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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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The growing demand of green maize 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 built a partial-equilibrium model simulating the agricultural sector and the biogas industry in Lombardy, under two alternative subsidization schemes. Results show that policy measures implemented in 2013 – reducing the average subsidy per kWh – may contribute to enforce the sustainability of the sector and decreasing its competition with agri-food chains: maize demand for biogas would decrease, compared to the old scheme, lessening the market clearing price and reducing land demand for energy purposes.

Keywords: biogas / land use / market simulation / mathematical programming / policy analysis.

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1. Introduction

Biogas production from energy crops has grown strongly over the last years in Italy, as a consequence of the subsidization policy. The wide majority of Italian biogas facilities are located in the Po Valley Regions (Piedmont, Lombardy, Veneto and Emilia-Romagna), an area characterized by an intensive agriculture and a high degree of urbanization. With one of the highest concentrations in Europe, Lombardy is the region that holds the main share of biogas plants in Italy (361 at the beginning of 2013, equal to 40% at national level).

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 the share of maize area allocated for biogas production increased from 0.4% in 2007 to more than 10% of arable crop mix in 2012, reaching 18.2% in Lombardy (Mela and Canali, 2014). Therefore such competition may put under pressure agri-food supply chain, among which some important Protected Designation of Origin, such as Grana Padano and Parma ham.

Public policies have had a key role in shaping and stimulating the spread of biogas plants. With the introduction of the feed-in tariff (FIT) in 2009,[2] agricultural biogas production have received a strong boost, mirrored by the exponential growth occurred in Italy between 2009 and 2012 (Figure 1). This incentive system has shaped the organizational models and the technology implementation adopted by farms for biogas: plants with an electric capacity less than 1 MWe were entitled to receive the all-inclusive feed-in tariff equal to 0.28 €/kWh for 15 years,[3] leading the majority of biogas plants to build a capacity slightly less than 1 MWe in order to maximize subsidies.[4] Most of biogas facilities in Italy produce therefore only electric energy since economic incentives were high enough to support it, notwithstanding cogeneration (production of electricity and heat) would allow a more efficient utilization of biogas (CRPA, 2008).

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[2] See Law 99/23 July 2009.

[3] With the introduction of the Law 99/23July 2009, biogas plants up to 999 KWe, fell within the mechanism of the all-inclusive feed-in tariff of 0.28 €/kWh produced, ensured for a period of 15 years. Biogas plants having an installed power capacity bigger than 1 MWe fell within the *Green Certificates* incentive mechanism system, guaranteed by the Government for a period of 15 years. In the biogas sector, the number of certificates issued by the GSE (Gestore Servizi Energetici – Italian National Grid Operator) corresponded to the plant's electricity production multiplied by a factor of 1.8. As a result, according to data from the GSE on certificate buyback prices and on power wholesale prices, average remuneration from *Green Certificate* for biogas power between 2011 and 2013 was 22.3 € c/kWh.

[4] 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).

Previous studies (e.g. Haas et al., 2011; Britz and Delzeit, 2013) suggest that public support to renewable energy may distort entrepreneurial choices when subsidies assure higher profits at lower risk (as in the case of FITs) that, in turn, implies additional costs charged to taxpayers (Chinese et al., 2014). At a time of economic stagnation, public debate arose in Italy focusing on such high costs of renewable energy support (Galeotti, 2012) prompting, in 2012,[5] the Italian Government to introduce an incentive structure tuned with those in force in other European countries (Hahn et al., 2010). From January 2013, the subsidies (comprised in a range between 0.236 and 0.085 €/kWh, see Table 1) have been reduced and further decreased with the increase of plant size. 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. In the present paper the two different incentive systems described above will be hereafter referred to as *pre* 2013 and *post* 2013 policy system.

The evolution of Italian biogas market and incentive policy has been examined in some recent papers.[6] Carrosio (2013) proposed an analysis based on the neo-institutional lens. In particular, he argued that the dominance of one particular organizational model – i.e. 999 kWe plants using a mix of livestock manure and energy crops – was the result of a monopolistic gas market associated to a particular incentive system and uncertainty about the technology. These elements have promoted an *isomorphic structure* less than effective in using biogas production, with low environmental efficiency. Chinese et al. (2014), investigated the effect of *pre* 2013 and *post* 2013 Italian biogas support schemes, focusing on the optimal plant size, feedstock mix and profitability, using a spatially biogas supply chain optimization model. Such simulation makes assumptions on maize supply, using cultivation and harvesting cost as a proxy for input price. Main results, showed that the *post* 2013 new regulation should move the system toward small optimal plant size, mainly fed by manure, and so reducing the pressure induced by energy crop-based plants.

Building upon and improving existing literature, the aim of this paper is to analyze the impact of biogas production in Lombardy on maize demand, price and, in turn, on economic sustainability for other agri-food supply chains. To do so, we build up a partial equilibrium framework, by explicitly modeling and integrating demand-side biogas industry and supply-side agricultural sector. Using such a modeling framework we perform a comparative-static exercise, deriving market clearing

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[5] Decree of the Ministry of Economic Development of 6 July 2012

[6] 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 CAP policies (i.e. CAP 2014-2020 reform) affect the adoption of agro-energy production in Emilia Romagna and Tuscany, respectively.

price and quantity for maize under *pre* and *post* 2013 support scheme. This integrated model allows then to emphasize the effects of different energy policies for biogas production on maize equilibrium price and, in turn, on the differential demand of land for maize silage, energy production and biogas plant profitability. Furthermore, in so doing, we quantify the differential effects of energy policies, mediated by maize price, on non-biogas food supply chains, and in particular on the more important Italian PDO cheese and on Parma ham production. More in general, this aspect is of paramount importance in Lombardy agricultural context, where recent changes in the CAP (such as the removal of milk quota scheme from March 2015 and the constraints related to green payments) will put the livestock and milk sector under growing competitive pressure.

This paper is the first application to Italian biogas sector of a partial equilibrium framework, firstly adopted by Delzeit et al. (2010) in Germany. Such approach allows to add relevant contributions as compared to papers on similar topic in Italy (i.e. Chinese et al., 2014) in terms of *equilibrium displacement effects* under different energy policy options: i) Comparison of market clearing price for maize before (actual) and after (estimated) the introduction of biogas sector, and under *pre* and *post* 2013 biogas energy policies; ii) differential demand of land for maize silage; iii) differential biogas energy production and profitability.

The paper is structured as follows: Section 2 provides the problem setting, relates it to the relevant literature 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 Modeling framework for biogas production

Biogas production from agricultural biomass is based on bulky raw products (energy crops, manure and/or by-products), with small-scale, localized demand and high unitary transportation costs. This demand depends on location decisions of numerous bioenergy processing plants which are driven to a large extent by regional heterogeneity in production (yield) and transport costs of feedstock, especially if there is small spatial variability in other factors affecting biogas production, such as input and output prices, investment costs and operational costs (Delzeit et al. 2011). Biomass demand for energy production, 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. In order to carry out an integrated assessment of agricultural and bioenergy sector accounting for alternative policy scenarios, several interdisciplinary approaches have been developed by combining micro-economic and multi-criteria methodology (Delzeit et al., 2011; Rozakis et al., 2012a), 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 order to assess how the Italian subsidies to biogas production influence agricultural markets we apply a partial equilibrium model on two areas of Lombardy region; such model couples a demand-side biogas industry model and a supply-side agricultural model.

