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The Impact of Different Energy Policy Options on Feedstock Price and Land Demand: The case of Biogas in Lombardy.

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Abstract

The effectiveness of bioenergy subsidisation policy in greenhouse gas mitigation and their hypothetical effect on the increase of the agricultural commodity prices, have led to a lively debate at the international level. The issue recurred in Italy as well, as a consequence of the growing demand of green maize for biogas production in the Po Valley. Such emerging activity has been accused to increase land rents and maize price, jeopardizing, in turn, important agri-food chains. The aim of this thesis 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.

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L'efficacia delle politiche di incentivazione delle bioenergie nell'abbattimento dei gas serra e i loro possibili effetti sull'incremento dei prezzi dei beni agricoli, ha portato allo sviluppo di un intenso dibatto a livello internazionale. La crescente domanda di insilato di mais destinato alla produzione di biogas verificatasi in Pianura Padana, ha evidenziato anche in Italia queste problematiche, soprattutto per quanto riguarda l'aumento del prezzo del mais, degli affitti dei terreni agricoli e i possibili effetti negativi che questo comporterebbe per le filiere agroalimentari tradizionali. Scopo di questa tesi è dunque analizzare l'entità di questo fenomeno quantificandone gli effetti sul prezzo del mais e sulla domanda di terreno destinato a colture energetiche a livello regionale. È stato quindi implementato un modello di equilibrio parziale in grado di simulare il settore agricolo e del biogas in Lombardia, sotto due differenti ipotesi di politiche incentivanti. I risultati mostrano come le politiche di incentivazione entrate in vigore nel 2013 – riducendo la media dei sussidi per kWh prodotto – possono contribuire a rafforzare la sostenibilità del comparto biogas e a ridurne la competizione con le altre filiere agroalimentari: in confronto a quanto si verifica sotto le precedenti politiche di incentivazione, la domanda di mais per la produzione di biogas si riduce, abbassando il prezzo di equilibrio di mercato e riducendo inoltre la domanda di terreno per scopi energetici.

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Keywords: Climate Change / Policy Analysis / Mathematical Programming / Biogas / Market Simulation / Land Use.

JEL codes: C61, Q11, Q21, Q42.

Introduction

The fight against climate change over the last twenty years has resulted in great efforts made at the international level to reduce greenhouse gas (GHG) emissions. Particular attention has been paid to this issue at the European level, where a real agenda of climate policy has been set up in order to promote the introduction of renewable energy sources in place of traditional fossil fuel. Nowadays, indeed, the energy production sector is still the primary driver of anthropogenic GHG emissions (35%). Nevertheless it is immediately followed from Agriculture Forestry and Other Land Use (AFOLU) sector with the 24% of total GHG emissions, primary due to the livestock, rice production and deforestation. AFOLU cover a major role than Industry (21%), Transport (14%) and Building (6.4%) sectors (Smith et al., 2014). Considering that the efficiency gains in terms of GHG emissions reduction are larger in this sector than in others, and that GHG mitigation can be done via photosynthesis removing CO_2 from the atmosphere, in the last years several incentive policies have been introduced to facilitate the spread of bioenergy produced from agricultural biomasses. However, the rapid growth in bioenergy production from energy crops has the potential to affect food security in developing countries and traditional agri-food supply chains (e.g., the livestock sector) in developed countries through its impact on food and feed commodity prices. Higher demand for energy crops induces higher energy crop prices, providing greater incentives for farmers to increase such acreage. The more hectares that are converted to the production of energy crops, the fewer hectares that are available for food and feed crops. Therefore, this process generates competition for land between fuel and food/feed crops, which threatens to nullify the benefits due to the introduction of bioenergy: When crop land expansion for the cultivation of energy crops occurs in a forest area with higher carbon stock value, the effect on greenhouse gas mitigation can be extremely negative; if there is no land conversion, the competition between food, feed and fuel crops can have a negative effect on overall agricultural commodity prices.

Recently, the Renewable Energy Directive was devised by the European Commission in order to set a scheme of mandatory sustainability requirements for biomass and bioenergy production. To be eligible for public support and to be considered for European Union targets for greenhouse gas mitigation, bioenergy must now satisfy cross-compliance criteria and regulations regarding the preservation of soil and water quality and biological diversity. Member States must report on the impact of bioenergy on land use, biodiversity, water and soil quality, greenhouse gas emission mitigation, and changes in agricultural commodity prices that are correlated with the biomass used for bioenergy production. Moreover, the use of by-products such as agricultural (manure, crop waste) and industrial residues is strongly advocated.

At the national level, biogas production from agricultural biomass is one of the most important sources of bioenergy, which, as a consequence of subsidisation policy, has grown strongly in recent years. In Italy, biogas plants are mainly concentrated in Regions of Po Valley (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 (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 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.

As pointed out by Carrosio (2013), the huge expansion of biogas plants has been mainly driven by dedicated subsidization schemes. In particular the feed-in tariff (FIT) introduced in Italy in 2009, has boosted agricultural biogas production between 2009 and 2012, shaping the technology adoption by farmers. Under such scheme, all plants with an electric capacity up less than 1 MWe were entitled to receive the all-inclusive feed-in tariff of 0.28 €/kWh for 15 years, leading the majority of biogas plants to build a capacity slightly less than 1 MWe in order to maximise subsidies (Carrosio, 2013). 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 utilisation (CRPA, 2008; Mela and Canali, 2014).

This aspect is in line with previous studies (e.g. Haas et al., 2011; Britz and Delzeit, 2013) pointing out the distortive effect of renewable energies subsidization when, like in the FITs case, a higher profitability is assured associated to a diminished level of risk, charging taxpayers with associated additional costs (Chinese et al., 2014). Fostered by the economic downturn, public debate arose in Italy on costly support to renewable energy (Galeotti, 2012) prompting, in 2012, 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 have been reduced and further decreased with the increase of plant size. Moreover, in order to encourage the utilisation 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).

The evolution of Italian biogas market and incentive policy has been examined in some recent papers.[1] 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 livestock manure and energy crops), and less than efficient in energy use and environmental outcomes. Chinese et al. (2014), used a linear programming approach to study the effect of current and past Italian biogas incentive systems on plant dimension, input blend and profits. Such simulation makes assumptions on maize supply, using cultivation and harvesting cost as a proxy for input price. Main results show that the 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 improving existing literature, the aim of this thesis is to analyse 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 modelling and integrating

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[1] 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.

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 under past and current 2013 support scheme. This integrated model allows us 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 work is the first application to Italian biogas sector of a partial equilibrium framework, firstly adopted by Delzeit (2010) in Germany. Such approach allows to add relevant contributions as compared to researches 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 structure of the thesis is the following. In the first chapter, we analyse the relations between climate change, bioenergy and food security. In the second chapter, we provide a review of the relevant literature on bioenergy modelling. In the third chapter, we describe the approach followed to build up our integrated partial equilibrium model and the policy framework under which it has been implemented. The data used and the model specifications are illustrated in the fourth chapter and the final results are described in the fifth and last chapter.

Chapter 1

Definitions and Framework: Relations between Climate Change, Bioenergy and Food Security.

1.1 Climate Change

The Earth's climate has changed several times throughout history. Probably due to small variations in the Earth's orbit, just in the last 700,000 years, seven cycles of glacial retreat and advance have taken place, with the end of the last ice age about 7,000 years ago, which was the beginning of the current climate era – and of human civilisation (NASA, 2015). However, today, climate change is defined by what is often referred to as "global warming", which is generated from anthropogenic greenhouse gas (GHG) emissions such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). This shift in the composition of the global atmosphere due to the increase in the GHG levels leads to greater warming, inducing statistically significant variations in either the mean state of the climate or in its variability for a persistently wide timeframe (VijayaVenkataRaman et al., 2012). Climate change therefore can be due to natural internal and external processes or to continuing anthropogenic modifications in the atmosphere's composition (IPCC, 2007). Regardless of that, the evidence and effects described below are directly or indirectly attributable to human activities.

