A.D. MDLXII

UNIVERSITÀ DEGLI STUDI DI SASSARI
SCUOLA DI DOTTORATO DI RICERCA
Scienze e Biotecnologie
dei Sistemi Agrari e Forestali
e delle Produzioni Alimentari

Indirizzo: Produttività delle piante coltivate

Ciclo XXVI

ENVIRONMENTAL SUSTAINABILITY OF BIOENERGY CROPPING SYSTEMS IN SARDINIA: AN ANALYSIS BASED ON LIFE CYCLE ASSESSMENT AND FARMERS' PERSPECTIVES

Dr. Stefania Solinas

Direttore della Scuola Prof. Alba Pusino

Referente di Indirizzo Prof. Rosella Motzo

Docente Guida Dr. Giovanna Seddaiu

Anno accademico 2012 - 2013

CONTENTS

SUMMARY

This research aims to assess the environmental impacts derived from a possible development of energy crops in Sardinia. Assessment was supported by qualitative analysis aimed to highlight the stakeholders' perspectives in understanding environmental effects and in promoting energy crops local development.

Perspectives were evaluated through a stakeholders' involvement approach. We found that environmental impacts are not among the priority motivations that lead farmers to practice these energy crops. Afterwards, some farmers' profiles were estimated through the *Multiple Correspondence Analysis*. We found that perspectives on positive environmental effects caused by energy crops are strongly related to positive expectations on their introduction into local cropping systems.

Finally, we focused attention on assessing the environmental sustainability associated to substitution of some traditional crops with energy crops in Sardinia. The *Life Cycle Assessment* methodology was used in order to assess these environmental impacts, through a "cradle to farm gate" approach. Findings suggest that replacement of traditional crops with energy crops might produce controversial benefits in terms of environmental sustainability variation. Introduction of rapeseed into cereal cropping systems should show positive effects on environmental farming sustainability, whereas use of maize and artichoke for energy purpose might determine null or negative environmental outcomes, respectively.

INTRODUCTION

Over the centuries, humankind has depended more and more on natural resources availability in the world. In fact, the population growth has produced an increase of natural resources exploitation in order to guarantee own well-being. The necessity to preserve natural resources for the future generations has been the main driver for the developing of sustainability concept (Kemp and Martens, 2007; Kuhlman and Farrington, 2010; Bettencourt and Kaur, 2011). On the other hand, the urgency of tackling new environmental challenges - *e.g.* biodiversity loss, deforestation, land degradation, land use change, water scarcity, climate change - have determined a continue re-thinking of sustainability over the time. These issues necessarily have produced consequences on more spheres of human life (*i.e.* economical, social and institutional) beyond the environmental one, that have required to search for urgent and complex solutions (van der Leeuw *et al.*, 2012).

Basically, the sustainability concept cannot leave aside from the close interactions between different human activities involved in the use of resources. At the same time, it preserve the natural systems survival (Todorov and Marinova, 2011). This is a crucial issue because only through the understanding of these interdipendencies it would be possible to address the stakeholders' decisions in order to ensure a balanced use of natural resources (O'Connor, 2006; Gavrilescu, 2011). The worsening of concerns regarding food and energy security that have occurred in recent decades have produced a high mutual interdipendencies, and permanent transformations from environmental point of view on a global scale. This means that possible environmental failures in a certain region might threaten human sustainability in other regions (Kissinger *et al.*, 2011). Indeed, environmental change such as natural resources depletion represents a bundle of complex processes and it can depends on causes directly or indirectly derived from events occurred elsewhere (Kissinger and Rees, 2010).

The inherent complexity of human and environmental dimensions affected by sustainability has required the involvement of several and different actors' points of views (policy makers, citizens, researchers, etc.) in order to formulate and implement rational strategies for sustainable development. This needs because the distinction among social, economic, institutional and environmental sustainability is not clearly definited. It represents an useful device aimed to better understand the complexity of a specific system. (Bruckmeier, 2009). In other words, there are various approaches to sustainable development that reflect the diversity of challenges faced by individual realities that cannot leave aside from own cultural background and customs. Although sustainability represents a global challenge, many practical responses can only be identified at the local level and they should consider the temporal and spatial scale (Mayer, 2008; Diaz-Chavez, 2011).

The dynamic evolution and the complexity of challenges that the sustainability have established as own targets result hardly manageable in the context of traditional sciences (Sala *et al.*, 2013a). The Sustainability Science (SS) might be considered as an emerging discipline aimed to better understand the dynamic interactions between natural systems and society in order to identify a pathway towards sustainable development (Komiyama and Takeuchi, 2006; Clark, 2007; Jerneck *et al.*, 2011; Wiek *et al.*, 2012; Sala *et al.*, 2013a). Anyway, the new science is not devoid of crucial issue regarding both the better identification of problems related to sustainability and the transitions to solutions based on an integrated and partecipatory approach (Jerneck *et al.*, 2011; Sala *et al.*, 2013a). Briefly, the SS requirements regard to adoption of holistic and system wide approaches, shift from multi- to trans-disciplinarity, change of temporal and spatial scale perspectives and encourage a greater involvement of stakeholders (Anderson *et al.*, 2012; Lang *et al.*, 2012; Sala *et al.*, 2013a; van Kerkhoff, 2013).

The sustainability is a worldwide concept based on stakeholders' involvement and system-wide analysis. These aspects also characterized the life cycle approach that might represent an useful tool in order to sustainability assessments (Zamagni, 2012; Sala *et al.*, 2013a). In fact, the SS should not leave aside from taking into consideration environmental, economic and social consequences caused by a supply chain of products in order to achieve more sustainable production and preserve natural resources (Sala *et al.*, 2013b). Although the life cycle methodologies, - *e.g.* Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and social (sLCA) - would need for additional improvements they represent useful tools in order to evaluate the complexity of sustainability on the whole. (Finkbeiner *et al.*, 2010; Guinée *et al.*, 2011; Halog and Manik, 2011; Jørgensen *et al.*, 2013; Sala *et al.*, 2013a, b).

At the institutional ground, nowadays seeking of sustainability plays a crucial role into the policy agendas worldwide. The future European Union (EU) strategy for the next decade underlines the great relevance to ensure a sustainable growth through the promotion of more efficient, green and competitive economy based on more balanced use of natural resources (European Commission, 2010a). This also means that it is necessary to build synergies among different policies - such as energy and agricultural policies - in order to achieve these targets (European Commission, 2011). Specifically to agricultural sector, the next Common Agricultural Policy would tackles critical challenges - *e.g.* food security, environmental safeguard, climate change impacts and territorial balance) - that will lead EU to make crucial choices for the long-term regarding its agriculture and rural areas (European Commission, 2010b). In fact, the demand for food, feed and raw material for bioenergy production represents a thorny issue in order to the environmental consequence in terms of sustainable agricultural production, land use competition and biomass availability for energy target (Harvey and Pilgrim, 2011; Murphy *et al.*, 2011; Dicks *et al.*, 2013; Spiertz, 2013). In other words, the current debate is focused on the necessity of find an equilibrium between food and energy production, especially in terms of land and biomass availability (Panoutsou *et al.*, 2009; Krasuska *et al.*, 2010; Rathmann, 2010; Thrän *et al.*, 2010; Bird *et al.*, 2013).

The evaluation of bioenergy sustainability might be an useful mean in order to support stakeholders' decisions, especially in terms of farmers' choices on adoption of energy crops into own cropping systems (Villamil *et al.*, 2012; Johnson *et al.*, 2013). Since the energy crops cultivation could produce positive and negative environmental impacts, both the application of LCA procedure and the analysis of farmers' perspectives might provide useful information in order to support the farmers' decisions and to foster compliance of farmers in introducing these crops into the local farming systems (Paulrud and Laitila, 2010; Rossi and Hinrichs, 2011; van Dam and Junginger, 2011; Fazio and Monti, 2011; Goglio *et al.*, 2012; Qu *et al.*, 2012; González-García *et al.*, 2013; Malça *et al.*, 2013; Milazzo *et al.*, 2013; Bacenetti *et al.*, 2014).

In the light of these considerations, this study is aimed to evaluate the environmental sustainability of a possible bioenergy cropping systems development in Sardinia. The assessment - based on Life Cycle Assessment application - has been supported by qualitative analyses in order to put on evidence the stakeholders and farmers' perspectives in understanding environmental sustainability of energy crops and in expecting positive development of this system in Sardinia.

REFERENCES

1. Anderson M. W., Teisl M., Noblet C., 2012. Giving voice to the future in sustainability: Retrospective assessment to learn prospective stakeholder engagement. Ecological Economics 84, 1-6.

2. Bacenetti J., Fusi A., Negri M., Guidetti R., Fiala M., 2014. Environmental assessment of two different crop systems in terms of biomethane potential production. Science of the Total Environment 466-467, 1066-1077.

3. Bettencourt L. M. A., Kaur J., 2011. Evolution and structure of sustainability science. PNAS 108 (4), 19540-19545.

4. Bird D. N., Zanchi G., Pena N., 2013. A method for estimating the indirect land use change from bioenergy activities based on the supply and demand of agricultural-based energy. Biomass and Bioenergy 1, 1-3, forthcoming.

5. Bruckmeier K., 2009. Sustainability between Necessity, Contingency and Impossibility. Sustainability 1, 1388-1411.

6. Clark W. C., 2007. Sustainability Science: A room of its own. PNAS 104 (6), 1737-1738.

7. Diaz-Chavez R. A., 2011. Assessing biofuels: Aiming for sustainable development or complying with the market?. Energy Policy 39, 5763-5769.

8. Dicks L. V., Bardgett R. D., Bell J., Benton T. G., Booth A., Bouwman J., Brown C., Bruce A., Burgess P. J., Butler S. J., Crute I., Dixon F., Drummond C., Freckleton R. P., Gill M., Graham A., Hails R. S., Hallett J., Hart B., Hillier J. G., Holland J. M., Huxley J. N., Ingram J. S. I., King V., MacMillan T., McGonigle D. F., McQuaid C., Nevard T., Norman S., Norris K., Pazderka C., Poonaji I., Quinn C. H., Ramsden S. J., Sinclair D., Siriwardena G. M., Vickery J. A., Whitmore A. P., Wolmer W., Sutherland W. J., 2013. What Do We Need to Know to Enhance the Environmental Sustainability of Agricultural Production? A Prioritisation of Knowledge Needs for the UK Food System. Sustainability 5, 3095-3115;

9. European Commission, 2010a. The CAP towards 2020: Meeting the food, natural resources and territorial challenges of the future. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM (2010) 672 final, Brussels, 2010.

10. European Commission, 2010b. EUROPE 2020 A strategy for smart, sustainable and inclusive growth. Communication from the Commission, COM(2010) 2020, Brussels, 2010.

11. European Commission, 2011. A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM (2011) 21 final, Brussels, 2011.

12. Fazio S., Monti A., 2011. Life cycle assessment of different bioenergy production systems including perennial and annual crops. Biomass and Bioenergy 35, 4868-4878.

13. Finkbeiner M., Schau E. M., Lehmann A., Traverso M., 2010. Towards Life Cycle Sustainability Assessment. Sustainability 2, 3309-3322.

14. Gavrilescu M., 2011. 2.66 Sustainability. Comprehensive biotechnology (Second Edition) 2, 905-923.

15. Giannoccaro G., Berbel J., 2012. The Determinants of Farmer's Intended Behaviour Towards the Adoption of Energy Crops in Southern Spain: an Application of the Classification Tree-Method. Bio-based and Applied Economics 1 (2), 199-212.

16. Goglio P., Bonari E., Mazzoncini M., 2012. LCA of cropping systems with different external input levels for energetic purposes. Biomass and Bioenergy 42, 33-42.

17. González-García S., Bacenetti J., Negri M., Fiala M., Arroja L., 2013a. Comparative environmental performance of three different annual energy crops for biogases production in Northern Italy. Journal of Cleaner Production 43, 71-83.

18. Guinée J. B., Heijungs R.,Huppes G., 2011. Life Cycle Assessment: Past, Present, and Future. Environm Sci. Technol. 45, 90-96.

19. Halog A., Manik Y., 2011. Advancing Integrated Systems Modelling Framework for Life Cycle Sustainability Assessment. Sustainability 3, 469-499.

20. Harvey M., Pilgrim S., 2011. The new competition for land: Food, energy, and climate change. Food Policy 36, S40-S51.

21. Jerneck A., Olsson L., Barry N., Anderberg S., Baier M., Clark E., Hickler T., Hornborg A., Kronsell A., Lövbrand E., Persson J., 2011. Stricturing sustainability science. Sustain Sci 6, 69-82.

22. Johnson T. L., Bielicki J. M., Dodder R. S.,. Hilliard M. R., Kaplan P. O., Miller C. A., 2013. Advancing Sustainable Bioenergy: Evolving Stakeholder Interests and the Relevance of Research. Environmental Management 51, 339-353.

23. Jørgensen A., Herrmann I. T., Bjørn A., 2013. Analysis of the link between a definition of sustainability and the life cycle methodologies. Int J Life Cycle Assess 18, 1440-1449.

24. Kissinger M., Rees W. E., 2010. An interregional ecological approach for modelling sustainability in a globalizing world—Reviewing existing approaches and emerging directions. Ecological Modelling 221, 2615-2623.

25. Kissinger M., Rees W. E., Timmer V., 2011. Interregional sustainability: governance and policy in an ecologically interdependent world. Environmental Science & Policy 14, 965-976.

26. Komiyama H., Takeuchi K., 2006. Sustainability science: building a new discipline. Sustain Sci 1, 1-6.

27. Krasuska E., Cadórniga C., Tenorio J. L, Testa G., Scordia D., 2010. Potential land availability for energy crops production in Europe. Biofuels, Bioprod, Bioref. 4, 658-673.

28. Kuhlman T., Farrington J., 2010. What is Sustainability?. Sustainability 2, 3436-3448.

29. Kemp R., Martens P., 2007. Sustainable development: how to manage something that is subjective and never can be achieved?. Sustainability: Science, Practice, & Policy 3 (2), 5-13.

30. 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. Sustain Sci 7 (Supplement 1), 25-43.

31. Malça J., Coelho A., Freire F., 2013. Environmental life-cycle assessment of rapeseed-based biodiesel: Alternative cultivation systems and locations. Applied Energy (2013), http://dx.doi.org/10.1016/j.apenergy.2013.06.048, forthcoming.

32. Mayer A. L., 2008. Strengths and weaknesses of common sustainability indices for multidimensional systems. Environment International 34, 277-291.

33. Milazzo M.F., Spina F., Vinci A., Espro C., Bart J.C.J., 2013. Brassica biodiesel: Past, present and future. Renewable and Sustainable Energy Reviews 18, 350-389.

34. Murphy R., Woods J., Black M., McManus M., 2011. Global developments in the competition for land from biofuels. Food Policy 36, S52–S61.

35. O'Connor, 2006. The "Four Spheres" framework for sustainability. Ecological Complexity 3, 285-292.

36. Panoutsou C., Eleftheriadis J., Nikolaou A., 2009. Biomass supply in EU27 from 2010 to 2030. Energy Policy 37, 5675-5686.

37. Paulrud S., Laitila T., 2010. Farmers' attitudes about growing energy crops: A choice experiment approach. Biomass and Bioenergy 34, 1770-1779.

38. Qu M., Ahponen P., Tahvanainen L., Gritten D., Mola-Yudego B., Pelkonen P., 2012. Practices and perceptions on the development of forest bioenergy in China from participants in national forestry training corse. Biomass and Bioenergy 40, 53-62.

39. Rathmann R., Szklo A., Schaeffer R., 2010. Land use competition for production of food and liquid biofuels: An analysis of the arguments in the current debate. Renewable Energy 35, 14-22.

40. Rossi A. M., Hinrichs C. C., 2011. Hope and skepticism: Farmer and local community views on the socio-economic benefits of agricultural bioenergy. Biomass and Bioenergy 35, 1418-1428.

41. Sala S., Farioli F., Zamagni A., 2013a. Progress in sustainability science: lessons learnt from current methodologies for sustainability assessment: Part 1. Int J Life Cycle Assess. 18 (9), 1653-1672.

42. Sala S., Farioli F., Zamagni A., 2013b. Life cycle sustainability assessment in the context of sustainability science progress (part 2). Int J Life Cycle Assess. 18 (9), 1686-1697.

43. Spiertz H., 2013. Challenges for Crop Production Research in Improving Land Use, Productivity and Sustainability. Sustainability 5, 1632-1644.

44. Todorov V., Marinova D., 2011. Modelling sustainability. Mathematics and Computers in Simulation 81, 1397-1408.

45. Thrän D., Seidenberger T., Zeddies J., Offermann R., 2010. Global biomass potentials - Resources, drivers and scenario results. Energy for Sustainable Development 14, 200-205.

46. van Dam J., Junginger M., 2011. Striving to further harmonization of sustainability criteria for bioenergy in Europe: Recommendations from a stakeholder questionnaire. Energy Policy 39, 4051-4066.

47. van der Leeuw S., Wiek A., Harlow J., Buizer J., 2012. How much time do we have? Urgency and rhetoric in sustainability science. Sustain Sci, 7 (Supplement 1), 115-120.

48. van Kerkhoff L., 2013. Developing integrative research for sustainability science through a complexity principles-based approach. Sustain Sci, DOI 10.1007/s11625-013-0203-y.

49. Villamil M. B., Alexander M., Silvis A. H., Gray M. E., 2012. Producer perceptions and information needs regarding their adoption of bioenergy crops. Renewable and Sustainable Energy Reviews 16, 3604-3612.

50. Wiek A., Ness B., Schweizer-Ries P., Brand F. S. Farioli F., 2012. From complex systems analysis to transformational change: a comparative appraisal of sustainability science projects. Sustain Sci 7 (Supplement 1), 5-24.

51. Zamagni A., 2012. Life Cycle sustainability assessment. Int J Life Cycle Assess 17, 373-376.

CHAPTER 1

Opportunities, uncertainties and environmental issues related to energy crops development: a stakeholders' perspectives analysis

Abstract

Energy crops can assume an important and strategic role in contrasting negative effects caused by environmental changes in Europe. On the one hand, energy crops represent a possible alternative for adapting agriculture to changed environmental features and, on the other hand, they can mitigate negative environmental effects due to production of conventional energy, so contributing to reduce fossil fuels dependence. However, in certain regions such as Sardinia, some critical issues have limited energy crops development as yet. This study aims to evaluate the possibility of developing energy crops in Sardinia according to stakeholders' perspectives. Perspectives were evaluated through a stakeholders' involvement approach based on SLIM (Social Learning for the Integrated Management and sustainable use of water at catchment scale) analytical framework and they were analyzed in order to put on evidence the main critical points that potentially can foster or, vice versa, discourage farmers to introduce energy crops into their cropping systems. Particular relevance was assigned to the role of environmental factors in affecting stakeholders' perspectives. Regarding the main empirical findings, a common opinion that we found, reveals that positive environmental impacts associated to energy crops cultivation is not the main reason that lead farmers to practice these crops or that induce other stakeholders to promote energy crops development.

Keywords: energy crops, stakeholders' perspectives, diagnostic framework, environmental issues, Sardinia.

1. INTRODUCTION

Relevance of the environmental issues (*e.g.* climate change impacts, pollution, and desertification) has dramatically increased into the scientific debate and the common opinion during the last years. Nowadays, implementing strategies and actions to contrast these impacts and to minimize negative environmental effects are among the most crucial challenges for policy makers worldwide (European Commission, 2008; EEA, 2010; Edenhofer *et al.*, 2012).

Great attention by part of scientists and policy makers has been put on environmental impacts of agriculture and on its role for mitigation. Environmental impacts associated to functioning agricultural systems have affected many regions worldwide in different ways and magnitudes, and the Mediterranean countries are considered among the most affected ones (Matei *et al.*, 2009; European Commission, 2009a). In a long run perspective, Mediterranean agricultural systems might undergo significant changes due to productivity and yields decreasing, difficulty in water provision, plant and animal biodiversity, reduction and loss of soil fertility (European Commission, 2009b). In order to manage these possible impacts, the European Union (EU) has promoted a range of policies aimed at adapting agricultural systems to climate and environmental changes so as to foster a sustainable agriculture development (Iglesias *et al.*, 2007; European Commission, 2010; Olesen *et al.*, 2011).

In this perspective, energy crops could assume an important and strategic role. Indeed energy crops cultivation and the consequent bioenergy production can induce meaningful effects in the environmental, social and economic domains. Firstly, because in some Mediterranean marginal areas - where environmental conditions limit the profitability of many agricultural systems - energy crops could represent one possible alternative or complementary crops in the traditional cropping systems (Zegada-Lizarazu et al., 2010; González-García *et al.*, 2012). Secondly because the agro-energy supply-chain - *i.e.* the production and distribution of bioenergy derived from energy crops products and/or by-products - might play an indirect role for mitigating negative environmental effects by reducing the fossil fuels dependency (Escobar *et al.*, 2009; García *et al.*, 2013). Finally, other positive implications can arise such as energy security, recovery of degraded soils, and creation of new sources of income for farmers. However, around the energy crops development an international debate has raised in the last decades regarding possible negative environmental, social and economic implications such as impacts on food prices, loss of biodiversity, increase of greenhouse gases emissions due to land use change, deforestation, loss of fertile soils availability for agriculture, increase of water demand, change of traditional landscapes, and competition between food and non-food crops. In the light of these considerations, it becomes a priority to guarantee the environmental and socio-economic sustainability of bioenergy production systems (Diaz - Chavez, 2011; GBPE, 2011; Tait, 2011; Afionis and Stringer, 2012; Erb et *al.*, 2012; Mangoyana et *al.*, 2013).

The complex and dynamic nature of sustainability requires flexible and transparent decision-making processes that embrace a diversity of knowledges and values. For this reason, stakeholders' engagement in environmental and socio-economic decision-making has been increasingly sought (vanDam and Junginger, 2011; Anderson *et al.*, 2012; Sala *et al.*, 2013 and embedded into national and international policies. There is evidence that stakeholders' participation can enhance the quality of policy decisions by considering more comprehensive information inputs (Reed, 2008). Researchers should explore stakeholders' values, information needs, and the factors affecting stakeholders' decision making, since the knowledge they generate should reach its widest potential use (Reed, 2008). Local and scientific knowledge can be integrated to provide a more comprehensive understanding of complex and dynamic socio-ecological systems and processes (Nguyen *et al.*, 2013). The local knowledge can also be used to evaluate the appropriateness of potential technical and site-specific solutions to environmental and socio-economic issues such as the development of energy crops in the cropping systems (Johnson *et al.*, 2013).

Concerning Italy, the bioenergy production has showed continuous growth. Nowadays biomass from agriculture as energy crops amounts to about 3 million tones (Scarlat *et al.*, 2013).

Sardinia is among the Italian Regions where the development of the energy crops sector could possibly foster positive economic and social opportunities. It is a fact that since years certain farmers have just switched from cereals to energy crops, especially rapeseed (*Brassica napus* var. *oleifera* D.C.) (Deligios *et al.*, 2013). Although only few experiences have been successful for several reasons, there are opportunities for increasing energy crops cultivation - not only rapeseed - due to some conducive institutional and economic conditions that could directly or indirectly promote their introduction in the cropping systems. The current serious economic and social crisis that some traditional agro-food sectors, such as the dairy sheep farming system (Roggero *et al.*, 2011), are facing, might force farmers to consider switching from traditional activities towards alternatives like energy crops cultivation.

Moreover, the wide presence of abandoned chemical and sugar factories that could be transformed for production of agro-energies from local vegetable oils could promote the development of a local agro-energy supply-chain in a middle run term.

On the other hand, energy crops development has not largely occurred in Sardinia. It is a fact that small volume of raw biomaterial arisen from energy crops does not allow Sardinian producers to compete into the world market. Moreover, the lack of local warehouses and adequate processing plants imply that farmers must sell oil seeds produced to processors in the northern - central Italy. Probably, the low productivity of the energy crops experienced by farmers in the recent past has also limited their diffusion. However, it is likely that the scarcity of information about energy crops growing and agronomic requirements have entailed their low diffusion and low yield.

In the light of these considerations, the aim of this chapter was to explore farmers' and other stakeholders' perspectives regarding energy crops cultivation in Sardinia, and to identify and profile potential adopters and priorities to be taken into account if the energy crops development is to be promoted. We expect the results of this study to improve the effectiveness of future efforts towards the energy crops development, also for other areas than Sardinia, at research level by identifying potential research questions and at policy-making decision level by identifying more desirable instruments and initiatives. Finally, particular relevance is put on valuating the role of environmental issues in conditioning stakeholders' perspectives.

2. MATERIALS AND METHODS

2.1 Methodological framework

The analytical framework applied in this study was developed within the Social Learning for the Integrated Management (SLIM and sustainable use of water at catchment scale) Project[1]. This framework represented a useful tool to better understand the role of stakeholders in complex natural resources management situations (Blackmore, 2007; Steyaert and Jiggings, 2007; Steyaert *et al.*, 2007). The SLIM approach aimed at deconstructing and analyzing the main constraints and priorities of natural resources management through facilitated interaction among stakeholders. In fact, it was focused on the social learning concept based on interaction among stakeholders around issues characterized by complexity, interdependencies, uncertainty and controversy such as natural resources management (SLIM, 2004; Ison *et al.*, 2007).