Following the approach proposed by Delzeit (2010), we first applied at 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). Moreover, in order to assess the impact of biogas production to the agricultural sector, an arable agricultural supply model is needed. 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 are supposed to maximize individual welfare subject to resource and agronomic constraints (see Section 2.1.2). By coupling ReSI-M (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 model delivers the market-clearing prices and quantities under different energy policy scenarios, allowing also to estimate the changing demand of land for maize silage in the agricultural sector (see Section 2.1.3).

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 (2010). The aim of regionalized location model ReSI-M was to simulate, using a sequential process, the number of plants established in German regions based on independent, decentralized investments, accounting for their location in sub-regions and for their typology; such typology is classified according to plant size and feedstock mix at given feedstock prices. Through an iterative maximization of the ROI (Return on investment, computed as the ratio between operational profits and total investments) the model estimates the optimum level biogas plants in each area under investigation.

Operational profits $\pi_{c,s}$ for a specific biogas plant type *s* established in the location region *c* are defined as the difference between output y times price p (revenue), operational costs *oc* net of feedstock, and feedstock costs. The latter are determinate as the sum of per unit transport costs *tc* and feedstock price *w* multiplied by the variable input demand *x*. Formally,

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

Unitary transport cost *tc* depends on the regional availability of feedstock, which is determined by spatially specific parameters. These are the share of arable land on total land and its spatial distribution, feedstock yields and the amount of feedstock already used (see model specifications below).

The number of plants built $n_{c,s}$ of a specific type *s* at price *w* is assumed to depend on plants' ROIs. For each plant, ROI is calculated from yearly operational profit $\pi_{c,s}$ as defined in (1) and total investment costs I_s:

$$ROI_{c,s\,(w)} = \frac{\pi_{c,s}}{I_s} \quad (2)$$

The objective of the location model is to determine the total feedstock demand *d* for regions *c* at given feedstock demand prices *w* (3). Total regional demand *d* is obtained as sum of plant type *s* specific feedstock demand *x* times their specific-location number *n*:

$$d_c(w) = \sum_s n_{c,s}(w)\, x_s \quad (3)$$

The model is implemented through an iterative approach: in a first step, unitary transportation costs for the defined regions and plant types are derived. In a second step ROI for each location-type combination is maximized, assuming different maize prices and the combination with the highest ROI is chosen. After each iteration, the regional feedstock availability is reduced by the demand from simulated plant, which causes, in turn, the increase of transport costs. During subsequent iterations these steps are repeated while minimal total transport costs for each location-plant type combination are determined by solving independently standard minimization (LP) problem – Transportation Problems (see Domschke and Drexl, 2005), given regional maize and manure availability.

From all possible locations and plant types, the combination with the highest ROI is chosen in any iteration. The iteration process continues until the type-location combination ROI exceeds an assumed minimum interest rate or the feedstock is out of stock. The model specification is defined below (Delzeit et al. 2009b) as key objective function and side conditions, while indices, parameters and decision variables are displayed in Figure 2.

Objective function:

$$\max \pi = \sum_{s\in S}\sum_{p\in P}\frac{r_s - v_s - \eta_{sp} - f_s}{I_s} - \sum_{s\in S}\sum_{c\in C}\sum_{k\in K}\sum_{f\in F}\left(\frac{tm_{sck} * z_{sc}}{I_s} + \frac{tr_{sck} * x_{sc}}{I_s} + \frac{tn_{sck} * y_{sc}}{I_s}\right) \tag{4}$$

S.t.

5) $\sum_{s\in S} z_{sc} \leq b_{cp} \qquad \forall\, p \in P, c \in C$

6) $\sum_{c\in C} z_{sc} = \sum_{s\in S} d_s * s_s * 1.08 \qquad \forall\, s \in S$

7) $\sum_{c\in C} y_{sc} = \sum_{s\in S} dm_s * s_s \qquad \forall\, s \in S$

8) $\sum_{c\in C} x_{sc} = \sum_{s\in S}(z_{sc} * f_z + y_{sc} * fm)$

9) $z_{sc} \geq 0 \qquad c \in C, s \in S$

10) $x_{sc} \geq 0 \qquad c \in C, s \in S$

11) $y_{sc} \geq 0 \qquad c \in C, s \in S$

12) $\pi > 0$

where:

13) $tc0_{sck} = \alpha_s + \left(\sqrt{\frac{d_s}{e_c * \Pi * share_c}} + tkout_{ck} - 1\right) * \beta_s$

14) $tr_{sck} = \delta_s + \left(\sqrt{\frac{d_s}{e_c * share_c * \pi}} + tkout_{ck} - 1\right) * \lambda_s$

15) $tc1_{sc} = \sqrt{\frac{\sum_{s\in S} d_s}{e_c * \Pi * share_c}} * \beta_s$

16) $tm_{sck} = (tc0_{sck} + tc1_{sc}) * 1.33$

Condition (5) ensures that maize transported from regions to plants doesn’t exceed that produced in a region. Input of maize and manure for a plant at a certain capacity is related with the transports in condition (6) and (7). Additionally, for maize, a loss of 8% is considered. Constraint (8) relates the inputs to the residues for each plant sizes. Constraints (9) to (12) determine the value range for variables. Transportation costs for maize (13) and residues (14) are represented by a cost term for the first kilometer; from the transport costs for further km, the first kilometer is subtracted. In the case of maize, additional transport costs arise as maize is used and are also a function of land distribution in the respective region (15). Total transportation costs for maize are represented by (16); the factor 1.33 accounts for the fact that streets are never in a straight line.

An overview on ReSI-M is provided in Figure 3.

2.1.2 The agricultural model (MAORIE)

The agricultural sector model belongs to the MAORIE family of models (Modele Agricole de l'Offre Regionale INRA Economie, see Carles et al. 1997) in which the arable crop sector is represented by a sub-model for each farm in the sample; the sub-models are assembled in a staircase structure. The models purpose is to anticipate farmers' behavior concerning land allocation for various crops. Each producer f maximizes an objective function represented by expression (17). Yields and feedstock availability at given prices are taken directly from agricultural statistics; decision variables take their values in a feasible domain delimited by a system of institutional, technical and agronomic constraints (relationships 18–22). Indices, parameters and decision variables are displayed in Figure 4.

Objective function:

$$\max \sum_{f \in F} \sum_{y \in Y} g_{y,f} xf^{j}_{y,f} + \sum_{f \in F} \sum_{d \in D} (p^{j}_{d} \gamma^{j}_{d,f} - c_{d,f}) xe^{j}_{d,f} \quad (17)$$

S.t.

Land resource constraints:

$$\sum_{y \in Y} xf^{j}_{y,f} + \sum_{d \in D} xe^{j}_{d,f} \leq w_f \sigma_f \quad \forall f \in F \quad (18)$$

Quota on sugar-beet cultivated area:

$$x^{j}_{1,f} \leq w_f \sigma_{1,f} \qquad \forall f \in F \quad (19)$$

Agricultural and flexibility constraints:

$$\sum_{y \in Y} i_{y,v} xf^{j}_{y,f} + \sum_{d \in D} i_{d,v} xe^{j}_{d,f} \le \pi_v w_f \, \sigma_f \quad \forall f \in F \quad (20)$$

Non-negativity constraints:

$$xf^{j}_{y,f}, \; xe^{j}_{d,f} \ge 0 \quad \forall y \in Y \quad \forall d \in D \quad \forall f \in F \quad (21)$$

For each energy crop $d \in D$ and for each m-tuple of prices $j \in J$, the agricultural model provides the quantities q^{j}_{d} proposed by the farmer maximization gross margin. Therefore, we have:

$$q^{j}_{d} = \sum_{f \in F} \gamma_{d,f} \, xe^{j}_{d,f} \quad (22)$$

Outputs of the agricultural model are quantities of crops supplied by the agricultural sector for predefined sets of maize silage prices supplied by biogas sector. Only maize silage is considered as energy crop for biogas and a grid of all possible prices at which it can be sold at farm gate is constructed.

