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MULTIDISCIPLINARY AND INNOVATIVE METHODOLOGIES FOR SUSTAINABLE MANAGEMENT IN AGRICULTURAL SYSTEMS

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Abstract

Sustainability issues have driven academic researchers towards the definition of methodological tools to assess the impacts derived from products and services and to make them more ecologically friendly, economically profitable and socially suitable, and whose results have to be clear and understandable to a broad public. In the evaluation of complex socio-environmental systems, like agricultural ones, uncertainty often arises and the quality of decision processes can be a high concern. This paper presents the conceptual and methodological framework of an Italian research project entitled "MIMeSMAS", i.e. Multidisciplinary and Innovative Methodologies for Sustainable Management in Agricultural Systems. Through a multi-disciplinary, multi-methodological, systemic and participatory approach, the project attempts to define an integrated approach for the assessment of environmental, economic and social sustainability of innovative agricultural practices in Mediterranean areas. The project activities are carried out by four Italian research institutions in order to bring together agronomic, hydraulic and mechanical expertise and to conduct a combined implementation of Life Cycle methodologies (LCA, LCC and s-LCA) and multi-criteria analysis tools. The approach is applied to assess and rank alternative cropping systems scenarios; results are expected to help optimising the management of soil, water and energy macro-systems of perennial crops (olive), horticultural crops (artichoke) and dedicated energy crops (giant reed). In this paper the theoretical concept of the project, the preliminary results of project's activities linked to the identification of experimental trials scenarios and to the definition of specific indicators are presented.

Key words: agricultural sustainability, life cycle methodologies, multidisciplinary approach, multi-criteria decision analysis, participatory approaches

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1. Introduction

Since long time now, researchers from different scientific fields debate extensively about agricultural sustainability by considering, from several points of view, all multifarious aspects and implications. Although the early idea of sustainability is backdated to the German forestry studies of the 18th century (Caradonna, 2014; Spindler, 2013), as it is known, the Brundtland Commission's definition represents the undisputed milestone on this subject (WCED, 1987).

Nevertheless, only two years later the American Agronomy Society coined a less known definition of sustainable agriculture as an activity "that, over the long term, enhances environmental

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quality and the resource base on which agriculture depends; provides for basic human food and fiber needs; is economically viable; and enhances the quality of life for farmers and society as a whole" (Weil, 1990).

It is now well recognised that achieving sustainable agricultural production needs a special effort to overcome the sector-based perspective and to provide solutions to real-world problems through scientific and socially robust knowledge (Brandt et al., 2013). In this sense, it is possible to frame the research on sustainable agriculture within the umbrella of the so-called "Sustainability Science" (SS): "a solution-oriented discipline that studies the complex relationship between nature and humankind, conciliating the scientific and social reference paradigms which are mutually influenced- and covering multi temporal and spatial scales. The discipline implies a holistic approach, able to capitalize and integrate sectorial knowledge as well as a variety of epistemic and normative stances and methodologies towards solutions' definition" (Sala et al., 2013a).

By examining the latest scientific literature on sustainability discourses, Kajikawa et al. (2014) argued that agricultural sustainability is the more representative disciplines-focus issue that provides also the most numerous links with other fields within the overall landscape of the sustainability research. In the last years, several scholars stressed the importance of a comprehensive framework approach in sustainability studies that increasingly recognize the urgency to adopt *multi-inter-trans-disciplinary approaches* to deepen the complexity of sustainability issues (Brandt et al., 2013; Lang et al., 2012; Mattor et al., 2014; Mobjörk, 2010; Polk, 2014; Serrao-Neumann et al., 2015). Especially in terms of transdisciplinary approaches, several, but not univocal, definitions linked to agricultural sustainability research have been proposed. However, as well summarised by Darnhofer (2014), the most important and frequent characteristics of a transdisciplinary research are the follows: the integration of disciplinary paradigms; the co-production of knowledge with non-academics actors; the use of participatory methods and the application to real-life problems.

In this sense, it is possible to affirm that the aim of transdisciplinary approaches in sustainable agriculture studies is to go further the limits of multidisciplinary and interdisciplinary research (Nagabhatla et al., 2015; Vandermeulen and Van Huylenbroeck, 2008) to get toward a combined approach inspired by both the so-called hard sciences and the soft ones. Such mixed methodological procedures can borrow different methods moving from opposite paradigms, like positivism-oriented approaches and constructivist-oriented ones (Iofrida et al., 2014), to work together in an integrated conceptual framework. Furthermore, an integrated assessment of complex issues - like sustainability concerns - requires "a mutual interdependence of participatory and modelling approaches in assisting policy-making" (Hisschemöller et al., 2001).

In the light of these considerations, this paper presents the conceptual and methodological framework, as well as the preliminary results, of a national research project entitled "MIMeSMAS" (Multidisciplinary and Innovative Methodologies for Sustainable Management in Agricultural Systems). Starting from a multi-disciplinary and systemic approach, the project attempts to pursue a twofold purpose. The first one is the definition of an unprecedented methodological framework that, with an innovative and integrated approach, can contribute to increasing the knowledge about agricultural sustainability assessment. Secondly, the implementation at experimental and farm scale is functional to achieve solutions in real-world scenarios of different agricultural systems by highlighting the potential effects in terms of environmental, economic and social impacts, examined individually through specific analysis tools and finally combined in a holistic approach. Furthermore, from a trans-disciplinary point of view, the project aims to test participative models to conduct the sustainability assessment in co-learning pathways with non-academic stakeholders. The project involves four Italian research institutions that will assess alternative scenarios useful to optimizing agricultural practices for permanent crops (olive), horticultural crops (artichoke) and dedicated energy crops (giant reed).

In the next paragraph a description of project is fulfilled by distinguishing in sub-paragraphs the general framework, the experimental activities and the cross-cutting analysis (common for each scenario) related to life cycle evaluations and participatory activities. Finally, in the last paragraph, some preliminary results, at this stage of the project, are reported.

