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SUSTAINABLE AND RESILIENT AGRICULTURE
FOR FOOD AND NON-FOOD SYSTEMS

OLIVE-MIRACLE

Deliverable 1.3

List of Indicators

Work Package 1

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EXECUTIVE SUMMARY

In task 1.3 a literature review was performed to individuate a set of environmental sustainability indicators (ESI) that allow the identification of the interconnections existing between the olive production and the surrounding environment. Meanwhile, thresholds, which will allow us to establish environmental sustainability references, were defined on the basis of expert's evaluation after the review and stakeholder consultations in tasks 3.2 and 3.3. Indicators and thresholds will be used to compare different olives agro-ecosystems management options under current and future climate (WP4).

1.INTRODUCTION

Over the last decades there has been an increasing awareness of the strict relationships between agriculture and the environment, which has led towards a widespread demand for more environmentally friendly models of agriculture.

The ongoing debate on agriculture sustainability is lively also in the sector of olive tree cultivation, which represents the main land and water user in large areas of the Mediterranean basin, exerting positive and negative pressures on the environment. As the adoption of intensive management practices is expanding in many agro-systems, public concern about the environmental impact of olive farming is increasing, and efficient policies to encourage diffusion of sustainable cultivation models are invoked.

Some recent trends point towards the development of more eco-friendly models of production in the olive sector, with the diffusion of organic farming and integrated production. This will enhance olive potentiality as an environment preserving pillar, as olive trees make a major contribution towards atmospheric CO_2 fixation, which has been estimated at more than 900 thousand tons per year over the period 1990–2004, thus mitigating climate change (CAP, 2008).

The implementation of strategies to increase sustainability level into olive farms requires however adequate methodologies to quantitatively measure the impact of management practices on the agro-ecosystems, in order to assess the optimal balance between the creation of economic value and the reduction of negative environmental impacts.

After the publication of the Brundtland report (WCED, 1987), which proposed the first definition of sustainability, countless studies have been devoted to translating the principles into practical protocols, most characterized by the application of sustainability assessment methods in order to evaluate the environmental performance of farms.

Despite the considerable amount of studies and experiences accumulated so far, the application of environmental indicators in the olive growing sector is still rare and no consensus can be found on which indicator to use.

This is essentially due to the high complexity of agro-ecosystems, which depends largely also on the systems boundaries, which varies according to objectives of the assessment, the scale of the analysis and the type of stakeholders involved. The assessment method to be set up must be capable to capture and account for all the elements and factors with a role in the system dynamic.

After the reviewing phase which occupied the first part of the task activities, plus the first round of stakeholder consultation, the following factors have been evidenced as being the most relevant factors of environmental risk in olive systems.

Soil erosion. Soil losses tend to increase due to the expansion of olive cultivation on soils not fully adequate for olive cropping, and by the diffusion of intensive and aggressive management practices. Damages to soils are heavier where vegetation soil cover is removed and managed by tillage.

Energy consumption. Intensification of cultivation increases energy consumption of fossil fuels either directly by mechanization of field operation, or indirectly by fertilizer industries, thus impacting on carbon footprint of the farm.

Water use. Olive farming in most cultivation areas is traditionally a rain fed culture. However, intensification is often characterized by the adoption of irrigation, despite the fact that olive trees have typically low water requirements. Where olive farming extends the adoption of irrigation, a risk of overexploitation of water resources is real, especially in densely populated region where scarcity of water resources generates competition between agriculture, urban and industrial uses.

Biodiversity. The traditional olive cultivation was associated with a varied biodiversity, which offers diversified habitats to many species of insects, birds, reptiles and small mammals. The trend towards intensification of olive growing, with heavy mechanization and high chemicals input, is detrimental to the coexistence of numerous animal and vegetal species, with a negative impact also on the incidence of pests and diseases.

Environment pollution. Modern olive groves make massive use of chemicals such as fertilizer, pesticides and herbicides. Problems may arise from air and water pollution on surface and underground waters polluting water reservoirs. The risks are higher in densely populated areas neighboring olive fields, which is the common situation in many European regions. Biodiversity is also threatened.

After this very short introduction to the problem it should be clear that analyzing and quantifying the environmental impacts of agriculture is a demanding task. Many aspects need to be taken into account, as well as many risks of different nature. Furthermore, a full assessment requires the evaluation not only of risks, but also of beneficial externalities deriving from the agricultural activities (e.g. atmospheric carbon fixation), which are a relatively recent notion.

This document relates the activities conducted within Task 1.3. After this introduction, Section 2 describes the literary review and illustrates the results. Section 3 describes the approach chosen for selecting and structuring the indicator list, which is reported in Section 4. Section 5 finally exposes individually all the indicators which have been chosen.

2.LITERATURE REVIEW

Olive orchards constitute an agricultural production of great importance for producers and consumers of all countries lining the Mediterranean basin. Although in recent years new producers such as United States of America, Argentina and South Africa enter the market, the countries of the Mediterranean area remain the main producers covering about 93% of the world production of olives. By ensuring more than 40% of the Mediterranean production (37% of the world production), Spain is the biggest producer of olives in the world, followed by Italy (with more than 17% of the Mediterranean production) and Greece (with 16% of the Mediterranean production) (FAOSTAT, 2014). However, the production in all Mediterranean countries is mainly due to millions of growers managing, in most cases, very small farms and adopting different type of cultivation and different levels of mechanization (Salomone and Ioppolo, 2012). Because of its characteristics in terms of amount and size of farms involved and value added generated (mainly due to the olive oil), olive production holds an important position within the agricultural sector and the social and economic structure/web of many of the producer-countries. Moreover, olive grow cultivation, as well as other agricultural productions, can be the driver of significant environmental impacts such as land degradation, GHG emissions and resources depletion.