Interdependencies occur when a specific action could affect ecological processes so that to change adversely the use of resources by other individuals in different spatial-temporal scale.

Complexity emerges from natural, technical and social factors that inevitably involve changes in public policy, organizations and different stakeholders with their own perspectives and perceptions related to particular issues. Complexity makes difficult to understand effects of different solutions for a specific issue. Thus, they cause uncertainty in various fields (*e.g.*, in the ecological, technological, economic and policy context) that often moves to un-coordination among stakes and contradictions regards to goals and

[1] The SLIM project was funded into the Fifth European Framework Programme (http://slim.open.ac.uk).

methods of management implementation. Controversy emerges from bringing into question real existence of issues, their origin, their hypothetical cause-effect relationships and how they should be managed and by whom.

Complexity, interdependencies, uncertainty and controversy make unlikely the identification of a single solution from one group of experts. Moreover, the SLIM framework assumes that change in practices do not emerge just thinking and acting more efficiently, but also through change of the system of interest (from S2 to Sn) (Figure 1), that requires a change of perceptions, roles and values that stakeholders recognize in it through social learning processes.

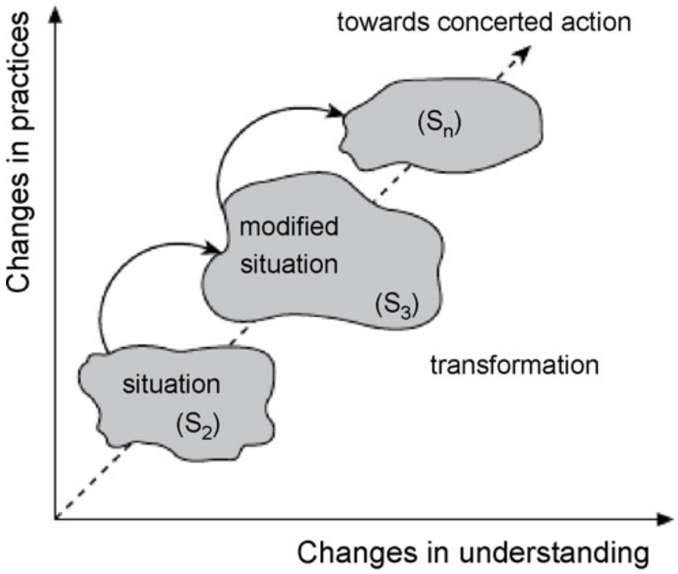


Figure 1 - Transformational change, in terms of changes in practice with changes in understanding in a complex situation (Source: SLIM, 2004)

Two concepts played a relevant role in the SLIM framework: 1) systems of interest and 2) multiple perspectives (Collins *et al.*, 2007). A "systemic perspective" could not exclude that a system is to be thought with the environment and context to which it belongs to, and on the basis of stakeholders' perspectives. A system of interest is in general a partial view of a specific situation since it represents the multiple and various stakeholders perceptions of it. Therefore it is necessary to consider its boundaries dynamics to better understand a situation and to identify desirable concerted actions.

The SLIM framework is constituted by five variables: 1) history of the situation, 2) stakeholders and stakeholding, 3) institutions and policies, 4) environmental constraints, 5) facilitation to foster stakeholders interactions that could affect the adoption of a production systems. The SLIM framework is based around these variables emerging from a dynamic iterative and interactive participatory process between stakeholders, after the boundaries of the system of interest have been defined (Roggero *et al.*, 2006).These variables were characterised both as factors influencing transformational change of the context and as variables that can be affected by transformational change, into a two-way view (Figure 2). In other terms, changes in issues, practices and understanding involves also changes in perception of the main elements (Steyaert and Jiggins, 2007).

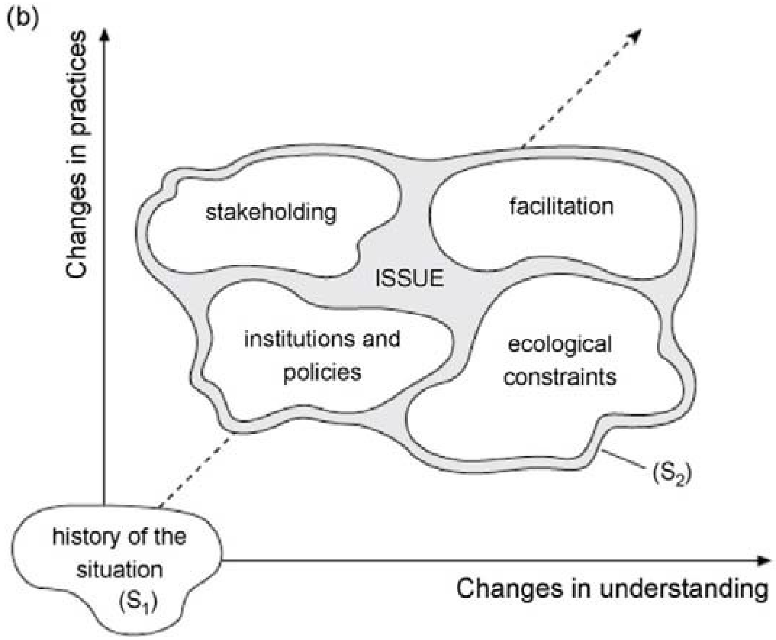


Figure 2 - Transformational change in a social learning approach evaluate history, institutions and policies, ecological constraints, stakeholders and stakeholding and facilitation to move towards concerted action (Source: SLIM, 2004).

History. Each agri-environmental and natural resource management issue exists in a specific historical, social, cultural and institutional frame that it is perceived in different ways by different stakeholders. This means, for example, that a certain policy or management practice that may have worked in a particular environmental and socio-economic context it may be completely inappropriate in another one. Policy makers are often aware of the contrast between policy targets and their effective practical implementation. This contrast derives from insufficient knowledge of the historical background of the situation in which policies or practices are implemented. The historical analysis of a specific context makes clearer how the local stakeholders perceive a problem and it allows, firstly, to define a wide set of hypotheses about the reasons that led to the current situation, secondly to identify stakeholders and institutions that are involved and, finally, how different actors could be encouraged to overcome the present situation through the identification of concerted actions.

Stakeholders and stakeholding. The nature of interests is important to construct the debate and to foster the understanding of the issue under consideration. Therefore different stakeholders' categories have social roles and objectives which are not necessarily convergent with respect to the decisions and choices to be implemented. The different views and the diversity of stakes are instrumental in the decision making and in the natural resources management. Stakeholding expresses the concept that individuals or groups actively construct and promote their stakes in relation to those of others. New stakes can emerge by social interaction among stakeholders.

Ecological constraints. This variable represents identifiable and quantifiable factors that affect the functions of an ecosystem. But their understanding is partial since each stakeholder has his/her own perception of the ecological factors and of the processes affected by them. The understanding of the system of interest depends on the specific experience and this is useful to identify different views about the same issue. Therefore, considering the different perspectives and complexity of the relationships between human activities and the ecological processes characterized by multiple spatial and temporal scales, the ecological constraints are intended within the framework as the perceptions of stakeholders about the relationships between people and the environment rather than an objective description. People implement practices depending on their own awareness and knowledge of ecological processes and relationship between them and a specific system of interest. Fragmentary and limited perceptions and knowledge regarding the ecological processes of an ecosystem often result in inconsistency between the objectives and results of adopted practices. This difficulty derives from complex interactions between human activities and multiple ever-changing ecological processes.

Facilitation. This variable refers to learning processes among multiple stakeholders. It comes from a combination of different skills, activities and tools that brings about systemic change in complex situations for implementation of shared actions. Facilitation can foster and support different activities: 1) experiential learning thanks to which stakeholders can learn through observation, measurement and interpretation of the outcomes of doing something. 2) Co-learning through shared actions, such as participatory experiments, observations and measurements so as to check and understand the results of their actions together 3) Learning about learning, through which actors become more aware of collective learning process in which they have participated and explore the advantages of shared actions. Different stakeholders can better interact to each other thanks to facilitation and then they can understand "what they are doing" and "why they are doing what they do". In other words, stakeholders involved in the facilitation processes are guided in the collective analysis in order to identify shared strategies that generally lead to concerted more conscious and sustainable actions.

Institutions and policies. In the SLIM framework the term "institution" is used with double meanings: 1) public and private organizations that rule the individual behaviour, 2) system of rules imposed on the social life of individuals by society and which are accepted by the community since they are considered as legitimate praxes. In general, an institutionalized behaviour is therefore "something to do". In other words, it is a binding rule, a social norm to which to adapt.

The management of natural resources and agro-environmental issues are widely influenced by the institutional context characterized by complex legal and fiscal policies, activities of organizations involved in decision-making processes and policy implementation and several practices accepted by the community.

2.2 Data collection and analysis

Information was collected through semi-structured interviews carried out from November 2011 to November 2012 and articulated on the basis of the SLIM framework variables. The target population for this study was the stakeholders, mainly farmers, in two different areas of Sardinia, both characterized by recent attempts to introduce energy crops in the cropping systems and/or to develop a bioenergy production chain: the Nurra Plain in the North-West of Sardinia and the Arborea district in the central western Sardinia.

Thirty-five stakeholders from the two case studies areas and also some representatives of institutions at regional level were interviewed following a semi-structured checklist of questions that aimed to obtain information about the main factors that have influenced, or could influence in the future, the energy crops development in Sardinia. The sample was selected throughout the Nurra and Arborea regions.

The list of selected stakeholders is reported in Table 1.

Table 1 - List of interviewed stakeholders

Categories	Nurra Plain	Arborea	Sardinia	Total
Farmers	18	3	-	**21**
Industrials	2	2	-	**4**
Cooperative representatives	-	3	-	**3**
Regional administration representatives	-	-	2	**2**
Farmers' Unions representatives	-	-	2	**2**
Professionals (Agronomists)	-	1	-	**1**
Researchers	-	-	2	**2**
Total	**20**	**9**	**6**	**35**

The answers were analyzed on the basis of the SLIM analytical framework that allowed us to deconstruct the "energy crops issue" through five variables, in order to identify strengths and weaknesses, to compare stakeholders' perceptions and to put on evidence which were the most important factors that could encourage (or constrain) the development of energy cropping systems in Sardinia.

2.2.1 Nurra case study

In the Nurra Plain, similarly to many areas of Sardinia, the most relevant farming activities are represented by dairy sheep livestock - mainly for producing cheese, but also meat - and the livestock farms are characterized by greater production scales with respect to the general dimension of Sardinian sheep livestock farms (Madau, 2010). Other important agricultural activities for the rural economy are cereals, horticulture, grape-growing and olive-growing systems. However, cereals cultivated areas have experienced a dramatic decrease in the last years. A dynamic agro-food and agro-industrial systems traditionally characterized the Nurra Plain economy given the presence of several agro-food industries, especially milk processing plants and wine and olive-oil industries. Recently, some farmers have tried to switch part of their cultivated lands from cereals or from grazing to energy crops, rapeseed in particular, in order to find more convenient solutions in terms of use of lands and farm income. In the last five-year period, a biogases plant was constructed and some industrial bioenergy programs were also developed with important impacts on the traditional farming systems.

2.2.2 Arborea case study

The Arborea district is characterized by much more intense farming systems than that of the Nurra Plain, and is mostly based on dairy cattle livestock and irrigated forage systems (double rotation of silage maize (*Zea mays* L.) and Italian ryegrass (*Lolium multiflorum* Lam.) for hay production. The area was a large marine wetland until the 1920s and most of the lands were reclaimed and converted to agricultural production. The majority of farmers belong to an only Farmers' Cooperative which is mainly responsible for the collective purchase of farm inputs, technical assistance and marketing. Furthermore, farmers are also members of a Milk Processing Cooperative, which processes and sells milk products (Nguyen *et al.*, 2013).

In 2005, Arborea was designated as the only Nitrate Vulnerable Zone (NVZ) in Sardinia (Regione Autonoma della Sardegna 01/2005) under the Nitrate Directive (ND, 1991/676/EEC). The nitrate pollution problem has been considered to be mainly associated with intensive dairy cattle farming systems (170 dairy cattle farms and 35,000 cows in 5500 ha), a shallow water table and sandy soils (more than 90% of sand). The implementation of the ND has resulted in a series of obligations related to the distribution of organic effluents (slurry and manure) such as a maximum N rate of 170 kg ha^{-1} year^{-1} from organic fertilizers and a ban on the spreading of organic fertilizers during winter from 15 November to 15 February (Nguyen *et al.*, 2013). This has meant that farmers have to purchase mineral N fertilizers to meet total N crop requirements, thus increasing production costs: yet with farm sizes insufficient to receive total effluent, they have to pay to export excess manure and slurry or rent land outside the NVZ.

Since the construction of a biogases plant in 2009 several farmers are provide slurry as raw material for the bioenergy production[2].

3. RESULTS

3.1 History

In the last two decades, different and local specific conditions have leaded Sardinian farmers to cultivate energy crops oriented mainly to the production of biodiesel and biogases.

[2] More details are provided in the Paragraph 3, into the variable *History* of the results.

In the 90ies, the cultivation of energy crops - especially but not exclusively rapeseed - was promoted by the financial aid granted to oilseed crops provided by the MacSharry Reform of the Common Agricultural Policy (CAP) in 1992. However the dramatic decrease and the successive abolition of the CAP aid have progressively moved farmers to abandon the cultivation of these crops.

Afterwards, interest on bioenergy has been renewed due to the current economic crisis of traditional agricultural and livestock sectors and to obligation to comply with European and national normative. In the light of agricultural input prices increasing and output prices decreasing, some farmers have modified their productive activities investing in non food and non feed productions. In the Nurra region, some farmers have re-introduced rapeseed into the cropping systems since they have viewed more convenient market perspectives for these productions than traditional agricultural activities (*e.g.* grain cultivation and sheep dairy). They have been encouraged by advantageous withdrawal price of oilseeds that is offered by a specific industrial group thanks to the mediation of a seed company representative. This is been possible due to affordable market price of rapeseed from 2009 onwards.

Furthermore, the poor profitability associated to traditional crops in Nurra region has leaded other farms to practice cardoon (*Cynara cardunculus* L. var. *altilis*) on lands that would otherwise been abandoned. This behaviour has been encouraged by an industrial group that has offered to purchase cardoon as raw material to produce biomaterials.

In a second situation, the biodigester implanting is viewed as a profitable opportunity by farmers. Indeed in the Nurra region, someone has preferred to use their traditional agricultural production - *e.g.* maize - as a raw material for biodigester due to higher economic convenience with respect to alternative destinations such as animal feed.

In the Arborea area, the construction of the biodigester plant was first promoted by the Farmers' Cooperative which gathers the majority of farmers and is mainly responsible for the collective purchase of farm inputs, technical assistance and product marketing. The costs for the construction were covered by an industrial company that is benefiting from the sale of energy. Famers provide free the raw material (mainly slurry) for biodigester whereas the industrial company gives to farmers' cooperative a yearly compensation arisen from energy selling and also thermal energy produced by the plant.

The biodigester plant was seen by the majority of farmers as an opportunity for more efficiently managing, or for fewer farmers for solving, the problem associated to the high volumes of cattle slurry that could not be fully distributed in the NVZ. From this point of view, the biodigester plant is considered by the majority of farmers as an opportunity, in fact it is allowing to save in terms of farm costs for the excess slurry and manure disposal that otherwise are to be exported outside the NVZ with increased production costs. However, some farmers have doubts about the benefits of the biodigester in terms of environmental protection since its functioning depends on agricultural activities and transport that use polluting raw materials (*e.g.* fossil fuels, fertilizers, herbicides etc.). According to others, more caution should have been taken before doing this sort of investment because its impact depends from several factors such as subsidies availability, political contest and market trend of renewable energy.

In both case studies, farmers' unions, local institutions, and researchers had a marginal role in the development of energy crops cultivation and industrial valorization. Anyway, these groups of stakeholders played and are still playing different roles as specified in the following sections.

3.2 Stakeholders and stakeholding

The main stakes are reported as follows on the basis of perspectives by each category of stakeholders.

Farmers. The willingness of farmers to introduce energy crops in their farming systems is mainly associated to the possibility to maintaining and/or increasing the farm income, that, in turn, depends on the withdrawal prices promoted by the industrial companies. However, farmers in the Nurra area that have grown rapeseed in the recent past, highlighted also other reasons such as the benefits of rapeseed in the cereal-based crop rotation on the overall soil productivity. Several farmers have also claimed that there are currently other crops in which they are addressing their interest as raw materials for the biodigesters in Nurra and Arborea, such as triticale and maize, respectively. Nevertheless, the majority of farmers are skeptical about completely replacing the traditional farming systems with energy cropping farming systems, on the basis of several reasons.

Firstly Sardinia region would not be able to produce the adequate amount of raw material needed to (real or supposed) industrial plants for production of biomaterial and bioenergy. In their opinions, plants should have a production capacity hardly feasible in Sardinia and it would need to import raw material.

Secondly in order to produce the correct amount of oilseeds it would detract land to traditional crops, *e.g.* food and feed crops. Regards to this issue, the mostly of interviewed farmers would not replace the traditional food crops such as grain and maize, with energy crops on an ongoing basis, even if they have claimed to be aware that currently oilseeds market price is higher than grain price.

Thirdly other renewable energy sort (*e.g.* solar and wind energies) are viewed as better than bioenergy because they could be used more easily for self-use. In recent years regional available subsidies were aimed at installing small photovoltaic systems and wind turbines, even if they were not used directly by farmers. This is a not encouraging situation for farmers who have highlighted to be in a disadvantageous position compared to other stakeholders.

Finally farmers often have not suitable machinery for growing energy crops farming operations supporting crop risks totally. This has represented a difficulty when farmers have not achieved a good production level or they have not harvested at all since they have suffered an economic loss.

Industrial companies. The main interest of industrialists is to obtain the raw material needed for feeding the plants. In the Nurra area, the promotion of rapeseed and cardoon with farmers was oriented to achieve industrial needs related to the growing market demand of non fossil fuels and biomaterial productions. In order to arouse farmers' interest in the Nurra region, they made an agreement where the withdrawal price of rapeseed was specified on the basis of market quotation In the case of cardoon, the agreement between farmers and the industrial company specified inputs prices. In the Arborea region, industrialists have agreed with farmers for a yearly payment and the access to the thermal energy produced in the biodigester that is used in the farms for animal feed and water heating. Therefore, according to the industrialists' perspectives, they are balancing their stakes with those of other farmers, while, at the same time, promoting environmental-friendly purposes such as natural resources conservation (*e.g.*, cardoon is advertised as a crop with especially low agronomic input requirement including low water demand).

Institutions. Representatives of Regional Council and of Regional Agricultural Department have underlined a lack of programming and promotion initiatives in favour of energy crops and bioenergy systems development. This is considered of outmost relevance in order to identify possible economic interests and benefits among

stakeholders, especially for farmers who intend to cultivate energy crops and for industrialists who intend to process them.
Although no direct incentives for energy crops were dedicated in the past Rural Development Plans as well as in other regional policies, the Regional Administration demonstrated interest on energy crops systems through funding some research projects on energy crops issues.

Researchers. In recent decades, energy crops have been subject of the research for the local scientific community. Specifically, they have focused on rapeseed and cardoon in order to assess the effect of different agricultural practices on crops productivity and their adaptability to local environmental conditions. During the interviews, researchers highlighted that further research is needed to fill the knowledge gaps in terms of local data on productivity of a range of different energy crops and to give responses to questions put by agricultural and industrial sectors in Sardinia.

Farmers Unions. The interest of farmers' unions in the energy sector was associated mainly to the investments in small photovoltaic plants at farm scale, rather than in the energy crops. In fact, the interviewed representatives of the farmers' unions claimed that small-scale photovoltaic plants would allow farmers to diversify their cropping systems, generating an additional income from energy cost saving and from selling the extra energy produced. They perceived potential positive impacts from energy crops development, but especially for cropping systems that could pursuit a dual purpose, both traditional and energetic goals.

3.3 Ecological constraints

It is a common opinion among stakeholders that energy crops would represent a suitable response to contrast environmental problems, offering an alternative to fossil fuels overexploitation and consequently reducing greenhouse gases (GHGs) emissions. Nevertheless, interviewed stakeholders have generally underlined that energy cropping systems would provide a small contribution compared to the magnitude and complexity of the environmental issues. Moreover, the majority of stakeholders believe that positive effects derived from bioenergy production systems could be weakened or annulled if other productive sectors do not provide their own contribution for reducing GHGs emissions and environmental pollution. Although stakeholders have generally highlighted the utility of energy crops regarding environmental issues, their willingness to play a role in the development of a bioenergy sectors was strongly linked to the potential profitability associated to energy crops cultivation and energy transformation.

The main ecological constraints arisen from each stakeholders' category are reported as follows.

Farmers. The farmers in the Nurra area, who have recently experienced energy crops cultivation, adopted a wide range of agricultural practices that had a strong influence on crops productivity, especially in the case of rapeseed. This variability was associated by farmers to their technical inexperience, but these outcomes let emerge several critical issues in the energy crops cultivation. Some farmers obtained low yields because of late seeding (between November and December), while others found difficulties to grow rapeseed if the seedbed was cloddy and stony. Some problems were also reported regarding the harvesting phase because wind could increase the losses of seed affecting yields. In order to minimize this risk, some farmers harvested during the night to increasing harvest efficiency since seeds are less dry.

Some farmers in the Nurra area believe that energy crops are a good option for enhancing crop rotation benefits due to their positive impacts on pests control and soil fertility (accumulation of organic matter for the high crop residues, improvement of soil structure due to root system types, etc.). In fact, farmers observed that rapeseed is a good preceding crop for winter cereals. Moreover, both rapeseed and cardoon are considered crops with low input requirements, able to achieve good yields even with low water availability.

Even if both rapeseed and cardoon are considered to be adapt to difficult environmental conditions (*e.g.* high temperatures and drought), most of the farmers have highlighted more interest in rapeseed compared to cardoon, beyond the favorable economic conditions, for two reasons: 1) cropping practices are more difficult for cardoon than for rapeseed and 2) achievable cardoon and rapeseed yields are seen as insufficient to satisfy the industrial demand.

Regarding the potential competition in land use between food and non-food crops, farmers have heterogeneous views, from no competition to drastic changes in the local agricultural system asset.

Industrialists. According to industrialists, no competition between food and energy crops exist in Sardinia. The rationale underlining is that many abandoned and marginal lands could be cultivated by energy crops, especially by crops with low water requirements as for example both rapeseed and cardoon are considered.

According to the representative of the seed company that played an important role in the first experiences of rapeseed cultivation in the Nurra area, this crop showed to be well adapt to the local environmental conditions and that, if grown in marginal lands, could bring about socio-economic benefits by creating new market and, in turn, new employment opportunities.

<u>Institutions.</u> The interviewed institutional stakeholders consider energy crops as a rational economic alternative for agricultural production in abandoned lands.

<u>Farmers' Unions</u>**.** They highlighted some issues regarding the cropping practices that would require to be adjusted such as the best date of sowing and harvesting for rapeseed, considering the impact of temperature on germination and emergence and of wind on seed losses, and the water availability for maize.

<u>Researchers' perspectives</u>. The risk of competition between food and non-food crops is perceived as currently limited by the increasing availability of abandoned lands that could be re-cultivated with energy crops. Moreover, they highlighted that there are not local ecological constraints for oil crops introduction in Sardinian cropping systems. Indeed, this would have positive impacts in terms of agronomic (*e.g.* crop rotation benefits), economic and production diversification. Furthermore, energy crops could provide an important contribution to combat environmental problems for example in terms of green GHGs emissions reduction, but only if the energy obtained by oilseeds is higher than the energy used during the crop cycle.

Researchers affirmed that farmers' difficulties to cultivate energy crops could depend on switching from traditional agricultural practices towards not well-known ones. With regards to rapeseed cultivation, they believe that farmers have adopted the same practices of winter grain cereals, without taking into account differences for instance in the rapeseed competition against weeds and, hence, the need of higher caution in the weed control.

Table 2 shows an attempt to attribute a degree of sensitivity to stakeholders on agro-ecological features, expressed on a scale from 1 to 3 and associated with each stakeholders category that were interviewed. This table was built on the basis of what was perceived by the working group during the interviews with stakeholders. Scores do not indicate specific position on issues under consideration, but only the level of relevance that stakeholders attributed them, leaving aside from attribute them a positive role. Summarizing similar opinions emerged from interviews. In fact, it must be underlined that, regarding production of GHGs emissions, weak sensitivity on this issue was generally expressed by stakeholders. On the other hand, significant importance was generally assigned to land use competition issue, with exception for industrialists and, partially, for farmers.

Table 2. - Sensitivity of stakeholders on agro-ecological features

Agro-ecological features	***Farmers***	***Industrialists***	***Institutions***	***Farmers' Unions***	***Cooeratives representatives***	***Agronomists***	***Researchers***
Crop rotation effects (soil fertility, pests control, etc.)	3	2	2	3	2	3	3
Crop input requirements	2	2	1	2	1	2	3
Competition for traditional cropping systems	2	1	3	3	3	3	3
Sensitivity to environmental impacts (GHGS emissions)	2	2	2	2	2	2	2
Agricultural practices	3	2	1	3	1	2	3

Legend: 1: no specific sensitivity; 2: weakly sensitivity; 3: strong sensitivity.

