# Sustainability assessment of olive grove in Andalusia: A methodological proposal

**Jose A. Gomez-Limon[1], Laura Riesgo[2]**

[1] Instituto de Investigacion y Formacion Agraria y Pesquera (IFAPA), Centro Alameda del Obispo, Apartdo 3092, 14080 Cordoba (Spain), Phone: +34 957016051, e-mail: josea.gomezlimon@juntadeandalucia.es
[2] Dept. of Economics, Pablo de Olavide University, Ctra. De Utrera, km.1, E-41013 Sevilla (Spain), phone: +34 954349851, e-mail: laurariesgo@upo.es

**Paper prepared for presentation at the 120th EAAE Seminar "External Cost of Farming Activities: Economic Evaluation, Environmental Repercussions and Regulatory Framework", Chania, Crete, Greece, date as in: September 2 - 4, 2010**

# Sustainability assessment of olive grove in Andalusia: A methodological proposal[1]

José A. GÓMEZ-LIMÓN

Instituto de Investigación y Formación Agraria y Pesquera (IFAPA)

Centro Alameda del Obispo. Apartado 3092. 14080 Córdoba (Spain)

Phone: +34 957016051. E-mail: josea.gomezlimon@juntadeandalucia.es

Laura RIESGO

Dept. of Economics. Pablo de Olavide University

Ctra. de Utrera, km. 1. E-41013 Sevilla (Spain)

Phone: +34 95434 9851. E-mail: laurariesgo@upo.es

## Abstract

Recently the olive sector has had important changes in Andalusia due to both the enlargement and the intensification of farming. The expansion of the olive grove in Andalusia is causing sustainability problems, not only from the socio-economic dimension (profit reduction) but environmental (erosion, water pollution or biodiversity losses). The main objective of this study is to develop a methodology to analyse the sustainability of the olive grove farms in Andalusia. This methodology will allow us to bear with the three dimensions of sustainability (economic, social and environmental) as well as to obtain a precise diagnosis of the olive grove through a selection of a set of indicators. This methodology will be applied in future research works in order to build a basis to help both decision-making processes and implementation of public policies.

Keywords: Olive tree, Sustainability, Indicators.

[1] This research has been financed by the Ministry of Science and Innovation and for the European Regional Development Fund (ERDF) through the research project SUSTENAGRI (AGL2009-12553-C02).

# 1. Introduction

## 1.1. Olive grove as a multifunctional agricultural system

Andalusia is the main olive production area worldwide with a total land of 1.5 million of hectares (30% of the agricultural land of Andalusia, 59% of the total olive grove land in Spain, 30% of the total olive grove land in the EU and 19% worldwide). In macroeconomic terms, the olive grove is the second agricultural subsector after the horticultural subsector creating an income of 2,660 million Euro in 2007 (26% of the total agricultural production of Andalusia –10,227 M€–).

The olive grove production is one of the sectors with more job creations per hectare so it is sometimes called a "social crop". The olive sector creates 32% of the total employment in the Andalusian agriculture (91,327 direct jobs) even more than in other dynamic agricultural subsectors such as horticulture. In sum, the olive grove production means the main activity in more than 300 towns in Andalusia particularly in those where the olive grove is single-crop farming (CAP, 2008).

Finally it is worth highlighting the environmental relevance of the olive grove. Traditionally the olive grove in Andalusia was associated with a high biodiversity being an example of a "natural high-value agricultural system". This was possible due to the low intensity olive farming (low 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, during the last years this ecological richness has diminished due to the "modernisation" of the olive grove. This modernisation was based on the enlargement (new farms that imply a single-crop system in large areas of Andalusia) and intensification of the crop (intensive use of fertilisers, pesticides and machinery and farms with uncovered soil). In spite of the modernisation process, many olive systems are associated to natural ecosystems as it has been recognised including 138,536 olive grove hectares (10% of the olive grove land in Andalusia) in Natura 2000.

In summary, the olive systems provide a set of goods and services to the society in Andalusia. Some of these goods and services are "commercial" since they are commercialised by the market such as the olive oil. However other goods and services are "public" or non-commercial since they have no market to be commercialised in (e.g. the contribution of olive systems to support the rural areas where olive trees are being grown). Due to the lack of a market for public goods, olive growers do not receive any monetary compensation. The concurrence of production systems that provide both commercial and public goods to the society and a possible "market failure" (unsuitable supply of public goods due to the lack of incentives for a suitable supply -remuneration- ) makes the olive system as a multifunctional agricultural system (Viladomiu and Rosell, 2004; Arriaza et al., 2008).

## 1.2. Recent development of the Andalusian olive grove and sustainability problems

The olive grove area in Andalusia has reached historical levels. Spain's accession to the European Union (EU) and the Common Agricultural Policy (CAP) encouraged the enlargement and intensification of the olive systems during the last two decades in Andalusia. This rapid expansion has caused however some sustainability problems.

The first consequence of this expansion was an increase in olive production (Barea and Ruiz Avilés, 2009). Spain's accession to the European Community (now, EU) in 1986 caused an expansion in the olive sector since olive grove had a most favourable treatment than before Spain's accession. This expansion, called "new olive growing", was reflected in an enlargement of the olive area and in the intensification through both higher density plantation and the introduction of irrigation. As a consequence Spain has doubled its olive oil production between 1990 and 2008. This increase in the olive oil supply in Spain, jointly with other factors, reduced the olive oil prices in the international market being below 2 €/kg in 2009(Lanzas and Moral, 2008). This supply pressure and the increase of production costs shape the olive sector with profitability losses. Many studies showed that given the current olive oil prices half of the Andalusian olive farms are unsustainable from an economic and social perspective (Pérez Hernández, 2008).

The enlargement and intensification of the olive grove caused negative environmental impacts (Beaufoy and Pienkowski, 2000; Guzmán-Álvarez, 2005; García Brenes, 2007; Gómez Calero, 2009):

a) *Soil erosion.* This environmental impact has become worse in the last years since the expansion of the olive grove towards soils with unfavourable conditions for agricultural production (steep slopes, torrential rains, high soil erosion). These adverse conditions and the deficient management of the soils by farmers damaged the spontaneous vegetation (farms with uncovered soil). The agricultural and fishery regional ministry (CAP, 2008) reported the soil situation in Andalusia: 29.7% of the olive farms have moderate soil erosion (12-50 t/ha·year), 11.8% show 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 80s most olive trees were non-irrigated but the intensification of the crop caused that at present more than 300,000 hectares of olive grove exist. In spite of being a crop with low water requirements and usually irrigated with high-efficient irrigation systems (water extractions are between 1,500 and 2,000 $m^3$/ha·year), the pressure on water resources is high. Most of the water used in the Guadalquivir basin is consumed by irrigated olive farms. Increasing water extraction causes not only the overexploitation of water resources but jeopardises the satisfaction of water demand in the basin.

c) Non-point source water pollution. Water quality from olive systems has getting worse due to the regular use of agrochemical products (mainly herbicides and fertilizers). Increasing non-point source water pollution in rivers, dams and aquifers produced several sanitary alarms such as the prohibition of drinking water from dams surrounded by olive trees. These alarms led to the removal of some agrochemical products (simazine or diuron). In spite of these exclusions water quality is still at risk by olive grove agricultural practices.

d) *Biodiversity loss*. One of the main characteristics of the traditional olive grove in the 80s was the high biodiversity associated with the crop. The presence of trees and scrubland provided an assorted habitat similar to meadows where a number of insects, birds, reptiles and mammals were living. However the intensification of olive farms has changed this situation (disappearance of the vegetable cover, water pollution, insecticide use and soil erosion) and both the number and the diversity of animal species has diminished in olive systems.

e) *Damages in traditional agricultural landscapes*. Traditionally olive grove coexisted with other crops such as pastures, vineyards or cereals. By contrast the only living specie during the whole year is the olive grove.