Accordingly, a prominent literature has been devoted to the identification of the interactions between the olive orchard production and the surrounding environmental, social and economic systems by using different methods, approaches and set of indicators. Parra-Lopez et al. (2006) used a multi-criteria decision-making tool to compare different olive farming alternatives based on their environmental values, namely values that were assigned to specific environmental aspects. Hence, indicators related to soil erosion, soil fertility, use of irrigation water, water and atmospheric pollution and biodiversity were selected. With the aim to identify the most efficient and environmental friendly olive production systems, other authors measured the soil loss, the runoff and the nutrient loss (Francia Martinez et al.,2006) to evaluate the effects of no-tillage practice. To assess the effects of cover crops, Burguet et al., (2016) adopted as indicators the organic matter content, the soil moisture, the soil water repellency, while Lopez-Vicente et al., (2016) simulated the runoff and the run-on. Instead, by using the LCA methodology Salomone and Ioppolo (2012) assessed the processes that along the oil chain production (including the olive production) give rise to the most significant environmental problem such as water ecotoxicity, eutrophication and global warming. De Gennaro et al., (2012) integrated two methods, the Life Cycle Assessment and the Life Cycle Costing, in order to focus on identifying an olive growing system able to reduce production costs without worsening environmental sustainability which in turn was analysed in terms of abiotic depletion, acidification, photochemical oxidation and terrestrial ecotoxicity.

The aim of this literature review is to understand the path that was followed for identifying different environmental, social and economic aspects characterizing the olive-grown system and for selecting the appropriated indicators to describe those aspects. Accordingly, the sources of this review were analysed according to their issues (research problem), aims, method applied, set of indicators selected and rationale.

In order to better focus on the review objectives, i.e. drawing useful indications for building an appropriate set of indicators for the problem under study, the literature review has been performed by applying a common scheme identifying for each of the bibliographic source:

- *The authors*;
- the *research* problem, namely the main issue under investigation;
- the *aims* that the research wished to achieve;
- the *method* adopted;

- the i*ndicators* that have been chosen or developed;
- the *rationale* of the research, that is, the logic behind the overall approach and methods.

The review concentrated preferably on researches conducted in the Mediterranean basin, and considered only peer reviewed research articles. The work identified more than 20 published papers with relevant information to the task activities. The summarized reviewed is reported in Table 1.

TABLE 1. Summary of the literary review on sustainability indicators for olive tree cultivation. Complete references are reported in the References section.

Authors	Research problem	Aims	Method	Indicators	Rationale
De Gennaro et al 2012	Innovations to improve environmental performances, but innovations to be introduced in the agricultural steps should also consider their economic feasibility.	Environmental and economic assessment of two olive-growing systems: the “High Density” (HDO) and the “Super High Density” (SHDO) to face with a very high competitive scenario (due to new world producers and to obligations for farmers at national and EU level).	Life Cycle Assessment and the Life Cycle Costing (functional unit is 1t of olives in the reference period of 48 years; life cycle phases, starting from the production of the inputs used in the agricultural phase (fertilizers and pesticides) until the production of olives	Environmental analysis: abiotic depletion, acidification, photochemical oxidation and terrestrial ecotoxicity, Economic Analysis: Net Present Value and Internal Rate of Return (based on estimate the initial investment (plantation costs) and the flows of operating costs and revenues of the two models over the entire reference period.	Identifying an olive growing system able to reduce production costs without worsening environmental sustainability
Salomone, Ioppolo 2012	In Sicily, production is characterized by 8 different predominant cultivars and a variety of different practices and techniques for the agricultural production of olives and for their processing into olive oil. Depending on these differences, the production of olive oil is associated with several adverse effects on the environment, both in the agricultural and olive oil production phases.	Assessment of the environmental impacts of activities connected to olive oil production, in order to identify the processes which give rise to the most significant environmental problems and to design a more efficient and environmentally friendly local olive oil chain.	LCA and LCIA Functional unit: 1000 kg of olives. LCIA has included both the problem-oriented methods (midpoints) and the damage oriented methods (endpoints). Comparison of 9 scenarios defined based on different management of specific sub-processes (see tab. 4)	10 Impact categories (midpoint): photochemical oxidation, terrestrial ecotoxicity, marine aquatic ecotoxicity, fresh water aquatic ecot., human toxicity, ozone layer depletion pot., global warming pot., eutrophication potential, acidification potential, abiotic depletion Damage categories (endpoint): Land use, Climate change human health, Terrestrial ecotoxicity, Aquatic eutrophication	Designing strategies through the analysis of the sub-processes. Improving single sub-processes to make the entire process efficient/environmental friendly. Therefore, the rationale is based on optimization!
Romero-Gàmez	Olive grove cultivation tends	Assessment of the potential	LCA with midpoint approach	Impact categories (midpoint): Climate	Environmental impacts of the