1.1.1 Evidence and Effects

Data provided by the Inter-governmental Panel on Climate Change (IPCC, 2014) points out that the atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have all shown large increases, growing by about 40%, 150% and 20%, respectively, between 1750 and 2010. This is basically due to traditional fossil fuel emissions, but also to net land use change emissions. The increase in GHG emissions could lead to greater warming, which, in turn, could have effects on the world's climate modification, leading to the climate change phenomenon. Persistent emissions of GHGs are capable of increasing warming and long-lasting alterations in all elements of the climate system, increasing the pervasive and irreversible impact on ecosystems and people (IPCC, 2014). It is therefore a growing crisis for economics, health and safety, and food production and security. For example, shifting weather patterns jeopardise food production by altering the intensity and the return time of precipitation, causing rising sea levels, and increasing the risk of catastrophic flooding.

On the basis of the Inter-governmental Panel on Climate Change's Fifth Assessment Report (IPCC, 2013), the World Nuclear

Association (WNA, 2014) established that the evidence for rapid climate change is compelling:

i. More than 50% of the observed increase in globally averaged temperatures since 1951 is *extremely likely* (95 – 100% of probability) to have been due to anthropogenic activities.

ii. GHGs have *likely* contributed to an overall surface warming in the range of 0.5°C to 1.3°C since the mid-20th century (66 -100% of probability).

iii. Human activities have *likely* induced the retreat of glaciers since the 1960s and to the reduction of the ice in Greenland since 1993, and have *very likely* (90 -100% of probability) contributed to ice retreat in the Arctic sea since 1979.

iv. The global sea level rose at an average rate of 0.2 cm per year between 1971 and 2010. This growth was faster from 1993 to 2010, i.e., approximately 3.2 mm per year.

v. It is *very likely* that there is a significant impact of human activities on the increase of the overall average sea level generated from thermal expansion and glacier mass loss due to anthropogenic activities.

vi. Since 1970, more heavy and long-lasting droughts have been recorded, especially in the tropics area.

vii. Pervasive alterations in extreme temperatures have been recorded over the last fifty years. Heat waves have become closer together, while periods of intense cold and frost have become rarer.

viii. The concentration of methane in the atmosphere rose from 715 ppb in 1750 to 1820 ppb in 2011.

ix. The combined radiative forcing due to increases in CO_2, CH_4 and N_2O is +2.83 W/m^2, and *very likely* its rate of growth since 1750 has had no precedent in more than 10,000 years.

Limiting global warming would require significantly reductions in greenhouse gas emissions in order to limit the damage from climate change. In order to address this global issue, over the last thirty years, several initiatives have been developed and taken by different countries and organisations such as the Inter-govermental Panel on Climate Change (IPCC), the United Nations Framework Convention on Climate Change (UNFCCC), and the United Nations Environment Programme (UNEP). Indeed, to adapt and mitigate climate change, climate policies are necessary and require an intensive level of international cooperation.

1.1.2 International Agreement on Climate Change Mitigation and the Evolution of European Climate Policy

The first concrete step in the international cooperation in climate change mitigation was made in 1988, when the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) established the Inter-govermental Panel on Climate Change (IPCC) in order to expand knowledge about the possible effects of global warming (Magsig, 2008). Global warming was, for the first time, considered in an official document in 1990, when, in its first report, the IPCC remarked about the importance of taking action in the form of a multilateral agreement to counteract this phenomenon (IPCC, 1990). The ensuing treaty, the United Nations Framework Convention on Climate Change (UNFCCC), was signed at the Rio Earth Summit[2] by 192 states in 1992. The governments agreed on the aim to "stabilize the GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (Art. 2 UNFCCC) and a non- mandatory target was implemented which required developed countries to take the

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[2] United Nations Framework Convention on Climate Change, UN Doc A/CONF.151/26, adopted 09/05/1992 (entered into force 21/03/1994).

initiative to address the problems of global warming, reducing their greenhouse gas emissions to 1990 levels (Art. 4(2) UNFCCC). However, it was soon clear that more stringent rules would be needed to face climate change. The negotiations that followed led to the Kyoto Protocol[3] in 1997, which marked an important starting point in the development of future climate policy, setting an overall reduction of 8% of greenhouse gas emissions by 2008-2012.

The European Commission realised that, to achieve this goal, it would be necessary to strengthen the actions taken in the Member States and at the EU level. Consequently, in 2000, the European Climate Change Program (ECCP) was established with the purpose of identifying all "elements of a European Climate Change strategy" and suggesting "common and coordinated policies and measures on climate change" for several economic areas (European Commission, 2000). As was well documented in Magsig (2008), following the adoption of the ECCP, the EU implemented various measures on energy taxation, emissions trading, energy efficiency improvement, renewable energy incentives, and other activities to reduce GHG emissions[4].

In 2001, the Renewable Electricity Directive 2001/77/EC set a target for 21% of total electricity to be produced from renewable sources by 2010 (European Commission, 2001). In 1997, the share of green electricity in the EU was 12.9%. A national indicative target was defined for electricity generation from renewable sources in each Member State (MS). Driven by this Directive, renewable electricity production increased in the EU to 641 TWh in 2010, out of which 334 TWh was hydro power, 155 TWh wind, 123 TWh biomass, 23 TWh solar and 6 TWh geothermal (Scarlat et al., 2015). The share of renewable electricity has risen steadily,

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[3] Kyoto Protocol to the United Nations Framework Convention on Climate Change, UN Doc FCCC/CP/1997/7/Add.1, adopted 11/12/1997 (entered into force 16/02/2005)

[4] E.g. Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources and Directive 2003/87/EC.

reaching 13.6% in 2005 and 19.5% in 2010 (Eurostat, 2013); despite very important growth, the EU did not reach the target of 21% expected for 2010. In that year, hydro power again contributed the largest share of renewable electricity production (10.1%), followed by wind (4.5%), biomass (3.7%), and solar power (0.7%). It is, however, important to underline that the biggest growth in electricity production realised between 2000 and 2010 took place in wind, with a 127 TWh increase, followed by biomass, with 89 TWh (Scarlat et al., 2015).

In continuity with Directive 2001/77/EC, in 2003, the Biofuels Directive 2003/30/EC set a target for 2010 for biofuels and other renewable fuels to replace petrol and diesel by 5.75% of all of the petrol and diesel used in transport (European Commission, 2003). Although the data point out that the target was not met in 2010, biofuel consumption in transport has increased from 125 PJ in 2005 (1.0% biofuels) to 556 PJ biofuels in 2010 (4.4% biofuels), below the target of 5.75% (EurObserv'ER, 2011; Eurostat, 2013).

In January 2007, with the Green Paper entitled "A European Strategy for Sustainable, Competitive and Secure Energy" (European Commission, 2006), the Commission established a comprehensive and integrated climate and energy policy (European Commission, 2007). For the first time, the Commissioner for Energy Policy and the Commissioner for the Environment combined their efforts to tackle the challenges of a renewable energy supply and global warming (Mehling and Massai, 2007). In particular, the following objectives have been defined (Magsig, 2008):

1) A 30% reduction of greenhouse gas emissions by 2020 compared to 1990 levels, provided that similar efforts would also be made by other developed countries;
2) A 20% reduction of GHG emissions by 2020 relative to 1990 levels, regardless of the efforts made by other countries.

3) A 20% share of green energy within the total energy blend by 2020, as well as a consumption of 10% of biofuels within the overall European transport fuel used by 2020;
4) A 20% reduction in energy expenditures through energy efficiency improvements by 2020.

After the establishment of such ambitious targets by the European Council, the Commission worked out the policy framework to achieve these goals: The Renewable Energy Directive (RED) 2009/28/EC[5] on the promotion of renewable energy sources requires the MS to increase the quota of renewable energy to 20% of overall energy consumption and to 10% of green energy in transport by 2020 (European Council, 2014). The RED indicates national targets, which are legally mandatory rather than indicative goals for the share of green energy. Each Member State has its own target for the share of renewable energy and a share of 10% of energy from renewable energy sources in transport (Scarlet et al., 2015). Moreover, the Fuel Quality Directive 2009/ 30/EC sets an additional target of a 6% GHG reduction in fossil fuels used for transport by 2020 (European Commission, 2009a). Bioenergy is expected to be the main contributor to the 2020 goals (more than half of the 2020 renewable energy target; Atanasiu et al., 2010); for this reason, the use of bioenergy raises several issues relating to its sustainability and its effectiveness in reducing GHG emissions. Articles 16, 17 and 18 of the RED contextualise the concept of sustainability and the compliance criteria for transportation biofuel. Regarding solid biomass used for electricity and heat production, the RED requests supplementary explanations of its sustainability from the Member States, but the high share of energy crops identified in the National Renewable Energy Action Plans (NREAPs) has raised a debate about the possible competition between bioenergy promotion, the availability of agricultural commodities and

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[5] EC, Directive 2009/28/EC, repealing Directives 2001/77/EC and 2003/30/EC., on the promotion of energy from renewable sources.

bioenergy's ability to reduce greenhouse gas emissions (Atanasiu, 2010).

