Abstract

Together, sustainable management of natural resources and climate action form one of the three objectives of the 2014–2020 Common Agricultural Policy. This objective is being addressed by replacing the existing direct payments under Pillar 1 with a basic payment, combined with an additional payment conditional on farmers undertaking agricultural practices beneficial for the climate and the environment, a policy referred to as *greening*.

In this study, the impact of *greening* was assessed using a hybrid model calibrated using Positive Mathematical Programming. The model describes the macro-types of farm production in a Mediterranean agricultural area.

The results show that *greening* was not beneficial throughout the study area and only some farm types have been particularly affected. However, greening appears to have a positive impact on curtailing the use of chemicals, particularly nitrogen, and on crop diversity.

JEL classifications: C61, Q01, Q18

Key words: agricultural policy; supply analysis; mathematical programming

1. Introduction

Since the 1990s, the European Union (EU) has progressively and structurally reformed the Common Agricultural Policy (CAP), which today includes two pillars that have specific objectives and tools. The CAP reform process was accompanied by a re-specification of the objectives of the CAP in line with the EU 2020 strategy document, which promotes agriculture's contribution to smart (i.e. encouraging knowledge and innovation), sustainable, and inclusive growth (European Commission, 2010; European Commission, 2011).

The sustainable management of natural resources and climate action together form one of the three post-2013 objectives of the CAP, and are addressed by replacing the existing direct payments under Pillar 1 with a basic payment, supplemented by an additional payment conditional on farmers respecting certain 'agricultural practices beneficial for the climate and the environment'. This so-called 'green (henceforth, *greening*) is financed in part (30%) from national direct payment envelopes, and requires, among other things, crop diversification and the maintenance of existing grassland. The novelty of this approach lies in its attempt to define and fund EU-wide mandatory green standards through Pillar 1 direct payments (Matthews, 2013). The greening comprise three basic elements: diversifying cultivation, the maintaining of permanent grassland and the maintaining of the Ecological Focus Areas.

The new CAP's integration of more environmental concerns has increased the demand for tools to help assess the impact of decisions on agriculture and on its economic and physical environment (Gohin, 2006; Balkhausen et al., 2007). Economic models can provide these types of evaluation using available agricultural information for the entire EU. Specifically, the micro-economic approach of mathematical programming models allows the technical aspects of agricultural production to be taken into account (Godard et al., 2008). To deal with these challenges conventional policy analysis models have to be adjusted (Buysse et al., 2007). Within the current agricultural economics mathematical programming toolkit, two main types of programming models can be distinguished: Normative Mathematical Programming (NMP) and Positive Mathematical

Programming (PMP). PMP calibrates mathematical programming models to observed behaviour during a reference period using the information provided by the dual variables of the calibration constraints (Howitt, 1995; Arfini and Paris, 1995; Paris and Howitt, 1998; de Frahan et al., 2007).

Many analyses of the impact of farm policy reforms have been conducted using mathematical programming models, which can be grouped into three categories farm-type models, regional models, and hybrid approaches according to how they represent farm heterogeneity in time and space (Britz et al., 2012). Farm-level modelling allows the behaviour of individual farms to be modelled. However, in practice, only a limited number of representative farms are modelled (Ittersum et al, 2008; Louhichi et al, 2010). This is due to a lack of information regarding individual farms, as well as a need to preserve empirical tractability. Models that operate at regional levels are more suited for representing the aggregate behaviour of a region, but poorly address farm- and field-level heterogeneity. Hybrid models combine the strengths of farm- and regional-level approaches, accounting for economic feedback loops and for heterogeneity at the representative-farm level (Britz et al., 2012).

The objective of the present paper is to evaluate the impact of *greening* in an irrigated area using a hybrid model calibrated by the PMP methodology. The study area is an irrigated area of the Mediterranean located in Italy's west-central Sardinia. The Water User Association (WUA) of Oristano constructed, operates, and maintains the drainage systems in this region, and provides irrigation water. This area is representative of many Mediterranean areas because of the structural characteristics of the farm types, as well as the types of cultivation practiced. The wide variety of farm types involved in the area facilitated evaluation of the impacts of greening.

The model used represents the various farm types operating in the area, with each representative farm type weighted to represent agricultural activity as a whole.

The model was calibrated using PMP methodology; in particular, the Röhm and Dabbert approach (2003) was used for the forage crops produced on the farms and for animal feed.

The characteristics of the dual value of forage crops in the presence of feeds purchased on the market are addressed and discussed from a methodological standpoint, and measures of greening and relative aspects are defined mathematically.

The results show that, for the area as a whole, there are no compelling data supporting the effectiveness of new CAP instrument. Greening particularly interferes with the management of specialist dairying farms, which constitute a small but economically significant proportion of the area. Specialist dairying farms are particularly affected because they are structured to produce large amounts of corn silage for livestock feed; recent increases in the price of corn silage due to the increased production of biogas have pushed farmers to increase cultivation beyond the limits of *greening*. The conflict between the expanded production of maize for biogas and *greening* constraints may represent a conflict between the mechanisms of the greening policy and the new CAP objectives of developing the cultivation of biomass for energy production. However, *greening* appears to be successful in decreasing the use of chemicals, particularly nitrogen[1] and on crop diversity .

The next section will present the materials and methods of the paper. First, greening measures used in recent studies will be presented. The methods of the present paper specifically the two PMP approaches used for the model calibration will then be given. The final section of the materials and methods focuses on empirical analysis, with a description of the study, the economic model, and the modelling of greening measures and simulated scenarios. After the description of the results, the paper terminates with the discussion and conclusions.