et al 2017	to move from traditional low-density to new high-density cropping systems with irrigation producing the major change.	environmental impacts associated to the olives production phase from the extraction of the raw materials to the oil mill gate. Good description of the systems (Tab. 5)	Comparison of eight traditional different systems (8 traditional, 3 intensive and 1 super-intensive).	change, Acidification, Freshwater eutrophication (eutrophication) and Freshwater ecotoxicity (ecotoxicity).	single practice within the cropping systems.
Francia Martínez et al 2006	Many orchards are confined to slopes or rugged land, occupying large parts of mountains and hills of the Mediterranean landscape. The low plant density combined with poor vegetation cover of the soil increases the vulnerability of the orchards to soil erosion.	Effects of three different soil management (No tillage with plant strips, No tillage without plant strips, Conventional till) on soil erosion, runoff and nutrient loss in Spain	Field measurements through galvanized enclosure, drawer collector on erosion plots. Measurements of soil loss and chemical analysis	Soil erosion, runoff, nutrient loss.	Analysis of a specific environmental issue: soil erosion and what this implies.
Chamizo et al., 2017	No-till management and the establishment of plant cover are implemented in olive crops to prevent soil erosion and increase soil organic carbon. The effect of these conservation practices on the net CO2 exchange at the ecosystem scale has not been explored so far.	Assessment of the effect on Net CO_2 exchange of resident vegetation cover (weeds) in irrigated olive orchard. Two treatments were applied: with weeds in the alleys and weeds removed with glyphosate herbicide.	Field measurement through eddy covariance towers	CO_2 fluxes, weed biomass, crop productivity.	CO_2 fluxes related to the cycle of weed biomass.
Burguet et al., 2016	Soil water repellency can potentially occur with different intensity and persistence in olive groves with different management and in different environmental conditions perform evaluate.	Assessment of soil water repellency in olive groves in different environmental conditions and management: abandoned and commercial farms under permanent cover crop, conventional tillage and herbicide use. Furthermore, influence of soil properties such as organic matter (OM) and soil moisture on soil water repellence is assessed.	Methodology of Water Drop Penetration Time. Soil analysis	Soil Water Repellency persistence. Soil moisture and OM content	Different practices (soil management) can affect the property of soils to be repellent to water.
Lopez-Vicente et al, 2016	The spatial and temporal stability of runoff (Q) and runon (Qin) magnitudes and	Assessment of the effects of conventional tillage and cover crops on runoff (Q) and runon (Q_{in})	Computed by the distributed rainfall-run-off model DR2 model.	Run-off and Runon	Relation between practices and soil water characteristics (parameters in the model)

	patterns in woody crops.is not well known yet.	in an olive orchard.			
Parra-Lopez et al., 2006	Are the organic and integrated olive farming systems better than the conventional system in terms of environmental performances?	Assessment of the environmental performances of three different olive farming systems (conventional, integrated and organic).	Multi criteria analysis based on experts' knowledge.	Environmental values which are determined by the environmental performances of the three farming systems and regards soil erosion, soil fertility, biodiversity, air pollution, water contamination, use of irrigation water	When information relevant for urgent decision-making is not available, is partial or is time and resource demanding, the utilization of experts' knowledge is justified.
Egea and Perez, 2016	The cultivation of olive groves, , is important not only from an agrarian perspective but also in regards to the regional landscape, natural and cultural heritage and environmental management. Therefore, olive farming provides a potentially suitable study-case to analyse the multifunctional behaviour of agricultural systems.	Analysis of the sustainability of olive oil (PDO) Protected Designations of Origin. Organic, integrated and conventional farming were compared and ranked.	Multicriteria techniques (Analytical Network Process)	Ten criteria grouped in three clusters: economic, environmental and socio-cultural and asked experts.	The clusters and criteria are related to definitions (see table 2). In turn, the definitions refer to general targets.
Russo et al., 2015	Management of weed in the high density olive orchard	Assessment of the environmental sustainability of five methods of weed control.	LCA	ADP, Abiotic Depletion Potential; AP, Acidification Potential; EP, Eutrophication Potential; GWP, Global Warming Potential; ODP, Ozone layer Depletion Potential; POPC, Photochemical Ozone Creation Potential; PED, Primary Energy Demand	Identification of the environmental burdens of each of the analysed method.
Duarte et al., 2008	The intensification of production leads to the abandonment of traditional olive groves (at low density) that instead show high levels of biodiversity and low rates of soil erosion. Furthermore, the abandonment would result in increased fire risk, and major changes to the traditional Mediterranean landscape.	Analysis of different aspects related to traditional olive groves and to their potential abandonment	strengths, weaknesses, opportunities and threats (SWOT) analysis was conducted with the participation of the stakeholder platform (representatives of different types of farmers, olive processing units, extension officers and farmers' organisations).	Economic: Net revenues, Net profitability Consequences of olive growing abandonment in situ, in terms of soil and water conservation	Sustainability related to consequences of abandonment.

