Integrated economic and environmental assessment of agro-ecological systems

Abstract

This study aims at combining biophysical and monetary sustainability assessment tools to support agriculture policy decision-making. Three methodological steps are considered: i) the environmental impacts of farms are assessed using Life Cycle Assessment; ii) the most relevant indicators of agriculture damages on ecosystems quality are aggregated into an index; iii) the farms index scores are integrated with farm assets, land and labour, into the Sustainable Value Approach (SVA) as indicator of natural resources used by farms. Crops farms show higher sustainable value using their economic and environmental resources, while mixed farms need to improve their resources use efficiency.

KEYWORDS: Farm sustainability, Ecosystem quality damage, Sustainable value, Integrated assessment.

1. Introduction

1.1. An integrated sustainability assessment of agro-ecosystems

Agro-ecosystems are arguably the most managed ecosystem in the world (Stoorvogel et al. 2004; Wei et al., 2009). In the past, agro-ecosystems were managed and evaluated overemphasizing their social and economic components (Wei et al., 2009). According to different authors, this has caused many alterations of ago-ecosystems like land degradation, loss of biodiversity, groundwater depletion, greenhouse gasses emission and erosion (Conway, 1985; van der Werf and Petit, 2002; Dale and Polansky, 2007). The increasing concern about the negative impacts of agricultural activities on natural resources underlies the development of many methods for their evaluation (van der Werf and Pertit, 2002; Payraudeau and van der Werf, 2005). Pretty et al. (2008), defined agriculture sustainability as the capability of agricultural systems to: (i) integrate biological and ecological processes, (ii) minimize the human-made inputs, and (iii) make productive use of farmers' knowledge and their collective capabilities. Several models integrate biophysical and economic assessment of agro-ecosystems sustainability (for a thorough review see Janssen and van Ittersum, 2007). Stoorvoegel et al., (2004) propose an integrated biophysical and economic approach (the Trade-off Analysis Model) to assess sustainability of agro-ecosystems, highlighting the role of temporal and spatial scales to supply policy-makers with useful indicators. Wei et al. (2009) used the force-pressure-state-impact-response approach to identify the interactions between biophysical and economic models in order to provide a comprehensive evaluation of farm's performance. Paracchini et al., (2015) presented another approach to sustainability assessment at different spatial level (farm, farming region, etc.) in combination with a wide range of indicators. An interesting examination of the pros and cons of using aggregate indicators for agricultural sustainability assessment is presented by Gomez-Limon and Sanchez-Fernandez (2010). Usually, these "indicator lists" (Gasparatos et al., 2009) are created in order to capture sustainability issues relevant for a specific context and therefore, they are not widely applicable. The maintenance of the economic, biological and physical components that make up an agro-ecosystem is determinant for its sustainability (Belcher et al. 2004). Moreover, the complex trade-offs between these components claim for a holistic approach to agro-ecosystems sustainability assessment in order to identify sustainable management practices (Pacini et al., 2015). However, the dependency of farms activities on natural resources and human-made resources ask for a better understanding of the links between environmental indicators, farm management activities and policies. Integrated sustainability assessment tools could be appropriate to identify policies priorities towards sustainable agro-ecosystems.

This paper is further structured in the following way. Section 2 focuses on the logical framework and the methodologies used in the assessment of environmental and socio-economic impacts of the farms' activities inside the “Alta Murgia” National Park (hereinafter Park). In Section 3 the main results are presented. The paper ends with a discussion and conclusions (Section 4).

1.2. Methodological framework

To account for the requirements of sustainability assessment of agro-ecosystems described above, we structured our analysis in three stages: (i) the life cycle environmental impacts assessment of the studied farms, (ii) the aggregation of some impacts categories into the ecosystem quality damage index, and (iii) the incorporation of this index into the Sustainable Value Approach (SVA) algorithm. Fig. 1 illustrates the approach to assess sustainability of agricultural production systems combining Life Cycle Assessment (LCA) and SVA.