### 1.3. Objective

The enlargement of the olive grove in Andalusia and its impacts make necessary to analyse the sustainability of this crop. This study aims to develop a theoretical framework and a methodology to evaluate the sustainability of olive farms. The three dimensions of sustainability (economic, social and environmental) were considered in the analysis and a set of indicators were selected in order to obtain a precise diagnosis of the olive farms in Andalusia.

The methodology developed in this study will be applied in future research works in order to build a basis to help in both the decision-making process and the implementation of public policies in the olive sector (e.g. policy reforms regarding agricultural revenues, agro-environmental issues, agricultural management systems and rural development, as well as the implementation of the future Andalusian Law of Olive grove).

## 2. Theoretical framework

### 2.1. Conceptualisation of 'sustainable agriculture'

The World Commission on Environment and Development (WCED), known as *Brundtland Commission*, proposed the most extended definition for "sustainable development". It was defined as that "development which meets the needs of current generations without compromising the ability of future generations to meet their own needs". This definition has been the dominant paradigm that guided not only development process but the design and implementation of public policies since the 90s.

Agriculture plays an important role in human development since it produces the basic goods for satisfaction of basic human needs (e.g. food). Actually "sustainable agriculture" is a necessary condition for real sustainable development (Convoy and Barbier, 1990).

But, what "sustainable agriculture" means is a question difficult to answer. There was a scientific debate on how is possible to meet resources' preservation and production growth to satisfy food and fibre requirements as the world's human population expands. Trying to cope with this issue several definitions and alternative approaches can be found. In any case, there is a broad consensus on considering agricultural sustainability as the one that satisfies the following requirements (Raman, 2006): a) enhance food security, b) protect natural resources and prevent degradation of the environment, c) be economically viable and d) be socially acceptable. Taking these requirements into consideration, agricultural sustainability can be defined using the *"patchwork" approach*, as a concept that encompasses tree main dimensions (Yunlong and Smit, 1994; Raman, 2006):

- *Environmental sustainability*. Sustaining the preservation of biological productivity and ecosystem services is basic to sustainable agriculture. Indeed, agricultural sustainability can be defined as the ability of ensuring greater agricultural productivity while simultaneously conserving natural resources and preventing depreciation of ecosystems.

- *Economic sustainability*. To be sustainable agriculture should be economic viable, ensuring not only adequate profitability for farmers (microeconomic approach) but positive contribution to national/regional income (macroeconomic approach).

- *Socio-cultural sustainability*. Agriculture should be socially and culturally relevant, i.e. it should ensure food security and equitable income distribution as well as contribute to the viability of rural communities.

Operational aspects of agricultural sustainability include the space context. This study aims to analyse the Andalusian olive grove. Like most related works in the literature, olive farm is considered as the basic unit for the analysis of agricultural sustainability. This option has been adopted since farms are the targets of public policies aiming the governance of the agricultural sector (van der Werf and Petit, 2002; van Passel et al., 2007).

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

Quantitative approaches to measuring agricultural sustainability are based on 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 (Hansen and Jones, 1996). After evaluating pros and cons of each theoretical framework, there is a wide scientific agreement in considering the construction and calculation of sustainability indicators as the most adequate approach to analyse agricultural sustainability (Hansen, 1996; Becker, 1997; Smith and McDonald, 1998; Ness et al., 2007). This study follows this methodological framework in order to evaluate the sustainability of olive farms in Andalusia.

The methodology is structured on the basis of two basic criteria. First, *reliability* of the approach to evaluate sustainability is needed. Reliability requires the selection of indicators based on the characteristics of olive systems in Andalusia as well as an acceptable questionnaire design to collect primary data at farm level in order to calculate the indicators. Secondly, *applicability* of the evaluation approach (i.e. easy, rapid and inexpensive method) is also required to promote its implementation in the design of agricultural policies.

Reliability and applicability cannot be achieved simultaneously but a balance between both criteria must be preserved when sustainability is analysed. To do this, we consider indicators as primarily sources of information that reduce the uncertainty of decision-making processes. In addition, we assume that the gross value of an indicator (the value before deducting the cost of obtaining the indicator's level) is given by the expected benefit increase due to the governance improvement in the olive sector (Pannell and Glenn, 2000).

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

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

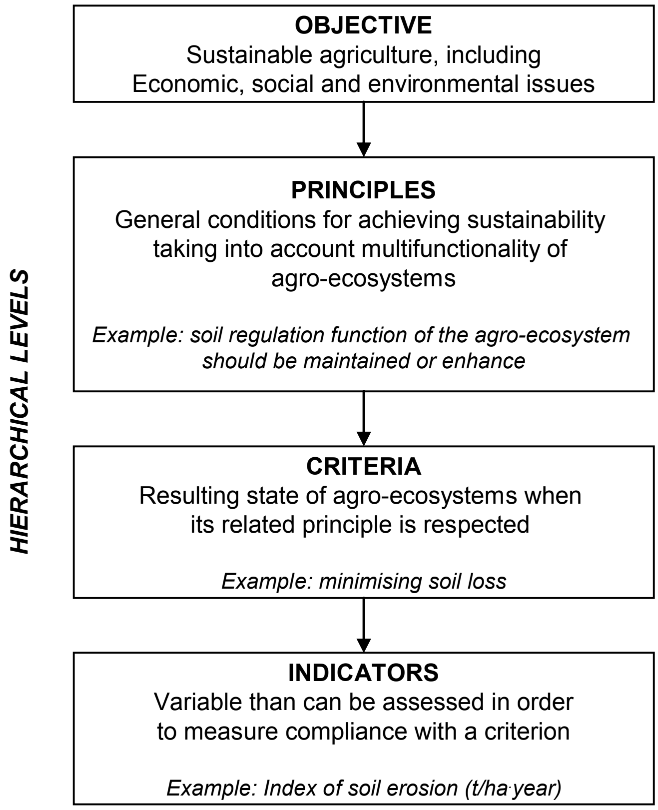
- *Principles*. This first hierarchical level is related to the multiple functions of the agroecosystem which includes the three pillars of sustainability: the economic, environmental and social dimensions. Principles are general conditions for achieving sustainability and they should be considered universally applicable to agricultural systems.

- *Criteria*. A criterion is the resulting state of agricultural systems when its related principle is respected. Criteria are specific objectives relating principles to a state of the agroecosystem (olive systems). Indeed, criteria are more concrete than principles and therefore easier to link indicators to.