2. Greening measures: characteristics and literature review

The European Council and the European Parliament have recently published the new CAP regulations for 2014–2020. These regulations concern supporting rural development through the European Agricultural Fund for Rural Development (No. 1305/2013); the financing, management,

[1] Units of nitrogen fertilizer (N).

and monitoring of the CAP (No. 1306/2013); the rules for direct payments to farmers under support schemes within the framework of the CAP (No. 1307/2013); and the common organization of the markets for agricultural products (No. 1308/2013).

One of the main new features of the 2014–2020 regulations is payment for agricultural practices that are beneficial for the climate and the environment (henceforth, *greening payment*). This payment earmarks 30% of the currently available national envelope for the implementation of sustainable farming practices.

The requirements of this measure are in addition to *cross-compliance* constraints, which are requirements intended to protect the basic environmental conditions necessary to agriculture. These constraints comprise three basic elements:

I. diversifying cultivation by growing at least two crops on farms where the arable land exceeds 10 ha, and at least three crops where arable land exceeds 30 ha, and by limiting the main crop to 75% of the arable land and the two main crops to 95% of the arable land;

II. maintaining permanent grassland at the national, regional, or farm level;

III. maintaining at least 5% (7% from 2017) of the arable land of farms larger than 15 ha as Ecological Focus Areas; these areas may take the form of fallow land, terraces, landscape features, buffer strips, hectares of agro-forestry, strips of eligible hectares along forest edges, areas with short-rotation coppice, afforested areas, areas with catch crops or green cover, or areas with nitrogen-fixing crops.

The system provides for *greening equivalency*, whereby environmentally beneficial practices already in place may be used instead of these basic requirements. For example, organic producers or farmers who participate to (or who are involved in) agro-environmental schemes will not have to meet additional requirements, as their practices are accepted as already providing clear ecological benefits. To avoid double funding under these conditions, payments made through rural development programs must take into account the basic greening requirements.

2.1. Literature review

Since 1985, there has been a gradual integration of environmental objectives and motivations into the CAP; at the same time, there continues to be a mismatch between the scale of the environmental challenges facing EU farmland and the scale of the policy response (Allen and Hart, 2013).

The integration of environmental concerns with the CAP has been characterised by a gradual shift in emphasis towards more targeted, regionally defined, and programmed approaches; these approaches are generally embodied in agro-environmental measures and in Pillar 2, and are supported by cross compliance. While these elements all remain in the current proposals, a major new element the introduction of green direct payments via Pillar 1 has come into play. Their introduction is coupled with a net reduction in the Pillar 2 budget over the upcoming programming period (Hart and Little, 2012). In formulating its proposed revisions of the post-2013 CAP, the European Commission opted to pursue further integration mainly through Pillar 1, through the introduction of a 'green' payment for farmers who follow a specified set of mandatory farm practices (Matthews, 2013). EU investments in research and development activities are required for the successful implementation of greening practices (Singh et al., 2014).

Several studies on the possible impact of greening in Europe have been conducted in recent years. Some studies have a qualitative nature, and others use econometric and mathematical programming approaches.

Allen et al. (2012) argue that the Ecological Focus Areas have the greatest potential, with much of this potential depending, in practice, on precisely how proposals evolve, the final form they take, the scope for tailoring interventions to local circumstances, the behaviour of EU Member States, and the response by farmers. The PBL Netherlands Environmental Assessment Agency (Westhoek et al. 2012) pointed out that the impact of crop diversification and permanent grassland measures will be negligible, as most farms already meet these criteria. They argue that the most effective measure would be the EFA criteria, where changes will be seen in the levels of production and GHG emissions in the EU.

Chiron et al. (2013) analysed the potential impacts of future CAP land use on the abundance of the 20 farmland bird species included in the French Farmland Bird Indicator (FBI). Chiron et al.'s study demonstrates that the relative abundances of specialized farmland bird species depend on both crop-cover type and the total area being cultivated. Model predictions show a general decline in the abundance of farmland birds between 2007 and 2020. The loss of farmland birds is predicted to be less pronounced in the greening scenario, although the predicted FBI values have relatively large errors. To optimize the effectiveness of the CAP on biodiversity at the national and continental levels, policies should be tested at smaller levels, such as regions or farmlands; the policies that represent the best options for biodiversity at these sublevels should then be combined to create a national plan.

Schulz et al. (2014) explored farmers' prospective responses to the greening. Their analysis was based on discrete choice experiments using a sample of 128 German farmers. Participants were asked to choose between a greening option, which had a given set of management prescriptions, and an 'opt-out' alternative, which offered a set cut of the single direct payment. Schulz et al. found that farmers' choices were driven by greening policy attributes, personal and farm characteristics, and interactions between these two groups of variables. While farmers overall perceived greening as a costly constraint, not all farmers were equally affected, nor were all greening provisions regarded as equally demanding. Specialised arable farms on highly productive land and intensive dairy farms were most likely to opt out of greening and voluntarily forgo part of their single payment entitlements.

Villanueva et al. (2015) perform an ex-ante assessment of AES in permanent cropping, analyzing several issues that have received little attention from researchers, such as Ecological Focus Areas (EFA) and collective participation. Their results show that almost half of the farmers would be willing to accept it up to 2% for low monetary incentives per additional 1% of the farmland devoted to EFA, while the rest would do it for moderate-to-high monetary incentives per additional 1% of

EFA. However, for a high share of EFA (e.g., 5–7%) higher incentives would presumably be required due to the intrinsic spatial restrictions of olive groves.

Wąs et al. (2014) used a farm-optimization model with PMP techniques to estimate the potential effects of greening for 218 types of Polish farms. They found that a majority of Polish farms were already compliant with the new requirements, and that the adjustment of the remaining farms to the new requirements created only small changes in cropping structure and had a negligible impact on the income generated by the Polish farming sector. The Shannon index was used (Shannon, 1948) to verify crop diversification requirements for different types of farms.

