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The impact of different energy policy options on feedstock price and land demand for maize silage: The case of biogas in Lombardy

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HIGHLIGHTS

- We investigate biogas production in Lombardy under two alternative policy scenarios.
- We model the biogas sector using a partial equilibrium approach.
- Past legislation significantly increases maize demand and its market clearing price.
- New incentive system favors manure based plants (130 kWe) decreasing maize demand.
- Wider, new policy mitigates past distortions and negative effects on maize price.

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ABSTRACT

The growing demand of maize silage for biogas production in Northern Italy has triggered an intense debate concerning land rents, maize prices and their possible negative consequences on important agri-food chains. The aim of this work is to quantify the extent to which the rapid spread of biogas raised the maize price at regional level, increasing the demand of land for energy crops. For this purpose we applied a partial-equilibrium framework simulating the agricultural sector and the biogas industry in Lombardy, under two alternative schemes of subsidization policy. Results show that policy measures implemented in 2013 – reducing the average subsidy per kWh – may contribute to enforce the complementarity of the sector with agri-food chains, decreasing the competition between energy and non-energy uses. Compared to the old scheme, maize demand for biogas would decrease, lessening the market clearing price (as well as feed opportunity cost for livestock sector) and reducing land demand for energy purposes.

1. Introduction

Biogas production from energy crops has strongly grown over the last years in Italy, as a consequence of the subsidization policy. Despite the biogas policy scheme concerns the whole Country, in Italy biogas plants are mainly concentrated in regions of the Po Valley (i.e. Lombardy, Piedmont, Emilia-Romagna and Veneto), whose agricultural systems are highly productive and urban areas are densely populated. With one of the highest concentrations in Europe, Lombardy is the region with the highest share of biogas plants in Italy (361 at the beginning of 2013, equal to 40% at national level, Peri et al., 2013).

However, as many biogas plants use maize silage, such emerging activity has been accused to increase maize demand with two main consequences: i) pushing up (locally) land rent price and ii) raising its opportunity cost as livestock feed in a region where, before the proliferation of biogas plants, animal production represented about 60% of the value of agricultural production (Cavicchioli, 2009). According to such criticism, in Italy maize area devoted to biogas plants has grown sharply between 2007 (below 0.5% of arable crop mix) and 2012 (10% of arable crop mix), covering more than 18% of arable land in Lombardy (Mela and Canali, 2014). Therefore this competition may put under pressure agri-food supply chain, among which some important Protected Designation of Origin (PDO), such as Grana Padano and Parma ham.

As pointed out by Carrosio (2013), the huge expansion in the number of biogas plants has been mainly driven by dedicated subsidization schemes. In particular the feed-in tariff (FIT) introduced in

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Italy in 2009,[1] has boosted agricultural biogas production between 2009 and 2012 (Fig. 1) shaping the technology adoption by farmers (Chinese et al., 2014). Under such scheme, all plants with an electric capacity up less than 1 MW electric (MWe) were entitled to receive the all-inclusive feed-in tariff of 0.28 €/kWh for 15 years,[2] leading the majority of biogas plants to build a capacity slightly less than 1 MWe in order to maximize subsidies (Carrosio, 2013).[3] Such incentive system has oriented the majority of biogas plants toward the exclusive production of electric energy, rather than cogeneration (production of electricity and heat) even if the latter would be more efficient in terms of biogas utilization (CRPA, 2008; Mela and Canali, 2014).

This consideration is in line with previous studies (e.g. Haas et al., 2011; Britz and Delzeit, 2013) pointing out the distortive effect of subsidization mechanism for renewable energies, like the FITs. this payment scheme assures a higher profitability, associated to a diminished level of risk, charging taxpayers with associated additional costs (Chinese et al., 2014). As a result, the level of public support to renewable energy has been put under discussion (Galeotti, 2012), leading to a new biogas subsidization structure in 2012,[4] more in line to those adopted in other European Countries (Hahn et al., 2010). The new support scheme applied from January 2013 and provides, with respect to previous policy, a payment reduction in absolute terms and new criteria more favourable for smaller plants (see Table 1). Moreover, in order to encourage the utilization of manure and by-products instead of energy crops, the subsidies have been related to the type of feedstock used in the blend (Gaviglio et al., 2014). In the present paper the two different incentive systems described above will be hereafter referred to as *pre* 2013 and *post* 2013 renewable energy policy system.

The evolution of Italian biogas market and incentive policy has been examined in some recent papers.[5] Carrosio (2013) proposed an analysis based on the neo-institutional lens. In particular, he argued that the incentive system associated to technology uncertainty led to a non-competitive market structure, resulting in one prevalent model of biogas production (999 kWe plants fed with a blend of energy crops and livestock manure), with low efficiency in energy use and environmental outcomes. Chinese et al. (2014), used a linear programming approach to study the effect of *pre* 2013 and *post* 2013 Italian biogas incentive systems on plant dimension, input bend and profits. Such a simulation makes assumptions on maize supply, using cultivation and harvesting cost as a proxy for input price. Main results show that the *post* 2013 new regulation would make the system to shift toward smaller plant size, mainly fed by manure, and so reducing the pressure induced by energy crop-based plants.

Building upon and extending existing literature, the aim of this paper is to analyse the impact of biogas production in Lombardy on maize silage demand, price and, in turn, on potential competition with other agri-food supply chains in terms of opportunity cost for maize silage. To do so, we build up a partial equilibrium framework, by explicitly modelling and integrating demand-side biogas industry and supply-side agricultural sector. Using such a modelling framework we perform a comparative-static exercise, deriving market clearing price and quantity for maize silage under *pre* and *post* 2013 support scheme. This integrated model allows then to emphasize the differential effects[6] of alternative energy policies for biogas production on maize silage equilibrium price and, in turn, on the related outcomes, such as energy production, biogas plant profitability and allocation of land devoted to biogas production.

This paper is the first application to the Italian biogas sector of a partial equilibrium framework, firstly developed by Delzeit (2010) and Delzeit et al. (2012) for the German biogas sector. In particular, we applied this method in different areas and under different policy schemes. From this perspective, our contribution to the literature is twofold. Firstly, we can assess the suitability of the proposed methodology when applied to a specific reality. Secondly, from the modelling exercise we can draw important policy implications for the Italian agro-energy subsidization schemes.

Moreover, we add to the existing literature on similar topics in Italy (i.e. Chinese et al., 2014) contributions in terms of *equilibrium displacement effects* under different renewable energy policy options, through: i) the comparison of market clearing price for maize before (actual) and after (simulated) the introduction of biogas sector, and under *pre* and *post* 2013 biogas energy policies; ii) the estimation of differential biogas energy production and profitability; iii) the related differential demand of land for maize silage.

The structure of the paper is the following. Section 2 briefly reviews the relevant literature on bioenergy modelling, describes models used to build up our partial equilibrium framework, and motivates our methodology. Additionally, data and models parameters are described. In Section 3 we illustrate and explain the model results under alternative policy scenarios. Section 4 summarizes the main findings and draw policy implications.

2. Methods

2.1. Modelling framework for biogas production

Agricultural biogas production uses bulky biomass inputs (energy crops, manure and/or by-products), with localized demand and high transportation costs (Delzeit, 2010). This demand, in turn, influence regional markets for bioenergy feedstock (Mertens et al., 2014) and will interact with the market for crops devoted to non-biogas uses. Such “side-effects” call for a comprehensive assessment of all these inter-linked markets. The impact of alternative agricultural and bioenergy policies has been assessed using different approaches like micro-economic and multi-criteria methodology (Rozakis et al., 2013), partial-equilibrium framework (Delzeit et al., 2012), mixed integer linear programming (Chinese, 2014), nonlinear programming (Stürmer et al., 2011), survey information and farm-household mathematical programming (Bartolini and Viaggi, 2012), Positive Mathematical Programming integrated models (Donati et. al, 2013), dynamic mathematical programming (Bartolini et al., 2015), multi-agent modelling approach (Mertens et al., 2014) or using approaches based on geographical information systems (Delzeit et al., 2009a; Fiorese and Guariso, 2010; Sorda et al., 2013).

In the present study, we apply a partial equilibrium model on two areas of Lombardy Region in order to assess the impact of Italian subsidies for biogas production on energy and agricultural markets, using a demand-side biogas industry model and a supply-side agricultural model.

[1] See Law 99/23 July 2009.

[2] With the introduction of the Law 99/23 July 2009, biogas plants up to 999 KWe, were entitled to receive a single payment (feed-in tariff, FIT) of 0.28 €/kWh, ensured for 15 years. The same time span of subsidization was assured to plants bigger than 1 MWe, under the *Green Certificates* system.

[3] According to the Law 99/23 July 2009, FIT, more profitable than the *Green Certificates* incentive mechanism, was available only for plants below the threshold of 1 MWe. Within this category, plants that better maximize the profits were those with capacity slightly less than 1 MWe (999 kWe), more efficient and able to produce more energy compared to smaller plants (e.g. 250 kWe).

[4] Decree of the Ministry of Economic Development of 6 July 2012.

[5] More in general, many studies analyzed the agro-energy sector in Italy from different view point. For example, Donati et al. (2013) investigated the water requirements of energy crops production in Emilia Romagna. Bartolini and Viaggi (2012) and Bartolini et al. (2015) studied how different Common Agricultural Policies (i.e. CAP 2014–2020 reform) affect the adoption of agro-energy production in Emilia Romagna and Tuscany, respectively.

[6] Such simulated differential effects are not free of potential distortions due to assumptions made to render the modelling exercise tractable, as explained in Section 2.2.2.