Add Figure 1: A framework for an integrated sustainability assessment of Agro-ecosystems

The sustainable value of different farms and agricultural sectors (specialized crop and mixed farms) is calculated to compare their role in safeguarding the sustainability of agro-ecosystems. The farms’ contribution to environmental sustainability can be monitored using the LCA. Within the LCA methodological framework, the ReCiPe impact assessment method has been chosen in order to combine both a problem and damage-oriented approaches. Although traditional LCA is a steady-state tool, which does not account for the uniqueness of the environmental systems affected and their sensitivities to emissions sources (Reap et al., 2008) this bias has been reduced by means:

1. Choosing the most affected environmental impact categories by this site-specificity bias, such as: acidification, eutrophication, toxicity (Reap et al., 2008).
2. Further reducing the impact categories used according to the main geo-morphological and ecological characteristics of the studied area

Moreover, while the ReCiPe method uses the data on registered species at the European or Global level, in this study, the selected impact categories were normalized according the data at the Mediterranean spatial level[1]. The ReCiPe methodology assumes that the quality of ecosystems is adequately represented by the diversity of species (Goedkoop et al., 2009). Hence, the chosen impact categories relate to terrestrial acidification, terrestrial ecotoxicity and freshwater ecotoxicity, freshwater eutrophication and natural land transformation (measured in terms of *species lost*yr)* have been considered as good proxy of the damages caused to ecosystems quality (Wagg et al., 2014; Chapin III et al., 2000). Assuming a linear

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[1] Data form 2000 have been used according to Brooks et al. (2002) in order to be consistent with the normalization procedure used into ReCiPe impact assessment method.

addictive relationship, an aggregated index has been designed (the ecosystem quality damage index), accounting for the overall effects of farms’ management activities on ecosystems quality. The ecosystem quality damage index has been incorporated into the SVA algorithm representing the natural resources used by farms to create value added for the society. However, the SVA outcomes compensates for the negative impacts generated by farms with the positive ones. Therefore, the value contribution (the Return to Cost ratio) for each form of capital was calculated in order to identify on which resource form (capital, land, labour, natural) the efforts should be focused in order to achieve a more sustainable agro-ecosystem.

2. - Materials and methods

To broaden the general insights on the integration and combination of sustainability assessment tools and to answer the call for methodological pluralism in holistic sustainability assessment (Gasparatos et al., 2009), this study performs a sustainability evaluation of farming systems both at the farm level and at the regional level. Therefore, LCA and SVA are integrated. Combining these two methods is feasible because they satisfy the request of complementarity, consistency and ability to address all the perspective of sustainability (Van Passel and Meul, 2012).

This paper addresses the following research questions: a) is it possible to combine biophysical and monetary sustainability assessment tools in a meaningful and consistent way to agro-ecosystems; b) could this methodology be used to structure policy measures to improve the sustainability of agriculture in natural areas. Application of this method is illustrated in a case study involving 14 mixed and specialized crops farms located in the Park. All the relevant farm characteristics are summarized in Table 1.

Add table 1: Average descriptive statistics of the data sample of Crop and Mixed farms

2.1 - The LCA approach

An attributional LCA was performed to analyse the interactions between agricultural activities and the environment, allowing the evaluation of the main environmental impacts of farms' activities. The goal of this LCA study was to assess the relationships between farms activities and ecosystems quality loss within the Park. A sample of 14 commercial farms was used. Economic data were referred to the year 2013. Data related to farm management strategies, yield, fertilizers and pesticides uses, water consumptions, as well as techniques of animal husbandry (semi-wild or tethering), types and amount of animals feeding materials, etc., were collected by means of questionnaires directly submitted to farmers. An area based functional unit (FU) was selected for this study. In order to account for land size effect, each farm has been regarded as a single production unit, and it has been employed as reference for the estimation of environmental impacts. Therefore, the FU used in this study was a farm with 40 ha of UAA, which was the surface of the less extensive farm in our sample. For each farm, a detailed cradle-to-farm-gate life cycle assessment, including on and off farm pollution and avoided impacts, was performed (Figure 2).

Add figure 2: System boundaries used for the environmental impact assessment of the sampled farms.