Ahmadi et al (2015) explore how Scottish beef and sheep farms might be affected by the greening and flat rate payments under the current CAP reforms using an optimizing farm-level model. The results show that the greening measures of the CAP did not have much impact on net margins of most of the beef and sheep farm businesses, except for ‘Beef Finisher’ farm types where the net margins decreased by 3%. The move to regionalized farm payments increased the negative financial impact of greening on most of the farms but it was still substantially lower than the financial sacrifice of not adopting greening measures.

Regarding the studies using the mathematical programming methodology, the modelling of greening measures is missing. Solazzo et al (2014) show the greening measures implementation in a positive mathematical programming model. However their study refers to old proposals of the European Commission, European Parliament and Council.

In general in the existing literature the model results concern only the economics aspects and don’t refer to the input uses as nitrogen, water and labour.

3. Applied methodology

The PMP methodology was developed to calibrate agricultural supply models, and assumes a profit-maximising equilibrium during the reference period. It recovers additional information from observed activity levels in order to specify a non-linear objective function, such that the resulting non-linear model exactly reproduces the observed behaviour of farmers (Howitt, 1995; Arfini and

Paris, 1995; Paris and Howitt, 1998; Heckelei and Wolff, 2003). In 2012, Heckelei et al. reviewed the development and utilization of the most important PMP models.

The *standard* approach (Arfini and Paris, 1995) involves 1) Specification of a linear programming model bound to the observed activity levels by calibration constraints, so as to derive the differential marginal cost vector (μ); 2) Estimation of a quadratic variable cost function, which is assumed to capture all farming conditions not modelled in an explicit way; and 3) the formulation of a quadratic programming model, which includes the variable cost function in the objective function. The standard approach model exactly reproduces the behaviour observed in the base year and can be used to perform simulations on several parameters of the model, including product and factor prices, subsidies, and resource availability.

With *j* denoting crops, the quadratic programming model can be written:

$$\begin{aligned} &\text{Max}\, Z = \sum_j \left(r_j - AC_j(x_j)\right) x_j \\ &s.t. \sum_j a_{i,j}\, x_j \leq b_i \qquad (1) \\ &x_j \geq 0 \end{aligned}$$

where Z denotes the objective function value; x_j represents the production activity levels (i.e. hectares allocated to crop *j*); r_j denotes average revenue per unit of activity (selling, CAP coupled payments); $a_{i,j}$ represents the scalar element of a matrix of coefficients in the resource and policy constraints (Index *i*); b_i is the vector of the available quantities of the resources land, labour, and water; and $AC_j(x_j)$ denotes average variable cost function per unit of activity, and has the following form:

$$AC_j(x_j) = \alpha_j + \frac{1}{2}\beta_j x_j \qquad (2)$$

where α and β are the parameters to be estimated.

Multiple sets of cost-function parameters satisfy the marginality conditions of Equation (2). One of the options for determining these parameters is the following (Arfini and Paris, 1995):

$$\alpha_j = c_j \;;\quad \beta_j = \frac{\mu_j}{x_j^0} \qquad (3)$$

where c_j are the observed accounting costs and μ_j are the dual values determined by means of the following calibration constraints:

$$x_j \leq x_j^0 (1 + \varepsilon) \qquad [\mu_j] \qquad (4)$$

where x^0_j are the observed variable levels and ε is a small positive number (Howitt, 1995).

In the standard approach, the parameters of the cost function for each activity are determined separately for each land-use activity. Different production technologies for the same or similar crops are thereby considered as separate activities and different crops.

Röhm and Dabbert (2003) propose a different modelling approach, given that the elasticity of substitution is expected to be higher between variants of the same crops than between different crops. Denoting the crops with *j* and the variants with *v*, the quadratic programming model can be written as:

$$Max\ Z = \sum_j \sum_v \left(r_{j,v} - AC_{j,v}(x_{j,v})\right) x_{j,v}$$

$$s.t. \sum_j \sum_v a_{i,j,v}\, x_{j,v} \leq b_i \qquad (5)$$

$$x_{j,v} \geq 0$$

where average variable costs per unit of activity ($AC_{j,v}$) are defined as:

$$AC_{j,v}(x_{j,v}) = \alpha_{j,v} + \frac{1}{2} \beta_{j,v}\, x_{j,v} + \frac{1}{2} \gamma_j \sum_v x_{j,v} \qquad (6)$$

The Röhm and Dabbert approach (2003) introduces an additional slope parameter not included in Equation (2), and which is common to all variants (different production techniques) of the same crop. As a result, there are two sets of slope parameters, one for each crop (γ) and another for all variants of the same crop (β).

As with the standard approach, multiple sets of cost function parameters satisfy the marginality conditions. The option to determine these parameters chosen by Röhm and Dabbert is:

$$\alpha_{j,v} = c_{j,v}\ ; \quad \beta_{j,v} = \frac{\mu_{j,v}}{x^0_{j,v}}\ ; \quad \gamma_j = \frac{\mu_j}{\sum_v x^0_{j,v}} \qquad (7)$$

where $c_{j,v}$ are the accounting costs and the other parameters can be determined on the basis of the results of the original linear problem, using two sets of additional calibration constraints:

$$\sum_v x_{j,v} \leq \sum_v x^0_{j,v} (1 + \varepsilon_1) \qquad [\mu_j] \tag{8}$$

$$x_{j,v} \leq x^0_{j,v} (1 + \varepsilon_2) \qquad [\mu_{j,v}] \tag{9}$$

where ε_1 and ε_2 are small positive numbers ($\varepsilon_1 < \varepsilon_2$); μ_j are dual values associated with crops; and $\mu_{j,v}$ are dual values associated with crop variants.