1.2 Biomass and Bioenergy

Biomass can contribute to minimising the utilisation of traditional fossil fuels (petrol) and mitigating GHG emissions. This result is based on the concept that the utilisation of bioenergy, produced via biomass combustion, does not increase GHG emissions like the utilisation of fossil fuel, provided that the reductions in GHGs through its utilisation are not nullified by emissions due to biomass production and transformation. In this paragraph, we define the following key concepts: Biomass, bioenergy, renewable and sustainable.

Bioenergy is driven by organic materials; the chemical energy present in these materials (biomass) can be converted into energy that is suitable for anthropogenic activities using thermic, chemical, biological or mechanical processes (Bessou et al., 2011).

The prefix "bio" comes from the Ancient Greek "ϐίος" ("life") and means that the origin of the energy is due to the metabolism of living organisms. In the energy sector, biomass refers to biological material which can be used to produce energy in the form of electricity, heat or fuel for transport. The energy produced from biomass, therefore, is named bioenergy, and in contrast to fossil energies, whose formation takes millions of years, it is renewable on a human time scale. However, it is also important to underline that the term "renewable" is not synonymous with "sustainable".

Renewable resources can be divided into two main types of natural resources: Flow resources and renewable stock resources (Bessou et al., 2011). Flow resources, such as solar or hydro energies, are non-limited resources. The availability of renewable stock resources, particularly biomass, depends on natural factors such as land, water, etc. and on their rate of growth and anthropic production/consumption rates. In the energy field, Renewable Energy Sources (RES) are defined as all energy coming from renewable sources, e.g., hydro energy, solar energy, bioenergy, etc. Considering biomass, "renewable" means that, theoretically, it can be endlessly available. However, as explained above, this depends on its management: If biomass is obtained through good agricultural practices and is environmentally friendly, socially favourable, and economically viable, this renewable energy source can be considered sustainable (Bessou et al., 2011). The topic of sustainability has become crucial in the bioenergy sector, to the extent that, at the end of 2006, the United Nations Executive Board for Clean Development Mechanisms released an official definition of "Renewable Biomass" which also introduces the dimension of sustainability (UNFCCC, 2006). The document enshrined the concept of "renewable biomass", and it established that the land use to produce renewable biomass shall not change unless land areas are reverted to forest. Moreover, it established a second criterion that was implicitly linked to the first:

> "*Sustainable management practices are undertaken on these land areas to ensure in particular that the level of carbon stocks on these land areas does not systematically decrease over time*" (UNFCCC, 2006).

This is, therefore, a key element when comparing the GHG emissions from bioenergy and traditional fossil energy. The notion of the carbon neutrality of combusted biomass is focused on the concept that the carbon dioxide released during the energy production process originates in the atmosphere, where it returns; if land conversion (Land Use Change, see Section 1.3) due to biomass production leads to new, additional carbon dioxide emissions, the carbon neutrality of bioenergy can be offset. Therefore, to be renewable, biomass must be produced under sustainable management practices criteria.

1.2.1 Transportation Biofuels

Transportation biofuels are made from several typologies of biomass and can be liquid or gaseous. Bioethanol and biodiesel are the most important typologies commonly employed as transportation biofuels.

Bioethanol

Bioethanol is an alcohol (C_2H_5OH) obtained by the fermentation of several types of biomass, such as sugar cane, maize, wheat, soya, sweet sorghum, sugar beet or potatoes. Used basically as a petrol substitute and additive, this alcohol accounts for almost 90% of all biofuel production (IRGC, 2008); it may be substituted for or blended with gasoline having a fossil origin in different percentages in petrol-driven cars.

Biodiesel

In contrast to bioethanol, biodiesel is not produced through biomass fermentation, but is extracted from animal fat and vegetable oils such as rapeseed, soya, and palm oil. Chemically, bioethanol can be defined as being composed of fatty acid methyl esters; consequently, the oil derived from biomass is frequently processed via transesterification with methanol in order to obtain biodiesel. Like bioethanol, biodiesel can be used as a transportation biofuel and is usually sold blended with diesel in low percentages. Europe is the largest biodiesel market at the global level.

Second-generation biofuels

The term “second-generation” refers to technologies for producing ethanol, biodiesel, and other biofuels (butanol and biomethane) from a larger range of non-edible biomass. As shown later, this is important in order to avoid competition for land between food/feed crops and energy (fuel) crops. Biomass employed to produce second generation biofuels therefore includes agricultural and forestry residues, grasses, algae, short-rotation woody crops, and municipal solid waste. The utilisation of perennial and deep-rooted second-generation energy crops, such as fast-growing trees, would enhance carbon sequestration and reduce the use of water, fertilisers, and pesticides.

1.2.2 Bioenergy for Heat

Since ancient times, firewood has been the traditional source of heat for domestic purposes, such as local heating and food preparation. Burning biomass to obtain heat is therefore an ancient use of bioenergy, and it is still the main form of domestic energy in several developing countries. The availability of solid biomass for heat (e.g., chips, pellets, and briquettes, but also vegetal coal and wood) has created renewed interest in the utilisation of solid biofuels as a heating source for domestic use. Modern stoves and furnaces, which have significantly improved efficiency in the production of heat, makes them suitable for household use and district-scale heating systems where a sustainable supply of suitable biomass is achievable (IRGC, 2008). Biomass can alternatively be used in the supply of heat for other applications: The combustion of biomass can be employed to guarantee the correct temperature during the fermentation and distillation of bioethanol, and can also produce electricity through cogeneration (see Paragraph 1.2.4).

1.2.3 Bioenergy for Electricity

Biomass can also be employed to produce electricity using several proceedings. Solid biomass, such as energy crops, agricultural residues, wood chips, wood pellets or municipal solid waste, can be combusted jointly with traditional fossil fuels (co-firing). Electricity generated from well-managed, sustainable biomass can provide an affordable, consistent, and low-carbon source of renewable electricity, thereby making a valuable contribution to the reduction of greenhouse gas emissions.

Biogas obtained from anaerobic digestion is commonly used for power generation, either using gas engine generators or through co-firing with natural gas. Biogas can be obtained from almost any kind of biomass, including from the primary agricultural sectors (i.e. energy crops, crop residues, livestock manure, and slurry) and various organic waste streams coming from the agro-industrial sector, as well as urban waste (Holm-Nielsen et al., 2009). In considering energy crops as a substrate suitable for anaerobic digestion, the most common are grain crops, grass crops, and maize. Maize silage is considered to be the most suitable energy crop for biogas production (Braun et al., 2008).

1.2.4 Bioenergy for Combined Heat and Power

Cogeneration or combined heat and power (CHP) systems represent an advanced technology that can significantly improve the overall efficiency of energy use where both heat and electrical power are needed. The main forms of biomass employed are: energy crops, agricultural residues, forest residues, wood waste, agricultural biogas, municipal solid waste, and food processing residue. Cogeneration would allow a more efficient utilisation of biogas through the simultaneous production of electricity and heat. Due to low efficiency in the transportation of hot water and to the relatively dispersed nature of biomass resources such as agricultural residues or wood waste, fully biomass-fuelled CHP plants are not very common and lend themselves to community-scale operations of less than 50 MWe (IEA, 2005).