- *Indicators*. An indicator is a variable of any type than can be assessed in order to measure compliance with a criterion. Indicators should provide a representative picture of sustainability of agricultural systems in all its aspects (economic, social and environmental).

The structure of the hierarchical framework is show in Figure 1.

*Figure 1. SAFE Hierarchical Framework*




Adapted from Sauvenier et al. (2006).

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

# 3. Methodology

## 3.1. Outline of the methodology

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

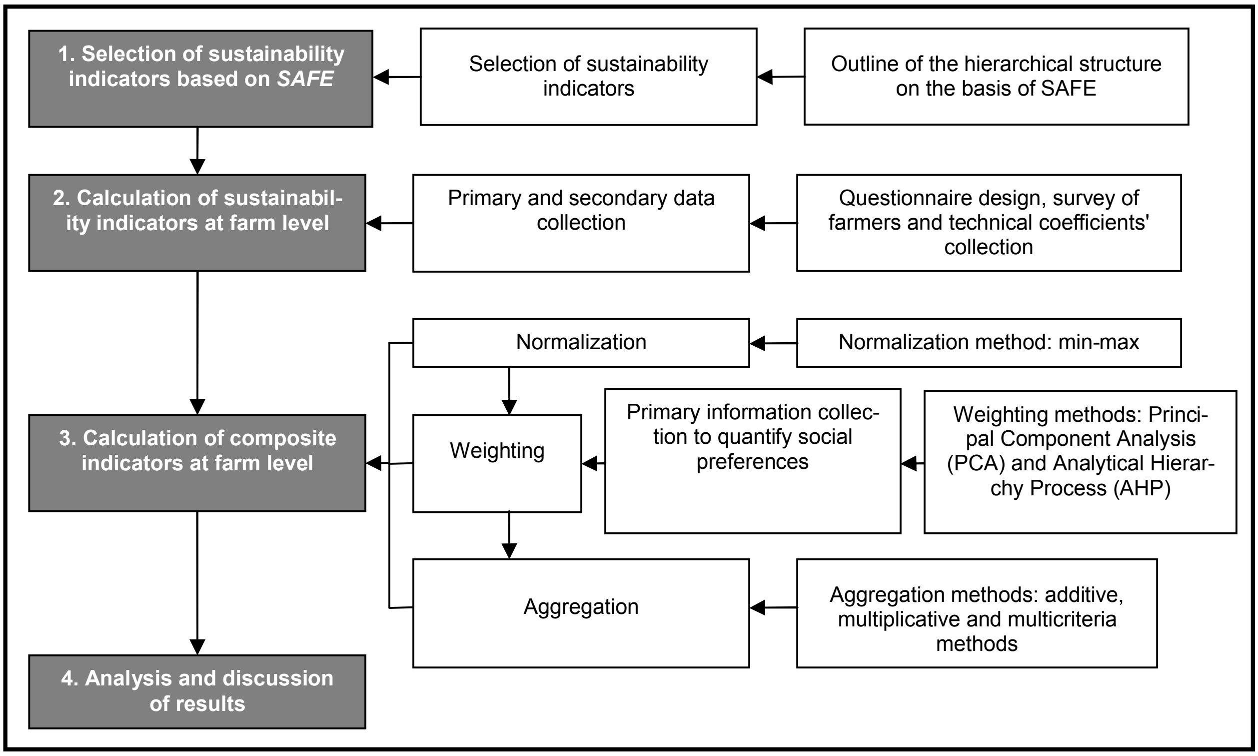
1. *Selection of basic indicators*. Using SAFE as a methodological framework, a number of principles and criteria regarding agricultural sustainability of olive systems in Andalusia were defined (see Section 4). Taking into account these specific principles and criteria some sustainability indicators were identified on the basis of an exhaustive literature review (see Section 5). As a result we established a hierarchical structure for our case study with 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 will be 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 spread of results*. Carrying out steps 2 and 3 will permit us to carry out a comparative and critical analysis of results in future research. Conclusions derived from this analysis must improve the governance of agricultural management in the case study.

***Figure 2. Methodology outline***




Own elaboration.

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

# 4. Selection of principles, criteria and indicators

According to SAFE analytical framework the first step is to build the structure of the hierarchical framework including principles, criteria and indicators. In order to collect specific sustainability indicators for our case study, an exhaustive review of agricultural sustainability literature was carried out. Table 1 shows a proposal of principles and criteria.

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

| SUSTAINABILITY DIMENSIONS | PRINCIPLES | CRITERIA |
|---|---|---|
| ECONOMIC SUSTAINABILITY | Farmers' economic sustainability. Economic viability of olive farms. | Adequate farmers' income |
| | | Stability of farmers' income |
| | | Warranted capacity to change adaptation. |
| | Public economic sustainability. Food security and wealth creation | Maximising production value |
| | | Stable production value |
| | | Maximising the contribution to the regional economy |
| | | Minimising subsidy's dependence |
| SOCIO-CULTURAL SUSTAINABILITY | Social sustainability. Contribution to rural development | Maximizing job creation |
| | | Warranted capacity to remunerate jobs |
| | | Warranted intergenerational transfer of farms |
| | | Adequate population density in rural areas. |
| | Cultural sustainability. Conservation of cultural heritage | Warranted supply of quality food |
| | | Enhancing or protecting the visual quality of the landscape |
| | | Protecting cultural and landscaping values |
| ENVIRONMENTAL SUSTAINABILITY | Biodiversity protection | Warranted 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 ecosystem |
| | | Optimising energy balance |

Own elaboration.

A set of indicators was identified in order to evaluate the sustainability of olive systems in Andalusia. Indicators have been selected considering the following criteria (Bell and Morse, 2008; Sauvenier et al., 2006; van Calker et al., 2006; von Wirén-Lehr, 2001; Walter and Stutzel, 2009): 1) solid analytic basis, 2) measurability, 3) relevance for system's sustainability, 4) clearness, 5) policy relevance, 6) dependent on time-space scales and 7) adaptation. In addition to these criteria and according to Pannell and Glenn (2000) we only select those indicators that require reasonable costs and time spent to be calculated.

Analysing agricultural sustainability needs a multidisciplinary approach as well as the participation of stakeholders (Raman, 2006; Purvis et al., 2009). In order to cope with these requirements, a panel of 18 experts helped in the implementation of the SAFE analytical framework. This panel of experts is composed of scientific experts in agricultural economics (2), sociology and rural development (2), ecology and environmental management (2) and olive agronomy (2) from academic institutions as well as of experts from the olive sector (2 experts from the agricultural and environmental regional government, 2 experts from agricultural professional organisations, 3 technical managers, an agent of the Spanish Association of Olive Municipalities and 2 olive growers).

This panel of experts met twice in order to discuss a preliminary methodological proposal. This debate led to a consensus on principles, criteria (see Table 1) and basic indicators that should be followed in order to analyse olive grove sustainability.

# 5. Sustainability indicators

This section analyses 27 sustainability indicators selected by the panel of experts.