3.4 Institutions and policies

From farmers' perspectives, the first experiences of energy crops cultivation have been prompted by the MacSharry Reform of the Common Agricultural Policy (CAP) in 1992. In fact, it provided subsidies for oilseed crops through a direct payment per hectare (Regulation EC No. 1765/92) which persuaded farmers to grow these crops. During this period, oilseed crops were extensively cultivated in Sardinia. On the other hand, financial aid was solely granted on the basis of cultivated land, leaving aside the productivity in terms of oil seeds. This contributed to the lack of particular attention by farmers for energy crops cultivation. In fact, when the CAP aid was progressively suppressed energy crops were abandoned and afterwards farmers did not reveal other specific interest regarding energy crops cultivation up to the attempt to cultivate rapeseed described above, except for someone that received the subsidy provided by Regulation EC No. 73/2009. This regulation established a specific support to farmers who adopted a two-years crop rotation based on interchange between autumn winter cereals and crops that improve soil fertility such as oilseed crops in the same area. However, difficulty in compliance to these requirements limited the possibility to access to this support.

The current institutional and regulatory framework for the interviewed farmers is primarily represented by the Rural Development Programme (RDP) 2007-2013 that does not include any specific measure regarding energy crops. However, the RDP included subsidies for renewable energy production with special reference to photovoltaic plants. In the next programming period 2014-2020, the regional policy have to adapt to the European norms related to climate change and energy package by 2020 (Directive 2009/29/EC) through a simplification of licensing procedures for renewable energy production such as installation of wind and photovoltaic plants for self-use energy production. Therefore, investments for energy crops are still lacking.

The stakeholders involved in the analysis highlighted contrasting positions about the role of institutions and policies should play in fostering energy crops development in Sardinia. In terms of expectations and suggestions, someone hopes for a regional plan of financial incentives for energy crops whereas others hope for policies that guarantee minimum prices for energy crops products. Furthermore, some suggestions were aimed at providing land zoning in order to individuate areas suitable to energy crops cultivation and, at the same time, to reduce competition between food and non-food crops.

3.5 Facilitation

The experiences of energy cropping systems in the case studies areas were triggered by dissemination activity which especially involved farmers and industrialists. These activities were occurred considering the specific characteristic of the area and who were the stakeholders involved. In the case of rapeseed cultivation, a seed company representative facilitated the relationships between farmers and the industrial company interested in purchasing the oil from seeds. Some meetings were organized where information regarding cultivation contracts and withdrawal prices offered by the industrial company were discussed. However, most of the farmers had already a professional and “friendly” relationship with the seed company representative. This aspect played a crucial role in farmers’ decision on cultivating rapeseed at the conditions proposed by the industrialist company. Personal friendship was an important trigger also in facilitating the relationship between farmers and the biodigester owner in the Nurra area.

At Arborea, the high level of aggregation of farmers into cooperatives has historically facilitated shared farmers’ decision in this area. This was also the case for the realization of the biodigester plant.

All stakeholders underlined the importance of dialogue and opinions exchange because this is the best way to provide useful information and to increase awareness for farmers’ decisions. An important issue arisen during the interviews was the lack of an adequate level of training and extension service, especially among farmers of Nurra. Technical innovation, cooperation and spread of information among stakeholders are seen as more and more strategic in the future as well as a higher effort of research (university and research institutes) in order to increase technical information available for farmers.

3.6 Opportunities and threats for the development of an energy production chain based on energy crops in Sardinia

The development of a bioenergy supply-chain in Sardinia could be difficult for various reasons. Firstly, the demand of raw materials for already existing and potential new industrial plants for biomaterial and bioenergy production would be hardly satisfy with energy crops cultivation in Sardinia, leading to high amounts of raw materials imports. Secondly, there is a quite common criticism against the replacement of traditional cropping systems, based on winter cereals and forage maize, with energy crops, although many stakeholders claimed to be aware that currently oilseeds market prices are higher those of grain cereals. Thirdly, other renewable energy systems (*e.g.* solar and wind energies) are generally viewed as better than bioenergy because they could be used more easily for self-use. In recent years, regional available subsidies were aimed at installing small photovoltaic systems and wind turbines, but farmers had very few advantageous from these plants. This is a not encouraging situation for farmers who have highlighted to be in an unfavorable position compared to other stakeholders. Finally, farmers often have not suitable machineries for growing efficiently energy crops and, for farms where many operations are made by third-party contractors; there is not interest in the possibility to invest for machineries.

There is no doubt that if farmers had access to storage warehouses and processing plants - for instance managed by small farmers' cooperatives - they could see the bioenergy system with new interest. However, a more balanced arrangement between stakeholders needs is to be ensured in the future, in particular in terms of income distribution along the bioenergy-production chain. For example, in the past farmers had to pay for the transport of oilseeds to the storage site.

Several farmers claimed that it would be necessary to implement various actions in order to disseminate information about energy crops techniques and bioenergy production impacts at regional level. Some farmers underlined that it would be useful to attenuate their distrust and skepticism about bioenergy production and also to encourage them to try non-traditional crops. Regional institutions (*e.g.* extension services), farmers' unions and researchers are seen as the ones to implement these activities. Furthermore, in the farmers' perspectives, policy makers should be guarantors of the other stakeholders expectations, balancing interests among farmers, industrialists and credit institutions, but giving more attention to farmers' goals by implementing a regional programme regarding energy crops. They also claimed that regional institutions should facilitate the relationship between farmers and industrialists or at least ensure that the established agreement are respected specifically with regards to the established withdrawal prices in order to avoid speculative actions against farmers' interests.

Cooperation among farmers and other stakeholders should be fostered and strengthened, especially in Nurra, because in Arborea farmers already operate in a cooperative system. Most of the farmers believe that in order to attenuate the constraints for the development of a bioenergy chain in Sardinia, it is important to improve the relationship with farmers' unions and credit institutions. Moreover, farmers pointed out that the role of credit

institutions should be enhanced: they have not only to grant and facilitate the access to financial credit, but also to invest directly into the bioenergy chain.
In the view of the industrialists, the efficiency of the bioenergy supply-chain could be improved fostering a "culture of innovation" which, they claimed, does not exist. Specific programmes in order to foster innovation, research and development could be very useful to identify advanced and sustainable energy production systems.
According to researchers, local institutions should provide strict policy addresses for supporting bioenergy production. Furthermore, farmers' unions should be mediator between farmers and industrialists, specifically regarding the contents of agreement. Furthermore, scientific research could have some important roles within bioenergy chain because it should improve human knowledge and promote new innovative processes in this field.

4. DISCUSSION

Different studies have underlined that stakeholders' perspectives might play a critical role in order to design a framework on possibility of energy crops and bioenergy development (Rossi and Hinrichs, 2011; Stidham and Simon-Brown, 2011; Qu *et al.*, 2012; Villamil *et al.*, 2012; Mbzibain *et al.*, 2013). Generally these studies put on evidence the importance of social, institutional and farming context in conditioning bioenergy development at local farming level. In this view farmers' perspectives analyses have given relevant information on potential opportunities in introducing these crops (Rossi and Hinrichs, 2011; Ostwald *et al.*, 2013). These researchers have found local specific outcomes; therefore any generalization can be accurately done.
In our study, Sardinian farmers' choices appear to be mainly conditioned by market opportunities and policy and institutional support (Figures 3 and 4).

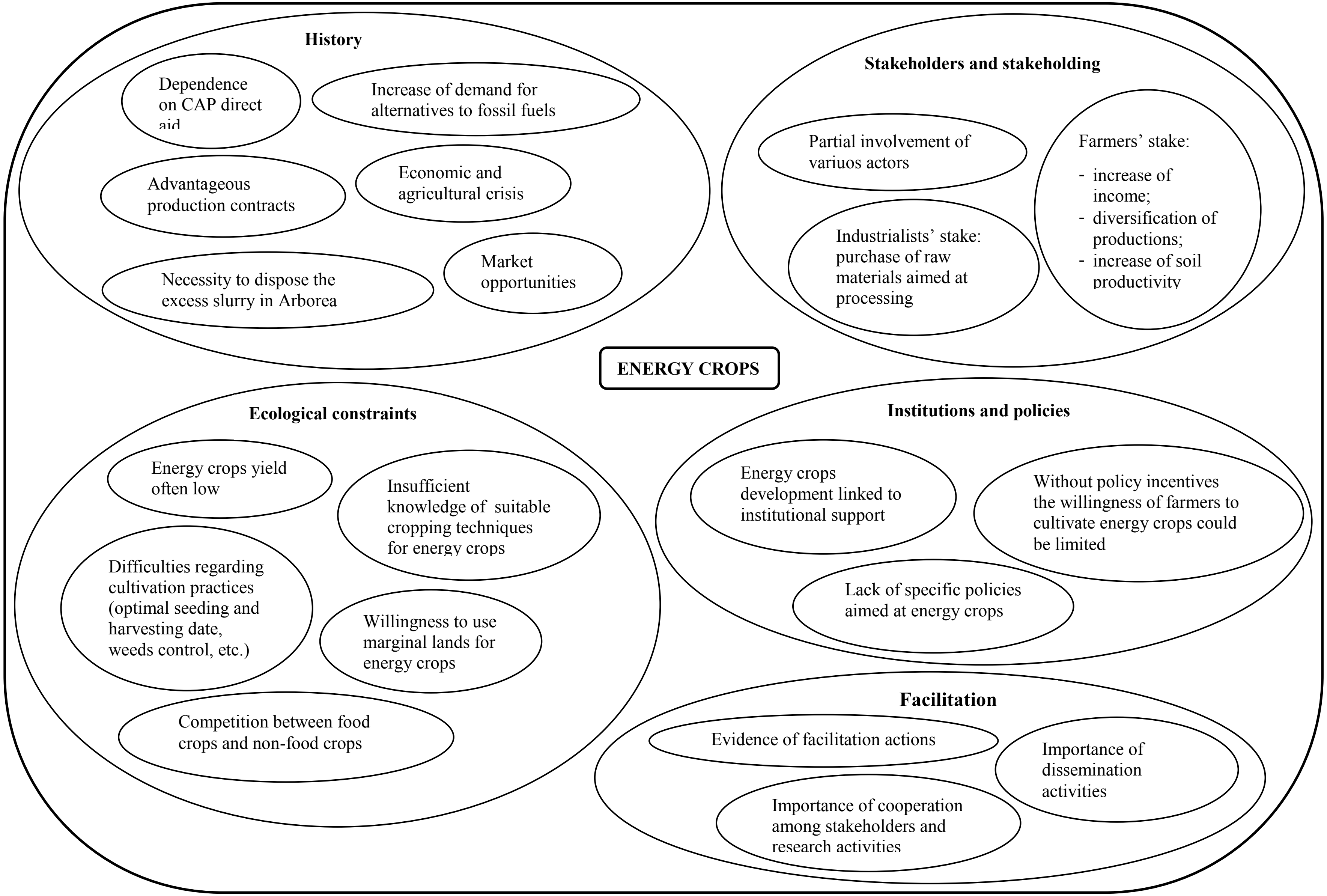


Figure 3 - Systems map about strategic factors for energy crops development in Sardinia according to stakeholders' perspectives

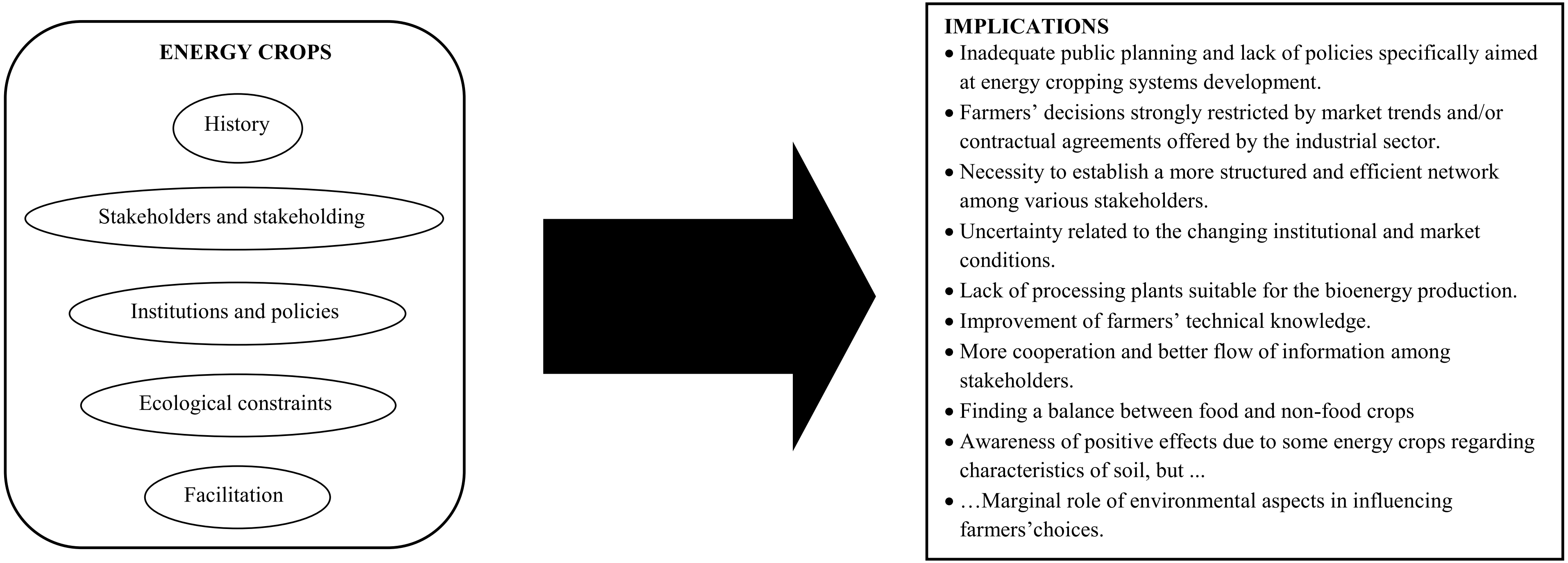


Figure 4 - Implications emerged from the stakeholders' perspectives analysis for the energy crops development in Sardinia

Energy crops cultivation will become a rational alternative with respect to traditional farming only in case that farmers can achieve economic convenience in producing it. However, uncertainties exist due to high volatility of market and institutional conditions. Possible development of rapeseed and cardoon cultivation will not leave aside from setting long term and favorable conditions for farmers on withdrawal prices of raw materials to industrialists in order to achieve profitability. In the case of production of biomass for biodigesters, their use for energy production has important consequence in terms of market price due to potential increase of demand. This is a relevant issue in the case of farming products that can be addressed both to satisfy food and energy needs such as maize. A potential risk associated to an increase of maize demand for biodigester might be represented by a consequent increase of prices of a certain product leaving aside its market destination. Therefore, in the case of maize, it might imply not only higher selling prices and thus higher revenues for who produce it for energy scope, but also higher costs for who use local maize for feed.

On the other hand, the lack of specific regional normative about energy crops actually does not incentive farmers to invest in energy cropping systems. Stakeholders agree to the past experiences recorded at local scale, especially regarding oilseed crops, have occurred due to favorable policies measures that fostered farmers to cultivate energy crops, but this incentivizing institutional contest is so far to be perceived today by farmers and other stakeholders.

It must be underlined that only some categories of stakeholders have participated to develop local bioenergy supply chains in Sardinia. In this contest institutions and farmers' unions can play a strategic role in aggregate all possible actors into a productive environment characterized, especially in Nurra, by farmers' preponderance individualism. On the contrary, the cooperative environment in Arborea has fostered a high level of participation and sharing among stakeholders.

However, on the basis of stakeholders' perspectives, bioenergy production would entail multiple benefits for farmers in terms of additional income, energy self-sufficiency, improvement of chemical-physical characteristics of the soil. Furthermore, energy crops cultivation could be an opportunity of using lands which otherwise would remain uncultivated. In this sense, the competition between food crops and energy crops would be reduced.

According to this perspective, rapeseed is not generally considered a threat for traditional cropping systems but it is viewed as an additional crop with respect to the traditional ones. At the same time, if cardoon is practiced in the marginal lands it could represent another positive alternative for farmers, although some doubts exist by part of farmers about cardoon, in particular about its yield and the crop technique. The energy crops are also considered by stakeholders an efficient reaction to the local phenomenon of rural areas abandonment and consequently a correct alternative to value marginal lands in economic terms.

A lack of findings and information characterizes literature on motivations that lead farmers to introduce bioenergy crops and especially, on the role of environmental issues in conditioning their choices and stakeholders' perspectives (Ostwald *et al.*, 2013). However, contrarily to other similar researches (Perrotti, 2011; Rossi and Hinrichs, 2011), it is appeared as a common opinion that environmental impacts of bioenergy is not a critical factor that stakeholders take into account in the decision to practice these crops. Generally, according to stakeholders agriculture and livestock do not play a remarkable role in producing negative environmental externalities (*e.g.* greenhouse gases emissions) both at local and global scale. Energy crops practice could indirectly even minimize these impacts because this sort of crops is functional to bioenergy production. In other terms, energy crops cultivation represents a preparatory phase into the bioenergy supply chain and in this sense it contributes to reduce use of fossil fuels with positive environmental implications.

Furthermore, in case of use of slurry for biodigester, it is common opinion that it produces a meaningful reduction of pollution phenomena. On the other hand, in farmers' opinion these implications appear to be non influential in conditioning farmers' choices on adopting energy crops. In others words, although they admit the benefit of bioenergy to face some environmental issues such as GHGs emissions, pollution also due to fossil fuels, they consider more important economic aspect.

5. CONCLUSIONS

This paper aimed to put on evidence the strategic factors that could effects energy crops development in Sardinia. A stakeholders' perspectives analysis was applied to this objective. In this sense SLIM framework is revealed to be particularly suitable for this finality due to inherent presence of complexity, uncertainty, interdependencies and controversy features that characterize this research issue. Indeed agronomic, social, economic, institutional and environmental aspects all contribute to define the complexity of energy cropping systems development. In the light of the interviewed stakeholders' perspectives, the development of energy cropping systems can depend on several reasons that represent uncertainty factors and reflect perspectives of involved stakeholders such as:

- price market instability regarding agricultural input and output;
- change in institutional and policy contest;
- environmental effects derived from a widespread cultivation of energy crops in terms of competition between food e non-food crops and reduction of GHGs emissions;
- reduction of dependence from fossil fuels;
- economic (first of all) and environmental) sustainability of bioenergy production in Sardinia in a long run.

It is evident that the possible adoption of energy crops into cropping systems can affect ecological processes. This interdependency can change use of resources in a long term and perspectives of stakeholders regarding the issue. Furthermore different perspectives and perceptions can move un-coordination and contradiction among stakeholders. For example, goals of management can differ between farmers and industrials, most of all regarding sustainability of practices in a long run and economic convenience to cultivate energy crops. However, it is a common opinion that the agricultural sector should be put in condition of practice energy crops and it would be possible to achieve an agreement between farmers and industrialists in order to avoid distortions of local productions and safeguard the farmers' economic interests. Moreover, it would be desirable in a future perspective that first of all at institutional level it is planned a specific normative about energy crops and bioenergy production. Indeed it would need rules that specify the role of all stakeholders involved without anyone is advantaged. Furthermore, information and specific studies should be disseminated regarding for instance cultivation technique, availability of incentives and the conditions to practice these crops in order to minimize the land use competition (*e.g.* what sort and how much land is it possible to occupy?) and so to foster a correct development of a bioenergy supply-chain and so the farmers' choices. In this context research could provide a meaningful contribute, even if the best condition should be that all stakeholders are involved in the decision making processes in order to attain the common welfare of territory. In this sense since farmers would play a crucial role in this supposed bioenergy supply chain as producer of biomass, future research should examine farmers' category in order to identify different behavioural profiles based on factors which they consider the most strategic regarding to energy crops adoption in own cropping systems.

REFERENCES

1. Afionis S., Stringer L. C., 2012. European Union leadership in biofuels regulation: Europe as a normative power? Journal of Cleaner Production 32, 114-123.

2. Anderson M. W., Teisl M., Noblet C., 2012. Giving voice to the future in sustainability: Retrospective assessment to learn prospective stakeholder engagement. Ecological Economics 84, 1-6.

3. Blackmore C., 2007. What kinds of knowledge, knowing and learning are required for addressing resource dilemmas? - a theoretical overview. Environmental & Policy 10, 512-525.

4. Commission of the European Communities, 2010. The CAP towards 2020: Meeting the food, natural resources and territorial challenges of the future. Communication from the Commission COM (2010) 672 final.

5. Commission of the European Communities, 2011. Proposal for a regulation of the European Parliament and of the Council on support for rural development by the European Agricultural Fund for Rural Development (EAFRD), SEC(2011) 1153, SEC(2011) 1154, COM(2011) 627 final.

6. Collins K., Blackmore C., Morris D., Watson D., 2007. A systemic approach to managing multiple perspectives and stakeholding in water catchments: some findings from three UK case studies. Environmental Science & Policy 10, 564-574.

7. Commission of the European Communities, 2009a. White Paper. Adapting to climate change: Towards a European framework for action, SEC(2009) 386, SEC(2009) 387, SEC(2009) 388, COM(2009) 147 final, Brussels.

8. Commission of the European Communities, 2009b. Commission Staff Working Document accompanying the White Paper. Adapting to climate change: Towards a European framework for action. Adapting to climate change: the challenge for European agriculture and rural areas, SEC(2009) 417, COM(2009) 147 final, Brussels.

9. Deligios P. A., Farci R., Sulas L., Hoogenboom G., Ledda L., 2013. Predicting growth and yield of winter rapeseed in a Mediterranean environment: Model adaptation at a field scale. Field Crops Research 144, 100-112.

10. Diaz-Chavez R. A., 2011. Assessing biofuels: Aiming for sustainable development or complying with the market? Energy Policy 39, 5763-5769.

11. Edenhofer O., Madruga R. P., Sokona Y., Seyboth K., Matschhoss P., Kadner S., Zwickel T., Eickemeier P., Hansen G., Schlömer S., von Stechow C., 2012. Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, pp.1076.

12. EEA, 2010. The European environment - state and outlook 2010: synthesis. European Environment Agency, Copenhagen, pp. 222.

13. Erb K.-H., Haberl H., Plutzar C., 2012. Dependency of global primary bioenergy crop potentials in 2050 on food systems, yields, biodiversity conservation and political stability. Energy Policy 47, 260-269.

14. Escobar J. C., Lora E. S., Venturini O. J., Yáñez E. E., Castillo E. F., Almazan O., 2009. Biofuels: Environment, technology and food security. Renewable and Sustainable Energy Reviews 13, 1275-1287.

15. European Commission Directorate-General for Agriculture and Rural Development, 2008. Climate change: the challenges for agriculture. Fact Sheet, European Communities, pp. 35

16. GBE, (2011). The global bioenergy partnership sustainability indicators for bioenergy. Global Bionergy Partnership Secretariat, Food and Agricultural Organization of the United Nations (FAO) Climate, Energy and Tenure Division, Rome, Italy, pp. 202.

17. González-García S., García-Rey D., Hospido A., 2012. Environmental life cycle assessment for rapeseed-derived biodiesel. Int J Life Cycle Assess 18, 61-76.

18. González-García S., Bacenetti J., Negri M., Fiala M., Arroja L., 2013. Comparative enviromental performance of three different annual energy crops for biogases production in Northern Italy. Journal of Cleaner Production 43, 71-83.

19. Iglesias, A., Avis, K., Benzie, M., Fisher, P., Harley, M., Hodgson, N., Horrocks, L., Mone, M., Webb, J., 2007. Adaptation to Climate Change in the Agricultural Sector. Report to European Commission Directorate – General for Agriculture and Rural Development. AEA Energy & Environment and Universidad de Politécnica de Madrid, AGRI-2006-G4-05, ED05334 – Issue 1, pp. 138.

20. Ison R., Röling N., Watson D., 2007. Challenges to science and society in the sustainable management and use of water: investigating the role of social learning. Environmental Scienze & Policy 10, 499-511.

21. Johnson, T.L., Bielicki, J.M., Dodder, R.S., Hilliard, M.R., Ozge Kaplan, P., Andrew Miller, C., 2013. Advancing Sustainable Bioenergy: Evolving Stakeholder Interests and the Relevance of Research. Environmental Management 51, 339-353.

22. Madau F., 2010. Aspetti economici dell'agricultura irrigua in Sardegna. Rapporto Irrigazione, INEA. Quintily Grafica s.r.l., Roma, pp. 90.

23. Mangoyana R. B., Smith T. F., Simpson R., 2013. A systems approach to evaluating sustainability of biofuel systems. Renewable and Sustainable Energy Reviews 25, 371-380.

24. Matei M., Stancu A., Vukovic P., 2009. The Interdipendence between Agriculture and Climate Change. A European Perspective. Paper presented in the 113th EAAE Seminar, Belgrade, Dicember 2009, pp. 11.