Dulja et al. 2013	Agriculture has an important share into environmental pollution and natural resources degradation, hence is necessary to find alternative agricultural systems, that mimic natural systems and are friendly to the environment; those have higher economical efficiency concerning production level and costs.	Comparison of organic and conventional systems in terms of sustainability, which is assessed with special focus on environmental and economical performance.	Comparison between an organic and conventional olive-producing farms in two Apulia case-studies, using a sustainability assessment based on the Environmental Accounting Information System (EAIS), that integrates together environmental (soil organic matter, soil erosion, genetic and landscape biodiversity, EPRIP, etc) and economical indicators (gross margin).	The Water Use Indicator (WUI), Soil erosion, Soil organic matter content, Soil organic matter input/output, Agricultural landscape diversity, Herbaceous plant biodiversity, Arbour Biodiversity Indicator, Ecological Infrastructure Indicator, Nitrogen surplus, Phosphorus surplus, Environmental potential risk of pesticide use, Gross margin	Sustainability is evaluated with a “financial balance” analogy, where the gain in “environmental capital” is assessed as variation between the balances of two consecutive years, accounting for environmental “profits and losses” assessed through indicators.
Dantsis et al. 2010	No widely accepted method for the creation of a scientifically substantiated system of indicators and indices has been developed so far, and high heterogeneity exists as regards data collection, analysis, scale, issues, and the final goals. Heterogeneity exists also as far as the spatial scale of the assessment, from the field to a regional, national or even an international scale. Different site-specific conditions owed to the natural environment, the agro-technical and socioeconomic conditions have raised the need for more granular scales of assessment	The purpose of this is to select a set of representative indicators, in order to analyze the potential impacts (environmental, social and economic) on agricultural sustainability at regional scale, for the thirteen geographical regions of Greece Indicators were selected according to their ability to describe the pressures of agricultural production systems on sustainability. This regions are presented in this paper	Data were collected from randomly chosen farms with questionnaires, and then scaled up at regional level through a weighted mean. The proposed composite indicator aggregates environmental, social, and economic indicators into a unique measure and thus represents the level of agricultural sustainability in a given region. The aggregation of individual indicators is performed using the Multiattribute Value Theory (MAVT) performed with Hierarchical PREference Analysis (Web-HIPRE), available through the Internet.	A set of indicators was individuated from literature review, and grouped in the following subsets: *i) Environmental indicators(*fertilizers, pesticides, water consumption, farm management practices, type of farming systems); *ii) Social indicators* (farmer’s age and education, pluriactivity, family size, employement); *iii) Economic indicators* (farm financial resources, farm structure)	Setting up a sustainability assessment which aggregate environmental, social and economic aspects, at the most appropriate granularity for a national-level assessment.
Gómez-Limón et al. 2012	The increasing importance of Olive cultivation in Andalusia brought about significant	The goal is to analyze the farm-level eco-efficiency of olive farms in the region of Andalusia,	Eco-efficiency is formulated it as a ratio between net income and a measure of environmental	Economic results variable: Net income Environmental pressure variables: erosion, biodiversity, pesticide risk, Water	The concept of “eco-efficiency”, is not coincident with that of “sustainability”.

	environmental pressures with regard to soil erosion, use of polluting inputs, excessive water consumption and biodiversity reduction. Reliable sustainability assessments are needed. The authors believe that a site-specific approach is necessary to depict the state of the environment accurately	distinguishing between managerial eco-efficiency and program eco-efficiency, the latter representing the eco-efficiency due to the characteristics – endowment of natural resources – of the particular olive farming system farms belong to. This in order to answer the following questions: How much does the eco-efficiency of olive farms depend on the endowment of natural resources and/or their management by farmers? What structural and socio-demographic variables influence the eco-efficiency of these farms? Are the farms that receive institutional financial support more eco-efficient?	(ecological) performance, which aggregates the n-environmental pressures into a single environmental pressure score. The empirical assessment has been implemented on a representative sample of Andalusian olive farms, divided into three subsamples, one for each of the following Systems: i) Traditional mountain groves; ii) Traditional plain groves; iii) Irrigated intensive groves.	use, Nitrogen ratio, Energy ratio. Socio-economic variables: farmer's and farm features.	Sustainability is concerned with the absolute pressure that economic activities exert on the absorptive capacity of ecosystems. That is, even if the relative level of environmental pressure generated by a particular economic activity is low, the absolute level of environmental pressure may still exceed the threshold of compatibility with the performance of vital functions of natural ecosystems. However, using eco-efficiency has been considered convenient for at least two basic reasons: i) eco-efficiency improvements may represent the most cost-effective way to achieve a reduction in environmental pressures ii) policy-makers may find it easier to adopt policies aimed at achieving improvements in eco-efficiency than other more radical policies that directly restrict the level of economic activity.
Proietti et al., 2014	The information about the quantification of the amount of agriculture carbon (of different agricultural systems like olive growing system) is very limited because their productive role is usually considered rather than their ecological role.	Assess the impact of the individual phase and material in order to propose potential actions to reduce emissions. Removals and emissions were calculated and compared in order to identify the break-even point.	LCA Assessment of the Carbon footprint of the entire olive growing system. The IPCC formula the carbon and CO2 stock of the olive grove since its planting was calculated (analysing all of the dendrometric and fruit yield data).	GWP to give a measure of the Carbon footprint. It is an indicator that quantifies the carbon footprint. This factor describes the radiation forcing impact of one mass-based unit of a given greenhouse gas related to an equivalent unit of carbon dioxide over the given period of time of 100 years (GWP100).	Identification of the environmental burdens of each of the analysed method. The entire process was analysed in its individual phases and materials used in detail.