## 5.1. Economic sustainability indicators

According to the panel of experts, economic sustainability of olive grove deals with two principles: a) farmers' economic sustainability, i.e. 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 cope with three criteria: a1) to achieve adequate olive farmer's income, a2) to reach stable farmer's income and a3) to guarantee farmers' capacity for change adaptation. In addition, public economic sustainability tackles the following four criteria: b1) to maximise production value, b2) to reach stable production value, b3) to maximise the contribution to the regional economy and b4) to minimise subsidies' dependence.

In order to quantify the achievement of each criterion, we selected 7 indicators (Table 2).

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

| PRINCIPLES | CRITERIA | SUSTAINABILITY INDICATORS (*acronym*) [measurement unit] |
|---|---|---|
| **Farmers' economic sustainability. Economic viability of olive farms.** | Adequate farmers' income | Olive farmer's profitability (*PROFITOLIV*) [€/ha·year] |
| | Stability of farmers' income | Changes in farmer's profitability (*PROFITVAR*) [dimensionless] |
| | Warranted capacity to change adaptation. | Adaptation index (*ADAPTIND*) [dimensionless] |
| **Public economic sustainability. Food secu-** | Maximising production value | Production value (*PRODVAL*) [€/ha·year] |

| | | |
|---|---|---|
| **rity and wealth creation** | Stable production value | Changes in sales (*SALESVAR*) [dimensionless] |
| | Maximising the contribution to the regional economy | Contribution to Agricultural Added Value (*CONTRAAV*) [€/ha·year] |
| | Minimising subsidy's dependence | Percentage of income from subsidies (*PERCSUBV*) [dimensionless] |

Own elaboration.

### *5.1.1. Olive farmer's profitability (PROFITOLIV)*

Net profit is defined as gross income minus total expenses in a given period, including depreciation on capital goods (PROFITOLIV in €/ha·year).

Only those olive farms with positive values of PROFITOLIV will be sustainable in the long run. By contrast, negative values of this indicator mean a continuing loss of farmer's assets and eventually lead to abandonment of agricultural activity. Olive farms' sustainability increases with higher PROFITOLIV positive values.

### *5.1.2. Changes in farmer's profitability (PROFITVAR)*

Changes in farmer's profitability over a period of time may be quantified through measures of dispersion in time series of annual profits. These changes were calculated by a coefficient of variation of indicator PROFITOLIV over last 8 years.

Farmers were more efficient on inputs use and showed high willingness to invest on their farms (Moschini and Hennessy, 2001; Vercammen, 2007) when facing low risk environment (yearly stability of farmer's income). As a result stability of farmer's income over a period of time (low values of PROFITVAR) means high economic sustainability of olive farms.

### *5.1.3. Adaptation index (ADAPTIND)*

Olive farm's viability not depends solely on income and costs (profit and time stability) but on farm adaptation to changes such as technological changes, policy reforms, changes in agricultural or inputs markets or environmental changes (climate change). However change adaptation is quite difficult to quantify since a) it is a non-observable variable, b) it is a complex variable and c) it is intangible (dimensionless). Coping with these difficulties an *ad hoc* index is developed as a *proxy* to quantify farmer's capacity to change adaptation.

The indicator ADAPTIND is defined as a mathematical function of a set of variables such as a) average slope of the land as a determining factor of technologies applied in the farm, b) irrigation water availability to potential irrigation transformation of the farm, c) farmer's age (i.e. young farmers show high willingness to cope with change) and d) farmer's education (i.e. educated farmers show high willingness to cope with change). Thus ADAPTIND is expressed as a weighted sum of this set of the variables:

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

where $w_i$ shows the importance of each variable on 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* shows farmer's age (dimensionless) and *EDUCATION* shows farmer's education (dimensionless).

Weights of each variable, $w_i$ , were obtained from the panel expert valuation through the implementation of the AHP (Saaty, 1980). Resulting weights were $w_{slope}$=37.1%; $W_{water}$=18.8%; $w_{age}$=23.0% and $w_{education}$=21.1%.

ADAPTIND values are bounded between 0 and 1. While zero value implies a null adaptation to changes, a value of 1 means an optimum adaptation to changes. Those farms with high values of this indicator are viable in the long run and thus more economic sustainable.

#### *5.1.4. Production value (PRODVAL)*

The contribution of olive farms to food security can be approached by their production value (€/ha·year). The indicator PRODVAL is positive, since a zero value means crop abandonment. Those farms with high values of this indicator show higher economic sustainability.

#### *5.1.5. Changes in sales (SALESVAR)*

Changes in sales made by farmers over a period of time may be quantified through measures of dispersion. These changes were calculated by a coefficient of variation of indicator PRODVAL over last 8 years.

Variation of production values due to changes in yields or prices must be assessed as a negative change in agricultural sustainability. Public economic sustainability needs stable agricultural production every year minimising the risk derived from scarce olive stocks to satisfy the demand and making possible stability in the olive oil supply chain. As a result high values of the indicator SALESVAR mean lower economic sustainability of olive farms.

#### *5.1.6. Contribution to Agricultural Added Value (CONTRAAV)*

Contribution of olive farms to regional wealth can be assessed through the Gross Added Value (GVA). GVA is defined as income from output sales minus expenses due to intermediate consumption goods. The indicator CONTRAAV shows the value added in the olive oil supply chain by olive farms being thus a *proxy* to quantify olive farms' contribution to regional GDP.

Negative values of this indicator show a wealth loss in the regional society (i.e. low economic sustainability of olive farms from a public perspective). By contrast positive values of

CONTRAAV mean a positive contribution to regional wealth (i.e. high economic sustainability of olive farms from a public perspective).

### *5.1.7. Percentage of income from subsidies (PERCSUBV)*

Economic viability of olive farms excluding subsidies help to achieve acceptable levels of economic sustainability from a public perspective. A zero value of the indicator PERCSUBV means the highest sustainability, since the olive farms would not depend on public support. High values of this indicator indicate lower economic sustainability.

## 5.2. Socio-cultural sustainability indicators

Socio-cultural sustainability of olive farms deals with two principles: a) social sustainability since olive farms contribute to rural development and b) cultural sustainability since olive farms contribute to the conservation of cultural heritage (Table 3). According to the panel of experts' consideration, social sustainability needs to cope with four criteria: a1) to maximise job creation, a2) to guarantee that olive sector is capable to remunerate jobs properly, a3) to guarantee intergenerational transfer of olive farms and a4) keeping an adequate population density in rural areas. Achieving cultural sustainability requires dealing with three criteria: b1) to guarantee quality food supply, b2) to enhance or protect the visual quality of landscape and b3) to protect cultural and landscaping values.

In order to quantify the achievement of each criterion, we selected 9 indicators (Table 3).

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

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

Own source.

### *5.2.1. Total labour (TOTLAB)*

One of the most relevant social roles of agriculture is job creation in rural areas. Total labour in olive farms was selected as an indicator to quantify social implications of olive farms in rural areas (TOTLAB). This indicator is positive and a zero value implies crop abandonment by farmers. High values of TOTLAB show labour-demanding olive farms and thus the most social sustainable farms.

### *5.2.2. Apparent labour productivity (PRODLAB)*

Fulfilling a social role requires not only to generate labour but to take incomes in to guarantee a properly remuneration of jobs. Apparent labour productivity 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.