We perform successive iterations parametrically optimizing for all possible prices for silage maize (p_{maize} = {30…70 €/ton}) providing a wide range around the typical average maize prices of 45 €/ton, in order to obtain corresponding optimal quantities produced. While performing such iterations, the model extends the optimal sample quantities and land allocation to the universe of represented farms using appropriate weights. Aggregating the outputs of the model we obtain the agricultural supply function for maize silage at NUTS 3 (Nomenclature of Territorial Units for Statistics)[7] level. Final outputs of the model provide at the same time optimal crop mix distributions in each region under study beside the supply of feedstock available for biogas production.

2.1.3 The integrated model

For the purpose of our research Lombardy (NUTS 2 region) is splitted in NUTS 3 level regions; the above mentioned models were applied on two NUTS 3 regions, namely Brescia and Cremona. To find the optimal number of plants at a certain size and location, we apply the iterative approach as discussed in Section 2.1.1, assuming a grid of all possible maize prices (p_{maize} = {30…70 €/ton}).

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[7] For a description, see: http://ec.europa.eu/eurostat/ramon/nuts/basicnuts_regions_en.html.

Since feedstock availability decreases over iterations and per unit transport costs increase, profits decrease during the interactive process. Consequently, any location-size plants combination with a ROI below the minimum level of interest rate in a given iteration will never be considered in any subsequent iteration, speeding up the process further.

Results are regional feedstock demand curves originating from biogas production. Market clearing prices and quantities for each NUTS 3 region can be calculated by intersecting maize demand curves from ReSI-M with maize supply curves from MAORIE. An overview on the underlying logic of this partial equilibrium approach is provided in Figure 5.

2.2 Case study for the Lombardy region: data and model specifications

Lombardy is the region with the largest number of biogas plants in Italy. At the beginning of 2013 there were 361 plants, particularly concentrated in the plain of Brescia (68 biogas plants, with a total installed power equal at 50 MWe) and Cremona (137 biogas plants, with a total installed power equal at 101 MWe). 73% of Lombardy plants had an installed power capacity between 500 kWe and 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 tons of maize silage, 800,000 tons of other energy crops, and 5,000,000 tons of manure coming from livestock are used (Peri et al., 2013). The sharp increase of biogas plants in Lombardy began in 2009 (Figure1), when maize grain covered 253,741 hectares with a production of 2,944,814 tons and the area for maize silage was 113,090 hectares, producing 6,411,200 tons; maize (grain and silage) covered 35% of Utilised 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 (Figure 6).

2.2.1 Demand-side biogas industry model

We distinguished 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 current legislation (Table 1). We apply ReSI-M modeling framework in Brescia (BS) and Cremona (CR) NUTS 3 regions. ROI for several type-location combinations is determined 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 simplification has been necessary for a matter of model tractability and may induce a slight overestimation in maize silage demand.[8]

Regarding the demand for maize silage from biogas plants we set 2012 as reference year, the last year before the beginning of the new incentive system and for which detailed data are available (Fabbri et al., 2013) mainly as an outcome of a research project funded by Lombardy Region to assess the economic and environmental impact of biogas on agri-food supply chains, hereafter referred as Eco-biogas project (Regione Lombardia, 2013).

We assume that transport costs for maize are fully paid by the biogas plant.[9] We account for different shares of arable land within the NUTS 3 regions, so that transportation costs increase as the amounts of feedstock necessary to feed the existing plants during the iteration process increase. Moreover, even though Brescia and Cremona have high livestock densities, in order to analyze the effects of new policies on the overall profitability of the plants, we assume that also transport costs for manure are fully paid by biogas plant.

We have excluded mountain and urbanized areas (as classified by the Italian National Institute of Statistics, ISTAT) as possible locations for biogas plants, assuming that zoning laws and low feedstock availability prevent installation of plants in these areas. Driving distances and in turn the intra-regional transportation costs of feedstock have been estimated by computing mean and variance of the share of arable land for each NUTS 3 region.

Exogenous data used to determine profits (production and processing costs) for biogas plants are taken from the literature (Frascarelli, 2012; Ragazzoni, 2011); data on revenues are derived from electricity prices according to past and the current legislation (policy *pre* and *post* 2013, see Table 1). Assumptions on average energy efficiency and maximum operating hours were also taken from Frascarelli (2012). Transportation costs for maize are extracted from Delzeit (2010). Data on the

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[8] Such conversion has been necessary as the version of ReSI-M employed (see Delzeit, 2010) considers exclusively maize silage as energy crop in the blend.

[9] In the market for maize silage, it is commonly agreed that harvest and transport costs are paid by the buyer (in this context farms hosting a biogas plant)

amount of manure available for biogas production have been taken from the Decision Support System ValorE[10] (Acutis et al., 2014) and Regione Lombardia (2013) data.

2.2.2 Supply-side agricultural model

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 NUTS 2 region. RICA is the Italian version of the FADN (Farm Accountancy Data Network).[11]

As the sharp growth of biogas plants installation began in 2009 (Figure 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 (for 57 farms with an average of 10 activities per farm) and 300 constraints.

The main crops cultivated by those farms are: maize grain, soft wheat, soya bean, durum wheat, maize silage, alfalfa and other grain legumes.

Data used at farm and crop level were: prices (€/ton), yield (ton/hectare), subsidies (€/ton and €/hectare depending on the type of crop) and variable costs (€/hectare). Variable cost includes: fertilizers and soil ameliorants, seeds and seedlings purchased, water, crop protection, lubricants and fuels, electrical energy, running maintenance of equipment, land improvements and maintenance of buildings , salaries, wages of hired labor as well as social taxes.

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.[12] Therefore, in order to investigate the extent to which the regional biogas sector can grow without incurring in significant

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[10] 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

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

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

competition with agri-food supply chains, maize silage produced in livestock farms is intended exclusively for the livestock feeding 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. Although this is a simplification of the agricultural model and limits its impact assessment of land demand for maize silage to farms specialized in Cereals, Oilseeds and Protein crops, we are able to assess potential undesirable side effects mentioned in Section 1 by estimating the market clearance price of maize silage purchased by biogas plants.

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 feed costs in livestock farms. The differential impact of biogas energy policy on agri-food supply chains is then mediated by market clearing price of maize silage. To better explain such multiple impacts of biogas production under different policy incentive systems (Policy *pre* and *post* 2013) three scenarios are introduced:

- Scenario_0: *reference scenario*. It simulates the crop supply (and land allocation) in 2008, thus before the biogas industry take off. Scenario_0 crop supply is simulated by ignoring the effect of regional maize demand for biogas and assuming average market price for crops and maize silage (30 €/ton) during 2008 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 simulated. The iteration process produces the optimum allocation of land at sample level, such value for maize silage is then extended to the universe of represented farms (TF 13 and 14) giving the simulated hectares of maize potentially available for biogas production and, in turn, the simulated amount of maize 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 silage maize 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. 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, 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 (Tables 5 and 6).