2. Material and method

2.1. General research framework

The research project takes into account the complexity of the sustainability issues, by articulating operative activities at different levels (experimental and farm-based), according to three general research questions: which are the possible innovative experimental protocols for sustainable management of resources (in terms of soil, water and energy)? Which are the environmental, economic and social effects of the implementation of these innovative systems? How implement jointly different methodological tools and how create new pathways to transfer scientific knowledge from scientists to actors involved in the validation and interpretation of results?

Answering to similar questions on sustainability implies for scientists to take some challenges, as argued by Brandt et al. (2013), like as, for example, that to talk a common language starting from different "[…] ontological assumptions, epistemological commitments and methodological choices" (Darnhofer et al., 2015). The project starts from a multifaceted theoretical setting (Fig. 1). In particular, a *systemic* approach is obtained by including specific research activities focused on three main components (named generically "macro-systems") that considered simultaneously and in all their specific features contribute to explain the most part of sustainability in agricultural systems. The complexity due to the *multi-disciplinary* feature of the research project is tackled through the involvement of an experts' team in agricultural hydrological models, agronomic methods, mechanical engineering and agricultural economic and policy analysis. Finally, a *multi-methodological* approach is followed by using different analysis tools useful to evaluate from different point of view the overall sustainability of the processes under study.

In operational terms, the project is structured in four main work packages (WP) articulated in specific sub-activities (tasks) each of which represents an input for the following phase (Fig. 2).

In particular, the project's research activities consist in the following principal steps: (i) characterisation of crop production systems in relation to the main issues linked to the efficiency utilisation of soil, water and energy resources; (ii) definition of a common methodological protocol and of a structured set of biophysical and socio-economic indicators; (iii) implementation of the methodological protocol for the experimental activities and farm case studies; (iv) development of sustainable management options.

The multi-methodological character of the project is pursued through a joint application of agronomic, hydraulic and mechanic models for cropping systems and through a combined implementation of Life Cycle methodologies (LCA, LCC and s-LCA) that are cross-cutting for each scenario analysed.

The multi-dimensional indicators obtained from the experimental activities and life cycle analysis are integrated through Multi-Criteria Decision Analysis (MCDA) in order to rank the alternative scenarios and mixed (quali-quantitative) participatory techniques are used to involve local actors in a knowledge pathway able to identify, as main upshot, a real-world support for private decision and policies making.

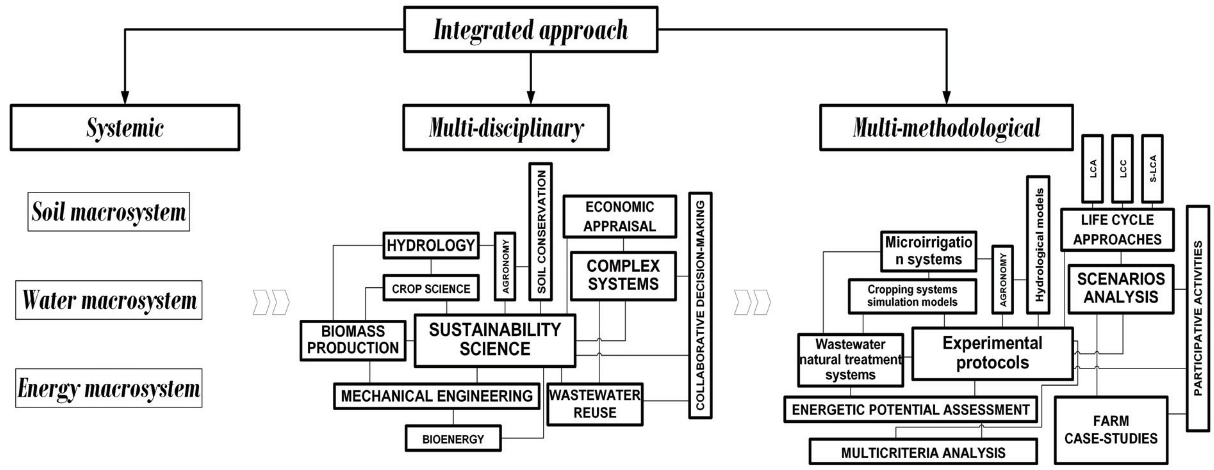

Fig. 1. Theoretical concept of MIMeSMAS project

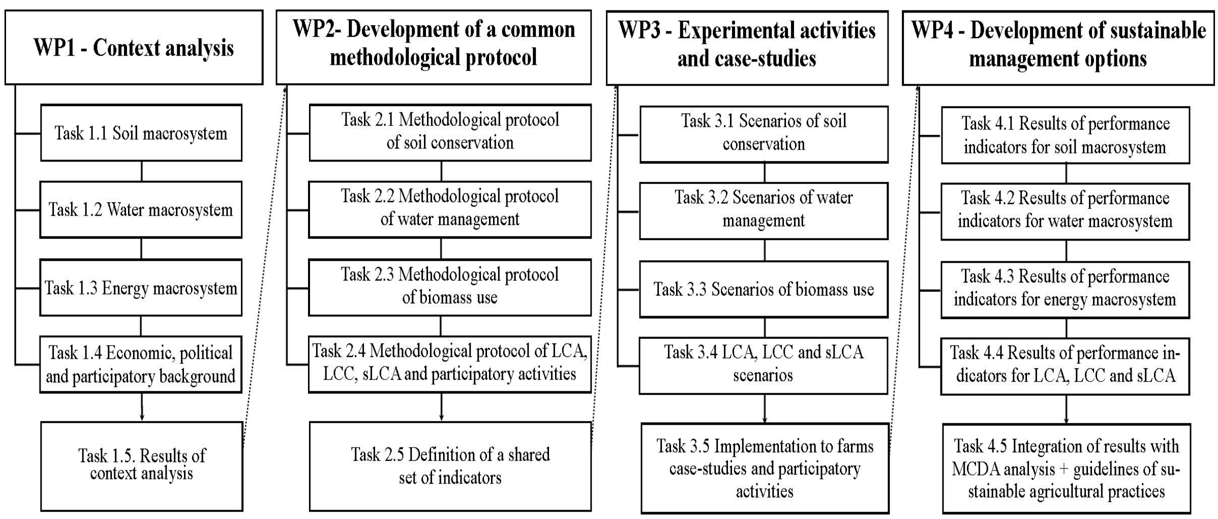

Fig. 2. Operational framework of MIMeSMAS project

2.2. Experimental activities and case studies

By detailing the second work package related to the common methodological protocol, an overview of the experimental activities on each so-called “macro-systems” considered is provided below. It is necessary to clarify that the following explanation considers separately the experimental activities merely in order to a greater understanding of different case studies. However, coherently with the project framework design, all resource typologies (soil, water, and energy) are included and analysed, simultaneously, within each scenario studied. In terms of “soil macro-system”, the research activities are aimed to assess the effects in terms of hydrological runoff and erosion and provide guidance on the efficiency to forecast runoff and erosion of widespread hydrological models and to assess the impacts of different growing techniques on soil quality.