25. Mbzibain A., Hocking T. J., Tate G., Ali S., 2013. Renewable enterprises on UK farms: Assessing levels of uptake, motivations and constraints to widespread adoption. Biomass and Bioenergy 49, 28-37.

26. Nguyen T. P. L., Seddaiu G., Roggero P. P., 2013. Hybrid knowledge for understanding complex agri-environmental issues: nitrate pollution in Italy, International Journal of Agricultural Sustainability, 1-19.

27. Olesen J.E., Trnka M., Kersebaum K.C., Skjelvag A.O., Seguin B., Peltonen-Sainio P., Rossi F., Kozyra J., Micale F., 2011. Impacts and adaptation of European crop production systems to climate change. Europ. J. Agronomy 34, 96–112.

28. Ostwald M., Jonsson A., Wibeck V., Asplund T., 2013. Mapping energy crop cultivation and identifying motivational factors among Swedish farmers. Biomass and Bioenergy 50, 25-34.

29. Perrotti D., 2011. Agro-energy production as a driving force in the socio-ecological transition of rural environments: a significant case study within the Alta Murgia National Park. Paper published in 10th International Conference of Territorial Intelligence, Liège 2011., Liège: Belgium (2011).

30. Qu M., Ahponen P., Tahvanainen L., Gritten D., Mola-Yudego B., Pelkonen P., 2012. Practices and perceptions on the development of forest bioenergy in China from participants in national forestry training corse. Biomass and Bioenergy 40, 53-62.

31. Reed, M.S., 2008. Stakeholder participation for environmental management: A literature review. Biological conservation 141 (10), 2417-2431.

32. Roggero P. P., Seddaiu G., Toderi M., 2006. Stakeholder Analysis for Sharing Agro-environment Issues Towards Concerted Action: a Case Study on Diffuse Nitrate Pollution. Ital. J. Agron. / Riv. Agron. 4, 727-740.

33. Roggero, P.P., Bagella, S., Deligios, P., Ledda, L., Gutierrez, M., 2010. Gestione dell'abbandono dei seminativi italiani in aree svantaggiate. In: Proceedings of the "Giornata di studio: Situazione dei seminativi nel quadro dell'agricoltura italiana". Accademia dei Georgofili ed., Firenze, Italy, pp. 147-173.

34. Rossi A. M., Hinrichs C. C., 2011. Hope and skepticism: Farmer and local community views on the socio-economic benefits of agricultural bioenergy. Biomass and Bioenergy 35, 1418-1428.

35. Sala S., Farioli F., Zamagni A., 2013. Progress in sustainability science: lessons learnt from current methodologies for sustainability assessment: Part 1. Int J Life Cycle Assess. 18 (9), 1653-1672.

36. Scarlat N., Dallemand J.F., Motola V., Monforti-Ferrario F., 2013. Bioenergy production and use in Italy: Recent developments, perspectives and potential. Renewable Energy 57, 448-461.

37. SLIM, 2004. SLIM framework: Social Learning as a policy approach for sustainable use of water. A field-tested framework for observing, reflecting and enabling. pp.43.

38. Steyaert, P., Jiggins, J., 2007. Governance of complex environmental situations trough social learning: a synthesis of SLIM's lessons for research, policy and practice. Environmental Science & Policy 10, 575-586.

39. Steyaert P., Barzman M., Billaud J.-P., Brives H., Hubert B.,, Ollivier G., Roche B., 2007. The role of knowledge and research in facilitating sociallearning among stakeholders in natural resources management in the French Atlantic coastal wetlands. Environmental Science & Policy 10, 537-550.

40. Stidham M., Simon-Brown V., 2011. Stakeholder perspectives on converting forest biomass to energy in Oregon, USA. Biomass and Bioenergy 35, 203-213.

41. Tait J., 2011. The ethics of biofuels. GCB Bioenergy 3, 271-275.

42. vanDam J., Junginger M., 2011. Striving to further harmonization of sustainability criteria for bioenergy in Europe: Recommendations from a stakeholder questionnaire. Energy Policy 39, 4051-4066.

43. Villamil M. B., Alexander M., Silvis A. H., Gray M. E., 2012. Producer perceptions and information needs regarding their adoption of bioenergy crops. Renewable and Sustainable Energy Reviews 16, 3604-3612.

44. Zegada-Lizarazu W., Elbersen H. W., Cosentino S. L., Zatta A., Alexopoulou E., Monti A., 2010. Biofuels, Bioprod. Bioref. 4, 674-691.

CHAPTER 2

Analysis of farmers' perspectives about the environmental impacts of energy crops through the multiple correspondence approach

Abstract

The promotion of bioenergy production is commonly justified by the belief that they can contribute to mitigate greenhouse gases (GHGs) emissions. On the other hand, some agro-environmental issues are recognized as negatively associated to bioenergy chains such as possible land-use competition between food and energy crops. It is a fact that these controversial agro-environmental implications are not often address according to farmers' perspectives and this could limit the energy crops systems development at local scale. The aim of this study was to analyze farmers' profiles in relation to their perspectives on possible agro-environmental impacts caused by energy crops cultivation in Sardinia and on the extent to which these perspectives could influence farmers' willingness to grow these crops in the future. Specifically, we focused our analysis on farmers who experienced energy crops cultivation. Basically, the reduction of GHGs emissions and the land use competition derived by switching from traditional to energy crops were the two agro-environmental impacts here considered. Farmers' profiles were analyzed through the application of the Multiple Correspondence Analysis. We found that perspectives on positive agro-environmental effects associated to energy crops cultivation are strongly related to an optimistic farmers' attitude about the possible re-energy crops introduction into local cropping systems. This suggests that environmental impacts might not represent constraint factors in farmers' decision to introduce energy crops in their farming systems.

Keywords: energy crops, farmers' perspectives, Multiple Correspondence Analysis, GHGs emissions, land use competition.

1. INTRODUCTION

Generally one of the rationale for promoting bioenergy production and for fostering energy crops development is based on understanding that they can contribute to mitigate greenhouses gases (GHGs) emissions (Muller 2009; Fritsche *et al.*, 2010, Fernando *et al.*, 2010; Don *et al.*, 2011). It is expected that carbon emitted in form of CO_2 from combustion is more than balanced by carbon fixed in photosynthesis associated to energy crops cultivation. On the other hand, several authors have underlined that this is a simplified rationale because GHGs are also emitted during crop growth and their associated processes such as farm management, feedstock, transport, etc. (Popp *et al.*, 2011; Stavi and Lai, 2013). In addition, other gases beyond CO_2 can be emitted by farming systems (*e.g.*, nitrous oxide and methane) and energy crops cropping systems do not represent an exception (Don *et al.*, 2011).

However, at local scale, the extent to which energy crops could play a significant role in reducing GHGs emissions depends on how widespread is the possible conversion of land from traditional or food crops to energy crops. In other terms, for understanding the impact of energy crops in mitigating environmental effects is relevant to assess the impact of - direct and indirect - land use changes due to the conversion of traditional cropping systems to energy crops (Fritsche *et al.*, 2010; Osborne and Jones, 2012).

The potential competition between food and energy (or non food) crops has been and is still an important issue widely argued by scientists, policy makers and other institutions throughout the world (World Bank, 2008; FAO, 2008; OECD-FAO, 2008). This is because the strategic objective to expand the bioenergy production needs to a consequent enlargement of new arable land or a substitution of lands covered by food crops with energy crops (Hellmann and Verburg, 2010; Rathmann *et al.*, 2010; Popp *et al.*, 2011, Harvey and Pilgrim, 2011; Murphy *et al.*, 2001).

On the other hand, the environmental implications of energy crops cultivation are not often managed according to local rural stakeholders perspectives and, particularly, to local farmers' views and goals. As put on evidence by Rossi and Hinrichs (2011), farmers usually tend to be seen instrumentally by policy makers, as they are considered ready and unquestioning providers concerning the adoption of energy crops. Vice versa they should be recognized as key rural actors with their needs, views and perspectives that need to be analyzed and understood prior to any local initiative oriented towards the energy crops development at local level (Rossi and Hinrichs, 2011; Villamil *et al.*, 2012). This implies that energy crops development need to be based on farmers (and generally stakeholders) participation and promoted, on the one side, taking into account farmers perspectives on the overall potential impacts of energy crops and, on the other side, fostering a better understanding by farmers on the contribution of energy crops systems for revitalizing rural areas economy and protecting the environment. As underlined by Paulrud and Laitila (2010), policy makers must have information on how farmers value the role characteristics of energy crops in order to develop strategies and incentives aimed to promote their cultivation.

In Sardinia (Italy), farmers located in the geographic region of Nurra (North-western Sardinia) experienced the cultivation of energy crops - specifically rapeseed (*Brassica napus* var. *oleifera* D.C.) - in 2009. Because of several reasons (*e.g.* scarce technical knowledge on rapeseed requirements and agricultural techniques, logistic difficulties, etc.) this attempt failed and nowadays energy crops are rarely cultivated in this area. However a latent demand exists by part of farmers and geographical and agronomic characteristics of arable land in the region appear suitable for this energy crop cultivation (Deligios *et al.*, 2013).

The main research questions we wanted to address were: “Which is the farmers’ degree of willingness to introduce energy crops in their farming systems?” and “Are the farmer’ perceptions on the agro-environmental impacts of energy crops relevant for influencing their willingness to grow these crops?”

In the light of these considerations, an important research question concerns knowledge of farmers’ perspectives on possibility of future development of energy crops at local level and on environmental effects caused by these crops. This in order to individuate possible farmers’ profiles able to perceive both positive environmental effects caused by energy crops growing and good possibility of development for the sector.

The aim of this paper was hence to analyze farmers’ profiles according to their perspectives on potential agro-environmental impacts of energy crops cultivation in Sardinia and which factors, considering structural, productive and behavioural factors, are mostly associated to the emergence of these perspectives. In particular, we carried out a survey on a sample of farmers located in the Nurra case study area who have cultivated energy crops in the past in order to evaluate the relationship between their beliefs on the possible re-introduction of energy crops in their cropping systems and their perspectives on agro-environmental effects of these crops. Basically two agro-environmental effects were taken into account: reduction of produced GHGs emission and possible competition in land use derived by substitution of traditional crops with energy crops.

A Multiple Correspondence Analysis (MCA) was applied in order to analyze farmers’ profiles and to evaluate the relationship between different factors and willingness to grow energy crops in the future. MCA and similar approaches have been widely used in agricultural studies for individuating farmers’ profiles according to their objectives and/or to their perspectives on specific issues (Solano *et al.*, 2000, 2001a, 2001b; Siegmund-Schultze and Rischkowsky, 2001; Thenail, 2002; Moreno Peréz *et al.*, 2011).

2. MATERIALS AND METHODS

2.1 The Multiple Correspondence Analysis

MCA is a methodology able to analyze the pattern of relationships among many categorical dependent variables (Abdi and Valentin, 2007; Blasius *et al.*, 2009; Greenacre, 2010). In the MCA, a set of observations is described by a set of nominal variables and each variable can be articulated in more levels. Each level is represented by a binary form (0 or 1). However it deals with both qualitative and quantitative data, taking into account that quantitative data might be transformed into classes (Greenacre, 2010).

Factors scores are attributed to each observation and to each category with the objective to represent relative frequencies of distances between individual rows and/or columns in a low-dimensional space (Abdi and Valentin, 2007; Blasius *et al.*, 2009). For this reason, MCA is also view as a generalization of principal components analysis with qualitative (categorical) variables.

A standard correspondence analysis on an indicator matrix (J_k x M) is used in order to apply MCA, where J_k is the vector of the levels for each K nominal variable (with $\sum J_k = J$), and M is the number of observations. Two sets of factors scores are provided by performing MCA on the matrix. These - for the rows and for the columns respectively - are generally scaled as to allow their variance to be equal to the corresponding eigenvalue (λ).

It must be specified that proximities are meaningful only between points from the same set (*i.e.,* rows with rows, columns with columns). Two cases can be individuated: 1) the proximity between levels of different nominal variables means that these levels tend to appear together in the observations; 2) the levels of the same nominal variable cannot occur together, the proximity between levels means that the groups of observations associated with these two levels are themselves similar.

MCA was performed using the SAS© 9.0 software.

2.2 The case study

MCA was applied on a sample of 15 farms located in the Nurra case study area in the North-East of Sardinia, Italy (Figure 1). The Nurra area is characterized by a range of different farming systems. A great part of the farms is dedicated to sheep livestock and arable lands are mostly dedicated to grazing (Table 1). These farms dimension, on average, is greater than the Sardinian mean sheep farms both in terms of land size and in terms of number of sheep (Madau, 2010). Also cereals (*e.g.*, wheat, corn, barley and oats) are widely cultivated despite a strong reduction that has occurred in the last decades and their relatively low incidence on total arable land basis. Furthermore, horticulture, grape-growing and olive-growing represent important and dynamic farming activities in this region.

Figure 1 - Aerial photograph of the Nurra area. Flags represent the locations of the sampled farms

Our survey was carried out on a sample of farms that in the recent past have attempted to cultivate rapeseed for energy production. This crop is currently almost absent in the cropping systems in Nurra and in Sardinia. The choice to grow rapeseed in 2009 was driven by economically convenient withdrawal prices offered by industrial producers for purchasing rapeseed as raw material for biofuel production. This was possible due to affordable market prices of this energy crop since 2009. These advantages progressively decreased in the following years and hence farmers decided to abandon the rapeseed cultivation because of its scarce profitability and of some technical and logistic problems (see chapter 1 of this dissertation).

The rationale of the choice to carry out the survey considering this sample of farmers is related on the belief that they were likely more aware and skilled for evaluating the agro-environmental implications associated to the introduction of rapeseed, or other energy crops, in cropping systems than farmers who did not make this experience.

Table 1 - Percentage of cultivated area for different cropping systems in the Nurra area (data are referred to the year 2011)

Cropping system	Incidence in terms of arable land
Cereals	2.1%
Legumes	0.1%
Potatoes	0.2%
Vegetables	1.2%
Energy and industrial crops	-
Fruit trees	0.1%
Citrus fruits	0.1%
Vines	1.4%
Olive trees	2.1%
Pastures	83.6%
Annual forages	6.7%
Meadows	1.6%
Other	0.9%
Total	**100.0**

Source: ISTAT (2013)

Fifteen semi-structured interviews were carried out in 2012 through farm visits. They were focused on getting both quantitative and qualitative information about farms and farmers' characteristics. A summary of the main farmers and farms characteristics of the studied sample are reported in Table 2.

MCA was applied on the following variables:

- Opinion on energy crops effects on land use competition;
- Opinion on energy crops effects on greenhouse gases emission;
- Opinion on adopting energy crops in the future;
- Age of farmer;
- Farm size (land area);
- Cultivated area with rapeseed (in the past).

The first two variables serve to catch the opinions of farmers regarding possible agro-environmental effects derived by energy crops cultivation in the next future. Both variables can assume two levels: high impact or low impact (Table 3).

The third variable represents farmer's perspectives on future cultivation of energy crops. It was selected in order to take into account if a positive perspective on agro-environmental effects is associated to a positive attitude towards growing energy crops in the future. Also this variable varies according to two levels: good and bad perspectives.

The other variables were selected in order to evaluate how agro-environmental perspectives are associated to age of farmers, to overall size of farms and to the size of the cultivated area with rapeseed in the past. These latter variables vary according to two levels.

Table 2 - Main structural characteristics of the studied farms

Characteristics	Values
Structural characteristics	
Farm arable land (ha)	81.1 ha (min 16 ha; max 200 ha)
Age of farmers	≥ 50 years old: 46,7% < 50 years old: 53,3%
Farmer-land relationship	Landowner: 73.3%; Tenant: 13.3%; Mixed: 13.3%
Main production	Cereals: 60.0%; Cerals-livestock: 20.0%; Livestock. 6.7% Others: 13.3%
Rapeseed cultivation (past experience)	
Land covered by rapeseed (ha)	16.7 ha (min 4.5 ha; max 43 ha)
Grain yield ($t\ ha^{-1}$)	960 $t\ ha^{-1}$ (relative to 13 farms*)

*Rapeseed was not harvested in two farms in 2009

Table 3 - Selected variables and their levels

Variable	Category	Variable code
Opinion on energy crops effects on land use competition	Low impact = 0 High impact = 1	CompetN CompetY
Opinion on energy crops effects on greenhouse gases emissions	Low impact = 0High impact = 1	GHGN GHGY
Opinion on adopting energy crops in the future	Not positive = 0 Positive = 1	FutUseN FutUSeP
Age of farmer	≥ 50 years old = 0 < 50 years old = 1	Age1 Age2
Farm size	< 60 hectares = 0 ≥ 60 hectares = 1	Size1 Size2
Cultivated area with rapeseed (in the past).	< 10 hectares = 0 ≥ 10 hectares = 1	RapSize1 RapSize2

Concerning the age we individuated the over and under 50 years old farmers' categories whereas relatively to farm size we distinguished farms equal or larger than 60 hectares from farms smaller than 60 hectares. In the case of land cultivated by rapeseed in the past, the threshold was fixed at 10 hectares.

3. RESULTS

The sum of the two first eigenvalues was 55.9%, therefore more than half of total variability was explained by the first two dimensions (Figure 2). The first dimension (λ = 29.7%) separated farmers who think that energy crops can be cultivated in the next future from who affirm that these crops could not generate any reduction in GHGs emissions and that a certain degree of potential competition in the land use could be determined by rapeseed. In other words, according to this dimension, positive environmental effects of energy crops are perceived by farmers who also believe that opportunities for the development of energy crops systems in Sardinia exist.

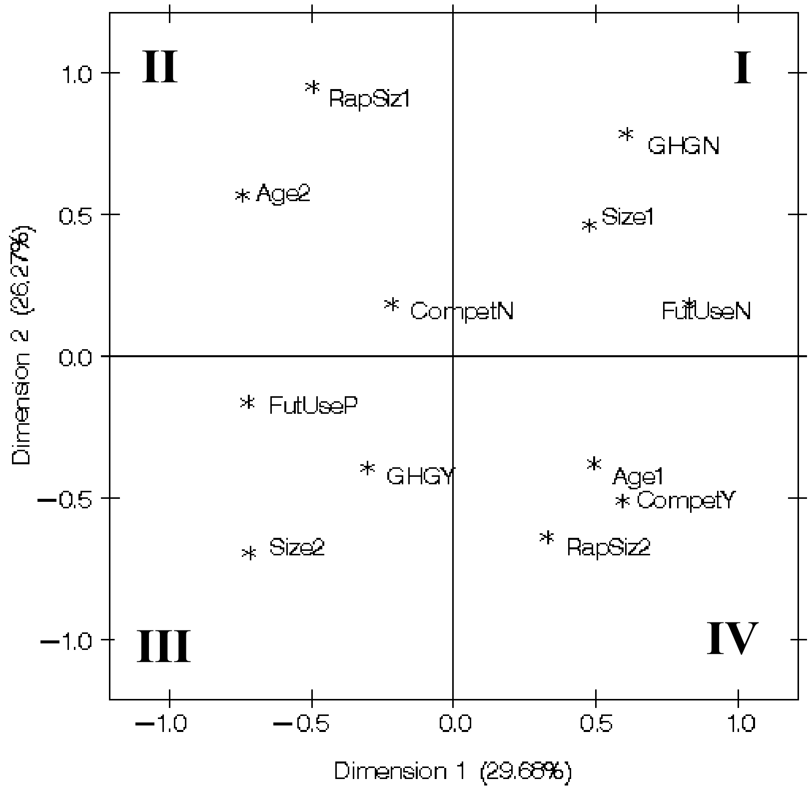


Figure 2 - Multiple Correspondence Analysis results

Furthermore, this dimension collocates in the same direction who considers energy crops development as a good opportunity with who operates in greater farms (in terms of arable land) and with younger farmers.

The second dimension (λ = 26.2%) separates farmers who operate in greater farms and that in the past grew energy crops in larger areas from the others. Along this dimension, farmers who think that energy crops could generate significant positive effects in terms of GHGs emissions and farmers who believe that these crops could cause land competition were located together.

Relatively to the agro-environmental variables, MCA results suggest that perceptions of positive effects for GHGs emissions are strongly related to positive farmers' attitudes to grow these crops in the future. Similar relationship was found between the willingness towards future energy crops cultivation and the belief of no land use competition. These relationships depend on proximity of the category FutUseP to both environmental categories GHGY and CompetN, implying that these categories are correlated.

On the basis of the MCA findings, four different farmer's profiles can be individuated, each one represented by the levels of the different variables in each quadrant of the bi-plot.

It must be underlined that profiles described by I and II quadrants are opposite to the profiles in the III and IV quadrants. This depends on the inherent characteristics of MCA and it indicates that no proximity between levels of the same variable was found. Therefore, the selected variables and their categories result to be representative of non-homogeneity between observations.

The first profile (I quadrant) is represented by farmers with smaller farm size. In their perspectives, any positive environmental effects in terms of reduction of GHGs emissions associated to energy crops cultivation is expected. At the same time, they seem to be skeptical regarding a future development of energy crops in Sardinia.

The second profile (II quadrant) is represented by younger farmers. In the past, they cultivated a small portion of their farm with rapeseed. On the other hand, they claimed that any competition might exist between energy crops and traditional crops.

The third profile (III quadrant) individuates farmers who operate on larger farms. This farmers' category is optimistic for energy crops development in the next future and they think that energy crops can be beneficial to the environment due to their contribution in reducing GHGs emissions.

The last profile (IV quadrant) is represented by older farmers. They had cultivated rapeseed on large lands in the past and in their opinion energy crops might produce land competition.

4. DISCUSSION

MCA or similar approaches have been applied by several authors in order to put on evidence farmers' characteristics and/or perspectives in relation to structural farming aspects (Moreno-Peréz *et al.*, 2011; Castel *et al.*, 2011; Maass *et al.*, 2012), and to investigate the relationship between farmers/farms' characteristics and farmers objectives (Solano *et al.*, 2000; Solano *et al.*, 2001a, 2001b; Siegmund-Schultze and Rischkowsky, 2001; Thenail, 2002). However, the association between farmers' attitudes and perceived agro-environmental impacts have been taken into account very rarely. Considering a sample of Costa Rican dairy farmers, for example, Solano *et al.* (2001a) found that environmental friendly productions is among the main objectives of farmers. MCA analysis showed that environmental friendly purposes were strictly related to risk averse by part of farmers and to hardworking.

Also in our study, MCA proved to be an adequate tool for getting an overview of the farmers' perspectives on the agro-environmental effects of energy crops in association to other structural and behaviour features. We found that positive expectations on future development of energy crops in the farming systems were associated to positive perspectives on the perceived agro-environmental effects derived by energy crops cultivation. This suggests that the enhancement of the farmers' awareness with respect to agro-environmental issues around energy crops cultivation is to be promoted since it could be a trigger factor in conditioning energy crops development in the case study area and in Sardinia. However, we admit that other factors than the perspectives on the agro-environmental impacts of energy crops cultivation could have strongly influenced farmers' attitude whether continuing to grow energy crops, *e.g.* educational level, type of practiced crops, farm income (Jensen *et al.*, 2007). Nevertheless, in this study we aimed to specifically explore the role of agro-environmental perspectives on shaping farmers' choices, and the results seem to highlight that these perspectives could be important or, at least, not constraining. It must be underlined that these perspectives concerns farmers that have practiced energy crops cultivation in the past. This means that - at least in a part of farms - other factors differently from environmental issues have prevented continuation of energy crops farming since 2009. Moreover, larger farms were found to be positively associated to good expectations for future development of energy crops in Sardinia and to positive beliefs on the role of energy crops as environmental friendly cropping systems. At policy decision level, the implications of these results could be to promote initiatives to increase public environmental awareness around bioenergy systems in order to increase the responsibility and, at the same time, the "response-ability" of the actors (*i.e.*, farmers) to take conscious decisions. The impact of these initiatives is expected to be greater for larger farms that could likely exploit more easily opportunities offered by introducing energy crops in the farming systems without completely converting from traditional to energy crops. Another important implication of promoting the propensity of bigger farms on investing in energy crops in the future is related to advantages for industrialists who could satisfy more easily the need of local amounts of biomass from energy crops by involving a fewer number of farms.

The belief about a no influential role of energy crops in affecting land use competition was found to be related to younger farmers. This can depend on several factors and we have not empirical information on the reasons at the basis of this profile. However, this result could be interpreted as associated to a greater "dynamism", higher capacity to cope with management and technical risks and higher education skills with respect to older farmers. Furthermore, it is important to highlight that younger farmers of our sample dedicated a relatively small portion of their farm area to rapeseed in the past, and this could have influenced their perspective about very marginal competition role of energy crops towards traditional cropping systems.

Another reason that could explain the perspective of any land competition might be represented by particular distribution of cropping systems in Nurra, characterized by a high incidence of grasslands. Probably these farmers view as positive or at least non negative the effects arisen from land substitution because it might reduce this incidence in favour of more profitable practices such as energy crops without significant impact by an agronomic, landscape or productive point of view at territorial scale.

5. Conclusions

Our analysis highlighted that perspectives on positive environmental effects caused from energy crops - specifically reduction in GHGs emission and no land competition due to switching from traditional crops towards energy crops - are strongly related to positive farmers' expectations on possible re-introduction of energy crops into local cropping systems. This suggests that, perceived positive agro-environmental impacts of energy crops by farmers might contribute to create conducive conditions for the development of bioenergy production systems at local scale.

