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A farm-level linear programming model to compare the atmospheric impact of conventional and organic farming

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Summary

1. Introduction

“In 2008 6.6% of the Italian GHG emissions, excluding emissions and removals from LULUCF (Land Use Land Use Change and Forestry) originated from the agricultural sector”, Ispra - Institute for Environmental Protection and Research, National Inventory Report 2010 (6.1.1., 135).

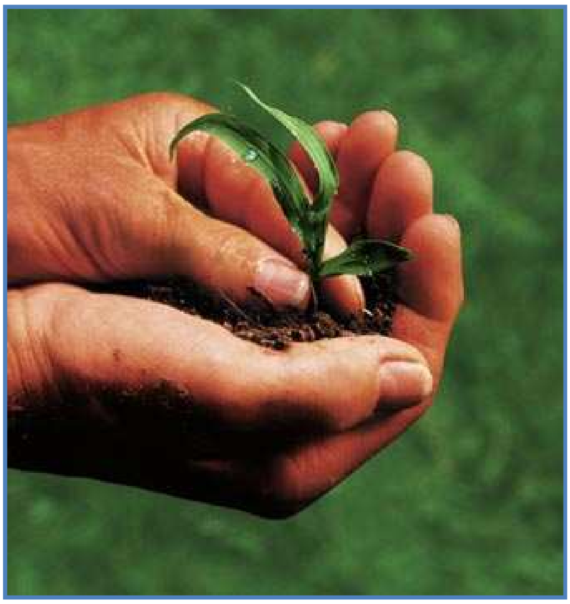
1.1. Background

In Europe, the multi-functional value of the agricultural activity has been recognised since the very beginning of the 1990’s, with the Agriculture Commissioner Mac Sharry. Since those early years, farmers have come to be viewed not only as the producers of food and other goods but also as the stewards of the countryside. They have been alleged to produce common goods that do not have a market value but do have a social value for the collectivity. Examples of these common goods are: landscape, cultural heritage, quality of food, safety of food, safeguard of biodiversity, clean air.

With regard to a pollution-free atmosphere, the 2009 FAO report on the sustainability of farming systems declares that agriculture contributes to global warming with a percentage between 10% and 12% of total emissions, providing an estimate of 5,1 – 6,1 Gt CO2 equivalents per year (FAO, 2009). Consequently, it has become extremely important for public authorities to better understand how the new forms of agricultural techniques, like organic farming, can reduce green house gas emissions. The main process that connects agriculture and the atmosphere is the photosynthesis with the relative fixation of carbon and nitrogen in the vegetal tissue. Through the photosynthetic process the plants synthesize glucose for self nourishment by using the carbon dioxide available in the air, water and solar energy. In this fashion plants withdraw carbon from the atmosphere and transfer it into the vegetal tissue and the soil. The nitrogen that is necessary to the plants come from the rain and from the action of microorganisms (*rhizobium* gender) living in the roots of some *Leguminosae* that withdraw nitrogen from the air and transfer it into the soil (thus making it possible the reduction or elimination of synthetic fertilisers). Nitrogen, a gas which is the main component of the air, is not directly usable by the plants: the task of these microorganisms is the mineralization so that it is turned into a form (nitrate) which is usable by the plants and easily washed away.

There is no doubt that modern agriculture cannot cope with demand without the help of fertilisation. EU Regulation no 834/2007 prescribes that in organic farming the soil fertility is to be reached through periodical rotations, legumes and green manures and is to be maintained by the application of manure and other organic material obtained in organic farming activity. The process of carbon capture and storage has a positive balance: the capture through photosynthesis in order to self-produce glucose, which happens at sunlight, exceeds the emissions due to cellular breathing that happens at night. The total effect of an agricultural activity depends on several elements, yet. On the one hand through the photosynthetic process the agricultural activities allow to store carbon in the plants and in the soil, on the other hand when mechanical operations take place the soil emits carbon. Air stimulates the microbial fauna into the transformation of organic residuals, breathing and releasing carbon dioxide. Depending on the type of crop and soil this effect may be negligible or instead affect seriously the green house gas emissions. In general terms, the relevant question concerns the total balance of the farm activities, either with a direct or an indirect impact upon the atmosphere.

The fourth assessment report of the IPCC has recommended some practices: increase crops' variety, store carbon in soil and increase soil organic content, avoid unnecessary farming, synchronise fertilisers' use according to the needs of the soil, do not waste the crops' residuals, adopt rotations with legumes. The same IPCC report, which is cited in the 2009 Fao report on low GHG emissions agriculture, recommends two priorities for organic farming: increase the crops' and livestock's productivity in conditions with poor external inputs and select plants and animals that be fit to adapt to poor external inputs conditions. These priorities are to be considered in the general context where the constraints are given by the environmental sustainability, the economic efficiency and the social responsibility.



With specific regard to the types of green-house gases, it has been established that the gases that mostly contribute the genesis of green-house effect are three: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Although watery vapor may be important, it is not under humans' control. The impact of the three gases is different as regard global warming and is measured by the global warming potential, that is the radiant force of 1 kg of gas that remain in the atmosphere for 100 years. Conventionally, the warming potential of carbon dioxide is equal to unity, when the methane has a warming potential of twenty-one and nitrous oxide of three hundred and ten.

1.2. Objectives

At the core of this research effort there is the fact that in the organic farming there are no atmospheric emissions coming from synthetic products and the carbon sequestration is likely to be higher than in conventional farming, due to care to the health of the soil and to biodiversity. There are however some controversial effects, concerning the two gases with highest warming potential and particularly methane, whose emission come from manure handling and the enteric fermentation of the animals, two activities that are often important in organic farms.

Purpose of this work is the scientific assessment of the contribution of organic farming to the mitigation of climate change on behalf of the agricultural sector, in order to consider these environmental benefits in agro-environmental policies.[1] The relevant data come from the FADN database: the representative farms are obtained through a cluster analysis of the 10266 farms of the database. The methodology that has been adopted is the mathematical programming, applied at farm level in homogeneous clusters that are representative of the regional agrarian system. The perspective is the sustainability of the agricultural activity, in economic, social and environmental meaning.

The expected result from the simulations is a positive differential in the atmospheric impact between conventional farming and organic farming, provided a sound assessment is made not only of the GHG emissions but also of the prospect to store carbon. The quantification of the gap in net carbon storage is the prerequisite for the design of adequate public policies in favor of organic farming, when it comes to the social benefit of climate change mitigation.

1.3. Normative system

Considering that climate change mitigation is the focus of the enquiry and provided that organic farming is the most common form of agriculture that is sustainable along the years, it is necessary to focus the legislative background in which Italian farmers operate. Alongside the scientific and institutional definition of organic farming, the normative prescriptions are reviewed both regarding the European and the Italian context. A few notes are given about the future of the Common Agricultural Policy.

[1] The term mitigation of climate change refers to the activities that reduce the causes of the climate change, that is the emissions of green house gases in the atmosphere. Conversely, adaptation to climate change is the process of reducing the negative effects of climate change.

1.3.1. Definition of organic farming

1.3.1.1 Academic literature

The mostly cited definition has been written by Lampkin (1994), who wrote that the purpose of organic farming is “to create integrated, humane, environmentally and economically sustainable production systems, which maximises reliance on farm-derived renewable resources and the management of ecological and biological processes and interactions, so as to provide acceptable levels of crop, livestock and human nutrition, protection from pest and disease and an appropriate return to the human and other resources”.
Quite properly, Rigby and Caceres (2001) have underlined the complexity, noting that different authors have put into evidence different aspects of the organic farming. Northbourne (1940), allegedly the first to use the term organic farm, has underlined the concept of a small, independent unit, who is relatively free from dependence upon industrial inputs. Scofield (1986) on the other hand underlined the different concept of “wholeness”, meaning that all the activities of the organic farm are systematically connected into a one “whole”. And similarly Mannion (1995) advocated a “holistic” view of the organic farm. Raviv (2010) underlines that although organic farmers do not use chemical fertilisers and pesticides, nor antibiotics and hormones, it does not shrink to “a primitive back-to-nature trend” because it is based upon a continuous process of research and innovation.

1.3.1.2 IFOAM

The International Federation of Organic Agriculture Movement has adopted – in March 2008 – the following definition: “Organic agriculture is a production system that sustains the health of soils, eco-systems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved.”
This definition comprehends the point of views from different geographic areas, thus with a general meaning and without concrete prescriptions. In fact, in September 2005 at the General Assembly held in Adelaide Australia, IFOAM pronounced the Principles of Organic Agriculture, which may be viewed as its pillars: health, ecology, care and fairness.[2]

1.3.1.3 Federbio

The FEDERBIO’s statute report its definition of organic agriculture, here called with the italian word “organica” instead of the word “biologica”.[3]

[2] The definition and explanation of each principle is available on IFOAM’s website.
[3] Cfr. http://www.federbio.it/statuto.php.

"Organic agriculture deals with those agricultural models and methodologies that - in gaining awareness of the complex realm of nature, of its constitutive elements (mineral, natural and animal realm) and their interactions (with respect to the planet Earth as a whole) - choose methods and instruments that:

- promote an environmentally friendly and fair development;
- are adaptive with such realm of nature and with the complex realm of humans, in their biological, physiological, psychological, social and ethical consequences;
- exclude the usage of genetically modified organisms and rather help the natural processes of plants and animals, and however exclude artificial growth systems.

1.3.2. The legislation

1.3.2.1 The 2007 EC regulation

After the action plan presented by the Commission in 2004 with a Communication to the Council and to the Parliament, in 2007 the European Council has enacted a new Regulation on organic agriculture no. 834, namely "on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91". In article no 1 it is declared that "This Regulation provides the basis for the sustainable development of organic production" with the additional purpose of ensuring the effective functioning of the internal market. Besides the definitions, the objectives and the principles, the rules comprehend the requirements of the national certification systems and the agronomic prescriptions as well. Although many of these prescriptions have remained the same as in the preceding 1991 Regulation, it is worth noting that the rules concerning the organic method of production have been grouped together into a single article, n. 12 which reads "Plant production rules". This is the content:

1) "organic plant production shall use tillage and cultivation practices that maintain or increase soil organic matter, enhance soil stability and soil biodiversity, and prevent soil compaction and soil erosion";
2) soil fertility is to be reached and maintained through cultivation of legumes, green manures or deep-rooting plants in an appropriate multiannual rotation program;
3) soil fertility is to be increased through the incorporation in the soil of livestock manure or organic material, both preferably composted, from organic production;
4) prevention of damages caused by pests and diseases must rely upon protection through the natural enemies, the choice of appropriate species and varieties, appropriate rotations, cultivation techniques and thermal processes;
5) other products of plant protection, fertilisers and soil integrators may be used only in accordance with article n. 16;
6) seeds must be produced according to organic agriculture;
7) genetically modified organisms may not be used.

More norms that are contained in the 42-article Regulation concern the transformation, import from non-EU countries, aquaculture.

1.3.2.2 The law of implementation (EC Reg. No 889/2008)

Commission Regulation No. 889/2008 laying down "detailed rules for the implementation of Council Regulation (EC) No 834/2007" was enacted on September 5th 2008 and applied since January 1st 2009. It features specific norms regarding production, labeling and control of organic products.

In the preamble there is an executive definition – though with a general content – since it goes that "Organic plant production is based on nourishing the plants primarily through the soil ecosystem". It is worth noting the adverb "primarily", which concerns the exceptions and the case limits of the norm. For instance, with regard to the production methods allowed in article No. 12 of Regulation n. 834/2007, the article No. 3 of Regulation No. 889/2008 admits some exceptions when the methods thereby mentioned do not allow achieving plants' nutritional needs, and annex No. 1 summarises these cases and the conditions.

With respect to zoo-technical activities, Regulation No. 834/2007 recommends care of animals' welfare and prescribes that animals have access to meadows and open spaces every time that conditions are positive. The Regulation No. 889/2008 presents an additional norm that forbids "landless livestock production" (art. 16). In addition it prescribes that in the same farm the zoo-technical activities may be run both in organic and conventional technique, provided that a clear distinction and separation of the relative units is established.

1.3.2.3 The EU "logo" Regulation

The Commission Regulation No. 271/2010 has introduced the new logo of EU organic agriculture, which has been applied since July, 1st 2010.

1.3.2.4 The National legislation

Legislative decree No. 220/1995

At the National level, the law which is in force is the Legislative Decree 17 march 1995, n. 220 which regulates the certification system. The provisions acknowledge the national and the regional list of organic operators, set the governance of the control authorities with prescriptions for operators and control bodies alike. The Ministry of Agriculture is established as the coordination and control authority, with particular regard to the administrative and scientific activities connected to the application of the European norms. By the Ministry it is established the Committee for monitoring the control bodies, with the task of counseling about the measures of authorization and denial of the control bodies. General control is the task of the Ministry in accordance with the Region and the Provinces.[4]

The norms of the decree provide that the authorised control bodies perform the controls that are committed by European norms according to an action plan, formulated yearly by the control body. The plan is transmitted within November 30th for subsequent year to the Regions and autonomous provinces and the Ministry of Agriculture, which is enabled to formulate comments and observation within thirty days. The control body is committed to perform its activity according to the action plan, eventually with the changes brought about upon the Ministry demand.

Legislative decree No. 217/2006 and legislative decree No. 75/2010

Another legislative act referring to organic farming is the Legislative Decree n. 217/2006, which regulates the use of fertilisers, including the organic fertilisers. [5] This decree has been enacted in conformity with CE regulation n. 2003/2003, which disciplines the use of fertilisers in the territory of the European Union. The legislative act provides for control measures and sanctions (under the supervision of the Ministry of Agriculture) for producers that market fertilisers that are not allowed under the communitarian Regulation. For traceability purposes, the decree established by the Ministry the Registry of fertilisers and the Registry of fertilisers' producers. Subsequently, in the Legislative Decree No. 75/2010, where controls and sanctions are confirmed, new norms are added and it is provided for the types of organic fertilisers that are admitted for sale.

Legislative decree No. 279/2004 (converted into law No. 5/2005)

An issue which has attracted the legislator's attention is the co-existence of several forms of farming, namely organic farming, genetically modified and conventional. Each type of agriculture is unique and shall be protected from other forms' interference, lest the consumers are unable to identify them and express true choices (*co-existence principle*). Special attention has been paid to trans-genetic products too, for which a market demand is there, identified by typical consumers with a high willingness to pay. The Decree-Law n. 279/2004 provides urgent measures in this regard and has been converted into law with Law n. 5/2005.

Table 1: registers of operators

Regional registers of organic operators		
THREE SECTIONS		
Agricultural producers	Transformers	Spontaneous products pickers
AGRICULTURAL PRODUCERS SECTION		
Organic farms	Farms in conversion	Mixed farms

[4] There are 17 control bodies that are accredited by the Sincert and after being authorised by the Ministry of Agriculture can operate in the whole National territory.

[5] Annex no. 13 part II includes the register of the fertilisers that are admitted following the exceptional conditions within regulation no. 889/2008.

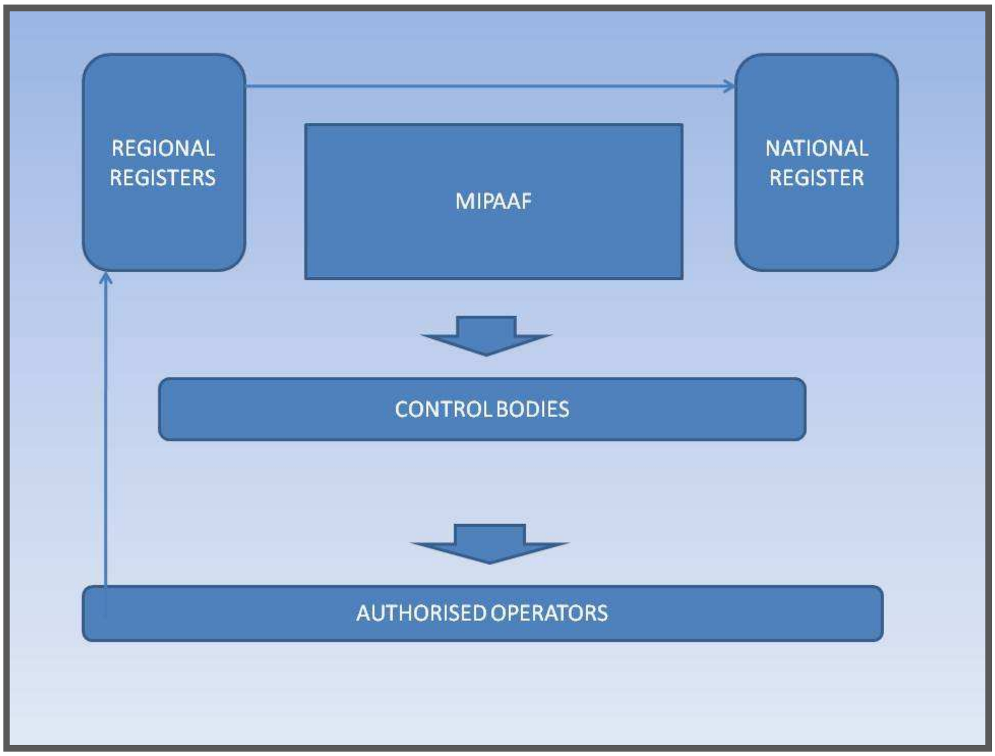


Figure 1: the certification system

The Ministerial Decree that implements EU regulations (decreto 27 novembre 2009)

The Ministry of Agriculture has enacted a ministerial decree that implements Regulation No. 834/2007 and Regulation No. 889/2008, so that the application is homogeneous on the entire national territory. Examining this document allows devising more detailed normative prescriptions:

1. First the arable crops and horticultural products may be cultivated on the same surface only after a rotation with two different activities, where one is with legume or green manure.
   These are the exceptions:
   - the winter cereals (wheat, barley, oats, rye, spelt) and tomatoes in protected environment may ensue themselves after maximum two cycles, that must be followed by two cycles of different species, where one is legume or green manure with 70 days minimum length;[6]
   - rice may ensue itself after maximum three cycles, followed by at least two cycles of different species, one with legume or green manure;
   - hortages with short cycle may ensue themselves for three cycles, followed by a tuber or green manure;
   - crop cutting does not ensue itself. At the end of the cycle, which must last maximum six months, the crop cutting is put underground and followed by at least a tuber or green manure.
2. With regard to zoo-technical activities, in a certified organic farm it is possible to have only organic livestock.

[6] If the cereals (excluding rise) succeed for two cycles they must be of a different species.

3. It is confirmed the communitarian provision of a maximum number of livestock per hectare, corresponding to 170 kg N/year, which must be fixed by each Region.
4. The livestock's feeding must be with forages and feed that are produced internally or by other organic farms.

1.3.2.5 The Regional legislation

The regional law actually in force is Law n. 28 of 1997. Like the national law, the provision deals primarily with the legal and organizational requirements for organic producers: it introduces the regional list, acknowledge the association and deals with the authorities in charge of the control and the connected sanctions.

With regard to technical aspects, the Law makes explicit reference to the European regulation.

Table 2: European Legislation

Reg.(EEC) no 2092/1991	Organic production and labeling of organic products
Reg.(EC) no 2003/2003	Use of fertilisers
Reg.(EC) no 834/2007	Organic production and labeling of organic products
Reg.(EC) no 889/2008	Detailed rules for the implementation of Reg. (EC) no 834/2007
Reg.(EC) no 967/2008	Amending Reg. (EC) no 834/2007
Reg.(EC) no 1235/2008	Detailed rules for implementation of Reg.(EC) no 834/2007 as regards the arrangements for imports of organic products from third countries
Reg.(EC) no 1254/2008	Amending Reg. (EC) no 889/2008
Reg.(EC) no 537/2009	Amending Reg (EC) no 1235/2008
Reg.(EC) no 710/2009	Amending Reg. (EC) n. 889/2008 as regards detailed rules on organic aquaculture animal and seaweed production
Reg.(EC) no 271/2010	EU organic farming logo

Table 3: National Legislation

D. Lgs. n. 220/1995	Certification system
D.L. n. 279/2004	Co-existence of conventional, organic, trans-genetic farming
Legge n. 5/2005	Conversion into law of D.L. n. 279/2004
D. Lgs n. 217/2006	Use of fertilisers

1.3.2.6 The norms of the *Codex Alimentarius*

The UN International body that operates within WHO and FAO, the *Codex Alimentarius* formulates norms that are finalised at harmonising the National standards. The organic agriculture is defined as a "holistic" management system, that promotes and improves the health of the ecosystem, the biodiversity, the natural cycles and soil's biological activity and that reduces the usage of external productive factors.