2.4 Models validation

To verify whether and to what extent the industrial model fits the productive reality in Lombardy, we set the same policy framework under which plants existing in 2012 were built, namely the *pre* 2013 policy framework, and we fix 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 tons/year of maize silage in Brescia and 1,870,000 tons/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. Figure 7 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 - 7MW 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.

Acting as a profit maximization model, ReSI-M chooses the plant typology that maximizes ROI (999 kWe, more efficient but using more maize), minimizing the heterogeneity of the simulated plants. 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 installed power capacity between 500 kWe and 1000 kWe).

To test the agricultural model's ability to reproduce farmers' behavior, we compare simulated and observed crops pattern. As explained above, for a matter of model calibration, we have chosen 2008 as reference year. The validity of the arable sector model has been checked by comparing optimal crop mix from LP supply model with the observed ones. The LP supply model allocates, for each crop (*k*) the level of arable land (hectares) 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*) of the predicted values from the observed values (23) and then calculating total weighted absolute deviation (*TWD*) in order to have a global index of the representativeness of the model (24).

$$AD\left(x_k^{obs}, x_k^{opt}\right) = \left\lfloor \frac{x_k^{opt} - x_k^{obs}}{x_k^{obs}} \right\rfloor \quad (23)$$

$$TWD\ \left(x^{opt}\right) = \frac{\sum_k \left(\left\lfloor \frac{x_k^{opt} - x_k^{obs}}{x_k^{obs}} \right\rfloor * \frac{x_k^{obs}}{\sum_k x_k^{obs}} \right)}{\sum_k \left(\frac{x_k^{obs}}{\sum_k x_k^{obs}} \right)} \quad (24)$$

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 20%) and in line with the values found in the literature for MAORIE type models (Kazakçi et al. 2007; Rozakis et al., 2012b).

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 surfaces simulated by the model, we observe lower AD values because 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 the two products. The agriculture supply model is therefore enough representative of farmers' behavior 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 sections 2.1.2 and 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 a partial equilibrium model of maize silage demand and supply for biogas production 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 double impact on agricultural sector and agri-food supply chains is measured in terms of change in maize silage price, affecting feed cost for livestock farms, and in terms of changing demand of land for maize silage.

In Scenario_0, the simulated hectares of maize silage potentially available for biogas production (assuming an exogenous price of 30 €/ton equal to the average market price for the maize silage in 2008) is equal to zero in Brescia and quite low (1,738 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 tons in Brescia and 1,248,266 tons in Cremona, 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 tons in Brescia and 1,870,549 tons in Cremona (tables 5 and 6). Maize silage demand is therefore estimated under such upper and lower bounds (figures 8 and 9).

Figure 8 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 €/ton, the demand is totally inelastic in both provinces, this means that, for prices lower than 55 €/ton, 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 €/ton),[13] pre 2013 policies would make it to rise to 57 €/ton in Brescia (+56%) and 60 €/ton 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

In line with the actual observed trend, simulated plants are big sized (999 kWe). In addition to the current (2012) installed 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 (Table 5).

In Scenario_2 we introduced the new 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). Consequently the equilibrium price of maize silage decreases significantly in both areas, in comparison with Scenario_1: 38 €/tons in Brescia and 42 €/tons in Cremona (Figure 9), to levels closer to actual price in 2012 (36.9 €/ton), in line with the actual maize silage market price in Lombardy (ca. 40 €/ton in 2014).[14] As show in Table 6, land required to produce market clearing quantities of maize silage amounts to 879,915 ha (8.18% of UAA) in Brescia and 1,590,005 ha (19.67% of UAA) in Cremona. Land required for biogas feeding is then far lower with respect to Scenario_1 (Table 7); consequently the impact of biogas production on land allocated to maize silage is mitigated under the new incentive system with respect to the old one (Scenario_1). The new incentive system would therefore decrease the pressure on agri-food supply chains by diminishing both the demand of land for energy crops and the feed costs for livestock farms (by lowering silage maize prices).

The simulated (new) plants are smaller (130 kWe) and the demand for maize silage (used maize[15]) decreases, compared to Scenario_1, from 2,157,623 to 327,963 tons (−1,829,660 tons, -85%) in

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

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

Brescia and from 577,017 to 341,739 tons (−235,278 tons, -41%) in Cremona.[16] The smaller quantity decrease in Cremona is due to the large amount of maize feeding 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 (1,000 tons/years rather than 18,000 of 999 kWe) given their lower ratio between used maize and installable power (Tables 5-6). Consequently, 43 MWe in Brescia (compared to 120 MWe of Scenario_1) and 44 MWe in Cremona (compared to 32 MWe of Scenario_1).

Finally, we can compare the effect of *pre* and *post* 2013 energy policies on the Return on Investments (ROI) of simulated plants, under different silage maize prices (Figure 10). 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 (from 30 €/t to 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 Figure 10, 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 €/ton; the introduction of the new incentive system fosters small plants (130 kWe), which, however, shutdown when the price of maize exceeds 55 €/ton.

4. Conclusions and policy implications

This paper studies the effects of two alternative energy policies for biogas subsidization on the market equilibrium of the maize silage, as main energy crop in Lombardy. We adopt a partial equilibrium approach, simulating (with Linear Programming models) agricultural supply and biogas demand of maize silage for biogas production under two policy scenarios. In so doing we measure, on one side the effects of biogas introduction and, on the other, the consequences of different biogas subsidization systems, also compared to pre-biogas period. The change in policy option displaces simulated market equilibria, yielding different prices and quantities of maize silage, from which, in turn, we derive the demand of land for maize silage and biogas installable power. A comparison can

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[16] 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).

then be made both between the outcomes of market equilibria under different subsidization schemes and among actual (pre-biogas, until 2008) and simulated maize silage prices. Such comparison, along with the change in demand of land for maize silage, measures the competition exerted by biogas industry against agri-food supply chains. The bigger is the rise in simulated maize silage price (with respect to pre-biogas price) the bigger will be the demand of land devoted to such crop, and consequently subtracted to grain maize. Such double effect raises feed costs for livestock farms, harming consequently animal products (meats and milk) supply chains that are of paramount importance in Lombardy region. The extent of such effect differs between the two policy Scenarios, in which we have simulated, as alternative market equilibria, what would have been happened if, after 2012, the incentive system would have not changed (*pre* 2013 policy, Scenario_1) or if it would have changed as it is actually happened (*post* 2013 policy, Scenario_2). Such comparative static exercise allows to compare and to evaluate the two subsidization systems in terms of main market outcomes.

According to 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 (999 kWe, with a 2:1 maize-manure ratio) assuring higher profitability (measured as ROI) that would cause an increase in demand for maize silage, with consequent negative effects on the price (rising).Therefore, if the incentive policies would had remained unchanged, in areas with the highest density of plants a significant competition could had occur between the biogas sector and agri-food supply chains (cow and pork meat and milk sectors) even in the short term.

With the new incentive system (*post* 2013 policy), the simulated market conditions would had been different, compared to the above mentioned policy option, with smaller plants, in terms of installable power (i.e., 130 kWe), having a maize slurry ratio of 1:10. As a result, the maize demand from the biogas sector would have decreased, attenuating, in turn, 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 an hypothetical situation of competition, the system moves to a situation of complementarity between the biogas sector and regional meat and milk sectors.