For additional data, the Ecoinvent database (version 2.2) was consulted, especially for raw materials production and transports. Simapro 7.3.3 was used as a calculation platform. Transports inside the farm were excluded from the system boundaries. The use of manure and recycling of seeds were accounted in the system as prevented impacts due to the avoided production of, respectively, nitrogen and phosphorus fertilizers and commercial seeds. The amount of fertilizer produced was determined based on the mean N and P content of respectively bovine and sheep manure (Brentrup et al., 2000, Azeez et al., 2010). The emissions of N fertilizer and manure were calculated according to Brentrup et al. (2000), using different references to estimate the N-balance for the different crops (Ryden et al., 1984; Köpke and Nemecek, 2010, Garabet et al., 1998). The leaching fraction of applied P fertilizers was estimated according to Nest et al. (2014). Pesticide emissions were assessed using the PestLCI model (Dijkman et al., 2012). Methane emissions to air and N_2O emissions to water and soil from livestock breeding and grazing were assessed using the IPCC tier 2 approach (IPPC, 2006). For the life cycle impact assessment (LCIA) the endpoint ReCiPe method (Goedkoop et al., 2012) was used, which integrates the 'problem oriented approach' of CML-IA (Guinée et al., 2002) and the 'damage oriented approach' of Eco-indicator 99 (Goedkoop and Spriensma, 2001). Both these approaches have strengths and weaknesses related to: (i) the level of uncertainty and (ii) the interpretability of the results. The Recipe methods implements both strategies and has both midpoint (problem oriented) and endpoint (damage oriented) impact categories. The ReCiPe normalization factors were based on the European or World economic systems, whereas policy makers often were interested in using lower geographical level as reference systems (Sleeswijk et al., 2008). In this study, the selected impact categories were normalized based on the rate of yearly species lost for the Mediterranean basin in the year 2000 as explained by Brooks et al. (2002). Taking into account the "*conceptual and data limitations*" existing for the inclusion of biodiversity and ecosystems quality into the LCA framework (Toumisto et al., 2012, Curran et al., 2011; Schmidt, 2008) the selected impact categories were considered good proxy to assess the damages produced by farms activities to the quality of ecosystems, landscapes and wildlife habitats. The others impact categories associate with the human health and resources areas of protection (see Goedkoop et al., 2012) were exclude form the study. The assumption for this choice was that the Park Authority was more interested in understanding how agriculture activities affected biodiversity and ecosystems' quality at the local level, which can provide a more direct link to political goals (Sleeswijk et al., 2008). Land occupation (agricultural and urban) impact categories are usually estimated using as baseline the species richness on the type of land ignoring human distortion (De Schryver et al., 2010). Therefore, these impact categories are also excluded from the study to avoid damages overestimation.

2.2 - The Sustainable Value Approach (SVA).

The SVA is a value-oriented sustainability assessment methodology which aims to answer the question of "where environmental and social resources should be allocated in order to achieve an optimal overall return" (Figge and Hahn, 2009).The SVA methodology assumes that a firm contributes to sustainable development whenever it uses its resources more efficiently than other companies, reducing or unchanging the overall resource used (Van Passel and Meul, 2012). The opportunity cost of a resource form is the cost of the most valuable alternative and can be calculated as:

$$opportunity\ cost\ = value\ added_{benchmark} / resource\ _{benchmark} \qquad (1)$$

A firm creates sustainable value when it uses resources more efficiently than the benchmark, accordingly, by subtracting the opportunity cost from the efficiency of resource use for the company (2).

$$value\ spead_i\ = value\ added_i/capital_i\ -\ value\ added_{benchmark}/resource_{benchmark} \qquad (2)$$

Therefore, the sustainable value of the *company$_i$* is assessed by summing up the value contribution for every form of resource (3) that has been estimated by multiplying the *value spread $_i$* for a certain form of resource by the amount of resource used by *company$_i$*.

$$sustainable\ value_i\ = \frac{1}{n}\sum_{s=1}(value\ spread_i^s * capital_i^s) \qquad (3)$$

According to Van Passel et al. (2007), dividing for the number of resource forms considered (*n*) allowed to correct for the overestimation of value created, avoiding double counting (Figge and Hahn, 2005).