In the Standard and Röhm and Dabbert approaches the dual value referring to the marginal activity vanishes and consequently the slope coefficient is equal to zero. Setting the dual value for the land constraint equal to the observed land rental value, the dual value for the marginal activity becomes greater than zero and it is possible to recover a non-zero slope coefficient for this activity also (Gohin and Chantreuil, 1999; Röhm and Dabbert, 2003).

4. Empirical analysis

4.1. Study area and data

The study area is located in Italy, in west-central Sardinia, and covers about 54,000 ha of agricultural land. The Water User Association (WUA) constructed, operates, and maintains the drainage systems in this region, and also provides irrigation water. Since the mid-2000s, WUA has operated the Eleonora d'Arborea dam, which holds approximately 450 million m^3 (Mm^3) of water, 120–130 Mm^3 of which is available for farming. This water is distributed to 36,000 ha comprising 26 irrigation districts, which are clustered into four categories according to the technological characteristics of the irrigation network.

The first category includes all districts where the farms receive water under high pressure. However, the model divides these districts into two sub-categories to specifically differentiate the productivity and irrigation issues of dairying farms in the *Arborea* zone. The second category includes all farms with low-pressure water. In the districts of the third category, the water resource is at a higher altitude than the area it serves, with gravity allowing water to be transported to farms via open channels. The remaining 18,000 ha, the fourth category, receive sufficient water from rainfall, and are therefore not served by the irrigation facilities of the WUA.

The major cropping systems are based on cereals (wheat and corn) and forage (alfalfa, clover, and ryegrass). Large areas are also devoted to vegetable crops (artichokes, watermelons, and tomatoes); rice, fruit (especially citrus), and olives; vineyards are also very important. Farming outside of the WUA is predominantly non-irrigated, but some crops are locally irrigated using farm wells. Of the total land outside the WUA, 55% is dedicated to pastures (Giraldo, 2014)

With respect to livestock, cattle breeding for dairy milk production is very important in the Arborea region, which has an organized local system for the collection, processing, and packaging of milk. The sheep milk sector is also an important component of the local economy, and involves almost 372,000 sheep and a number of milk processing plants.

In the study area the production of corn silage for biogas has in recent years become of economic interest because of the price increase, and considering the coupled payment removal for tomato wheat and rice sectors.. In particular the *Specialist dairying* and *Mixed cropping* farms has reacted strongly to the corn silage price rise by increasing production.

The agricultural production of the study area was reconstructed to reflect the situation in 2010. This year was chosen because of the availability of data from the sixth General Census of Agriculture; these data were integrated with Farm Accountancy Data Network (FADN) data, as well as with data from WUA records. The production conditions for the various crops and livestock were defined on the basis of interviews with farmers and agronomists from private and public institutions, as well as from information provided by local cooperatives. The phases of cultivation were reconstructed, and data were collected on the use of chemicals, crop irrigation requirements, and production. Similarly, the feed requirements of the various categories of livestock were specified, along with the feeding rations and the products obtained. The prices of inputs and products were also reconstructed.

4.2. Economic model

a) General structure

A hybrid economic model was used, which represented the productive system of the study area via thirteen types of representative farms. The productive system was also divided into four categories according to the technological characteristics of the irrigation network: (1) high pressure, (2) low pressure, and (3) gravity within the WUA facilities sub-area, as well as (4) rain-fed in the other sub-area.

Table 1 lists the thirteen farm types, shows some of their main characteristics and those that in the 2010 don’t respect the diversification and EFA constraints. Moreover the specialist sheep will be interested by the maintaining permanent grassland.

Table 1

The structural and economic characteristics of these farm types were obtained using data for the FADN farms within this geographical region: specialist rice, specialist citrus fruits, specialist dairying, specialist market garden vegetables under glass, mixed cropping, specialist sheep. Additional analysis and elaboration were carried out to capture differences among farms of the same type. For the farm types of specialist dairying, mixed cropping, and specialist sheep, a cluster analysis was carried out to subdivide farms of these three types into more homogeneous groups taking into consideration some structural, economic and managerial aspects.

In this study a hierarchical and a non-hierarchical clustering methods have been integrated. The hierarchical cluster analysis was performed based on the method of average linkage between groups, which involves measurement of intervals with Euclidean squared distance for selected characteristics of the population. This resulted in a preferable number of groups. The number of groups was indicated using a non-hierarchical definitive k-means method that clustered the FADN farms by maximizing the internal similarity of the groups (Dono et al, 2013).

For the farm type of specialist dairying, the total FADN sample was divided into two groups according to performance; the better-performing group had more economically efficient feeding and a shorter calving interval. The mixed-cropping type farms were divided into five homogeneous groups that differed according to cropping patterns, structural characteristics, and location. Finally, the specialist sheep-type farms were grouped into three groups, mainly according to their use of irrigated forages[2].

All of the thirteen farm types are representative of the average of the various characteristics within the FADN sample. Representativeness was ensured by using the FADN database and other local sources to accurately reflect resource use and economic results of the study area. Each farm type was multiplied by the proportion of farms in the study area it was assumed to represent; here, the technological characteristics of the irrigation network were also taken into account (Dono et al., 2012)[3]. This procedure yielded twenty-five macro-farm types (*mt*), which take into account farms type, representativeness, and technological characteristics of the irrigation network.