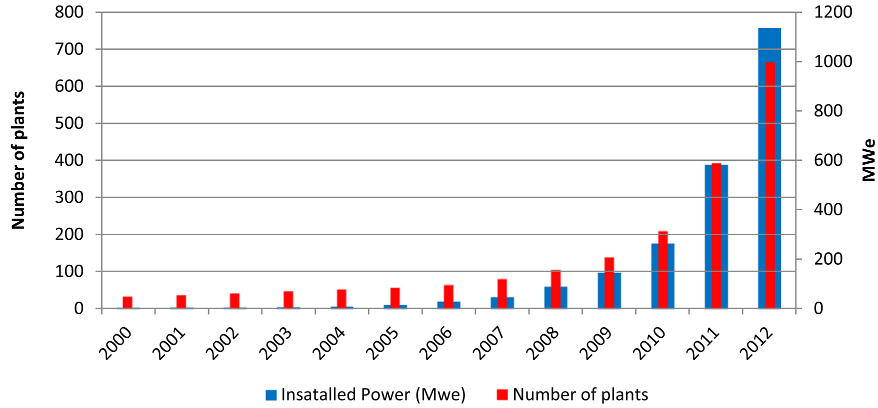

Fig. 1. Number of biogas plants and installed Power in Italy between 2000 and 2012 years. Source: Readapted from Fabbri et al. (2013).

Table 1
Policy changes in agricultural biogas incentive system.Source: Readapted from Chinese et al. (2014).

Policy intervention parameters	*Pre* 2013 policy (Law 99/23 July 2009)	*Post* 2013 policy (Decree 6 July 2012)		
Incentive value	Feed in tariff for plants up 999 kWe (280 €MWh)	**Size class**	**Energy crops (€ MWh)**	**Animal byproducts based (€ MWh)**
	Green Certificate for plants > 1000 kWe (223 € MWh^{-1}; average 2011–13)	1–300 kWe	180	236
		301–600 kWe	160	206
		601–1000 kWe	140	178
		1001–5000 kWe	104	125
Substrate based tariff differentiation	None	Different tariffs depend on the ratio between energy crops and by-products (eg. manure or food industry residues): when lower than 30% the plants receive the incentive for energy crops, otherwise it receives the incentive for energy by-products.		
Time horizons	15 Years	20 Years		

Following the approach proposed by Delzeit (2010) and Delzeit et al. (2012), we firstly applied at the Lombardy context a location model based on linear programming that estimates regional demand for maize silage from biogas production as a function of prices and further explanatory factors such as transport costs and economic profitability of biogas plants (see Section 2.1.1). Secondly, in order to assess the impact of biogas production to the agricultural sector, an arable agricultural supply model is developed. Using the bottom-up approach proposed by Sourie and Rozakis (2001) to investigate the energy crop sector in France, we built an agricultural model in which farmers maximize their welfare under resource and agronomic constraints (see Section 2.1.2). By matching the industrial location model (demand function of maize silage by biogas plants) to the agricultural model (supply of maize silage for biogas plants) we built a partial equilibrium model of maize silage for biogas industry; such a model delivers the market-clearing prices and quantities under different energy policy scenarios, allowing also to estimate the differential demand of land for maize silage in the agricultural sector (see Section 2.2.3).

2.1.1. *The industrial model (ReSI-M)*

The starting point of our analysis is the ReSI-M (Regionalised Location Information System – Maize) model, developed by Delzeit et al. (2009a), (2009b), (2012) and Delzeit (2010) simulating, through an iterative maximization of the Return on investment (ROI), the optimum number of plants established in German regions.

Operational profits $\pi_{c,s}$ for each plant typology s established in the location region c are computed by subtracting the costs for input procurement (biomass) and other costs oc (fixed and variable costs), from plant revenue ($y_s p_s$). The former costs are the sum of transport costs tc and feedstock price w multiplied by the variable input demand x. Formally,

$$\pi_{c,s} = y_s p_s - (tc_{c,s} + w) x_{c,s} - oc_s \tag{1}$$

Input availability (feedstock) in the region affects transport cost tc, and it depends on specific features of nearby agricultural systems like the amount and the distribution of arable land, its biomass yield and the extent of biomass already allocated to biogas production. We compute tc following Delzeit (2010) and Delzeit et al. (2012):

$$tc_{r_1,r_2,t} = \alpha_t + m_{r_1,r_2}\beta_t + \sqrt{\frac{x_t}{\pi e_{r_2} b_{r_2,cur}}}\,\beta_t \tag{2}$$

where α_t represents per unit transport costs of maize within a ray of 1 km around the plant, including maize loading; β_t is per unit cost for each additional kilometer around the plant; m_{r_1,r_2} is inter regional distance between the region where the plant is located (r_2) and the region where feedstock is taken (r_1). The last term as a whole represents intra-regional transport costs, where x_t is maize demand to feed the plant; e_{r_2} and b_{r_2} are, respectively, maize yield and arable land share in the region where the plant is located. After each iteration of the model, the share of arable land is diminished ($b_{r_{2,cur}}$)according to the area devoted to feed each additional plant, raising feedstock transportation costs.

Plant density, typology s and location c is driven by each plant's profitability at input price w, with profitability expressed in terms of ROI:

$$ROI_{c,s(w)} = \frac{\pi_{c,s}}{I_s} \tag{3}$$

where $\pi_{c,s}$ is the yearly operational profit and I_s is the total investment cost.

The plant type-location with the highest ROI is chosen iteratively by the model: in the region with lower transportation costs (and then a higher availability and density of feedstock) is located the first simulated plant. After each model iteration, available biomass input diminishes and additional simulated plants incur in higher transportation costs. The increase of transport costs affect plant operational profits (1) and consequently plant ROI (3), who progressively decrease. The iteration process continues until ROI falls below a predefined interest rate threshold or the input biomass is out of stock.

Given exogenous input prices w, the model yields the optimal input demand d in each region c as an aggregation of each plant demand:

$$d_c(w) = \sum_s n_{c,s}(w) x_s \tag{4}$$

where $n_{c,s}$ is the number of plants in region c and x_s is the input demand of each plant.

The model specifications (key objective function and side conditions, indices, parameters and decision variables) and the ReSI-M flowchart are explained in details in Delzeit et al. (2009b), Delzeit (2010) and Delzeit et al. (2012).

2.1.2. The agricultural model (MAORIE)

This model is an adaptation of the MAORIE model (Modele Agricole de l'Offre Regionale INRA Economie, see Carles et al., 1998) in which the arable crop sector is represented by a sub-model for each farm in the sample and the sub-models are than assembled in a block angular structure with no common constraints.[7] Each farmer f optimizes a profit function (5) that equals the total gross margin from non-energy crops and from energy crops. The gross margin of energy crops is expressed as a function of the crops' price (p_d^j) which is parametrically imposed in multiple runs of the model. Various type of constraints are included, like land availability (6), sugar beet quota (7), agronomic constraints (8) and non-negativity constraints (9). The model therefore simulates farmer choices in terms of crop mix and land allocation (Rozakis et al., 2001; Kazakçi et al., 2007), following a normative perspective where a subgroup of agronomic constraints, namely flexibility constraints, is the means to approach the actual crop mix.[8] Decision variables, indices and parameters are explained more thoroughly in Fig. 2.

Objective function:

$$\max \sum_{f \in F} \sum_{y \in Y} g_{y,f} xf_{y,f}^j + \sum_{f \in F} \sum_{d \in D} (p_d^j \gamma_{d,f}^j - c_{d,f}) xe_{d,f}^j \tag{5}$$

S.t.

Land availability:

$$\sum_{y \in Y} xf_{y,f}^j + \sum_{d \in D} xe_{d,f}^j \le w_f \sigma_f \quad \forall f \in F \tag{6}$$

Sugar-beet quota:

$$x_{1,f}^j \le w_f \sigma_{1,f} \quad \forall f \in F \tag{7}$$

Agronomic constraints:

$$\sum_{y \in Y} i_{y,v} xf_{y,f}^j + \sum_{d \in D} i_{d,v} xe_{d,f}^j \le \pi_v w_f \sigma_f \quad \forall f \in F \ \forall v \in V \tag{8}$$

Non-negativity constraints:

$$xf_{y,f}^j,\ xe_{d,f}^j \ge 0 \forall y \in Y \ \forall d \in D \ \forall f \in F \tag{9}$$

The model outputs the optimal crop mix distributions supplied by farms at each level of the predefined vector of exogenous prices p_d^j. Consequently the produced quantity q_d^j of energy crops for each p_d^j is calculated and a corresponding supply curve can be estimated.

[7] Farms are considered separately: do not share resources among them, so there are no common variables and constraints.

[8] Individual crops or classes of crops, i.e. oilseed crops, respect average historic percentages observed at the regional level. For instance if a highly profitable crop's land share never exceeds 30%, we assume that farmers are bound by soil characteristics or they follow agronomic rules specific to the region.

2.2. Case study for the Lombardy region: data and model characterization

Lombardy is a NUTS 2 region (Nomenclature of Territorial Units for Statistics)[9] with the largest number of biogas plants in Italy. At the beginning of 2013 there were 361 plants, particularly concentrated in two NUTS 3 regions: Brescia (68 biogas plants, with 50 MWe of installed power) and Cremona (137 biogas plants, with 101 MWe of installed power). 73% of Lombardy plants had an installed capacity from 500 kWe to 1000 kWe, 4% above 1000 kWe, 10% between 250 and 500 kWe, and 13% less than 250 kWe. To feed them it is estimated that each year about 3,000,000 t of maize silage, 800,000 t of other energy crops, and 5,000,000 t of manure coming from livestock are used (Peri et al., 2013). The sharp increase of biogas plants in Lombardy began in 2009 (Fig. 1), when maize grain covered 253,741 ha with a production of 2,944,814 t and the area for maize silage was 113,090 ha, producing 6,411,200 t. In 2009 maize (grain and silage) covered 35% of Utilized Agricultural Area (UAA hereafter), mainly used as feed for livestock that represent the main production of Lombardy agriculture, both in terms of heads, compared to national values (48% of swine, 26% of cattle and 24% of poultry heads) and in value: animal productions represented 60% of Lombardy agricultural production value (Cavicchioli, 2009).