High values of PRODLAB mean higher sustainability of farms from a social perspective, since olive farms helps to job creation in the long run.

### *5.2.3. Risk of agricultural abandonment (ABANDON)*

Agricultural abandonment is a consequence of a set of factors, such as low profitability of agriculture in less favoured areas (i.e. presence of environmental handicaps), lack of perceived future opportunities among young people in rural areas and best paid jobs in neighbouring territories.

The indicator ABANDON is quantified through farmers' responses to the question "In what extent do you think that farm transfer is guaranteed after your retirement?". Responses varied between 100% when the farm transfer is guaranteed and 0% when nobody will manage the farm after farmer's retirement. Therefore high values of ABANDON mean lower social sustainability of olive farms.

### *5.2.4. Percentage of family and permanent labour (FAMPERLAB)*

Olive farming shows seasonal part-time employment since labour is mainly demanded during harvesting (between 45% and 60% of total labour in olive farms is demanding in harvesting). This labour attribute do not help rural development in olive systems, since part-time seasonal activities do not increase population density in rural areas.

The indicator FAMPERLAB quantifies the weight of family and permanent labour (usually residents in rural areas) over total labour demanded by olive farms. This indicator is bounded between 0 and 1. A value of one implies that labour demand is covered by family members or permanent workers, usually residents close to olive farms. By contrast, a value of zero means that labour demand is covered only with part-time seasonal workers. High values of FAMPERLAB show higher social sustainability of olive farms.

### *5.2.5. Guarantee of origin membership (ORIGIN)*

Within agricultural social requirements quality food supply is expected. In order to quantify this criterion two indicators has been included in the analysis. First, we analyse if the olive farm is included in one of the 14 Guarantees of Origin (DOP) recognised by the Andalusian government for the production of extra virgin olive oil production. The indicator ORIGIN varies between 1 if the olive farm is a member of a DOP and zero if not. A value of one shows an olive farm with higher cultural sustainability.

### *5.2.6. Percentage of olive oil classified as extra virgin olive oil (VIRGINOIL)*

Another indicator that helps to quantify quality food supply is the percentage of extra virgin olive oil produced by the farm. The extra virgin olive oil is the highest quality olive oil produced. Since the indicator VIRGINOIL is measured as a percentage, it is bounded between 0 and 1. High values (close to 1) show that most of the olive oil production has the highest quality.

### *5.2.7. Percentage of farm planted with crops other than olive grove (OTHERCROP)*

One of the cultural sustainability criteria is to protect the visual quality of agricultural landscape. In order to cope with this criterion, two indicators are considered in this analysis. Visual quality of olive grove landscape in Andalusia includes contrasting colours and textures by a mixture of olive trees and other crops (Arriaza et al., 2004).

The first indicator (OTHERCROP) is defined by the percentage of land covered by crops other than olive trees (e.g. ranches, water flows). Breaking single-crop farming contributes to enhance visual quality of agricultural landscape. This indicator ranges between 0 and 1. A zero value shows a single-olive farm which does not enhance visual quality of landscape (the lowest cultural sustainability) whereas 1 shows a multiple-crop farm with greater visual quality of agricultural landscape (the highest cultural sustainability).

### *5.2.8. Soil cover (COVER)*

Soil cover contributes to enhance landscape valuation. This indicator is defined as the percentage of days during the year in which vegetation covers the soil. In this case a zero value implies an uncovered soil and a low-value landscape. By contrast soils with vegetation cover were high-value landscape by the society.

### *5.2.9. Index of protection of olive heritage (HERITAGE)*

Agricultural landscape is not the only olive heritage but the protection of a number of anthropogenic elements such as hundred-year-old olive trees, ranches, old mills for making olive oil, stone walls, hedges, etc. The protection of olive heritage is considered as an intangible factor and an ad hoc index was developed to quantify this heritage (HERITAGE).

The indicator HERITAGE is defined as a mathematical function of a set of variables such as the presence of a) hundred-year-old olive trees, b) ranches or old mills for making olive oil, c) stone walls, terraces, hedges or similar heritage elements and d) rural tourism activities in the farm. This indicator is a weighted sum of these variables:

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

where *HERITAGE* is the index of protection of olive heritage (dimensionless); *HUND_OLIV* shows the presence of hundred-year-old olive trees in the farm (dimensionless): No = 0; Yes = 1; *RANCH_MILL* shows the presence of ranches or old mills for making olive oil in the farm (dimensionless): No = 0; Yes = 1; *HEDGES* shows the presence of stone walls, terraces, hedges or similar heritage elements in the farm (dimensionless): No = 0; Yes = 1; and

*TOURISM* shows the presence of rural tourism activities (rural houses, guide tours, etc.) in the farm (dimensionless): No = 0; Yes = 1.

Weights, $w_i$, were obtained from the panel expert valuation through the implementation of the AHP. Resulting weights were $w_{hund\_oliv}$=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 since none of the heritage elements were available at the farm. The higher the value of HERITAGE is the higher socio-cultural sustainability of the olive farm.

## 5.3. Environmental sustainability indicators

Environmental sustainability of olive grove copes with two principles: a) biodiversity protection, and b) natural resources protection (Table 4). Within the SAFE analytical framework, these principles are related with a number of criteria. According to the panel of experts' consensus biodiversity protection needs to cope with four criteria Table 2 shows that farmers' economic sustainability deals with three criteria: a1) to guarantee olive grove genetic diversity, a2) to protect or enhance biological diversity and a3) to protect or enhance habitat diversity (ecosystem). A combination of the three levels of biodiversity (genetic, biological and habitat diversities) is included in this criterion (Primack, 1993). Natural resources protection will be achieved when b1) soil erosion is minimised, b2) soil fertility is protected or enhanced, b3) soil and water quality is protected or enhanced and b5) the agricultural energy balance is optimised.

In order to quantify the achievement of each criterion, we selected 11 indicators (Table 2).

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

| PRINCIPLES | CRITERIA | SUSTAINABILITY INDICATORS (*acronym*) [measurement unit] |
|---|---|---|
| **Biodiversity protection** | Warranted olive grove genetic diversity | Number of olive grove varieties (*NUMVAR*)<br>[olive grove varieties] number |
| | Enhancing or protecting biological diversity | Index of biological diversity (*DIVERSIND*)<br>[dimensionless] bounded [0,1] |
| | | Pesticide risk (*PESTRISK*)<br>[kg rat/ha· year] |
| | Enhancing or protecting habitat diversity (ecosystem) | Percentage of land planted with crops other than olive grove (*OTHERCROP*)<br>[%]bounded [0,1] |
| | | Percentage of non-arable land (river flows, hedges, terraces, etc.) (*NONARABLE*)<br>[%]bounded [0,1] |
| **Protection of natural resources (soil and** | Minimising soil erosion | Eroded soil (*EROSION*)<br>[t/ha· year] |

| | | |
|---|---|---|
| **water)** | 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] |

Own elaboration.

### *5.3.1. Number of olive grove varieties (NUMVAR)*

Genetic diversity of olive grove is a natural heritage that should be protected for future generations. However latest olive farming practices are inclined to the homogenisation of olive grove. In order to quantify the contribution of olive farms to protect filogenetic resources of olive grove a new indicator is include in the analysis. This indicator aims to calculate the number of olive grove varieties in the farm (NUMVAR).