The economic model was calibrated using PMP methodology and can be written as follows:

$$\text{Max}\, Z = \sum_{j,mt} \left(r_{j,mt} - AC_{j,mt}(x_{j,mt})\right)x_{j,mt} + \sum_{mt} qmilk_{mt} * \; pmilk_{mt} + \sum_{mt} heleg_{mt}\, sfp_{mt}$$

$$- \sum\nolimits_{i,mt} pb_i \, xb_{i,mt} \; - \sum\nolimits_{mt} pf \; xf_{mt}$$

$$s.to$$

$$\sum_j a_{"land",j,mt}\, x_j \le b_{"land",mt} \qquad \forall\, mt \qquad [\lambda_{"land",mt}] \qquad (10)$$

$$\sum_j a_{"water",j,mt}\, x_j \le b_{"water",mt} + xb_{"water",mt} \qquad \forall\, mt \qquad [\lambda_{"water",mt}]$$

$$\sum_{\mathrm{j}} a_{"labour",\mathrm{j,mt}}\, \mathrm{x_j} \le \mathrm{b}_{"labour",\mathrm{mt}} + \mathrm{xb}_{"labour",\mathrm{mt}} \qquad \forall\, mt \qquad [\lambda_{"labour",\mathrm{mt}}]$$

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[2] The clustering variables used are: return on equity, gross margin over milk, illness score and reproductive capacity for the specialist dairying; return on equity, gross margin, percentage of arable land and irrigated area for mixed-cropping and specialist sheep.

[3] E.g. specialist dairy farms that use high-pressure irrigation in the Arborea area, specialist citrus farms that use high-pressure irrigation, specialist rice farms that mainly operate using gravity irrigation, specialist sheep farms that mainly operate in the rain-fed sub-area.

$$\sum_{jf} nutry_{jf,nt}\, y_{jf,mt}\, x_{jf} + nutrxf_{nt}\, xf_{mt} \geq r_{nt,mt} \qquad \forall\, nt, mt \qquad [-\lambda f_{nt,mt}]$$

$$x_{j,mt}, xf_{nt,mt}, xb_{i,mt} \geq 0$$

where, in conjunction with previously defined symbols, $qmilk_{mtd}$ and $pmilk_{mtd}$ are the milk production and the price; $heleg_{mt}$ and sfp_{mt} are the eligible area and the single farm payment according to the CAP decoupled payments; pb_i are the prices of *i* additional resources ($xb_{i,mt}$; e.g. external labour, pumping water); pf is the price of purchased feed (xf); $nutry_{jf,nt}$ is the unitary content of the various nutrients (*nt*) in the forage crops; $y_{jf,nt,mt}$ are the yields of forage crops (*jf*); $nutrxf_{nt}$ is the unitary content of the various nutrients (*nt*) in the purchased feed; $r_{nt,mt}$ are the animal requirements in terms of each nutrients (*nt*) for the total number of animals.

Note also the dual values ($\lambda_{i,mt}$) of the resource constraints of land, labour, and water, as well as the dual values ($\lambda f_{nt,mt}$) of the feed constraint. In the calibrated model, these dual values assume the values of the resource market price considering the land rental value to overcome the marginal activity problem, the prices of additional resources (water, labour) and the price of purchased feed.

The first order conditions of the model eq. (10) for the activities are the following

$$r_{js,mt} - c_{js,mt} - \mu_{js,mt} - \sum_i \lambda_{i,mt}\, a_{i,js,mt} \leq 0 \tag{11}$$

$$-c_{jf,mt} - \mu_{jf,mt} - \sum_i \lambda_{i,mt}\, a_{i,jf,mt} - (-\lambda f_{"ntb",mt})\, nutry_{jf,"ntb"}\, y_{jf,mt} \leq 0 \tag{12}$$

where, in conjunction with previously defined symbols, the *js* set defines the crops for sales, the *jf* set defines the forage crops used for animal feed and the element “*ntb*” is the binding nutrient.

b) Calibration of forage crops

As discussed in Section 2.2, Röhm and Dabbert (2003) proposed a modelling approach that, unlike the standard approach, would take account the greater elasticity of substitution among crop variants than among different crops. In this approach an additional slope parameter common to all variants of the same crop is considered other than the specific slope parameter for each variants, as for example the deficit irrigation techniques (Cortignani and Severini, 2009).

The Röhm and Dabbert approach can also be used for similar crops, to allow for a greater elasticity of substitution among closely related activities that define groups of similar crops (Blanco et al., 2008).

In the model used in the present study the nutritional requirements of animals were partially met by feed purchased on the market. During the calibration phase, this feed purchasing can result in very high dual values for the forage crops produced on farms and used for animal feed, because the market value of the binding nutrient is also considered. In the standard PMP approach, this could result in very different cost-parameter levels that do not reflect the real characteristics of the crops, considering the very different production of the forage crops observed for the baseline year.

Thus, the dual value of the calibration constraint (μ_{jf}) for each forage crop (*jf*) is equal to:

$$\mu_{jf,mt} = -c_{jf,mt} - \sum_{i} \lambda_{i,mt}\, a_{i,jf,mt} \; - \left(-\lambda f_{\text{"ntb"},mt}\right)\; nutry_{jf,\text{"}ntb\text{"}}\; y_{jf,,mt} \qquad (13)$$

where $c_{jf,mt}$ is the production cost; $\sum_i \lambda_{i,mt}\, a_{i,jf,mt}$ is the opportunity cost of the binding resources; $\lambda f_{\text{"ntb"},mt}$ is the dual value of the feed constraint, and $nutry_{jf,\text{"}ntb\text{"}}\; y_{jf,,mt}$ is the yield of the forage crop in terms of the binding nutrient ("ntb"). Specifically:

$$-\lambda f_{\text{"ntb"},mt} = -\frac{pf}{\text{nutrxf}_{\text{"ntb"}}} \qquad (14)$$

where $\frac{pf}{\text{nutrxf}_{\text{"ntb"}}}$ is the price of purchased feed in terms of the binding nutrient (“*ntb”*).

In other words, $\lambda f_{\text{"ntb"},mt}$ is the market value of the binding nutrient and therefore the whole component ($\lambda f_{\text{"ntb"},mt}\;\; nutry_{jf,\text{"}ntb\text{"}}\; y_{jf,mt}$) is the value of the forage crop produced on the farm in terms of the market price of the binding nutrient.