Below we describe the data set and assumptions that have been introduced in order to model the biogas industry (feedstock demand) and the agricultural sector (feedstock supply) in Brescia and Cremona, which together hold the 52% of the installed power of Lombardy (Fig. 3).

2.2.1. Demand-side biogas industry model

We set five possible size classes of biogas plants (130, 250, 530, 999 and 2000 kWe) operating in cogeneration (i.e. the combined production of heat and power – CHP) and with different maize and manure shares (see Table 2). Size class segmentation reflects differences in output prices (energy sold by biogas plants) according to the two different subsidization policies compared, i.e. *pre* 2013 and *post* 2013 policies (see Table 1). While under *pre* 2013 policy the only plant size threshold was 1 MWe (all plants below that size were more subsidized, see Section 1, footnote 3 and 4), under *post* 2013 policy the incentive structure is more segmented, according to plant size. Furthermore, also planning horizon used to calculate yearly operational profit in (Eqs. (1) and 3) has been set according to the duration of plant subsidization, as established by each policy (15 years for *pre* 2013 and 20 years for *post* 2013). We apply ReSI-M modelling framework described in 2.1.2. to Brescia (BS) and Cremona (CR) provinces, assuming a vector of exogenous input (maize) prices ($p_{d \in \{\text{maize}\}}^j = \{30 \ldots 70$ €/t$\}$). ROI for each combination of type-location plant is computed in both NUTS 3 regions according to their size and feedstock density.

Concerning the energy crop mix we consider only maize silage, so we have converted the remaining energy crops (approximately 1/4 on the total) in maize equivalent units, based on their energy efficiency (Frascarelli, 2012). Such a simplification has been necessary for a matter of model tractability and may induce a slight overestimation in maize silage demand.[10]

Regarding the demand for maize silage from biogas plants we set 2012 as reference year, the last one before the beginning of the new incentive system and for which detailed data are available mainly as an outcome of a research project funded by Lombardy Region to assess the economic and environmental impact of biogas

[9] NUTS classification can be found at: http://ec.europa.eu/eurostat/ramon/nuts/basicnuts_regions_en.html.

[10] This conversion has been necessary as the version of ReSI-M employed, kindly provided to us from the Authors (Delzeit, 2010; Delzeit et al., 2012), considers exclusively maize silage as energy crop in the blend. See Britz and Delzeit (2013) for an extended version of ReSI-M (ReSI-M2012), in which additional inputs are taken into account by the model.

Indices/Sets

$y \in Y$	non-energy crop index (for sugar beets y = 1)
$d \in D$	energy crop index (|D| = m)
$f \in F$	index for farms
$v \in V$	agronomic constraints index
$j \in J$	index for parametrically imposed prices (only energy crops)

Parameters

$g_{y,f}$	non-energy crop *y* gross margin in farm *f* (€/ha)
$\gamma_{d,f}$	energy crop *d* yield in farm *f* (tons/ha)
$c_{d,f}$	energy crop *d* production cost in farm *f* (€/ha)
p^j_d	vector *j* of energy crop *d* selling price parametrically imposed (€/ton)

Parameters

w_f	coefficient (weight) to report sample farm arable land to the universe of regional arable land
σ_f	farm *f* total arable area (ha)
$\sigma_{1,f}$	maximum amount of land for sugar beet in farm *f* (ha)
π_v	maximum share allowed for crops under agronomic constraint *v*
i_{yv}	agronomic constraints dichotomous coefficient = 0 if non-energy crop *y* is not subject to agronomic constraint *v*; =1 otherwise
i_{dv}	agronomic constraints dichotomous coefficient = 0 if energy crop *y* is not subject to agronomic constraint *v*; =1 otherwise

Decision variables

$xf^j_{y,f}$	non-energy crop *y* area in farm *f* (ha) under a vector of *j* exogenous prices
xe^j_{df}	energy crop *d* area in farm *f* (ha) under a vector *j* of parametrically imposed prices.

Fig. 2. Indices, parameters and decision variables of the agricultural model (MAORIE). Source: readapted from Rozakis et al. (2001).

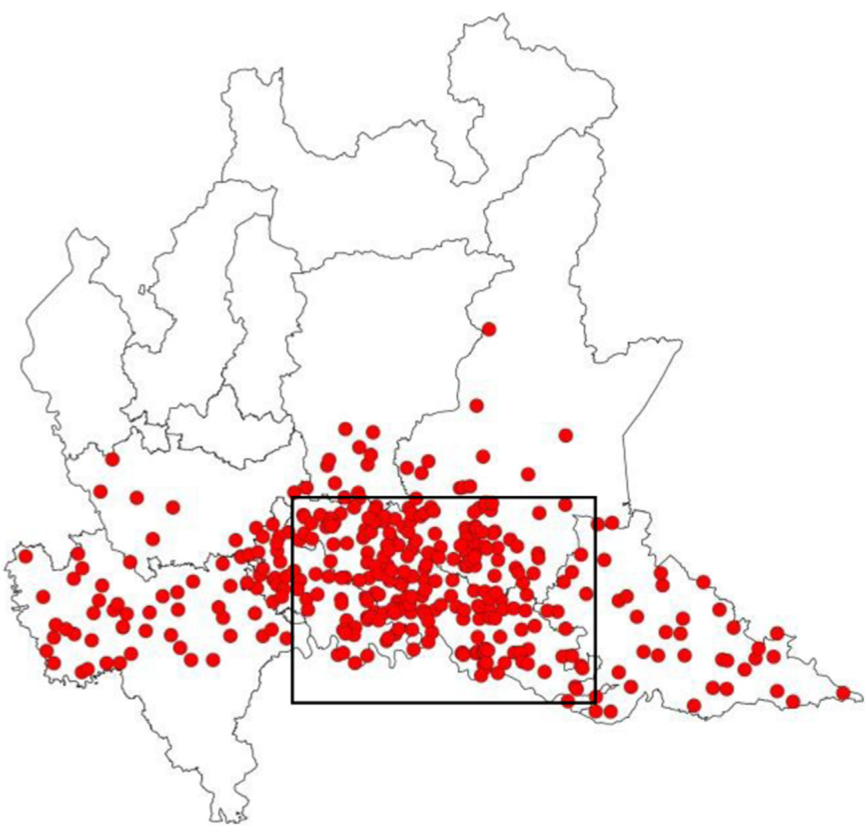

Fig. 3. Biogas plants in Lombardy Region and area under investigation (plain of Brescia and Cremona). Source: Geo-referenced data, readapted from Bertoni (2013).

on agri-food supply chains, hereafter referred as Eco-biogas project (Regione Lombardia, 2013; Fabbri et al., 2013).

As in Delzeit (2010), biogas plants are charged of transportation costs for maize silage. Moreover, even though Brescia and Cremona have high livestock densities, to account for the effects of new policies on plants profitability, also transportation costs for manure are assumed to be paid by biogas plants. Mountain and urbanized areas (as classified by the Italian National Institute of Statistics, ISTAT, 2011) have been considered not suitable for biogas production, as a consequence of both landscape planning laws and low agricultural input availability. Transportation costs for maize have been calculated according to Eq. (2). Parameters of Eq. (2)

Table 2
Feedstock mix of biogas plants for power classes in Lombardy Region (reference year 2012).Source: Authors elaboration on Regione Lombardia (2013) data.

Power (kWe)	Maize Silage (t/year)	Manure (t/year)	Reside (t/year)
130	1000	10,000	10,680
250	4000	12,000	18,162
530	10,000	13,000	17,621
999	18,000	9000	29,708
2000	33,000	24,000	44,760

have been computed using Lombardy data, with the only exception of per unit transportation costs per km for maize and manure (α_t and $\beta_t$in Eq. (2)) that are instead taken from Delzeit (2010), assuming that a similar technology is used in Lombardy to transport maize and manure.[11] As regard the share of arable land on total land ($b_{r2,cur}$) we calculated these values using Italian National Institute of Statistics (ISTAT, 2011) data, that provides land use information at municipal, provincial and regional level. Maize need per plant size (x_t), maize yield (e_{r_2}) and inter-provincial distance (m_{r_1,r_2}) between the province where the plant is located and the province where feedstock is taken are computed using the information and data collected within the Eco-Biogas project (Regione Lombardia, 2013) and the Geographical Information System.

Exogenous data used to determine profits (operating and production costs) for biogas plants are drawn from the literature (Frascarelli, 2012; Ragazzoni, 2011); revenues are computed using plant-gate withdrawal prices for electricity as established by past and the current legislation (*pre* and *post* 2013 polices, see Table 1). Further assumptions on plant efficiency and operating hours per year are also taken from Frascarelli (2012). Data on the amount of manure available for biogas production have been taken from the Decision Support System ValorE[12] (Acutis et al., 2014) and from Regione Lombardia (2013).

2.2.2. Supply-side agricultural model

We apply to Lombardy Region the model described in Section 2.1.2. Only maize silage is considered as energy crop for biogas and its selling price is parametrically imposed within the same vector mentioned in Section 2.2.1 for the industrial model, i.e. $p^j_{d\in\{\text{maize}\}}=\{30\ldots70\ €/t\}$. For all other crops the price is considered constant and in line with the market price observed in Lombardy during 2008.[13]

The model extends the optimal sample quantities and land allocation to the universe of represented farms using appropriate weights (w_f in Eqs. 6–8) taken from RICA weighting system (see below for the description of RICA). Aggregating the outputs of the model we obtain the agricultural supply function for maize silage in Brescia and Cremona.