1.3 Bioenergy and Land Use Change

Land-use change is deemed to be one of the most significant environmental impacts to address, in particular, because of its impact on greenhouse gas emissions and wider ecosystems. Accurate assessments of the impacts related to Land Use Change have increased the amount of criticism from economists and international organisations, which call for further analysis of the effects of bioenergy. Moreover, the EU and other countries have adopted a legislative system (certification) for different typologies of bioenergy in order to impose sustainability criteria concerning biomass production (see Section 1.6).

At the same time, precisely because the majority of the feedstocks that are now employed to produce bioenergy are also important globally traded food and feed commodities, the impact of bioenergy on food and feed prices has been strongly debated, especially after the occurrence of price spikes between 2007 and 2011. It is therefore necessary to clarify the impact of bioenergy production on land demand, and the difference between direct and indirect land use change, in order to clarify the possible consequences due to the introduction of bioenergy on agricultural commodities and greenhouse gas emissions.

Direct and indirect land use changes are defined as follows:

We observe **Direct – Land Use Change (D-LUC)** when the introduction of bioenergy generates an increase in the demand for energy crops. This happens because farmers have an incentive to satisfy this demand by producing more feedstock for bioenergy production. Notwithstanding that, in some cases, this increase in production could be obtained from increasing the yield (output) of existing cropland, frequently the use of land is changed (from food/feed crops to fuel crops), or cropland area is increased, using other previously uncultivated land (e.g., forests). The cropland expansion phenomenon due to the cultivation of energy crops is known as the Direct – Land Use Change effect (D-LUC). The release of carbon from the expansion of cropland for bioenergy production from virgin land can nullify the concept of the carbon neutrality of combusted biomass (see Section 1.2). Theoretically, it is possible to keep track of the land-use before potential cropland expansion to observe direct land-use change (Bentivoglio and Rasetti, 2015), and the negative impact on GHGs emissions due to the cultivation of energy crops is easily identifiable when the cropland expansion occurs in forest areas, which have a higher carbon stock value.

When biomass for bioenergy is produced on cropland that is already cultivated, there is no direct land use change effect observable. However, the reduction of agricultural products for food and feed generates an increase in their prices in response to the reduced supply. In turn, the increase in food/feed prices induces an incentive to expand cropland areas elsewhere for their production. The release of carbon from the expansion of cropland for the production of displaced agricultural products, which is known as the **Indirect – Land Use Change (I-LUC)** effect, could nullify the carbon benefits associated with bioenergy programs, jeopardising the biodiversity, soil quality, and natural resources in a specific area (Perimenis et al., 2011; Copenhagen Economics, 2011; Bentivoglio and Rasetti, 2015). In other words, indirect land use effects are mainly market related effects; the increase in the market prices of agricultural products is the link between bioenergy promotion and indirect effects (see Delzeit et al., 2011; Zilberman et al., 2010).

The greenhouse gas effects of I-LUC are hardly quantifiable with precision in relation to a specific bioenergy project, particularly because the causes are often complex, correlated, and interlinked. Moreover, the significant uncertainties involved in the quantification of land use change (direct and indirect) effects can have a significant impact (positive or negative) on the benefits with respect to climate change mitigation due to bioenergy production (IAE, 2011). If land conversion occurs only within the land already used for crops, the effects on greenhouse gas emissions are minimal. On the other hand, if forests are cleared to produce agricultural products as a replacement for food or feed crops areas, the global increase in GHG emissions is significant.

The increase in GHGs due to ILUC effects make assumptions as to both the location and the typology of the land conversion (Liska and Perrin, 2009; Kammen et al., 2008): If the conversion consists in clearing and burning forests, which is then followed by cattle pasturage, the greenhouse gas detriments are higher; but, if the land is converted to low-tillage and mixed farming, the detriments can be considerably diminished (Harvey and Pilgrim, 2011). Biomass for bioenergy production can also lead to the assimilation of CO_2 (via photosynthesis), and this can improve the mitigation benefits. One example is the reforestation realised on degraded land with carbon-depleted soil, or when the soil quality (and consequently, its productivity) is restored after appropriate land management and biomass selection for bioenergy production. There are several options to minimise the direct and indirect land use change effects: First, by improving the yield of existing cropland or by integrating food and energy production; second, by using abandoned or degraded lands for biomass production; third, by using agricultural residues; and, finally, by co-producing bioenergy with another product (LEI, 2013). Such sustainable, integrated food-energy systems (IFES) have the potential to reduce the impact and the competition for land generated by bioenergy production (Bogdanski and Ismail, 2012; Bogdanski et al., 2010).

1.4 Impact of Bioenergy on Food Commodity Prices

In recent years, the amount of bioenergy has undeniably increased around the world. This expansion has been driven primarily by the sharp increase in energy prices and by climate change mitigation policies in an attempt to reduce the harmful effects of energy production from traditional fossil fuels on global warming. Because it uses biomass as input, bioenergy production is directly linked to the agricultural sector, and, in turn, with the prices of agricultural goods (see preview Section). Due to price inelastic food demand and land supply, the increase in the prices of agricultural commodities can be significant (Ciaian et al., 2011).

As pointed out by Janda et al. (2011), one of the stronger forces through which bioenergy has affected agricultural commodity prices is the change in land use from food and feed crop production to fuel crops, i.e. as biomass devoted to bioenergy production. This phenomenon occurs when the demand for energy crops increases, resulting in higher prices for them. Higher energy crop prices generate greater incentives for farmers to increase the land area intended for their cultivation. As more land is converted to energy crop production, less land is available for food and feed crops (Alexander and Hurt, 2007). The consequent scarcity of food crops drives food price inflation.

The hypothetical effect of bioenergy subsidisation policy on the increase in agricultural commodity price developments has induced a lively debate at the international level. On the one hand, several international organisations, such as the World Bank and the International Monetary Fund, claim that bioenergy has had a negative impact on food crop prices: According to the World Bank's study, almost 80% of agricultural commodity price increases could be ascribed to bioenergy production (Mitchell, 2008). The International Monetary Fund calculated that the growing demand for maize and soybeans due to the extension of biofuel production accounted, respectively, for 70% and 40% of the increase in their prices (Lipsky, 2008). Similarly, the FAO (2008) and the OECD (2009) also claim that the expansion of bioenergy production is related, directly or indirectly, with the recent increase in food prices.

On the other hand, policymakers in Europe and the United States minimise the impact of bioenergy on recent food price trends. The United States Department of Agriculture (USDA) agrees that the demand for energy crops for bioenergy has affected food commodity prices, but claims that it is not the main factor. According to the data provided by the USDA, only 3% of the 40% increase in agricultural commodity prices can be ascribed to bioenergy production (Reuters, 2008). Likewise, the EU Commission (2008) considers that the development of energy prices has influenced food commodity prices by increasing the input costs for agricultural crops (fertilisers) and their transportation costs; but regarding the impact of bioenergy (biofuel) on agricultural commodity prices, the Commission's view is that it is negligible and not able to affect the agricultural market: Europe uses "less than 1% of its cereal production to make ethanol. This is a drop in the ocean" (European Commission, 2008).

The link between the trends in fossil fuel energy prices and agricultural crop prices, and their parallel increase in price volatility has been investigated in the literature using three types of approaches. First, an integrated analysis is used to calculate the long-run relationship between fuel and agricultural crop prices (Campiche et al., 2007; Yu et al., 2006; Hameed and Arshad, 2008; Imai et al., 2008). However, the absence of a theoretical basis regarding the relationship between fuel and biomass prices, and the fact that the channel of price transmission is not identified, are the primary weaknesses of these empirical studies (Ciaian et al., 2011). Second, theoretical models are built to detect and relate the pathways of adjustment between energy crops, food and feed crops, and bioenergy and energy markets (de Gorter and Just, 2009; Saitone et al., 2008). This branch of literature presents interesting perspectives, although it also has shortcomings due to the scarcity of theoretical models to date. Finally, general equilibrium (CGE) models and partial equilibrium (PE) models (see Chapter 2) have been developed to simulate the relationship between biomass, bioenergy, and energy price development (Hayes et al., 2009; Birur et al., 2008; Tokgoz, 2009). The main limitation of the CGE and PE models is due to the assumed price transmission elasticities, on which the simulated effects of the models largely depend.