Tanasijevic et al., 2015	Climate change can have relevant consequences on olive growing system in terms of cultivable areas and crop processes.	Understanding the impacts of foreseen climate change on olive cultivation in the Mediterranean countries and region by comparing a baseline climate, defined for year 2000, with a future one assumed for 2050. Focusing on crop evapotranspiration, irrigation requirements and water stress impacts on rainfed olive cultivation, while considering the expected shifting of the flowering time and future changes in the areas suitable for cultivation, insight regarding agricultural water management at different scales and promote active management strategies optimizing water use and yield production can be identified.	Assessing crop evapotranspiration, irrigation requirements and water stress impacts on rainfed olive cultivation while considering the expected shifting of the flowering time and future changes in the areas suitable for cultivation	Temp. requirements, phenological dates, crop evapotranspiration (ETc) and irrigation requirements (NIR).	Climate change will affect specific crop aspects and processes such as the evapotranspiration that in turn influence the capacity of crops to survive in an environment under specific conditions.
Hemmati et al. 2013	Modern olive tree farming is based on higher planting densities, which impact on energy use efficiency. Concerns about farming sustainability requires to improve energy efficiency.	Compare the production systems of flat and sloping olive orchards and analyze the effect of land situation (flat and sloping) on use of energy input resources	Development and comparison of Cobb-Douglas functions for both types of systems	Fixed energy equivalents for the input factors and output variables, to calculate energy efficiencies.	Sloping orchards ensure higher yields than flat ones. Analysis of energy use efficiency allows a more comprehensive systems evaluation.
Notarincola et al., 2004	The organic system scores worse than the conventional one in many LCA's environmental categories. the organic system is characterised by higher production costs due to the organic lower yields (not considering external costs). Nevertheless, if external costs	To identify environmental performances and all costs, including external costs, of organic and conventional olive oil to understand how they affect the market price.	Combination of Life Cycle Assessment (LCA- environmental burdens) and Life Cycle Costing (LCC-cradle-to-gate costs) of organic and conventional extra-virgin olive oil	LCA impact categories: Energy Consump. (EC), Glo. Warm. Pot. (GWP), Ozone DepL. Pot. (ODP), Human Tox. Pot.(HTP), Freshwater Aquatic Eco-toxicity Pot. (FAETP), Marine Aquatic Eco-toxicity Pot. (MAETP), Terrestrial Eco-toxicity Potential (TETP), Acidification Pot. (AP), Nutrification Pot. (NP), Photochemical Oxidant Creation Pot. (POCP) and Land Use (LU). LCC -conventional company	The assessment of a product must be based on the assessment of the environmental performances and its total costs by including external costs.

	(which are not actually paid by the farmer and by the olive oil companies), why organic oil has a higher market price than the conventional one?			costs, -less tangible, hidden and indirect costs, -external (social) costs.	
Taxidis et al. 2015	Low intensive farming systems use better practices and diminish gas emissions. Organic farming systems are known to use less energy than conventional ones, but there is limited research in the comparison of organic and conventional olive groves in energy flow along with gas emissions.	Study the energy flows and CO2 emissions in conventional and organic olive groves.	A number of organic and conventional olive groves were selected in Lesvos Island (Greece). The energy consumed by each farm was estimated on the management schedule, the duration of each operation, the number of machines and laborers, the field operation inputs and the production coefficients (e.g. fuels and fertilizers). Machine and human labor was converted into energy units by conversion factors. The fuel consumed by the machinery was used to determine fossil energy. Carbon dioxide, CH4, and N2O, and CO2-equivalents emissions.	Production factors were aggregated into seven groups: fertilizers, fuel, plant protection products, labor, machinery, transportation, and harvesting nets, whose variability was studied for each farming system × variety combination	Manipulation of genetic material (cultivar choice) and of the farming system (organic or conventional) may be effective in ameliorating energy use efficiency of olive groves.

3. APPROACH

There has been considerable debate during the past decades over the concept of agricultural sustainability. A broad consensus exists around the definition proposed by the World Commission on Environment and Development (WCED), known as Brundtland Commission (1987), which was developed to elucidate the notion of sustainable development, that goes like this: "*development which meets the needs of current generations without compromising the ability of future generations to meet their own needs*". Though this definition is widely accepted worldwide, it has not always been very clear as to how translate it in the agricultural sector, and particularly in very specific sectors such as the olive tree culture.

With the intention of restricting our analysis to the environmental sustainability, as required by the project DOW, it was agreed to start from a provisional definition based on the above-mentioned more general definition and our expert knowledge, which conceives agricultural sustainability as the "ability of ensuring greater agricultural productivity, ensuring food security, while simultaneously conserving natural resources and preventing degradation of the environment, maintain economic viability and socially acceptable".

This first definition implies that whatever sustainability assessment will be adopted, it must be capable of handling multiple aspects at once. Intuitively it is derived the awareness that the use of multiple individual indicators must be looked for, along with a methodology to aggregate them to build up a composite indicator or a procedure to derive ultimately a comprehensive judgment and/or a quantitative metric.

Many studies have been appeared claiming that indicators which consider many aspects of the environmental impacts at the same time are more useful to address the complexity of agricultural systems (Bastianoni et al., 2007). Thus, one of the most important features of an indicator is its ability to summarise, focus and condense extensive datasets (obtained from complex environmental parameters) to a manageable amount of meaningful information (Godfrey and Todd, 2001).

The literature review which was conducted in the first part of the activities in this task, has shown that a variety of assessment tools has been already developed in the past, including Life Cycle Assessment (LCA), Cost–Benefit Analysis (CBA), Environmental Impact Assessment (EIA) and Sustainability Standards with Principles, Criteria and Indicators (PC&I).

PC&I is the most universal and versatile among these tools, as it is nothing else than a thematically structured list of principles and criteria with a corresponding checklist of indicators. PC&I can be used for a wide range of applications such as ecocertification at the management unit level, policy evaluation at the regional or national level, or as a generic assessment tool for specific sustainability issues.

This approach allows a relatively rapid transfer of available expert knowledge into an operational environmental impact methodology, which appears particularly appropriate to the objectives of the Olive-Miracle project, in consideration of the constraints and running activities.

Together with the literature review, the other relevant sources of information were expert knowledge and stakeholder consultation, which backboned an analysis focusing on the challenges of olive growing today and for the foreseeable future

The objective was to find a set of indicators that encompasses the elements of the system under consideration, while keeping a reasonable level of complexity.

Here the challenge was to find a sufficient number of indicators, so to not overlook key elements of the system, and at the same time it was paid attention as to not include too many of them, which could made data collection and processing difficult to handle at a reasonable cost, while making the message expressed by the indicators difficult to understand and to apply.