However further researches is needed in order to understand the extent to which this relationship is strong and widespread in Sardinia and to explore in-depth drivers and factors that influence farmers' choices and behaviours. Furthermore a basic rationale for achieving an adequate and efficient adoption of energy crops in the future by part of farmers that believe in positive environmental effects is presence of empirical scientific findings that support this opinion. So more research in the field of evaluation of environmental effects derived from energy crops cultivation and from diffusion of these crops into the cropping systems of Nurra region will be promoted in order to increase knowledge of the real environmental effects produced at local level. As consequence, understanding scientific information on environmental issues could change farmers' perspectives. In case of generally positive empirical results, it could strengthen farmers' belief in the environmental role played by energy crops. Vice versa the skeptic farmers could re-modulate their perspectives. In case of negative scientific findings, it could derive a generally skepticism in farmers, with serious implications on decision of introducing energy crops in the local farming systems. Finally, a change in perspectives caused by more empirical evidences on the environmental effects of energy crops could play a role in making decision by part of farmers, with implications on the future perspectives of introduction of these crops into local cropping systems.

REFERENCES

1. Abdi H., Valentin D., 2007. Multiple Correspondence Analysis. in Salkind N. (ed.) Encyclopedia of Measurement and Statistics. Thousand Oaks (CA), Sage, pp. 13.

2. Blasius J., Greenacre M., Groenen P.J.F., van de Velden M., 2009. Special Issue on Correspondence Analysis and Related Methods. Editorial. Computational Statistics and Data Analysis: 3103-3106.

3. Castel J.M., Mena Y., Ruiz F.A., Camúñnez-Riun J., Sánchez-Rodriguez M., 2011. Changes occurring in dairy goat production systems in less favoured areas of Spain. Small Ruminant Research 96, 83-92.

4. Deligios, P. A. Farci R., Sulas L., Hoogenboom G., Ledda L., 2013. Predicting growth and yield of winter rapeseed in a Mediterranean environment: Model adaptation at a field scale. Field Crops Research 144, 100-112.

5. Don A., Osborne B., Hastings A., Skiba U., Carter M.S., Drewer J., Flessa H., Freibauer A., Hivönen N., Jones M.B., Lanigan G.J., Mander U., Monti A., Njakou Djomo S., Valentine J., Walter K., Zegada-Lizarazu W., Zenone T., 2012. Land-use Change to Bioenergy Production in Europe: Implications for the Greenhouse Gases Balance and Soil Carbon. GCB Bioenergy 4, 372-391.

6. FAO, 2008. The State of Food and Agriculture. Biofuels: Prospects, Risks and Opportunities, Rome, pp.138.

7. Fernando A.L., Duarte M.P., Boléo S., Mendes B., 2010. Environmental Impact Assessment of Energy Crops Cultivation in Europe. Biofuels Bioproduction & Biorefining 4, 594-604.

8. Fritsche U.R., Sims R.E.H., Monti A. 2010. Direct and Indirect Land-use Competition Issues for Energy Crops and their Sustainable Production – an Overview. Biofuels Bioproduction & Biorefining 4, 692-704.

9. Greenacre M.J., 2010. Correspondence Analysis. Wires: Computational Statistics 2, 613-619.

10. Harvey M., Pilgrim S., 2011. The New Competition for Land: Food, Energy, and Climate change. Food Policy 36, S40-S51.

11. Hellmann F., Verburg P.H., 2010. Impact Assessment of the European Biofuel Directive on Land Use and Biodiversity. Journal of Environmental Management 91, 1389-1396.

12. ISTAT (2013). Estimate of crop, flower and pot plant production and area. ISTAT, http://dati.istat.it/Index.aspx?lang=en

13. Jensen K., Clark C. D., Ellis P., English B., Menard J., Walsh M., de la Torre Ugarte D., 2007. Farmer willingness to grow switchgrass for energy production. Biomass and Bioenergy 31, 773-781.

14. Maas B.L., Katunga Musale D., Chiuri W.L., Gasessner A., Peters M., 2012. Challenges and opportunities for smallholder livestock production in post-conflict South Kivu, eastern DR Congo. Tropical Animal Health Production 44, 1221-1232.

15. Madau F., 2010. Aspetti economici dell'agricultura irrigua in Sardegna. Rapporto Irrigazione, INEA. Quintily Grafica s.r.l., Roma, pp. 90.

16. Moreno-Pérez O.M., Arnalte-Alegre E., Ortiz-Miranda D., 2011. Breaking Down the Growth of Family Farms: A Case Study of an Intensive Mediterranean Agriculture. Agricultural Systems 104, 500-511.

17. Muller A., 2009. Sustainable Agriculture and the Production of Biomass for Energy Use. Climatic Change 94, 319-331.

18. Murphy R., Woods J., Black M., McManus M. 2001. Global Developments in the Competition for Land from Biofuels. Food Policy 36, S52-S61.

19. OECD-FAO, 2008. Bioenergy, Food Security and Sustainability. Towards a New International Framework, June, Rome, pp. 18.

20. Osborne B., Jones M.B., 2012. Introduction: Impact of Land Use Change for Bioenergy Production on Greenhouse Gases Emissions. GCB Bioenergy 4, 371.

21. Paulrud S., Laitila T., 2010. Farmers' Attitudes about Growing Energy Crops: A Choice Experiment Approach. Biomass and Bioenergy 34, 1770-1779.

22. Popp A., Lotze-Campen H., Leimbach M., Knopf B., Beringer T., Bauer N., Bodirsky B. 2011. On Sustainability of Bioenergy Production: Integrating Co-emissions from Agricultural Intensification. Biomass and Bioenergy 35, 4770-4780.

23. Rathmann R., Szklo A., Schaeffer R., 2010. Land Use Competition for Production of Food and Liquid Biofuels: An Analysis of the Arguments in the Current Debate. Renewable Energy 35, 14-22.

24. Rossi A.M., Hinrichs C.C., 2011. Hope and Skepticism: Farmer and Local Community Views on the Socio-economic Benefits of Agricultural Bioenergy. Biomass and Bioenergy 35, 1418-1428.

25. Siegmund-Schultze M., Rischkowsky B., 2001. Relating Household Characteristics to Urban Sheep Keeping in West Africa. Agricultural Systems 67, 139-152.

26. Solano C., Bernués A., Rojas F., Joaquõín N., Fernandez W., Herrero M., 2000. Relationships between Management Intensity and Structural and Social Variables in Dairy and Dual-purpose Systems in Santa Cruz, Bolivia. Agricultural Systems 65, 159-177.

27. Solano C., León H., Peréz E., Herrero M., 2001a. Characterising Objective Profiles of Costa Rican Dairy Farmers. Agricultural Systems 67, 153-179.

28. Solano C., León H., Peréz E., Herrero M., 2001b. Who Makes Farming Decisions? A Study of Costa Rican Dairy Farmers. Agricultural Systems 67, 181-199.

29. Stavi H., Lai R. 2013. Agriculture and Greenhouse Gases, a Common Tragedy. A Review. Agronomy Sustainable Development 33, 275-289.

30. Thenail C., 2002. Relationships between Farm Characteristics and the Variation of the Density of Hedgerows at the Level of a Micro-region of Bocage Landscape. Study Case in Brittany, France. Agricultural Systems 7, 207-230.

31. Villamil M.B., Alexander M., Heinze Silvis A., Gray M.E., 2012. Producer Perceptions and Information Needs Regarding their Adoption of Bioenergy crops. Renewable and Sustainable Energy Reviews 16, 3604-3612.

32. World Bank, 2008. The Challenges of High Food and Fuel Prices. Paper to the Commonwealth Finance Ministers Meeting, 6–8 October, pp. 23.

CHAPTER 3

From traditional to energy cropping systems: a comparative Life Cycle Assessment analysis in Sardinia (Italy)

Abstract
It is a common opinion that biomass crops could have various advantages over conventional energy and other renewable energy sources such as possibility to occupy abandoned land, to diversify the farmers' income and to make new opportunities for rural areas. However, in order to guarantee their environmental sustainability, a critical point regards the accurate estimation of environmental externalities produced (e.g. land use change, natural resources management, emissions), especially in terms of differentials between them and traditional crops. This study is aimed to evaluate the environmental sustainability associated to possible substitution of some traditional crops with alternative crops addressed to renewable energy production in Sardinia. A Life Cycle Assessment methodology was used in order to assess environmental impacts associated to some traditional and energy crops, through a "cradle to gate" approach. Afterwards, we effected some simulations in order to individuate hypothetical combinations between observed crops as to assess possible differences between cropping systems in terms of environmental burdens. This quantitative procedure allows us to indentify the environmental "hot spots" in order to give useful information for supporting both farmers and policy makers' decisions. Among the main findings, we found that replacement of traditional crops with energy crops might produce controversial benefits in terms of environmental sustainability variation. Specifically, introduction of rapeseed into cereal cropping systems should show positive effects on environmental farming sustainability, whereas use of maize and artichoke for energy purpose might determine null or negative environmental outcomes, respectively.

Keywords: energy crops, cropping systems, sustainability, Life Cycle Assessment, environmental impacts.

1. INTRODUCTION

The European Union (EU) has played a central role in addressing various environmental issues in the last decades. It has occurred through provision of different policy strategies to foster sustainable development inside and outside Member States (European Commission, 2005a; Manners, 2008; Vanden Brande, 2009; Afionis and Stringer, 2012; European Commission, 2013). The rationale underline is that environmental issues cannot be promoted solely by environmental policy itself in order to achieve sustainable development finalities. In fact, it would be necessary an integration between policies in order to take into account the pressures that several productive sectors (*e.g.* agriculture, fisheries, transports and energy) press on environment (European Commission, 2004, 2009). In this perspective, the EU has put increasing attention to environmental issues related to different and alternative uses of natural resources since their rapid depletion (*e.g.* loss of biodiversity, climate change impacts, desertification, food and energy security, raw materials depletion) has become a priority emergency for the humankind (European Commission, 2005b, 2009; Bringezu *et al.*, 2012; Montanarella and Vargases, 2012).

Emerging these considerations, the future EU strategy for next decade highlights the great importance to ensure a sustainable growth through the promotion a more efficient, green and competitive economy based on a more adequate use of natural resources (European Commission, 2010a; European Commission, 2013). The best mean to achieve these objectives and to solve the current emergencies has been individuated in promoting a combination of policies in order to improve the synergies and to face the settlements between various policies (European Commission, 2011).

Under this framework, nowadays it is opportune considering that European energy policy cannot be developed aside from agricultural policy. An important issue in this view concerns the objective to jointly face the need to reduce the greenhouse gases (GHGs) emissions to limit climate change impacts and the need to weaken dependency from fossil energy sources since both have implications for at least two sectors, *i.e.* the energy and agriculture, each one closely connected with each other. For this reason, through the implementation of the European Directive 2009/28/EC about renewable energy (see also European Commission, 2012), the EU has provided a bundle of criteria and a certification system in order to ensure the overall sustainability of biofuels production even on the basis of worldwide growing of energy demand (van Dam *et al.*, 2010; GBEP, 2011; Scarlat and Dallemand, 2011; European Commission, 2013; Levidow, 2013; Mangoyana *et al.*, 2013). In fact during the last decade (2002-2012) the area cultivated with oil seeds is progressively increased (+19%) in the EU Member States and it reflects the actual pressure for individuating alternative energy sources in order to limit the dependency from fossil fuels (FAOSTAT, 2013). However, on the one hand, the growing energy demand is partially satisfied by biomasses of forest and agricultural source, on the other hand, this production is deducted by food purpose with meaningful consequences in terms of food price volatility, land use competition, more pressure on natural resources, etc. (Ciaian and Kancs, 2011; Harvey and Pilgrim, 2011; Murphy *et al.*, 2011; Paul, 2013).

The EU has sought a solution regarding the increased demand of raw material and the scope of establishing a strategy into own sector policies aimed to find an equilibrium between food and energy productions, specifically in terms of land and biomass availability (Panoutsou *et al.*, 2009; Krasuska *et al.*, 2010; Rathmann, 2010; Thrän *et al.*, 2010). Specifically to agricultural sector, the next Common Agricultural Policy (CAP) would face important challenges (*e.g.* food security, environmental safeguard, climate change impacts and territorial balance) that will lead EU to make strategic choices for the long-term future of its agriculture and rural areas (European Commission, 2010b). In the CAP perspective, the agricultural systems should evolve in order to be adaptable to new environmental conditions, and at the same time, to constrain undesirable effects such as loss of biodiversity, rural abandonment and soil degradation. However, this might be promoted meeting a plurality of productive, economic, social, and environmental needs that can also appear controversial, but these should be satisfied without leaving aside from intensification of production and consequent more exploitation of natural resources and land use (Darnhofer *et al.*, 2010; Scarlat *et al.*, 2013). Furthermore a harmonic and sustainable agricultural adaptation to new environmental conditions might be promoted taking into account other European policies, first of all energy policy in the case of energy crops development. In other terms, given the general objective to increase renewable energy sources, introduction of energy crops in the European agricultural systems should be faced into an integrated perspective between agricultural and energy policies as to better taking into account all the potential controversial productive and environmental challenges associated to energy crops cultivation. It must be underlined that the theme of how conciliate potential controversial impacts has been debated in Europe and throughout the world (EEA, 2006; Monti *et al.*, 2009; Uchida and Hayashi, 2012).

According to some authors, biomass crops could have various advantages over conventional energy and over some other renewable energy sources specifically because they can occupy abandoned land, diversify the farmers' income and make new opportunities for rural development areas (Fernando *et al*., 2010; Zegada-Lizarazu and Monti, 2011; Erb *et al.*, 2012). However their diffusion could not be sustainable in case of some externalities (*e.g.* land use change, natural resources management, deforestation) are not carefully estimated (Fritsche *et al.*, 2010; Van Stappen *et al.*, 2011; Bird *et al.*, 2013). Introduction of new crop - *e.g.* as energy crops - into traditional cropping systems therefore needs to precise information and assessment on their environmental impacts, site and agronomic features, and resources management in order to support farmers' decisions on adoption of bioenergy crops (Zegada-Lizarazu *et al.*, 2010; Ballarin *et al.*, 2011; Giannoccaro and Berbel, 2012).

In the light of these considerations, this study is aimed to evaluate the environmental sustainability associated to substitution of some traditional cropping systems with alternative systems based on crops addressed to renewable energy production in Sardinia. The objective is to evaluate the differences between traditional and possible alternative energy cropping systems from an environmental point of view. This is because Sardinia represents a suitable territory for introducing energy crops cultivation, such as rapeseed and some *Cardueae* species (*e.g.* globe artichoke and cultivated cardoon) (Solinas *et al.*, 2011; Ledda *et al.*, 2013). Furthermore, the economic crisis that has lately affected the agricultural and livestock sector has fostered the introduction of energy crops that would occupy the abandoned arable land nowadays from cereal and forage and often located in marginal areas (Solinas *et al.*, 2011). However, in the face of this opportunity, some economic (*e.g.*, asymmetries between demand and supply of vegetable oil locally) and agronomic (*e.g.*, characteristics and fertility of soils, climate conditions) limitations that have so far hampered the development of the sector can be individuated (Deligios *et al.*, 2011; Solinas *et al.*, 2011). This suggests to accurately assess environmental impacts in order to put on evidence the real environmental implications associated to energy crops cultivation in Sardinia and to provide information for addressing an harmonic and sustainable energy crops development.
A Life Cycle Assessment (LCA) methodology was used in order to assess environmental impacts. It is a methodology widely used for evaluating environmental burdens in agricultural production systems with reference to both crops and cropping systems (Haas *et al.*, 2000; Audsley *et al.*, 2003; Brentrup *et al.*, 2004; Fazio and Monti, 2011; Goglio *et al.*, 2012). LCA was applied for different traditional and energy crops that characterize or that are suitable for the Sardinian cropping systems. On the basis of findings some hypothetical combinations between crops have been simulated in order to assess possible differences between traditional and energy cropping systems in terms of environmental impacts.
This quantitative procedure allows us to indentify the environmental "hot spots" in order to give useful information for supporting both farmers and policy makers' decisions.

2. Materials and methods

The Life Cycle Assessment (LCA) is a quantitative tool for evaluating the potential environmental impacts related to products or services aimed to identify possible improvement in terms of environmental burdens reduction and management of resources (Baumann and Tillman, 2004).

According to ISO standardization guidelines, the LCA framework consists in four stages: i) goal and scope definition, ii) Life Cycle Inventory analysis (LCI), iii) Life Cycle Impact Assessment (LCIA), and iv) interpretation. Briefly, in the first step, the aim and the subject of the LCA study are established including a functional unit and the system boundaries. The LCI consists of collection and quantification of inputs and outputs for a given product system throughout its life cycle (*e.g.* extraction of raw materials, use of inputs, emissions of substances due to inputs listed in the inventory. In the LCIA phase the potential environmental burdens are evaluated on the basis of the inventory analysis, *i.e.* the magnitude of the potential impact of individual substances is associated to each impact category and they are assessed. Impact categories correspond to particular environmental issues, such as climate change, human toxicity, etc.. The final step in an LCA study is related to the interpretation of the results obtained from the previous three steps. In this phase is possible to draw conclusions, identify "hot spots" and formulate recommendations (ISO 14040, 2006).

The Simapro 7.3.3 software has been used to carry out the LCA study and analyze scenarios regarding the environmental impacts of different crops production under consideration.

2.1 Goal and scope definition

The main goal of this study is to assess the environmental sustainability of cropping systems aimed to energy production in Sardinia. Specifically, the assessment from an environmental perspective is associated to possible substitution of some traditional cropping systems with systems characterized by crops for energy production. In other words a comparative analysis was carried out through hypothetical combinations among some of the most important cropping systems and others that could potentially become meaningful reality for socio-economic development of Sardinia and that are related to the production of bioenergy. Specifically the LCA analysis focused on the following annual crops: durum wheat (*Triticum turgidum* L. subsp. *durum*), barley (*Hordeum vulgare* L.), maize (*Zea mays* L.), ryegrass (*Lolium multiflorum* Lam.), triticale, rapeseed (*Brassica napus* L. var. *Oleifera* D.C.), artichoke (*Cynara cardunculus* L. subsp. *Scolymus* (L.) Hegi, cv. Spinoso Sardo). Fallow and bare fallow was included within cereal cropping systems under assessment because they are common practices for land management adopted by Sardinian farmers. Indeed, they aim to improve the soil structure for next sowing (fallow) and also to avoid the spread of weeds (bare fallow). Some of these crops are traditional in the Sardinian cropping systems - *e.g.* wheat, maize, triticale, ryegrass, artichoke - whereas others are addressed to energy production (rapeseed), and others have dual-purpose production - food and no food - such as maize and artichoke.

2.1.1 Functional unit and system boundaries

The functional unit chosen in this study was the hectare of land. This choice depends on the analysis goal as well as the environmental impact categories. Moreover, it supports the assessment of impact on the land underlining the relationships between environmental burdens variations and levels of inputs used in the cultivation practices (Haas et al., 2000; Goglio *et al.*, 2012). In this way it allows to identify impact categories mainly affected by the agricultural phase. Finally, the functional unit based on land fosters the comparison between various products with different end use (*e.g.* food crops and energy crops) (Fazio and Monti, 2011).

The system boundaries adopted for this study was from “cradle to farm gate”. According to ISO standards (2006) they define the unit process that have to be included in the analysis, therefore they can strongly affect the results of LCA analysis (Muench and Guenther, 2013). For this reason it is essential that its choice should be in line with goal that herein is assessment of environmental burdens produced by some crops cultivated at regional level. Moreover, the evaluation related to impacts arisen only from implementation of agricultural practices in order to identify their possible improvements does not seem to require the overcoming of farm gate.

In this study the crops under consideration generally produce more than one output *e.g.* grain and straw (co-products), heads, oilseeds, and residual biomass in general (by-products). In this case, according to ISO standards (2006), it is necessary to apply the allocation of inputs and environmental burdens between different outputs. There are various allocation approaches that can be applied based on avoiding allocation, splitting the processes into several sub-processes; expanding of system boundaries, or using a physical casuality principle such as mass, energy or economic value of outputs (Goedkoop *et al.*, 2010; Malça *et al.*, 2013). However - given the scope of this study and the land-basis measures of environmental impacts - we took into account the agricultural processes on the whole, without considering allocation by products (or byproducts). Basically in case of artichoke two different processes were run in order to highlight global differences between the solely production of food and the conjoint production of food and residual biomass for energy purpose. It should allow us to analyze differences considering the entire production process and not only regarding to impacts allocation among outputs.

2.1.2 Impact categories assessment

The LCIA was run in converting inventory data into quantitative information regarding environmental impacts (Audsley *et al.*, 1997). This phase was carried out according to ISO standards, *i.e.* developing different steps: impact category definition, classification, characterization and also two optional steps normalization and weighting (Baumann and Tillman, 2004). Concerning the selection and computation of impact categories (classification and characterization phases) it was used CML2 baseline 2000 methodolgy (Center of Environmental Science of Leiden University, NL) aimed to evaluate the so-called mid-point impacts (*i.e.* the total amount of substance-equivalents released), whereas regarding the optional steps it was applied Eco-indicator 99 (Goedkoop and Spriensma, 2001) in order to express the single environmental impacts value as total score, and evaluating the so-called end-point impacts (*i.e.* the potential damage deriving from the emissions). The identification of impact categories (Table 1) basically consists in specifying of environmental burdens that could consider rilevant on the basis of goal and scope definition (Baumann and Tillman, 2004).

Table 1 - The main impact categories based on CML2 methodology

Impact Category	**Characterisation factor**	**Unit-equvalent**
Depletion of abiotic resources	Abiotic Depletion Potenzial (ADP)	kg Sb (antimony)
Climate change	Global Warming Potential (GWP)	kg CO_2
Ozone layer depletion	Ozone Depletion Potential (ODP)	kg CFC-11 (chlorofluorcarbon)
Human toxicity	Human Toxicity Potential (HTP)	kg 1,4-DB (dichlorobenzene)
Freshwater acquatic ecotoxicity	Freshwater Acquatic Ecotoxicity Potential (FAEP)	kg 1,4-DB (dichlorobenzene)
Marine acquatic ecotoxicity	Marine Acquatic Ecotoxicity Potential (MAEP)	kg 1,4-DB (dichlorobenzene)
Terrestrial ecotoxicity	Terrestrial Ecotoxicity Potential (TEP)	kg 1,4-DB (dichlorobenzene)
Acidification	Acidification Potential (AP)	kg SO_2
Eutrophication	Eutrophication Potential (EP)	kg PO_4^{3-}
Photochemical oxidation	Photochemical Ozone Creation Potenzial (POCP)	kg C_2H_4 (ethylene)

The impact categories used in this study were calculated according to following equation:

$$IC_i = \sum_j E_j . CF_{ij}$$

where IC_i is a generic impact category, *i.e.* an indicator value for impact category related to functional unit considered; E_j represents the release of emission or consumption of resources *j* per functional unit; CF_{ij} is the characterization factor for emission or resources *j* that contributes to impact category *i* (Brentrup *et al.*, 2004). For instance, concerning "Climate Change" category the characterization factor of CO_2 is 1 and for CH_4 is 21. It means that in terms of climate change the emission of 21 kg of CO_2 is equivalent of 1 kg of CH_4 (Fazio and Monti, 2011). In brief, in the first phase of LCIA, *i.e.* classification, the LCI results are appointed to different impact categories. It could occur that some results need to be associated to more environmental burden categories. The second step is quantitative. In fact, in the characterization phase the measures of environmental load are calculated per each category applying characterization factors according the equation previously described (Baumann and Tillman, 2004).

These results represent the environmental impacts at midpoint level (*e.g.* acidification, eutrophication phenomena, or toxicity of specific compounds). In other words, they can be considered as a parameter in a cause-effect chain between stressors collected in inventory and the category endpoints (Udo de Haes *et al.*, 1999; Bare *et al.*, 2000). These latter categories concern relevant aspect of society that need to protection, *i.e.* human health and environment in terms of valuable ecosystems and resources depletion that are indicated as damage categories. Hence the endpoint approach is aimed to aggregate the different midpoint impact categories on the basis of their burdens on the damage categories that is endpoint categories (Jolliet *et al.*, 2004; Goedkoop *et al.*, 2013).

The aggregation of impact categories in damage categories facilitates the LCI analysis and improves the interpretation of findings. This operation is also more effective if the endpoint categories are expressed as total score because it allows us to compare the environmental impacts between different products under consideration. In this sense, the Ecoindicator 99 methodology was applied in this study related to implementation of optional phasis of LCIA *i.e.* normalization, grouping and weighting. Moreover, after the first two phases of LCIA it is not possible to express an opinion on the related importance of findings obtained.