The experimental analysis on hydrological effects are conducted in olive growing contexts typical of semi-arid Mediterranean areas and particularly significant in terms of agronomic and ecological impact on soil, especially in Calabria region where olive crops play an essential role in landscape enhancement and hydrological defence. Indeed, while in the past the careful and constant work of farmers allowed to maintain a dynamic balance between farming and the environment, since several decades high levels of mechanization and the increasingly abandonment of traditional techniques of soil management have occurred. This resulted the increased processes of runoff and erosion due to both the soil compaction and the removal of vegetation cover. The European agricultural policies have been geared, by European Regulation No 1782/2003, to promote soil conservation practices through by maintaining the land in “Good Agricultural and Environmental Condition” (GAEC) defined in the context of cross-compliance mechanism (EC, 2003). However, according to Bombino et al. (2011) “the information about the impacts of different management practices on soil losses is still insufficient and does not allow a proper evaluation of the erosive risks in hilly olive groves across the different local conditions”.

Soil management issues in the Mediterranean cultivated areas, like in Calabria, concerns the identification of crop models environmental friendly and with low hydrological and energetic impacts, able to combine conflicting objectives, i.e. to maintain an adequate level of soil coverage during the rainy period and, on the contrary, to contain it during the period of drought. Some authors suggest the use of specific mathematical models to predict the effects of plant cover on soil loss (Bombino et al., 2002, 2004, 2011; Zema et al., 2012a).

In particular, the experimental activities on “soil macro-system” are arranged in cultivated areas, typical of semi-arid environment, in which will be hydraulically isolated plots (Wischmeier and Smith type) equipped with devices for measuring variables and hydrological adopted different methods of soil management in terms of weed control. To this end, in experimental plots, three weed control practices commonly adopted in Mediterranean olive growing are simulated and their hydrological effects are measured.

Conventional chemical weed control is compared with conservative practices, i.e. minimum chemical weed, mechanical weed and total removing of herbaceous cover.

Referring to “water macro-system”, the activities research includes the construction of an experimental irrigation field using micro-irrigation systems. In Mediterranean regions, characterized by water scarcity, climate changes and increasing water demand, the sustainable management of water resources is now an urgent need especially for the agricultural sector that is by far the biggest user of freshwater. However, especially in the Mediterranean area, the use of high irrigation water volumes and fertilizers are considered as essential elements to achieve high crop productivity.

Therefore, the use of treated wastewater for irrigation can play an important role in water resource management in order to increase environmental and economic sustainability of the entire production process (Barbagallo et al., 2012, 2014; Molari et al., 2014; Zema et al., 2012b). Indeed, the agronomic reuse of non-conventional water can produces many advantages, among which the improvement of soil fertility by delivering nutrient compounds held in wastewaters, the reduction of conventional water use and the reduction of the damage caused to the environment by dumping untreated or poorly treated wastewater into water bodies.

Furthermore, some benefits can be attributed to the reduction of technical and economic difficulties arising from the management of wastewater treatment plants as well as to the saving for farmers due to the reduction of the amount of fertilizers to add in the irrigation water.

Improving the sustainability of irrigation practice also means to use deficit irrigation techniques in order to obtain satisfactory yields and economical cost-effectiveness. The use of irrigation techniques, such as the micro-irrigation, combined to the fertilizing properties of the wastewater, can produce environmental, social and economic benefits, if wastewater is treated with efficient and cheap treatments.

Among the available wastewater treatment techniques, natural treatment systems such as constructed wetland (Toscano et al., 2013, 2015) has low operational and management costs and it is able to improve water quality through efficient pollutant removal.

Within the project’s activities, wastewaters treated with natural systems are used to irrigate horticultural crops and “no food” biomasses. Constructed wetland systems (phytoremediation systems) are analysed in order to evaluate their efficiency in terms of possible reuse of treated wastewater for crop irrigation. The experimental irrigation field, constituted by several parcels, are located near the constructed wetland treatment plant. Wastewater effluents from constructed wetland are used for crop irrigation. Reservoir effluents are also used for crop irrigation in order to compare the performance of various natural wastewater treatment systems.

Different restitutions of crop evapotranspiration are considered during the irrigations. In order to evaluate the efficiency of the treatment systems - taking into account the regulatory limits for wastewater irrigation reuse - physical, chemical and microbiological analyses are carried out on wastewater samples collected at the influents and effluents of wastewater treatment systems. In order to evaluate the effects of irrigation using treated wastewater on soil and plants, physical, chemical and microbiological analyses are carried out on wastewater samples collected at the end of filtration unit of the micro-irrigation system. The applicability and sustainability of the irrigation methods are evaluated, in terms of efficiency, water requirements of crop, yield and health hazards linked with the use of treated wastewater for crops irrigation.

In particular, the following measures are monitored to determine micro-irrigation system performance: rate of pressure loss, time and effort required by a skilled operator to clean filters. In order to rank emitter clogging, drip lines discharge rate are computed. In order to evaluate the effects of different amount of irrigation volumes, physical, chemical and hydraulic analyses are carried out on soil samples. In particular, undisturbed soil samples are collected at the beginning of experimental activity and ant the end of each crop life cycle. According to the standard method, the soil texture (percentage of fine soil, sand, silt and clay) and chemical characteristics will be determinate for each soil sample.

