusions

The methodological approach used to assess the agricultural sustainability of olive groves in Andalusia has three main advantages. First, the approach includes all three dimensions of sustainability (economic, socio-cultural and environmental). Secondly, the indicators were selected on the basis of olive grove cultivation practices in Andalusia, as confirmed by the panel of experts that supported this research. Thirdly, this methodology for analysing olive farm sustainability is useful, as indicator calculation can be easily assessed by carrying out a survey on olive farmers.

The methodological approach presented in this paper is currently being applied to a representative sample of olive farms in Andalusia. For this purpose we rely on the information provided by an *ad hoc* survey as our main source of data (primary data) to calculate the indicators. A specific questionnaire has been designed taking into account a population of 176,468 olive farms in Andalusia, according to the latest official data. Two-stage sampling has been employed to obtain a representative sample of olive farms. First, six agricultural districts have been randomly chosen, comprising 459,156 hectares of olive groves (31.3% of Andalusian agricultural land devoted to olive production). In each of these districts, 80 olive growers have been randomly selected for interviews and 480 valid questionnaires have been obtained. The survey was based on personal interviews and was conducted between May and September 2010.

In order to calculate the indicators, data collated from the survey has been complemented with additional information (secondary data), which is valid for all farms in the sample. This information has been collected from two main sources: a) scientific literature for technical coefficients valid worldwide, required to compute environmental pressures (e.g., the amount of nitrogen or energy contained per unit of input used or output produced on the farms, the amount of the active matters included in the agrochemicals used or the lethal dose of 50% of these active matters) and b) official statistics for input and output prices valid at regional level required to calculate sales and direct costs.

Having calculated sustainability indicators at farm level, we are now undertaking an in-depth analysis of the results obtained, including the calculation of sustainability composite indicators (Gómez-Limón and Riesgo, 2009; Gómez-Limón and Sanchez-Fernandez, 2010), as explained in Fig. 2 (methodology outline). Publication of the results obtained and the analyses performed are forthcoming.

The empirical evaluation of the sustainability of olive farms is expected to answer the following questions:

a) To what extent is olive farm sustainability heterogeneous in Andalusia? On the basis of farm heterogeneity, how many types of olive farms can be observed?
b) Which aspect of sustainability (economic, social or environmental) has a greater influence on overall olive farm sustainability?
c) Which structural variables (plantation density, farm size, farmers' socio-demographic characteristics, etc.) have a greater influence on olive farm sustainability?
d) Do agricultural policies support sustainable farms to a greater extent than unsustainable farms?
e) What differences in sustainability are identified between organic, integrated and conventional olive farming?

Responses to these questions may help guide policymaking in agriculture on the basis of the following policy frameworks:

a) *Olive Farming Act in Andalusia*. This law, currently under approval, regulates that olive farmers will be remunerated by the regional government of Andalusia for providing public goods (environmental and social goods). The implementation of the methodological approach presented in this paper may help identify the key issues to be considered in order for this Act to be applicable in a real setting.
b) *Farm income policy*. The results of implementing this methodological approach may also help to reconcile CAP subsidies and farm sustainability. For example, both the conditionality and modulation of CAP subsidies might be implemented on the basis of the sustainability scores (indicators) obtained by each farm.
c) *Agro-environmental policy*. Furthermore, the methodology presented may help to analyse the impact of agri-environmental schemes on farm sustainability, allowing a modulation in the environmental payments perceived by farmers, i.e. increasing/decreasing payments as sustainability indicators improve/deteriorate.
d) *Farm structure policy*. Once structural variables that shape olive farm sustainability are identified, farm structure policy might be changed in order to promote more sustainable farms.

Thus, the empirical application currently being implemented is expected to help to improve the governance of olive farming in Andalusia.

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