The indicators list conceived for OLIVE-MIRACLE, was designed around the following criteria:

Model-based – This criterion requires that each indicator included in the list be obtainable directly as an output of the simulation model (Olivecan) utilized for the scenario analysis, or indirectly by calculation from output variables.

Reliability - Reliability pertains to the capacity of the indicators to effectively represent locally-specific characteristics determined of olive systems.

Applicability – This concerns the capacity of the indicators to support management design, i.e. to implement feasible strategies and agricultural policies.

Intuititive meaning – In order to be applied, definition and rationale of each of the indicators should be easily understandable by end users.

A number of indicators has been individuated and structured according to the SAFE (Sustainability Assessment of Farming and the Environment Framework) methodology, which was developed by Sauvenier et al. (2006) and van Cauwenbergh et al. (2007), following the PC&I approach, and recently applied to olive cultivation in Andalusia by Gomez-Limon & Riesgo (2010).

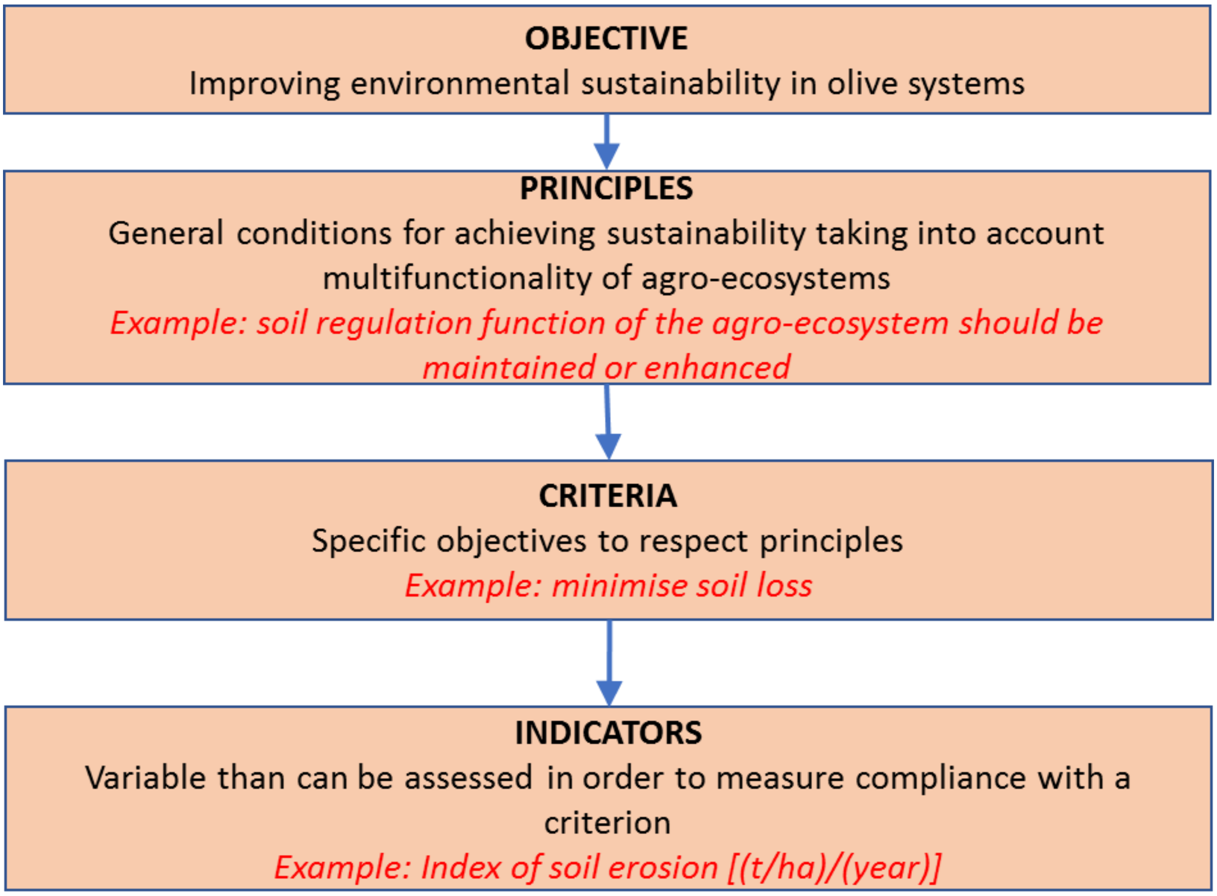
BASIC CONCEPTS

The general aim of the SAFE methodological 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 which allow to realize the principles to a given state of the agroecosystem. 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 the impact of any 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. The structure of the SAFE hierarchical framework (adapted from Sauvenier et al. 2006)



4. FROM VULNERABILITY TO SUSTAINABILITY

Climate change exposes agroecosystems to several variations which are potentially harmful depending on the capacity to react and adapt. In this view it is useful to approach the analysis by looking first at the *vulnerability* of agroecosystems. The vulnerability concept is used since the 1970s in risk management issues to describe the fragility of complex systems such as countries or communities subjected to severe environmental threats or to severe socio-economic crisis. The term became increasingly popular after 2000, when it started to be used by the *Intergovernmental Panel on Climate Change* (IPCC) to assess the potential impacts of increasing temperature at regional and global levels (IPCC, 2001). Since then, vulnerability has become a key point for the global change science research community for discussing and defining adaptation and mitigation plans.

According to its most widely accepted definition (IPCC, 2001), vulnerability refers to the degree to which a system is susceptible to or unable to cope with adverse effects of climate change (including climate mean, variability, and extremes), and it is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Following this definition, it is possible to considered vulnerability of olive agroecosystems to a specific stress as a threat to its sustainability. If the systems are vulnerable to climate risks without the capacity of coping with adverse climatic events, the outcome might be a situation of vulnerability that undermines sustainability in the medium and long term.