The *Codex* has enacted guidelines for organic agriculture (the most recent dates back to 2007) that are at present being updated. These norms are equivalent to the norms of the European Regulation as long as concern is about the soil's fertility: it is likely that the European legislators have found inspiration in the *Codex* for the definition of Regulation No. 834/2007.[7] With respect to the defense from pests and diseases, instead, further requirements are added by the *Codex*. As a whole, the measures of protections are the following:

- natural enemies, including the release of predators and parasites;
- biodynamic mixture with rock flour and manure;
- mulching and mowing;
- pasture;
- mechanical controls such as traps, barriers, sounds and lights;
- steam sterilization when appropriate rotation for soil's renewal cannot take place.

1.3.3. The CAP Reform

The Common Agricultural Policy has been designed to accomplish three general objectives: regulate the market, support farmers' income, support rural development. In the early years of the European Union, market intervention with price support and quotas aimed primarily at ensuring the food provision to EU citizens and avoid shortages, whereas at present the market intervention leans toward the correction of inefficiencies in providing public goods and rewarding farmers for the provision of positive externalities. In the set of legislative measures that concerns European Agricultural Policy, a key role is played by EC Regulation No. 1782/2003, which established common norms for every support system. It established the Single Farm Payment, the requirements of Conditionality – that is compulsory rules concerning public health, plants' and animals' health, animals' welfare – and forced the member states to provide that agricultural land be kept in good agronomic and environmental conditions.

This legislative measure made a change with respect to the past since it separated the subsidy from the produced quantity and established a progressive reduction of the financial subsidies to different cultivations. Now it has been updated by Regulation No. 73/2009.

[7] In the preamble and in regulation no. 834/2007 article no. 33, the Codex Alimentarius is mentioned with regard to recognition of imported goods.

EC Regulation No. 1290/2005 established the European Fund of Rural Development and Regulation No. 1698/2005 regulated the communitarian support to rural development. The measures thereby are finalized at pursuing important objectives: environment protection, natural areas and territory, improve the competitiveness of agricultural and forest sector, improve quality of life in rural areas. Article No. 39 provides for agro-environmental payments, in favor of farmers that are voluntarily committed to environmental obligations. The norms specify that the payments are linked to the commitments that go beyond compulsory requirements of Regulation No. 1782/2003 and as such are eager to raise particular interest in the organic farmers.

Table 4: the CAP Reform

Directive No. 43/1992	*Conservation of habitat, flora and fauna*
Reg. (EEC) No. 2078/1992	*Amended by REG. N. 1257/1999*
Reg. (EC) No. 1257/1999	*Amended by REG. N. 1698/2005*
Reg. (EC) No. 1782/2003	*Amended by REG. N. 73/2009*
Reg. (EC) No. 1290/2005	*Finance (FEAGA, FEASR)*
Reg. (EC) No. 1698/2005	*Rural development support (agro-environmental premia)*
Reg. (EC) No. 73/2009	*Common rules for direct support to farmers, single farm payment, conditionality.*

In October 2011 the European Commission has publicly declared a set of legal proposals for the CAP reform covering the period 2013-2020. The basic structure of two pillars is maintained, the first dealing with market regulation and income support and the second with rural development. In the first pillar, milk and sugar quotas are likely to be abolished. The base *premium* which used to be linked to historical *premia* is to be replaced with a *premium* on a regional basis, where homogeneous regions perceive the same amount. In addition to the base premium there is the possibility to receive a so-called *green premium* whereby some requisite beyond conditionality must be accomplished: diversification of crops (at least three different crops[8]), keeping permanent meadows, using a part of the agricultural area (at least 7%) for ecological purposes such as set-aside, terraces, landscape functions, forestry and hedges. A cap is going to be put over the total amount of subsidy for the single farm. The proposals involve the definition of active farmer, whereby the subsidy shall exceed the percentage of five percent of total income (or maybe non-agricultural income). Additional subsidies are possible for disadvantaged areas.

With regard to the second pillar, six priorities are envisaged: innovation and research, competitiveness and sustainability, the market structure and risk management, the safeguard of ecosystem, the efficient use of resources with low input of carbon, the reduction of poverty.

[8] The highest share shall be no more than 70% and the lowest no less than 5%.

1.3.4. Legal definition of farm

The Italian civil code, article n. 2135 defines the agricultural entrepreneur as the person who runs one of the following activities: land cultivation, forestry, animal breeding and connected activities. As second comma addresses, land cultivation, forestry and animal breeding are identified as those activities that are finalised at the care of a biological cycle, either vegetal or animal, and that can utilise land, forestry or natural water. An important judgment of the Supreme Court – 9th April 1998 no. 3686 – declared that no-land breeding is excluded from the agricultural activities since it falls within the category of the industrial establishments. Finally, comma no. 3 identifies the connected activities i.e. the activities - run by the same entrepreneur with the prevalent use of farm resources - that are finalised at the manipulation, conservation, transformation or marketing of the products that are obtained with the land, forest cultivation or animal breeding.

2. Methods

"The basic motivation for using programming models in agricultural economic analysis is straightforward, because the fundamental economic problem is making the best use of limited resources. The use of optimization models is therefore a perfect combination with neoclassical economic theory, which perceives economic agents as optimisers".
[Buysse J., Van Huylenbroeck G., Lauwers L., Normative, positive and econometric mathematical programming as tools for incorporation of multi-functionality in agricultural policy modeling, Agriculture, Ecosystems and Environment, 120, 2007.]

Methodological individualism is the main hypothesis of the work. The farmer is assumed to be a rational agent that maximises net income. This is obviously a simplifying assumption since the farmer might well have other sources of motivation: environmental concern, care for the farm, attention to the future just to make a few examples. Thus the focus of the analysis and the results are contingent upon this assumption.
It is assumed that, on the basis of self-interest, the farmer tends to maximise net income by reacting to economic incentives through changes both in the land use and in the adoption of conventional or organic farming techniques. The simulation also allows estimating the agricultural impact on the environment, particularly regarding the sequestration of greenhouse gases in soil and plant biomass.
The relevant data come from the FADN database. The representative farms are obtained through a cluster analysis of the 10266 farms of the database.

2.1. Mathematical programming: basic concepts

The technique of mathematical programming has been applied in different topics of agricultural and environmental issues. A typical model can be written in the following form:

$$\max Z = \sum_{i=1}^{N} c_i X_i$$

$$st \quad \sum_{i=1}^{n} a_{ji} X_i \leq b_j \quad all \;\; j = 1....M$$

$$and \quad X_i \geq 0 \quad for \;\; all \;\; i = 1....N.$$

Where Z is called the objective function, X is the vector of decision variables and b is the vector of the available resources. The problem is to maximise the value of the objective functions according to the fulfillment of the resources' constraints and the non-negativity requirements.
The most typical application has been the problem of the optimal allocation of crops: different crops are envisaged in a geographical region or in a single farm and the question goes how to share the available land with every type of activity. Other optimization problems may concern the use of water or the mix between different types of fertilisers. In fact, most models aim at providing recommendations about the most efficient, i.e. economically rewarding, way to run the agricultural activity. After recognition of the activities that may be done in a specific area, the simulations check

whether or not existing distribution is optimal or instead, a different portioning of the land should be assigned.

With respect to the problem of the farmer's optimal crop, in the simplest case in which two inputs exist that is land and labor, the problem is written in the following form:

$$\begin{aligned}
&\max Z = c_1 X_1 + c_2 X_2 \\
&st \quad a_{LAND,1} X_1 + a_{LAND,2} X_2 = b_{LAND} \\
&\qquad a_{LABOR,1} X_1 + a_{LABOR,2} X_2 = b_{LABOR} \\
&and \;\; X_1 \geq 0, X_2 \geq 0.
\end{aligned}$$

In the model the decision variables X_1 and X_2 are the output of two agricultural activities, the coefficient *a* stands for the input requirement of land and labor for each activity and *b* stands for the farmer availability of land and labor. Provided that the selling prices are expressed by the coefficient *c*, the model assumes that the farmer maximises his revenue while the resources constraints are satisfied. The solution to the problem provides the value of X_1 and X_2 that maximise the total revenue.

An important result in mathematical programming is the duality theorem. It can be demonstrated that the solution to the problem above described is equivalent to the solution of its dual problem:

$$\begin{aligned}
&\min W = b_{LAND} \lambda_1 + b_{LABOR} \lambda_2 \\
&st \quad a_{LAND,1} \lambda_1 + a_{LABOR,1} \lambda_2 = c_1 \\
&\qquad a_{LAND,2} \lambda_1 + a_{LABOR,2} \lambda_2 = c_2 \\
&and \;\; \lambda_1 \geq 0, \lambda_2 \geq 0.
\end{aligned}$$

The dual problem can be described as the minimization of the total cost provided that the minimum amount of crop is produced for each activity. The coefficient λ_1 and λ_2 are the Lagrange multipliers in the primal model and represent the "shadow prices" of land and labor, that is the economic value of an additional unit of the resources. Whereas the primal problem consists in finding the allocation of the activities that maximise total revenue, provided the constraint on resources, in the dual problem the farmer's choices identify the marginal value of the resources, provided the constraints upon the level of production of each activity. The farmer is not willing to pay too much for the resources nor does he want to renounce resources that may be profitably employed in the two activities. In fact, the dual problem can be imagined as the minimization of the long-run cost: whereas the solution to the primal problem identifies the combination of the agricultural activities when labor and land are fixed, when the farmers can modify labor and land - i.e. in the long run - then the dual problem is solved as to find the optimal value of the resources' investments (Paris, 1991).

2.2. Mathematical programming models for simulations: a survey

In this paragraph a series of models is reviewed that use mathematical programming. Application concerns the optimal cropping pattern, the use of water, the mix of fertilisers.

A) Hassan- Arif Raza – Khan – Ilahi (Journal of agriculture and social science, 2005): optimal crop in the Punjab region

The paper by Hassan *et al.* (2005) - entitled *"Use of Linear Programming Model to Determine the Optimum Cropping Pattern, Production and Income Level: A Case Study from Dera Ghazi Khan Division"* - treats the problem of the optimal cropping plan in the Punjab region of Pakistan. The authors' research effort may be synthesized in the following question: "Is the actual distribution of crops the optimal allocation from an economic point of view?" That is: "Do farmers maximise – as a whole – the total profit?"

In view of answering this question with regard to the Pakistan's regional area, some hypotheses are made:

- an area of 3913 acres of land in the Punjab is chosen as the available land;
- five crops are considered as options for the farmers: wheat, Basmati rice, Irri rice, cotton, sugarcane;
- crop substitution may occur in the minimum land of 1 acre;
- time horizon is a crop season, that is one year;
- all producers are assumed to have identical input-output coefficients;
- farmers are assumed to maximise profits.

The objective function is the gross margin – that is total net income - and the following are the constraints of the linear programming model:

1. Land constraint.
2. Water constraint.
3. Capital constraint.
4. Maximum acreage.
5. Minimum acreage.
6. Non negativity constraints.

It is assumed that labour in the region is available so that labour supply does not limit production. All producers are assumed to have identical input-output coefficients.

The results show that the optimal cropping pattern is different from the actual pattern in a way that the researchers do not consider remarkable. As a matter of fact, the largest difference in the crop area regards cotton, for which the optimal pattern would set an increase by 10%. The other crop's acreage would diminish. Altogether, the optimal cropping pattern would reduce acreage by 1,64% and increase aggregate farm income by 2,91%.

Table 5: summary of survey literature

Paper by:	**Unit**	**Objective function**	**Positive / normative**	**Geography case study**	**Time horizon**	**Rate of discount**
Acs *et al.*	Farm	Labour income (GM)	N	NL	10	4.00%
De Cara – Jayet	Farm	GM; GHG	N	France	Static	
De Cara *et al.*	Farm	GM	N	EU-15	Static	
Hassan *et al.*	Region	GM	N	Pakistan	Static	
Havlik *et al.*	Farm	Exp. utility	N	France	Static	
Kanellopoulos *et al.*	Farm	GM	P	F/NL		
Kerselaers *et al.*	Farm	GM	N	Belgium	3	
Merel – Bucaram			P			
Pacini *et al.*	Farm	GM	N	Tuscany	Dinamic	
Pali *et al.*	Farm	GM	N	Uganda	3	
Reveredo Giha *et al.*	Regional farm system	GM	N	UK/D/F/I	Static	
Schipper *et al.*	Farm	Ec. surplus[9]	N	Costa Rica	20	0 - 10 %
Schneider	Farm	Profit: GM + subsidies	N	Australia	30	5.00%
Schneider *et al.*	Region	Ec. surplus[10]	N	US	Static	
Sharma *et al.*	Village, household	GM	N	Nepal	20	5.00%
Shrestha-Hennessy	Region	GM	N	Ireland	15	
Stoecker *et al.*	Farm	GM	N	US		

Note: GM: gross margin GHG: green-house gas (Source: own elaboration, 2011)

B). Schipper – Jansen – Stoorvogel (Netherland journal of agricultural science, 1995): optimal crop with application of a sustainability criterion

"Sub regional linear programming models in land use analysis: a case study of the Neguev settlement, Costa Rica". This paper treats a problem of optimal land use in the Atlantic zone of Costa Rica. The level of decision is the farm and the options available are limited to eight crops: cassava, logged forest, maize, palm heart, pasture with cattle, pineapple, plantain and tree plantation.

[9] The gross margin is defined as income minus labour cost and is considered to be equivalent to the economic return to land, own capital, management.

[10] In this case agricultural economic surplus is defined in a micro-economic fashion as the sum of the consumer's surplus and the producer's surplus.

In contrast with prevailing literature, the definition of sustainability does not draw on the Brundtland report. Instead, it follows the proposal by Pearce and Turner (1990): “maximising the net benefits of economic development, subject to maintaining the services and quality of natural resources over time”. Economic development is meant to be a vector including real per capita income and other social welfare elements such as nutrition, health and housing. In order that economic development occurs, each element of the vector shall increase or at least not decrease and the following rules must be satisfied:

1. use renewable resources at rates less or equal to the natural rate at which they regenerate;
2. keep waste flows to the environment at or below the rate at which the environment can assimilate;
3. optimise the efficiency in the use of non-renewable resources.

The application of the definition of sustainable economic development to the linear programming model calls for a sustainable land use and the rules call for using land and water at rates less or equal to the regeneration rate. With regard to land resource the researchers adopt two parameters that indicate quality and are used as sustainability criteria: these are soil nutrient depletion and biocide use. Impacts of policies are analyzed in different scenarios.

C. Sharma – Sankhayan – Singh (Journal of agricultural science, 2010): optimal crop in Nepal along a time-horizon of twenty years

“Analysis of Profitability and Risk in New Agriculture Using Dynamic Non-Linear Programming Model”. A watershed in Nepal is the area under scrutiny. Nine villages have been surveyed with interviews to 102 households: data regards the demographic profile, land use and cropping patterns, input-output of crops and livestock. Other data - prices, crop yields – were obtained by local agricultural authorities. The land for agricultural use sum up to 68.1 ha.

Mathematical programming is applied to discover the optimal cropping pattern. The objective function is aggregate gross margin of the watershed along twenty years, with an annual discount rate of 5%. For every year, the gross margin is given by the scalar product of two vectors: the row vector of annual gross margin per unit of crop and livestock in the local currency and the column vector of the units of crops (ha) and livestock (number).

The risk is taken into account by virtue of a variance-covariance matrix of yields and prices of crops: results show that farmers are more responsive to risk than to profit.

D. Pacini *et al.* (Agriculture, Ecosystems and Environment, 2004): economic incentives to farmers

The authors acknowledge that farmers are now viewed not only as food suppliers but also as the countryside’s stewards and the Common Agricultural Policy explicitly enrolls to the farmers the task of the preservation of the landscape and the protection of the natural resources.

More specifically, agro-environmental schemes have been introduced since the 90’s in order to compensate farmers for the economic losses in the input-output combination and for the role that they display in environment's protection. The paper presents a model of farmer behavior under an agro-environmental scheme. The underlying research question may be described as: which is the level of economic incentives to be enacted in order to make farmers provide the desirable amount of environmental benefits?

From an economic point of view two elements can be distinguished: first farmers must be compensated for the income foregone due to less damaging practices, second the policy ought to make reference to compensation for the public benefits that the farmers supply. Since environmental benefits are public goods the market mechanism does not provides socially efficient outcomes. Different means of intervention exist to reach the optimal level of environmental benefits. In a work by Hanley *et al.* (1998) it has been recommended the: "provider gets principle" (PGP). According to this principle, the optimal level of public goods is obtained by persuading farmers to avoid environmental damages and to improve the environment through economic incentives in the form of voluntary payments (and not through compulsory rules). This approach requires that four conditions be met:

- the suppliers of amenities can be identified;
- a means can be found to transfer resources according to marginal opportunity cost of supply;
- funding is available to finance the transfers;
- it is possible the identification of a socially optimal level (quote: "appropriate level of supply") of rural public good.

The EU payments to the farmers that adopt or maintain the organic farming fit the PGP description. However, the fourth requirement is not met because the payments are tailored to agronomic practices and not to environmental indicators (quote: "on requirements regarding the provision of environmental benefits").

Organic farming should be considered as a technique to achieve specific environmental objectives and not as a performance in itself. Though better performing than conventional farming on the whole, it does not perform better for all ecosystems, for all environmental aspects and with the same economic results.

Ecological-economic modeling aims at optimally calibrate agro-environment schemes by taking into account tradeoffs and opportunity costs of different farming systems. In order to achieve this goal a holistic view must be kept, so that conflicts among different environmental aspects are composed. Linear programming is well suited to embrace economic and ecological analysis.

In a previous paper the authors created an ecological-economic LP model of organic farming. It provides cases with a sensitivity analysis, scenario analysis: evaluation of impact of EU policies on sustainability.

The current work is designed to assess the optimal agro-environment scheme under Agenda 2000 regulation. Three steps are envisaged:

1. ecological-economic model through LP

2. assessment of income lost by conventional farmers in order to produce the environmental goods provided by organic farmers;
3. assessment of income lost by conventional farmers in order to produce the environmental goods that would be demanded by society under different sets of environmental sustainability thresholds.

Table 6: main results in Pacini *et al.* (2004)

EU AGENDA 2000 FOR DAIRY FARMS		
CONVENTIONAL DAIRY FARMS	- MILK QUOTA	- MARKET SUPPORT FOR MILK SECTOR
	- CROSS COMPLIANCE (10% SET ASIDE, DRAINAGE SYST.)	- INCOME SUPPORT FOR ARABLE CROP
ORGANIC DAIRY FARMS	- MILK QUOTA	- MARKET SUPPORT FOR MILK SECTOR
	- CROSS COMPLIANCE (10% SET ASIDE, DRAINAGE SYST.)	- INCOME SUPPORT FOR ARABLE CROP
	- EU ORGANIC PRODUCTION RULES	- INCOME SUPPORT SCHEME FOR ORGANIC FARMING

Provided that citizens care about the protection and safeguard of the environment, a social demand exists for the environmental benefits provided by the farmers. In line of principle this would be equal to the sum of the true individual willingness to pay of the citizens that live in the specific region. The solution which is adopted is to identify the social demand of environmental benefits with the indexes ESTs, "environmental sustainability thresholds". For computing purposes, the levels of these indexes are assumed as proxies for the social demand of environmental benefits and sustainability.[11] Of course, different levels of ESTs imply different levels of foregone farmers' income. A strong hypothesis is that prices of organic product are assumed to equal prices of conventional products: this is likely to be a reasonable assumption only as long as the agro-environmental scheme makes organic supply increase, so that organic prices get closer to conventional prices.

There are three versions of the model: conventional, organic and integrated/combined (which is an average of the two). Data elaborations are done separately for conventional and organic versions: rotations, technical coefficients; environmental coefficients. The following activities are considered: rotations (conventional: 18; organic: 26, integrated: 44), set-aside, green spaces, seasonal labor, fertilisers, ecological infrastructure activities (hedge and drainage systems), animal production activities, feeding stuff and straw. These are the constraints: land, milk quota, housing and tractors,

[11] Nitrogen leaching, nitrogen run-off, soil erosion, ground water balance, surface water balance, pesticide risk, biodiversity, hedge length, drainage system length.

labor requirements, feeding constraints, herd constraints, manure and slurry requirements, rotation constraints, legal constraints, tie rows, environmental sustainability thresholds.

The results of the comparison between organic farming and traditional farming system show that organic farming is more profitable particularly under Agenda 2000 provisions, but also in the case in which there is no EU support.

E. Acs – Berentsen - Huirne (Agricultural Systems, 2007): cost of conversion to organic farming in the Netherlands
"Conversion to organic arable farming in The Netherlands: A dynamic linear programming analysis". In the research presented in this article the area under scrutiny is a central region in The Netherlands. The research question is why few farmers convert to organic agriculture, and consequently the question posed is whether or not organic agriculture is more profitable than conventional agriculture. The time horizon in consideration is limited to ten years and the present value is obtained discounting future numbers at a rate of 4%.