In order to account for the company size, the Return to Cost Ratio (RTC) of farms was calculated (Van Passel et al., 2009) according to equation 4.

$$Return\ to\ Costs\ ratio_i\ =\ value\ added_i/(value\ added_i - sustainable\ value_i) \qquad (4)$$

A return to RTC higher than the unit means that the company is overall more efficient in resource allocation than the benchmark. The most criticized aspect of this method was the definition of the benchmark (Mondelaers et al., 2011). This because the method itself was not able to capture if the overall resources use ensure a sustainable outcome (Figge and Hahn, 2004a); and so the benchmark could be defined in such a way that it does not describe a sustainable resource use (Ang et al., 2011). Although, the choice of the benchmark strongly affects the explanatory power of the analysis (Figge and Hahn, 2005), Van Passel et al. (2007) showed in an application on Flemish dairy farms that the ranking of the companies does not differ between several types of benchmarks. An interesting alternative approach is the construction of a sustainability benchmark using appropriate agro-environmental farm models (Merante et al., 2015). Unfortunately, these models were not available to assess agricultural systems in the studied protected area. The average for each form of resources has been used as a benchmark in this study. To test the robustness of the sustainable value calculations, the rank correlation (Spearman's rho) of RTC using different benchmarks is calculated (Table 2). The correlations are high and significant.

Add table 2: Correlation between the Return-to-cost ratio using different benchmarks

The different forms of capital considered were: (i) labour, (ii) farm capital, (iii) used land (ha), (iv) ecosystems quality damage (species lost*yr). For each farm, labour was measured in Annual Working Unit (AWU); farm capital (assets) was calculated as the total capital minus the value of land to avoid overlapping, while the ecosystems quality damage index was calculated by summing up the outcomes of the considered environmental impact indicators of the LCA analysis. Therefore, in this study the Sustainable Value was expressed as function of farm capital, used land, labour and ecosystems quality damage (Equation 5).

$$sustainable\ value\ _i\, f\ (farm\ capital\ _i, used\ land\ _i\, , labor_i, ecosystem\ quality\ damage\ _i) \qquad (5)$$

This highly relevant selection of resource forms is ignored by previous studies. This is especially a concern for natural resources for which the choice was merely data driven without a sound selection method (see Ang et al., 2011; Van Passel et al., 2009; Van Passel et al., 2007). Only Merante et al. (2015) and Pacini et al. (2015) used agro-environmental models to outline environmental thresholds to be used as the reference benchmark.

3. - Results

There is large within-group variability in indicators scores between specialized crops farms and mixed farms. The ecosystem quality damage scores for the overall farms in our case study range between 3.60E-05 and 3.89E-02 species lost*yr as shown in Table 3. Specialized crop farms have less impact on the environment in terms of cumulative ecosystems quality damages, accounting for almost the 30% of the total estimated damages to ecosystems (Table 3).

*Add table 3: Characterization of the environmental impacts of Crop and Mixed farms (species lost*yr^{-})*

Specialized crop farms score better for impacts on freshwater and terrestrial ecotoxicity, while they have higher impacts for, terrestrial acidification, and transformation of natural land. Those results are due to the higher intensity in terms of human-made resources used in crop farms management, especially gasoil and seeds, but also fertilizers and pesticides. Usually, mixed farms produce only the forage needed for feeding the livestock and give greater reliance on natural pastures for grazing animals. Therefore, they have less cultivated land devoted to crop production that means a decreasing number of soil tillage operations and a less intensive use of chemicals. Moreover, seed' recycling is more widely practiced in mixed farms generating lower impacts on soil, natural land transformation and climate changes. The higher impacts of mixed farms on freshwater (ecotoxicity and eutrophication) and terrestrial ecotoxicity is determined by freshwater nitrogen and phosphorus leaching as a result of animals grazing and manure management.

The performance of farms within the two groups clearly differs (Figure 3). Overall, most of the specialized crop are sustainable showing a RTC higher than one, while most of the mixed farms are unsustainable showing RTC lower than one. However, both the two groups of farms exhibit frontrunners whit a RTC higher than one.

Add figure 3: Return to costs ratio using the average benchmarks

The possible determinants in our data set that can explain the difference in farms performances are explained by the differences in average capitals productivity and eco-efficiency between crops and mixed farms (Table 4).