Data on farm structure, costs and yields come from the RICA dataset. RICA (Rete Italiana di Contabilità Agraria) is the Italian network, managed by INEA (Istituto Nazionale di Economia Agraria, National Institute of Agricultural Economics) that gathers data on structure, production and accountancy from a representative sample of farms in each Italian NUTS 2 region. RICA is the Italian version of the FADN (Farm Accountancy Data Network).[14]

As the sharp growth of biogas plants installation began in 2009 (Fig. 1), we simulated farm supply of maize in the previous year (2008), in order to estimate maize supply function before the increase of silage maize demand from biogas sector. For this reason we have used farm data from 2008, considering such year as a baseline to simulate a reference scenario (see Section 2.3).

Data on farms specialized in Cereals, Oilseeds and Protein crops (Type of Farming 13 according to FADN classification, 29% of the regional sample) and farms specialized in other field crops (Type of Farming 14, 12% of the regional sample) have been extracted from RICA Lombardy sample. The sample is therefore composed by 36 farms for Brescia and 21 for Cremona. Accordingly, the model contains 570 variables (57 farms having, overall, 10 crop processes) and 300 constraints.

The more representative crops included in the farm sample are: maize grain, soft wheat, soya bean, durum wheat, maize silage and alfalfa.

Following Rozakis et al. (2013), parameters used at farm and crop level are: utilized agricultural area (ha), prices (€/t), yield (t/ha) and variable costs (€/ha). The latter includes all costs directly attributable to each specific crop.

On the basis of data from Regione Lombardia (2013) we estimated that livestock farms provides one third of maize silage necessary to feed biogas plants existing in 2012.[15] Maize silage produced in livestock farms is intended exclusively for the livestock feeding[16] and to feed no more than 1/3 of the biogas plants in 2012. This implies that, even if we consider the possibility to build biogas plants also in livestock farms (Type of Faming 41 according to FADN), in our model only farms without livestock can sell maize silage to the biogas plants simulated by ReSI-M. This simplification has been made for a matter of model tractability and implies that the simulated agricultural supply function may be potentially distorted by taking out the livestock sector from the modelling exercise. In so doing we do not allow for direct competition between livestock and biogas activity for maize silage, that, in turn, may led to underestimation or overestimation of supply functions, depending on the relative profitability of these activities. However, on one hand, we cannot quantify the extent of such potential distortion and, on the other hand (as better clarified in Sections 2.3 and 3), the impact of such limitation may be mitigated considering that the main interest of our simulation is in the *differential* effect of alternative subsidization polices.

2.2.3. The integrated model

Maize silage market for biogas production is simulated integrating the two model described in Sections 2.2.1 and 2.2.2 with a partial equilibrium approach.

Assuming a vector of all possible maize prices ($p_{maize}=\{30\ldots70\ €/t\}$) we derive, from the industrial model, the maize demand curve originating from biogas production and, from the agricultural model, the corresponding maize supply curve. Intersecting the two curves the equilibrium and the relative market clearing prices and quantities are obtained. An overview on the underlying logic of this partial equilibrium approach is provided in Fig. 4.

[11] We found similar technological assumptions and average values compatible with those adopted in our case study (Ragazzoni, 2011). Moreover, we have tested the sensitivity of our results, against a ±10% change in per unit transportation costs per km for maize and manure without finding any significant variation in model results.

[12] The Decision Support System ValorE is the outcome of a research project funded by Regione Lombardia. It is accessible, upon registration, at the following website (in Italian):
http://www.sistemaespertonitratilombardia.it/Default.aspx

[13] Average values obtained from data of Camere di Commercio, Industria, Artigianato e Agricoltura della Lombardia (Lombardy Chambers of Commerce, Industry, Agriculture and Handicraft).

[14] Further information on FADN are available at: http://ec.europa.eu/agriculture/rica/

[15] Such assumption is based on survey results from Eco-biogas project (Regione Lombardia, 2013).

[16] Such assumption is supported by actual data (Pieri and Pretolani, 2009;2013), according to which livestock heads did not change between 2008 and 2012, in spite of changes in maize silage price.

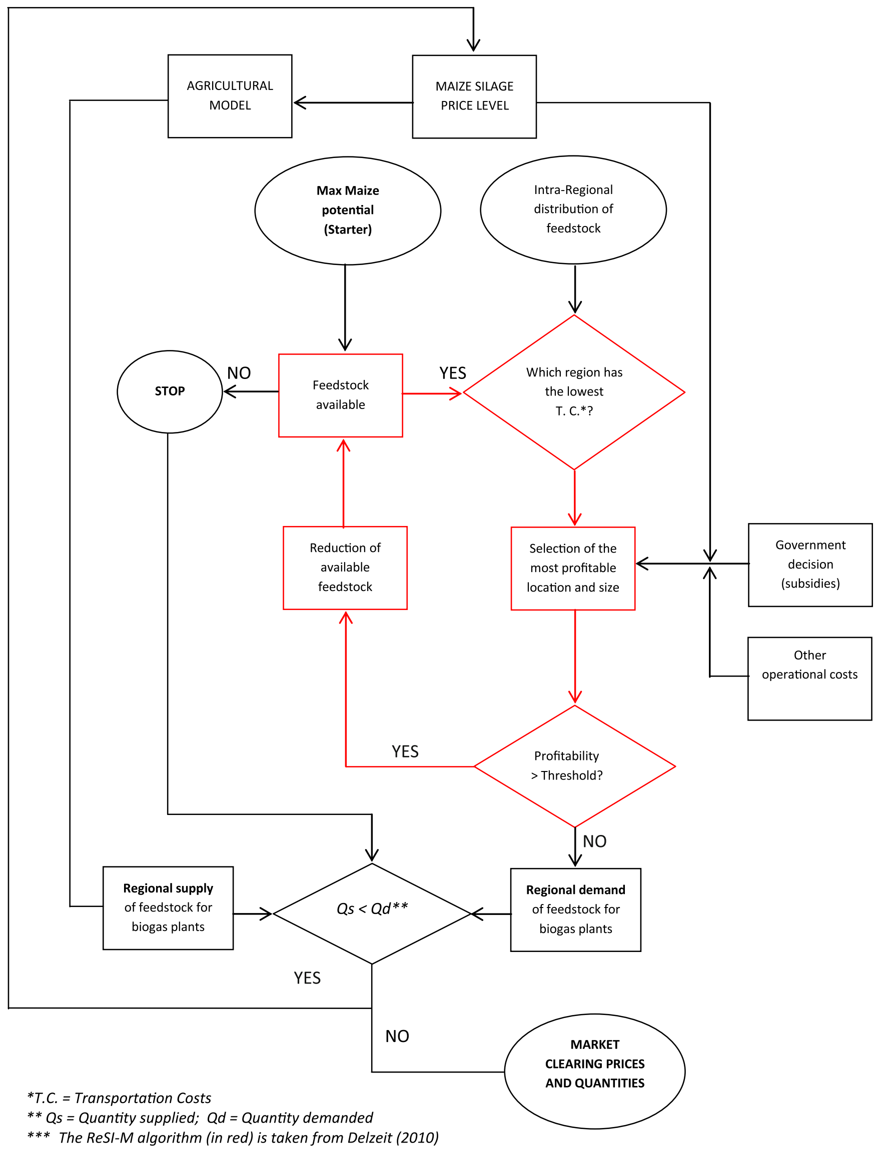

Fig. 4. Multi level model flowchart*** **T. C.=Transportation Costs,* ** *Qs=Quantity supplied; Qd=Quantity demanded,* *** The ReSI-M algorithm (in red) is taken from Delzeit (2010). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2.3. Policy scenarios

As mentioned at the end of the introduction, the multiple impacts of biogas sector are estimated using a partial equilibrium displacement approach simulating the maize silage market for biogas. In this framework, changes in biogas energy policy (*pre* and *post* 2013) have a direct impact on the demand-side biogas industry model, that is transmitted forward (changing the amount of energy supplied) and backward, shifting the demand for maize silage. Such shift displaces the market equilibrium, changing market-clearing quantity and price of maize silage for biogas production. Any change in market clearing price of maize silage has a double impact on the agricultural sector: firstly it changes, backward, the optimal land allocation in the supply-side agricultural model, and secondly, it rises or decreases the opportunity cost of maize silage for livestock farms. The differential price of maize silage (driven by the change in biogas policies) may indeed translate into a change of opportunity cost for livestock feed. Hence, although our model is not capable to assess the impact of biogas policies on livestock sector, it may however highlight possible effects in terms of opportunity cost for livestock feed, still useful for a qualitative analysis of these (not modelled) effects.

We introduced three scenarios to better explain such multiple impacts of biogas production under different policy incentive schemes (*pre* and *post* 2013 policies):

- Scenario_0: *reference scenario*. It simulates the crop supply (and land allocation) in 2008, thus before the biogas industry take off. In Scenario_0 crop supply is simulated by ignoring the effect of regional maize demand for biogas and assuming average (2008) market prices for maize silage (30 €/t) and for other crops as an exogenous variable. The agricultural supply model is then calibrated and validated under the conditions of this Scenario, while the demand-side biogas sector is not introduced. The iteration process produces the optimum allocation of land in each farm modelled in the agricultural model. From such optimal crop mix, the area allocated to maize silage is extended to the universe of farms represented in the sample (Type of Farming 13 and 14) using appropriate weights (see Section 2.2.2). Such reporting to the universe yields the simulated hectares of maize silage potentially available for biogas production in each area under investigation and, in turn, the simulated amount (t) of maize silage potentially available for biogas production. This scenario is the baseline used to measure the *change in demand for land for maize silage* induced by the biogas industry.