The normalization step is aimed to evaluate the magnitude of each impact category related to product system under consideration (Baumann and Tillman 2004; Brentrup, *et al.*, 2004). In particular, the aim is to relate the environmental impact values to a specific reference context and to adjust the findings so that they have a common dimension (Pennington *et al.*, 2004). In fact, it is possible that an indicator that has a inherently high value, actually represents a low contribution compared to total environmental burdens produced in a certain area. In this study, the results were normalized on Western European inhabitant due to the availability of data, in order to highlight the relative significance of the environmental findings (Brentrup *et al.*, 2004). The normalized values can be grouped and weighted as well. Grouping the impact categories into a smaller number of environmental indicators allow to rank them on basis of their importance for instance. In this way it is easier the interpretation of findings.

Weighting phase consists in a conversion process of different impact categories results (or normalized findings) using numerical factors based on subjective value choice - and not on scientific basis - depending on context under consideration. It is aimed to consider the relative importance of each environmental burdens respect to all the other (Baumann and Tillman, 2004). For this reason the weighting step is still a controversial part of LCA analysis (Pennington *et al.*, 2004). This step is aimed to facilitate comparison between environmental burdens because it allows to express them - both at midpoint and endpoint level - into a final score. The Ecoindicator 99 methodology - applied in this analysis - had associated the midpoint categories to three damage categories, *i.e.* human health, ecosystem quality and resource depletion.

Damage to human health produced by a substance effect was expressed as Disability-Adjusted Life Year (DALY) *i.e.* the sum of the present value of future years of lifetime lost due to premature mortality (*e.g.* for ill-healthness) and the present value of years of future lifetime adjusted for an average severity score related to any injuries or disability (Murray, 1994; Shopper *et al.*, 2000: Fox-Rushby and Hanson, 2001):

$$DALY = YLL + YLD$$

where YLL are the years of life lost and YLD are the years lived with disability. Specifically YLL are calculated multiplying number of deaths by the standard life expectancy at age of death, whereas YLD are computed as follows:

YLD = Y * L * DW

where Y is the number of incident cases, L is the average duration until death (or remission), and DW is the disability score as setted by World Bank (from 0 in case of death to 1 in case of no damage) (Anand and Hanson, 1997).

Concerning Ecosystem Quality (EQ) damage category, it is expressed as potentially disappeared fraction (PDF) of living species per square meter per year which was assumed 10% of the potentially affected species under toxic stress in a given environment (Hamers *et al.*, 1996; Goedkoop and Spriensma, 2001).

Resource Depletion (RD) was expressed in terms of energy needed to extract a specific raw material for balancing a decrease of future availability of abiotic resources (Goedkoop and Spriensma, 2001; Van Oers *et al.*, 2002).

Finally, the three damage categories were aggregated in terms of Ecopoint scores. An Ecopoint represents the annual environmental burden of the analyzed process or product and it is weighted on the average European inhabitant. Precisely, it corresponds to one thousandth of the annual environmental load per average European inhabitant. Therefore, the more estimated Ecopoints are related to more environmental impacts (Fazio and Monti, 2011).

2.1.3 Description of the cropping systems scenarios

The environmental impact results were used in order to obtain an evaluation of environmental dimension of sustainability through a comparative analysis between some traditional cropping systems and others aimed to bioenergy production in Sardinia. The cropping systems under consideration were chosen on the basis of the most meaningful agricultural systems production in Sardinia and others that could be an opportunity for socio-economic development of region. Moreover, it depends on the most likely scenario changes that would affect farms production in Sardinia and it's also related to data availability. The local agricultural sector is mainly based on cereals cultivation, *e.g.* wheat, that are sometimes developed in marginal areas with low fertility. In this situation, an energy crop as rapeseed could represent a good opportunity due to the improvement of the soil structure and the positive contribution to the control of pests, specifically when it is practiced in rotation with wheat (Zegada-Lizarazu and Monti, 2011).

The Sardinian artichoke (cv. Spinoso sardo) plays a strategic role in the local agricultural sector; the amount of residual biomass - that otherwise would not be used - could match the needs for energy production or cropping diversification, land use management and additional income for local farmers (Ledda *et al.*, 2013).

Regarding to the introduction of energy crops into livestock farms, it could trigger relevant changes in farming organization, since farms in general raises an amount of livestock proportional to land and manpower availability. Thus the energy crops cultivation can lead to an intensification of farming systems, in order to increase the land use efficiency. A common practice at local level is to set-aside lands into fallow and bare fallow. Generally the cereal farms prefer to apply bare fallow that over a shorter term increases the soil fertility. Conversely, the permanent fallow is mainly used in cereal-livestock farms as feed source. Anyway, these scenarios could be possible and advantageous if they are sustainable also from the environmental point of view, *i.e.* in terms of environmental burdens and natural resources depletion.

As described in the Figure 1, the substitution in the cropping systems regards both crops and land allocation. The LCA was focused on single crops and on rotation, *i.e.* a monoculture of maize in double-crop with ryegrass and triticale respectively. The former combination is commonly adopted into Sardinian cropping systems whereas the latter could be a good alternative to enhance the development of bioenergy cropping systems.

The LCA results were applied to the selected cropping systems in order to assess their environmental sustainability. In fact the Ecopoints calculated in the LCIA were referred to one hectare for single crops and they were applied to each simulated cropping systems. This step allowed us to underline both which crops and consequently which cropping systems was more or less sustainable from the environmental perspective.

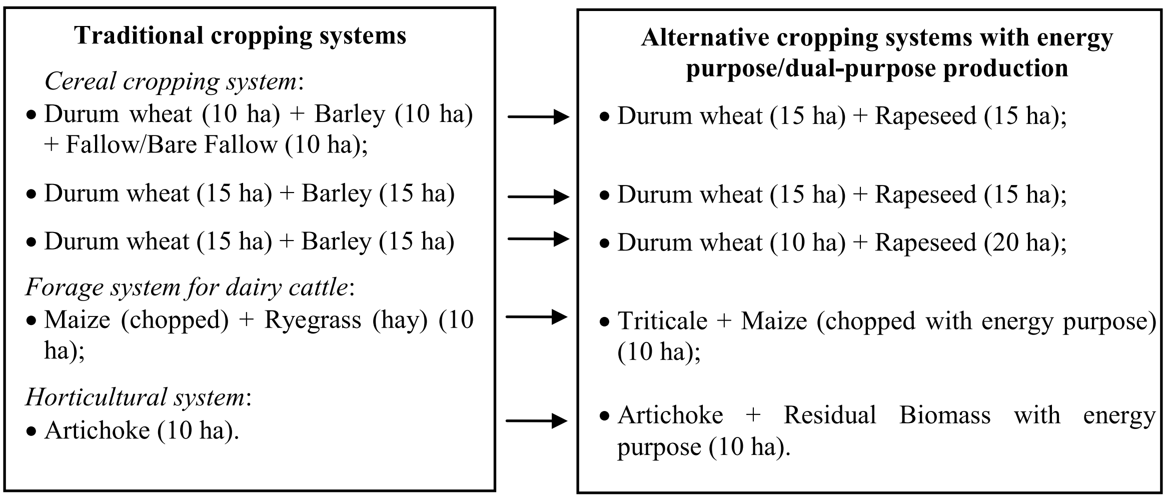
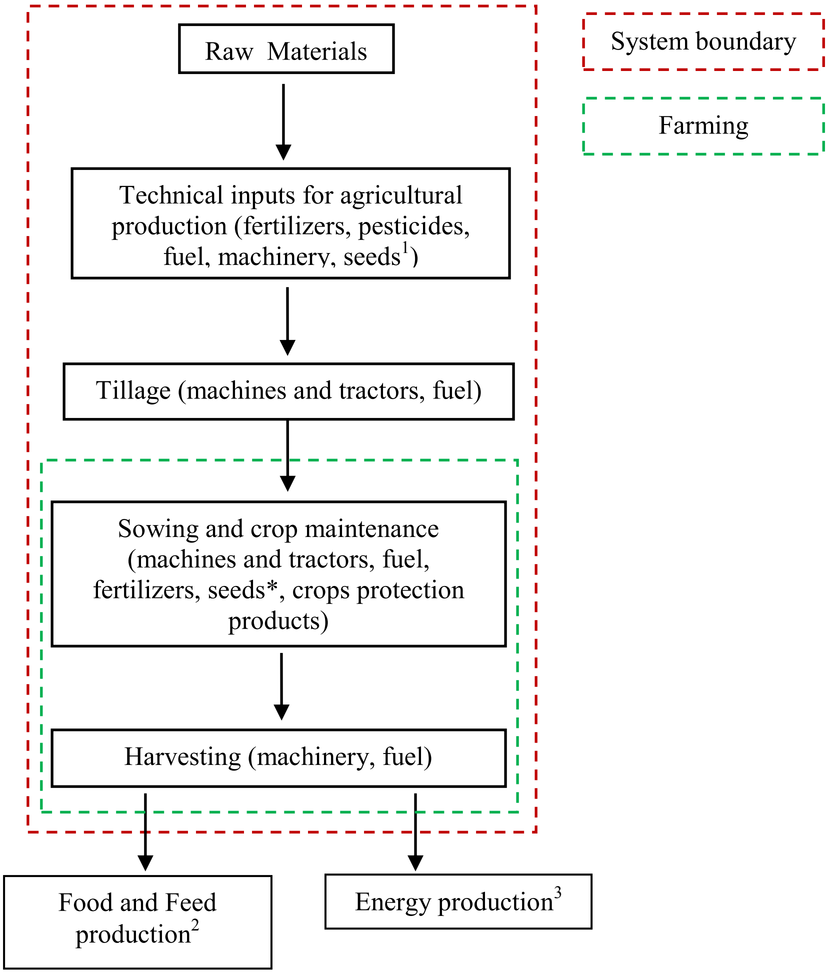


Figure 1 - Cropping systems scenarios

2.2 Inventory analysis

Technical inputs such as fertilizers, pesticides, seeds and machinery production were included in the system boundaries defined in this LCA analysis (Figure 2) (Audsley *et al.*, 1997; Mourad *et al.*, 2007). Moreover, all activities carried out for crops growth related to one hectare of land that are commonly applied by Sardinian farmers were considered. Secondary data (*i.e.* the upstream and downstream processes of the farming system) were directly derived from international databases, in particular the Ecoinvent 2.2 database (Frishknecht *et al.*, 2007; Hischier *et al.*, 2010). Since they were not exaustive, it was necessary to integrate with data taken from literature (Pellizzi, 1996; Bianchi *et al.*, 1997; Peruzzi and Sartori, 1997; Ribaudo, 2011), direct interviews to local farmers, and direct field measurements carried out as part of some national research projects[3]. This information was essentially aimed to increase the site-specific component included in the LCA analysis and to draft conclusion strictly related the local situation. The quantitative data regarding technical inputs and outputs were summarized in Table 2. It's clear that the data are quite different, especially in terms of soil tillage, fertilizer application pest and weed control. The features of machinery used during field operations, *e.g.* power, weight and fuel consumption were specifically considered (Table 3) because as highlighted by Audsley *et al.* (1997) they are deemed to strongly contribute to environmental burdens arisen from agricultural activity.

[3] AGROSCENARI for durum wheat, triticale and barley data, BIOENERGIE for rapeseed data, SIMBIOVEG and ORWEEDS projects regarding artichoke data.



Note: 1= Semi-dormant offshoots ("ovoli") were used in place of seeds for artichoke plant; 2= Food and Feed production regards durum wheat, barley, maize and ryegrass; 3= Energy production regards rapeseed, residual biomass of artichoke, maize and triticale.

Figure 2 - System boundary of analyzed crops

In this LCA study the main field emissions from fertilizers were included, specifically carbon and nitrose emissions, *i.e.* carbon dioxide (CO_2), nitrate, ammonia (NH_3) and nitrous oxide (N_2O). The CO_2 emission was considered specifically associated to slurry distribution for maize and ryegrass cultivation. CO_2 and N_2O emissions were estimated using emission factors definited by Intergovernmental Panel on Climate Change (2006). Concerning nitrate leaching, it was considering only one reference value for all crops on the basis of information reported by Giola *et al.*, (2012) regarding a simulation of local field data and tha is coherent with other studies carried out in the Mediterranean area (de Paz and Ramos, 2004).

Table 2 - Raw materials and products for the considered scenarios

Input flows	Units	Durum Wheat	Barley	Triticale	Maize	Ryegrass	Rapeseed	Artichoke
Seed[1]	kg·ha^{-1}	190	250	200	62,0000	42.5	8	1.5 plants·m^{2}
Treatments for crops protection								
Herbicides	l·ha^{-1}	1.5 (Atlantis)	-	0.5 (Atlantis)	4 (Lumax)	-	1.5 (Butisan S)	-
Fertilization								
Mineral fertilizers								
N		206 (ammonium nitrate, topdressing)	200 (urea, topdressing)	80 (urea, topdressing)	450 (Entec 26)	200 (Entec 26)	200 (ammonium nitrate, topdressing)	250 (urea, topdressing)
K	kg·ha^{-1}	-	-	-	-	-	-	150 (potassium sulphate)
N-P		150 (diammonium phosphate)	150 (diammonium phosphate)	120 (diammonium phosphate)	-	-	200 (diammonium phosphate)	138 (diammonium phosphate)
Organic fertilizers	m^{3}·ha^{-1}	-	-	-	52 (slurry)	27 (slurry)	-	-
Output flows								
Heads	number	-	-	-	-	-	-	40,000
Seed/grain	t·ha^{-1}	2.5	3	3.5	-	-	1.8	-
Forage		-	-	-	79	6	-	-
Residual biomass		5.9	4.7	9.44	-	-	-	4.5

Note: 1= Semi-dormant offshoots ("ovoli") were used in place of seeds for artichoke plant. The planting density is showed in the table

Table 3a - Field operations: data regarding agricultural machinery

Operations	Tractor		Operative machine			Fuel consumption	Working time
	Power (kW)	Weight (kg)	Type	Weight (kg)	Expected lifespan (h)	(l·ha^{-1})	(h·ha^{-1})
Ploughing							
Durum Wheat	75.0	4650	Disc plough	660	1600	60.0	3.30
Barley	75.0	4650	Disc plough	660	1600	60.0	3.30
Maize	96.9	5000	Three furrow plough	805	1600	52.9	0.5
Ryegrass	96.9	5000	Three furrow plough	805	1600	52.9	0.5
Rapeseed	75.0	4650	Disc plough	660	1600	60.0	3.30
Artichoke	75.0	4650	Disc plough	660	1600	39.5	2
Minimum tillage							
Triticale	75.0	4650	Cultivator combined with subsoiler	1320	2000	60.0	2
Milling							
Maize	96.9	5000	Hoeing machine	820	1500	14.4	0.416
Ryegrass	96.9	5000	Hoeing machine	820	1500	14.4	0.416
Harrowing							
Durum Wheat	75.0 "	4650 "	Drag harrow; spike tooth harrow	660 460	1800 2000	22.0 12.0	1 1.5
Barley	75.0	4650	Spike tooth harrow	460	2000	12.0	1.5
Maize	110.3	5630	Rotary harrow	1278	1500	23.4	0.458
Ryegrass	110.3	5630	Rotary harrow	1278	1500	23.4	0.458
Rapeseed	75.0	4650	Spike tooth harrow	460	2000	5.0	0.333
Artichoke	75.0	4650	Spike tooth harrow	460	2000	12.0	1
Bare fallow	102.0	5700	Disk harrow	1700	1500	18.1	1
Rolling							
Ryegrass	48.5	3035	Roller	600	2000	5.1	0.333
Rapeseed	75.0	4650	Roller	820	2000	12.0	1.5
Seeding							
Durum Wheat	59.5	2780	Fertiliser drill	680	1100	10.0	1
Barley	59.5	2780	Fertiliser drill	680	1100	10.0	1
Triticale	59.5	2780	Fertiliser drill	680	1100	10.0	1
Maize	67.1	3894	Pneumatic precision drill	850	1300	8.2	0.416
Ryegrass	67.1	3894	Mechanical drill	480	1100	8.2	0.416
Rapeseed	59.5	2780	Fertiliser drill	680	1100	10.0	1
Artichoke			Hand planting				
Fertilization							
Durum Wheat	59.5	2780	Fertiliser drill	680	1100	10.0	1
Barley	59.5	2780	Fertiliser drill	680	1100	10.0	1
Triticale	59.5	2780	Fertiliser drill	680	1100	10.0	1
	48.5	3035	Fertiliser spreader	119	1600	0.8	0.05
Maize	110.3	5630	Slurry spreader by tanker	6200	2000	20.2	0.666
	48.5	3035	Fertiliser spreader	119	1600	0.8	0.05
Ryegrass	110.3	5630	Slurry spreader by tanker	6200	2000	15.2	0.5
Rapeseed	59.5	2780	Fertiliser drill	680	1100	10.0	1
Artichoke	75.0	4650	Twin disk fertiliser spreader	190	1500	6.0	0.333

Table 3b - Field operations: data regarding agricultural machinery

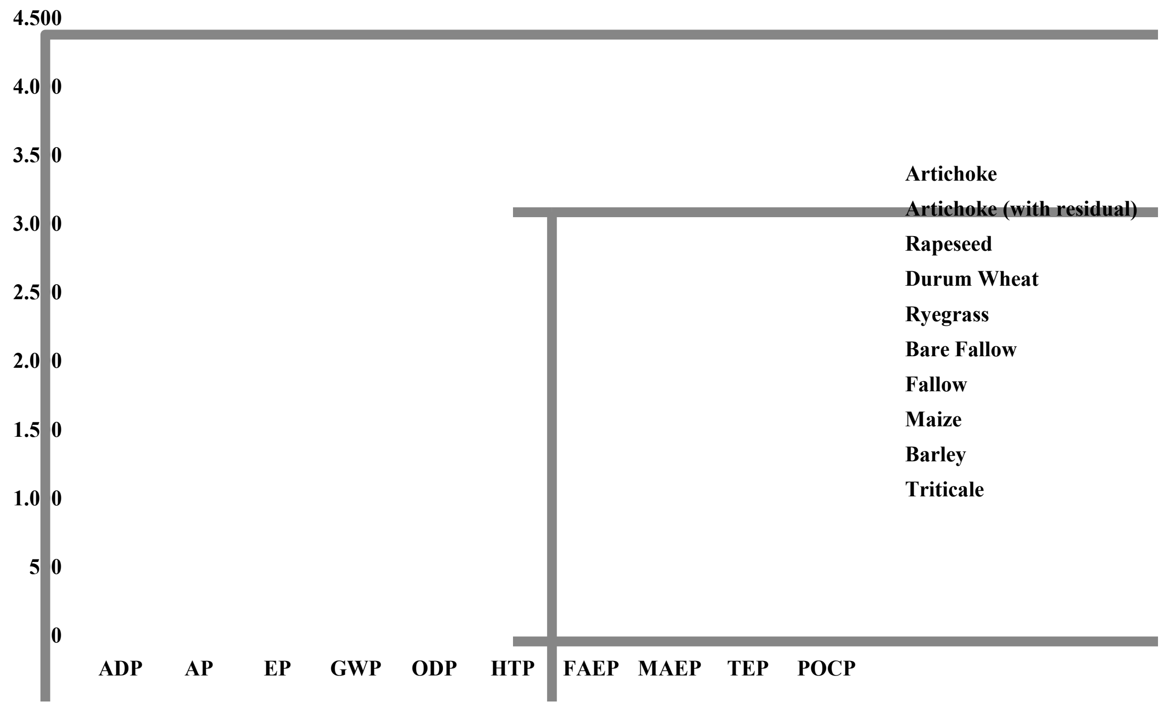
Operations	Tractor		Operative machine			Fuel consumption	Working time
	Power (kW)	Weight (kg)	Type	Weight (kg)	Expected lifespan (h)	($l \cdot ha^{-1}$)	($h \cdot ha^{-1}$)
Weeding							
Durum Wheat	59.5	4650	Sprayer	90	2000	5.0	0.5
Triticale	59.5	4650	Sprayer	90	2000	5.3	0.333
Maize	67.1	3894	Weed control tanker	200	1200	3.0	0.083
Rapeseed	59.5	4650	Sprayer	90	2000	5.0	0.5
Harvesting							
- Combine harvesting							
Durum Wheat	-	-	Combine harvester (219.9 kW)	12530	2800	40.0	0.75
Barley	-	-	Combine harvester (219.9 kW)	12530	2800	40.0	0.75
Triticale	-	-	Combine harvester (219.9)	12530	2800	40.0	0.75
Rapeseed	-	-	Combine harvester (81 kW)	6840	2800	15.0	0.833
Artichoke			Hand harvesting				
- Chopping							
Maize	-	-	Chopper (375 kW)	11280	2000	39.2	0.25
	112.0	5635	Trailer	19500	2000	39.2	0.25
- Cutting							
Ryegrass	67.1	3894	Conditioner mower	1720	1800	8.2	0.416
- Haymaking							
Ryegrass	48,5	3035	Tedder	320	1400	7.7	0,5
- Swathing							
Ryegrass	67,1	3894	Windrower	610	1100	11.5	0,583
- Rotobaling							
Durum Wheat	75.0	4650	Baler	2110	1200	22.5	0,75
Barley	75.0	4650	Baler	2110	1200	22.5	0,75
Triticale	75.0	4650	Baler	2110	1200	23.5	0,833
Ryegrass	96,9	5000	Baler	2690	1200	14.4	0,416
Artichoke	75.0	4650	Baler	5600	1500	35.3	0,833
- Residual biomass loading							
Durum Wheat	60.0	3400	Bale with front loader and fork	590	2000	7.9	0,416
Barley	60.0	3400	Bale with front loader and fork	590	2000	7.9	0,416
Triticale	60.0	3400	Bale with front loader and fork	590	2000	7.9	0,416
Artichoke	60.0	3400	Bale with front loader and fork	590	2000	7.9	0,416
Ryegrass	59,7	2964	Bale fork	90	2000	3.1	0,166

Note: The table contains only field processes; therefore transport, ensilage, storage are not included.

The choice of one value for all crops under consideration was depended on the scarcity of site-specific studies dedicated to different crops and that take into account all various factors (climatic conditions, soil features, etc.) that affect nitrate leaching rate. The NH_3 emissions were included on the basis of indications proposed by Brentrup *et al.* (2000) and Carozzi *et al.* (2013). With regard to pesticides, any direct emissions arisen chemical compounds application were not included in this analysis due to the lack of data adequate to compute the amount of these substances that achieve the different environmental sections (González-García *et al.*,2013a).

3. Results

Figure 3 reports the standardized impacts values (in terms of t/substance-equivalents) arisen from application of CML2 methodology aimed to estimate midpoints levels. We found that MAEP is the largely most affected category by each crop. This is only apparently a unexpected result because it could depend on the high level of pollutants generated in the upstream processes, and specially for the production of fertilizers - which negatively affected the marine ecosystem quality. Furthermore, the high level of emissions to ecosystem quality is mainly related to the emission of low amounts of certain substances, such as fluoridric acid, with an extremely high (*i.e.* more than 40.000) characterization factor on MAEP (1,4 DB Equivalents).



ADP = Abiotic Depletion Potential; **GWP** = Global Warming Potential; **ODP** = Ozone Depletion Potential; **HTP** = Human Toxicity Potential; **FAEP** = Freshwater Acquatic Ecotoxicity Potential; **MAEP** = Marine Acquatic Ecotoxicity Potential; **TEP** = Terrestrial Ecotoxicity; **AP** = Acidification Potential; **EP** = Eutrophication Potential; **POCP** = Photochemical Ozone Creation Potential.

Figure 3 - Standardized impacts of different crops (t/ substance-equivalents)

Differences among impacts by categories are very significant and it implies that some categories result to be marginally affected by crops cultivation.

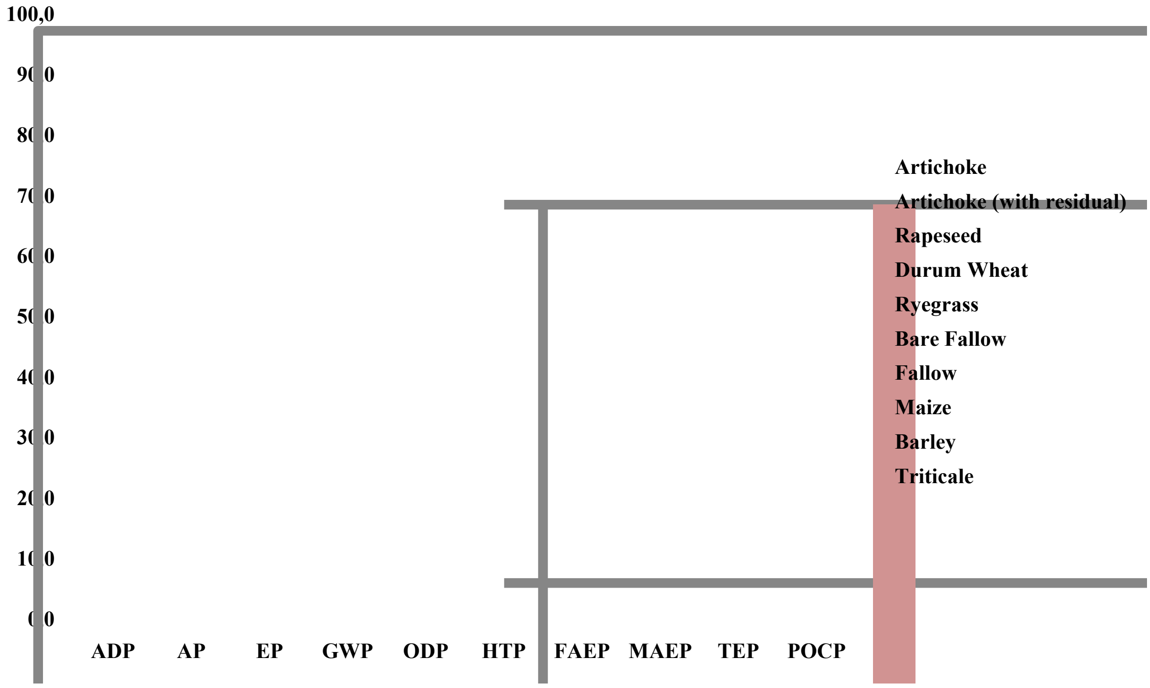
The maize shows the highest land-based impacts in all environmental categories. It basically depends on using slurry as main fertilizer. Specifically, significant use of machineries for spreading slurry represents the main impacting factor, followed by the use of slurry. Furthermore, a remarkable impact is associated to use of agricultural machinery for harvesting and to ensilage operations.