Combining the theoretical underpinning with empirical evidence in a unified framework, Ciaian and Kanks (2011a, b) overcomes these limitations. Due to a vertically integrated partial equilibrium model, the authors pointed out that the transmission between fuel prices and biomass prices occurs mainly through the bioenergy channel. These results suggest that bioenergy policies may have an impact on on agricultural commodities prices and that their effect is stronger than the increase in fossil fuel energy prices. The impact of bioenergy production on agricultural commodities prices is therefore an aspect to be carefully considered.

1.5 Bioenergy, Land Use Change and Food Security: The Environmental Trilemma of Climate Change

According to International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD, 2009) and Royal Society (2009) reports, the main factors that have increased competition in land use derive from the strong increase in the world population, which is expected to reach 9 billion by 2050, and the changing demand for food (in countries with large populations, such as China, the consumption of meat has been sharply rising). Although, as explained in Section 1.3, greenhouse gas emissions mitigation policy has concentrated on the use of fossil fuels, the displacement in land-use can also be an important aspect affecting greenhouse gas emissions: Carbon dioxide emissions related to land conversion and current agricultural land use are at least two and a half times greater than the total emissions due to global transport (IPCC, 2007). Thus, any increase in land use for food, feed or energy production should be done sustainably, without further aggravating anthropogenic GHG emissions (see Section 1.3). ‘Feeding the nine billion’ is a challenge that must be met from two directions: On the one hand, restricting greenhouse gas emissions from land-use changes that are arising due to the expansion of cultivated areas; on the other hand, improving the sustainability of the main crops and cultivation (Royal Society, 2009; Godfray et al., 2010). One example is the production of rice, which, although the increase in the demand for meat is frequently considered to be one of the most dangerous sources of additional GHG emissions, is the bigger contributor, at the global level, to methane emissions, which is 20 times more powerful than carbon dioxide in its greenhouse gas effect (IPCC, 2007).

As pointed out by Bentivoglio and Rasetti (2015), the exponential growth in bioenergy production has the potential to affect food security, mainly through its impact on food prices (see Section 1.4). As the income of people living in developing countries is expended on food purchases, rising food prices generate food insecurity, which is the lack of secure access to safe and nutritious food, and a healthy life (Timilsina and Shrestha, 2010).

There is thus a potentially vicious circle resulting from land use extension, increases in the risk of global warming, and the decreasing availability of land devoted to food and feed crops: When the demand for food, feed, and energy crops increases simultaneously, the land use change effect also increases, leading, in turn, to a further intensification in climate change, which may affect the yields of agricultural land, thus creating a potential vicious spiral (Harvey and Pilgrim, 2011). This is the trilemma issue.

Given the complexity of the problem and the efforts necessary to solve the food-energy-environment trilemma, new modes for the political governance of market economies are required. Sustainability regulations for bioenergy production have been developed in order to stem market distortions for food and feed commodities. Strategic direction and positioning of innovation to meet these challenges requires the fine tuning of new policy instruments in order to achieve the long-term objective of self-sufficiency apart from fossil fuel. This requires political governance and sustainability regulations in order to bring about long-term structural changes in the production of food, feed, and bioenergy, taking into account that none of these three elements can be treated in isolation.

1.6 New Sustainability Requirements for Bioenergy in Europe

The Renewable Energy Directive was devised by the European Commission (2009b) in order to set a scheme of mandatory sustainability requirements for biomass and bioenergy production. Similar criteria were established in the Fuel Quality Directive (FQD) 2009/30/EC (European Commission, 2009a) for the specification of traditional fossil fuels (petrol, diesel and gas) with a monitoring system to reduce greenhouse gas emissions. To be eligible for public support and to be considered for European Union targets on GHG mitigation, biofuels must now satisfy cross-compliance criteria and regulations regarding the preservation of soil and water quality, biological diversity, and the careful utilisation of fertilisers and pesticides. Several land categories for biofuel production are identified and excluded, such as high biodiversity value land (primary forests, protected natural areas, peat lands) and high carbon stock land (wetlands, forested areas). Moreover, such sustainability criteria include monitoring and reporting requirements: Member States must report on the impact of bioenergy on land use, biodiversity, water and soil quality, greenhouse gas emission mitigation, and changes in agricultural commodity prices which are correlated with the biomass used for bioenergy production.

After establishing sustainability criteria for biofuels and bioliquids, in 2010, the European Commission also enacted sustainability requirements for solid and gaseous biomass intended to produce electricity, heating, and cooling (COM(2010) 11). In this case, the sustainability criteria for biomass production also concern the containment of land use change effects and the protection of biodiversity, ecosystems, and carbon stocks (European Commission, 2010). Biomass cannot be sourced from land converted from high biodiversity value land or high carbon stock land. In order to minimise the risk of adopting inhomogeneous and even inconsistent criteria at the national level, the EU directive requires the Member States to set up national criteria and targets for biomass, establishing the same criteria set in the Renewable Energy Directive for biofuels (Scarlat et al., 2015).

For the first time, in 2012, the Commission released a proposal (COM(2012)595 final) in order to take account of the ILUC effects due to biomass devoted to bioenergy production. For this reason, the development of a second generation of biofuels from a wider range of non-edible biomass, such as algae, agricultural residues, and municipal waste, is fostered, because its development does not affect food and feed production and prices. The use of first generation biofuels (made from food crops such as cereal, sugar beets, and oil crops, see section 1.2.1) was limited to 5% of biofuels and bioliquids consumed in 2011 (European Commission, 2012).

The Commission also proposed including the ILUC effect in the computation of greenhouse gas emission savings: At least 60% of GHG emission savings must be from biofuels and bioliquids produced in new plants; in the case of existing installations, achieving a GHG emission savings of at least 35% by the end of 2017 and at least 50% by the end of 2018 is required (Scarlet et al., 2015). In order to promote second generation biofuels, which, theoretically, should not create an additional demand for land, provisions encouraging biomass cultivation in depleted and polluted lands no longer apply. Moreover, with the aim of counteracting the ILUC effect and accelerating the shift from first to second generation biofuels, on 28 April 2015, the European Parliament adopted a compromise text in which first generation biofuels (obtained from food and feed crops) should be reduced from 10% to 7% of energy consumption in the transport sector by 2020.

Chapter 2

Modelling Biomass Supply, Demand and Input for Bioenergy Production

Existing approaches for analysing the biomass market for the production of bioenergy (demand, supply, and impacts) can be approximately categorised into the following modelling areas: i) Computable general equilibrium (CGE) models, ii) partial equilibrium (PE) models, and iii) bottom-up farm level models.

This classification is useful to identify the strengths and limitations of existing approaches, although they are, to some degree, fictitious and general, because each model and approach is characterised by its own peculiarities, and frequently, contain elements of more than one category, or different approaches can be integrated among them.

Mathematical programming [linear programming (LP), non-linear programming (NLP), mixed integer programming (MIP), dynamic mathematical programming (DMP), and positive mathematical programming (PMP)] is frequently used in modelling the CGE, PE, and bottom-up farm level models, but the econometric approach and the agent-based model (ABM) also offer valuable analytical perspectives. The approach chosen is often determined as a function of the data available, the model specification, and the research scope.

In this chapter, we describe the main implementation of the three categories of models introduced above, their strengths and limitations, and the possibilities offered for the assessment of the impact of bioenergy production on the agricultural market.

2.1 Computable General Equilibrium Models

Computable general equilibrium (CGE) models have been employed to study the macro-economic effects of different policies over the last 25 years (Wicke et al., 2014).

The first policy analyses using CGE models were conducted by Shoven and Whalley (1984) to identify connections between taxation and trade, but subsequently, the CGE approach has also been applied to other topics, such as the immigrant labour force (Borjas, 2004), climate change mitigation (Block et al., 2006), and land use change effects (van Meijl et al., 2006).