- Scenario_1: in this scenario we simulate maize silage market, from 2013 onward, under the old incentive system (*pre* 2013 policy) accounting for the maize demand from plants surveyed at the end of 2012. Such amount represents the intercept at the upper side on the quantity axis (see "unavailable maize" in Fig. 6) in the estimated demand function. This makes the demand function to shift on the right, incorporating the effect of existing (at the end of 2012) plants on market clearing price. Plants are constructed with a planning horizon of 15 years (see Table 1). Farm supply and biogas industry demand are derived assuming different exogenous prices (from 30 € to 70 €) for maize silage.
- Scenario_2: in this scenario we simulate silage maize market, from 2013 onward, under the new incentive system (*post* 2013 policy), still accounting for the maize demand from plants surveyed at the end of 2012 (and therefore incorporating this effect on market clearing price estimation as in Scenario_1), but, assuming that biogas plants receive FITs according to the new *post* 2013 policy framework. Plants are constructed with a planning horizon of 20 years (see Table 1). Farm supply and biogas industry demand are derived assuming different exogenous prices (from 30 € to 70 €) for maize silage.

From market clearing quantities obtained in Scenario 1 and 2, we derive backward the optimal amount of land required for maize and downward the future installable power (see Tables 5 and 6). Note moreover that: i) the demand function change, in Scenario 1 and 2, as a consequence of different biogas subsidization policies; ii) the missing inclusion of livestock sector described in Section 2.2.2 affects only the supply function, which does not change across the two Scenarios. Since the estimated maize silage price in each scenario derives from the match between supply and demand functions, its value may be distorted in absolute terms. However, the *change* in estimated maize silage price (that mediates the *differential effect* of biogas policies) may be considered non-distorted. Therefore the comparison between outcomes from Scenario_1 and Scenario_2 allows to quantify the various differential effects of alternative subsidization policies, so that potential supply distortions mentioned in Section 2.2.2 appear mitigated.

Finally, the difference in the reference year between the agricultural and the industrial model can be matched inside both scenarios considering that the phenomenon we wish to investigate (the differential impact of biogas policy) has a direct effect only on the demand side, leaving unchanged the supply side. As a result, the market clearing price changes as a consequence of demand change, while the supply function is unchanged under the two scenarios (see Figs. 6 and 7).

2.4. Models validation

To verify whether and to what extent the industrial model fits the biogas production in Lombardy, we set the same policy framework under which plants existing in 2012 were built, namely the *pre* 2013 policy framework, and we fixed the maximum amount of available maize equal to the share of maize silage already used by these plants. Since 2012 biogas plants consumed about 800,000 t/year of maize silage in Brescia and 1,870,000 t/year in Cremona (Regione Lombardia, 2013), this is therefore the maximum amount of maize silage that we made available to the model in this first simulation. Fig. 5 compares the reported shares of installed power in Brescia and Cremona with the simulated shares from the modelling exercise. As we can see, the model fits quite well the actual situation. The difference of −7 MW observed in Brescia is due to the exclusion from the simulation of some medium and small plants, using mainly manure and then not affecting silage maize market.

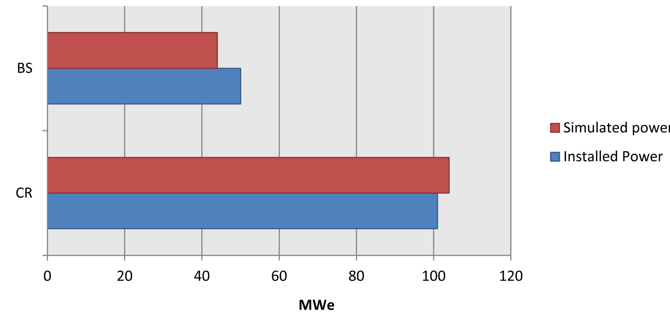

Fig. 5. Comparison between observed (installed) and simulated power (MWe) of biogas plants in Brescia (BS) and Cremona (CR). Reference year 2012. Source: Authors elaboration on results of ReSI-M model.

Acting as a profit maximization model, ReSI-M chooses the plant typology that maximizes ROI (999 kWe, more efficient but using more maize). Consequently, with the same quantity of maize silage, the simulation yields 43 MWe of installed power, against 50 MWe actually installed.

Differences between the two scenarios are smaller in Cremona than in Brescia as the former area shows less plant heterogeneity, with an average power closer to the plant class simulated by the model. It should be noted that the class of plants simulated by the model reflects well the real observed trend resulting from the *pre* 2013 policy (73% of Lombardy plants had an energy capacity between 500 kWe and 1000 kWe).

To test the agricultural model's ability to reproduce farmers' behaviour, we compare simulated and observed crops pattern. As explained above, for a matter of model calibration, we have chosen 2008 as reference year. Model validation has then been carried out by comparing optimal crop mix from Linear Programming (LP) supply model with the observed ones (2008). The LP supply model allocates, for each crop ($k=y \cup d$) the level of arable land (ha) that maximize farm gross margin x_k^{opt} to be compared with the observed land allocation level x_k^{obs} for the same crop. Such values are compared computing the Absolute Deviations (AD)[17] of the predicted values from the observed values and then calculating Total Weighted Absolute Deviation (TWD)[18] in order to have a global index of the representativeness of the model.

Absolute deviations between observed and predicted land allocation shown in Table 3, fit well the most representative crops and, consequently, the total weighted deviation is limited (below 22%) and in line with the values found in the literature for MAORIE type models (Kazakçi et al., 2007; Rozakis et al., 2012).

The high level of AD for maize silage is due to under-representation of such crop in the sample as sample farms are specialized mainly in cereals and other arable crops to be sold on the market. However, if we consider the summation of grain ad silage maize areas simulated by the model, we observe lower AD values since the model fits better the total maize area. Such summation it is appropriate as, at farm level, silage and grain maize surfaces are interchangeable: farmers are free to decide during the year whether to produce silage or grain maize according to the time of harvest and the expected market prices of

[17] $AD\left(x_k^{obs}, x_k^{opt}\right)=\left|\frac{x_k^{opt}-x_k^{obs}}{x_k^{obs}}\right|.$

[18] $TWD\left(x^{opt}\right)=\frac{\Sigma_k\left(\left|\frac{x_k^{opt}-x_k^{obs}}{x_k^{obs}}\right| * \frac{x_k^{obs}}{\Sigma_k x_k^{obs}}\right)}{\Sigma_k\left(\frac{x_k^{obs}}{\Sigma_k x_k^{obs}}\right)}.$

the two products. Therefore the agriculture supply model fits farmers' behaviour concerning land allocation for crops of interest for the present analysis. Optimal land allocation presented in Table 3 is referred to the sample; the model extends such results to the universe of farms represented in such sample (see Section 2.2.2) in Brescia e Cremona, yielding the maize silage production from which are computed the hectares potentially available for biogas production (see Table 4).

3. Results and discussion

The three above mentioned scenarios allow to estimate, with a partial equilibrium approach, maize silage demand and supply for biogas production without biogas subsidization policies and under two different energy policy schemes. Scenario_1 and _2 yield, for Brescia and Cremona, market clearing quantities and prices, energy production and the amount of land allocated for maize silage production. Consequently, a comparison between the two scenarios allows to quantify the impact of changing energy policy on the above mentioned outcome variables (installed power, prices, quantities and land allocation for maize silage). The impact on agricultural sector and agri-food supply chains is measured in terms of change in maize silage price, affecting the opportunity cost of maize silage for livestock farms, and in terms of changing demand of land for its cultivation.

In Scenario_0, the simulated hectares of maize silage potentially available for biogas production (assuming an exogenous price of 30 €/t equal to the average market price for the maize silage in 2008) is equal to zero in Brescia and quite low (1738 ha, 1.29% of total UAA) in Cremona (Table 4).

In estimating maize silage demand in Scenario_1 and _2 we have accounted for the amount of maize unavailable as already used by plants built till 2012 (529,952 t in Brescia and 1,248,266 t in Cremona,[19] see Tables 5 and 6). Furthermore we have bounded the demand of maize silage to the maximum amount that can be produced in each area (equal to total UAA for farms with Type of Farming 13 and 14) corresponding to 2,726,141 t in Brescia and 1,870,549 t in Cremona (see Tables 5 and 6). Maize silage demand is therefore estimated under such upper and lower bounds (see Figs. 6 and 7).

Fig. 6 shows the market equilibrium between estimated supply (MAORIE) and demand (ReSI-M) in Scenario_1 that yields market clearing prices and quantities, along with consequent relevant outcomes shown in Table 5. Up to 55–60 €/t, the demand is totally inelastic in both provinces, this means that, for prices lower than 55 €/t, the model is limited by maize silage unavailability, rather than by loss of plants profitability due to increase in maize silage price and transportation costs. Indeed, the maximum amount available is used as feedstock for biogas production. As compared to actual maize silage price in 2012 (36.9 €/t),[20] pre 2013 policies would make it to rise to 57 €/t in Brescia (+56%) and 60 €/t in Cremona (+64%). As silage and grain maize prices are strongly interlinked, such sharp increase would raise feed costs in livestock farms (in particular those specialized in cows and pigs). The amounts of land required to produce market clearing quantities of maize silage are 44,793 ha (25.6% of UAA) in Brescia and 30,421 ha of maize (22.6% of UAA) in Cremona, inducing a strong change in demand for maize silage as compared to Scenario_0. The same effects of this subsidization policy scheme is observed by Carrosio (2013), who argue that on local agricultural market the price for land and row materials can be significantly affected by biogas production.

In line with the trend observed until 2012, simulated plants are big sized (999 kWe).[21] In addition to the already installed (2012) power (101 MWe in Cremona and 50 MWe in Brescia), the new installable capacity amounts to 32 MWe in Cremona and to 120 MWe in Brescia (see Table 5).

In Scenario_2 we introduced the new renewable energy policy system (policy *post* 2013). Thus we repeat the Scenario_1, replacing the old policy framework with the new one. Table 6 reports main outcomes under Scenario_2 assumptions.