Finally, to ascertain the changes induced in soil hydraulic and transport properties at the end of wastewater application cycle, hydraulic conductivity curve is determined. Microbiological parameters are analysed on soil, water and plants in order to evaluate the health risk associated with the use of wastewaters for irrigation.

The experimental activities on “energy macro-system” provide a technical assessment of energy systems based on the use of biomass from agricultural by-products and dedicated crops.

This is achieved through the analysis of chemical and energy-related characteristics of different biomass, the storage properties, and the dimensional optimization of the energy system in relation to the local potential supply (de Menna et al., 2015). The main energy-related characteristics of biomass are identified from collected samples, where the experimental tests are conducted. For these samples, the energy yields of the fuel conversion in a small-scale pilot boiler, the storage properties and the environmental impacts in terms of emissions from the combustion of biomass are evaluated.

For the crop systems analysed in the previous experimental activities (i.e. olive growing and dedicated energy crops), the “energy macro-system” is analysed through the development of management options for the crops residuals valorisation finalized to energy production.

Furthermore, the same analysis are carried out with specific reference to the artichoke grown as horticultural system particularly interesting (in Sardinia and Sicily regions) also in terms of biomass energetic potential (Ledda et al., 2013).

The agronomical activities are organized into several phases: development of dataset on the artichoke crop residuals yields and their energy conversion at regional scale; identification of experimental protocols; agronomic characterization of artichoke crop residuals; application of a cropping system simulation model in order to evaluate the effect of different agricultural practices on the production of the artichoke crop residuals; assessment of the energy productivity of the artichoke crop residuals.

2.3 Cross-cutting analysis: life cycle approaches and participatory activities

As indicated in Fig. 2, a cross-cutting methodological approach used in this project is represented by Life Cycle Thinking (LCT), a conceptual model born, since the early ’90, to deepen the knowledge about all impacts generated by products and services during their life cycles, taking into account all inputs and outputs used (Guinée et al., 2002).

From this vision, it derived the “life cycle toolbox” that includes Life Cycle Assessment (LCA), Life Cycle Costing (LCC) useful for respectively environmental and economic assessment, as well as Social LCA - still to be defined - to evaluate the social consequences of production processes. According to the definition of SETAC (Fava et al., 1991), when LCA is applied to crop scenarios, the aim is to measure resources usage and environmental releases and to evaluate opportunities to achieve sustainability improvements.

Commonly, LCA methodology is implemented taking into account the same assumptions in the choice of system boundaries and procedures of allocation, the choice of environmental impact categories and the models for their interpretation, data requirements and quality criteria (Comandaru et al., 2012; Ghinea et al., 2014). In particular, for each crop studied in the project, the environmental impacts related to agricultural phase, transportation of agricultural products or by-products and industrial conversion for power generation, are considered.

In terms of system boundaries, the project's LCA analysis consider a cycle "from cradle to grave" in the case of dedicated energy crops, while "from cradle to gate" with an extension of the system related to the biomass conversion process for perennial and horticultural crops for which only residuals are destined to energy purposes.

From experimental activities on crops scenarios, primary data, linked to input and outputs used in the production systems are used to realize the LCA inventory. Similarly, through the same data detection mode and also by adapting experimental results to farm realities, a costs inventory is realized to conduct a LCC analysis by taking into account all cash flows (i.e. all the costs and revenues) associated to all phases, according to other applications of several scholars (De Gennaro et al., 2012; De Luca et al., 2014; Falcone et al., 2015; Iotti and Bonazzi, 2014; Mohamad et al., 2014; Pergola et al., 2013; Strano et al., 2013).

In particular, each input and output considered in LCA analysis is transformed in monetary values and all other costs associated to them (e.g. variable costs of labour, disposal, etc. and fixed costs as shares of insurance, taxes etc.) are included, in order to calculate the total cost of every single process within the entire production system. Obtained data are used to perform also profitability analysis of investments by assessing the overall life cycle cost through appropriate financial indices as the Net Present Value (NPV) and the Internal Rate of Return (IRR) to assess the economic and financial trend of investments during the whole life cycle.

Therefore, a unique inventory of data is utilised to obtain complementarity between LCA and LCC analyses - that are conducted using the same functional unit and system boundary - in order to interpret jointly environmental and economic results of sustainability (De Luca et al., 2014; Falcone et al. 2015; Strano et al., 2013;).

Concerning the social dimension sustainability, the project's methodological choice starts by the assumption that a sustainability assessment have, necessarily, contemplate the inclusion of social aspects, whether included as a one of the "three pillar", albeit connected with the others, or as general umbrella within which to consider the other aspects. It is increasingly recognised the need of further research development to integrate, with more scientifically robust methods, the results of sustainability assessment, especially when coming, at the same time, from different issues (environmental, economic and social), strictly interconnected among them.

From a life cycle perspective, a promising but still new concept, is the so-called Life Cycle Sustainability Assessment (LCSA) (Kloepffer, 2008; Sala et al., 2013a, 2013b) in which the three well-known dimensions of sustainability (environmental, economic, and social) are integrated by using the three independent methodologies (LCA, LCC and s-LCA). However, according to Onat et al. (2014), despite the studies on methodological aspects are in expansion, the real cases of applications of LCSA are highly limited. Furthermore, if the integration of methods appears to be a critical challenge, the definition of appropriate indicators from environmental, economic and social points of view, when related to the stakeholder's *desiderata*, is a more critical point. This is particularly true especially for local-based assessments, because social indicators that are necessarily context-dependent.

This is the reason why the evaluation approaches have to take into account not only the expert's opinions on the choice of impact indicators but also the viewpoints of other subjects, both those directly or indirectly affected (i.e. public stakeholders through regulatory measures and privates with managerial behaviours) (De Luca et al., 2015). Participation, in this sense, can play a key role to make the assessment legitimate and adherent to reality (Iofrida et al., 2014).