More recently, CGE models have also been applied to investigate the effects of bioenergy policies on land-use changes due to the introduction of energy crops in the agricultural crop pattern and greenhouse gas emissions resulting from bioenergy (Banse et al., 2008; Taheipour and Tyner, 2012; Laborde and Valin, 2012). The CGE model LEITAP (Landbouw Economisch Instituut Trade Analysis Project), is currently being extended to represent the production, consumption, and trade of biofuel products derived from first generation energy crops (Nguyen and Tenhunen, 2013). Due to the Global Trade Analysis Project (GTAP), computable general equilibrium models have been applied to study agricultural market settlements and land conversion at the global level (Narayanan and Walmsley, 2008). These structural models are able to solve different utility and profit maximisation functions [see Robinson et al. (2014)]. The main advantage offered by CGE models is their comprehensiveness in terms of the key economic relations between the different input factors under investigation, accounting for these interlinkages through their complete coverage of sectors, input factors, and countries. This allows the identification of market adjustments and related changes in terms of trade, market balances, and factor markets (Wicke et al., 2014). Consequently, CGE models are able to test the economic and environmental effects of extant and hypothetical policies.

Another strength of computable general equilibrium models is that they encompass the entire range of economic activity. Consequently, through the application of CGE models to the bioenergy field, it is possible to estimate the global welfare impact of bioenergy incentive policies in different countries and regions through an overall view of the entire set of policy systems in force in these countries and regions. This family of models is therefore helpful in analysing the effects of bioenergy production and incentive systems in the short/medium term, particularly when they are employed with a higher level of disaggregation or when the sectoral and intra-regional interlinkages are sizeable.

However, there are also significant limitations that make the application of these models difficult: If, on the one hand, their comprehensiveness provides information on the global economic effects of extant and hypothetical policies on market adjustments, on the other hand, their high level of aggregation limits the degree to which a bottom-up dataset can be actually correlated within the larger model (Hoefnagels et al., 2013). Moreover, to represent aggregated behaviour using smooth mathematical functions and to calibrate CGE models with a restricted dataset, heavy simplifications and behavioural assumptions are necessary, and although theoretically, it is possible to add more complex relationships, data, and detail in terms of the considered sectors, the mathematical relationships within this family of models essentially remain highly aggregated and simplified (Wicke et al., 2014).

2.2 Partial Equilibrium Models

Like CGE models, partial equilibrium models also follow the same neo-classical framework, assuming that the market is at equilibrium and moves to another equilibrium after each economic shock, i.e. the supply price adjusts to equal the demand price. However, under the framework of PE models, the economic system is not represented comprehensively. Consequently, the basic assumption of this family of models is that the interrelation with other sectors of the economy is negligible. PE models are indeed applied to investigate specific sectors (e.g., trade, agriculture), for which they are preferred over CGE models because of their capacity to disaggregate the sector with more preciseness. Although the structure is usually similar between PE models, their framework can vary strongly in the function of their economic assumptions (e.g., welfare function optimisation). The partial economic models used to investigate the agricultural sector are called agricultural sector models or ASM (Nguyen and Tenhunen, 2013; Witzke et al., 2008; Müller, 2006; Heckelei, 2002, 1997; McCarl, 1992). Some of them are static or comparatively static (e.g., SWOPSIM, RAUMIS) and therefore suitable to emphasise the components of decision-making, while others are dynamic (e.g., AGLINK, ESIM) and consequently employed to investigate the decision-making process.

PE models are largely used to investigate the welfare or other impacts on a feedstock market due to different policy options or technological changes, including the case of the biomass devoted for bioenergy production [see e.g., De Gorter and Just (2009) and Babcock et al. (2011)]. Models such as CAPRI (Common Agricultural Policy Regionalised Impact; see Britz and Witzke, 2014) comprise a large number of activities and NUTS

(Nomenclature of Territorial Units for Statistics)[6] 2 regions, providing a high degree of information in the supply and demand construction. The main PE models that are suitable to analyse the impact of bioenergy production on the feedstock market (price and quantities) are: the IMPACT model (Rosegrant et al., 2012); the FAPRI-CARD model (Devadoss et al., 1989); FASOMGHG (Beach et al., 2012); the ASMGHG model (Schneider et al., 2007) and GLOBIOM (Havlık et al., 2011), although there are many others. The IMPACT model (International Model for Policy Analysis of Agricultural Commodities and Trade) has been developed to assess the effect of first generation biofuels on the world market for food and feed crops (Msangi et al., 2007). The multi-commodity market model, FAPRICARD, has been applied to analyse indirect land-use changes due to bioenergy production. The FASOMGHG model (Forest and Agricultural Sector Optimization Model with Greenhouse Gases) simulates the optimal land allocation over time to other competing activities in the U.S. forestry and agricultural sectors in order to assess the associated impacts on commodity markets and simulate the environmental effects due to land use change and production practices, including a detailed accounting of the changes in net greenhouse gas emissions (Beach et al., 2010). The ASMGHG (Agricultural Sector and Greenhouse Gas Mitigation Model) and GLOBIOM (Global Biosphere Management) models follow a bottom-up approach to estimate the level of production on the basis of explicit production cost calculation using data with highly detailed geographic representations. Their supply function for biomass considers various management hypotheses and a great variety of agricultural crops and forest commodities (Wicke et al., 2014).

The advantage derived from the utilisation of PE models is their great level of flexibility in entering data: While CGE models necessitate a large amount of information and massive datasets, in the case of PE models, the data must be entered only for the sectors under investigation, limiting distortion due to dataset

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

rebalancing. However, as already mentioned, PE models also have some limitations: The first is the absence of links between the sectors not considered. Moreover, as bioenergy is interconnected with agricultural commodities, forest products, and energy sectors, focusing attention on only one of these three fields can cause feedback from the sector not considered by the model to be missed. One possibility to fix this issue is to integrate two models and to utilise them simultaneously, thereby establishing links between the different model approaches: Recently, the Kiel Institute for the World Economy (IFW), in collaboration with the University of Bonn, coupled the Dynamic Applied Regional Trade (DART) CGE model with the RAUMIS (Regionalised Agricultural and Environmental Information System) PE model in order to take international developments into account and to study the regional impact of bioenergy markets. Moreover, it also develops a location model (ReSI-M, Regionalised Location Information System – Maize) for the identification of the optimal locations, numbers, and sizes of biogas plants across Germany on the basis of the minimisation of the transport costs for the maize used to produce biogas, subsequently linking this model with the DART-RAUMIS system (Delzeit 2010; Delzeit et al., 2010; Kretschmer et al., 2009). Others examples of this model collaboration can be found in large projects such as SEAMLESS (System for Environmental and Agricultural Modelling Linking European Science and Society; van Ittersumet al., 2008) and IMAGE (Integrated Model to Assess the Global Environment; Bouwman et al., 2006). This category of models, in which individual models are integrated into an interdisciplinary framework in order to overcome their individual weaknesses, can be also classified separately as Integrated Assessment Model – IAM. An overview of such integration activities is given in the Global Change Biology (GCB) Bioenergy journal, review article 'Model collaboration for the improved assessment of biomass supply, demand, and impacts.' (Wicke et al., 2014). However, most IAMs employed to analyze bioenergy policies, are among the more complex existing in literature, issue that involve sophisticate parametrization and calibration before their application.

2.3 Bottom-up Farm Level Models

Following the approach proposed by Ciaian et al. (2013), bottom-up farm level models can be divided in function by the type of farm represented: individual (real) farms (e.g., Evans et al., 2006; Buysse et al., 2007a) or farm type. The farm type group, in turn, can be divided into two sub-typologies: farm groups such as in the CAPRIFT (Common Agricultural Policy Regionalised Impact Modelling System – Farm Type; Gocht and Britz, 2011) or representative (e.g., average) farms such as in the FSSIM (Farm System SIMulator; Louhichi et al., 2010). Modelling individual (real) farms has some advantages compared to farm types: The high level of heterogeneity present in the sample allows the better identification of the impact of different external agents (policy options, bioenergy) among farms and reduces distortions in response to policy and market signals. The main limitations are represented by the heavy parametrisation requirement, as well as the model validation (calibration), which is more difficult and sensitive in comparison with farm type based models.