By assigning a higher premium per kWh produced, the new incentive system is intended to reward smaller plants (lower than 300 kWe), whose input has an energy crops/manure ratio significantly lower, with respect to bigger plants (see Table 2). Accordingly, the equilibrium price of maize silage decreases significantly in both areas in comparison with Scenario_1: 38 €/t in Brescia and 42 €/t in Cremona (see Fig. 7), to levels closer to actual price in 2012 (36.9 €/t) and in line with the actual maize silage market price in Lombardy (ca. 40 €/t in 2014).[22] As show in Table 6, land required to produce market clearing quantities of maize silage amounts to 14,299 ha (8.18% of UAA) in Brescia and 26,500 ha (19.67% of UAA) in Cremona, far lower with respect to Scenario_1 (see Table 7). The impact of biogas production on land allocated to maize silage is therefore mitigated under the new incentive system with respect to the old one.

The simulated (new) plants are smaller (130 kWe) and the demand for maize silage (used maize[23]) decreases, compared to Scenario_1, from 2,157,623 to 327,963 t (−1,829,660 t, −85%) in Brescia and from 577,017 to 341,739 t (−235,278 t, −41%) in Cremona.[24] The smaller quantity decrease in Cremona is due to the large amount of maize silage already used to feed plants built until 2012 that is made unavailable for new plants; such constraint is far smaller in Brescia. Moreover, under Scenario_2, the increase of biogas plants is not limited by maize availability but by the loss of profitability due to incentives reduction. This is due to the lower quantity of maize silage needed for small plants to operate (1000 t/years rather than 18,000 of 999 kWe) given their lower ratio between used maize and installable power (Tables 5 and 6). Consequently, 43 MWe in Brescia (compared to 120 MWe of Scenario_1) and 44 MWe in Cremona (compared to 32 MWe of Scenario_1). The new incentive system would consequently decrease the pressure on agri-food supply chains by diminishing both the demand of land for energy crops, along with a substitution of maize silage with other crops in the supply model, and reducing the (opportunity) feed costs for livestock farms (by lowering maize silage prices). At first glance these results seem divergent with respect those of Delzeit (2010) and Britz and Delzeit (2013), who found higher competition for maize in regions with high availability of manure. These Authors explained such outcomes correlating availability of manure and maize. On one hand, the lack of manure can limit biogas production, but, on the other hand, in regions with a large amount of manure, maize can became scarce

[19] These values derive from the assumption that livestock farms provide 1/3 of maize silage required to feed plants built until 2012 (overall 794.928 t in Brescia and 1.872.400 in Cremona). Such amounts have been consequently reduced by 1/3 according to the above mentioned assumption.

[20] Average values obtained from data of Camere di Commercio, Industria, Artigianato e Agricoltura della Lombardia (Lombardy Chambers of Commerce, Industry, Agriculture and Handicraft).

[21] Also in this case a similar result can be found in Carrosio (2013), who identified the correlation between the past biogas incentive system and the establishment of a dominant (unsustainable) biogas organizational model.

[22] Average values obtained from data of Camere di Commercio, Industria, Artigianato e Agricoltura della Lombardia (Lombardy Chambers of Commerce, Industry, Agriculture and Handicraft).

[23] As explained above, used maize is computed by subtracting unavailable maize for plants built until 2012 from market clearing quantities.

[24] A similar result of the application of the new incentive system is also confirmed in the case study of Friuli-Venezia-Giulia Region (see Chinese et al., 2014).

Table 3
Comparison between actual crop mix and optimal crop mix in Cremona (CR) and Brescia (BS) using RICA sample data.Source: Authors elaboration on RICA data and results of agricultural model described in Section 2.2.2.

	Observed crop mix in CR (ha)	LP Optimal crop mix in CR (ha)	CR Absolute deviation	Observed crop mix in BS (ha)	LP Optimal crop mix in BS (ha)	BS Absolute deviation
Maize (grain and silage maize)	568.41	651.14	0.146	383.84	382.66	0.003
Grain maize	559.41	596.54	0.066	375.26	382.66	0.020
Silage maize	9.00	54.60	5.067	8.58	0.00	1.000
Soft wheat	171.70	189.44	0.103	51.09	51.09	0.000
Other grain legumes	62.92	43.07	0.316	–	–	–
Soybean	62.69	0.00	1.000	2.56	0.00	1.000
Tomato	17.88	17.88	0.000	–	–	–
Lettuce	17.79	17.79	0.000	–	–	–
Sugar beet	15.14	7.29	0.518	–	–	–
Mellon	14.29	17.15	0.200	–	–	–
Durum wheat	10.71	10.51	0.019	–	–	–
Watermelon	10.38	10.38	0.000	–	–	–
Sunflower	7.21	0.00	1.000	–	–	–
Grassland	2.97	0.00	1.000	18.42	0.00	1.000
Alfalfa	1.96	0.00	1.000	29.48	53.10	0.801
Savoy cabbage	1.34	1.34	0.000	–	–	–
Other forage crops	1.25	1.25	0.000	–	–	–
Potato	1.00	1.00	0.000	–	–	–
Herbage of gramineae	0.59	0.00	1.000	35.7	55.32	0.550
Barley	–	–	–	21.08	0.00	1.000
Total weighted abs. dev.			**0.213**			**0.187**

Table 4
Scenario_0: simulated hectares of maize silage potentially available for biogas production and their incidence on Utilized Agricultural Area (UAA) under the average market price of 2008 (before the growth of biogas plants).Source: Authors elaboration on ISTAT data and results of agricultural model described in Section 2.2.2.

	Brescia	Cremona
Simulated hectares of maize potentially available for biogas production	0	1738
Simulated amount of maize potentially available for biogas production in TF 13–14 (t) assuming an average yield of 60 t/ha	0	104,316
Total UAA (ha)	174,784	134,660
Share of land required for maize (% Total UAA)	0	1.29

Table 5
Scenario_1: Estimated market clearing prices and quantities of maize silage under *pre 2013 policy*; main outcome of the model are in bold.Source: Authors elaboration on results of partial equilibrium model described in Section 2.

	Brescia	Cremona
Average actual maize silage price in Lombardy in 2012 (€/t)	36.9	36.9
Market clearing price (€/t)	**57.6**	**60.6**
Increase in market price compared to 2012 (%)	*56*	*64*
Market clearing quantities (t) (A)	**2,687,584**	**1,825,283**
Unavailable maize (tons used to feed plants at 2012) (B)	529,952	1,248,266
Maximum amount of maize (100% UAA TF 13–14, tons)	2,726,141	1,870,549
Used maize (tons need to feed simulated plants) (A–B)	2,157,623	577,017
Increase in maize demand: Used/Unavailable (%)	*407*	*46*
Land required for maize (ha)	**44,793**	**30,421**
Share of land required for maize (% Total UAA)	25.62	22.59
Installed Power until 2012 (MWe)	50	101
Future installable Power (MWe)	**120**	**32**
Total Power (Current + installable Power, MWe)	170	133
Increase in power: Installable/installed until 2012 (%)	*240*	*32*
Used maize/Installable Power (t/MWe)	17,980	18,032

Table 6
Scenario_2: Estimated market clearing prices and quantities of maize silage under *post 2013 policy*; main outcome of the model are in bold.Source: Authors elaboration on results of partial equilibrium model described in Section 2.

	Brescia	Cremona
Average actual maize silage price in Lombardy in 2012 (€/t)	36.9	36.9
Market clearing price (€/t)	**37.9**	**42.0**
Increase in market price compared to 2012 (%)	*3*	*14*
Market clearing quantities (t) (A)	**857,915**	**1,590,005**
Unavailable maize (tons used to feed plants at 2012) (B)	529,952	1,248,266
Maximum amount of maize (100% UAA TF 13–14, tons)	2,726,141	1,870,549
Used maize (tons need to feed simulated plants) (A–B)	327,963	341,739
Increase in maize demand: Used/Unavailable (%)	*62*	*27*
Land required for maize (ha)	**14,299**	**26,500**
Share of land required for maize (% Total UAA)	8.18	19.67
Installed Power until 2012 (MWe)	50	101
Future installable Power (MWe)	**43**	**44**
Total Power (Current + installable Power, MWe)	93	145
Increase in power: Installable/installed until 2012 (%)	*86*	*44*
Used maize/Installable Power (t/MWe)	7627	7767

and consequently its market clearing price increases. Manure availability is therefore an important factor, to take carefully into account. In the present analysis, we can explain the decreasing maize demand under Scenario_2 focusing on tree different parameters: i) regional manure density and availability; ii) the related regional transportation cost for manure[25]; and, iii) the manure demand of simulated plants. Considering the higher amount of manure necessary to feed 130 kWe plants, during the iteration process manure transportation costs increase rapidly, causing loss of profitability for further plants. This effect, combined with subsidies reduction due to the new policy system, shortly pushes the plants' profitability towards zero, limiting the number of simulated plants. This explains the lower maize demand in comparison with Scenario_1. Notwithstanding, also if we do not consider transportation costs for manure, the high amount of manure needed to feed 130 kWe plants, runs out quickly the available manure during the iteration process in both regions, limiting in any case the effects on maize demand and on its market

[25] As explained in Section 2.2.1, we consider also transportation cost for manure in order to emphasize the effects of new policy on plants' profitability.

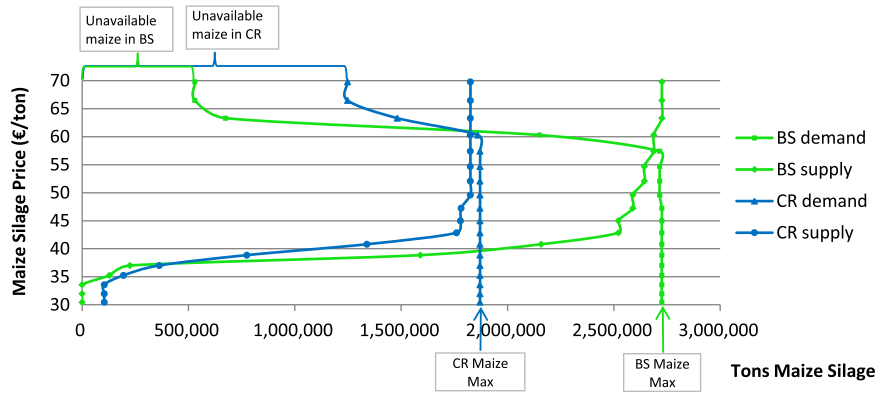

Fig. 6. Scenario_1: Estimated market clearing prices and quantities in Brescia (BS) and Cremona (CR). Source: Authors elaboration on results of partial equilibrium model described in Section 2.