However, the characterization phase allows us to better compare the differences between the crops. Hence, impacts of other crops were expressed relatively to the maize impacts for each category (maize = 100) and are showed in Figure 4.

Also ryegrass is characterized by the application of slurry, but is generally showing lower environmental burdens than maize, due to lower amount of slurry applied to the crop. Specifically, ryegrass represents the second more impacting crop in the GWP category (58%), whereas triticale and artichoke - with harvesting of residual biomass for energy purposes - result to be the most impacting crops in the other categories.

Triticale is the second worst in five categories out of ten: ADP (33% with respect to maize impact), AP (35%), EP (44%), and ODP (34%). High burdens mainly depend on considerable use of inorganic fertilizers and machinery for harvesting biomass and for baling operations. Artichoke with residual biomass harvesting results to be the second most impacting crops in other four categories: FAEP (51%), MAEP (58%), TEP (29%), and POCP (47%).

The environmental impact generated by artichoke principally due to significant use of inorganic fertilizers plays a critical role in affecting ecotoxicity on the whole. Regarding the HTP, burden of both artichoke and triticale amounts to 30% that is the second worst impact after the maize.



ADP = Abiotic Depletion Potential; **GWP** = Global Warming Potential; **ODP** = Ozone Depletion Potential; **HTP** = Human Toxicity Potential; **FAEP** = Freshwater Acquatic Ecotoxicity Potential; **MAEP** = Marine Acquatic Ecotoxicity Potential; **TEP** = Terrestrial Ecotoxicity; **AP** = Acidification Potential; **EP** = Eutrophication Potential; **POCP** = Photochemical Ozone Creation Potential.

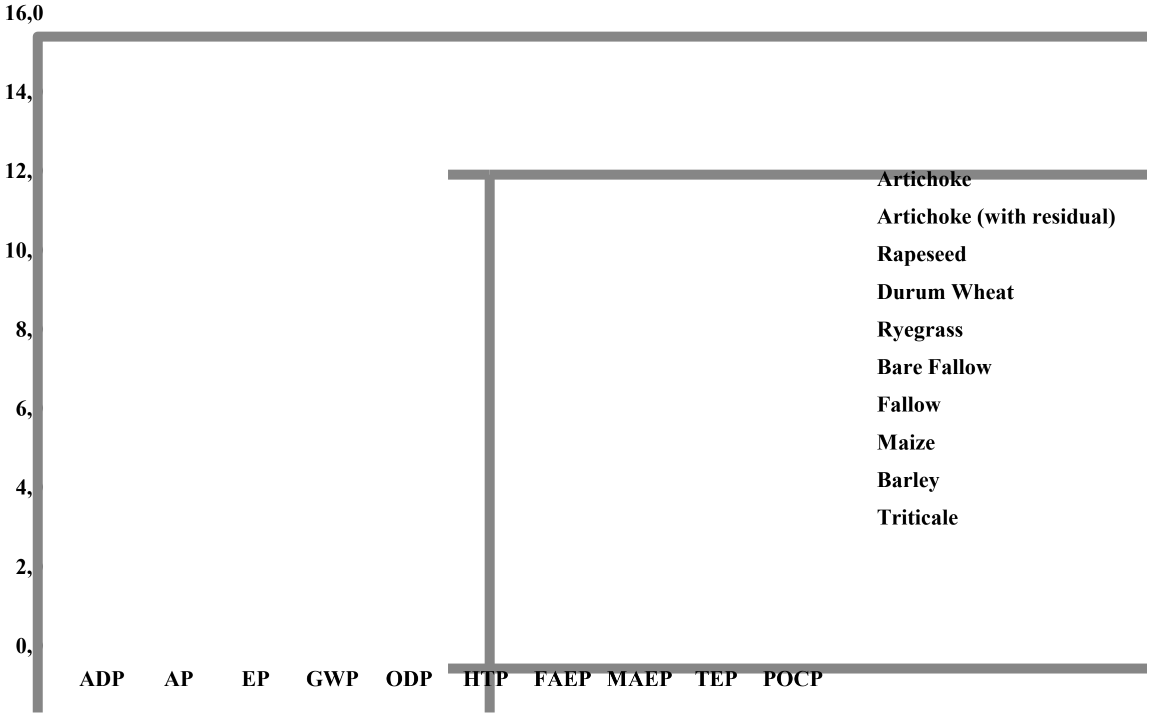
Figure 4 - Characterization on the most impacting scenario (i.e. Maize)

Generally, the remaining crops significantly differ from maize in each category. Except for fallow (substantially any environmental burden) and bare fallow (not remarkable burdens), rapeseed shows the lowest land-based impact in each category. Environmental load is equal to about 19% of maize impact regarding EP category, whereas in the others categories the impacts are ranging from less than 3% (GWP) to 9% (MAEP) compared to maize. These results might depend on the lower agronomic inputs requirements by this crop in Sardinia compared to other considered crops.

The artichoke performance in terms of environmental impacts varies depending on the destination of products. In the case of residual biomass use for energy production, the mechanical operations of harvesting and stocking residuals show an environmental burdens increase in all categories with respect to only artichoke harvesting for food purpose (not including the exploitation of residues).

The results for the other crops reveal that the environmental burdens of durum wheat, ryegrass and barley generally vary from about 20% to 30% with respect to the maximum estimated values. Specifically, in comparison with maize, the impact of durum wheat ranged from 22 to 24%, except for EP categories in which reached38%. Ryegrass scored 27-28% except, for GWP, whereas barley impacts vary from 20% to 38%.

Estimated impacts are normalized on the total emissions of EU inhabitants specifically inhabitant equivalent and are represented in Figure 5. All observed crops show the highest normalized impact in correspondence of MAEP, also if magnitude - excluding farrow and bare farrow - significantly differ among them (from 1,3 for rapeseed to more than 14 for maize). Compared to the high level of emissions pointed out in the standardization phase, the relative difference among the impact categories is significantly reduced in the normalized results, even though the MAEP is still the most impacting category under all the considered scenarios. This is mostly due to the fact that the average emission on this category, for all the human activities in the EU15 is considered basically high, conversely, the relative weight of other impact categories has been slightly increased, meaning that the overall emission in the EU15, in the specific categories, is normally lower.

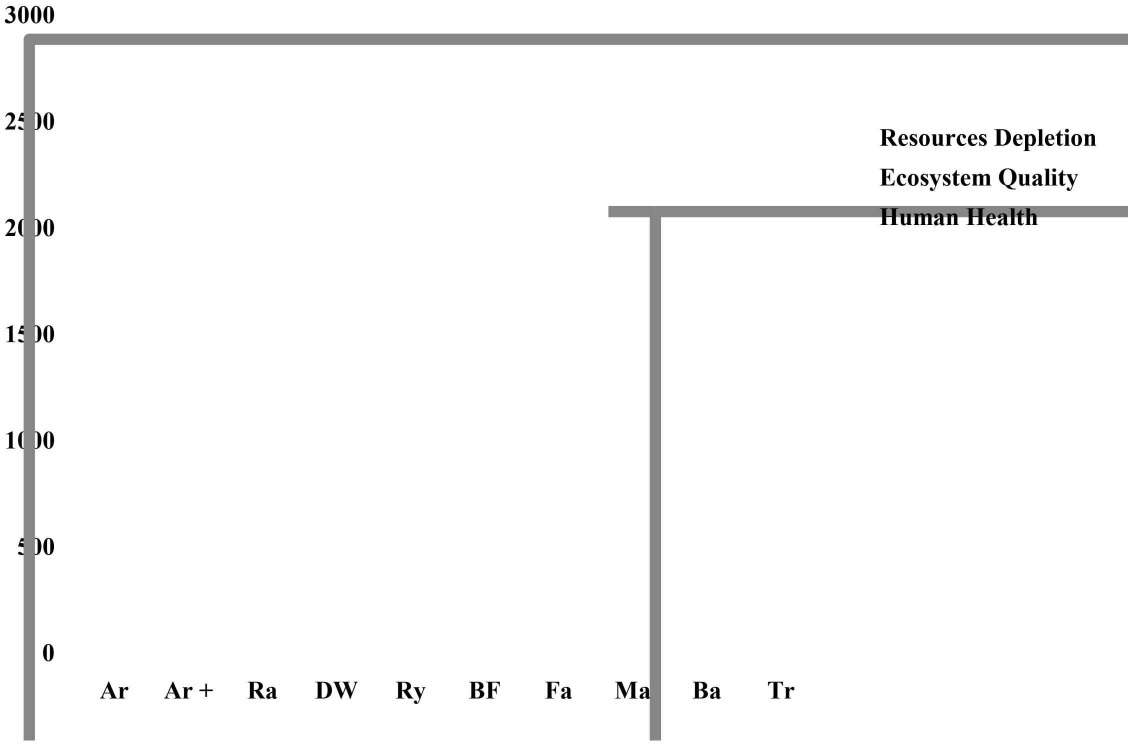


ADP = Abiotic Depletion Potential; **GWP** = Global Warming Potential; **ODP** = Ozone Depletion Potential; **HTP** = Human Toxicity Potential; **FAEP** = Freshwater Acquatic Ecotoxicity Potential; **MAEP** = Marine Acquatic Ecotoxicity Potential; **TEP** = Terrestrial Ecotoxicity; **AP** = Acidification Potential; **EP** = Eutrophication Potential; **POCP** = Photochemical Ozone Creation Potential.

Figure 5 - Normalized impacts per unit land – EU inhabitant equivalent

MAEP is followed in order of relevance by FAEP and by TEP, also if normalized impacts in this category are from 10 to 65 times lower than estimated impacts in MAEP according to the sort of crops. An important result concerns the insignificant impact of each crop in terms of OLD.

The estimated impacts by damage categories in terms of Ecopoints are reported in Figure 6. Human Health (HH) is the most affected damage category for each crop followed by Resources Depletion (RD). On the contrary, Ecosystem Quality (EQ) is scarcely damaged by each observed crop. This apparently contrasts with results reported in Figg. 4 and 5 that showed crops, maize *in primis*, produce impacting emissions of ecotoxicity compounds in marine water, fresh water, and terrestrial environment. This can be explained by different targets associated to implementation of CML 2 and Eco-indicator 99, because the former serves to estimate midpoint impacts in terms of emissions and the latter is functional for estimating endpoint impacts that regards damages. It means that high emissions do not necessarily mean high level of damage.



Ar = Artichoke; **Ar +** = Artichoke with residuals; **Ra** = Rapeseed; **DW** = Durum Wheat; **Ry** = Ryegrass; **BF** = Bare Fallow; **Fa** = Fallow; **Ma** = Maize; **Ba** = Barley; **Tr** = Triticale.

Figure 6 - Ecopoints on land basis

However, it was shown that global impact of maize corresponds to more than 2.700 Ecopoints. Among the energy cropping processes, global impact of triticale amounts to 33% than maize, whereas artichoke (with residuals) impact is equal to 23%. It must be underlined that impact arisen from rapeseed cultivation corresponds to only 5% of the maize impact.

Finally, we simulated the probable environmental effects derived from switching from some traditional cropping systems to alternative energy cropping systems. Simulations were carried out taking into account rational hypotheses of substitution according to the Sardinian agricultural characteristics. However, these formulated hypotheses allow us to describe some possible scenarios and they partially reflect the possible options of substitution at farm level.

Some of the considered scenarios and the related estimated differences in environmental impacts – in terms of Ecopoints - are reported in Table 4.

Switching from artichoke cultivation only dedicated to food production to artichoke cultivation for both food and biomass for energy scope production might generate an environmental impact increase by about 35%. Passing from a traditional system characterized by maize in double loop with ryegrass to double loop with triticale any significant difference in total environmental impact might be highlighted due to similar estimated values of Ecopoints between ryegrass and triticale.

On the other hand, in case of introduction of rapeseed in traditional rotational cropping systems, agricultural environmental burdens might significantly decrease. The entity of the decrease depends on sort of substitution. For example, we considered the case of a farm in which lands are equally subdivided among wheat, barley and fallow (bare or not). In case of barley and fallow are abandoned in favour of rapeseed and arable lands are equally cultivated by wheat and rapeseed, environmental impact might decrease, also if weakly (about -9%). Vice versa, considering the susbsitution of barley with rapeseed (without abandoning fallow), the decrease might tend to be more significant (more than 50%).

Table 4 - Cropping systems scenarios

Traditional cropping system					Energy cropping system				Impact increase
Crops	D. Wheat	Barley	B.Fallow	Total	***Crops***	D. Wheat	Rapeseed	Total	
Ecopoints	656	665.19	8.86	1,330	***Ecopoints***	656	144.9985985	801	
Ha	10	10	10	30	***ha***	15	15	30	
Total	6,566	6651.9	88.6	**13,306**	***Total***	9,849	2175.0	**12,024**	***-9.6%***
Crops	D. Wheat	Barley	Fallow	Total	***Crops***	D. Wheat	Rapeseed	Total	
Ecopoints	656	665.19	0.00	1,321	***Ecopoints***	656	145	801	
Ha	10	10	10	30	***ha***	15	15	30	
Total	6,566	6651.9	0.0	**13,218**	***Total***	9,849	2,175	**12,024**	***-9.0%***
Crops	D. Wheat	Barley		Total	***Crops***	D. Wheat	Rapeseed	Total	
Ecopoints	656	665.19		1,321	***Ecopoints***	656	145	801.62	
Ha	15	15		30	***ha***	15	15	30	
Total	9,849	9977.8		**19,827**	***Total***	9,849	2,175	**12,024**	***-39.4%***
Crops	D. Wheat	Barley		Total	***Crops***	D. Wheat	Rapeseed	Total	
Ecopoints	656	665.19		1,321	***Ecopoints***	656	145	801	
Ha	15	15		30	***ha***	10	20	30	
Total	9,849	9977.8		**19,827**	***Total***	6,566	2,900	**9,466**	***-52.3%***
Crops	Maize	Ryegrass		Total	***Crops***	Maize	Triticale	Total	
Ecopoints	2,773	921.71		3,694	***Ecopoints***	2,773	917	3,691	
Ha	5	5		10	***ha***	5	5	10	
Total	13,865	4608.5		**18,474**	***Total***	13,865	4,589	**18,455**	***-0.1%***
Crops	Artichoke			Total	***Crops***	Artichoke (with residuals)		Total	
Ecopoints	480			480	***Ecopoints***	688		688	
Ha	10			10	***ha***	10		10	
Total	4,808			**4,808**	***Total***	6,886		**6,886**	***43.2%***

4. DISCUSSION

Several studies have highlighted advantages and disadvantages of energy crops cultivation, but the debate on environmental sustainability of bioenergy is still running (Muller, 2009; Dalla Marta *et al.*, 2010; Fernando *et al.*, 2010; Harvey and Pilgrim 2011; Murphy *et al.*, 2011; Bringezu *et al.*, 2012; Uchida and Hayashi, 2012; Bird *et al.*, 2013; Felten *et al.*, 2013; Mangoyana *et al.*, 2013; Bacenetti *et al.*, 2014). A variety of factors can play a critical role in turning a crop the perfect candidate for bioenergy production. Monti *et al.* (2009) indicated that energy crops ideally should provide high levels of dry matter yields and, at the same time, they should show low requirements in terms of use of inputs or should not require additional investments for their practice. However, a positive result is mainly dependent on energy cropping management, especially regarding cultivation technique and production inputs use that are the most responsible factors of environmental impacts. In this sense, agronomic aspects represent a critical factor in order to introduction of energy crops into traditional farming systems due to consequent effects on the environment (Fernando *et al.*, 2010; Zegada- Lizarazu *et al.*, 2010).

In this study, we found that environmental impacts generated by energy crops in Sardinia widely vary among energy crops under consideration. Maize is the most impacting crops, principally due to high volumes of slurry used in the production as fertilizer. Giola *et al.* (2012) found that use of slurry in maize cultivation is an important source of high values of nitrogen leaching in Sardinian arable lands. This might explain the relevant environmental burdens of maize.

Rapeseed shows the lowest impact levels in each category. Similar results were carried out by Fazio and Monti (2011) and Baquero *et al.* (2013). Low environmental impacts might depend on agronomic technique adopted since it is generally characterized in Sardinia by any use of water irrigation and poor requirement of inputs. On the other hand, literature has showed that rapeseed reveals significant levels of environmental burdens in case of intensive agricultural practices (González-García *et al.*, 2013b). This implies that agronomic techniques and sites where crops grown should be carefully selected in order to minimize these impacts.

In common with the other traditional crops cultivated for food or feed purposes, energy crops showed the highest impact with reference to the MAEP category. According to Fazio and Monti (2011), this might depend on significant use of chemical and organic fertilizers that are among the responsible factors negatively affect the marine ecosystem quality. The rationale underline in the LCA approach is that industrial - in the case of chemical - or agro-zootechnical - in the case of organic - fertilizers production highly contribute to generate pollution, with serious implications in marine ecoxicity.

According to empirical evidences found in this study environmental burdens arisen from introduction of energy crops in Sardinian farming systems have been evaluated. However, this assessment cannot be considered aside from cropping systems types and the possible scenarios for the introduction of energy crops. More specifically, some probable scenarios of rapeseed, maize and artichoke introduction for energy purpose needs to be considered.

These scenarios should fit rational agronomic and farming choices, especially concerning land use change and land suitability for the considered crops.
Therefore, in case of artichoke, we hypothesized an addition of the biomass harvesting process to traditional artichoke production. In the case of maize, the change of target (food/feed or energy) does not implicate any process change, hence environmental impacts associated to maize production should not modify switching from food/feed towards energy purpose in terms of agro-technique, for sure, shifting a crop from the food/feed to the energy chain can lead to Indirect Land Use Change (ILUC) effects, that have not been evaluated in this study.
However, maize is generally cultivated in rotation with other crops, ryegrass and triticale *in primis*. Therefore we assessed possible differences on environmental burdens caused by replacing the associated crop in its own cropping system (from ryegrass to triticale). In the case of rapeseed, we took into account some scenarios characterized by introducing rapeseed into cereal cropping systems.
It must be underlined that a few LCA studies focused on comparing several environmental burdens on agricultural systems have been carried out, but generally differentials have been estimated only among different scenarios for single crops (Bacenetti *et al.*, 2014). The present study pointed out that a cropping system perspective can give more useful information on environmental effects arising from a possible development of energy crops in Sardinia, enriching the findings related to a basic intra-crop comparison and providing more evidences in term of environmental sustainability.
The first hypothesis - related to artichoke - basically corresponds to a comparison between artichoke cultivation without and with residual biomass harvesting. In this scenario, environmental impact might increase by 43% (in terms of Ecopoints) mainly due to implementation of additional harvesting and transport processes. This means that the residual biomass use of artichoke, although potentially convenient in terms of energy production, results critical by an environmental sustainability point of view, given the state of technology and agronomic techniques used. It suggests that it would be useful to improve efficiency in machinery use in order to decrease the environmental burdens. Furthermore, adoption of practices based on minimizing use of fertilizers need to be achieved as to limit impacts on marine, freshwater, and terrestrial ecotoxicity.
The second hypothesis - related to maize - concerns the change of production target, without modifying the covered land, and the replacement of ryegrass with triticale. On the basis of the LCA results, the environmental impact variation was essentially equal to

zero. This suggests that, excluding the ILUC effects, any significant difference should be expected switching from food or feed to energy target both at crop level (maize) and at cropping system level (substituting ryegrass with triticale into the maize rotation option). This occurs because the replacement of ryegrass with triticale seems to scarcely change the environmental burdens, on average. The high negative effects caused by ryegrass especially on GWP and MAEP (mainly due to slurry use and ploughing operation) might be balanced by the significant negative impacts from triticale cultivation on other impact categories, *e.g.* MAEP, ADP, and EP (basically due to baling and transport operations).

The third hypothesis – related to rapeseed – is based on a *status quo* characterized by co-presence of durum wheat, barley and fallow (bare or not) and concerns a partial substitution of cereals with rapeseed. We found that in case of replacing barley and fallow with rapeseed, environmental impacts might tend to decrease despite the null environmental effect caused by fallow. It suggests that rapeseed might generate positive environmental effects if introduced into cereal cropping systems. These effects appear to be progressively more significant in case of only replacing of barley and, especially, durum wheat that reveal important contribute of rapeseed in improving environmental benefits. In our opinion, these findings give comforting information on environmental sustainability associated to introduction of rapeseed in Sardinia, above all considering that usually rapeseed has been introduced in Sardinia replacing cereals (Solinas *et al.*, 2011).

Finally, it must be underlined that considerations arisen from LCA need to be considered as general guidelines, more than specific indications, because the measure of impacts in terms of Ecopoints shows some not negligible weak points if applied on agricultural systems, *e.g.* difficulty to precisely quantify interactions between crop and soil type or climate, that can affect some impact categories such as EP, FAEP or MAEP (Monti *et al.*, 2009). However, use of Ecopoints for assessing possible environmental benefits caused by introduction of energy crops allowed to individuate the outcomes in terms of reduction of damages. In the light of evidences reported in Table 4, an expected decrease of environmental impacts produced, as main consequence, an improving of human health since HH is the most affected damage category on the whole.

5. Conclusions

Life Cycle Assessment (LCA) was applied on some traditional and energy crops in Sardinia in order to evaluate probable changes in environmental impacts due to possible replacement of food/feed crops with energy crops. Furthermore LCA results allowed us to assess impacts variations arisen from possible substitutions between different cropping systems. Analysis was carried out through a land-based approach and it points out that maize reveals the worst environmental performance, especially because of large using of organic fertilizer. Vice versa, rapeseed appears to be the most environmental sustainable crop due to low inputs requirements that its cultivation needs in the Sardinian context. LCA analysis also found that marine water ecotoxicity is the impact category most affected by all observed crops due to considerable use of fertilizers as well as the global warming potential is affected by emissions due to harvesting machinery operations, especially in the case of triticale. Concerning the damage category, human health showed the most significant damage by each crop.

The analysis findings suggest that replacement of traditional crops with energy crops might produce controversial benefits in terms of environmental sustainability variation. Specifically, introduction of rapeseed into cereal cropping systems should show positive effects on environmental farming sustainability, whereas use of maize and artichoke for energy purpose might determine null or negative environmental outcomes, respectively. It means that results are encouraging enough regarding the introduction of energy crops into Sardinian cropping systems, whereas they suggest that any reduction in environmental burden should be expected in case of conversion from food/feed to energy targets in case of single specific crop (*e.g.*, maize, artichoke).

However, these findings should be taken into account with caution, although the LCA procedure appears suitable for analyzing agricultural production, Firstly, some environmental factors could be not considered because are related to site-specific characteristics (*e.g.*, previous crops invested, soil erosion). This lack nowadays represents a critical shortcoming in the LCA analysis. Secondly, environmental assessments were performed given invariant technology and agronomic techniques. It implies that a change in technology or in use of inputs could produce different outcomes and, as a consequence, new environmental "hot spots" could come to light from LCA analysis. Finally, more empirical evidences - also using LCA procedure - need to be found as to support farmers'choices and policy makers' decision in order to ensure the sustainable development of energy crops in Sardinia.

REFERENCES

1. Anand S., Hanson K., 1997. Disability-adjusted life years: a critical review. Journal of Health Economics 16, 685-702.

2. Audsley E., Alber S., Clift R., Cowell S., Crettaz P., Gaillard G., Hausheer J., Jolliett O., Kleijn R., Mortensen B., Pearce D., Roger E., Teulon H., Weidema B., van Zeijts H., 2003. Harmonisation of Environmental Life Cycle Assessment for Agriculture. Final Report. Concerted Action AIR3-CT94-2028. European Commission. DG VI Agriculture, Silsoe Research Institute, Silsoe, UK.

3. Bacenetti J., Fusi A., Negri M., Guidetti R., Fiala M., 2014. Environmental assessment of two different crop systems in terms of biomethane potential production. Science of the Total Environment 466-467, 1066-1077.

4. Ballarin A., Vecchiato D., Tempesta T., Marangon F., Troiano S., 2011. Biomass Energy production in agriculture: A weighted goal programming analysis. Energy Policy 39, 1123-1131.