The minimum value of NUMVAR is 1 (e.g. one variety is grown in the farm) indicating the least sustainable olive farm.

### *5.3.2. Index of biological diversity (DIVERSIND)*

Olive grove biological diversity includes several living beings. Quantifying species richness at farm level is a very hard task out of this study scope. An *ad hoc* indicator was developed to analyse biological diversity at olive farms (DIVERSIND).

This indicator was developed on the basis of an exhaustive literature review on olive grove biodiversity (see Duarte et al., 2009). According to the panel of experts' experience the indicator DIVERSIND is defined as a mathematical function of a number of variables: a) presence of vegetation cover (flora and fauna protection), b) maintenance of vegetation cover through sheep's reaping (the least harmful soil management method), c) piled branches up after pruning (refuge areas for some species), d) remain olives on the olive trees after harvesting (olives for fauna feeding) and e) subsurface drip irrigation or without ferti-irrigation (minimising animal poisoning):

$$DIVERSIND = w_{cover}COVER + w_{tooth}TOOTH + w_{piled}PILED + w_{olive}OLIVE + w_{irrig}IRRIG \quad [3]$$

where *DIVERSIND* is the biological diversity index (dimensionless); *COVER* shows the presence of vegetation cover (dimensionless): No = 0; Yes = 1; *TOOTH* shows maintenance of vegetation cover through sheep's reaping (dimensionless): No = 0; Yes = 1; *PILED* shows the piled branches up after pruning in the olive farm (dimensionless): No = 0; Yes = 1; *OLIVE*: presence of olives on the olive trees after harvesting (dimensionless): No = 0; Yes = 1; *IRRIG*: subsurface drip irrigation or without ferti-irrigation (dimensionless): No = 0; Yes = 1.

In this case, not all biological diversity criteria can be applied to all olive farms (i.e. the latter indicator can be calculated only in irrigated olive farms). This requires estimating two set of weights, one for irrigated farms (including the five criteria) and another for non-irrigated farms (including four criteria). Weights for irrigated olive farms were: $w_{cover}$= 56.6%; $w_{tooth}$= 9.6%; $w_{piled}$= 13.0%; $w_{olive}$= 9.8% and $w_{irrig}$=11.0%. Weights for non-irrigated olive farms are: $w_{cover}$ = 63.6%; $w_{tooth}$ = 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 an optimum biodiversity in the farm. By contrast a zero value shows that none practice is developed in order to protect or enhance biological diversity in the olive farm. Therefore values of DIVERSIND close to 1 indicate higher environmental sustainability.

### *5.3.3. Pesticide risk (PESTRISK)*

Olive grove biodiversity depends as well on chemical pesticides use for soil (herbicides) and pest management (insecticides). Pesticides help to control pests but its use also reduce the population of non-target species. A specific indicator is included to quantify the biocide activity of 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 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 the 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 showing organic olive farms. These production systems are the most sustainable from an environmental perspective since they have the highest value of biodiversity protection. Higher values of PESTRISK show a reduction in biodiversity and in environmental sustainability of olive farms.

### *5.3.4. Percentage of land planted with crops other than olive grove (OTHERCROP)*

This indicator achieves two criteria since it contributes to quality of agricultural landscape (see Section 5.2.7) and to biodiversity (i.e. as a *proxy* of heterogeneity in land use as well as ecosystem diversity). A zero value of OTHERCROP means a single-olive farm without a variety of ecosystems (i.e. lowest environmental sustainability). However, higher values of the indicator indicate several crops/land uses and thus the existence of some ecosystems.

### 5.3.5. *Percentage of non-arable land (NONARABLE)*

This indicator assesses the value of non agricultural ecosystems in olive farms such as river flows, rocks, etc. Considering these ecosystems is reasonable since they constitute the habitat of some species that do not live on olive grove systems but in their surroundings.

The lowest value of this indicator is zero showing the most unfavourable situation for environmental sustainability. Environmental sustainability increases when the value of NONARABLE rises.

### 5.3.6. *Eroded soil (EROSION)*

Soil erosion is one of the main environmental problems in olive systems (Gómez Calero et al., 2003 and 2009). An indicator is included to estimate soil loss (EROSION) taking into account edafoclimatic conditions of the case study and crop management. This indicator is defined using the revised universal soil loss equation (Gómez Calero and Giráldez, 2009):

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

where *EROSION* is the soil eroded (t/ha·year); *R* is rainfall-runoff erosivity factor and depends on amount of rainfall and peak intensity sustained over a period (dimensionless); *K* is 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 and reflect the effect of cropping and management practices on erosion rates; and P is the support practice factor and reflects the impact of support practices on the average annual erosion rate (dimensionless).

The indicator EROSION is positive and high values (high soil loss) implies olive farms with limited capacity to protect soil and consequently less sustainable farms from environmental perspective.

### 5.3.7. *Soil organic matter (ORGMAT)*

Soil quality and quantity must be protected. Soil stock variations are quantified through the indicator EROSION but soil quality needs to be measured. One of the main determinants of soil quality is the soil organic matter.

An *ad hoc* indicator was developed to analyse soil organic matter at olive farms (ORGMAT). The panel of experts' reached a consensus to define the indicator ORGMAT as the following mathematical function:

$$ORGMAT = w_{works} WORKS + w_{cover} COVER + w_{pruning\_rest} PRUNING\_REST \qquad [6]$$

where *ORGMAT* is the index of soil organic matter (dimensionless), *WORKS* is farm works to maintain vegetation cover (dimensionless): More than one farm work per year = 0; None farm works per year = 1; *COVER* is a vegetation cover (dimensionless): No = 0; Yes = 1; *PRUNING_REST* is the milling of pruning rests (dimensionless): No = 0; Yes = 1.

The panel of experts estimated the weights ($w_i$) following the AHP method. Results were: $w_{works}$=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 adequate management practices to increase soil fertility (i.e. the most sustainable olive farm). By contrast a zero value means the least sustainable olive farm in order to maintain soil fertility.

### *5.3.8. Nitrogen balance (NITROGENBAL)*

Nitrogen is an essential nutrient (macronutrient) for olive grove. However, an excess amount of nitrogen on soils may generate severe environmental damages. Nitrogen excess dissolves through rainfall or irrigation generating non-point source water pollution (eutrophication of water bodies). In addition excess amount of nitrogen may speed soil bacteria denitrification. This denitrification process emits to the atmosphere nitrogen oxides which causes greenhouse effect (300 times higher than the $CO_2$ effect). Due to both negative externalities an indicator to quantify the impacts of nitrogen use in agriculture is included. Nitrogen balance (NITROGENBAL) is defined as the physical difference (excess/deficit) between nitrogen content of inputs (fertilisers) and outputs (harvesting). The difference between both quantities is the nitrogen liberated to the environment.

This indicator is not bounded. Negative values of NITROGENBAL mean that nitrogen emission to the environment does not occur (higher environmental sustainability). Higher positive values of NITROGENBAL imply less environmental sustainable olive farms.