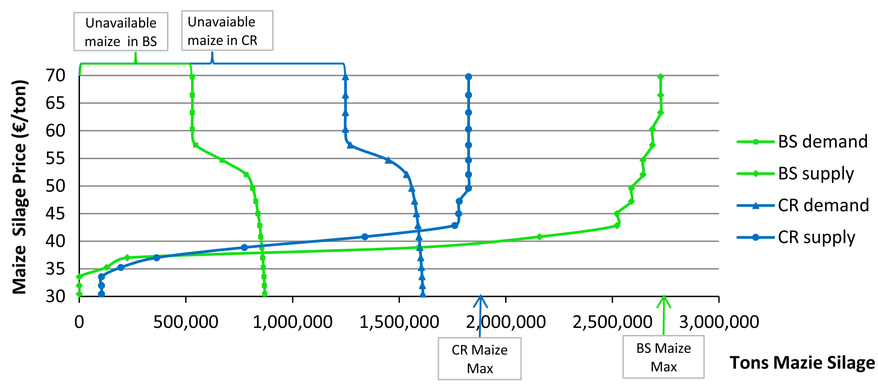

Fig. 7. Scenario_2: Estimated market clearing prices and quantities in Brescia (BS) and Cremona (CR). Source: Authors elaboration on results of partial equilibrium model described in Section 2.

clearing price. The above observation along with the comparison between the different shape of each demand function between Scenario_1 and Scenario_2, makes plausible that market clearing prices and quantities would be ever higher in the former than in the latter. This difference would be reflected in terms of opportunity cost for maize silage, highlighting, therefore, lower potential competition (in Scenario_2 than in Scenario_1) between biogas and livestock sector for maize silage allocation. To conclude the analysis regarding the shift in feedstock mix between simulated plants under pre and post 2013 policy framework, it is also useful distinguish between the energy content and the mass content of maize and manure present in the blend of simulated plants. As show in Table 2, the 999 kWe plants simulated under the pre 2013 policy framework, have a maize manure ratio 2: 1 (18,000 t/years of maize vs. 9000 t/years of manure). In mass terms maize is the 66.6%, but its contribution as feedstock energy is 95%, reflecting the higher energy content of maize. This pattern is still present under Scenario_2, in which 130 kWe plants are fostered. Despite a 1:10 maize manure ratio (1000 t/years of maize vs. 10,000 t/years of manure) and a mass content in manure raised to more than 90%, the share of energy from maize silage stands close to 50%, highlighting the strong link between this crop and biogas production.

Finally, we can compare the effect of *pre* and *post* 2013 energy policies on the Return on Investments (ROI) of simulated plants, under different e maize silage prices (Fig. 8). In particular, we report the ROI of the first plant simulated by the model (under old and new policy) for each level of maize price exogenously imposed (p_{maize}={30…70 €/t}). The trend shown in Cremona is similar to those in Brescia. Note that, all simulated plants after the first, have decreasing ROI because of increasing transportation costs (see Section 2.1.1).

Plant size having the greater ROI under Scenario_1 is 999 kWe, while under Scenario_2 is 130 kWe. As shown in Fig. 8, with the pre 2013 policy regime the plants simulated by the model have significantly higher ROI than those simulated under the *post* 2013 policy regime. Such difference in ROI decrease as maize prices increase. Under the old incentive system the maize price threshold that sets at zero the ROI is 63 €/t; the introduction of the new incentive system fosters small plants (130 kWe), which, despite using less maize, shutdown when the price of maize exceeds 55 €/t.

4. Conclusions and policy implications

This paper studies the effects of two alternative energy policies schemes for biogas subsidization on the market equilibrium of the maize silage, as main energy crop in Lombardy. We adopted a partial equilibrium approach, simulating agricultural supply and biogas demand of maize silage for biogas production under two alternative policy scenarios. In so doing we measured, on one side, the effects of biogas introduction and, on the other, the consequences of different biogas subsidization systems. Such a comparative static exercise allows indeed to compare and to evaluate the two different biogas subsidization policies analyzed in the present article, in terms of main market outcomes. The change in policy option displaces simulated market equilibria, yielding different prices and quantities of maize silage devoted for biogas production, from which, in turn, we derive the related demand of land for maize silage and biogas installable power. According to the evidence of the present work, the old biogas subsidization system (*pre* 2013 policy), based on the feed-in tariff, would foster investments in bigger plants (e.g. 999 kWe) assuring higher profitability that would lead to an increase in demand for maize silage, with consequent negative effects on its (rising) price. Therefore, if the incentive policies had remained unchanged, in areas where the density of plants is remarkably high, a significant competition could have occurred between the biogas sector and agri-food supply chains (cow and pork meat and milk sectors) even in the short run.

In comparison with the above mentioned policy option, the new incentive system (*post* 2013 policy), simulates different market conditions, which allow the adoption of smaller plants (e.g.130 kWe), and a lower maize slurry ratio. As a result, the maize demand from the biogas sector should significantly decrease, relaxing the pressure on the demand of land for maize silage. We observe, therefore, an important first effect due to the introduction of the new incentive policies: the distribution of biogas plants is strongly linked to the availability of manure; from a hypothetical situation of competition, the system moves to a situation of complementarity between the biogas sector and regional meat and milk sectors.

The lower ROI of biogas plants under new policies should however contain the installed capacity in the future as the profit margins, achievable under the current regulatory framework, are significantly lower than those made with the past system of incentives. Moreover, the plants' profitability is more sensitive to the increase of the maize price compared to the past incentive system. It is therefore an obvious choice to exploit the manure and by-products, a key condition for the containment of plants operating costs. The likely effects of new incentive system are twofold. On one hand it may discourage further investments on biogas sector, but, on the other, it would reduce distortive effects on the maize market related to agri-food supply chains. Such conclusion may indicate a possible way to use incentive systems to mitigate competition between agricultural sector and bioenergy production, also in areas out of the present case study.

Results and policy implications of the present work should be considered taking into account some limitations of the underlying modelling framework. First of all, to make tractable the partial equilibrium model, we have excluded livestock farms from the supply side sample, under plausible assumptions (i.e. livestock farms providing 1/3 of maize silage used to feed plants built until 2012). Such a simplification limits all the analysis on the demand of land for biogas crops to the universe of farms represented in the sample (those specialized in arable crops: Type of Farming 13 and 14 according to FADN classification). Furthermore, excluding livestock farms from the modelling exercise does not allow a direct competition between biogas and animal feed for maize silage allocation. Therefore, the competition between biogas and livestock sector is investigated exclusively in terms of differential opportunity costs for maize silage under the two different energy policies schemes tested in the present article. A future potential extension would require to model explicitly also the behaviour of livestock farms by including them in the agricultural model. This shortcoming may be overcome by Positive Mathematical Programming (PMP) to better represent unobserved preferences of farmers, as in recent papers on energy crops modelling (Donati et al., 2013). Another interesting extension to overcome the aforementioned limitations concerns the improvement of the spatial accuracy of the model and its integration with an Agent Based Modelling approach. The spatial dimension is indeed highly relevant because of the important role of feedstock transportation cost on the demand side and because the establishment of one biogas plant might change the investment opportunities for other farmers in the surrounding area. Finally, further developments should also pertain the quantification of Direct Land Use Change (D-LUC) that occurs on crop mix distribution at the equilibrium price. For a more accurate quantification of such changes, the supply model should account explicitly for crop mix allocation constraints established by the new Common Agricultural Policy (2014–2020) in

Table 7.
Comparison between scenarios 1–2 in terms of market clearing price, installed power and land use change in Brescia (BS) and Cremona (CR).Source: Authors elaboration on results of partial equilibrium model described in Section 2.

	BS/S1	BS/S2	**BS diff. (S1 – S2)**	CR/S1	CR/S2	**CR diff. (S1 – S2)**
Market clearing price (€/t)	57.6	37.9	– **19.7**	60.6	42.0	– **18.6**
Market clearing quantities (t)	2,687,584	857,915	– **1,829,669**	1,825,283	1,590,005	– **235,278**
Total Installed Power (MWe)	170	93	– **77**	133	145	+ **12**
Land required for maize (ha)	44,793	14,299	– **30,494**	30,421	26,500	– **3921**
Share of land for maize (% Total UAA)	25.62	8.18	– **17.44**	22.59	19.67	– **2.92**

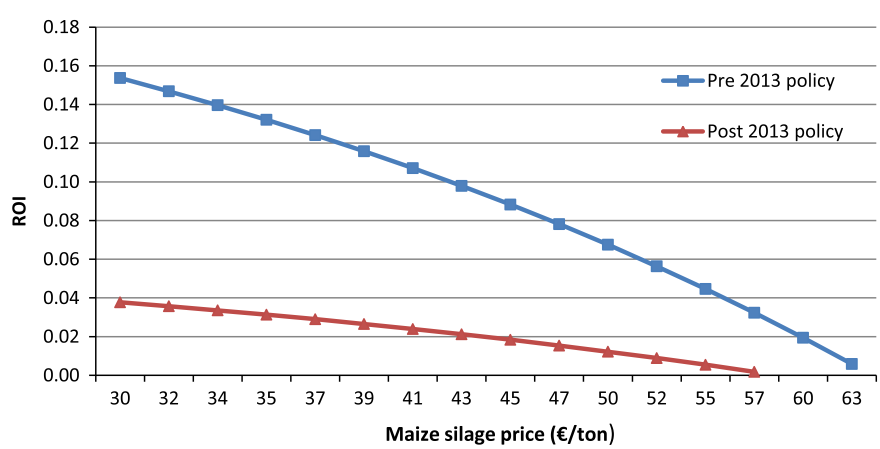

Fig. 8. Return on Investment for the first plant (s1 interaction) built in Cremona as a function of maize silage price (€/t): comparison between *pre* 2013 – Scenario_1 – and *post* 2013 – Scenario_2 – policies. Source: Authors elaboration on results of partial equilibrium model described in Section 2.

particular by the so called "greening" [26] that bounds first pillar payments to permanent pastures maintenance, crop diversification and a certain share of farmland devoted to ecological focus areas (EFA). In so doing we shall overcome another potential limitation of the current version of the agricultural model.