Assessments of climate change vulnerability and risk are shown to be of critical importance because they inform decisions as to where resources for adaptation are best invested.

In Olive-Miracle a close relationship between sustainability and vulnerability of olive groves was identified, on the ground that some of the features which make a given agrosystem maintain its productive attitudes over time, are more vulnerable than others to particular stresses. This notion considers the possibility that even a system which is currently sustainable, can nonetheless increase its vulnerability to environmental stresses. This is expected if extreme climatic events become more frequent in time, undermining system resources stock (e.g. soils, water), and ultimately to diminish the whole system sustainability. An agricultural system that is unable to cope with frequent extreme climatic events is vulnerable and will not adapt to changes associated to more frequent and more severe stress events. This poor adaptive capacity is a significative symptom of a general lack of sustainability of the system, which impacts negatively on the system capacity to maintain its productivity level. A direct or indirect quantitative assessment of the potential damages suffered by a system exposed to adverse climatic conditions can be taken as a measure of its vulnerability, thus providing objective criteria to evaluate the sustainability of that system.

All that considered, a system that will result to be highly vulnerable to extreme climatic events has a high potential to be unsustainable upon increasing frequency of that events.

5. INDICATORS LIST

Based on the concepts and methodologies outlined above, two indicator lists were proposed, one aiming at quantifying vulnerability aspects (Table 2), and the other addressing sustainability issues more closely (Table 3).

Table 2 - Framework for the assessment of vulnerability

General Principles	Criteria	Indicator	Description
Farming performances	**Crop Yield**	Dry biomass	Rate of dry biomass accumulation per year per unit of surface
		Yield interannual variability (e.g. 30 yrs CV)	Variability of annual yield calculated for a multi annual period
		Yield variation trend (yes/no, *p-value*)	Variability of annual yield calculated for a multi annual period
		Yield trend variation rate (⍰yield/year)	Variation trend of yield calculated over a period of at least 30 years
		Average annual yield	Average yield calculated over a period
	Cropping Management	Management Intensity	Aggregated indicator accounting for plant investment, presence of irrigation and the average number of field operations based on standardized coefficients
		Water Use Efficiency	Amount of harvested dry matter per unit of water.

The **General principles** of the list focus essentially on the Farming performances, which denote how the system respond to the overall surrounding environmental conditions (soil, climate, etc.). Change in such conditions will turn into different degrees to which farming systems, more specifically cropping systems, experience harm because of specific hazards or threats.

The essential criteria to assess vulnerability are Crop Yield and Cropping Management; the former being an outcome of the crop simulation model, and gives a global index of the system performance; the latter derives on general information on grow planting design, farm organization and equipment and input level (high/low fertilization/irrigation).

The set of chosen Indicators allow to compare the crop performances under the current climate scenario (baseline) with those under future climate scenario, so that the potential cropping system vulnerability to climate change will be assessed.

As far as the indicator framework for the assessment of sustainability (Table 3), three General Principles have been individuated: i) Resource stocks, which refer to the maintenance of the natural resources stocks, assimilating to the "natural capital" with an economic analogy; ii) Externalities, referring to the negative impact of the agrosystem on the surrounding environment, and iii) Agroecosystem functionalities, which account for the functions that are responsible of system productivity and of specific ecosystem services.

Table 3 - Framework for the assessment of the environmental sustainability

General Principles	Criteria	Indicator	Description
Resource stocks	Resources use/loss	Water Consumption	Amount of irrigated water supplied for growing season
		Runoff	Runoff is estimated as a proxy for indicating the rate of soil loss due to erosion
Externalities	Pollution	Pest attack risk	Adimensional indicator of the estimated potential risk from insect population model [stimato dal modello insetti a parte]
		NEE	Net Ecosystem Exchange: amount of CO2 biomass emission per year per unit surface
		Nutrient loss	Potential amount of nutrients (nitrogen) lost as leachate below the soil root exploration zone.
Agroecosystem functionalities	Soil Fertility	SOM content	Content of soil organic matter in the soil
		SOM variations rate	Rate of SOM variation

5. VULNERABILITY INDICATORS

DRY BIOMASS

Name	Dry Biomass
abbreviation	DB
description	Rate of dry biomass accumulation per year per unit of surface
rationale	A high biomass accumulation indicates tree health, overall fertility of the agrosystems and is correlated with yield
Model	(direct model output)
units	Kg ha^{-1} yr^{-1}
Threshold value	Historical mean for the area – (reference period:2000-2015)

YIELD INTERANNUAL VARIABILITY

Name	Yield interannual variability
abbreviation	YIV
description	Variability of annual yield calculated for a multi annual period ($n > 30$)
rationale	Yield variability depends essentially on weather interannual variability but can be attenuated by genotype and management practices. More stable olive groves are better suited to cope with climate change
Model	The indicator is calculated a Coefficient of Variation of yield for a period of at least 30 years
Units	%
Threshold value	10% (arbitrary value based on expert's opinion)

YIELD VARIATION TREND

Name	Yield variation trend
abbreviation	YVT
description	Presence (yes or no) of a yield variation over time
rationale	An increasing or decreasing rate over years indicates whether a given grow is a well or bad performing one.
Model	The index is calculated as the statistical significance (*p value*) of the slope of the regression line between yield and years ($n = 30$ at least).
Units	%
Threshold value	0.10