The minor land use (LU) for biogas production observed under post 2013 policies is in line with the European Parliament’s strategy for biofuel. The new legislation approved on 28 April 2015 establishes indeed that first-generation biofuels (from crops grown on agricultural land) should account for no more than 7% of energy consumption in transport by 2020, instead of the 10% previously planned. The use of farmland to produce biofuel (or biogas) crops reduces in fact the area available for food crops and induce, consequently, pressure to free up more land (Indirect Land Use Change effect).

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 valorize the manure and by-products; key condition for the containment of plants operating costs. The new incentive system will therefore most likely eliminate past distortions but also could slow down investments in agricultural biogas plants.

Results and policy implications of the present work should be considered taking into account some limitations of the underlying modeling 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). A future potential extension would require to model explicitly also the behavior of livestock farms by including them in the agricultural model. Such change would make the modeling exercise far more complex, requiring additional constraints to calibrate the agricultural model. Such shortcoming may be overcome by Positive Mathematical Programming (PMP) to better represent unobserved preferences of farmers, as in recent papers on energy crops modeling (Donati et al., 2013).

Further developments should also pertain the quantification of Direct Land Use Change (D-LUC) that occur on crop mix distribution at the equilibrium price, considering as well the Indirect Land Use Change (I-LUC) caused by the shift from maize grain for livestock to maize silage for biogas. This would allow a cost-benefit analysis of biogas production in Lombardy and the costs for the community in terms of energy production and saved CO_2 emissions.

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Table 1 – Policy changes in agricultural biogas incentive system.

Policy intervention parameters	***Pre* 2013 policy (Law 99/23 July 2009)**	***Post* 2013 policy (Decree 6 July 2012)**		
		Size class	**Energy crops (€ MWh)**	**Animal byproducts based (€ MWh)**
Incentive value	Feed in tariff for plants up 999 kWe (280 € MWh) Green Certificate for plants > 1000 kWe (223 € MWh^{-1}; average GC buy-back value plus average power wholesale price 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 animal by-products (from farming and the food industry): if it is below 30% the plants receive the incentive for energy crops, otherwise it receives the incentive for energy byproducts.		
Time horizons	15 Years	20 Years		

Source: Readapted from Chinese et al. (2014)

Table 2 – Feedstock mix of biogas plants for power classes in Lombardy region (reference year 2012).

Power (kWe)	Maize Silage (t/year)	Manure (t/year)	Reside (t/year)
130	1,000	10,000	10,680
250	4,000	12,000	18,162
530	10,000	13,000	17,621
999	18,000	9,000	29,708
2000	33,000	24,000	44,760

Source: Authors elaboration on Regione Lombardia (2013) data.

Table 3 – Comparison between actual crop mix and optimal crop mix in Cremona (CR) and Brescia (BS) using RICA sample data.

	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**

Source: Authors elaboration on RICA data and results of agricultural model described in Section 2.2.2

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).

	Brescia	Cremona
Simulated hectares of maize potentially available for biogas production	0	1,738
Simulated amount of maize potentially available for biogas production in TF 13-14 (tons) assuming an average yield of 60 ton/ha	0	104,316
Total UAA (ha)	174,784	134,660
Share of land required for maize (% Total UAA)	0	1.29

Source: Authors elaboration on Istat data and results of agricultural model described in Section 2.2.2

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.

	Brescia	Cremona
Average actual maize silage price in Lombardy in 2012 (€/ton)	36.9	36.9
Market clearing price (€/ton)	**57.6**	**60.6**
Increase in market price compared to 2012 (%)	*56*	*64*
Market clearing quantities (tons) (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 (ton/MWe)	17,980	18,032

Source: Authors elaboration on results of partial equilibrium model described in Section 2.

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.

	Brescia	Cremona
Average actual maize silage price in Lombardy in 2012 (€/ton)	36.9	36.9
Market clearing price (€/ton)	**37.9**	**42.0**
Increase in market price compared to 2012 (%)	*3*	*14*
Market clearing quantities (tons) (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 (ton/MWe)	7,627	7,767

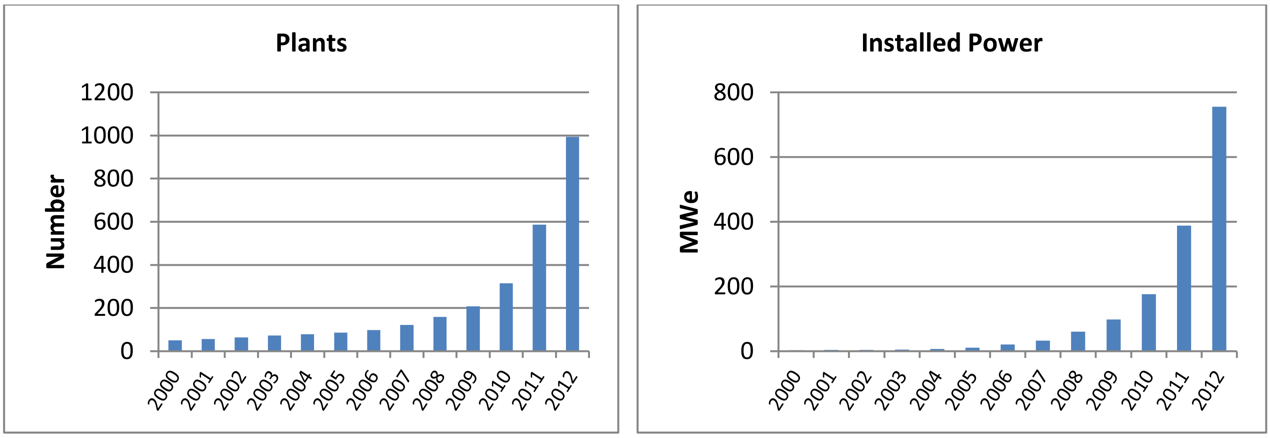
Source: Authors elaboration on results of partial equilibrium model described in Section 2.

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).

	BS/S1	BS/S2	**BS diff. (S1 -S2)**	CR/S1	CR/S2	**CR diff. (S1 -S2)**
Market clearing price (€/ton)	57.6	37.9	**-19.7**	60.6	42.0	**-18.6**
Market clearing quantities (tons)	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	**-3,921**
Share of land for maize (% Total UAA)	25.62	8.18	**-17.44**	22.59	19.67	**-2.92**

Source: Authors elaboration on results of partial equilibrium model described in Section 2.

Figure 1 – Number of biogas plants and installed Power in Italy between 2000 and 2012 years.



Source: Readapted from Fabbri et al. (2013).

Figure 2 - Indices, parameters and decision variables of the industrial model (ReSI-M).