2.3.1 Farm Mathematical Programming Models

The majority of farm models are based on mathematical programming: At given prices and unit costs, a general maximisation (or minimisation) function, subject to a set of constraints represented by production possibilities (e.g., agronomic constraints) and policy impositions (e.g., greening), is solved in terms of input choice and land allocation. The standard formulation process for MP models can be found in Hazell and Norton (1986). The output of MP models can be used to emphasise the components of decision-making (comparative-static approach) or to investigate the decision-making process (dynamic approach). The main advantages related to MP models are:

i. It permits the simulation, due to its primal based approach, of farmer behaviour under different policy options and technologies, facilitating interdisciplinary research on agro-environmental interaction;

ii. It allows the modelling of complex policy constraints under which behavioural functions cannot be easily identified (Heckelei and Wolf, 2003);

iii. It is flexible in terms of combining policy, economic, and agronomic constraints (Ciaian et al., 2013);

iv. It can easily consider elements of economic theory, such as the new institutional transactions cost theory (Buysse et al., 2007b);

v. It is suitable for ex-post analyses (for which past observations are necessary), but also for ex-ante analyses, allowing the evaluation of new technology or policy options (in terms of technological choice, land use change, production);

vi. A large amount of information and massive datasets are not required to run an MP model, as occurs with other alternative approaches.

In recent years, several farm MP models have been exploited to investigate various topics regarding agricultural systems. The FARMIS (Farm Modelling Information System; Offermann et al., 2005; Onate et al., 2006; Riesgo and Gomez-Limon, 2006; Semaan et al., 2007), FSSIM (Farm System SIMulator; Louhichi et al., 2010); AGRISP (Agricultural Regional Integrated Simulation Package; Arfini and Donati, 2011) and CAPRI-FT (Common Agricultural Policy Regionalised Impact Modelling System – Farm

Type; Gocht and Britz, 2011) models have recently been used to assess the effects of EU Common Agricultural Policy. FAMOS (FArM Optimisation System; Schönhart et al., 2011) has been used to handle landscape and resource conservation problems (see also Bamière et al., 2011; Schuler and Kachele, 2003). MAORIE (Modele Agricole de l'Offre Regionale INRA Economie; Carles et al. 1997) has been used to investigate the energy crop sector in France. Again in France, AROPAj (Jayet et al., 2000; De Cara and Jayet, 2011) has also been applied to investigate agro-environmental policies.

2.3.2 Econometrically Estimated Farm Models

The second approach described in the literature is represented by econometrically estimated farm models. The econometric approach is less common compared to mathematical programming. Most of these models derive from modifications of the standard profit maximisation model developed by Chambers (1988), in which, in each representative farm, profit (or utility) maximisation is considered to derive behavioural functions representing first order conditions, where constraints and/or assumptions regarding the functional form ensure regularity in the model (Ciaian et al., 2013). The primary advantage of this dual approach is represented by its full empirical simulation tool, and, in turn, by the possibility of testing different behavioural assumptions (Gocht and Britz, 2011). Moreover, given an adequate data set, the econometric models allow testing for the effects of different parameters on the system in its entirety (Howitt, 2005). However, the main limitation of this approach is the great computational time and its data-intensive structure. Another drawback is that the incorporation of subsequent constraints in the model cannot be easily performed and the selection of a functional form is limited because of analytical restrictions in estimating the behavioural function (Heckelei and Wolff, 2003). Again, only ex post analysis can be effectuated, limiting the analysis only to changes in existing policies. For this reason, econometric models are rarely used to investigate the impact of different policy options on the agricultural sector.

2.3.3 Econometric-Mathematical Programming Models

The third category of bottom-up farm level models is represented by the so-called "Econometric-mathematical programming" approach, introduced by Heckelei and Wolff (2003). Based on multiple observations, this approach represents an alternative to Positive Mathematical Programming (PMP) and allows the estimation of the parameters of the programming model using the optimal conditions as the estimating equations (Ciaian et al., 2013). This permits the incorporation of estimated parameters in the programming models built for various simulation scenarios. Consequently, the advantages of econometric-mathematical programming (EMP) models are that the limitations of the functional form that is typical of PMP are minimised, and new sectors can be investigated according to the estimated functions (Buysse et al., 2007b). However, notwithstanding their attractiveness, EMP models are rarely used for policy analysis, primarily because of the difficulties in finding data and solving numerical problems.

2.3.4 Agent-based Models

The fourth and last category of farm level models present in the literature is the agent-based model (ABM). Agent-based modelling is a massive simulation tool which has been developing over the last few years and has been employed in several scientific areas. In this category of models, a system is modelled as a sequence of autonomous agents. Each of these autonomous decision-making entities evaluates its own condition and selects its choice on the basis of a set of rules (Bonabeau, 2002). With regard to the agricultural sector, the greatest advantages of AB models are represented by the explicit modelling of farm interactions (likewise, the simulation of tradable factors among farms) and the evaluation of the spatial dimensions of different sectors (Happe, 2004), aspects which are hardly identifiable using standard MP and EMP models. An example of an AB model is AGRIPOLIS (Agricultural Policy Simulator; Kellermann et al., 2008), which was developed by the Leibnis Institute of Agricultural Development in Central and Eastern Europe (IAMO) to analyse how farm structures can change within a specific region in response to different policy options. Recently Mertens at al., (2015) developed an AB model to investigate the market context on biomass supply for biogas production, identifying maize silage price increase and competition for it between dairy farms and biogas plants especially when there is a deficit of maize silage in the market.

However, although AB models are very interesting for investigating topics such as structural changes in agriculture, the main problem with these models is represented by their parameterisation and calibration, which are extremely complex and sensitive. Consequently, AB models are not yet suitable for large-scale assessments.

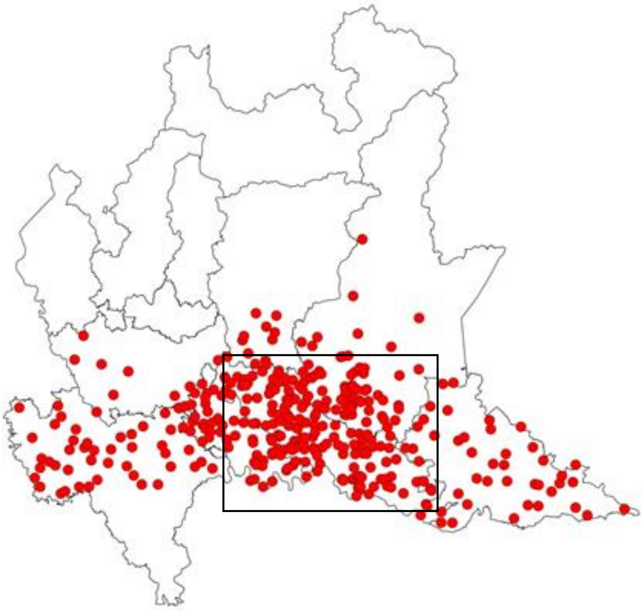
Chapter 3

Case Study for Biogas Production in Lombardy

Lombardy is a NUTS 2 region 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 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. In 2009 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 policy framework under which biogas growth in Lombardy and the modelling framework are introduced in order to model the biogas industry (feedstock demand) and the agricultural sector (feedstock supply) in Brescia and Cremona, which together hold 52% of the installed power in Lombardy (Figure 1).

Figure 1 – Biogas plants in Lombardy region and area under investigation (plain of Brescia and Cremona).



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

3.1 Policy Framework

Biogas production from agricultural residues and energy crops began to be incentivised because its conversion into electricity can help to achieve national targets in terms of cutbacks in greenhouse gas emissions (see Chapter 2). In particular, this kind of bioenergy was seen by policy-makers as a good opportunity to support the farmers' incomes, especially in light of the declining degree of protection ensured by the Common Agricultural Policy. Moreover, the development of this new agricultural – bioenergy sector has been considered to be a good opportunity also for the development of other economic sectors, *in primis*, those providing assistance to it.

As pointed out in Chapter 2, with Directive 2001/77/EC, the European Union started to incentivise the production of electricity from RES, and a national indicative target was defined for electricity generation from renewable sources in each Member State.

The Italian government recognised EU Directive 2001/77/CE with DL 387/2003 and the DM of 24/10/2005. The concept of a "green certificate" (*certificati verdi*) was introduced for the first time in Italy: Producers of green energy would obtain "green certificates" according to the quantity of energy produced. Subsequently, the possessor of green certificates would sell them to other providers of electric energy from non-renewable sources, which were now obliged to enter an annual minimum amount of electricity produced from renewable sources into the electric system. Consequently, the monetary revenues derived from the sale of green certificates provided an incentive for renewable energy production.