An increasing literature deepens these topics in life cycle studies, but several scholar affirm that only few explicit analyses has been made until now, both in terms of integration of results and of participatory approaches into life cycle methodologies (Jørgensen, 2013; Mathé, 2014; Sala et al., 2013a, 2013b). An integrated assessment of complex issues - like sustainability concerns - requires "a mutual interdependence of participatory and modelling approaches in assisting policy-making" (Hisschemöller et al., 2001). In this sense, the Multi-Criteria Decision Analysis (MCDA) serves a two-fold purpose. Firstly, it allows conducting a joint assessment moving from analyses methodologically different and integrating their results. Secondly, it permit to directly incorporate the preferences of different interest groups or stakeholders (Banville et al., 1998; Estévez et al., 2013; Macharis et al., 2012), providing useful information to be spent, for example, in the improvement of political actions based on new contextual knowledge. Recently, MCDA and participatory approaches have been applied to LCA studies (Bachmann, 2012; Castellini et al., 2012; De Felice et al., 2013; Malloy et al., 2013; Mathé, 2014; Recchia et al., 2011; Yue et al., 2014). However, the use of these methodologies for integrating different life cycle results remains a little explored field.

Starting from these assumptions, the MIMeSMAS project attempts to conduct an integrated assessment of agricultural systems sustainability setting up the most suitable environmental, technical and economic indicators with the contribution of different expertise from the project's team.

These indicators are measured through experimental activities conducted at both pilot-scale (one for each site and scenario considered) and specific evaluation analysis at farm-scale selected in the study areas. For the same contexts, social indicators are selected by researchers starting from the context analysis carried out in the first phase of the project and, in a second phase, are validated through inclusive participatory activities.

The analysis is based on literature review and focus groups with regional officials and experts in the sector. Participatory activities are carried out through a joint use of qualitative procedures, starting from the "stakeholder theory" (Mitchell et al., 1997), the "Q-methodology" application (Stephenson, 1953) and Delphi analysis, in order to define the stakeholder's sample to be involved and the social sustainability dimensions to be assessed (Iofrida et al., 2014). Direct and proxy indicators measurement are developed to elaborate the data gathered from secondary sources (official statistics and literature) and primary ones (with semi-structured questionnaires and direct interviews conducted at farm level) according to De Luca et al. (2015).

Participative activities among stakeholders are carried out in order to facilitate reflection and promote social learning processes (Toderi et al., 2007) and by sharing the research results to create new knowledge and new learning spaces between researchers and local stakeholders (Allan et al., 2013).

Finally, once the indicators are defined and measured, for each agricultural system studied, multi-criteria tools are used to integrate environmental, economic and social sustainability results derived from the application of the others methodologies. MCDA are also used to weight each indicator according to the preferences of the actors involved, in particular through the application of the Analytic Hierarchy Process (AHP) by Saaty (1990). This weighting process will permit to compare different categories, to rank the scenarios, and to quantify the sustainability of the agricultural systems in a comparative way between scenarios of analysis.

3. Preliminary results

Summarising the results of the first year of MIMeSMAS project, a twofold direction of research activities can be distinguished. Firstly, the characterization of analysing contexts and of the identification of crops systems is significant for agricultural sustainability issues. Subsequently, the definition of methodological protocols has been carried out, in an integrated approach, to pursue the objective of a holistic assessment of alternative agricultural management options.

As already mentioned, the project aims to define a multidisciplinary methodological framework to assess the agricultural sustainability through an all-embracing way. At the same time, the project aspires to implement this methodology in different cultivated areas by choosing different crops systems as representative for each area in terms both of agronomic and economic relevance, and also for potential benefits of alternative management options in real farm contexts.

At this stage of the project three outcomes derived from the first year of projects' activities can be outlined: first, the identification of crops variety to be studied derived from an in-depth analysis of the territorial contexts and their sustainability issues. Secondly, the definition of alternative management scenarios evaluated through experimental-based and farm-based analysis (Table 1).

Finally, the selection of specific indicators derived from the hydraulic, agronomic and mechanical model used in experimental activities as well as the life cycle indicators related to the assessment of environmental, economic and social impacts (Tables 2 and 3).

Table 1. Crops systems identified and related experimental scenarios

Local-based case-studies in Mediterranean areas	***Experimental scenarios***	
Giant reed plantations (Sicily/Emilia Romagna)	Sicily: - Treated wastewater (TWW) with phytoremediation systems; - Micro-irrigation with different TWW levels and conventional water (CW) - Energetic Potential assessment of biomass.	Emilia Romagna: - Different levels of irrigation; - Energetic Potential assessment of biomass.
Artichoke plantations (Sicily/Sardinia)	Sicily: - Treated wastewater (TWW) with phytoremediation systems; - Microirrigation with different levels of TWW and conventional water (CW); - Energetic Potential assessment of by-product biomass.	Sardinia: - # 5 Artichoke botanical varieties; - Water and nitrogen in late spring; - Energetic Potential assessment of by-product biomass.
Olive orchards (Calabria)	Calabria: - Chemical weed control; - Minimum chemical weed; - Mechanical weed; - Total moving of herbaceous cover control. - Energetic Potential assessment of by-product biomass and herbaceous cover biomass.	

Table 2. Indicators measured with experimental activities on soil, water and energy macro-systems