Mathematical programming is applied at a farm-unit decision level: as usual the actual value of the flow of gross margins is the objective function. The representative farm can produce either in conventional or in organic practice. Conventional crops are: winter wheat, spring barley, ware potatoes, seed potatoes, sugar beet, onion, carrot. The organically-grown crops are the same as the conventional plus in addition: spring wheat, winter barley, kidney bean, green pea, alfalfa, celeriac and grass-clover.

Some constraints are applied to both conventional and organic practice whereas others are designed to account for the requirements of the organic agriculture: rotation requirements, nutrient balances, pesticide and fertiliser requirements.

On a ten years' horizon, organic farming proves to be more profitable. Conversion from conventional to organic farming implies additional costs and takes two years minimum. Nevertheless, the researchers find that the optimal cropping plan would prescribe to adopt organic farming after a two years' period of conversion from conventional agriculture.

F. Pali *et al.* (Makerere University, 2005): optimal mix of nitrogen sources
"Using Linear Programming to Optimize the Use of Biomass Transfer and Improved Fallow Species in Eastern Uganda". Rather than the problem of the optimal crop, in this paper a different problem is faced, namely the optimal mix of "organic and inorganic soil improvement options". The unit of analysis is the farm and the objective function is the gross margin. On farm trials with ten farmers were conducted in order to investigate the effectiveness of different sources of nitrogen. Results showed that the optimal treatment prescribes a mix between organic and inorganic fertilisers: though all soil improvement options were profitable, thus possible to be adopted by farmers, not all of them were optimal. Provided that some practices require more effort, the labour

issue is investigated, with the result that it should not be weighted equally along the year since the opportunity cost is higher during the peak season.

G. De Cara – Jayet (European Review of Agricultural Economics, 2000): optimal crop with an assessment of greenhouse gas emissions

“Emissions of greenhouse gases from agriculture: the heterogeneity of abatement costs in France”. The focus of the paper is on the assessment of greenhouse gas emissions from the French agricultural system. The authors acknowledge that close to the industrial sector and transport, agriculture has come to be a concrete source of greenhouse gas emissions. Then they limit the analysis to three factors, which are judged to be the most relevant in agricultural activities: nitrous oxide, methane and carbon storage.

Analysis is run at the farm level: eighty-two types of farm are envisaged by dividing the French territory according to its geography and the technical orientation of the activity. Ultimately, a total of 691 are the different types of farms which are considered, i.e. 691 models are run. The objective function is the gross margin and the basic problem of the optimal cropping pattern is considered before the issue of greenhouse gas emissions. Choices have been limited to fourteen activities, representative of the French agricultural production.

The production constraints are divided into five categories: crop rotations, cattle nutritional needs (energy and proteins), initial endowments of fixed factors (land and livestock), bovine livestock demography and restrictions of CAP measures.

Data have been collected in 1990 using the French Farm Account Data Network: a sample of 7000 farmers representative of the 480000 farms of the French agricultural system. Results show that the potential of agriculture for climate change mitigation in France is positive and at low cost when afforestation on set-aside is envisaged.

H. De Cara-Houzé-Jayet (Environmental and Resource Economics, 2005): optimal mix of emissions abatement

“Methane and Nitrous Oxide Emissions from Agriculture in the EU: A Spatial Assessment of Sources and Abatement Costs”.

The research question of this paper is quite ambitious as the authors aim to give account of the emissions' abatement cost in the European Union. The agricultural system of the European Union is summarised in twenty-four activities and the geography is limited to fifteen national countries. As regard to atmospheric pollution, two greenhouse gases are under inspection – methane and nitrous oxide – which are the most important in agriculture and included in the Kyoto protocol, too. Under these conditions, abatement costs are examined with particular attention to the magnitude and to heterogeneity across regions. Results show that heterogeneity of abatement costs is substantial: the consequence is that the effectiveness of incentive- based policies changes from one farmer to another.

I. Stoecker *et al.* (Management Science, 1985): optimal allocation of water resources

"A linear dynamic programming approach to irrigation system management with depleting groundwater".

In this article it is not the optimal crop the normative issue, rather the use of water from an aquifer in semi-arid plains of Texas. In this area the land is irrigated with groundwater and the production of the crops depend upon the availability of groundwater and the technology to use it. Linear programming is used in a two stage process in order to find out the optimal temporal sequence of investments in stock resources (step 1) and the optimal allocation of water and irrigation resources (step 2). The results indicate that it is more efficient to intensify the water irrigation rather than extend it to a prolonged period of time.

J. Shrestha-Hennessy (Irish Journal of Agriculture and Food Research, 2007): the economic effects of decoupling subsidies from production

"Analysing the impact of decoupling at a regional level in Ireland: a farm-level dynamic linear programming approach".

Public payments to farmers can be associated to or decoupled from the level of production. Decoupling leads to a different distribution of the subsidies, with regional differences too. In this work where the Irish agriculture is considered a clustering technique is used to group farms according to various criteria. Unit of analysis for the optimisation procedure is the region: the total gross margin of the farm in a region is maximised under the constraints about regional milk quotas and land quotas. Results showed that the majority of beef farmers had higher profits under decoupling; furthermore, though regional differences were found most beef farmers were expected to de-stock. As regard tillage farmers, most farmers were expected to decrease production when decoupling was implemented.

K. Reveredo Giha (Aspects of applied biology, 2006): economic evaluation of legumes

"Economic and environmental analysis of the introduction of legumes in livestock farming systems".

Legumes have become increasingly important for their role as soil fertilisers. Their use is largely adopted by organic farmers and by those farmers that adopt low input systems of agriculture. Mathematical programming is used to discover the effect of the introduction of legumes on the profitability of farms. In this paper four types of farms have been considered: a meat sheep farm located in France, a dairy cattle farm in Germany, a dairy sheep farm located in Italy (Sardinia) and a meat sheep farm in Great Britain. The gain of legumes introduction is due to the cost savings that are possible for the reduction in the use of fertilisers for forages.

L. Merel – Bucaram (European Review of Agricultural Economics, 2010): model calibration

"Exact calibration of programming models of agricultural supply against exogenous supply elasticities". In this recent paper a crucial problem is dealt: the calibration of the model. After the estimation of the parameters, some of them are slightly changed in order to analyse the performance of the model under different conditions and verify the robustness of the results. In this case the parameters under examination are those referring to the elasticity of supply: more specifically, the

elasticity of supply with respect to the own price of the commodity. The authors design the calibration problem and determine the conditions in which it has solutions, showing that the solution is unique.

M. Schneider (Agriculture Ecosystems and Environment, 2007): carbon sequestration

"Soil organic carbon changes in dynamic land use decision models"

In this model the land use optimization framework includes the benefits that are obtained from carbon sequestration. This is obtained by designing an objective function, in which the gross margin is not the unique variable to be optimised, but it is summed up to the subsidies from carbon sequestration or it is decreased by the taxes from carbon emission. The purpose is to demonstrate that it is possible to implement dynamic carbon sequestration rates in land use decision models.

N. Schneider-McCarl-Schmid (Agricultural Systems, 2007): optimal mix of mitigation strategies

"Agricultural sector analysis on greenhouse gas mitigation in US agriculture and forestry"

It is hereby described a general model of the American agricultural sector which features different options for the mitigation of the greenhouse gas effect. It consists of 20.000 variables and 5.000 equations. The objective function is the total economic surplus and the equations of the constraints refer to resource limits, demand and supply balances, trade balances, crop mixture. The objective of the analysis is to consider the optimal mix of mitigation strategies: changes in crop intensity and destination of crop to grassland, control of the livestock diet and pasture management, fertilization reduction, reduction in fuel consumption, reduction of tillage, afforestation, rotation changes, bio-energy. In fact, at different levels of carbon prices there are different farming practices that are the best for mitigation purposes. The results show that the level of carbon prices influences the weight of the strategies and a mixed portfolio tends to prevail.

O. Kerselaers *et al.* (Agricultural Systems, 2007): economic potential for conversion

"Modelling farm-level economic potential for conversion to organic farming"

With a linear programming model at the farm level, an enquiry is made into the factors that inhibit conversion to organic farming in Belgian agriculture. Using data from the farm accountancy network (FADN), the sector expertise and the literature, the results show that economic potential for conversion is greater than farmers perceive due to institutional failures and lack of information.

P. Havlik *et al.* (European review of agricultural economics, 2005): multi-functionality and risk aversion

"Joint production under uncertainty and multi-functionality of agriculture: policy considerations and applied analysis".

In this linear programming model at the farm level, the farm is assumed to produce both commodity and non commodity output i.e. close to beef also grassland biodiversity is meant to be a valuable output. Uncertainty is introduced in output prices' levels and the farmers are assumed to be risk averse. The impact of various policy measures upon the environmental goods is analyzed, where an environmental good is identified by the number of hectares that are managed in a prescribed way.

Four scenarios were envisaged and the results underlined the importance of agri-environmental payments since general policy measures (like price support or decoupled subsidies) cannot have a direct effect upon non commodity output e.g. biodiversity.

Q. Kanellopoulos *et al.* (Journal of agricultural economics, 2010): positive mathematical programming (one year)

"Assessing the Forecasting Performance of a Generic Bio-Economic Farm Model Calibrated With Two Different PMP Variants".

In this article data refer to one single year and positive mathematical programming is applied. The authors recognise that positive mathematical programming often requires arbitrary assumptions for calibration and show how it is possible to reduce arbitrariness and stick closer to farmers' actual decision making.

Table 7: main results of models

Paper by:	**Year**	
Acs *et al.*	2007	Organic farming is more profitable than conventional farming.
De Cara – Jayet	2000	Potential for mitigation in agriculture is positive, at low cost when afforestation is possible.
De Cara *et al.*	2005	Emission abatement costs are heterogeneous among farmers.
Hassan *et al.*	2005	Farmers behave efficiently: actual and optimal cropping pattern do not differ significantly.
Havlik *et al.*	2005	Necessity of agri-environmental schemes to support multi-functionality of agriculture.
Kanellopoulos *et al.*	2010	Calibration of positive mathematical programming model.
Kerselaers *et al.*	2007	Institutional failures and informative gaps make farmers misperceive the real opportunities of the conversion to organic farming.
Merel – Bucaram	2010	Calibration of model.
Pacini *et al.*	2004	Organic farming is more profitable than conventional farming.
Pali *et al.*	2005	Optimal mix of inorganic and organic fertilisers.
Reveredo Giha *et al.*	2006	Importance of legumes.
Schipper *et al.*	1995	Importance of sustainability criteria.
Schneider	2007	Carbon sequestration rates are incorporated in dynamic land use decision models.
Schneider *et al.*	2007	A mixed portfolio of mitigation strategies.
Sharma *et al.*	2010	Farmers are more responsive to risk than to profits.
Shrestha-Hennessy	2007	Decoupling leads to higher profits for beef farmers.
Stoecker *et al.*	2007	Time-related efficient use of irrigation.

3. The model

"Il più grande scopo dell'agricoltore è quello di ottenere dal regno vegetabile tutto quello che può essere atto alla nutrizione degli animali utili all'uomo, affinché questi rendano alla terra coi liquami che producono quegli elementi che servir debbono alla riproduzione di quanto non solamente i detti animali, ma noi stessi le togliamo colla non interrotta consumazione. Contribuisce così ogni animale ad una riproduzione di vegetabili molto maggiore di quella ch'egli stesso consuma; ed è appunto nell'eccesso di cotesti prodotti che noi troviamo di che provvedere ai tanti nostri bisogni e piaceri. Questo rapporto tra la sussistenza degli animali, la quantità dei letami che offrono, ed il loro uso ed effetti costituisce il vasto e sublime oggetto della più utile fra le arti".
[Del governo delle pecore spagnuole e italiane e dei vantaggi che ne derivano, Vincenzo Dandolo, Milano 1804]

3.1. The model's assumptions

In economic terms, the problem of climate change is to be referred to the so called "tragedy of the commons". This is a typical problem that arises with common resources, for instance the meadows, when the property rights are not assigned. Actually, if a meadow is publicly owned, every nearby shepherd has free access to it. As a consequence the shepherd will let the graze in the pasture as long as possible, disregarding the grass' rate of growth: the economic incentive is such that it is convenient to let the animals in the pasture because the grass is free and publicly owned. As a consequence of this behavior, the grass in the meadows will soon run out and sooner or later there might be no pasture left for any shepherd. In economic terms, the cause of this "tragedy" is that the private cost of grazing for the shepherd is lower than the social cost for the community. Without a public intervention or the assignment of the property rights, the social result would be an excessive exploitation of the meadow and eventually a desertification process.[12]

As a matter of fact, atmosphere is a common resource and free access to it determines an excessive exploitation due to the negative externalities involved. As the economic theories recall, it is socially efficient to devise a public intervention that correct this "market failure": the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto protocol have been the political answers to the problem. These nation-wide agreements have found a cooperative solution to the problem by calling for a general reduction of green house gas emissions. The seriousness of the issue at stake – atmosphere is the basic element of life – have made politicians more careful than in other circumstances, like for instance fisheries, in which the exploitation of the resource seems to have proceeded too far beyond the desirable limit. Up to now the commitments have been expressed at a general level, without specifying for each country the sector in which emissions have to be cut. However recommendations about sustainable forms of farming have been provided since 1997's Kyoto protocol: appropriate use of rotations, recycling waste as nutrient resources, use of nitrogen-fixing plants, reduce unnecessary tillage, reduce chemicals usage. The fourth assessment report of

[12] Cfr. Hardin(1975).

the International Panel on Climate Change (IPCC) calls for a sequence of measure that can be adopted in agricultural activities to reduce the atmospheric emissions and mitigate climate change.

The model that follows describes in mathematical terms the role of the farm in the climate change mitigation system. In such system the farm plays a typical role since it stands both as carbon emitter and as carbon sink. Important natural processes are involved: the photosynthetical process, the degradation of organic matter into humus, the assessment of carbon storage in wood and soil. Since the policy makers have recently paid attention to the behaviour of the farms the model contemplates a hypothesis of public intervention with the objective of climate change mitigation. It is necessary to remark that the interaction of the involved natural processes is more complex than the model describes. The quest for a balance between analytical focus and descriptive power is the reason why some natural processes are neglected as well as some aspects of the farm activity.

The purpose of the model is to evaluate from an economic point of view the different environmental performance of the agricultural techniques, with a particular attention to the difference when the activity is managed in a conventional or organic system. Using mathematical programming, in the linear form, the model provides a description of the farmers' behaviour: in line with the assumptions of self-interest the farmer is assumed to maximise net income and react to economic incentives by changing the partition of land. In addition, the description of the farmer's behaviour is integrated with the atmospheric impact of its activity, which corresponds to the capacity to permanently store gases in plants and soil. Provided that the objective of the policy makers is assumed to be the social welfare, and particularly the prevention of pollution and protection of a clean atmosphere, the connection between farmers' behaviour and policy makers' goals is modelled: by choosing an appropriate level of the policy variables – not only economic subsidies but also price support or input taxation– the hypothetical policy maker can modify the farmers' behaviour and achieve in society a reduction in the atmospheric green house gas emissions.

The implicit assumption behind the linear programming model is that an optimal pattern exists: economic theory predicts that since environmental benefits are public goods the market mechanism does not provides socially efficient outcomes and thus the policy makers is entitled to use different means of intervention to reach the "second best", that is the level of environmental benefits that is socially desirable. Provided that different forms of public regulation can be envisaged, according to the "provider gets principle" the optimal level of public goods is obtained by persuading farmers to avoid environmental damages and to improve environment through economic incentives in the form of voluntary payments (and not through command and control). The model is an application of such framework: it is made of an objective function and a series of constraints: land, labour, rotations, fertilisation, nitrogen-carbon cycle. The relevant data come from the FADN database: the representative farms which are obtained through a cluster analysis of the 10600 farms of the database are the basic content for the run of the simulations. Agricultural parameters are integrated with reports from agricultural associations about most common rotations and technical coefficients. The farm structure is identified at a general level with four categories: arables, fruit-trees, natural areas and animal husbandry. Then ten land uses are identified: forest, meadows, set-aside, cereals, intensive, forages, rise, fruit-trees, low input fruit trees, vineyard. As regard to animal husbandry, four types: dairy cattle, meat cattle, ovine and pigs. While each representative farm is characterised by a partition of its land according to the land use and the animal production types, the model simulation allows devising the ideal allocation of activity and quantifying the atmospheric impact.

Exogenous processes (processes that are not considered in the model)

- Soil erosion phenomena. In particular, soil erosion can diminish the organic matter that turns into humus.
- The process of silage. The carbon emission due to the process of fermentation is considered to be negligible.
- Tares and buildings often occupy a significant part of total farm area, including hedges.
- Wild breeding.
- Irrigation is not considered.
- The management of meadows and gardens. As a matter of fact, besides being sources of animal nutrition and carbon sinks, gardens and meadows can have economic impacts when they are kept for recreational purposes.
- It is assumed that in the stables the breeders practice a housing on straw.
- The labour units of the farm (ULA), defined in FADN database as the number of permanent workers (both family or not), are not considered directly. Labour required (related to field activities and husbandry) is divided into field crops, fruit trees and zoo-technical activity, and is computed in total hours along the year.
- Subsidies related to Nature 2000 and disadvantaged areas are no more considered.

The concept of "farm"

- The farm is composed of a single, unique body, thus it cannot have a mixed technical orientation: the activities are all either conventional or organic.
- The total agricultural area does not change: there is no account for purchase, hire or sales of agricultural area.

- The basic productive structure is fixed: there is no room for the introduction of fruit trees that do not exist since the beginning of the period. The zoo-technical activity exists only if it is present at the beginning of the period.
- Because the fruit trees and the natural areas are fixed, the variables that are optimised are only those under rotation that is arable crops and the animal husbandry.
- The analysis considers the farm according to the definition of entrepreneurial farmer of the Civil Code, art. No. 2135. In this definition the “no land breeding” farms are excluded since they fall into the category of industrial establishments (Supreme Court, labour section, 9th April 1998, judgment no. 3686).
- When there is husbandry, it is considered to be held on stables (no grazing) with straw (no grid).
- The farm is managed autonomously, without rents or other contractors.
- The objective function of the farm is the discounted sum of the yearly net incomes, along a horizon of ten years.

The model’s application

What is the amount of public subsidies that should be given to the farmers in order to compensate for the loss of income when they switch from conventional to organic farming? If organic farming systems provide social benefits then the society would welcome an economic support to organic farmers. The model provides a partial view since the benefits that are considered are only those connected to the mitigation of climate change. As a matter of fact organic products might have other benefits as well, especially from a nutritional point of view: these are not considered in the model.

These are the relevant variables:

Positive variables

SUC(cs) area for micro-activity

SUP(ro) area for macro-activity

ZOO amount of livestock

LAF(ot) work need for arable crops

HLT(ot) temporary work

QYT(cs,ot) total quantity of products

QYR(cs,ot) re-used quantity

QYV(cs,ot) sold quantity

QZV(zo) sold zoo-technical products

QY2(cs,ot) available secondary products

QV2(cs,ot) sold secondary products

QZ2 secondary product re-used for stabulation

QI2(cs,ot) unsold secondary product

DZF(di) zootechnical feed requirement

DZR(di,ot) in-farm feed availability

DZA(di) purchased feed

QZA(cm) amount of purchased agricultural goods

MNR manure

QNS(fe,cs,ot) fraction of fertiliser purchased for arable crops

QNA(fe,ua,ot) fraction of fertiliser purchased for fruit trees

NIF(ot) nitrogen requirement

NIZ nitrogen availability through manure

NIS(ot) purchased nitrogen for arable crops

NI1(ot) minimum nitrogen constraint

NI2(ot) maximum nitrogen constraint

VCS(ot,aa) variable costs of macro activity

VCA(ot,aa) variable costs for fruit trees

VCZ(aa) zoo-technical activities variable costs;

Variables

RN(ot,aa) net income

RNT(ot,aa) total net income

Z objective function

ZB	organic objective
ZC	conventional objective

The model maximises the objective function by selecting a value for all the variables. The object of choice for the area variables is a set of rotations: the farmer chooses a rotation among a set of possible rotations for the specific climate and layout. The rotations are expressed with a partition factor for each micro-activity and do not have a yearly computation.

Thus the optimal solution will provide a value for the area of the chosen rotation and it is then possible to calculate the area for each single crop that constitute the rotation. Thus the optimal crop is computed in a different way with respect to the models in the literature review. Here we have a single rotation that is made up of different crops: to be precise there is not an optimal crop but the choice of a rotation that is made up of different crops.