### *5.3.9. Residual herbicide use (RESHERB)*

Conservation tillage systems in olive grove led to higher herbicide use. Agrochemicals caused environmental and health damages through aquifers and reservoir water pollution. To quantify the impact of agrochemicals in the environment an indicator is defined. This indicator measures the active matter content of residual herbicides used in olive farms (RESHERB).

The lowest value of this indicator is 0 and reflects that none residual herbicide was used in the farm. This value suggests organic olive farming and consequently none damage is caused in the environment. Any increase of RESHERB should be considered as a negative environmental impact.

*5.3.10. Irrigation water use (WATERUSE)*

Irrigated olive farms take 47% of irrigation land in the Guadalquivir basin (CHG, 2008). Olive grove is then the main irrigation water consumption in the basin (864 $hm^3$/year or 26% of water demand). These water requirements caused water over-extraction and environmental damages in the Guadalquivir basin.

The indicator WATERUSE takes a zero value in non-irrigated olive farms. These farms show the highest environmental sustainability since water is not diverted for irrigation. However higher values of the indicator mean greater water use for irrigation and potential negative impacts on aquatic ecosystems (lower environmental sustainability).

*5.3.11. Energy balance (ENERGYBAL)*

Agriculture is a substantial emitter of greenhouse gases (GHG) due to farm mechanization (fuel consumption) and biological processes such as root respiration of crops, 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 to mitigate climate change (Lal, 2008; Smith et al., 2008).

An indicator to compute energy balance (ENERGYBAL) of olive farms is included (Guzmán Álvarez, 2007; Guzmán and Alonso, 2008). This balance is defined as the difference between energy content of the output (agricultural production) and the energy content of agricultural inputs (inputs use and farm works).

Positive values of ENERGYBAL mean that olive farms are using less energy than energy produced by the photosynthesis process. Higher positive values of this indicator show higher environmental sustainability. By contrast negative values of ENERGYBAL suggest less sustainable olive farms from an environmental perspective (energy consumption higher than energy production).

# 6. Conclusions

The methodological approach used to analyse agricultural sustainability of olive farms in Andalusia has three main advantages. First the approach included the three dimensions of sustainability (economic, social and environmental). Secondly indicators were selected on the basis of olive grove cultivation characteristics in Andalusia. Thirdly the utility of this methodology to analyse olive farms sustainability since the calculation of indicators can be done easily.

The methodological approach will be implemented in a sample of olive farms building a database. This database may help on the design and implementation of public policies to improve governance of olive grove in Andalusia. Empirical evaluation of olive farms may help to answer the following questions:

a) To what extent olive farms sustainability is heterogeneous in Andalusia? On the basis of heterogeneity of farms, how many olive farms types can be observed?

b) Which sustainability dimension (economic, social and environmental) has greater influence on olive farm sustainability?

c) Which structural variables (cropping system, plantation density, farm size, socio-demographic characteristics of farmers, etc.) have greater influence on olive farm sustainability?

d) Do agricultural policies support sustainable farms to a large extent than unsustainable farms?

e) Which sustainability differences are identified amongst organic, integrated and conventional olive farming?

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

a) *Andalusian Law of Olive grove*. This law includes "regional farm agreement" as a new policy tool. Olive farmers were remunerated by the regional government of Andalusia for providing public goods (environmental and social goods). The implementation of the methodological approach presented in this manuscript may help on identifying the key issues to include in the agreement.

b) *Farm income policy*. Results from the implementation of the methodology may also help to associate CAP policy subsidies and farm sustainability. For example, both the conditionality and modulation of CAP subsidies might be implemented on the basis of the sustainability value obtained by each farm.

c) *Agroenvironmental policy*. The implementation of the methodology may help to analyse the impact of agro-environmental schemes on farm sustainability. In case of sustainability deterioration stricter environmental standards should be defined.

d) *Farm structure policy*. Once structural variables that shaped olive farm sustainability were identified, farm structure policy might be changed in order to promote sustainable farms.

e) *Environmental policy*. Environmental policies (legislation on water, energy, etc.) have an influence on olive farm sustainability. Analysing policy impacts on farm sustainability may help to improve the implementation of such policies.

# References

ARRIAZA, M.; CAÑAS ORTEGA, J.F.; CAÑAS MADUEÑO, J.A. y RUIZ, P. (2004) “Assessing the visual quality of rural landscapes”, *Landscape and Urban Planning*, 69, pp. 115-125.

ARRIAZA, M; GÓMEZ-LIMÓN, J.A.; KALLAS, Z y NEKHAY, O (2008) “Demand for non-commodity outputs from mountain olive groves”, *Agricultural Economics Review*, 9, pp. 5-23.

BAREA, F. y RUIZ AVILÉS, P. (2009) “Estrategias de futuro para el sector oleícola andaluz”. En GÓMEZ CALERO, J.A. (ed.) *Sostenibilidad de la producción de olivar en Andalucía*, Consejería de Agricultura y Pesca-Junta de Andalucía; Sevilla.

BEAUFOY, G. y COOPER, T. (2009) *The Application of the High Nature Value Impact Indicator*, European Evaluation Network for Rural Development, European Commission’s Directorate-General for Agriculture and Rural Development, Brussels.

BEAUFOY, G. y PIENKOWSKI, M. (2000) *The environmental impact of olive oil production in the European Union: practical options for improving the environmental impact*, European Forum on Nature Conservation and Pastoralism y Asociación para el Análisis y Reforma de la Política Agro-rural. Comisión Europea, Bruselas.

BECKER, B. (1997) *Sustainability assessment: a review of values, concepts and methodological approaches, issues in agriculture*. Issues in agriculture nº 10, CGIAR-World Bank, Washington.

BELL, S. y MORSE, S. (2008) *Sustainability indicators. Measuring the incommensurable?*, Earthscan, London.

BLAIKIE, P. y BROOKFIELD, H. (1987) *Land Degradation and Society*, Methuen, London.

BYERLEE, D. y MURGAI, R. (2001) “Sense and sustainability revisited: the limits of total factor productivity measures of sustainable agricultural systems”, *Agricultural Economics*, 26, pp. 227-236.

CAP, Consejería de Agricultura y Pesca (2008) *El sector del aceite de oliva y la aceituna de mesa en Andalucía*, Consejería de Agricultura y Pesca - Junta de Andalucía, Sevilla.

CHG, Confederación Hidrográfica del Guadalquivir (2008) *Esquema de Temas Importantes*, Confederación Hidrográfica del Guadalquivir, Sevilla.

CONVAY, G.R. y BARBIER, E.B. (1990) *After the green revolution: Sustainable agriculture for development*, Earthscan Publications, London.

DUARTE, J.; CAMPOS, M.; GUZMÁN ÁLVAREZ, J.R. et al. (2009) “Olivar y biodiversidad”. En: GÓMEZ CALERO, J.A. (ed.) *Sostenibilidad de la producción de olivar en Andalucía*, Consejería de Agricultura y Pesca-Junta de Andalucía; Sevilla.

GARCÍA BRENES, M.D. (2007) “Los impactos ecológicos del cambio estructural. El olivar andaluz”. En: SANZ, J. (ed.) *El futuro del mundo rural*, Síntesis, Madrid, pp. 223-241.