Soil macro-system indicators	Chemical	L_{TOC} (Total Organic Carbon)		g C kg^{-1} soil
		Macronutrients		g N P K
	Physical	$I_{TEXTURE}$ (Soil texture)		mm
		IK_{sat} (Saturated hydraulic conductivity)		cm s^{-1}
		pH		-
	Agronomic	I_{TotSur} (Total Parcel Surface)		ha
		I_{Var} (Varietal type)		Qualitative var.
		I_{bCyc} (Cycle starting date)		DOY
		I_{dCyc} (Cycle duration)		DAP
		I_{Den} (Density)		n. plants m^{-2}
		I_N (Input N and other fertilizers)		kg ha^{-1} year^{-1}
		I_{nPest} (Pesticides input)		n. interventions and dosage (kg ha^{-1} year^{-1})
		I_{Till} (Tillage typology)		Qualitative var.
		I_{Depth} (Principal Tillage Depth)		cm
		I_{nTill} (N. of tillages)		n.
		I_{yield} (Principal Product Yield)		Kg ha^{-1}
		I_{HI} (Harvest Index)		%
Water macro-system indicators	Meteorological	R (Precipitations)		mm
		T (Temperature)		°C
		RH (Air moisture)		%
		WS (Wind speed at 2 m)		m s^{-1}
		SR (Net solar radiation)		MJ m^{-2} d^{-1}
	Water quality	pH		-
		CE (Electrical conductivity)		µS/cm
		SST (Total suspended solids)		(mg L^{-1})
		SAR (Sodium Adsorption Ratio)		-
		N_{TOT} (Total Nitrogen)		(mg L^{-1})
		P_{TOT} (Total Phosphor)		(mg L^{-1})
		BOD_5 Organic matter		(mg L^{-1})
		E. coli (Escherichia coli)		(UFC 100 ml^{-1})
	Irrigation	I_{nIrr} (Irrigations during irrigation season)		Number
		I_{Irr} (Distributed irrigation volumes)		(m^3 ha^{-1})
		UE (Distribution uniformity)		(%)
		R_d (Average flow reduction coefficient)		(%)
		Duration of irrigation season		start and end dates
		ET_0 (Reference evapotranspiration)		mm day^{-1}
		ET (Evapotranspiration)		mm day^{-1}
Energy macro-system indicators	Characterization	I_{resid} (management of residual biomass)		Qualitative var.
		Fresh weight		t ha^{-1} year^{-1}
		Water content		%
		Dry weight		t ha^{-1} year^{-1}
		Higher heating value		MJ kg^{-1} (x%DW)
		Bulk density		kg m^{-3}
		Prox Analysis (Ashes)		% DW
		Biogas (Extractives, Total lignin, Polysaccharides, Methane yield, CH_4)		% DW; m^3 kg^{-1} VM; %
	Conversion	Feedstock collection and treatment; Energy conversion; Energy production	Electricity and Heat consumption	kWh ha^{-1} year^{-1}
			Fuel consumption	l ha^{-1} year^{-1}
			Machinery	kg ha^{-1} year^{-1}
			Electricity yield	kWh ha^{-1} year^{-1}
			Heat yield	kWh ha^{-1} year^{-1}
			Biochemical methane potential	m^3 ha^{-1} year^{-1}
		Ashes	Amount	t ha^{-1} year^{-1}
			Disposal	t ha^{-1} year^{-1}
		Digestate	Amount	t ha^{-1} year^{-1}
			Disposal	t ha^{-1} year^{-1}

Table 3. Selection (not exhaustive) of indicators used for Life Cycle analysis (LCA, LCC, sLCA)

Life Cycle Indicators	*LCA*	Climate change (Global Warming Potential)	Kg CO_2 eq.
		Ozone Depletion (ODP)	Kg CFC-11 eq.
		Marine eutrophication (MEP)	Kg N eq.
		Freshwater eutrophication (FEP)	Kg P eq.
		Urban Land Occupation (ULOP)	m^2 a
	LCC	Total costs of production	€ ha^{-1}
		Net Cash Flows	€ ha^{-1}
		Net Present Value (NPV)	€ ha^{-1}
		Internal Rate of Return (IRR)	%
	sLCA	Health and safety working conditions	Direct or proxy indicators (quali/quantitative)
		Fair working conditions /Equal opportunities	Direct or proxy indicators (quali/quantitative)
		Area reputation /Contribution to economic development	Direct or proxy indicators (quali/quantitative)

3. Conclusions

The project presented in this paper is currently ongoing; therefore, some research activities are still in working progress. The focus of the project is the analysis of several agricultural ecosystems (giant reed, artichoke and olive) from a holistic and multi-disciplinary approach aimed to define management systems to optimize the use of soil, water and energy resources. The activities involve experimental trials and farm case studies to test and validate sustainable agricultural techniques that are analysed through LCA, LCC and sLCA tools, multi-criteria methodologies - to integrate environmental, economic and social results - and participatory approaches to legitimate the research activities.

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References

Allan C., Nguyen T.P.L., Seddaiu G., Wilson B., Roggero P.P., (2013), Integrating local knowledge with experimental research: Case studies on managing cropping systems in Italy and Australia, *Italian Journal of Agronomy*, **8**, 108-116.

Bachmann T.M., (2012), Towards life cycle sustainability assessment: drawing on the NEEDS project’s total cost and multi-criteria decision analysis ranking methods, *International Journal of Life Cycle Assessment*, **18**, 1698-1709.

Banville C., Landry M., Martel J.M., Boulaire C., (1998), A stakeholder approach to MCDA, *Systems Research and Behavioral Science*, **15**, 15-32.

Barbagallo S., Cirelli G.L., Consoli S., Licciardello F., Marzo A., Toscano A., (2012), Analysis of treated wastewater reuse potential for irrigation in Sicily, *Water Science and Technology*, **65**, 2024-2033.

Barbagallo S., Barbera A.C., Cirelli G.L., Milani M., Toscano A., (2014), Reuse of constructed wetland effluents for irrigation of energy crops, *Water Science and Technology*, **70**, 1465-1472.

Bombino G., Porto P., Zimbone S.M., (2002), *Evaluating the Crop and Management Factor C for Applying RUSLE at Pilot Scale*, Proc. 95th Annual International Meeting of ASAE and XVth World Congress of CIGR, Chicago, USA.

Bombino G., Porto P., Tamburino V., Zimbone S.M., (2004), *Crop and management factor estimate for applying RUSLE in range land areas*, Proc. ASAE Annual International Meeting, Ottawa, Ontario, Canada.

Bombino G., Tamburino V., Zema D.A., Zimbone S.M., (2011), *Hydrological effects of Different Soil Management Practices in Mediterranean conditions*, In: *Soil Erosion/Book 1*, Godone D., Stanchi S. (Eds.), Intech Open Press Publisher, Rieka, Croatia, 163-182.