On average, the highest sustainable farm maximizes the productivity of capital, labour and land while minimizes the one of the ecosystem quality damage index. Mixed farms perform well in terms of land productivity, while specialized crop farms display better results in terms of labour and capital productivity and have a lower impact on ecosystems' quality. From these sustainable value calculations, it can be advised that a clear focus on the reduction of ecosystems' quality damages of mixed farms and on the increase of land productivity of crop farms are important to strengthen the sustainability performance of agricultural activities within the Park.

Add table 4: Average resources productivities and eco-efficiency of Crop and Mixed farms.

4. – Discussions and Conclusions

In this paper, we explored the possibilities to integrate biophysical and monetary sustainability assessment tools, through combining the impacts of agriculture activities on ecosystems with the concept of natural capital; in such a way that a relevant selection of resource forms can be performed. To achieve this goal, we performed a case study where LCA and SVA were used to assess the sustainability of agricultural systems within the

Park .The methodology presented in this study allowed an integrated assessment of the economic and environmental dimensions of sustainability, providing decision-makers an overview of the effects of agriculture activities on local sustainable development. Moreover, the use of a benchmark to measure farms overall performances and their relative efficiency can be useful to highlight opportunities of improvement both at farm level and at higher spatial levels. It was our aim to develop a first framework for combining biophysical and monetary oriented tools to assess sustainability of agricultural systems. However, considering the large variability in farm accountancy data and agriculture management practices, a higher numbers of farms needs to be sampled, in order to avoid the inference on outcomes of frontrunners and laggards. Further research is needed to improve benchmarking such as e.g. efficiency frontiers, which require more data availability in order to secure its robustness. Although further improvement is desirable, the methodology developed in this research to measure farm sustainability proofs to be promising.

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Tables

Table 1: Average descriptive statistics of the data sample of Crop and Mixed farms

	Unit	Crop Farms		Mixed Farms	
Farm size and Land use		Mean value	Range	Mean value	Range
Cultivated area (UAA)	ha	178	40 - 410	313	94 - 1040
Crops area	ha	178	40 - 410	60	4 - 121
Grassland area	ha			224	19 - 1000
Forage area	ha			40	9 - 67
Farm intensity					
Annual crop production	q.li/ha	20	3 - 37	26	15 - 56
Annual livestock production[a]	q.li/yr			56	0 - 150
Herd size	number of heads			293	90 - 520
Financial capital	.000 EUR	96	22 - 318	173	16 - 307
Subsidies	.000 EUR	70	14 - 126	30	4 - 44
Labour	Average Work Unit	1	0,1 - 2	2	1 - 2

[a] The production of one of the mixed farms was excluded by the calculation because it is the only case that produce sheep meat

Table 2: Correlation between the Return-to-cost ratio using different benchmarks

Return-to-cost	Benchmark 1	Benchmark 2	Benchmark 3
Benchmark 1[a]	1	0.9428***	0.6131**
Benchmark 2		1	0.6440**
Benchmark 3			1

[a] Benchmark base using the average for each form of resources

* significant at 10%   ** significant at 5%   ***significant at 1%

Table 3: Characterization of the environmental impacts of Crop and Mixed farms (species lost*yr^{-})

		Terrestrial acidification	Freshwater eutrophication	Terrestrial ecotoxicity	Freshwater ecotoxicity	Natural land transformation	Ecosystem quality damage index
Farm 1	CF	1.88E-06	2.84E-07	-3.89E-08	4.43E-08	3.38E-05	3.60E-05
Farm 2	CF	1.44E-05	3.47E-07	6.17E-06	1.79E-07	6.43E-05	8.54E-05
Farm 3	CF	-6.73E-06	4.72E-07	-1.48E-05	-1.87E-08	1.75E-04	1.54E-04
Farm 4	CF	4.01E-03	3.99E-05	1.21E-04	5.31E-06	3.42E-03	7.60E-03
Farm 5	CF	1.80E-04	2.14E-03	1.11E-02	1.38E-03	2.00E-04	1.50E-02
Farm 6	CF	9.64E-05	2.27E-05	2.75E-05	2.46E-06	3.53E-04	5.02E-04
Farm 7	CF	1.03E-03	8.34E-06	1.98E-05	1.01E-06	4.82E-04	1.54E-03
Farm 1	MF	-6.94E-05	2.82E-03	1.46E-02	1.82E-03	8.38E-05	1.92E-02
Farm 2	MF	6.62E-06	2.21E-06	1.94E-05	3.76E-07	3.22E-04	3.51E-04
Farm 3	MF	7.54E-05	7.46E-04	3.86E-03	4.80E-04	7.86E-05	5.24E-03
Farm 4	MF	-3.79E-06	1.32E-08	1.36E-07	-4.28E-08	4.97E-05	4.60E-05
Farm 5	MF	2.39E-05	7.92E-04	4.09E-03	5.09E-04	5.38E-04	5.95E-03
Farm 6	MF	-3.93E-05	1.91E-04	9.72E-04	1.23E-04	1.26E-04	1.37E-03
Farm 7	MF	6.25E-04	5.58E-03	2.89E-02	3.59E-03	1.40E-04	3.89E-02
SD		0.001	0.002	0.008	0.001	0.001	0.01