The farm's life span

The perspective which is followed in developing the model is one of a short period. In fact the farm structure is kept constant. Fruit trees plantation does not change: the model cannot take into account structural changes like the plantation of new trees. Similarly, the zoo-technical density can change only within the limits of the existing stables: the model takes into account four types of breeding and a factor of expansion which implies the possibility that the stables were not fully utilised. Rotations do not have a timely flavor but are expressed according to partition factors. As a matter of fact, the flow of time is taken into account in the economic variables, which are either capitalised or discounted according to a specific rate of interest. Ten years is the horizon according to which the economic values are actualised.

The model's activities

The model considers four different levels of detail:

LEVEL 1 - super activity

Such a level describes a general structure of farm in terms of four components:

- ZOO - animal husbandry, described from the way animal breeding is carried on;
- NAT - natural surfaces (woods, meadows), described from main natural species present in such environment;
- ARB - tree crops, described from planted species and irrigation regime;

- SEM - arable crops and open field horticulture, described in terms of rotation schemes;

LEVEL 2 - macro activity

This set of activities gives a detail of super activities grouping activities with similar agro-technical inputs:

- ZOO.EL - dairy cattle
- ZOO.EC - meat cattle
- ZOO.OC - sheeps and goats
- ZOO.SU - swines
- NAT.PR - meadows
- NAT.BO - wood (and surface not cultivated nor mown)
- SEM.SA - fallow (set-aside)
- SEM.FO - forage crops
- SEM.CR - cereals
- SEM.RI - rice
- SEM.IN - intensive crops (maize, horticulture)
- ARB.AR - fruit tree crops
- ARB.AB - low inputs tree crops (e.g. citrus, olive tree, chestnut, wood crops)
- ARB.VT – grapevine

LEVEL 3 - FADN-entry (“rubrica”)

Such a level corresponds to crop and activity families (it: “rubriche”) used by the RICA (FADN) database. Such a grouping however is not homogeneous: sometime corresponding to a specific crop (e.g.durum wheat) but in other cases keeping together several crops, very different from market viewpoint (e.g. apple, cherry and peach are all together in a unique activity).

LEVEL 4 - Crop-product

When specified at the above levels, technical parameters cannot include productions, yields and related market prices. To solve this problem each activity has been linked to one specific crop depending on the region (which also reflects main Italian DOPs). It means that for one region, e.g. Emilia-Romagna, there will be just one crop product for every single FADN entry that is the combination FADN-entry and crop-product is unique for the region.

The case study: Emilia Romagna

FADN entry for field crops	**CODE**	**Emilia Romagna**	**CODE**
Maggese	MA	Fallow land	MA
Avena e miscugli estivi	D05	Oats	AVN
Altri cerali, Sorgo, Farro	D08	Sorghum	SOR
Legumi secchi e colture proteiche per la produzione di granella (comprese le sementi e i miscugli di cereali e di legumi secchi)	*F01*	Dried legumes	LEG
Erbai temporanei	D18A	Grass meadow	ERB
Altre piante raccolte verdi (erba medica)	D18B	Other green plants (alfalfa)	API
Terreni a riposo con e senza aiuti finanziari	I08AD22	Set aside	RIP
Frumento (grano) tenero e spelta	D01	Soft wheat	FTE
Frumento (grano) duro	D02	Durum wheat	FDU
Segala	D03	Rye	SEG
Orzo	D04	Barley	ORZ
Riso	D07	Rise	RIS
Granturco	D06	Maize	GTR
Patate (comprese le patate primaticce e da semina)	D10	Potatoes	PAT
Barbabietole da zucchero (escluse le sementi)	D11	Sugar beet	BBT
Piante sarchiate da foraggio (escluse le sementi)	D12	Forage plants	SAR
Ortaggi da pieno campo	D14A	Lettuce	LAT
Coltivazione in orti stabili: fragola, pomodoro da mensa, altro	D14B	Strawberry	FRA
Fiori e piante ornamentali all'aperto	D16	Flowers	FIO
Piantine per orticole, floricole e altro	D19	Decorative plants	PIA
Sementi da prato e altro	D20	Seeds	SEM
Tabacco	D23	Tobacco	TAB
Colza e ravizzone	D26	Colza	COL
Girasole	D27	Sunflower	GIR
Soia	D28	Soybean	SOI
Semi di lino	D30	Flax seeds	SLI
Canapa	D32	Canapa	CAN
Altre colture industriali, non menzionate altrove	D34	Other industrial crop	IND
Canna da zucchero	*D35*	Sugarcane	CZU

Table 8: RICA (FADN) entries for field crops

FADN ENTRY for fruit trees	**CODE**	**Emilia Romagna**	**CODE**
Frutta temperata a semi: melo, pero, fico, altro. Frutta a nocciolo: pesco, nettarina, albicocco, ciliegio, susino	G01A	Peaches	PES
Frutta di origine subtropicale – actinidia	G01B	Kiwi	KIW
Uve da tavola e Uva passa	G04C	Grapefruit	UVA
Vivai: Viti, fruttiferi, ornamentali e altro	G05	Garden centres	VIV
Altre coltivazioni permanenti – bacche, piccoli frutti	G06	Berries	BAC
Per la produzione di olive da tavola	G03A	Table olives	OTA
Vini di qualità	G04A	DOC wines	VIN
Altri vini	G04B	Wines	AVI
Frutta a guscio: mandorlo, nocciolo, castagno, noce, altro	G01C	Nuts	MAN
Agrumeti: arancio, mandarino, clementine, limoni, altri	G02	Lemons	LIM
Per la produzione di olive da olio	G03B	Oil olives	OLI

Table 9: FADN entries for fruit trees

Mathematical notation

- Technical coefficients are the parameters describing a crop management technique, i.e. the constant values – agricultural, economic and environmental – that are known at only one of the four scales: super-activity, macro-activity, FADN-entry or crop-product (for instance: yields, prices, labour requirements ….).
- Endogenous variable: a variable whose value is determined through the model’s run.
- Exogenous variable: a variable whose value is fixed *i.e.* it is determined after the model’s run.
- Policy variable: an endogenous variable that mirrors directly the effects of public intervention policies. In operation research it is referred to as decision variable. In the model the policy variable is the area of agricultural activity (and the amount of livestock units).
- Constraint: a relation among endogenous variables that is to be satisfied by the model.
- Objective function: a function of endogenous variables that is to be maximised or minimised through the values of the policy variables.

Conventions

1. The endogenous variables are indicated with capital letters.
2. Coefficients and exogenous variables are indicated with lower letters.
3. The index specifies an attribute of a variable or a coefficient.
4. When two or more indices exist for a variable or a coefficient, each is separated by a comma.
5. In the equations that define a variable or a coefficient, the defined variable/coefficient appears on the left-hand side of the equation.
6. Equations in which a variable or a coefficient is defined are indicated with a D; equations in which a constraint is set, with a C.[13]

[13] Also the definitions of the environmental coefficients, that are exogenous variables, are marked with a D.

3.2. Land use pattern and farm management

The land's distribution pattern is dependent upon the farmer's decisions. For instance, in a year when the price of forages is very high he could grow alfalfa, then in the following year – if the prices of maize have become more convenient – he can switch to the activity of maize.

The farm structure is identified according to four dimensions: the productive orientation, the macro-activities, the activities that take place and the crop production. Four productive orientations are possible: natural areas, plantation trees, arable crops and breeding activities. Each productive orientation is articulated into macro-activities. Every macro-activity may comprehend one or more (micro) activities that correspond to the FADN entry. At the finest level of detail is the crop production. Two parameters distinguish the coefficients of the different farms: climate and technical orientation.

PRODUCTIVE ORIENTATION	**MACRO-ACTIVITIES**	**ACTIVITIES Phyto-climatic region**	**ACTIVITIES Technical orientation**
NATURAL AREAS	FOREST	**1-2-3-4-5**	**B-C**
	MEADOWS	**1-2-3-4-5**	**B-C**
PLANTATION TREES	FRUIT TREES	**1-2-3-4-5**	**B-C**
	VINEYARDS	**1-2-3-4-5**	**B-C**
	LOW INPUT FRUIT TREES	**1-2-3-4-5**	**B-C**
ARABLE CROPS	FORAGES	**1-2-3-4-5**	**B-C**
	CEREALS	**1-2-3-4-5**	**B-C**
	INTENSIVE CROPS	**1-2-3-4-5**	**B-C**
	RISE	**1-2-3-4-5**	**B-C**
	SET ASIDE	**1-2-3-4-5**	**B-C**
ANIMAL HUSBANDRY	Dairy cows	**1-2-3-4-5**	**B-C**
	Cattle fattening	**1-2-3-4-5**	**B-C**
	Sheep breeding	**1-2-3-4-5**	**B-C**
	Pig breeding	**1-2-3-4-5**	**B-C**

Table 10: land distribution pattern

3.2.1. Land use pattern

D) sun. Natural utilised agricultural area

Eqsun $$sun = \sum_{uu \in un} sui_{uu} \qquad (1)$$

uu land use

un natural areas

COEFFICIENTS:

sun: natural areas (ha)

sui: initial areas (ha)

The equation defines the part of utilised agricultural area which is covered by natural plantation. According to model's assumption this area is treated as fixed, a parameter which is typical of the farm and it is not subjected to optimisation.

D) sro. Agricultural area in rotation

Eqsro $$sro = \sum_{uu \in ur} sui_{uu} \tag{2}$$

uu	land use
ur	land use in rotation

COEFFICIENTS:

sro: total area with rotation (ha)

sui: initial area

This equation identifies the part of agricultural area in which rotations of field crops take place.

D) sar. Total agricultural area with permanent crops

Eqsar $$sar = \sum_{uu \in ua} sui_{uu} \qquad (3)$$

uu	land use
ua	area with permanent crops

COEFFICIENTS:

sar: area with permanent crop (ha)

sui: initial area (ha)

This equation identifies the part of agricultural area which is assigned to stable activities with fruit trees. The model considers such activities as fixed parameters, that is to say parameters that are typical of the farm and are not subjected to optmisation.

D) SUP: areas with fruit trees activities

Eqsup $$SUP_{ua} = sui_{ua} \tag{4}$$

ua area with permanent crops

COEFFICIENTS: *sui*: initial area (ha)

VARIABLES: *SUP*: utilised agricultural area for macro-activity (ha)

The area variables that refer to the fruit trees are equal to the initial values, that are identified in the parameter *sui*. This is not true for the activities that refer to arable crops, which are submitted to optimization.

D) SUP: areas with natural activities

Eqsup $SUP_{un} = sui_{un}$ (5)

un natural areas

COEFFICIENTS:

sui: initial areas (ha)

VARIABLES:

SUP: utilised area for macro-activity (ha)

The area variables that refer to natural areas are equal to the initial values. In other words the total area located to forest and meadows does not change: it remains equal to the initial state.

3.2.2. Land constraints

C) Constraint of rotation area

Eqsautot $$\sum_{ro} SUP_{ro} \leq sro \quad , \qquad \text{with } SUP_{ro} \geq 0 \tag{6}$$

ro farm's rotation

VARIABLES:

SUP: utilised area for macro-activity (ha)

COEFFICIENTS:

sro: total area with rotations (ha)

This equation stands for the constraint of the rotation area: the sum of the areas with activity in rotation is to be lower or equal to the total area that is available for rotations.

C) Constraint of total crops

Eqsautot
$$\sum_{cs} SUC_{cs} \le sro \quad , \qquad (7)$$
$$with \ SUC_{cs} \ge 0$$

cs crop product

VARIABLES:

SUC: total area for micro-activity (ha)

COEFFICIENTS:

sro: total area in rotation (ha)

This equation stands for the constraint of the arable crops: the sum of the areas dedicated to the arable crops is to be lower or equal to the total area that is available for rotations.

3.2.3. Employment and breeding

C) maximum amount of livestock

- **Eqall** $ZOO_{zo,aa} \leq zoi_{zo} \cdot (1+ fzm)$ (8)

aa	year
zo	zoo-technical activity

VARIABLES:

ZOO: amount of livestock (lu)

COEFFICIENTS:

zoi: initial amount of livestock (lu)

fzm: coefficient of expansion

The amount of livestock is to be lower or equal to the maximum amount that animal houses can contain. The coefficient *zoi* is the initial amount, in the first year, for every type of breeding activity: it is assumed that animal houses are not utilised at the maximum and so in subsequent years the amount of livestock must be equal or lower to the initial amount multiplied for a factor of expansion that is slightly greater than one.

C-D) LAS: work requirement for arable crops

EqLAS

$$LAS_{ot,aa} = \sum_{cs} SUC_{cs,aa} \cdot lfs_{cs,ot} \qquad (9)$$

$$LAS \geq 0$$

ot technical orientation

aa year

cs agricultural activity

VARIABLES:

SUC: area for micro-activity (ha)

LAS: labor requirement (hours)

COEFFICIENTS:

lfs: unitary work requirement in arable crops (hours/ha)

The total amount of work that is necessary in arable crops' agricultural activities is equal to the sum of the labour need in every activity. Each activity is characterised by the coefficient *lfs* which stands for the unitary labour need with regard to arable crops.

C-D) LAZ: work requirement for breeding

EqLAZ

$$LAZ_{ot,aa} = \sum_{zo} ZOO_{zo,aa} \cdot lfz_{zo} \qquad (10)$$
$$LAZ \geq 0$$

ot	technical orientation
aa	year
zo	zootechnical activity

VARIABLES:

LAZ: labor requirement (persons)

ZOO: amount of livestock (lu)

COEFFICIENTS:

lfz: unitary work requirement in breeding (persons/lu).

The total amount of work that is necessary in the breeding activities is equal to the sum of the labour need in every activity. Each activity is characterised by the coefficient *lfz* which stands for the unitary labour need with respect to a specific type of breeding.

D) LAV: work requirement for permanent crops

EqLAV $$lav_{ot} = \sum_{ua} sui_{ua} \cdot lfa_{ua,ot} \cdot dur_{ua} / 12 \qquad (11)$$

ua permanent crop activity

ot technical orientation

COEFFICIENTS:

sui: initial areas (ha)

lfa: unitary work requirement in fruit tree activities (persons/ha)

dur: length of activity (number of months)

lav: total amount of work in fruit trees activities (persons)

Since permanent crops are fixed in the model, the connected work requirement is fixed, too. The total amount of work in fruit tree activities is measured as a parameter equal to the area times the work coefficient times the duration of the activity in months divided for twelve. Thus, differently from *LAS* and *LAZ*, which are endogenous variable, *lav* is introduced in the model as a coefficient.

D) HLT: temporary work

EqHLT $$HLT_{ot,aa} = LAS_{ot,aa} + (LAZ_{ot,aa} + lav_{ot}) \cdot hlav \tag{12}$$

aa year

ot technical orientation

VARIABLES:

HLT: temporary work (hours)

LAS: amount of work in arable activities (hours)

LAZ: amount of work in zootechnical activities (persons)

COEFFICIENTS:

lav: amount of work in fruit tree activities (persons)

hlav: coefficient of yearly work (hours/person.year)

The amount of temporary work is equal to the sum of the work need for arable crops (a variable) and animal husbandry (a variable) and fruit tree (a coefficient), times the amount of hours that a single person can work (2400).

3.3. Agricultural production

This part is a description of the production of vegetal and animal goods, which results from the work of the land and the livestock breeding. For some agricultural activities, the products may be re-used with destination the zoo-technical activities whereas for the other activities the unique destination is the market. The model takes into account the secondary market for the animal houses where the exchange product is the straw.

The model comprehends the problem of the livestock diet, according to the nutritional categories of the energy (expressed in forage units) and proteins (expressed in grams of protides). Once it is estimated, the global nutritional requirement can be satisfied either with the products of the farm or with products available within the market: the constraint must be that the sum of the two components exceeds the need for each nutritional category. In addition a balanced diet requires that the sum does not exceed a fixed percentage above unity for each category.

As regard the agricultural products, the land use is divided among macro-activities (*uu* index) but the yields are expressed with regard to the single micro-activities. In order to link the two measures, it is used the partition coefficient *fr*, which is indexed upon micro-activity and crop products, and which allows the passage from area variable (defined for micro-activities) and yields (defined for crop products).

The zoo-technical activities are grouped into four typologies: dairy cattle, meat cattle, ovine, pigs. The typologies are in one-to-one relationship with the sold products.

D) Land use pattern of permanent crop activities

Eqsua $$sua_{ca} = sui_{ua} \cdot fa_{ua,ca} \tag{13}$$

ua	permanent crop macro-activity
ca	permanent crop micro-activity

COEFFICIENTS:

sua: area with fruit trees (ha)

sui: initial area (ha)

fa: partition coefficient.

The area where a micro-activity with fruit-tree is managed is equal to the sum of the initial areas times a partition coefficient. The partition coefficient expresses the weight of the micro-activity *ca* within the macro-activity *ua*.

D) Yield of permanent crop

Eqqya $qya_{ca,ot} = y_{ca,ot} \cdot sua_{ca}$ (14)

ca permanent crop micro-activity

ot technical orientation

COEFFICIENTS:

qya: yield of fruit trees (tons)

y: unitary yield of fruit trees (tons/ha)

sua: total area with fruit trees (ha)

The total amount of production for a fruit tree activity is equal to the product between the total area of the activity and the unitary yield.

D) SUC: area of arables

EqSUC $$SUC_{cs,aa} = \sum_{ro} SUP_{ro,aa} \cdot fr_{cs,ro} \ \forall \ cs, aa \qquad (15)$$

cs	crop product (arable crop)
aa	year
ro	rotation

VARIABLES:

SUC: area for arable crop (ha)

SUP: area for macro-activity and rotations (ha)

COEFFICIENTS:

fr: coefficient of partition for arable crops.

The extent of the area with an arable crop is equal to the sum over all the rotations of the area of the rotation times the weight of the arable crop within the rotation. The coefficient *fr* represents the weight of the arable crop in the rotation.

D) QYT: total yield for micro-activity

EqQYT $QYT_{cs,ot,aa} = y_{cs,ot} \cdot SUC_{cs,aa} \; \forall \; cs, ot, aa$ (16)

cs	crop product (arable crop)
ot	technical orientation
aa	year

VARIABLES:

QYT: produced quantity (tons)

SUC: area of micro-activity (ha)

COEFFICIENTS:

y: unitary yield (tons/ha).

The variables *QYT* represent the total amount of agricultural goods that are produced in a year for a single agricultural activity. The coefficient "*cs*" bounds the validity of this equation to the arable crops. The unitary yield of a product is multiplied for the area in which that activity is run.

D) QYV: sold agricultural products

EqQYV $$QYV_{cs,ot,aa} = QYT_{cs,ot,aa} - QYR_{cs,ot,aa} \quad (17)$$

cs	crop product (arable crop)
ot	technical orientation
aa	year

VARIABLES:

QYV: sold quantity (tons)

QYT: produced quantity (tons)

QYR: re-used quantity (tons)

This block of equations defines the final destination of the agricultural products, namely the sale for the market or internal use. In the case of forages the produced quantity can be re-used internally for the nutrition of the livestock. The variable *QYV* is equal to the total quantity minus the quantity that is re-used.

C) QYR: re-used agricultural products

EqQYR $$QYR_{cs,ot,aa} \leq QYT_{cs,ot,aa} \forall cs, ot, aa \tag{18}$$

cs	crop product (arable crop)
ot	technical orientation
aa	year

VARIABILI:

QYR: re-used quantity (tons)

QYT: produced quantity (tons)

For every arable crop, the quantity that is re-used must be lower than the total quantity.

D) QZV: sold zoo-technical products

EqQZV $$QZV_{zo,aa} = fqz_{zo} \cdot ZOO_{zo,aa} \forall\, zo, aa \qquad (19)$$

zo zoo-technical activity

aa year

VARIABILI:

QZV: amount of zoo-technical product (kg)

ZOO: amount of livestock (lu)

COEFFICIENTI:

fqz: unitary yield of zoo-technical product (kg/lu)

These equations define the total quantity of zoo-technical products in every year. The unitary yield of a zoo-technical activity is multiplied for the amount of the livestock. The products of any zoo-technical activity are meant to be milk and meat, and the unity of measurement is the kilogram. The coefficient *fqz* stands for the unitary productivity of the zoo-technical activity *zo*: for every type of livestock a single product is associated, similarly to agricultural activities.

D) QY2: secondary product for animal houses

EqQY2 $$QY2_{cs,ot,aa} = QYT_{cs,ot,aa} \cdot fpa_{cs} \tag{20}$$

aa	year
cs	micro-activity with arable
ot	technical orientation

VARIABLES:

QY2: quantity of secondary product (tons)

QYT: quantity of main product (tons)

COEFFICIENTS:

fpa: ratio between straw and grain

This equation describes the production of straw to be used in animal houses. The coefficient "*fpa"* stands for the ratio between the straw and the grain, which is between 1:1 and 2:1 in dried matter.