Brandt P., Ernst A., Gralla F., Luederitz C., Lang D.J., Newig J., Reinert F., Abson D.J., von Wehrdenet H., (2013), A review of transdisciplinary research in sustainability science, *Ecological Economics*, **92**, 1-15.

Caradonna J.L., (2014), *Sustainability - A History*, Oxford University Press, New York.

Castellini C., Boggia A., Cortina C., Dal Bosco A., Paolotti Novelli E., Mugnai C., (2012), A multicriteria approach for measuring the sustainability of different poultry production systems, *Journal of Cleaner Production*, **37**, 192-201.

Comandaru I.M., Bârjoveanu G., Peiu N., Ene S.A., Teodosiu C., (2012), Life cycle assessment of wine: Focus on water use impact assessment, *Environmental Engineering and Management Journal*, **11**, 533-543.

Darnhofer I., (2014), Conceptual Framework, FarmPath - Farming transitions: Pathways towards regional sustainability of agriculture in Europe, FP7 Project, On line at: http://www.farmpath.eu/.

Darnhofer I., Sutherland L.-A., Pinto-Correia T., (2015), *Conceptual Insights Derived from Case Studies on “Emerging Transitions” in farming*, In: *Transition pathways towards sustainability in agriculture. Case studies from Europe*, Sutherland L.-A., Darnhofer I., Wilson G., Zagata L. (Eds.), CABI, Wallingford, 189-203.

De Felice F., Campagiorni F., Petrillo A., (2013), Economic and Environmental Evaluation via an Integrated Method based on LCA and MCDA, *Procedia - Social and Behavioral Sciences*, **99**, 1-10.

De Gennaro B., Notarnicola B., Roselli L., Tassielli G., (2012), Innovative olive-growing models: an economic and environmental assessment, *Journal of Cleaner Production*, **28**, 70-80.

De Luca A.I., Falcone G., Stillitano T., Strano A., Gulisano G., (2014), Sustainability assessment of quality-oriented citrus growing systems in Mediterranean area, *Quality - Access to Success*, **15**, 103-108.

De Luca A.I., Iofrida N., Strano A., Gulisano G., (2015), Social life cycle assessment and participatory approaches: a methodological proposal applied to citrus farming in southern Italy, *Integrated Environmental Assessment and Management*, **11**, 383-396.

de Menna, F., Vittuari, M., Molari, G., (2015), Impact evaluation of integrated food-bioenergy systems: A comparative LCA of peach nectar, *Biomass and Bioenergy*, **73**, 48-61.

EC, (2003), Council Regulation no 1782/2003 of 29 September 2003 establishing common rules for direct support schemes under the common agricultural policy and establishing certain support schemes for farmers and amending Regulations (EEC) No 2019/93, (EC) No 1452/2001, (EC) No 1453/2001, (EC) No 1454/2001, (EC) 1868/94, (EC) No 1251/1999, (EC) No 1254/1999, (EC) No 1673/2000, (EEC) No 2358/71 and (EC) No 2529/2001, Official Journal of the European Union, L 270/1 of 21 October 2003.

Falcone G., Strano A., Stillitano T., De Luca A.I., Iofrida N., Gulisano G., (2015), Integrated sustainability appraisal of wine-growing management systems through LCA and LCC methodologies, *Chemical Engineering Transactions*, **44**, 223-228.

Fava J., Denison R., Jones B., Curran M.A., Vigon B., Selke S., Barnum J., (Eds.), (1991), *A Technical Framework for Life-Cycle Assessments*, Report of the SETAC Workshop at Smugglers Notch Vermont, USA.

Ghinea C., Petraru M., Simion I.M., Sobariu D., Bressers H.T.A., Gavrilescu M., (2014), Life cycle assessment of waste management and recycled paper systems, *Environmental Engineering and Management Journal*, **13**, 2073-2085.

Guinée J.B., (2002), *Handbook on Life Cycle Assessment - Operational guide to the ISO standards*, Kluwer Academic Publishers.

Hisschemöller M., Tol R.S.J., Vellingaa P., (2001), The relevance of participatory approaches in integrated environmental assessment, *Integrated Assessment*, **2**, 57-72.

Iofrida N., De Luca A.I., Strano A., Gulisano G., (2014), *Social Life Cycle Assessment in a Constructivist Realism Perspective: A Methodological Proposal*, In: *Social LCA in progress 4th SocSem*, Macombe C., Loeillet D. (Eds), Pre-proceedings of the 4th International Seminar in Social LCA, Montpellier, France - November 19-21, Collection FruitTropThema, Cirad.

Iotti M., Bonazzi G., (2014), The application of life cycle cost (LCC) approach to quality food production: a comparative analysis in the Parma PDO ham sector, *American Journal of Applied Sciences*, **11**, 1492-1506.

Jørgensen A., (2013), Social LCA - a way ahead?, *International Journal of Life Cycle Assessment*, **18**, 296-299.

Kajikawa Y., Tacoa F., Yamaguchi K., (2014), Sustainability science: the changing landscape of sustainability research, *Sustainability Science*, **9**, 431-438.

Kloepffer W., (2008), Life cycle sustainability assessment of products (with Comments by Helias A. Udo de Haes, p. 95), *International Journal of Life Cycle Assessment*, **13**, 89-95.

Lang D. J., Wiek A., Bergmann M., Stauffacher M., Martens P., Moll P., Swilling M., Thomas C. J., (2012), Transdisciplinary research in sustainability science: practice, principles, and challenges, *Sustainability Science*, **7**, 25-43.

Ledda L., Deligios P.A., Farci R., Sulas L., (2013), Biomass supply for energetic purposes from some Cardueae species grown in Mediterranean farming systems, *Industrial Crops and Products*, **47**, 218-226.

Macharis C., Turcksin L., Lebeau K., (2012), Multi actor multi criteria analysis (MAMCA) as a tool to support sustainable decisions: State of use, *Decision Support Systems*, **54**, 610-620.

Malloy T.F., Sinsheimer P.J., Blake A., Linkov I., (2013), Use of multi-criteria decision analysis in regulatory alternatives analysis: a case study of lead free solder, *Integrated Environmental Assessment and Management*, **9**, 652-664.