CF = crop farms; MF = mixed farms; SD = standard deviation

Table 4: Average resources productivities and eco-efficiency of Crop and Mixed farms.

	Capital productivity (€/€)	Labour productivity (M€/AWU)	Land productivity (€/ha)	Eco-efficiency (€/species lost *yr)
Crop farms	1.79	1.40	514.09	2.82E+08
Mixed farms	0.997	0.44	848.90	1.75E+08

Figures

Figure 2: A framework for an integrated sustainability assessment of Agro-ecosystems

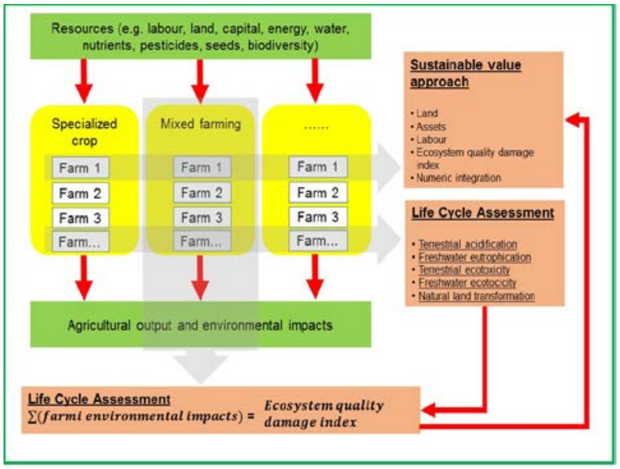

Figure 2: System boundaries used for the environmental impact assessment of the sampled farms.

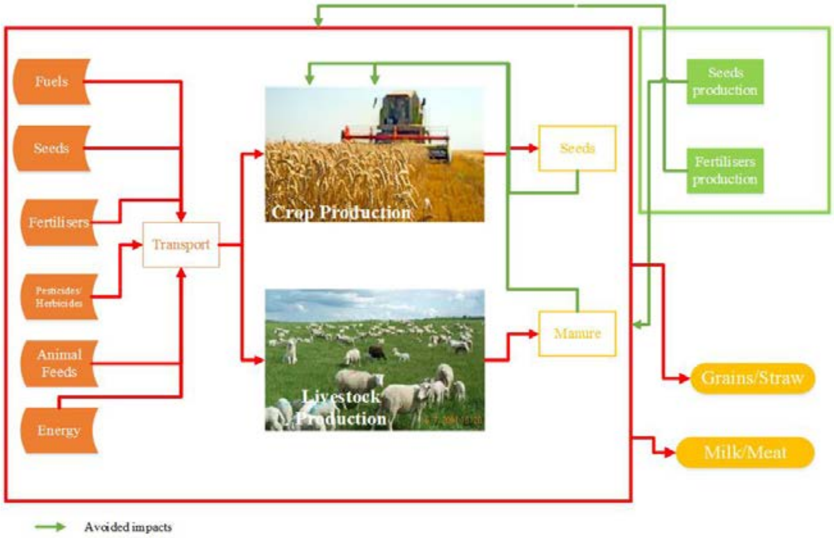

Figure 3: Return to costs ratio using the average benchmarks