The Röhm and Dabbert approach was used for the forage crops produced on farms and used as animal feeds. The additional slope parameter of the Röhm and Dabbert approach captures the opportunity cost of the market value of the binding nutrient common to all forage crops group (*fg*), and the specific slope parameter takes into account the specificities and characteristics of crops (*jf*).

The resulting average variable cost function ($AC_{j,mt}(x_{j,mt})$) for the forage crops (*jf*) becomes:

$$AC_{jf,mt}(x_{jf,mt}) = \alpha_{jf,mt} + \frac{1}{2}\beta_{jf,mt}\, x_{jf,mt} + \frac{1}{2}\gamma_{fg} \sum_{jf} x_{jf,mt} \qquad (15)$$

c) Modelling of greening measures

To simulate the application of the diversification constraints, a variable ($dx_{dj,ty}$) was included in the model. This variable takes into account the rules laid down for the different crops according to Regulation 1307/2013, and the relative delegated regulation, regarding the different crops (*dj*)[4]:

$$dx_{dj,mt} = \sum_{j} x_{j,mt} \qquad \forall\, dj, mt \qquad (16)$$

in order to regroup the *j* crops according to established rules considering the meaning of crop and that the shares of different crops must be calculated for the most relevant part of the cultivation period, given traditional national cultural practices. The first ten days of June were therefore used in the present study.

Two constraints pertain to diversification. The first requires that, for farms with arable land exceeding 10 hectares, each crop may not exceed 75% of the arable land in the selected period:

$$dx_{dj,mt} \leq 0.75\, Arl_{mt} \qquad \forall\, dj, mt, \quad if\ Arl_{mt} > 10\ ha \qquad (17)$$

where Arl_{mt} is the arable land.

The second constraints affects farms with over 30 hectares of arable land, and requires that the sum of the two main crops not exceed 95% of the arable land:

$$dx_{dj,mt} + dx_{djj,mt} \leq 0.95\, Arl_{mt} \quad \forall\, dj, djj, mt \quad with\ dj \neq djj \quad if\ Arl_{mt} > 30\ ha \qquad (18)$$

The regulation on maintaining permanent grassland has been specified at the farm level; specifically, grazing land should not decrease by more than 5%:

$$x_{'past',mt} \geq 0.95\, x^{0}_{'past',mt} \qquad \forall\, mt \qquad (19)$$

Where $x^{0}_{'past'}$ is the pasture area observed in the reference period.

Seven percent of the arable land was to be allocated to Ecological Focus Areas for farms with more than 15 hectares of arable land:

[4] The *dj* set is a mapping of *j* set that considers the rules of Regulation 1307/2013 and the relative delegated regulation.

$$\sum_j x_{j,mt} \leq Arl_{mt} - efa_{mt} \quad \forall\, mt \qquad if\ Arl_{mt} > 15\ ha \qquad (20)$$

where the efa_{mt} is 7% of the arable land less the sum of A_{fefa} areas of the various (*fefa*) features multiplied by the relative conversion factor (f_c) and/or the weighting factor (f_p):

$$efa_{mt} \geq 7\%\ Arl_{mt} - \sum_{fefa} f_{c_{fefa}} f_{w_{fefa}} A_{fefa} \quad \forall\, mt \qquad (21)$$

In other words the component $\mathrm{f}_{\mathrm{c}_{\mathrm{fefa}}}\, \mathrm{f}_{\mathrm{w}_{\mathrm{fefa}}}\, \mathrm{A}_{\mathrm{fefa}}$ considers that, according the annex X of the Regulation 1307/2013, the area of the various features (land lying fallow, terraces, landscape features,…) must be multiplied by the relative conversion factor and/or the weighting factor.

Note that all the constraints relative to greening measures are defined by *mt* macro farm-types in order to allows to consider the criteria of exclusion at farm level if needed (e.g. organic farms or others characteristics that determine the exclusion).

4.3. Simulated scenarios

The model was calibrated to the situation observed in 2010. Firstly, this model were transformed to the policy and market conditions observed in 2013 (Table2).

Table2

This involved the decoupling of payments for rice, processed tomatoes, and premium quality durum wheat; the recent relative price increase for corn silage, to be used to produce biogas, was also taken into account. The resulting model is henceforth termed *the 2013 scenario*, and serves as the baseline for the present study.

Two simulations were considered for the 2014–2020 CAP. The first simulation regards the application of the greening measures. The second considers also the direct payments (decoupled and coupled payments) provided by 2019. Italy has decided to apply the internal convergence of decoupled payments according to Irish model considering a one single region at national level. National-level choices regarding how to apply Article 52 of Regulation 1307/2013 in the study area will involve the sectors of dairy cattle and sheep, which will receive a payment per head of cows and ewe lambs. Regarding the arable sector, payments for leguminous crops, durum wheat, rice, and processed tomatoes are provided.

The impact of the two simulations respect to 2013 scenario was evaluated in terms of cropping choices, economic results, and input use. The Shannon Index was calculated to measure the impact on crop diversity[5]. Finally, the net income impact of the various macro farm-types was also considered.

The indicators chosen to assess the impact derive from the data characteristics and the used model. The Shannon Index is based on the numerosity of crops in farms and this information is included in the data FADN. Moreover, this indicator could identify and assess biodiversity with further developments (eg. individual species on pastures and EFA). The phases of cultivation were reconstructed and considered in the model; the data were collected on the use of chemicals, irrigation and labour requirements.