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References

Acutis, M., Alfieri, L., Giussani, A., Provolo, G., Di Guardo, A., Colombini, S., Bertoncini, G., Castelnuovo, M., Sali, G., Moschini, M., Sanna, M., Perego, A., Carozzi, M., Chiodini, M.E., Fumagalli, M., 2014. ValorE: an integrated and GIS-based decision support system for livestock manure management in the Lombardy Region (northern Italy). Land Use Policy 41, 149–162.
Bartolini, F., Angelini, L.G., Brunori, G., Gava, G., 2015. Impacts of the CAP 2014–2020 on the Agroenergy Sector in Tuscany, Italy. Energies 8 (2), 1058–1079.
Bartolini, P., Viaggi, D., 2012. An analysis of policy scenario effects on the adoption of energy production on the farm: a case study in Emilia–Romagna (Italy). Energy Policy 51, 454–464.
Bertoni, D., 2013. Agroenergie. In: Giuca, S., Giannini, M.S., Nebuoloni, A., Pretolani, R., Pieri, R., Cagliero, R., Marras, F., Gay, G. (Eds.), L'agricoltura Lombarda Conta. CSR s.r.l. Centro Stampa e Riproduzione, Roma, pp. 100–102.
Britz, W., Delzeit, R., 2013. The impact of German biogas production on European and global agricultural markets, land use and the environment. Energy Policy 62, 1268–1275.
Carles, R., Decouvelaere, F.X., Millet, G., Revel, A., Sourie, J.C., 1998. Nouveaux outils pour analyser les effets de la prochaine reforme de la C.A.P. sur les exploitations agricoles. Econ. Rural. 243, 56–64.
Cavicchioli, D., 2009. L'agricoltura. In: Pieri, R., Pretolani, R. (Eds.), Il sistema agroalimentare della Lombardia: rapporto 2009. Franco Angeli, Milano, pp. 159–179.
Cavicchioli, D., Bertoni, D., 2015. Effects of cap green Payments in Lombardy: a Comparison of proposed and approved Measures based on Census Data, in Marotta, G., Nazzaro, C., (Eds), CAP 2014–2020: Scenarios for European Agri-Food and Rural Systems Proceedings of the 51st SIDEA Conference. ISBN 978–88-97683–79-7.
Centro Ricerche Produzioni Animali (CRPA), 2008. Energia dal biogas - Prodotto da effluenti zootecnici, biomasse dedicate e di scarto (Energy from biogas - Produced from animal slurries, dedicated biomass and residues). Associazione Italiana Energie Agroforestali (AIEL), Legnaro, Padua, Italy.
Carrosio, G., 2013. Energy production from biogas in the Italian countryside: policies and organizational models. Energy Policy 63, 3–9.
Chinese, D., Patrizio, P., Nardin, G., 2014. Effects of changes in Italian bioenergy promotion schemes for agricultural biogas projects: insights from a regional optimization model. Energy Policy 75, 189–205.
Delzeit, R., Britz, W., Holm-Muller, K., 2009a. Modelling Regional Maize Demand for Biogas Production in Germany. Institute for Food and Resource Economics, University of Bonn, Germany.
Delzeit, R., Britz, W., Holm-Müller, K., 2009b. Modelling regional maize market and transport distances for biogas production in Germany, in: Proceedings of the 49th Annual Conference. German Association of Agricultural Economists (GEWISOLA), Kiel, Germany, September 30–October 2, 2009.
Delzeit, R., 2010. Modelling Regional Maize Markets for Biogas Production in Germany: The Impact of Different Policy Options on Environment and Transport Emissions (Doctoral Thesis). Institute for Food and Resource Economics, University of Bonn, Germany.
Delzeit, R., Britz, W., Holm-Müller, K., 2012. Modelling regional input markets with numerous processing plants: the case of green maize for biogas production in Germany. Environ. Model. Softw. 32, 74–84.
Donati, M., Bodini, D., Arfini, F., Zezza, A., 2013. An integrated PMP model to assess the development of agro-energy crops and the effect on water requirements. Bio-based Appl. Econ. 2 (3), 301–321.
Fabbri, C., Labartino, N., Manfredi, S., Piccinini, S., 2013. Biogas, il settore è strutturato e continua a crescere. L'informatore Agrario 11, 11–16.
Fiorese, G., Guariso, G., 2010. A GIS-based approach to evaluate biomass potential from energy crops at regional scale. Environ. Model. Softw. 25 (6), 702–711.
Frascarelli, A., 2012. Proceedings of the conference on Biogas e biomasse, nuovi incentivi e nuove opportunità, Bologna Fiere, 7 Novembre 2012.
Galeotti, M., 2012. Energia Rinnovabile, oltre il costo degli incentivi. IEFE Centre for Research on Energy and Environmental Economics and Policy.
Gaviglio, A., Pecorino, B., Ragazzoni, A., 2014. Produrre energia rinnovabile nelle aziende agro-zootecniche. Effetti economici delle attività introdotte nella normativa del 2012. Econ. Agro-Aliment. 2, 31–60.
Haas, R., Panzer, C., Resch, G., Ragwitz, M., Reece, G., Held, A., 2011. A historical review of promotion strategies for electricity from renewable energy sources in EU countries. Renew. Sustain. Energy Rev. 15 (2), 1003–1034.
Hahn, H., Rutz, D., Ferber, E., Kirchmayer, F., 2010. Examples for Financing of Biogas Projects in Germany, Austria, The Netherlands, Denmark and Italy. IEE Project 'BiogasIN', D.3.2., (WP3) 〈http://www.biogasin.org/files/pdf/Financing_of_biogas_projects_in_top_5_EU_countries.pdf〉.
Italian National Statistics Institute (ISTAT), 2011. Data from the VI National Agricultural Census Survey 〈http://dati-censimentoagricoltura.istat.it/〉.
Kazakçi, A.O., Rozakis, S., Vanderpooten, D., 2007. Energy crop supply in France: a min-max regret approach. J. Oper. Res. Soc. 58, 1470–1479.
Mela, G., Canali, G., 2014. How distorting policies can affect energy efficiency and sustainability: the case of biogas production in the Po valley (Italy). AgBioForum 16 (3), 194–206.
Mertens, A., Monderlaers, K., Claeys1, D., Lauwers, L., Buysse, J., 2014. Unravelling the informal silage maize trade: a multi-agent modelling approach. Poster paper prepared for presentation at the EAAE 2014 Congress 'Agri-Food and Rural Innovations for Healthier Societies'. Ljubljana, Slovenia.
Peri, M., Bartoli, A., Tesser, F., 2013. Le produzioni non alimentari. In: Pieri, R., Pretolani, R. (Eds.), Il Sistema Agro-alimentare Della Lombardia: Rapporto 2013. Franco Angeli, Milano, pp. 356–367.
Pieri, R., Pretolani, R. (Eds.), 2009. Il Sistema Agro-alimentare Della Lombardia: Rapporto 2009. Franco Angeli, Milano.
Pieri, R., Pretolani, R. (Eds.), 2013. Il Sistema Agro-alimentare Della Lombardia: Rapporto. Franco Angeli, Milano.
Ragazzoni, A., 2011. BIOGAS – normative e biomasse, le condizioni per fare reddito. L'informatore Agrario Edizioni, Verona, Italy.
Regione Lombardia, 2013. Analisi economica ed economico-ambientale della produzione di biogas: implicazioni per le filiere agroalimentari e le politiche regionali ECO-BIOGAS relazione finale (in Italian). Final Report of the ECO-BIOGAS research project, funded by Regione Lombardia 〈http://www.agricoltura.regione.lombardia.it/shared/ccurl/588/227/1713_ECOBIOGAS_RELAZIONE%20FINALE%20web.pdf〉.
Rozakis, S., Haque, M., Natsis, A., Borzecka-Walker, M., Mizak, K., 2013. Cost-effectiveness of bioethanol policies to reduce carbon dioxide emissions in Greece. Int. J. Life Cycle Asses. 18 (2), 306–318.
Rozakis, S., Sintori, A., Tsiboukas, k, 2012. Estimating utility functions of Greek dairy sheep farmers: a multicriteria mathematical programming approach. Agric. Econ. Rev. 13 (1), 111–120.
Rozakis, S., Sourie, J.C., Vanderpooten, D., 2001. Integrated micro-economic modelling and multi-criteria methodology to support public decision-making: the case of liquid bio-fuels in France. Biomass. Bioenergy 20, 385–398.
Sorda, G., Sunak, Y., Madlener, R., 2013. An agent-based spatial simulation to evaluate the promotion of electricity from agricultural biogas plants in Germany. Ecol. Econ. 89, 43–60.
Sourie, J.C., Rozakis, S., 2001. Bio-fuel production system in France: an economic analysis. Biomass. Bioenergy 20 (6), 483–489.
Stürmer, B., Schmidt, E., Eder, M.W., 2011. Impacts of biogas plant performance factors on total substrate costs. Biomass Bioenergy 35 (4), 1552–1560.

[26] See Cavicchioli and Bertoni (2015) for a detailed explanation of greening measures