D) QZ2: internal demand of secondary product

EqQZ2 $$QZ2_{aa} = \sum_{zo} ZOO_{zo,aa} \cdot fpzo_{zo} \tag{21}$$

aa anno

zo attività zoo-tecniche

VARIABLES:

QZ2: demand for re-used quantity (tons)

ZOO: amount of livestock (lu)

COEFFICIENTS:

fpzo: amount of straw which is demanded by every livestock unit (tons/lu)

The variable *QZ2* stands for the quantity of secondary product (straw) which is demanded by the breeding activity. It results from the sum of the quantities which are demanded by every type of livestock.

D) QV2: sold secondary product

EqQV2 $$QV2_{cs,ot,aa} = QY2_{cs,ot,aa} - QZ2_{aa} \qquad (22)$$

aa	year
cs	micro-activity
ot	technical orientation

VARIABLES:

QV2: sold secondary product (tons)

QY2: total amount of secondary product (tons)

QZ2: re-used quantity of secondary product for zoo-technical purposes (tons)

The variable *QV2* stands for the quantity of secondary product that is sold in the market. The variable *QY2* stands for the quantity of secondary product which the farmer obtained. Once the zoo-technical demand is satisfied, the secondary product is sold in the market.

D) MNR: manure

EqMNR $$MNR_{zo,aa} = ZOO_{zo,aa} \cdot fmnr_{zo} \tag{23}$$

zo	zoo-technical activity
aa	year

VARIABLES:

MNR: production of manure (kg)

ZOO: amount of livestock (lu)

COEFFICIENTS

fmnr: amount of manure produced by a single unit of livestock (kg/lu)

The variable *MNR* stands for the quantity of manure that is produced in every type of zoo-technical activity.

3.4. Livestock nutrition

In the management of the livestock nutrition, two nutritional factors are considered: forage units, representing the consumption of energy, and grams of protides to account for the need of proteins. For each factor the requirement is calculated as well as the availability within the farm and from the market. Then two constraints are placed: the minimum diet, whereby the requirement is to be lower than the total availability, and the maximum diet constraint that prevents from excessive nutrition.

D) DZF: zoo-technical feed requirement

EqDZF $$DZF_{di,aa} = \sum_{zo} ZOO_{zo,aa} \cdot fdz_{zo,di} \tag{24}$$

di	nutritional category
aa	year
zo	zoo-technical activity

VARIABLES:

DZF: zoo-technical feed needs (forage units FU, grams of protides)

ZOO: amount of livestock (livestock units)

COEFFICIENTS:

fdz: unitary feed needs (forage units/livestock units, grams of protides/livestock units).

These equations define the feed need of the livestock, on the basis of various nutritional categories.

D) DZR: in farm resources availability

EqDZR $$DZR_{di,ot,aa} = \sum_{cz} QYR_{cz,ot,aa} \cdot fdc_{cz,di} \qquad (25)$$

di nutritional category

ot technical orientation

aa year

cz agricultural products that are used for animals' diet

VARIABLES:

DZR: feed resources in the farm (forage units, grams of protides)

QYR: re-used quantity (ton)

COEFFICIENTS:

Fdc: nutritional values of the products that are used for the diet (forage units/ton, grams of protides/ton)

These equations define for each nutritional category the amount of resources that are available within the farm.

D) DZA: market feed

EqDZA $$DZA_{di,aa} = \sum_{cm} QZA_{cm,aa} \cdot fdm_{cm,di} \tag{26}$$

di nutritional category (forage units, protides)

aa year

cm market products for livestock nutrition

VARIABLES:

DZA: availability of feed resources through the market (forage units, grams of protides)

QZA: amount of market products that are bought (ton)

COEFFICIENTS:

fdm: nutritional value (forage units/ton, grams of protides/ton)

This equation defines the availability of resources through the products that are bought in the market.

C) Minimum diet

Eq. DZF1 $$DZA_{di,aa} + DZR_{di,ot,aa} \geq DZF_{di,aa} \tag{27}$$

di nutritional category (forage units, protides)

ot technical orientation

aa year

VARIABLES:

DZA: availability of feeding resources through the market (forage units, grams of protides)

DZR: in farm availability of resources (forage units, grams of protides)

DZF: zoo-technical feeding requirement (forage units, grams of protides)

This equation calls for the satisfaction of the nutritional need: the sum of the in-farm availability of resources and the market acquisition of resources is to be greater than or equal to the nutritional need.

C) Maximum diet

Eq. DZF2 $$DZA_{di,aa} + DZR_{di,ot,aa} \leq (1 + fen) \cdot DZF_{di,aa} \tag{28}$$

di nutritional category

aa year

ot technical orientation

VARIABLES:

DZA: availability of feed resources through the market (forage units, grams of protides)

DZR: in farm availability of resources (forage units, grams of protides)

DZF: zoo-technical feed requirement (forage units, grams of protides)

COEFFICIENTS:

fen: coefficient of excessive nutrition

This constraint introduces a limit to the excessive feed with regard to the nutritional elements.

3.5. Fertility balance

The balance of fertility is an important aspect of farm activities. The nitrogen requirement is computed with respect to arable crops and permanent crops. Then the availability is computed: resources come either from the market or from the manure of the livestock. Two constraints are envisaged: a minimum requirement constraint and a legal constraint that bounds the maximum amount of nitrogen per unit of land.

D) NIF: nitrogen requirement

Eq. NIF $$NIF_{ot,aa} = \sum_{cs} SUC_{cs,aa} \cdot nfs_{cs,ot} + \sum_{ua} sui_{ua} \cdot nfa_{ua,ot} \quad (29)$$

ot technical orientation

aa year

cs crop product (arable crops)

ua macro-activity with permanent crop

VARIABLES:

NIF: nitrogen requirement in all activities (kg)

SUC: extension of area for microactivity(ha)

COEFFICIENT:

nfs: nitrogen need on micro-activities (kg/ha)

sui: initial areas (ha)

nfa: nitrogen need on macro-activities (kg/ha)

This equation defines the total requirement of nitrogen within the farm. This is equal to the sum of nitrogen requirement for arable crops and for fruit trees activities.

D) NIA: nitrogen availability from market

Eq. NIA $$NIA_{ot,aa} = \sum_{fe}(\sum_{cs} QNS_{fe,cs,ot,aa} + \sum_{ua} QNA_{fe,ua,ot,aa}) \cdot fn_{fe} \qquad (30)$$

ot technical orientation

aa year

fe type of fertilizer

cs crop product (arable crops)

ua macro-activity with permanent crop

VARIABLES:

NIA: amount of nitrogen that is bought in all activities (kg)

QNS: amount of fertiliser that is bought for arable crops (kg)

QNA: amount of fertiliser that is bought for fruit trees (kg)

COEFFICIENT:

fn: nitrogen concentration in fertilisers

This equation defines the availability of nitrogen from the market.

D) NIZ: nitrogen availability from manure

Eq. NIZ $$NIZ_{aa} = \sum_{zo} MNR_{zo,aa} \cdot fnz_{zo} \tag{31}$$

aa year

zo zoo-technical activity

VARIABLES:

NIZ: amount of nitrogen that is available through manure (kg)

MNR: amount of manure (kg)

COEFFICIENTS:

fnz: nitrogen concentration in manure

This equation defines the estimate of the total amount of nitrogen that is available though the manure of the farm.

C) Minimum nitrogen

Eq. NI1 $$NIA_{ot,aa} + NIZ_{aa} \geq NIF_{ot,aa} \quad (32)$$

ot technical orientation

aa year

VARIABLES:

NIA: amount of nitrogen that is bought in the market (kg)

NIZ: amount of nitrogen that is available through the manure (kg)

NIF: nitrogen requirement (kg)

This constraint requires that in every year the total amount of nitrogen that is available in the farm is greater or equal to the nitrogen requirement.

C) Maximum nitrogen

Eq. NI2 $$NIA_{ot,aa} + NIZ_{aa} \leq (sar + sro) \cdot fnmx \qquad (33)$$

ot technical orientation

aa year

VARIABLES:

NIA: nitrogen that is available from the market (kg)

NIZ: nitrogen that is available from the manure (kg)

COEFFICIENT:

sar: total area with permanent crop (ha)

sro: total area with arable crops (ha)

fnmx: maximum amount of nitrogen per hectare (kg/ha)

This is a legal constraint according to which there is a maximum amount of nitrogen that can be distributed in the soil.

3.6. Economic results

This part is a description of the costs and revenues of the farm. The variable costs are distinct according to arable crops, permanent crops and animal husbandry. In the variable costs of the zoo-technical activity it is considered the amount of livestock as well as the amount of feed that is bought in the market.

It is hereby formalised the core of the objective function, that is the net farm income in a year, which is subsequently increased by the amount of public subsidies. Such income is then extended to ten years. The policy variable, that is the variable which is ideally managed by the public authority, is identified in the land partitions that are subject to rotations: cereals, forage, intensive crop, rice.

As the allocation of the macro-activities changes, then the values of the endogenous variables change accordingly and the coefficients stay constant.

The model maximises the objective function under the series of constraints by choosing one rotation. By executing the choice, the model assigns values to the endogenous variables, as the area variables. In this way the optimal land distribution pattern comes out.

D) VCS: variable costs of arable crops

Eqvcs

$$VCS_{ot,aa} = \sum_{cs,fe} QNS_{fe,cs,ot,aa} \cdot pfert_{fe,aa} + \sum_{cs} SUC_{cs,ot,aa} \cdot (fuel_{cs,ot} \cdot pfuel_{aa} + chem_{cs,ot} \cdot pchem_{cs,aa} + mac_{cs,ot} \cdot pmac_{aa}) \forall \; ot, aa \quad (34)$$

aa	year
fe	type of fertiliser
cs	crop product (arable crops)
ot	technical orientation

VARIABLES:

VCS: variable costs (euro)

QNS: amount of fertilisers that is used in arable (kg)

SUC: utilised area (ha)

COEFFICIENTS:

fuel: amount of fuel (litres/ha)

pfuel: price of fuel (euro/litre)

pfert: price of fertiliser (euro/kg)

chem: amount of chemicals (kg/ha)

pchem: price of chemicals (euro/kg)

mac: use of machinery (hours)

pmac: costo of machinery (euro/hour).

This equation defines the variable costs for arable crops' activities. Four productive factors are considered: fuel, fertiliser and chemicals, machinery. The workforce is considered separately in the equation for net income.

D) VCA: variable costs of fruit trees

Eqvca

$$VCA_{ot,aa} = \sum_{ua,fe} QNA_{fe,ua,ot,aa} \cdot pfert_{fe,aa} + \sum_{ua} sui_{ua} \cdot (fuela_{ua,ot} \cdot pfuel_{aa} + chema_{ua,ot} \cdot pchem_{ua,aa} + maca_{ua,ot} \cdot pmac_{aa}) \forall \; ot, aa \qquad (35)$$

aa	year
fe	type of fertiliser
ua	permanent crop macro-activity
ot	technical orientation

VARIABLES:

VCA: variable costs (euro)

QNA: amount of fertilisers that is used for permanent crops (kg)

COEFFICIENTS:

fuela: amount of fuel for permanent crops (litres/ha)

pfuel: price of fuel (euro/litre)

pfert: price of fertiliser (euro/kg)

chema: amount of chemicals (kg/ha)

pchema: price of chemicals (euro/kg)

maca: use of machinery (hours)

pmac: cost of machinery (euro/hour)

sui: initial area (ha).

This equation defines the variable costs for the permanent crops' activities. Four productive factors are considered: fuel, fertiliser and chemicals, machinery. The employment of workforce is considered separately in the equation for net income.

D) VCZ: zoo-technical variable costs

Eqvcz

$$VCZ_{aa} = \sum_{zo} [\, fuelz_{zo} \cdot pfuel_{aa} + chemz_{zo} \cdot pchemz_{zo,aa} + macz_{zo} \cdot pmac_{aa} \,] \cdot ZOO_{zo,aa} + \sum_{cm} QZA_{aa,cm} \cdot pac_{cm,aa} \ \forall\ aa \tag{36}$$

aa	year
zo	zoo-technical activity
cm	market feed products

VARIABILI:

VCZ: zoo-technical variable costs (euro)

QZA: amount of market feed products (kg)

ZOO: amount of livestock (lu)

COEFFICIENTI:

fuelz: fuel for zoo-technical activity (litres/lu)

pfuel: price of fuel (euro/litre)

chemz: amount of chemicals for breeding activities (kg/lu)

pchemz: price of chemicals (euro/kg)

macz: zoo-technical machinery (hours/lu)

pmac: price of machinery (euro/hour)

pac: feed buying price (euro/kg).

These equations define the variables *VCZ*, standing for the unitary cost of the zoo-technical activities. The employment of workforce is considered separately in the equation for net income.

D) RN: yearly net income

EqRN

$$RN_{aa} = \sum_{cs}(pvs_{cs,ot,aa} \cdot QYV_{cs,ot,aa}) + \sum_{ca} qya_{ca,ot,aa} \cdot pva_{ca,ot,aa} - VCA_{ot,aa} - VCS_{ot,aa} - VCZ_{aa}$$
$$+ QV2_{aa} \cdot pv2_{aa} + \sum_{zo}(pvz_{zo,aa} \cdot QZV_{zo,aa})$$
$$- HLT_{aa} \cdot wlt_{aa} - pbio_{aa} \cdot obio \quad \forall\, aa \qquad (37)$$

aa	year
cs	micro-activity with arable crops
ca	micro-activity with permanent crops
ot	technical orientation
zo	zoo-technical activity

VARIABLES:

RN: net income (euro)

QYV: amount of sold products (tons)

VCS: variable cost of arable crops (euro)

VCA: variable cost of permanent crops (euro)

VCZ: variable cost of zoo-technical activity (euro)

QV2: amount of sold secondary product (tons)

QZV: amount of sold zoo-technical product (tons)

HLT: amount of labour (hours).

COEFFICIENTS:

Pvs: selling price of arable crops (euro/ton)

Pva: selling price of permanent crops (euro/ton)

Pvz: selling price of zoo-technical products (euro/lu)

qya: quantity of fruits

py2: selling price of secondary product(euro/ton)

wlt: wage (euro/hour)

pbio: certification cost (euro)

obio: dichotomous coefficient for organic orientation

These equations define the net income for every year.

D) SUS: public subsidies

EqSUS $$sus_{aa} = sau \cdot sb_{aa} + sun \cdot sv_{aa} \quad \forall\ re, aa \tag{38}$$

These equations define the amount of public subsidies that accrue to the farm, as the sum of two components. The basic component is proportional to the agricultural utilised area and the green component is proportional to the area with natural elements.

aa year

COEFFICIENTS:

sus: amount of public subsidies (euro)

sau: utilised agricultural area (ha)

sun:natural area (ha)

sb: base subsidy (euro/ha)

sv: green subsidy (euro/ha)

D) RNT: total net income

EqRNT $$RNT_{aa} = RN_{aa} + sus_{aa} \forall \ aa \tag{39}$$

aa year

VARIABLES: *RNT*: total net income (euro)

RN: net income (euro)

EXOGENOUS VARIABLES:

sus: public subsidies (euro)

Equations that define the total net income as the sum of the net income and the public subsidies.

D) Z: total income

EqZ $$Z = \sum_{aa} RNT_{aa} \cdot (1+r)^{a0-aa} \qquad (40)$$

aa	year
a0	current year (2011)

VARIABLES:

Z: income over the time horizon (euro)

RNT: total net income in a year (euro)

EXOGENOUS VARIABLES:

r: discount rate

Equations that define the total income over the time horizon provided that the income of each year is actualised with the rate of discount *r*. Year 2011 is considered to be the base year and ten years before are the time horizon (2001-2010).

3.7. Carbon-nitrogen cycle

In this part the relationships are reported that describe the carbon flow (on a yearly basis) on the basis of the transformation processes taking place within the farm. Examples of such processes are the accumulation of a stock of carbon into soil and trees, the direct emissions that come from fuel burning, livestock metabolism, manure fermentation.

The model describes the carbon-nitrogen cycle as a post process, i.e. the optimization of the endogenous variables is a pre-requisite for the calculation of the equations of the carbon-nitrogen cycle. Once the model is run with the structural data of a representative farm and the optimal crop is obtained, then the environmental expressions are derived. Thus the following are the definitions of the exogenous variables that describe the environmental part of the model.

D) cnpn(un): stock of carbon in the biomass of natural areas

Eqcnpn $$cnpn_{un} = sui_{un} \cdot npp_{un,cl} \tag{41}$$

un natural land use

cl climate area

EXOGENOUS VARIABLES:

cnpn: stock of carbon in biomass of natural areas (tons)

COEFFICIENTS:

npp: net primary production (tons/ha)

sui: initial areas (ha)

The coefficient *cnpn* stands for the stock of carbon in net primary production of natural areas. The net primary production is multiplied for the natural area.

D) cnpa(ua): stock of carbon in biomass of permanent crops

Eqcnpa $$cnpa_{ua} = sui_{ua} \cdot npa_{ua,cl} \tag{42}$$

ua	permanent crop's land use
cl	climate area

EXOGENOUS VARIABLES:

cnpa: carbon assimilated in biomass of permanent crops(tons)

COEFFICIENTS:

sui: initial areas (ha)

npa: net primary production for permanent crops (tons/ha)

The coefficient *cnpa(ua*) stands for the stock of carbon in permanent crops' biomass. The unitary net primary production is multiplied for the area with permanent crops.

D) cnps(ot): stock of carbon in biomass of arable crops

Eqcnps(ot) $$cnps_{ot} = \sum_{cs} SUC_{cs} \cdot \frac{y_{cs,ot}}{hi_{cs,ot}} \cdot fcs_{cs} \tag{43}$$

ot technical orientation

cs micro-activities with arable crops

VARIABLES:

SUC: area of micro-activity (ha)

EXOGENOUS VARIABLES:

cnps: carbon content in arable crops' biomass (kgCO2eq)

COEFFICIENTS:

fcs: carbon content in biomass of crop (kgCO2eq/ton)

y: unitary yield (tons/ha)

hi: harvest index – ratio between commercial and total biomass

The coefficient *cnps* stand for the stock of carbon in the biomass of the field crops, which are represented by intensive crops, fodder, arable crops and rice. The result is obtained with the product of the area, the yield and the coefficient of carbon content; divided by the harvest index.

D) cwa: stock of carbon in wood

$$cwa_{aa} = (\sum_{un} cnpn_{un} + \sum_{ua} cnpa_{ua}) \cdot fw_{cl} \cdot (1 - fcut) \tag{44}$$

- *aa* year
- *un* natural land use
- *ua* permanent crops' land use
- *cl* climate area

EXOGENOUS VARIABLES:

cwa: total stock of carbon in the wooden tissue (kgCO2eq)

cnpn: carbon content in net primary production in natural areas (kgCO2eq)

cnpa: carbon content in net primary production in permanent crops (kgCO2eq)

COEFFICIENTS:

fw: yearly wood increase

fcut fraction of cut wood

Through the net primary production an estimate is provided of the stock of carbon in wooden tissues for all activities.

D) cwp: stock of carbon in cut wood of fruit trees

$$cwp_{aa} = cwa \cdot fcut/(1 - fcut) \tag{45}$$

- *aa* year

EXOGENOUS VARIABLES:

cwp: stock of carbon in cut wood of fruit trees (kgCO2eq)

cwa: total stock of carbon in the wooden tissue (kgCO2eq)

COEFFICIENTS:

fcut: cut coefficient

It is the amount of carbon which is stock in cut wood of the fruit trees.

D) cwc: stock of carbon in cut wood of forest

$$cwc_{aa} = cnpn \cdot fw_{cl} \cdot fcut \qquad (46)$$

- *aa* year
- *cl* climate area

EXOGENOUS VARIABLES:

cwc: stock of carbon in cut wood of forest (kgCO2eq)

cnpn: stock of carbon in natural areas' biomass (kgCO2eq)

COEFFICIENTS:

fw: yearly wood increase

fcut: cut coefficient

It is the amount of carbon which is stock in cut wood of the forest.

D) cres: carbon content in agricultural residuals

Eqcres $cres_{cs,ot,aa} = cnps_{cs,ot,aa} - QYT_{cs,ot,aa} \cdot fcy_{cs} - QY2_{cs} \cdot fcy2_{cs} \quad \forall cs,ot,aa$ (47)

cs	micro-activity with arable crops
aa	year
ot	technical orientation

VARIABLES:

QYT: total production (tons)

QY2: secondary product (tons)

EXOGENOUS VARIABLES: cres: carbon content in soil through residuals

cnps: carbon content in net primary production (kgCO2eq)

COEFFICIENTS:

fcy: carbon content in main product (kgCO2eq/ton)

fcy2: carbon content in secondary product (kgCO2eq/ton)

The exogenous variables "*cres*" stands for the carbon content in the agricultural residuals: it is obtained from the net primary production of arable crops, minus the primary product and the secondary product.