Indices / Sets

$s \in S$	current plant size
$p \in P$	current prices for maize
$c \in C$	current region
$k \in K$	Regions

Parameters

r_s	sum of revenues (in €/year)
v_s	sum of variables costs (in €/year)
η_{sp}	input costs per year (maize price times maize demand)
f_s	summed fixed costs (in €/year)
I_s	investment costs (€)
tm_{sck}	transport costs for maize (€/t)
tr_{sck}	transport costs for residues (€/t)
tn_{sck}	transport costs for manure (€/t)
α_s	costs for the first km of maize including up and unloading (€/t)
β_s	transportation costs for each additional km of maize (€/t per km)
δ_s	transportation costs for the first km of manure and residues (€/m3)
λ_s	transportation costs for each additional km of manure and residues (€/m3)
km_{sck}	driving distance (km)
b_{cp}	amount of maize produced in region at price (in tons)

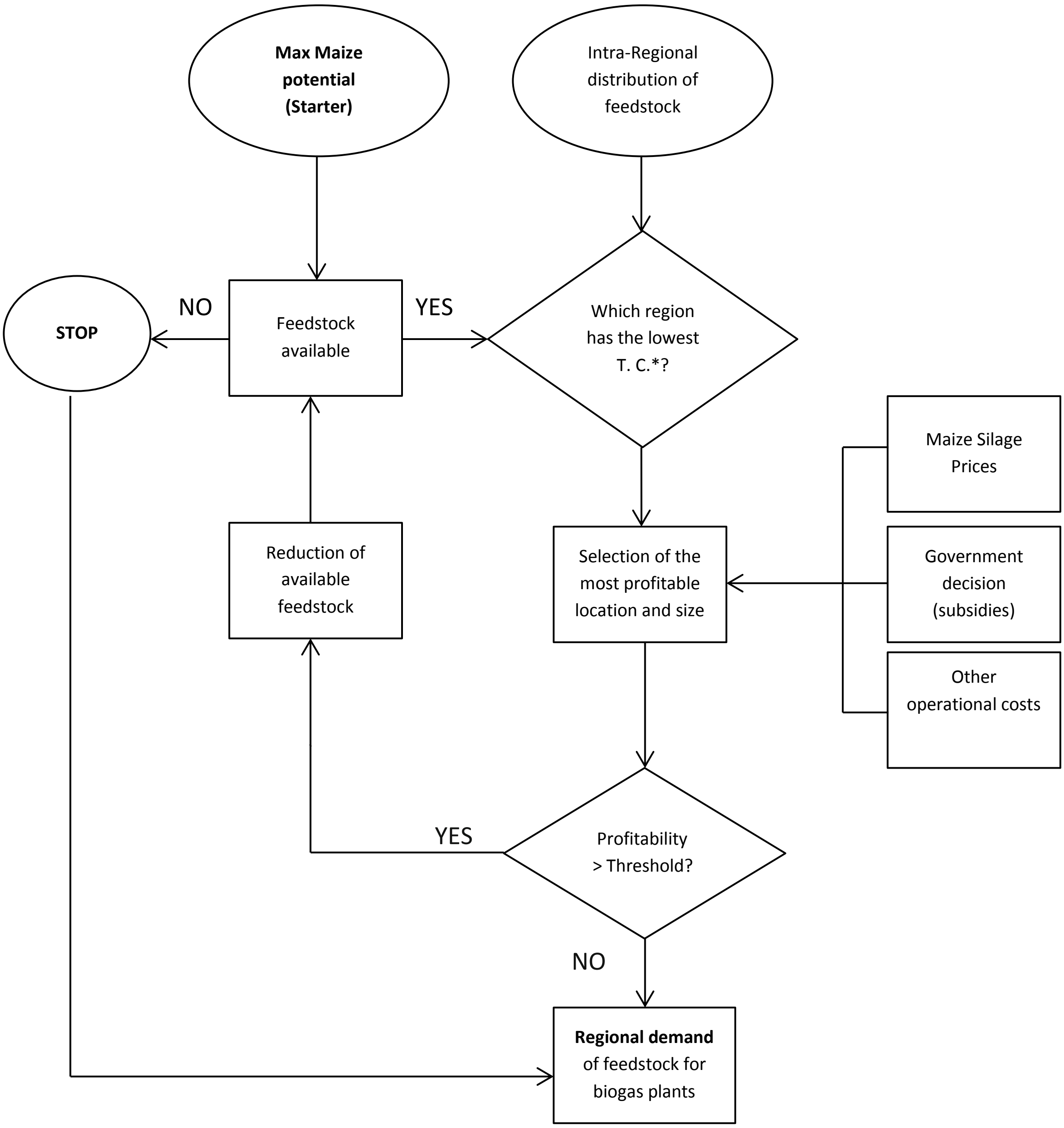
Parameters

d_s	demand of maize per capacity (in tons)
dm_s	demand of manure per capacity (in tons)
dr_s	residues per capacity (in tons)
s_s	share of input factor
fz	conversion factor for residues output from maize input
fm	conversion factor for residues output from manure input
$tkout_{ck}$	distance between c and k (km)
$tcin_{sc}$	driving distance within c (km)
$tc0_{sc}$	initial transport costs in current region
$tc1_{sc}$	additional transport costs with rising amount of used maize
e_c	yields in tons per hectare
$share_c$	factor derived from share on crop land on total land
$dens_c$	density factor for manure (m^3/km^2)

Decision variables

z_{sc}	transported amount of maize (in tons)
y_{sc}	transported amount of manures (in m^3)
x_{sc}	transported amount of residues (in m^3)
π	Profit

Figure 3 – Overview of ReSI-M.



**T.C. = Transportation Costs*

Source: Readapted from Delzeit (2010).

Figure 4 - Indices, parameters and decision variables of the agricultural model (MAORIE).

Indices/Sets

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

Parameters

σ_f	total arable land available on farm f (ha)
$\sigma_{1,f}$	max area on farm f for sugar beet for sugar production (ha)
π_v	max fraction of land permitted for crops included in agronomic constraint v
i_{yv}	binary coefficient of agronomic constraints = 1 if food crop y is concerned by agronomic constraint v; =0 otherwise
i_{dv}	binary coefficients of agronomic constraints = 1 if energy crop d is concerned by agronomic constraint v;=0 otherwise