5. Results

Greening scenario

The impact of greening was assessed by comparing the percentage change with respect to the 2013 scenario. The greening constraints lead to a reduction in corn silage (Table 3). This was because specialist dairying farms, which over-specialized in corn silage (to produce biogas) in the 2013 scenario, have to move back under the diversification constraints in the greening scenario. To achieve this diversification, they halved the area under cultivation for corn silage, highlighting the impact of replacing feeding corn silage with sorghum and triticale silage.

Table 3

[5] The Shannon index was developed in 1948 and it is one of the most frequently used indicators of biodiversity or crop diversity (Shannon, 1948). Its value is usually between 1.5 and 3.5, although it may sometimes exceed 4.5.

Even mixed farms reacted to the greening, although less relevant. Specifically, they reduced corn silage (which had been cultivated for biogas) and increased the production of vegetables (i.e. tomatoes, artichokes, and watermelons).

The Shannon index was reported for the type farms that most changed their cropping systems; an increase in this index indicates greater crop diversity . Greening measures increase or maintain Shannon index scores, such as the greater crop diversity that was observed in specialist dairying farms.

From an economic standpoint, the revenues from crops decreased because of reduced sales of corn silage for biogas; these reduced revenues were not compensated for by the small reduction in production costs, leading to a 2.1% reduction in net income (Table 4).

Table 4

This reduction was mainly because of the negative impact of greening on specialist dairying farms, due to the reduction in sales following the implementation of diversification constraints. The small decrease in the income of mixed farms most notably was due to maintaining of the arable area as Ecological Focus Area (Table 5).

Table 5

Given that greening is an environmental measure, it was of interest to analyse its effects on input use. As per Table 6, there was a general reduction in the use of chemical inputs, specifically nitrogen.

Table 6

The greening measures had a limited impact on water use. However, there was a further reduction in the consumption of water, which had already been observed in 2013. This decrease in water consumption could lead to cost and pricing problems for the WUA.

The application of greening was also associated with a reduction in extra labour but an increase in family labour. There was also a reduction in the quantities of feed purchased.

Greening and Direct Payments scenario

The coupled direct payments provided for in the 2015–2020 period will influence cropping patterns, thereby impacting income and resource usage. Regionalization and internal convergence will determine the allocation of decoupled direct payments among territories and sectors. The impact of greening and of direct payments was assessed by comparing the prospective percentage change compared to the 2013 scenario.

With regard to cropping patterns, area increases for crops for which there are coupled payments: wheat, rice, processing tomatoes, and leguminous crops (Table 3). This will result in a worsening of the Shannon index for certain types of farms.

The results indicate that there will be a smaller reduction in crop revenues (compared to the impact of only greening), considering the increased area of cultivation for some of the crops mentioned above. However there will be a negative impact on direct payments; while coupled payments will increase, there will be a significant loss of decoupled payments (Table 4).

Within the study area, decoupled payments are higher than the average as in the various historical reference periods, activities with high coupled payments (such as rice, processing tomatoes, cow's milk , wheat, sugar beet) were practiced.

The internal convergence of decoupled payments leads to a considerable loss of decoupled payments in favour of other territories. For the total area there is a net 7.5% loss of income (Table 4).

There is also an allocation of decoupled payments between the farm types (Table 5).

Specifically, the net income of specialist citrus fruit increases because they did not have decoupled payments; two specialist sheep farms increase their income through the coupled payments provided for legume crops; and the other specialist sheep farm will lose income because, having cultivated durum wheat in large quantities during the reference period, they have decoupled payments above the national base payment.

The intensification of cropping patterns leads to an increase in the use of inputs such as nitrogen, WUA water, and family labour, which are in general at the 2013 level (Table 6). However most notably, the greening measures seem to control the nitrogen use that might be expected to increase, considering the coupled payments for intensive crops.

6. Discussion and conclusions

In this study the impact of greening was assessed using a hybrid model, which was calibrated using the PMP methodology. In particular the Röhm and Dabbert approach (2003) was used to calibrate the forage crops, as this approach appears to more adequately consider the dual and production costs of these crops when feed is purchased on the market. In general, the Röhm and Dabbert approach could be useful in future developments to try to consider the possibilities offered by crop diversification and EFA measures also in terms of variants not observed (Cortignani and Severini, 2009).

The dimensional differentiation of the model is essential for this kind of analysis, because all farms with less than 10 ha of arable land are exempted from greening measures. The model is territorial, in the sense that there is competition for resources such as water and external labour among the various farm types, and some farm types could be involved indirectly. Another model characteristic is the specification of social (e.g. family and external labour) and environmental indicators (e.g. Shannon index and chemical inputs, as well as pressure on collectively owned water resources and private wells), which facilitated assessment of the impact of the new policy on sustainability throughout the territory.

The results of the modelling suggest that greening has some contradictory effects. First, many farms in the area study are below the application threshold, and therefore will not be affected. Those above the threshold will be affected, but production specialization can be maintained despite greening because participation is voluntary; participation will depend on whether the green payments are more or less than the lost revenues and additional costs resulting from applying greening constraints. Second, the analysis showed that greening might actually thwart strategy objectives such as the 2020 bioenergy development, clashing with European policy goals.

However, despite these negative aspects, greening appears to have some positive impacts. With regard to the environmental indicators used, greening was associated with a reduction in nitrogen use and greater crop diversity , specifically in farm types where the diversification measures are binding. In addition to having positive environmental impacts, the EFA measure could be relevant to income, especially when farmers cultivate nitrogen-fixing crops, which provide coupled payments. The maintenance of pasture in the study area does not yet have a significant impact, but in future climate scenarios in which the pastures are predicted to be less productive in the Mediterranean area, this measure could be crucial to maintain the area devoted to pasture.

Further developments of the analysis conducted in the present study might include the mechanism of participation for greening measures; the analysis could also be extended to other Mediterranean areas where specialization in the cultivation of wheat, corn, and tomatoes is important. Greater integration with other CAP environmental instruments, cross-compliance, and agro-climate-environmental measures might also yield interesting findings.