D) cemz: carbon emissions due to enteric fermentation

Eq_cemz $$cemz_{aa} = (cco2_{zo} + cch4_{zo}) \cdot ZOO_{zo,aa} + \sum_{zo} cmnr_{zo} \cdot fmat_{zo} \qquad (48)$$

aa year

zo zoo-technical activity

VARIABLES:

ZOO: amount of livestock (lu)

EXOGENOUS VARIABLES:

cemz: carbon emitted due to livestock metabolic process (kgCO2eq)

COEFFICIENTS:

cco2: emissione unitaria di co2 (kgCO2eq)

cch4: emissione unitaria di metano (kgCO2eq)

cmnr: carbon content in manure (kgCO2eq)

fmat: coefficient of manure degradation

These equations define the exogenous variables "*cemz*", which stand for the total amount of emissions that are due to enteric fermentation of livestock.

D) cmnr: carbon content in manure

Eqcmnr $$cmnr_{zo,aa} = MNR_{zo,aa} \cdot fcmr_{zo} \cdot (1 - fmat_{zo}) \tag{49}$$

zo zoo-technical activities

aa year

VARIABLES:

MNR: manure (kg)

EXOGENOUS VARIABLES:

cmnr: total carbon content of manure (kgCO2eq)

COEFFICIENTS:

fcmr: unitary carbon content in manure (kgCO2eq/kg)

fmat: loss of carbon due to manure fermentation

The exogenous variable "*cmnr*" stands for the carbon content of the manure which is produced by the livestock.

D) chmp: carbon content in soil

$$chmp_{ot,aa}=\{\sum_{cs}(cres_{cs,ot,aa}\cdot fk1s_{cs})+\sum_{zo}(cmnr_{zo,aa}\cdot fk1z_{zo})+\sum_{fe}[(QNS_{fe,cs,ot,aa}+QNA_{fe,ua,ot,aa})\cdot fk1n_{fe}] \\ +cwp_{ua}\cdot fk1w_{ua}\}\cdot(1-f\deg) \tag{50}$$

ot	technical orientation
aa	year
zo	zoo-technical activity
ua	permanent crop's land use

VARIABLES:

QNS: amount of fertiliser that is used in arable crops (kg)

QNA: amount of fertiliser that is used in permanent crops (kg)

EXOGENOUS VARIABLES :

cres: carbon content of residuals (kgCO2eq)

chmp: carbon content in soil (kgCO2eq)

cmnr: carbon content of manure (kgCO2eq)

COEFFICIENTS:

cwp: stock of carbon in cut wood of fruit trees

fk1s: isoumic coefficient of arables' residuals

fk1z: isoumic coefficient of manure

fk1n: isoumic coefficient of fertiliser

fk1w: isoumic coefficient of wood

fdeg: coefficient of degradation for humus

It is an estimate of yearly potential contribution to the stable organic matter of the soil (humus).

V) ccum: stock of carbon in humus

Eqccum: $$ccum_{ot,aa} = ccum_{ot,aa-1} + chum_{ot,aa} \tag{51}$$

aa year

cl climate area

EXOGENOUS VARIABLES

ccum: maximum amount of carbon that is possible to stock (kgCO2eq)

chum: real yearly increase in carbon content of humus (kgCO2eq)

The coefficient "*ccum*" measures the amount of organic carbon that has been cumulated along the years: it is assumed that the initial value is equal to zero.

D) chum: carbon content in humus

Eqchum $$chum_{aa} = \min[chmp_{ot,aa}, (c\max_{cl} - ccum_{ot,aa})/n] \quad (52)$$

aa: year

EXOGENOUS VARIABLES:

chum:	real increase of carbon content in soil (kgCO2eq)
chmp	potential increase of carbon content in soil (kgCO2eq)

COEFFICIENTS:

cmax	maximum amount of carbon in soil (kgCO2eq)
ccum	cumulated carbon content (kgCO2eq)

The coefficient "*chum*" measures the yearly real increase of carbon in soil's organic matter, whereas *"chmp"* is the potential increase.

D) cemi: emissioni atmosferiche

Eqcemi $$cemi_{aa} = \sum_{cs}(fuel_{cs} \cdot cfuel \cdot SUC_{cs}) + \sum_{ua}(fuela_{ua} \cdot cfuel \cdot SUP_{ua}) + \sum_{zo}(fuelz_{zo} \cdot cfuel) \cdot ZOO_{zo} + \\ + \sum_{ua} cwp_{ua} \cdot (1 - obio) \quad \forall aa \qquad (53)$$

aa	year
cs	micro-activity with arable
ua	land use with permanent crop
zo	zoo-technical activity

VARIABLES:

SUC: area for crop product (ha)

SUP: area for macro-activity (ha)

ZOO: amount of livestock (lu)

EXOGENOUS VARIABLES:

cemi: total amount of GHG emissions (kgCO2eq)

cwp: total amount of carbon in cut wooden tissue (kgCO2eq)

COEFFICIENTS

fr: partition coefficient

fuel: consumption of fuel (litres/ha)

cfuel: carbon in fuel (kgCO2eq/litre)

fmat: loss of carbon due to manure fermentation

obio: dichotomous coefficient for organic orientation

These equations define the emissions from the management of agricultural activities, as well as the management of natural areas. It is assumed that the organic farmer does not burn the cut wood whereas the conventional farmer does.

3.8. Notation

INDEXES

aa	Year
cl	climatic region
ca(ct)	crop product (fruit trees)
cs(ct)	crop product (arable crops)
ct	crop product
cz(ct)	crop product for animal husbandry
di	nutritional category
fe	type of fertiliser
ot	technical orientation
re	Region
ra(rt)	FADN entry (arable crops)
rs(rt)	FADN entry (arable crops)
rt	FADN entry
uu	land use (macro-activity)
zo	zoo-technical activity

SUB-INDEXES– land use

Table 11: land use

		BO	PR	SA	FO	CR	IN	RI	AR	VT	AB	R11	….	R53
		Forest	Meadows	Set-aside	Forage	Cereals	Intensive	Rise arables	Fruit trees	Wineyard	Low input fruit trees			
uu	Land use	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
ua(uu)	Permanent crops								**X**	**X**	**X**			
un(uu)	Natural area	**X**	**X**	**X**										
ur(uu)	Activities in rotation			**X**	**X**	**X**	**X**	**X**						
ro(uu)	Rotations											**X**	**X**	**X**

COEFFICIENTS – EXOGENOUS VARIABLES

cch4	carbon coefficient in livestock methane emission
cco2	carbon coefficient in livestock carbon dioxide emission
cemi	carbon emitted in atmosphere
cfert	carbon content in fertilisers' production
cfito	carbon content in chemicals' production
cfuel	carbon content in fuel
chem	amount of chemicals
chum	carbon in the humus
cm	commercial products for livestock feed
cmet(zo)	carbon in animal metabolism
cmnr(zo)	carbon in manure
cnpa(ua)	carbon in biomass of permanent crops
cnpn(un)	carbon in biomass of natural area
cnpr(ur)	carbon in biomass of total arable
cqz(zo)	carbon in sold zoo-technical products
cres(ct)	carbon in agricultural residuals
csom	carbon in organic matter
cwd	carbon in wood
dur	length of work need in agricultural activities
fcpro	carbon coefficient in sold products
fcq	carbon coefficient
fcq2	secondary carbon coefficient
fcz	carbon coefficient in zoo-technical products
fdc	nutritional value
fdeg	degradation coefficient of organic matter
fdz	nutritional need

fen	coefficient of excessive nutrition
fero	organic matter erosion coefficient
fert	amount of fertilisers
fk1c	transformation rate of residuals into organic matter
fk1n	transformation rate of fertilisers into organic matter
fk1z	transformation rate of manure into organic matter
fpa	straw/grain ration
fpzo	amount of straw for every animal
fqz	unitary yield of zoo-technical product
fr	partition coefficient
fuel	amount of fuel
fwn	wood coefficient
fzm	coefficient of expansion for animal house
hlav	hours of work
lfa	work need in fruit tree activities
lfs	work need in arable activities
lfz	work need in zoo-technical activities
npp	net primary production
pa	buying price
pchems	price of chemicals for arable crops
pchema	price of chemicals for fruit trees
pchemz	price of chemicals for animal husbandry
pfert	price of fertilisers
pfuel	price of fuel
pmac	cost of machinery
pmacz	cost of machinery
pv	selling price

pv2	selling price of secondary products
pvz	selling price of zoo-technical products
qz	unitary yield of zoo-technical product
rc	rotation coefficient
sau	UAA (utilised agricultural area)
sb	baseline subsidy
sro	total area in rotation
sun	natural area
sus	total public subsidies
sv	subsidy for green area
wlt	unitary wage of labour
Y	unitary yield
zoi	initial capacity of animal house

ENDOGENOUS VARIABLES

DZA(di)	availability of feed resources through the market
DZF(di)	zoo-technical feed requirement
DZR(di)	in farm availability of resources
HLT	temporary work
LAS	work need in agriculture
LAZ	work need in zootechnics
QNA	fertiliser bought for permanent crop
QNS	fertiliser bought for arable
QV2	sold secondary product
QY2	available secondary product
QYR(ct)	re-used quantity
QYT(ct)	total quantity

QYV(ct)	sold quantity
QZ2	re-used secondary product
QZA(cm)	quantity of market products that are bought
QZV(zo)	sold zoo-technical products
RN(aa)	net income
RNT(aa)	total net income
SUC(ct)	area for micro-activity
SUP(uu)	area for macro-activity
VCA(aa)	variable cost of fruit tree
VCS(aa)	variable cost of arable
VCZ(aa)	variable cost of zoo-technical activity
Z	objective function
ZOO(zo)	amount of livestock

3.9. Innovative aspects of the model

In the current model, the farmer is assumed to choose one among different possible rotations. The representative farm is characterised by the phyto-climate and the acclivity, so identifying a set of rotations that are possible to be implemented. Within the set, the rational farmer maximises the net income by choosing the optimal rotation. In this way a series of crops is identified, each with a partition factor that represents the weight of the crop in the rotation. The model output reports the levels of the variable *SUP*, the amount of area which is used by the rotation, and of the variable *SUC*, that is the area dedicated to each crop of the rotation. This is an important difference with respect to models such as Hassan *et al.* (2005) or Schipper (1995) where the optimal crop was the result of an optimization in which the decision variables were the amount of land dedicated to the single activity. Here the object of choice is the rotation and not the single activities, thus getting closer to the way of reasoning of the farmers.
Other important choices concern the livestock nutrition and the fertilisers. Part of the feed comes from re-used agricultural products and part comes from market's purchases. The optimal mix is an output of the model, which is contingent upon the level of the prices. Then the amount of nitrogen that is given to the soil can come either from the manure or from purchased fertilisers: similarly to Pali *et al.* (2005) it is the model's characteristic to structure and balance the two components.

It goes without saying that the process of choice is simultaneous. Once the model is solved, all the variables are determined and the trade-offs are compiled as to the amount of fertiliser that is purchased and the amount of feed that is purchased. It is important to underline that differently from the models here reviewed there is not the result of an optimal crop, rather the choice of a rotation. In order to stick closer to reality, it has been assumed that the farmer's reasoning takes into account rotations and not single crops. Thus the farmer chooses a single rotation as the optimal solution to the problem. Given the crops that constitute the rotation, it is possible to envisage an optimal allocation of available crops.

With regard to the environmental part, the model does not have a detailed focus such as in Schneider *et al.* (2007) where different mitigation strategies are envisaged. Here the net outcome of the environmental performance results from the capacity to stock carbon in the soil and in the plants, net of the emissions that are due to the human activity. However a result is produced in terms of comparison between organic farming and conventional farming, as a basis to design policy measure that aim to reward the atmospheric benefit of sustainable agriculture.

4. Results

4.1. Data

The farm data are obtained from the FADN database. With a cluster analysis the most representative farms have been obtained for the Emilia Romagna Region. Equivalently, the most common rotations have been compiled: for each phyto-climatic zone and type of land (plain, hill, mountain) the set of possible rotations is identified. The technical coefficients are based upon the agronomic manuals and the expertise of the researchers of the Department of Agricultural Sciences of the University of Bologna.

4.2. Computational software

The software that is used for the simulations is GAMS (General Algebraic Modeling System). The code is established in a primary file and a series of files that are included in the main with the GAMS command “include”. The “save and restart” feature is used to read the data and subsequently run the simulation. The data are read into the GAMS environment with the utility GDXXRW from a file excel. See the appendix for a more detailed description of the program structure.

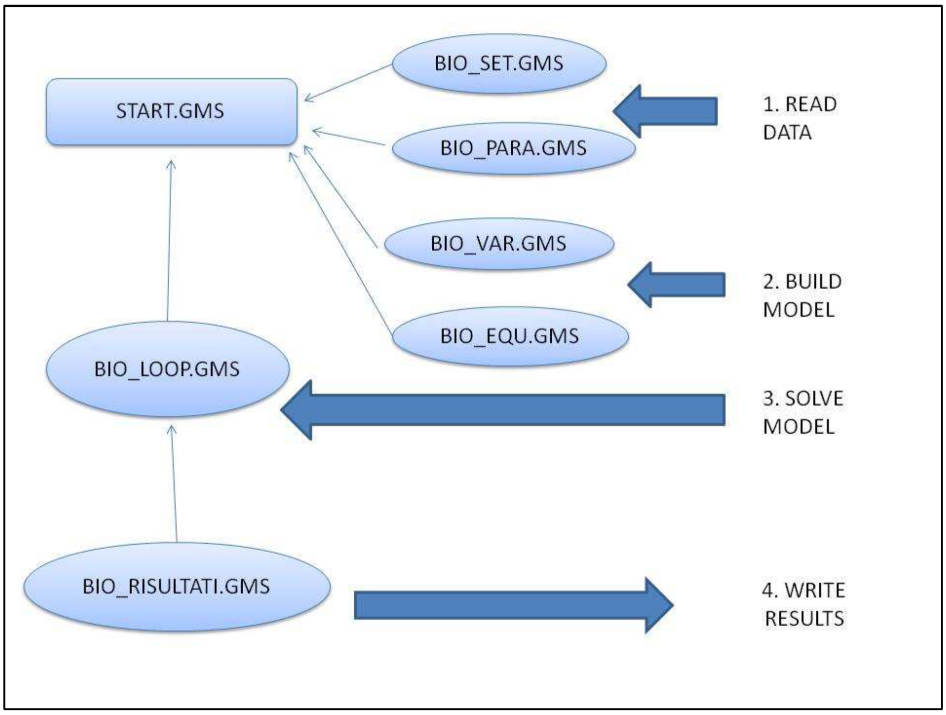


Figure 2: structure of the GAMS program

4.3. First simulation

- Phyto-climatic zone *Cold lauretum*

- Territory Plain
- UAA 3.50 hectares
- Arable crops 1.50 hectares
- Fruit trees 2.00 hectares

The first simulation was conducted on a farm of the Region Emilia-Romagna, which is representative of one of the most important clusters identified in the Region using the approach described in Vitali *et al.* (2012). . The cluster has the following characteristics: Utilised Agricultural Area is 3.5 hectares, with 0.30 ha forages, 0.55 ha cereals, 0.65 ha intensive crops, 0.04 ha low input fruit trees, 0.06 vineyards, 1.90 ha fruit trees. Thus, the total amount of area for rotational purposes is: 1.500 ha (sro) whereas the total amount of area for fruit trees is 2.000 ha (sar). There is no breeding activity.

The farm is located in a Mediterranean climate - the phyto-climatic sub-zone *cold lauretum* - and in the plains. A total of 124 rotations are found to be practiced in such a location. The process of optimization leads to the choice of a rotation with five crops in the conventional model and to a fallow rotation in the organic model. Projected income is negative in both cases: the farm has to suffer a loss, which turns up to be higher in the conventional case. Carbon sequestration is higher in the conventional case than in the organic model: it is due to the plants biomass which allows sequestering only in the conventional case. Results are displayed in the following table.

		MAD_CONV	MAD_BIO
r59	hectares		1,50
r76	hectares	1,50	
Grass meadow	hectares	0,33	
Alfalfa	hectares	0,27	1,50
Fallow land	hectares	0,24	
Barley	hectares	0,21	
Maize	hectares	0,45	
Gross margin	euro	-416347,00	-47907,00
Carbon fixation	kgCO2eq	0,81	0,24
GHG emissions	kgCO2eq	331,00	321,00

Table 12: results of first simulation.

The results show that the agricultural activity is not profitable and there is scope for the implementation of public subsidies. It is worth noting that in the conventional case the loss is ten times higher than in the organic case. Apparently counterintuitive is the fact that carbon sequestration may be higher in the conventional case. This is likely due in part to the fact that the organic farmer chooses the fallow solution: land is set aside and a limited carbon sequestration can be done by the uncultivated plants activity. On the contrary the conventional farmer cultivates several crops, which captures and stock carbon.

However, the net balance is then adjusted by the emissions, which are higher in the conventional case. At first sight it sounds as if the policy advice from this simulation is ambiguous since both carbon sequestration and emissions are higher in the conventional case. However, since the unit of measurement is the same – kgCO2eq – it is possible to compute the total effect. Since it is evident that carbon sequestration has a much lower impact, organic farming turns up to be the preferred system thank to the lower total emissions.

- Policy advice: Support organic farming

If the rotation that is optimal in the conventional case is applied to the organic model, the comparison can be made on the same allocation of crops. The table illustrates the situation in which both models choose rotation no. 76. In this case carbon sequestration is higher in the conventional model than in the organic model, because of the different sequestration capacity of the diverse cropping patterns. Furthermore, green house gas emissions are lower in the conventional model: this is due to the amount of fuel that is needed for the agricultural activity. In the organic system the mechanical operations require a higher expenditure in fuel, thus increasing emissions. The net computation of carbon sequestration and green-house gas emissions favour the conventional farming since mechanical operations are lower. It is to be noted though that the indirect emissions that derive from the production of industrial fertilisers and chemicals have not been computed. The inclusion of this impact is likely to counterbalance the result.

		MAD_CONV	MAD_BIO
r76	hectares	1,50	1,50
Grass meadow	hectares	0,33	0,33
Alfalfa	hectares	0,27	0,27
Soft wheat	hectares	0,24	0,24
Barley	hectares	0,21	0,21
Sunflower	hectares	0,45	0,45
Gross margin	euro	-416321,00	-421642,00
Net income 2010	euro	-37967,00	-38439,00
VC2010 field crops	euro	1413,00	1606,00
VC2010 fruit trees	euro	5496,00	5496,00
C fixation	kgCO2eq	0,35	0,30
GHG emissions	kgCO2eq	1398,00	1447,00

Table 13: results of first simulation with compulsory rotation.

4.4. Second simulation

- Phyto-climatic zone *Castanetum*
- Territory Plain
- UAA 23.00 hectares
- Arable crops 23.00 hectares
- Livestock 1264.136 lu – swines

The second simulation was conducted on a representative farm of the Regione Emilia Romagna, in the phyto-climatic zone *Castanetum*, with a utilised agricultural area of 23.00 ha, most of which dedicated to arable crops. In the farm there is a breeding activity, with 1264 livestock units of swines. Since the territory is plain, a number of twenty-two rotations are admitted in the farm's management.

Conventional case

In the conventional case, the model calls for a rotation with soft wheat and alfalfa. Income is negative, with a severe loss. Carbon sequestration and emissions are reported in the table. The breeding activity is not profitable.

		MAD_CONV	MAD_BIO
r118	hectares	23,00	
r131	hectares		23,00
Grass meadow	hectares	17,00	
Fallow land	hectares		23,00
Soft wheat	hectares	6,00	
Gross margin	euro	-191993,00	95951,00
Net income 2010	euro	-173976,00	8322,00
VC 2010 field crops	euro	20848,00	2199,00
VC 2010 fruit trees	euro	453,00	453,00
C fixation	kgCO2eq	1,16	0,01
GHG emissions	kgCO2eq	3631,00	471,00

Table 14: results of second simulation.

Organic case

Again, in the organic model the solution is the fallow land. Thus carbon sequestration is low and emissions are much lower than in the conventional case. The economic outcome is a substantial profit, though the breeding activity is not profitable.

If the public goal is participation in the strategies of the climate change mitigation, policy advice from this simulation is to support conversion to the organic farming, for which emissions are much lower. However this is reached at the cost of reducing agricultural production and choosing the fallow land. If the public authorities keep the intention to maintain agricultural production at sufficiently high level, then it is advisable to restore conventional farming in Emilia-Romagna, *castanetum* phyto-climate.