YIELD TREND VARIATION RATE

Name	Yield trend variation rate
abbreviation	YTVR
description	Variation trend of yield calculated over a period of at least 30 years.
rationale	It indicates the variation of the yield, i.e., whether the productive capacity of the grove is increasing or decreasing.
Model	The indicator is calculated as yield variation for a period of at least 30 years. The indicator is reported only if the trend is significant of at least $P<0.05$.
Units	Kg ha^{-1} $year^{-1}$
Threshold values	0

AVERAGE ANNUAL YIELD

Name	Average annual yield
abbreviation	AAY
description	Average yield calculated over a period
rationale	The average yield is the basic indicator of the productive capacity, which or Yield variability depends essentially on weather interannual variability, but can be attenuated by genotype and management practices. More stable olive groves are better suited to cope with climate change
Model	The yield is strongly dependent on the location. The yield is calculated as a percentage on the average of the geographic region.
Units	% (of the regional average)
Threshold values	Regional yield average for an equivalent grove type (reference period: 2000-2015)

MANAGEMENT INTENSITY

Name	Management Intensity
abbreviation	MI
description	Aggregated indicator, based on standardized fixed indices, which accounts for the level of management intensification (average number of field operations, presence of irrigation, planting intensity).
rationale	This indicator is a raw index of the intensification level of management, which in turn is associated to the energy consumption.
Model	For a given type of management system (e.g. high density or low density system), a 0 to 1 index is assigned based on a scoring system accounting for the average number of field operations (tillage, pruning etc.) irrigation (yes/no), mechanization level (….).
Units	Adimensional coefficient between 0 and 1

Threshold values	0.5 (arbitrary value based on expert’s opinion)

WATER USE EFFICIENCY

Name	Water Use Efficiency
abbreviation	WUE
description	Amount of harvested dry matter per unit of water.
rationale	WUE indicates the ability of the crop to yield on the ground of water available. In the view of forthcoming climate change, with more expected drought events, it indicates the capacity of the groves to survive.
Model	It is calculated from the output of simulation model
Units	Kg D.M. mm^{-1}
Threshold value	Regional average for a grove of a given type (e.g. irrigated or not, high/low planting intensity; reference period: 2000-2015).

6. SUSTAINABILITY INDICATORS

WATER CONSUMPTION

Name	Water consumption
abbreviation	WC
description	Amount of irrigated water supplied for growing season
rationale	Reduction or minimization of water input is a key component of any sustainability assessment. Water must be spared in order to allow coexistence with other water-consuming processes, mostly related to human activity, and to preserve biodiversity.
Model	(directly provided by simulation model)
Units	mm
Threshold values	50 % of total ET (arbitrary value based on expert’s opinion)

RUNOFF

Name	Runoff
abbreviation	ROFF
description	Surface water flow occurring when precipitation exceeds infiltration soil capacity
rationale	Runoff water is the main factor affecting soil erosion, hence it heavily affects in the long-term the orchard productive capacity, particularly in sleepy fields. It also impacts on the efficiency of water management, as it reduces the system capacity of full exploiting water natural and irrigation input.

Model	Provided by the simulation model, on the ground of soil and management characteristics of the site
Units	mm day^{-1}
Threshold value	[to do]

PEST ATTACK RISK

Name	Pest Attack Risk
abbreviation	PAR
description	Adimensional indicator of the probability attack of *Daucus oleae*, based on weather and crop ecophysiological variables (humidity, temperature, period of year, crop phenological stage).
rationale	A low pest attack risk is strictly associated to a minor use of pesticides, which lower the impact on the surrounding environment, and human health.
Model	The model is calculated from a dedicated model which simulates the potential level of pest infestation at given climate and crop status. An infestation index is derived from the estimated population level.
Units	Adimensional index between 0 (no risk) to 1 (maximum risk)
Threshold value	0.5 (arbitrary value based on expert’s opinion)

NET ECOSYSTEM EXCHANGE

Name	Net Ecosystem Exchange
abbreviation	NEE
description	Net Rate of CO2 biomass emission per year per unit surface
rationale	Net CO2 emission measures the capacity of the system to fix CO2 or alternatively to enrich atmosphere
Model	(directly provided by simulation model)
Units	Kg CO2 ha-1 yr-1
Threshold value	Historical average for the site (reference period: 2000-2015)

NUTRIENT LOSS

Name	Nutrient loss
abbreviation	NL
description	This indicator quantifies the estimated amount of nutrients (nitrogen) leaching below the root zone, which get lost.
rationale	Nitrogen leaching impacts on sustainability since it pollutes groundwater and it lowers fertilization efficiency.
Model	N lost as leached NO3 is calculated indirectly by the simulation model, which return the percolated water

	through soil water balance calculation. The index is derived from the percolated water amount associated with the time of the year and with the management intensification level.
Units	Mg L-1
Threshold value	50 mg L-1 in the groundwater (World Health Organization)

SOIL ORGANIC MATTER CONTENT

Name	Soil organic matter content
abbreviation	SOM
description	Content of soil organic matter in the soil
rationale	A minimum content of O.M. is important to ensure soil fertility, microbial activity, fertilization efficiency, water infiltration and storage, as well as to protect soil from erosion.
Model	Given by the available databases
Units	% of soil weight
Threshold value	1%

RATE OF SOIL ORGANIC MATTER VARIATION

Name	Soil organic matter content
abbreviation	RSOM
description	Variation of soil organic matter in time
rationale	Time variation of soil organic matters indicates that current soil management is not appropriate to preserve soil stability, and that is putting soil preservation at risk.
Model	Derived from simulation output – soil submodel
Units	% of soil weight
Threshold value	0%

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