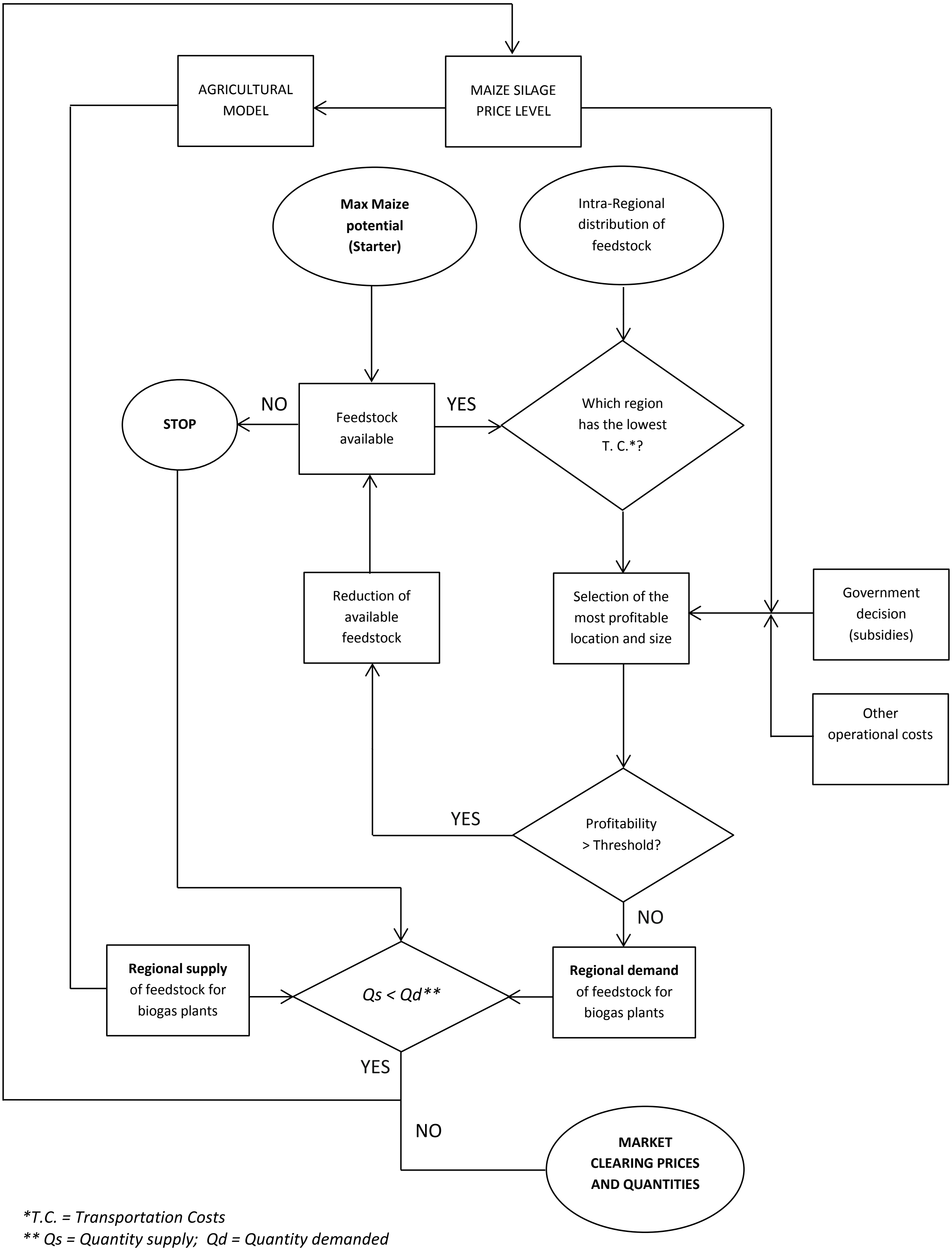
Parameters

$g_{y, f}$	gross margin for food crop y grown on farm f (€ ha−1)
$\gamma_{d,f}$	yield of energy crop d grown on farm f (t ha−1)
$c_{d, f}$	production cost for energy crop d on farm f (€ ha−1)
w_f	multiplier used to scale up arable land of farm f to the regional level

Decision variables

p^j_d	(parametrically treated) price at farm gate for energy crop d for jth set of prices (€ kg−1)
$xf^{\,j}_{y,f}$	area allocated to food crop y on farm f (ha) for jth set of prices (ha)
xe^j_{df}	area allocated to energy crop d on farm f (ha) for jth set of prices (ha)

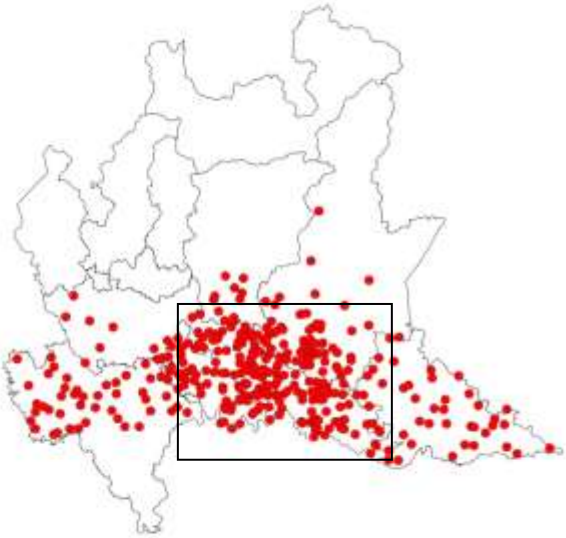
Figure 5 – Multi level model flowchart.



**T.C. = Transportation Costs*

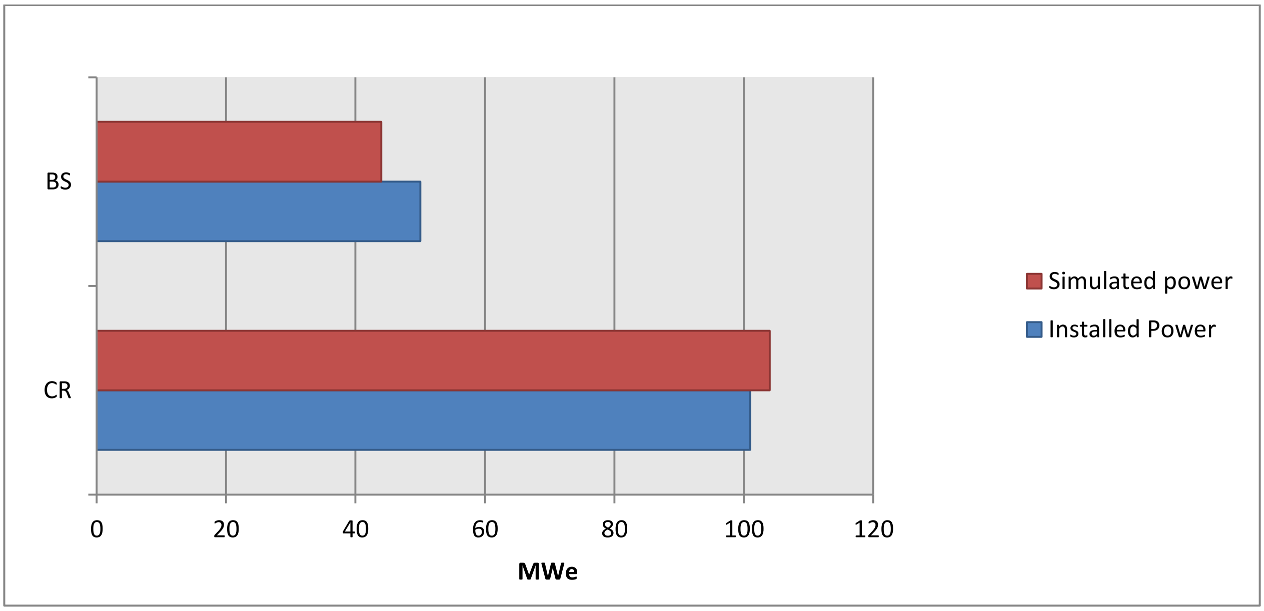
*** Qs = Quantity supply; Qd = Quantity demanded*

Figure 6 – Biogas plants in Lombardy region and area under investigation (plain of Brescia and Cremona).