- Policy advice Support organic farming

4.5. Third simulation

• Phyto-climatic zone	*Castanetum*
• Territory	Plain
• UAA	112.00 hectares
• Arable crops	94.00 hectares
• Natural area	18.00 hectares
• Livestock	1.492 lu meat cattle
	300.00 lu swines

The third simulation was conducted on a representative farm of the Regione Emilia Romagna, in the phyto-climatic zone *Castanetum*, with a utilised agricultural area of 112.00 ha, dedicated to arable crops, natural area and with a small percentage of fruit trees. In the farm there is a breeding activity, with about 300 livestock units of swines.

The result of the optimization is displayed in the following table:

		MAD_CONV	MAD_BIO
r118	hectares	94,00	
r131	hectares		94,00
Alfalfa	hectares	70,00	
Fallow land	hectares		94,00
Soft wheat	hectares	24,00	
Gross margin	euro	-7.697.737,00	577.890,00
Net income 2010	euro	697169,00	50413,00
VC 2010 field crops	euro	85333,00	9001,00
VC 2010 fruit trees	euro	546,00	546,00
C fixation	kgCO2eq	5,00	1,00
GHG emissions	kgCO2eq	14580,00	1639,00

Table 15: results of third simulation. API=alfalfa, RIP=fallow land, FTE=soft wheat.

The conventional model turns up with a rotation between soft wheat and alfalfa whereas the organic model chooses the fallow land. Income is negative in the conventional case but it is positive in the organic case. Carbon sequestration is higher in the conventional case but greenhouse gas emissions are much higher, too. Like in the previous simulation, the normative prescription in a climate change perspective is to subsidise organic farming in view of the minor emissions, at the cost of having fallow land.

- Policy advice Support organic farming

4.6. Fourth simulation

- Phito-climatic zone *Castanetum*
- Territory Hill
- UAA 17.00 hectares
- Fruit trees 0.50 hectares
- Natural area 16.50 hectares

This cluster represents the farms in the phyto-climatic zone *Castanetum* in a hilly area of the Region. The utilised agricultural area is seventeen hectares, of which a small part is cultivated with fruit trees (peaches) and the most with a natural area (mostly meadows and one hectare of forest). In this case there is no issue of optimal allocation of crops since arable crops are absent: the structure of the farm is not suitable to optimization and the comparison between organic and conventional farming systems is limited to a computational affair. The results of the comparison are displayed in the following table.

		MAD_CONV	MAD_BIO
Gross margin	euro	144756,00	139596
Net income 2010	euro	12998,00	12543,00
VC 2010 fruit trees	euro	761,00	761,00
C fixation	kgCO2eq	0,96	0,96
GHG emissions	kgCO2eq	152,00	149,00

Table 16: results of fourth simulation

The gross margin is higher in the conventional farming system, as well as the net income in the year 2010. The variable cost in 2010 and the carbon sequestration do not differ: this is the consequences of the data, which feature the same amount of input and same prices with regard to permanent crops. Instead, GHG emissions are lower in the organic farm: this is because the amount of carbon which is stored in the wooden tissue is burnt in the conventional system but it is not in the organic system.[14]

4.7. Fifth simulation

In the fifth simulation a cluster with the following characteristics is chosen.

- Phito-climatic zone *Castanetum*
- Territory Hill
- UAA 182.50 hectares
- Fruit trees 0.50 hectares
- Arable crops 182.00 hectares

[14] See equation no. 53.

- Breeding activity 230 lu swines

The results of the optimization are displayed in the table. The conventional farmer chooses rotation no. 145, which alternates soft wheat and sunflower whereas the organic farmer chooses rotation no. 150, which alternates maize and sunflower. In both cases the gross margin is negative, as well as the income in the last year. Variable costs for the field crops are higher in the organic farming system whereas they are equal for the fruit trees. Carbon sequestration is equal and the green house gas emissions are lower in the conventional system.

		MAD_CONV	MAD_BIO
r145	hectares	182,00	160,00
r150	hectares		22,00
Soft wheat	hectares	101,00	89,00
Maize	hectares		22,00
Sunflower	hectares	81,00	71,00
Gross margin	euro	-50684240,00	-58782075
Net income 2010	euro	-4450741,00	-5169486,00
VC 2010 field crops	euro	176246,00	211154,00
VC 2010 fruit trees	euro	1090,00	1090,00
C fixation	kgCO2eq	12,00	12,00
GHG emissions	kgCO2eq	47933,00	55558,00

Table 17: results of fifth simulation.

- Policy advice: Support conventional farming

Thus according to the fifth simulation, carbon sequestration is equal in conventional and organic farming system, despite the different rotation. The reason is that the maximum amount of carbon that is possible to store has been reached: the soil has a limited capacity to store carbon. The policy recommendation is to support conventional farming: organic farming might be capable of higher sequestration but when the maximum limit of carbon stock is reached it is not possible to go beyond.

4.8. Sixth simulation

In the sixth simulation a cluster with the following characteristics is chosen.

- Phito-climatic zone *Castanetum*
- Territory Hill
- UAA 38.00 hectares
- Fruit trees 15.00 hectares
- Arable crops 23.00 hectares
- Breeding activity 10.00 lu sheep and goats
  182.00 lu swines

The results of the simulation are displayed in the table.

		MAD_CONV	MAD_BIO
r145	hectares	23,00	19,00
r150	hectares		4,00
Soft wheat	hectares	13,00	10,00
Maize	hectares		5,00
Sunflower	hectares	10,00	8,00
Gross margin	euro	-6187917,00	-7187566,00
Net income 2010	euro	-542917,00	-631839,00
VC 2010 field crops	euro	21956,00	26133,00
VC 2010 fruit trees	euro	22440,00	22440,00
C fixation	kgCO2eq	4,40	4,34
GHG emissions	kgCO2eq	10839,00	11837,00

Table 18: results of sixth simulation.

The conventional farmer chooses rotation no. 145, which alternates soft wheat and sunflower, whereas the organic farmer splits the land in two rotations, adding to rotation no. 145 a monoculture of maize. As regard farm's income, the result is again a loss: the gross margin along ten years is around seven billion negative, with a higher loss for the organic farmer. This is reflected in the variable costs for the arable crops, which are higher for the organic farmer. The results of the carbon-nitrogen cycle are quite the same as the first simulation: carbon sequestration is higher for the conventional farmer and emissions are lower. Policy recommendation is to subsidise conventional farming.

- Policy advice Support conventional farming

4.9. Seventh simulation

In the seventh simulation a cluster with the following characteristics is chosen.

- Phito-climatic zone *Castanetum*
- Territory Hill
- UAA 22.00 hectares
- Fruit trees 10.00 hectares
- Arable crops 4.00 hectares
- Natural area 8.00 hectares

The results of the simulation are displayed in the table.

		MAD_CONV	MAD_BIO
r145	hectares	4,00	1,00
r150	hectares		3,00
Soft wheat	hectares	2,00	0,50
Maize	hectares		3,20
Sunflower	hectares	2,00	0,30
Gross margin	euro	-928625,00	-1091510,00
Net income 2010	euro	-80083,00	-4366,00
VC 2010 field crops	euro	3897,00	4366,00
VC 2010 fruit trees	euro	27096,00	27096,00
C fixation	kgCO2eq	1,65	2,17
GHG emissions	kgCO2eq	6698,00	6953,00

Table 19: results of seventh simulation. FTE=soft wheat, GTR=maize, GIR=sunflower.

Once again, the conventional farmer chooses soft wheat and sunflower whereas the organic farmer uses a part of the UAA with maize. Gross margin is negative, with a superior loss for the organic farmer. Differently from the previous simulation, the carbon sequestration is higher in the organic farming system. Green house gas emissions are higher for the organic farmer.

- Policy advice Support conventional farming

4.10. Eighth simulation

In the eighth simulation a cluster with the following characteristics is chosen.

- Phito-climatic zone *Castanetum*
- Territory Mountain
- UAA 37.00 hectares
- Arable crops 13.50 hectares
- Natural area 23.50 hectares

Initially the farm's land use is divided between forages, cereals and intensive crops. After the process of optimization, the fallow land is the choice. The results of the simulation are displayed in the following table.

		MAD_CONV	MAD_BIO
r178	hectares	13,50	13,50
Fallow land	hectares	13,50	13,50
Gross margin	euro	-530758,00	-206844,00
Net income 2010	euro	-47722,00	-18728,00
VC 2010 field crops	euro	1294,00	1346,00
C fixation	kgCO2eq	1,35	2,25
GHG emissions	kgCO2eq	222,00	218,00

Table 20: results of eighth simulation.

The gross margin is negative, with a slightly superior loss for the organic farmer. No surprise that the carbon sequestration is almost equal between the two systems. Green house gas emissions are higher for the conventional farmer.

- Policy advice Support organic farming

4.11. Ninth simulation

In the ninth simulation a cluster with the following characteristics is chosen.

- Phito-climatic zone *Castanetum*
- Territory Mountain
- UAA 103.00 hectares
- Arable crops 23.00 hectares
- Fruit trees 16.00 hectares
- Natural area 64.00 hectares

Initially the farm's land use with arable crops is divided between forages, cereals and intensive crops. After the process of optimization, the fallow land is the choice.
The results of the simulation are displayed in the table.

		MAD_CONV	MAD_BIO
r178	hectares	23,00	23,00
Fallow land	hectares	23,00	23,00
Gross margin	euro	-730239,00	194103,00
Net income 2010	euro	-68610,00	14315,00
VC 2010 field crops	euro	2221,00	2372,00
VC 2010 fruit trees	euro	45602,00	45602,00
C fixation	kgCO2eq	4,60	7,20
GHG emissions	kgCO2eq	9589,00	9575,00

Table 21: results of nineth simulation. RIP=fallow land.

Again, emissions are higher in the conventional system, when carbon sequestration is almost equivalent. Normative advice is to support organic farming.

- Policy advice   Support organic farming

4.12. Tenth simulation

In the tenth simulation a cluster with the following characteristics is chosen.

- Phito-climatic zone   *Fagetum*
- Territory   Mountain
- UAA   17.00 hectares
- Arable crops   6.00 hectares
- Natural area   11.00 hectares

Initially the farm's land use with arable crops is entirely dedicated to forage. After the process of optimization, the fallow land is the choice.
The results of the simulation are displayed in the table.

		MAD_CONV	MAD_BIO
r233	hectares	6,00	6,00
Fallow land	hectares	6,00	6,00
Gross margin	euro	-238446,00	-93030,00
Net income 2010	euro	-21439,00	-8423,00
VC 2010 field crops	euro	581,00	605,00
C fixation	kgCO2eq	0,60	1,05
GHG emissions	kgCO2eq	100,00	98,00

Table 22: results of tenth simulation.

This result means that agricultural activity is hardly profitable in mountain areas, too. In fact, the farm with initially a UAA divided between forages and natural areas, ends up with only natural area and a fallow land. With an almost equivalent carbon sequestration capability, the greenhouse gas emissions are higher for the conventional model, thus determining the normative recommendation to support organic farming.

- Policy advice   Support organic farming

4.13. The average cluster

A speculative exercise consists in building an average cluster for the farms in the Emilia Romagna Region. Such cluster has the mostly diffused phito-climatic zone and type of territory, and the following averaged dimensions. For simplicity, livestock is not considered.

- Phito-climatic zone *Castanetum*
- Territory Plain
- UAA 30.00 hectares
- Arable crops 12.00 hectares
- Fruit trees 8.00 hectares
- Natural area 10.00 hectares

Initially the farm's land use with arable crops is all dedicated to the listed crops. After the process of optimization, the fallow land is the choice.

		MAD_CONV	MAD_BIO
r233	hectares	12,00	12,00
Fallow land	hectares	12,00	12,00
Gross margin	euro	-740975,00	-478157,00
Net income 2010	euro	-70573,00	-47053,00
VC 2010 field crops	euro	1146,00	1225,00
VC 2010 fruit trees	euro	26174,00	26174,00
C fixation	kgCO2eq	0,56	1,89
GHG emissions	kgCO2eq	5705,00	5703,00

Table 23: results of simulation with average cluster.

Both systems have a negative income. Carbon sequestration is almost equal (slightly higher for organic) and greenhouse gas emissions are higher in the conventional case. The policy recommendation is to subsidise the organic farmers.

With respect to the average cluster, the following graphs illustrate the pattern of the net income (without subsidies) and the variable cost for arable crops along ten years.

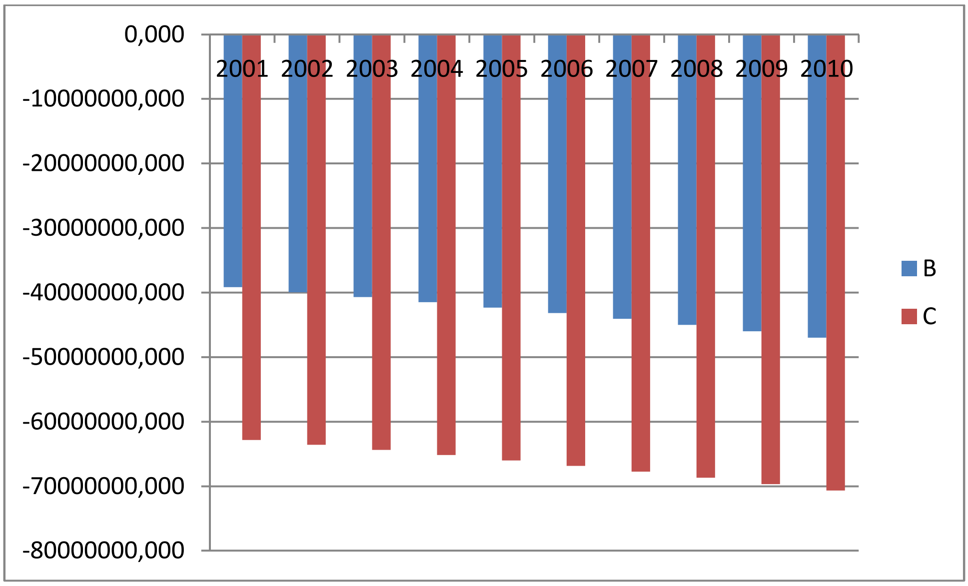


Figure 3: net income in ten years without subsidies

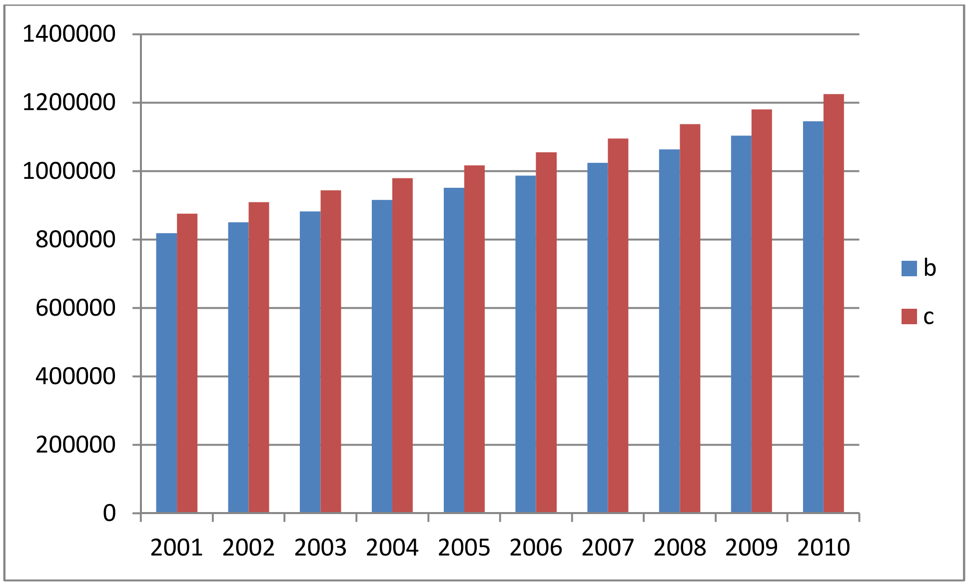


Figure 4: variable cost for arable crops along ten years

In the following graphs the level of green house gas emissions and of the carbon sequestration is depicted for the two agricultural systems, conventional farming and organic farming.

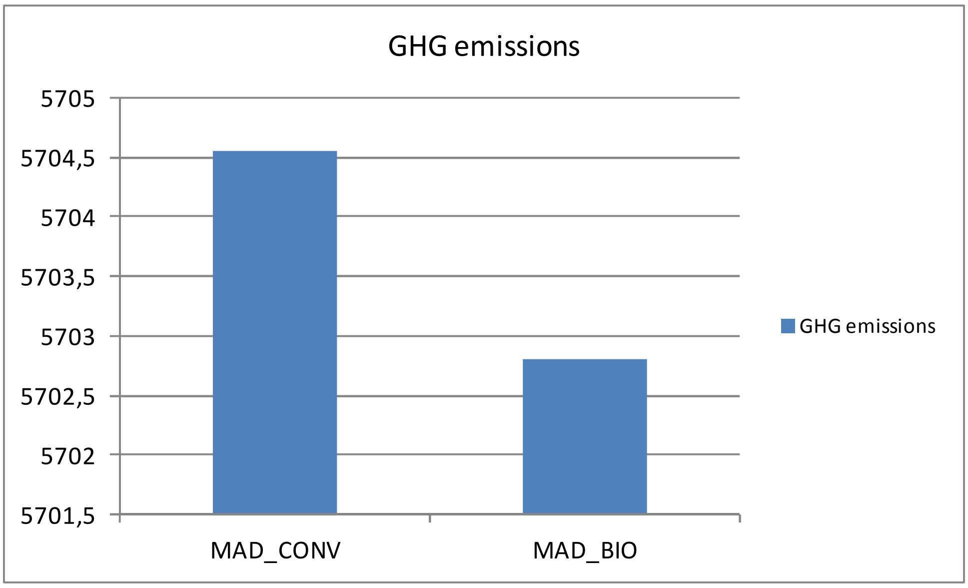


Figure 5: GHG emissions (Kg CO2eq)

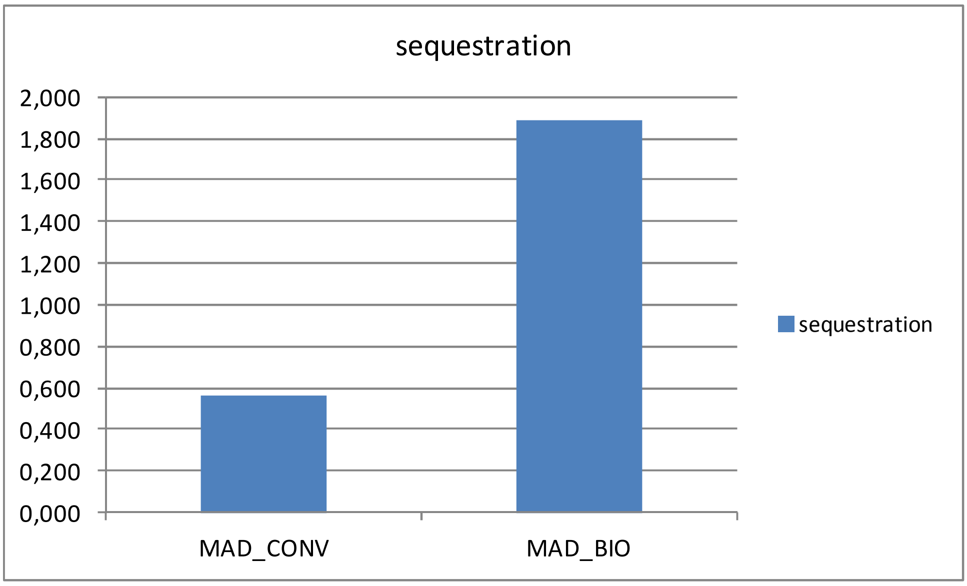


Figure 6: carbon sequestration (Kg CO2eq)

4.14. Discussion

	Higher income	Higher carbon sequestration	Lower GHG emissions
1st simulation	Organic	Conventional	Organic
1st simulation with same rotation	Conventional	Conventional	Conventional
2nd simulation	Organic	Conventional	Organic
3rd simulation	Organic	Conventional	Organic
4th simulation	Conventional	Equal	Organic
5th simulation	Conventional	Equal	Conventional
6th simulation	Conventional	Organic	Conventional
7th simulation	Conventional	Organic	Conventional
8th simulation	Conventional	Equal	Organic
9th simulation	Organic	Equal	Organic
10th simulation	Conventional	Equal	Organic
Average cluster	Conventional	Equal	Organic

Table 24: summary of results of the simulations

Summarising the eleven simulations that have been run, the results are the following. In seven cases out of eleven the conventional system produced a higher income than the organic farming (more precisely a lower loss). With regard to carbon sequestration in four cases it is higher in the conventional system, in four it is equal and in three it is higher in the organic system: the different optimal crop between conventional and organic system is the reason why only in three cases out of eleven the organic farm shows a superior capacity in carbon sequestration. Green house gas emissions are lower in the organic system in seven cases out of eleven.