GÓMEZ CALERO, J.A. (ed.) (2009) *Sostenibilidad de la producción de olivar en Andalucía*, Consejería de Agricultura y Pesca-Junta de Andalucía; Sevilla.

GÓMEZ CALERO, J.A. y GIRÁLDEZ, J.V. (2009) “Erosión y degradación de suelos”. En: GÓMEZ CALERO, J.A. (ed.) *Sostenibilidad de la producción de olivar en Andalucía*, Consejería de Agricultura y Pesca-Junta de Andalucía; Sevilla.

GUZMÁN ÁLVAREZ, J.R. (2005) *Territorio y medio ambiente en el olivar andaluz*, Consejería de Agricultura y Pesca, Junta de Andalucía, Sevilla.

GUZMÁN ÁLVAREZ, J.R. (2007) “Una estimación del balance energético y de emisiones de carbono del cultivo del olivo en España”. En: SANZ GÓMEZ, S. (ed.) *Congreso del sesquicentenario de la creación de la carrera de Ingeniero Agrónomo*, Asociación Nacional de Ingeniero Agrónomos, Madrid, pp. 295-303.

GUZMÁN, G.I. y ALONSO, A.M. (2008) “A comparison of energy use in conventional and organic olive oil production in Spain”, *Agricultural Systems*, 98, pp. 167-176.

HANSEN, J.W. (1996) “Is agricultural sustainability a useful concept?”, *Agricultural Systems*, 50, pp. 117-143.

HANSEN, J.W. y JONES, J.W. (1996) “A systems framework for characterizing farm sustainability”, *Agricultural Systems*, 51, pp. 185-201.

LAL, R. (2008) “Carbon sequestration”, *Philosophical Transactions of the Royal Society B*, 363, pp. 815-830.

LANZAS, J.R. y MORAL, E. (2008) “Situación actual del sector del aceite de oliva”. En: ANALISTAS ECONÓMICOS DE ANDALUCÍA (ed.) *Informe Anual del Sector Agrario en Andalucía 2008*, Analistas Económicos de Andalucía, Málaga, pp. 543-575.

LYNAM, J.K. y HERDT, R.W. (1989) “Sense and Sustainability: Sustainability as an Objective in International Agricultural Research”, *Agricultural Economics*, 3, pp. 381-398

MOSCHINI, G. y HENNESSY, D.A. (2001) “Uncertainty, risk aversion, and risk management for agricultural producers”. En: GARDNER, B.L. y RAUSSER, G.C. (eds.) *Handbook of Agricultural Economics*, Elsevier, Amsterdam, pp. 88-153.

NARDO, M; SAISANA, M.; SALTELLI, A. y TARANTOLA, S. (2005a) *Tools for composite indicators building*, Joint Research Centre-European Commission, Ispra (Italia).

NARDO, M; SAISANA, M.; SALTELLI, A. et al. (2005b) *Handbook on constructing composite indicators: methodology and user guide*, OECD, Paris.

NESS, B.; URBEL-PIIRSALU, E.; ANDERBERG, S. y OLSSON, L. (2007) “Categorising tools for sustainability assessment”, *Ecological Economics*, 60, pp. 498-508.

OECD, Organization for Economic Co-operation and Development y JRC, Joint Research Centre (2008) *Handbook on constructing composite indicators*, *Methodology and user guide*. OECD, Paris.

PANNELL, D.J. y. GLENN, N.A. (2000) “A framework for the economic evaluation and selection of sustainability indicators in agriculture”, *Ecological Economics*, 33, pp. 135-149.

PÉREZ HERNÁNDEZ, P.P. (2008) “La economía del cultivo del olivar: evolución y perspectivas”. En: ANALISTAS ECONÓMICOS DE ANDALUCÍA (ed.) *Informe Anual del Sector Agrario en Andalucía 2008*, Analistas Económicos de Andalucía, Málaga, pp. 293-313.

PRIMACK, R.B. (1993) *Essentials of Conservation Biology*, Sinauer Associates, Ltd. Boston, USA.

PURVIS, G.; LOUWAGIE, G.; NORTHEY, G. et al. (2009) “Conceptual development of a harmonised method for tracking change and evaluating policy in the agri-environment: The Agri-environmental Footprint Index”, *Environmental Science & Policy*, 12, pp. 321-337.

RAMAN, S. (2006) *Agricultural sustainability. Principles, processes and prospects*, Haworth Press, Binghamton, NY (USA).

SAATY, T.L. (1980) *The Analytic Hierarchy Process*, McGraw, New York.

SAUVENIER, X.; VALCKX, J.; VAN CAUWENBERGH, N. et al. (2006) *Framework for Assessing Sustainability Levels in Belgian Agricultural Systems—SAFE. Part 1: Sustainable Production and Consumption Patterns*. Final Report—SPSD II CP 28, Belgian Science Policy, Brussels, (Belgium).

SMITH, C.S. y MCDONALD, G.T. (1998) “Assessing the sustainability of agriculture at the planning stage”, *Journal of Environmental Management*, 52, pp. 15-37.

SMITH, P.; MARTINO, D.; CAI, Z. et al. (2008) “Greenhouse gas mitigation in agriculture”, *Philosophical Transactions of the Royal Society B*, 363, pp. 789-813.

van CALKER, K.J.; BERENTSEN, P.B.M.; ROMERO, C. et al. (2006) "Development and application of a multi-attribute sustainability function for Dutch dairy farming systems", *Ecological Economics*, 57, pp. 640-658.

van CAUWENBERGH, N.; BIALA, K.; BIELDERS, C. et al. (2007) "SAFE - a hierarchical framework for assessing the sustainability of agricultural systems", *Agriculture, Ecosystems and Environment*, 120, pp. 22-242.

van der WERF, H.M.G. y PETIT, J. (2002) "Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods", *Agriculture, Ecosystems and Environment*, 93, pp. 131-145.

van PASSEL, S.; NEVENS, F.; MATHIJS, E. y VAN HUYLENBROECK, G. (2007) "Measuring farm sustainability and explaining differences in sustainable efficiency", *Ecological economics*, 62, pp. 149-161.

VERCAMMEN, J. (2007) "Farm bankruptcy risk as a link between direct payments and agricultural investment", *European Review of Agricultural Economics*, 34, pp. 479-500.

VILADOMIU, L. y ROSELL, J. (2004) "Olive oil production and the rural economy of Spain". En: BROUWER, F. (ed.) *Sustaining agriculture and the rural environment, governance, policy and multifunctionality*, Edward Elgar Publishing, Cheltenham.

von WIRÉN-LEHR, S. (2001) "Sustainability in agriculture — an evaluation of principal goal-oriented concepts to close the gap between theory and practice", *Agriculture, Ecosystems and Environment*, 84, pp. 115-129.

WALTER, C. y STUTZEL, H. (2009) "A new method for assessing the sustainability of land-use systems (I): Identifying the relevant issues", *Ecological Economics*, 68, pp. 1265-1287.

YUNLONG, C. y SMIT, B. (1994) "Sustainability in agriculture: a general review", *Agriculture, Ecosystems and Environment*, 49, pp. 299-307.