Another interesting development could be an analysis of the dual value for the land constraint in the various scenarios. Many authors have shown that the new direct payments scenarios can determine changes on land markets (Ciaian et al., 2012; 2014; Gocht et al., 2013; Galko and Jayet, 2011). These impacts will be different depending on the Single Payments Scheme (historical, regional, hybrid) regionalization, internal convergence and coupled payments.

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Table 1 - Farm types, land and income per year. Farms affected by the greening mesaures (2010).

	Represented farms (n)	Farm land (ha)	Net Income (€ 000)	Diversification	EFA	Permanent grassland
WUA facilities						
Specialist rice	24	115	134			
Specialist citrus fruits	68	13	39			
Specialist dairying A	130	31	207	X		
Specialist dairying B	40	32	177	X		
Specialist market garden vegetables under glass	46	13	29			
Mixed cropping - Vegetables	562	22	36		X	
Mixed cropping - Rice	55	146	89			
Mixed cropping - Field crops and permanent crops	100	6	12			
Rainfed						
Mixed cropping - Vegetables and permanent crops	100	4	11			
Mixed cropping - Field crops	94	25	30			
Specialist sheep A	45	87	53			X
Specialist sheep B	188	41	10			X
Specialist sheep C	129	62	30			X

Table 2 - Prices and policy parameters in the various scenarios

	Prices	CAP
2010	2010	Decoupled payments - 2010 Coupled payments
2013	Price increase for corn silage - 2013	Decoupled payments - 2013
Greening	Price increase for corn silage - 2013	Decoupled payments - 2013 Greening constraints
Greening + DP	Price increase for corn silage - 2013	Decoupled payments with internal convergence Greening constraints Coupled payments

Table 3 - Cropping patterns impact and Shannon index of the application of the CAP reform scenarios (hectares and Δ %)

	2013	Greening	Greening + DP
Arable land	41,664	-3.4	-0.6
wheat durum	*6,862*	*-4.0*	*15.3*
rice	*1,511*	*0.0*	*10.8*
tomato processing	*933*	*-6.1*	*4.2*
barley/oats	*4,235*	*-13.2*	*-59.3*
artichoke	*1,919*	*-1.2*	*-1.8*
watermelon	*1,100*	*-1.3*	*-1.8*
corn silage for biogas	*4,117*	*-22.4*	*-24.2*
corn silage feed	*3,385*	*-10.9*	*-10.2*
other silage feed	*459*	*168.1*	*150.5*
alfalfa	*1,126*	*22.6*	*27.2*
clover	*9,880*	*-0.2*	*17.1*
ryegrass	*4,658*	*-9.8*	*-10.9*
other arable crops	*1,480*	*17.8*	*16.9*
Permanent grassland and permanent pasture	11,404	0.0	-4.6
Permanent crops	1,702	-	-
Total Agricultural Area	54,770	-2.6	-1.4
Shannon Index:			
Specialist rice	1.53	1.53	1.48
Specialist dairying	1.25	1.54	1.54
Mixed cropping	2.51	2.52	2.37
Specialist sheep	1.10	1.10	1.00

Table 4 - Economic impact of the application of the CAP reform scenarios (000 euros and Δ %)

	2013	*Greening*	*Greening + DP*
Revenues total	203,832	-2.1	-1.6
revenues crops	*114,182*	*-3.8*	*-2.9*
Direct payments	31,626	0.0	-13.5
coupled	*0*	-	*3316**
decoupled	*31,626*	-	*-24.0*
Costs	125,422	-2.0	-1.2
input	*62,873*	*-1.3*	*-0.1*
WUA water	*2,079*	*-2.3*	*-1.5*
water pumping	*274*	*-0.4*	*-0.6*
extra labour	*7,126*	*-5.2*	*-1.7*
feeds	*27,033*	*-1.2*	*-2.9*
other costs	*26,038*	*-3.8*	*-1.8*
Gross Margin	110,036	-1.6	-5.6
Net income	81,749	-2.1	-7.5

** Absolute value*

Table 5 - Macro farm-types net income impact of the application of the CAP reform scenarios (000 euros and Δ %)

	2013	*Greening*	*Greening + DP*
Specialist rice	3,399	0.0	-25.4
Specialist citrus fruits	2,666	0.0	5.5
Specialist dairying A	27,718	-4.3	-5.8
Specialist dairying B	7,581	-5.1	-8.1
Specialist market garden vegetables under glass	1,331	0.0	0.1
Mixed cropping - Vegetables	20,062	-0.8	-10.4
Mixed cropping - Rice	5,808	-0.3	-16.5
Mixed cropping - Field crops and permanent crops	1,303	0.0	-0.4
Mixed cropping - Vegetables and permanent crops	1,021	0.0	-2.8
Mixed cropping - Field crops	2,690	0.0	-6.8
Specialist sheep A	2,405	0.0	6.4
Specialist sheep B	1,871	0.0	6.2
Specialist sheep C	3,894	0.0	-5.4

Table 6 - Input use impact of the application of the CAP reform scenarios (absolute values and Δ %)

	2013	*Greening*	*Greening + DP*
Nitrogen* (tons)	10,292	-3.2	0.0
Total water (000 m^3)	102,011	-2.5	0.3
WUA water	*95,075*	*-2.6*	*0.3*
Water pumping	*6,936*	*-0.5*	*-0.7*
Total labour (000 hours)	5,046	-0.4	0.4
Family labour	*4,208*	*0.5*	*0.8*
Extra labour	*838*	*-5.2*	*-1.7*
Feeds (tons)	1,244	-1.0	-3.8

* Units of nitrogen fertilizer (N)