The results of the simulations show that in Emilia-Romagna the alleged environmental benefits of the organic farming systems basically hold but in some cases they are somehow questionable. Actually, despite the potential superiority with respect to carbon sequestration and green house gas emissions, when the perspective of self-interest is considered, prospective outcome is likely to change. This is partly due to the fact that a different land use pattern determines different consequences as regard the atmospheric impact. In fact, as the first simulation discloses, carbon sequestration may be neutralized when the optimal choice is the fallow land, in which the total biomass is near to zero. On the other hand, with an equal carbon sequestration capacity the

greenhouse gas emissions may well be higher in the organic system if mechanical operations are taken into account as the model does: it is well known - Padel and Lampkin (1994) - that organic farming systems are more labour costly than conventional systems. When the same rotation is forced to both systems in the first simulation, this effect is revealed.
However, if the fallow land is the optimal choice for the organic system like in the second and third simulations, then the green house gas emissions turn out to be lower, so determining a comparative advantage in environmental terms. In addition, if the indirect effect that results from the production of fertilisers and chemicals is taken into account there seems to be few doubts about the net balance in favour of the organic farming system.

The fourth simulation shows that when there are not rotational activities, the differences are small. As a matter of fact, data are almost equivalent with respect to the input of the fruit trees, so determining a quasi-similar result for the carbon cycle impact. However a small difference is envisaged with respect to emissions, as long as the conventional farmer burns the wooden parts and the organic farmer does not, therefore saving the total amount of carbon in wooden tissue.

In the fifth simulation a cluster is considered which is in the *Castanetum* zone and in a hilly region. The cluster is characterised by a large UAA, field crops and extensive breeding activity. Optimization shows that conventional activity is less damaging to the atmospheric impact when the maximum capability is reached for the soil to store carbon.

The sixth simulation remarks once again the strong labour-need character of the organic farming system. Results show that green house gas emissions are lower in the conventional farming system and carbon sequestration is higher.

In the seventh simulation, which features the same allocation of crops, the environmental results are contrasting: carbon sequestration is higher in the organic farming system but emissions are higher too. Thus policy recommendation is not straightforward. In the following simulations (eight, ninth and tenth) the optimal choice is the fallow land for both systems: it is convenient to give up cereals, intensive crops and forages. Since carbon sequestration is obviously equal and emissions are higher for the conventional farmer, the policy recommendation is to support organic farming.

The speculative exercise with the average cluster has not substantially modified the arguments of the last simulations. Organic farming has slightly lower emissions and the same carbon sequestration. If policy interventions are desirable to reward activities that are beneficial to the atmosphere and reduce the green-house gas effect, then organic farming should be slightly subsidised.

5. Conclusions

The model has proven to be capable to distinguish between conventional and organic farming systems, as regard the optimal crop allocation. Actually, in six out of eleven simulations the model renders different optimal crops for the two types of farming systems, while in the other cases the fallow land is the optimal choice. In all cases however the activity is not profitable and the outcome of the optimization is an economic loss.

With regard to the environmental part, the results are more tentative. The alleged benefits of the organic farming activity in comparison with conventional farming have been well documented in the literature[15]. With respect to the atmospheric impact, the net effect is the result of two contrasting actions: the emission of greenhouse gases in the atmosphere and the carbon sequestration in the soil and in the biomass. As the Regulation no. 834/2007 requires, a basic characteristic of the organic agriculture is to renounce the use of chemical fertilisers and pesticides: in this way important savings are obtained in the emissions of green house gases in the industrial sector. However, if the agricultural sector is considered in isolation – according to a partial equilibrium analysis -, the interplay of the actions gives rise to a more uncertain net outcome. Actually, the conversion to the organic system may imply a change in the cropping pattern, so distorting the comparison. However, even if the same cropping pattern results, contrasting effects are likely to counterbalance the results as the simulations have revealed in the case of the Emilia Romagna. This is basically due to the fact that organic practices are more labor intensive than conventional farming. Thus, especially in the case of intensive crops, the green house gas emissions for the organic farm are deemed to be higher than in the case of the conventional farm, with the consequence that, if the carbon sequestration does not differ much, the net atmospheric output is lower in the conventional system. In addition it is to be noted that the soil has a limited capacity to store carbon: if the maximum limit is reached the organic farming's advantage of a superior carbon sequestration finds a boundary (with respect to the soil component).

It is to be noted that in all the simulations the farms suffer huge losses despite the provision of two types of subsidies, a payment proportional to the UAA and a green payment: it follows that beyond the public subsidies that are needed to reward the organic farming activity when it carries social benefits in terms of lower greenhouse gas emissions, public subsidies are also needed in order to support farmers' income. Another consideration that emerged from the simulations is that carbon sequestration does not influence the results. Actually in terms of carbon dioxide equivalents, the sequestration of carbon has always a much lower amount compared with greenhouse gas emissions: thus the net effect is provided by the comparison of the greenhouse gas emissions of the two farming systems.

[15] Cfr. Goh (2011), Gomiero *et al.* (2008), Pimentel *et al.* (2005), Offerman and Nieberg (2000).

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7. References

- Acs, S., Berentsen, P., Huirne, R., (2007), Conversion to Organic Arable Farming in The Netherlands: A Dynamic Linear Programming Analysis, *Agricultural Systems*, 94.
- Bremner, J.M. and Blackmer A.M., (1978), “Nitrous Oxide: Emission from Soils During Nitrification of Fertiliser Nitrogen”, *Science*, 1978, 199, 295– 297.
- Buysse J., Van Huylenbroeck G., Lauwers L., (2007), “Normative, Positive and Econometric Mathematical Programming as Tools for Incorporation of Multifunctionality in Agricultural Policy Modelling”, *Agriculture, Ecosystems and Environment*, 120, 2007.
- De Benedictis, M., Cosentino, V., (1979), Economia dell’azienda agraria, Il Mulino.
- De Cara S., Houzé M., Jayet P., (2005), “Methane and nitrous oxide emissions from agriculture in the EU: a spatial assessment of sources and abatement costs”, *Environmental and Resource Economics*, 32, 2005.
- De Cara S., Jayet P., (2000), “Emissions of greenhouse gases from agriculture: the heterogeneity of abatement costs in France”, *European Review of Agricultural Economics*, 27 (3), 2000.
- De Cara S., Jayet P., (2009), “Greenhouse gas emissions from agriculture: estimates of marginal abatement costs in the EU-24 at the farm, regional and country levels”, Climate Change: Global Risks, Challenges and Decisions, IOP Publishing, Earth and Environmental Science, 6, 2009.
- Delgaard, R., Halberg N., Kristensen I., Larsen, I., (2006), “Modelling Representative and Coherent Danish Farm Types Based on Farm Accountancy Data for Use in Environmental Assessment”, *Agricultural Ecosystems and Environment*, 117(4), 223-237.
- FAO (2009), “Low Greenhouse Gas Agriculture: Mitigation and Adaptation Potential of Sustainable Farming Systems”, FAO, April 2009, Rev. 2 – 2009.
- Goh, K.M. (2011), “Greater Mitigation of Climate Change by Organic than Conventional Agriculture: A Review”, *Biological Agriculture and Horticulture*, 27, 205-230.
- Gomiero, T., Paoletti, M. G., & Pimentel, D. (2008), “Energy and Environmental Issues in Organic and Conventional Agriculture”, *Critical Reviews in Plant Sciences*, 27(4), 239-254.
- Hanley, N., Kirkpatrick, H., Simpson, I., Oglethorpe, D., (1998), “Principles for the provision of public goods from agriculture: modeling Moorland conservation in Scotland”, *Land Econ*. 74, 102–113.
- Hardin, G., (1975), “The Tragedy of the Commons”, in Economic Foundations of Property Law 2 (Bruce A. Ackerman ed., 1975).

- Hassan I., Raza M.A., Khan I.A., R. Ilahi, (2005), "Use of Linear Programming Model to Determine the Optimum Cropping Pattern, Production and Income Level: A Case Study from Dera Ghazi Khan Division", *Journal of Agriculture and Social Science*, 2005.
- Inea (2006). Lo scenario dell'agricoltura biologica in Italia. WP Sabio n. 1, Roma, Inea.
- Kerselaers E., De Cock L., Lauwers L., Van Huylenbroeck G., (2007). "Modelling farm-level economic potential for conversion to organic farming", *Agricultural Systems*, 94, 671-682.
- Lampkin N., (1994), Organic farming: sustainable agriculture in practice. In: Lampkin, N., Padel, S., (Eds.), The Economics of Organic Farming. An International Perspective. CABI, Oxford.
- Mannion A.M., (1995). Agriculture and environmental change. Temporal and spatial dimensions. Wiley. Sussex.
- Merel, P., Bucaram S., (2010), "Exact calibration of programming models of agricultural supply against exogenous supply elasticities", *European Review of Agricultural Economics*, 2010, published 16 august 2010.
- Northbourne, L., (1940). Look to the Land. Dent, London.
- Offermann, F., & Nieberg, H. (2000). "Economic Performance of Organic Farms in Europe". In "Organic Farming in Europe : Economics and Policy" (Vol. 5), University of Hohenheim.
- Pacini, C., Wossink A., Giesen, G., Huirne, Ruud, (2004), "Ecological-economic modelling to support multi-objective policy making: a farming system approach implemented for Tuscany", *Agriculture, Ecosystems & Environment*, 102, 2004, 349-364.
- Padel S., Lampkin N., (1994), "Farm level performance of organic farming systems" in Lampkin N., Padel S. (eds). The economics of organic farming. An international perspective, CAB International, Wallingford.
- Pali P.N., Delve R.J., Nkonia E., Bashaasha E., (2005), "Using Linear Programming to Optimise the Use of Biomass Transfer and Improved Fallow Species in Eastern Uganda", WP, Makerere University Uganda, 2005.
- Paris Quirino, (1991), "Programmazione lineare: un'interpretazione economica", Bologna, Il Mulino, 1991.
- Pathak H., (1999), "Emissions of nitrous oxide from soil", *Current science*, 77, 359 – 369.
- Pearce D.W., Turner R.K., (1990), Economics of natural resources and the environment, Harvester Wheatsheaf, New York.

- Pimentel D., Hepperly P., Hanson J., Douds D., Seidel R., (2005), “Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems”, *Bioscience*, Vol. n. 55, Iss. 7.
- Raviv M. (2010), Sustainability of Organic Horticulture, Horticultural Reviews, Vol. n. 36. Edited by Jules Janick, Wiley Blackwell.
- Reveredo Giha C., Topp C.F., Toma L., Wu L., (2006), ”Economic and environmental analysis of the introduction of legumes in livestock farming systems”, *Aspect of Applied Biology*, 79, 2006.
- Rigby-Caceres, (2001), Organic farming and the sustainability of agricultural systems, *Agricultural Systems* 68.
- Schipper R.A., Jansen D.M., Stoorvogel J.J., (1995), “Sub-regional linear programming models in land use analysis: a case study of the Neguev settlement, Costa Rica”, Netherland *Journal of Agricultural Science*, 43, 1995.
- Schneider U.A., (2007), “Soil organic carbon changes in dynamic land use decision models”, *Agriculture, Ecosystems and Environment*, 119, 2007.
- Schneider U.A., McCarl B.A., Schmid E., (2007), “Agricultural sector analysis on greenhouse gas mitigation in US agriculture and forestry”, *Agricultural Systems*, 94, 2007.
- Scofield, A., (1986), Organic farming — the origin of the name, *Biological Agriculture and Horticulture*, 4, pp. 1–5.
- Sharma R.K., Sankhayan P.L., Singh R., (2010), “Analysis of Profitability and Risk in New Agriculture Using Dynamic Non-Linear Programming Model”, *Journal of Agricultural Science*, Vol. 2, No. 1, 2010.
- Shrestha S., Hennessy T., (2007), “Analysing the impact of decoupling at a regional level in Ireland: a farm-level dynamic linear programming approach”, *Irish Journal of Agriculture and Food Research*, 46, 2007.
- Stoecker A.L., Seidmann A., Lloyd G.S., (1985), A linear dynamic programming approach to irrigation system management with depleting groundwater, *Management Science*, 31, 4, 1985.

Appendix A. RICA entry for fruit trees

ARB	Code	RICA field name
AR	AR.FRU	Frutta temperata a semi: melo, pero,fico, altro. Frutta a nocciolo: pesco, nettarina, albicocco, ciliegio, susino
AR	AR.ACT	Frutta di origine subtropicale actinidia
AR	AR.UVA	Uve da tavola e Uva passa
AR	AR.VIV	Vivai: Viti, fruttiferi, ornamentali e altro (inutilizzato)
AR	AR.BAC	Altre coltivazioni permanenti bacche, piccoli frutti
AR	AR.OTA	Per la produzione di olive da tavola
VT	VT.VIN	Vini di qualità
VT	VT.AVI	Altri vini
AB	AB.MAN	Frutta a guscio: mandorlo, nocciolo, castagno, noce, altro
AB	AB.AGR	Agrumeti: arancio, mandarino, clementine, limoni, altri
AB	AB.OLI	Per la produzione di olive da olio

RICA entry for field crops

ARA	Code	RICA field name
FO	FO.AVN	Avena e miscugli estivi
FO	FO.FAR	Altri cereali, Sorgo, Farro
FO	FO.LEG	Legumi secchi e colture proteiche per la produzione di granella(comprese le sementi e i miscugli di cereali e di legumi secchi)
FO	FO.ERB	Erbai temporanei
FO	FO.API	Altre piante raccolte verdi
FO	FO.RIP	Terreni a riposo con e senza aiuti finanziari
CR	CR.FTE	Frumento tenero e spelta
CR	CR.FDU	Frumento duro
CR	CR.SEG	Segala
CR	CR.ORZ	Orzo
RI	RI.RIS	Riso
IN	IN.GTR	Mais da granella
IN	IN.PAT	Patate (comprese le patate primaticce e da semina)
IN	IN.BBT	Barbabietola da zucchero (escluse le sementi)
IN	IN.SAR	Piante sarchiate da foraggio (escluse le sementi)
IN	IN.ORT	Ortaggi da pieno campo
IN	IN.FRA	Coltivazioni in orti stabili: fragola, pomodoro da mensa, altro
IN	IN.FIO	Fiori e piante ornamentali all'aperto
IN	IN.PIA	Piantine per orticole e altro
IN	IN.SEM	Sementi da prato e altro
IN	IN.TAB	Tabacco
IN	IN.COL	Colza e ravizzzone
IN	IN.GIR	Girasole
IN	IN.SOI	Soia

IN	IN.SLI	Semi di lino
IN	IN.CAN	Canapa
IN	IN.IND	Altre colture industriali non menzionate altrove
IN	IN.CZU	Canna da zucchero

Appendix B. Crop product for Emilia-Romagna region: fruit trees

ARB	Code	RICA field name	Crop product	English
AR	AR.FRU	Frutta temperata a semi: melo, pero,fico, altro. Frutta a nocciolo: pesco, nettarina, albicocco, ciliegio, susino	Pesco	Peaches
AR	AR.ACT	Frutta di origine subtropicale actinidia	Kiwi	Kiwi
AR	AR.UVA	Uve da tavola e Uva passa	Uva da tavola	Grapefruit
AR	AR.VIV	Vivai: Viti, fruttiferi, ornamentali e altro (inutilizzato)	UNUSED	Garden centres
AR	AR.BAC	Altre coltivazioni permanenti bacche, piccoli frutti	UNUSED	Berries
AR	AR.OTA	Per la produzione di olive da tavola	Olive da tavola	Table olives
VT	VT.VIN	Vini di qualità	Vini di qualità	DOC wines
VT	VT.AVI	Altri vini	Altri vini	Wines
AB	AB.MAN	Frutta a guscio: mandorlo, nocciolo, castagno, noce, altro	Noce	Nuts
AB	AB.AGR	Agrumeti: arancio, mandarino, clementine, limoni, altri	Limoni	Lemons
AB	AB.OLI	Per la produzione di olive da olio	Olive da olio	Oil olives

Crop product for Emilia-Romagna regione: field crops

ARA	Code	RICA field name	Crop product	English
FO	FO.AVN	Avena e miscugli estivi	Avena	Oats
FO	FO.FAR	Altri cereali, Sorgo, Farro	Sorgo	Sorghum
FO	FO.LEG	Legumi secchi e colture proteiche per la produzione di granella(comprese le sementi e i miscugli di cereali e di legumi secchi)	Legumi secchi	Dried legumes
FO	FO.ERB	Erbai temporanei	Erbai temporanei	Grass meadow
FO	FO.API	Altre piante raccolte verdi	UNUSED	Other green plants
FO	FO.RIP	Terreni a riposo con e senza aiuti finanziari	UNUSED	Set aside
CR	CR.FTE	Frumento tenero e spelta	Frumento tenero	Soft wheat

CR	CR.FDU	Frumento duro	Frumento duro	Durum wheat
CR	CR.SEG	Segala	Segala	Rye
CR	CR.ORZ	Orzo	Orzo	Barley
RI	RI.RIS	Riso	Riso	Rise
IN	IN.GTR	Mais da granella	Mais da granella	Maize
IN	IN.PAT	Patate (comprese le patate primaticce e da semina)	Patate	Potatoes
IN	IN.BBT	Barbabietola da zucchero (escluse le sementi)	Barbabietola da zucchero	Sugar beet
IN	IN.SAR	Piante sarchiate da foraggio (escluse le sementi)	UNUSED	Forage plants
IN	IN.ORT	Ortaggi da pieno campo	Lattuga	Lettuce
IN	IN.FRA	Coltivazioni in orti stabili: fragola, pomodoro da mensa, altro	Fragola	Strawberry
IN	IN.FIO	Fiori e piante ornamentali all'aperto	UNUSED	Flowers
IN	IN.PIA	Piantine per orticole e altro	UNUSED	Decorative plants
IN	IN.SEM	Sementi da prato e altro	UNUSED	Seeds
IN	IN.TAB	Tabacco	Tabacco	Tobacco
IN	IN.COL	Colza e ravizzone	Colza	Colza
	IN.GIR	Girasole	Girasole	Sunflower
IN	IN.SOI	Soia	Soia	Soybean
IN	IN.SLI	Semi di lino	Semi di lino	Flax seeds
IN	IN.CAN	Canapa	Canapa	Canapa
IN	IN.IND	Altre colture industriali non menzionate altrove	UNUSED	Other industrial crop
IN	IN.CZU	Canna da zucchero	UNUSED	Sugarcane

Appendix C. Structure of the GAMS program

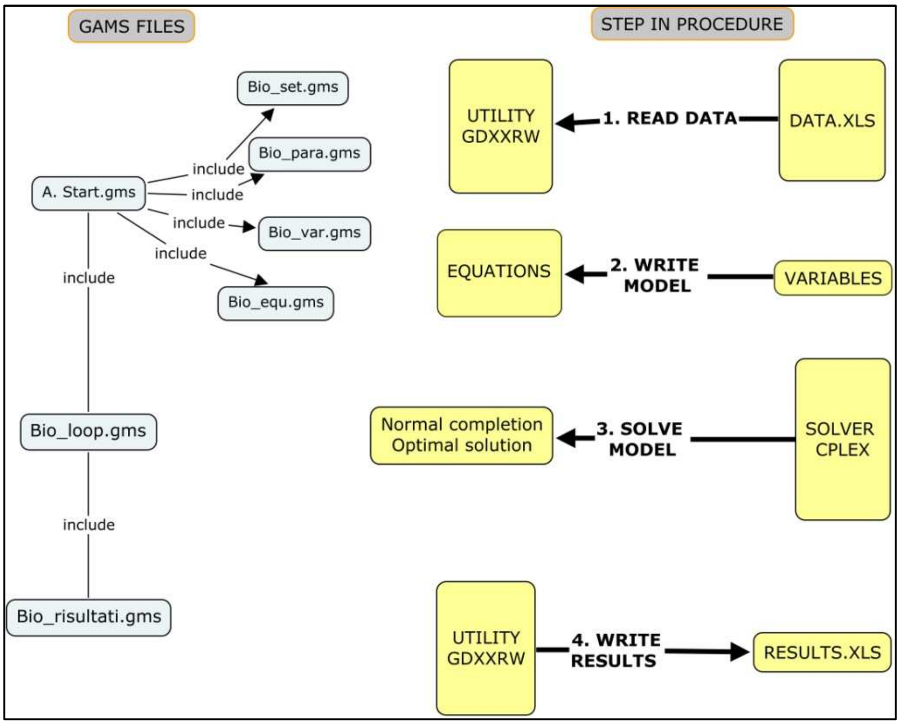

Figure 7: Structure of GAMS program. Source: own elaboration, software C-map.