Mathé S., (2014), Integrating participatory approaches into social life cycle assessment: the SLCA participatory approach, *International Journal of Life Cycle Assessment*, **19**, 1506-1514.

Mattor K., Betsill M., Huayhuaca C., Huber-Stearns H., Jedd T., Sternlieb F., Bixler P., Luizza M., Cheng A. S., (2014), Transdisciplinary research on environmental governance: A view from the inside, *Environmental Science & Policy*, **42**, 90-100.

Mitchell R. K., Agle B. R., Wood D. J., (1997), Toward a theory of stakeholder identification and salience: defining the principle of who and what really counts, *Academy of Management Review*, **22**, 853-886.

Mobjörk M., (2010), Consulting versus participatory transdisciplinarity: A refined classification of transdisciplinary research, *Futures*, **42**, 866-873.

Mohamad R.S., Verrastro V., Cardone G., Bteich M.R., Favia M., Moretti M., Roma R., (2014), Optimization of organic and conventional olive agricultural practices from a Life Cycle Assessment and Life Cycle Costing perspectives, *Journal of Cleaner Production*, **70**, 78-89.

Molari G., Milani M., Toscano A., Borin M., Taglioli G., Villani G., Zema D.A., (2014), Energy characterisation of herbaceous biomasses irrigated with marginal waters, *Biomass and Bioenergy*, **70**, 392-399.

Nagabhatla N., Padmanabhana M., Kühle P., Vishnudas S., Betz L., Niemeyer B., (2015), LCLUC as an entry point for transdisciplinary research - Reflections from an agriculture land use change study in South Asia, *Journal of Environmental Management*, **148**, 42-52.

Onat N.C., Kucukvar M., Tatari O., (2014), Towards life cycle sustainability assessment of alternative passenger vehicles, *Sustainability*, **6**, 9305-9342.

Pergola M., D'Amico M., Celano G., Palese A.M., Scuderi A., Di Vita G., Pappalardo G., Inglese P., (2013), Sustainability evaluation of Sicily's lemon and orange production: An energy, economic and environmental analysis, *Journal of Environmental Management*, **128**, 674-682.

Polk M., (2014), Achieving the promise of transdisciplinarity: a critical exploration of the relationship between transdisciplinary research and societal problem solving, *Sustainability Science*, **9**, 439-451.

Recchia L., Boncinelli P., Cini E., Vieri M., Pegna F.G., Sarri D. (Eds.), (2011), *Multicriteria Analysis and LCA Techniques With Applications to Agro-Engineering Problems*, Springer-Verlag London.

Saaty T.L., (1990), How to make a decision: the Analytic Hierarchy Process, *European Journal of Operational Research*, **48**, 9-26.

Sala S., Farioli F., Zamagni A., (2013a), Progress in sustainability science: lessons learnt from current methodologies for sustainability assessment: Part 1, *International Journal of Life Cycle Assessment*, **18**, 1653-1672.

Sala S., Farioli F., Zamagni A., (2013b), Life cycle sustainability assessment in the context of sustainability science progress (part 2), *International Journal of Life Cycle Assessment*, **18**, 1686-1697.

Serrao-Neumann S., Schuch G., Harman B., Crick F., Sano M., Sahin O., van Staden R., Baum S., Low Choy D., (2015), One human settlement: A transdisciplinary approach to climate change adaptation research, *Futures*, **65**, 97-109.

Spindler E.A., (2013), *The History of Sustainability. The Origins and Effects of a Popular Concept*, In: *Sustainability in Tourism: A Multidisciplinary Approach*, Jenkins I., Schröder R. (Eds.), Springer Fachmedien Wiesbaden, 9-31.

Stephenson W., (1953), *The Study of Behavior: Q-Technique and its Methodology*, University of Chicago Press, Chicago.

Strano A., De Luca A.I., Falcone G., Iofrida N., Stillitano T., Gulisano G., (2013), Economic and environmental sustainability assessment of wine grape production scenarios in Southern Italy, *Agricultural Science,* **4**, 12-20.

Toderi M., Powell N., Seddaiu G., Roggero P.P., Gibbon D., (2007), Combining social learning with agro-ecological research practice for more effective management of nitrate pollution, *Environmental Science and Policy*, **10**, 551-563.

Toscano A., Hellio C., Marzo A., Milani M., Lebret K., Cirelli G.L., Langergraber G., (2013), Removal efficiency of a constructed wetland combined with ultrasound and UV devices for wastewater reuse in agriculture, *Environmental Technology*, **34**, 2327-2336.

Toscano A., Marzo A., Milani M., Cirelli G.L., Barbagallo S., (2015), Comparison of removal efficiencies in Mediterranean pilot constructed wetlands vegetated with different plant species, *Ecological Engineering*, **75**, 155-160.

Vandermeulen V., Van Huylenbroeck G., (2008), Designing trans-disciplinary research to support policy formulation for sustainable agricultural development, *Ecological Economics*, **67**, 352-361.

WCED, (1987), *Our Common Future*, Oxford University Press, New York.

Weil RR., (1990), Defining and using the concept of sustainable agriculture, *Journal of Agronomy Education*, **19**, 126-130.

Yue W., Cai Y., Rong Q., Cao L., Wang X., (2014), A hybrid MCDA-LCA approach for assessing carbon foot-prints and environmental impacts of China' s paper producing industry and printing services, *Environmental Systems Research*, **3**, doi:10.1186/2193-2697-3-4.

Zema D.A., Bingner R.L., Denisi P., Govers G., Licciardello F., Zimbone S.M., (2012a), Evaluation of runoff, peak flowand sediment yield for events simulated by the annagnps model in a belgian agricultural watershed, *Land Degradation and Development*, **23**, 205-215.

Zema D.A., Bombino G., Andiloro S., Zimbone S.M., (2012b), Irrigation of energy crops with urban wastewater: Effects on biomass yields, soils and heating values, *Agricultural Water Management*, **115**, 55-65.