5. Baquero G., Esteban B., Puig R., Riba J.R., Rius A., 2013. Environmental life cycle assessment of rapeseed straight vegetable oil as self-supply agricultural biofuel. Renewable Energy 50, 142-149.

6. Bare J. C., Hofstetter P., Pennington D. W., Udo de Haes H. A., 2000. Midpoints versus Endpoints: The Sacrifices and Benefits. Int. J. LCA 5 (6), 319-326.

7. Baumann H., Tillman A. M., 2004. The Hitch Hiker's Guide to LCA: An Orientation in Life Cycle Assessment Methodology and Application. Studentlitteratur AB, Lund, Sweden, pp. 543.

8. Bianchi P. G., Castelli P. G., Centolani G., Cugudda L., Di Vittorio G., Ferrarotti M., Guadagni A., Lechi G. M., Milani G., Morini M., Mura M., Olivero G., Paiano G., Piccarolo P., Provolo G., Rebasti P., Sangiorgi F., Santoro R., Sicheri G., Toccolini A., 1997.Manuale di Agricoltura. Ulrico Hoepli Editore, 1997, pp. 2608.

9. Bird D. N., Zanchi G, Pena N., 2013. A method for estimating the indirect land use change from bioenergy activities based on the supply and demand of agricultural-based energy, Biomass and Bioenergy, forthcoming.

10. Brentrup F., Küsters J., Lammel J., Kuhlmann H., 2000. Methods to estimate on-fiield nitrose emissions from crop production a san input to LCA studies in the agricultural sector. Int. J. LCA 5 (6), 349-357.

11. Brentrup F., Küsters J., Kuhlmann H., Lammel J., 2004. Environmental impact assessment of agricultural production systems using the life cycle assessment methodology I. Theoretical concept of a LCA method tailored to crop production. Europ. J. Agronomy 20, 247-264.

12. Bringezu S., O'Brien M., Schütz H., 2012. Beyond biofuels: Assessing global land use for domestic consumption of biomass. A conceptual and empirical contribution to sustainable management of global resources. Land Use Policy 29, 224- 232.

13. Carozzi M., Ferrara R.M., Rana G., Acutis M., 2013. Evaluation of mitigation strategie sto reduce ammonia losses from slurry fertilisation on arable lands. Science of the Total Environment 449, 126-133.

14. Ciaian P., Kancs d., 2011. Interdependencies in the energy–bioenergy–food price systems: A cointegration analysis. Resource and Energy Economics 33, 326-348.

15. CML Baseline 2000 method. Leiden (NL): Centre for Environmental Studies (CML), University of Leiden, http://www.leidenuniv.nl/interfac/cml/ssp/lca2/index.html; 2001.

16. Dalla Marta A., Mancini M., Ferrise R., Bindi M., Orlandini S., 2010. Energy crops for biofuel production: Analysis of the potential in Tuscany. Biomass and Bioenergy 34, 1041-1052.

17. Darnhofer I., Bellon S., Dedieu B., Milestad R., 2010. Adaptiveness to enhance the sustainability of farming systems. A review. Agron. Sustain. Dev. 30, 545-555.

18. Deligios P. et al. 2011. Opportunità e limiti dei sistemi colturali erbacei per la produzione di energia in Sardegna. Conv. Energie Rinnovabili in Sardegna, Attività di ricerca e prospettive di sviluppo dell'Univ. di Sassari, 14 maggio 2011, Sassari.

19. de Paz J.M., Ramos C., 2004. Simulation of nitrate leaching for different nitrose fertilization rates in a region of Valencia (Spain) using a GIS-GLEAMS system. Agriculture,Ecosystems and Environment 103, 59-73.

20. EEA (European Environment Agency), 2006. How much bioenergy can Europe produce without harming the environment?. EEA, Copenhagen 2006, Report no. 7, 67pp.

21. European Commission, 2004. Integrating environmental considerations into other policy areas- a stocktaking of the Cardiff process. Commission Working Document, Brussels, COM (2004) 394 final, 2004.

22. European Commission, 2005a. On the review of the Sustainable Development Strategy: A platform for action. Communication from the Commission to the Council and the European Parliament, COM (2005) 658 final, Brussels, 2005.

23. European Commission, 2005b. Thematic Strategy on the sustainable use of natural resources. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM (2005) 670 final, Brussels, 2005.

24. European Commission, 2009. Mainstreaming sustainable development into EU policies: 2009 Review of the European Union Strategy for Sustainable Development. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM (2009) 400 final, Brussels, 2009.

25. European Commission, 2010a. The CAP towards 2020: Meeting the food, natural resources and territorial challenges of the future. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM (2010) 672 final, Brussels, 2010.

26. European Commission, 2010b. EUROPE 2020 A strategy for smart, sustainable and inclusive growth. Communication from the Commission, COM(2010) 2020, Brussels, 2010.

27. European Commission, 2011. A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM (2011) 21 final, Brussels, 2011.

28. European Commission, 2012. Proposal for a Directive of the European Parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources. COM(2012) 595 final, Brussels, 2012.

29. European Commission, 2013. Renewable energy progress report. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM (2013) 175 final, Brussels, 2013.

30. European Commission, 2013. Communication from the Commission to the European Parliament, the Council, Building the Single Market for Green Products, Facilitating better information on the environmental performance of products and organizations. COM(2013) 196 final, Brussels, 2013.

31. Erb K.-H., Haberl H., Plutzar C., 2012. Dependency of global primary bioenergy crop potentials in 2050 on food systems, yields, biodiversity conservation and political stability. Energy Policy 47, 260-269.

32. FAOSTAT, 2013. http://faostat3.fao.org/faostat-gateway/go/to/home/E

33. Fazio S., Monti A., 2011. Life cycle assessment of different bioenergy production systems including perennial and annual crops. Biomass and Bioenergy 35, 4868-4878.

34. Felten D., Fröba N., Fries J., Emmerling C., 2013. Energy balances and greenhouse gases-mitigation potentials of bioenergy cropping systems (Miscanthus, rapeseed, and maize) based on farming conditions in Western Germany. Renewable Energy 55, 160-174.

35. Fernando A. L Duarte M. P, Almeida J., Boléo S., Mendes B., 2010. Environmental impact assessment of Energy crops cultivation in Europe. Biofuels, Bioprod. Bioref. 4, 594-604.

36. Fox-Rushby JA., Hanson K., 2001. Calculating and presenting disability-adjusted life years (DALYs) in cost-effectiveness analysis. Health Policy and Planning 16 (3), 326-331.

37. Fritsche U. R., Sims R. E. H., Monti A., 2010. Direct and indirect land-use competition issues for Energy crops and their sustainable production – an overview. Biofuels, Bioprod. Bioref. 4, 692-704.

38. Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Heck T., Hellweg S., Hischier R., Nemecek T., Rebitzer G., Spielmann M., Wernet G., 2007. Overview and Methodology. Ecoinvent report No. 1. Swiss Centre for Life Cycle Inventories, Dübendorf, 2007.

39. Giannoccaro G., Berbel J., 2012. The Determinants of Farmer's Intended Behaviour Towards the Adoption of Energy Crops in Southern Spain: an Application of the Classification Tree-Method. Bio-based and Applied Economics 1(2), 199-212.

40. GBEP (Global Bioenergy Partnership), 2011. The Global Bioenergy Partnership Sustainability Indicators for Bioenergy. FAO/GBEP, pp. 204.

41. Giola P., Basso B., Pruneddu G., Giunta F., Jones J. W., 2012. Impact of manure and slurry applications on soil nitrate in a maize–triticale rotation: Field study and long term simulation analysis. Europ. J. Agronomy 38, 43-53.

42. Goedkoop M., Spriensma R., 2001. The Eco-indicator 99 A damage oriented method for Life Cycle Impact Assessment. Methodology Annex, 3rd ed., PRé Consultants, Amersfoort.

43. Goedkoop M., De Schryver A., Oele M., Durksz S., de Roest D., 2010. Introduction to LCA with SimaPro 7. PRé Consultants, Netherlands.

44. Goedkoop M., Heijungs R., Huijbregts M., De Schryver A., Struijs J., van Zelm R., 2013. Recipe 2008. A life cycle impact assessment method which comprises harmonised category indicators at hte midpoint and the endpoint level. First edition (version 1.08) Report I: Characterisation. pp. 126.

45. Goglio P., Bonari E., Mazzoncini M., 2012. LCA of cropping systems with different external input levels for energetic purposes. Biomass and Bioenergy 42, 33-42.

46. González-García S., Bacenetti J., Negri M., Fiala M., Arroja L., 2013a. Comparative environmental performance of three different annual energy crops for biogases production in Northern Italy. Journal of Cleaner Production 43, 71-83.

47. González-García S., García-Rey D., Hospido A., 2013b. Environmental life cycle assessment for rapeseed-derived biodiesel. Int J Life Cycle Assess. 18 (1), 61-76.

48. Haas G., Wetterich F., Geier U., 2000. Life Cycle Assessment Framework in Agriculture on the Farm Level. Int. J. LCA 5 (6), 345-348.

49. Hamers T, Aldenberg T, van de Meent TD., 1996. Indicator effect toxic substances (i-tox). RIVM report n. 607128001. Bilthoven (NL): RIVM; 1996, pp. 95.

50. Harvey M., Pilgrim S., 2011. The new competition for land: Food, energy, and climate change. Food Policy 36, S40–S51.

51. Hischier R., Weidema B., Althaus H.-J., Bauer C., Doka G., Dones R., Frischknecht R., Hellweg S., Humbert S.,Jungbluth N., Köllner T., Loerincik Y., Margni M. and Nemecek T., 2010. Implementation of Life Cycle Impact Assessment Methods. Ecoinvent report No. 3, v2.2. Swiss Centre for Life Cycle Inventories, Dübenford.

52. IPCC 2006. Guidelines for National Greenhouse Gases Inventories, Prepared by the National Greenhouse Gases Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

53. ISO 14040, 2006. Environmental Management – Life Cycle Assessment – Principles and Framework.

54. Jolliet O., Müller-Wenk R., Bare J., Brent A., Goedkoop M., Heijungs R., Itsubo N., Peña C., Pennington D., Potting J., Rebitzer G., Stewart M., Udo de Haes H., Weidema B., 2004. The LCIA Midpoint –damage Frameworj of the UNEP/SETAC Life Cycle Initiative. Int. J. LCA 9 (6), 394-404.

55. Krasuska E., Cadórniga C., Tenorio J. L, Testa G., Scordia D., 2010. Potential land availability for energy crops production in Europe. Biofuels, Bioprod, Bioref. 4, 658-673.

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

57. Levidow L., 2013. EU criteria for sustainable biofuels: Accounting for carbon, depoliticising plunder. Geoforum 44, 211-223.

58. Malça J., Coelho A., freire F., 2013. Environmental life-cycle assessment of rapeseed-based biodiesel: Alternative cultivation systems and locations. Applied Energy (2013), http://dx.doi.org/10.1016/j.apenergy.2013.06.048, forthcoming.

59. Mangoyana R. B., Smith T. F., Simpson R., 2013. A systems approach to evaluating sustainability of biofuel systems. Renewable and Sustainable Energy Reviews 25, 371-380.

60. Manners I., 2008. The normative ethics of the European Union. International Affairs 84 (1), 45-60.

61. Montanarella L., Vargases R., 2012. Global governance of soil resources as a necessary condition for sustainable development. Current Opinion in Environmental Sustainability 4, 559-564.

62. Monti A., Fazio S., Venturi G., 2009. Cradle-to-farm gate life cycle assessment in perennial energy crops. Europ. J. Agronomy 31, 77-84.

63. Mourad A. L., Coltro L., Oliviera P. A.P.L.V., Kletecke R., Paulo J., Baddini O.A., 2007. A Simple Methodology for Elaborating the Life Cycle Inventory of Agricultural Products. Int. J. LCA 12 (6), 408-413.

64. Muench S., Guenther E., 2013. A systematic review of bioenergy life cycle assessment. Applied Energy 112, 257-273.

65. Muller A., 2009. Sustainable agriculture and the production of biomass for energy use. Climatic Change 94, 319-331.

66. Murphy R., Woods J., Black M., McManus M., 2011. Global developments in the competition for land from biofuels. Food Policy 36, S52-S61.

67. Murray C.J.L., 1994. Quantifing the burden of desease: the tecnica basis for disability-adjusted life years. Bulletin of the World Health Organization 72, 429-445.

68. Panoutsou C., Eleftheriadis J., Nikolaou A., 2009. Biomass supply in EU27 from 2010 to 2030. Energy Policy 37, 5675-5686.

69. Paul H., Econexus, 2013. A foreseeable disaster: The European Union’s agroenergy policies and the global land and water grab. Franco (Ed.), pp. 40.

70. Pellizzi G., 1996. Meccanica e meccanizzazione agricola. Edagricole, Bologna, 1996, pp. 739.

71. Pennington D.W., Potting J., Finnveden G., Lindeijer E., Jolliet O., Rydberg T., Rebitzer G., 2004. Life cycle assessment Part 2: Current impact assessment practice. Environmental International 30, 721 - 739

72. Peruzzi A., Sartori L., 1997. Guida alla scelta ed all’impiego delle attrezzature per la lavorazione del terreno. Edagricole, Bologna, 1997, pp. 235.

73. Rathmann R., Szklo A., Schaeffer R., 2010. Land use competition for production of food and liquid biofuels: An analysis of the arguments in the current debate. Renewable Energy 35, 14-22.

74. Ribaudo F., 2011. Prontuario di agricoltura. Ulrico Hoepli Editore, 2011, pp. 1150.

75. Scarlat N., Dallemand J.-F., 2011. Recent developments of biofuels/bioenergy sustainability certification: A global overview. Energy Policy 39, 1630-1646.

76. Scarlat N., Dallemand J.-F., Banja M., 2013. Possible impact of 2020 bioenergy targets on European Union land use. A scenario-based assessment from national renewable energy action plans proposals. Renewable and Sustainable Energy Reviews 18, 595-606.

77. Shopper D., Pereira J., Torres A., Cuende N., Alonso M.,Baylin A., Ammon C., Rougemont A., 2000. Estimating the burden of desease in one Swiss canton: what do

disability-adjusted life years (DALY) tell us?. International Journal of Epidemiology, 29, 871-877.

78. Solinas S., Seddaiu G., Roggero P.P., 2011. Politiche agro-energetiche in Sardegna. Agriregionieuropa 26, 71-74.

79. Thrän D., Seidenberger T., Zeddies J., Offermann R., 2010. Global biomass potentials - Resources, drivers and scenario results. Energy for Sustainable Development 14, 200-205.

80. Uchida S., Hayashi K., 2012. Comparative life cycle assessment of improved and conventional cultivation practices for energy crops in Japan. Biomass and Bioenergy 36, 302-315.

81. Udo de Haes H. A., Jolliet O., Finnveden G., Huaschild M., Krewitt W., Müller-Wenk R., 1999. Best Available Practice Regarding Impact Categories and Category Indicators in Life Cycle Impact Assessment. Int. J. LCA 4 (2), 66-74.

82. van Dam J., Junginger M., Faaij A.P.C., 2010. From the global efforts on certification of bioenergy towards an integrated approach based on sustainable land use planning. Renewable and Sustainable Energy Reviews 14, 2445-2472.

83. Van Oers L, de Koning A, Guinee` JB, Huppes G., 2002. Abiotic resource depletion in LCA. Amsterdam (NL): Road and Hydraulic Engineering Institute; 2002, pp. 75.

84. Vanden Brande E., 2009. Green Civilian Power Europe. In: Orbie J. (Ed), Europe's Global Role: External Policies of the European Union. Ashgate, pp.157-179.

85. Van Stappen F., Brose I., Schenkel Y., 2011. Direct and indirect land use changes issues in European sustainability initiatives: State-of-the-art, open issues and future developments. Biomass and Bioenergy 35, 4824-4834.

86. Zegada-Lizarazu W., Elbersen H. W., Cosentino. S. L., Zatta A., Alexopoulou E., Monti A., 2010. Agronomic aspects of future energy crops in Europe. Biofuels, Bioprod. Bioref. 4, 674–691.

87. Zegada-Lizarazu W., Monti A., 2011. Energy crops in rotation. A review. Biomass and Bioenergy 35, 12-25.

Projects links

1. Agroscenari - Scenarios of adaptation to climate change in Italian agricolture, 2009-2014. Ministero delle Politiche Agricole Alimentari e Forestali (MiPAAF), http://www.agroscenari.it/

2. BIOENERGIE, 2006-2013. Consiglio per la Ricerca e la sperimentazione in Agricoltura (CRA). http://sito.entecra.it/portale/cra_progetto_dettaglio.php?id_progetto=%2229059d35-367a-34c9-4a7e-473c59e255fa%22&lingua=EN&opz_menu=6

3. ORWEEDS - Metodi indiretti per la gestione delle infestanti in orticoltura biologica, 2010-2012. Centro per lo studio delle relazioni tra pianta e suolo (CRA - RPS). http://www.aiab.it/index.php?option=com_content&view=article&id=643&Itemid=207

4. SIMBIOVEG - Sistemi e metodi di agricoltura biologica per il miglioramento della qualità delle produzioni vegetali e dell'ambiente, 2006- 2009. Scuola Superiore di Studi Universitari e di Perfezionamento Sant'Anna di Pisa. http://www.aiab.it/index.php?option=com_content&view=article&id=424:simbioveg&catid=4:progetti-di-ricerca

CONCLUSIONS

This research aimed to assess the environmental implications derived from a possible development of energy crops in Sardinia. Quantitative assessment was supported by qualitative analyses aimed to highlight the economic, farming and institutional contest that characterize Sardinian farming systems and, especially, these systems suitable for introducing energy crops or for orienting production to biomass to energy purpose. Specifically, relevance was put on understanding stakeholders and farmers' perspectives on practicing energy crops and the role of environmental issues in conditioning farmers' views and choices. This was evaluated preliminarily to a quantitative analysis, that assesses the environmental impacts of energy crops in Sardinia on the whole, considering the entire life of cycle of the cropping production.

In a first phase, we investigated on the possibility of developing energy crops cultivation in Sardinia on the basis of the perspectives of farmers and other stakeholders. Applying the analytical framework developed into the Social Learning for the Integrated Management (SLIM and sustainable use of water at catchment scale) Project, we used a stakeholders' involvement approach in order to evaluate which factors mainly might affect development of energy crops. This was assessed according to the stakeholders' perspectives as to put on evidence the most significant criticities and priorities and to give us a framework able to contextualize the research object.

Obviously, particular relevance was put on assessing the role of environmental issues in conditioning stakeholders' perspectives. Analysis was performed with reference to two specific territorial and productive realities: the Nurra and the Arborea regions, characterized by different elements in terms of farming, cropping systems, farmers' behaviours, and sort of energy crops cultivated.

Among the main results, we found that environmental impacts caused by energy crops cultivation does not represents a leading factor in conditioning energy crops development according to stakeholders' perspectives. In other terms, farmers and stakeholders are conscious on risks associated to agriculture and livestock in negatively affecting environmental externalities and on positive role that practices of energy crops could play in reducing environmental impacts, but at the same time these implications appear to be non influential in conditioning farmers' choices on adopting energy crops.

However, it is a common opinion in the specialized literature that environmental implications of energy crops cultivation are not often managed according to local rural stakeholders' perspectives and, particularly, to local farmers' views. Specifically to farmers, adoption of energy crops cannot leave aside from their perspectives on environmental burdens caused by these crops. This is because well knowledge and perceptions on environmental issues - together with economic and agronomic implications - should favourite a more harmonic and sustainable energy cropping systems development. Therefore, in the light of findings highlighted in Chapter 1, it was useful knowing more in depth farmers' perspectives on possibility of future development of energy crops at local level and on environmental effects caused by these crops. This in order to individuate possible farmers' profiles able to perceive both positive environmental impacts caused by energy crops growing and good possibility of development for the sector.

The second phase was devoted on this scope. With reference to the case study of the Nurra geographical region, we estimated some farmers' profiles according to their perspectives on environmental burdens of energy crops cultivation in Sardinia and on some structural, productive and behaviour factors. Specific attention was focused on who have already invested part of their own land in energy crops in the past as to verify possible relationship between their beliefs on possible re-introduction of energy crops in their own farms and their perspectives on environmental effects caused by them. On the basis of results preliminarily found, we focused attention on two specific environmental effects: reduction of produced greenhouse gases (GHGs) emissions and possible competition in land use derived by substitution of traditional crops with energy crops.

A Multiple Correspondence Analysis (MCA) was applied in order to estimate farmers' profiles, since its suitability in estimating relationship among different categories of factors (*e.g.*, structural, behavioural, technical, managerial) with the scope to individuate some farmers' profiles. We found that perspectives on positive environmental effects caused from energy crops in reducing GHGs emissions and not incentive land competition are strongly related to positive farmers' expectations on possible re-introduction of energy crops into local cropping systems. This implies that environmental burdens do not represent constraint factors in farmers' decision to introduce energy crops in their own farms.

As a consequence of estimated findings, more understanding scientific information on environmental issues by part of farmers could change their perspectives. For example, positive empirical evidences on environmental impacts derived from energy crops could strengthen farmers' belief in the environmental role played by energy crops and it might foster them to introduce energy crops. More understanding on these issues can also allow farmers to partially overcome some economic (*e.g.*, asymmetries between demand and supply of vegetable oil locally) and agronomic (*e.g.*, characteristics and fertility of soils, climate conditions) limitations that have so far hampered the development of the sector in Sardinia.

Hence, the last step was assessing the probable environmental impacts associated to a possible introduction of energy crops in the Sardinian farming systems. This was suggested by the need to accurately assess environmental impacts as to put on evidence the real environmental implications associated to energy crops cultivation and to provide information for addressing a sustainable energy crops development. A useful perspective was individuated in assessing impact differentials caused by replacement of traditional (food/feed purpose) crops with energy crops.

The last phase was addressed to assess environmental burdens derived from switching from traditional to energy systems (or to mixed systems). Our purpose was to individuate the environmental "hot spots" associated to each energy crops and to each scenario hypothesis in order to give useful information for supporting both farmers and policy makers' decisions.

A Life Cycle Assessment (LCA) methodology was used in order to assess environmental impacts. LCA analysis allowed us to assess the impact produced by each observed - traditional and energy - crop on the environment on the whole, through a "cradle to farm gate" approach. In other words, global environmental impact of each crop was assessed taken into consideration the technical inputs, agronomic and mechanical processes, and agricultural production during the entire life of cycle of an annual crop production. LCA analysis focused on the following annual crops: durum wheat (*Triticum turgidum* L. subsp. *durum*), barley (*Hordeum vulgare* L.), maize (*Zea mays* L.), ryegrass (*Lolium multiflorum* Lam.), triticale, rapeseed (*Brassica napus* L. var. *Oleifera* D.C.), artichoke (*Cynara cardunculus* L. subsp. *Scolymus* (L.) Hegi, cv. Spinoso Sardo), fallow and bare fallow. Rapeseed is a "pure" energy crop, whereas maize and artichokes was considered both in terms of food and energy crop.

LCA was performed through a land-based approach and it put on evidence that maize reveals the worst environmental burdens, whereas rapeseed appears to be the most environmental sustainable crop due to low inputs requirements that its cultivation needs.

The analysis findings suggest that replacement of traditional crops with energy crops might produce controversial benefits in terms of environmental sustainability variation.

Introduction of rapeseed into cereal cropping systems show estimated positive effects on environmental farming sustainability. On the contrary, use of maize and artichoke for energy purpose might determine null or negative environmental outcomes, respectively. Summarizing, LCA results are encouraging enough regarding the introduction of energy crops into Sardinian cropping systems, whereas they suggest that any reduction in environmental burdens should be expected in case of conversion from food/feed to energy targets in case of single specific crop.

In conclusion, positive implications should derive from both analysis on environmental impacts of energy crops and from stakeholders and Sardinian farmers' perspectives on introducing these crops in the next future. It was not an obvious result, given the controversial empirical evidences on environmental effects of energy crops and the skepticism that could characterize farmers and stakeholders in introducing innovations or replacing traditional crops in Sardinia. More research in this field need to be realized and more information on sustainability on the whole, not only in environmental terms, need to be done. However these results might give useful information for supporting energy crops development in Sardinia.

ACKNOWLEDGEMENTS

More people have contributed to this research.

I wish to thank:

Dr. Laura Altea, Dr. Oumelkheir Belkheiri, Dr. Davide Bellavite, Dr. Chiara Cappai, Dr. Alberto Carletti, Dr. Laura Chessa, Dr. Paola Deligios, Dr. Clara Demurtas, Dr. Luca Doro, Dr. Francesco Fava, Dr. Simone Fazio, Dr. Filippo Gambella, Dr. Luca Gennaro, Dr. Djangsou Hagassou, Dr. Luigi Ledda, Dr. Marcello Lubino, Dr. Andrea Monti, Dr. Thi Phuoc Lai Nguyen, Dr. Luigi Podda, Prof. Pier Paolo Roggero, Dr. Giovanna Seddaiu and the interviewees (Farmers, Industrials, Cooperative's representatives, Regional Administration's representatives, Farmers' Unions representatives, Professionals (Agronomists) and Researchers).