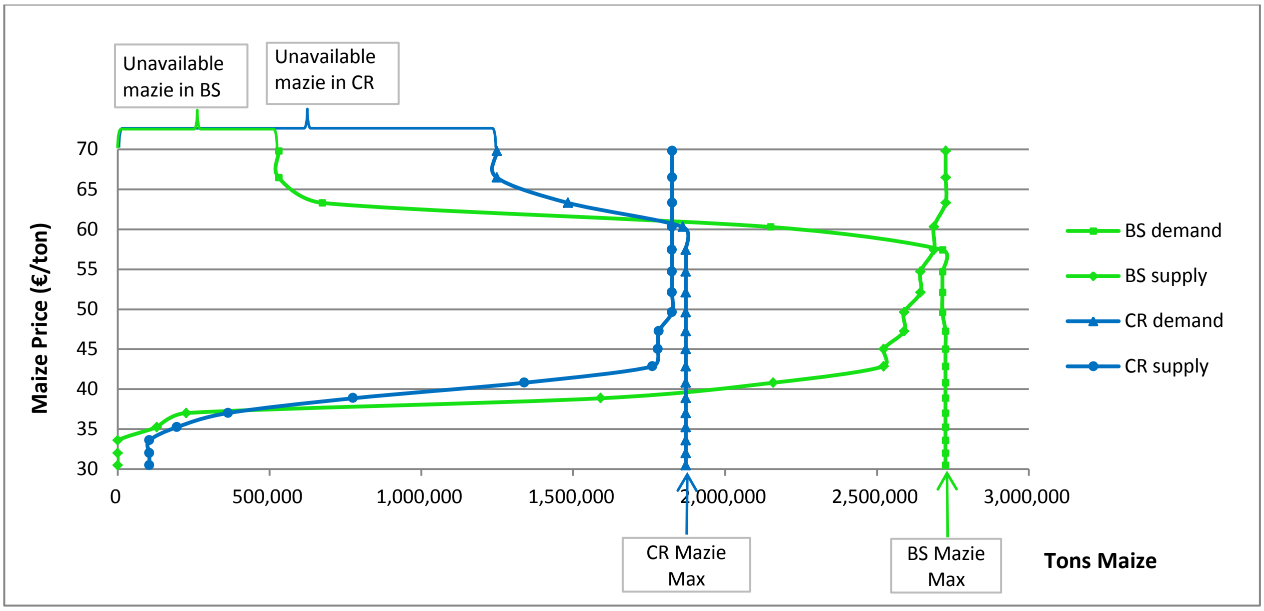
Source: Geo-referenced data, readapted from Bertoni (2013).

Figure 7 – Comparison between observed (installed) and simulated power (MWe) of biogas plants in Brescia (BS) and Cremona (CR). Reference year 2012.



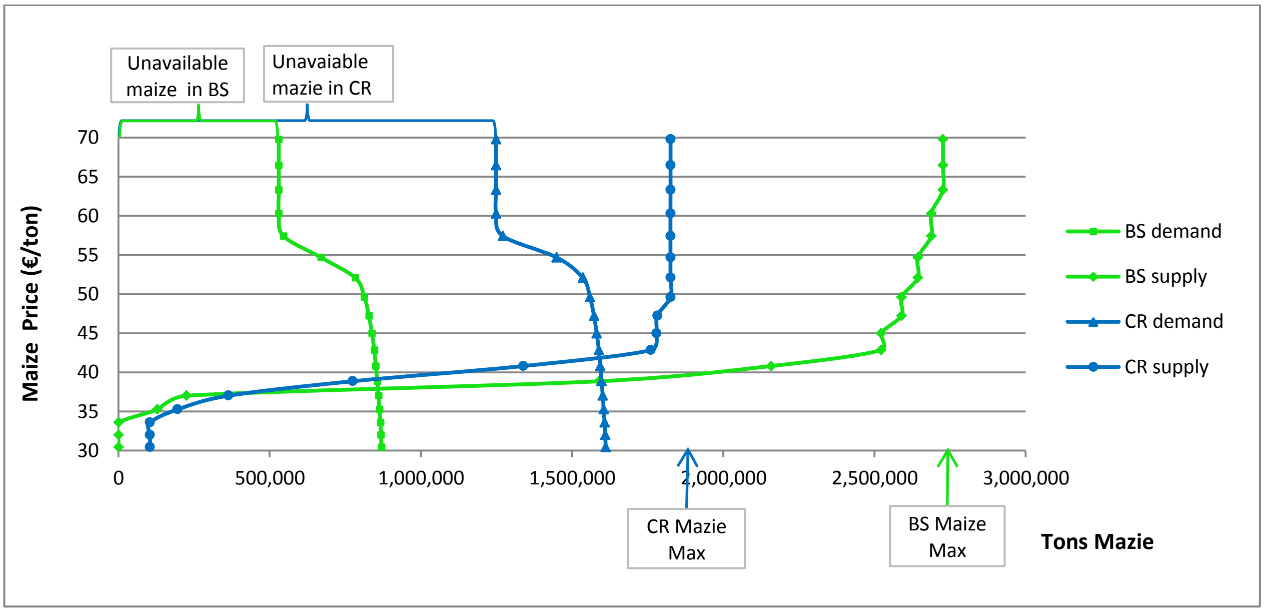
Source: Authors elaboration on results of ReSI-M model.

Figure 8 – Scenario_1: Estimated market clearing prices and quantities in Brescia (BS) and Cremona (CR).



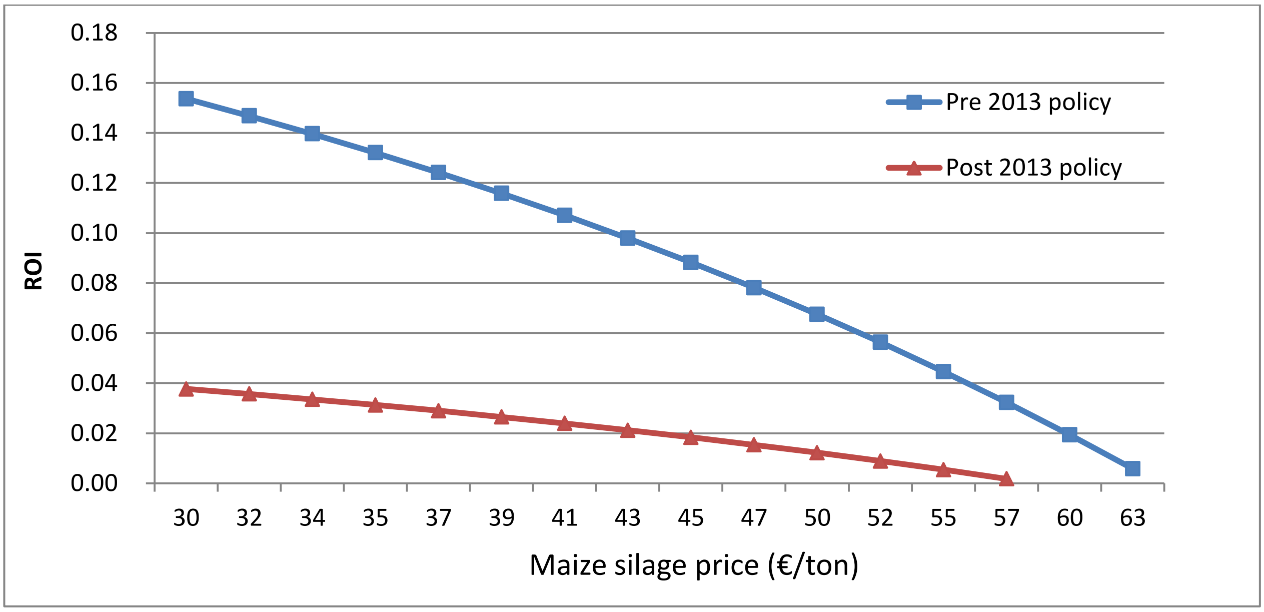
Source: Authors elaboration on results of partial equilibrium model described in Section 2.

Figure 9 – 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.

Figure 10 – Return on Investment for the first plant (s1 interaction) built in Cremona as a function of maize silage price (€/ton): 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.