Green certificates have evolved over time. Initially, their duration was 12 years, independent of the typology of green energy put on the market. From the beginning of 2008 (Law no. 222/2007 and Decree 159/2007), their lifetime was prolonged to 15 years and the number of green certificates given to producers was correlated with the typology of renewable energy sources used to produce the renewable energy (see Table1).

Table 1 – Multiplications coefficients for green certificates calculation.

Source	Coefficient
Solar	(according to decree 19 February 2007)
Wind	1.0
Geothermal	0.9
Wave and tide energy	1.8
Hydraulic different from the previous point	1.0
Biodegradable residues, biomass different from the following point	1.3
Biomass and biogas produced by agricultural activities, livestock breeding and forest (from short chain)	1.8
Landfill gas and residual gas from gas purification processes and biogas different from those of the previous point	0.8

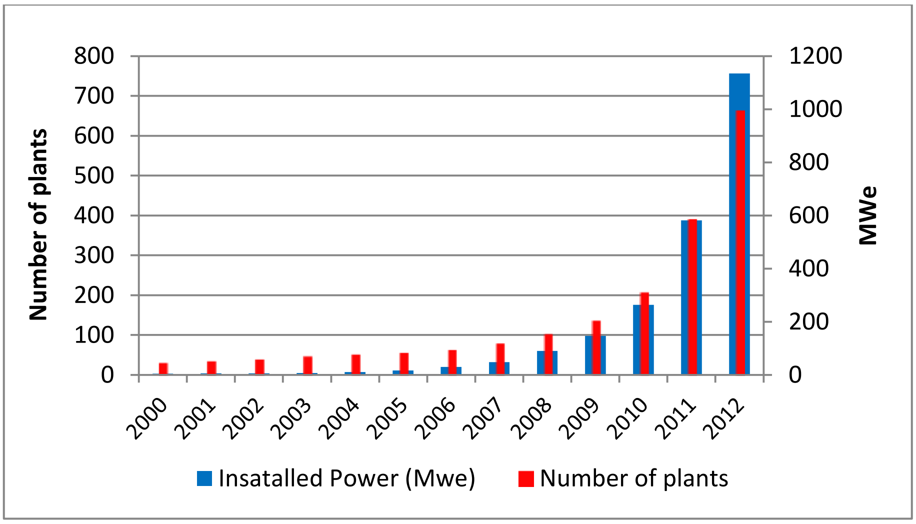
Source: Readapted from GSE (2010)

Law n. 1195, “Measures for enterprises development and internationalization”, which is related to Law n. 244 of 24/12/2009 and Law n.222 of 29/11/2007, established the highest multiplicative factor (1.8) for the assignment of the number of green certificates to be conferred for biogas derived from energy crops and/or agricultural residues, available for a maximum range of 70 km (GSE, 2010). Moreover, for biogas and biomass plants below 1 MWe of electric power built after December 31, 2007, it was possible to opt for an alternative and more advantageous subsidisation system in which green certificates were replaced by the “omnicomprensiva” (all included) rate, which is equal to 0.28

€/kWh of the energy produced. As in the case of green certificates, the producers can benefit from this all-inclusive feed-in tariff for 15 years, after which they will have to sell the energy produced at market prices (Mela and Canali, 2014).

Therefore, the huge expansion of biogas plants has been driven by this dedicated subsidisation scheme. In particular, the feed-in tariff (FIT) introduced in Italy in 2009[7] boosted agricultural biogas production between 2009 and 2012 (Figure 2), shaping the adoption of technology by farmers. As explained above, the possibility given to plants with an electric capacity up to 1 MWe to receive an all-inclusive feed-in tariff of 0.28 €/kWh for 15 years led the majority of biogas plants to build a capacity of slightly less than 1 MWe in order to maximise the subsidies.[8]

Figure 2 – Number of biogas plants and installed Power in Italy between 2000 and 2012 years.



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

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[7] See Law 99/23 July 2009.

[8] 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 maximised their profits were those with a capacity of slightly less than 1 MWe (999 kWe), which were more efficient and able to produce more energy, compared to smaller plants (e.g., 250 kWe).

The Renewable Energy Directive (RED) 2009/28/EC[9] for the promotion of renewable energy sources requires the MS to increase their quota of renewable energy to 20% of overall energy consumption and10% of green energy in transport by 2020. As pointed out in Section 1.6, regarding solid biomass used for electricity and heat production, the RED asks for supplementary explanations from Member States of its sustainability, prompting the greater utilisation of agricultural residues (basically, crop residues and manure) instead of energy crops.

As a consequence, in 2010, the Italian government developed a National Action Plan (*Piano d'Azione Nazionale*) for renewable energy which illustrates the Italian strategy to meet the objectives set by the RED.

These objectives are implemented through the Legislative Decree 28 of March 3, 2011 and the Ministerial Decree of July 6, 2012. The decree sets subsides for biogas plants built from 2013 onwards. Beginning in January 2013, the subsidies (comprised in a range between 0.236 and 0.085 €/kWh, see Table 2) have been reduced and are further decreased with the increase in plant size. Moreover, in order to encourage the utilisation of manure and by-products instead of energy crops, the subsidies have been related to the type of feedstock used in the blend. To conclude, a national registry for biogas plants has been established. The facilities enrolled on the registry have access to the new incentive system for 20 years, although the amount of MWe installable in one year is limited (170 MWe in 2013; 160 MWe in 2014 and 2015).

Only plants with 0.1 MWe or less can be built without registration, and at the same time, all of the facilities under 0.6 MWe powered in farms are prioritised. This shows a new government strategy regarding biogas production: On the one hand, the construction of sustainable small-medium biogas facilities, fed by agricultural residues, is still promoted; on the other hand, the level of subsidisation is reduced.

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[9] EC, Directive 2009/28/EC, repealing Directives 2001/77/EC and 2003/30/EC., on the promotion of energy from renewable sources; see Chapter 1, Par.1.2.

Table 2 – 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 by-products based (€ MWh)**
Incentive value	Feed in tariff for plants up 999 kWe (280 € MWh) Green Certificate for plants > 1000 kWe (223 € MWh^{-1}; average 2011–13)	1 – 300 kWe	180	236
		301 – 600 kWe	160	206
		601 – 1,000 kWe	140	178
		1,001 – 5,000 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		

Source: Readapted from Chinese et al. (2014)

The two different incentive systems described above will be hereafter referred to as *pre* 2013 and *post* 2013 policy system.

3.2 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. As shown in Capter 2, the impact of alternative agricultural and bioenergy policies can been assessed using different approaches (CGE models, PE models or bottom-up farm-level models), applying mathematical programming [linear programming (e.g. Delzeit et al., 2009,a,b; Rozakis et al., 2013), 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)] but also using micro-economic and multi-criteria methodology (Delzeit et al., 2012; Rozakis et al., 2012), multi-agent modelling (Mertens et al. 2014) or other approaches based on geographical information systems (Delzeit et al., 2009a; Fiorese and Guariso, 2010; Sorda et al., 2013).

In this thesis we built an integrated model following a partial equilibrium approach. We apply this model on two areas of Lombardy region, in order to assess the impact of Italian subsidies for biogas production on energy and agricultural markets. 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 (ReSI-M) 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 Paragraph 3.2.1). 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 maximise their welfare under resource and agronomic constraints (see Section 3.2.2). 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 3.2.3).

3.2.1 The Industrial Model (ReSI-M)

The starting point of our analysis is the ReSI-M (Regionalised Location Information System – Maize) model, developed by Delzeit (Delzeit et al., 2009a,b, Delzeit, 2010 and Delzeit et al., 2012) simulating, through an iterative maximisation of the ROI (Return on investment), 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 costs for input procurement (biomass) and other costs oc, from plant revenue ($y_s p_s$). The former are the sum of transport costs tc and feedstock price w multiplied by the variable input demand x. Formally,

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

Input availability (feedstock) in the region affects transport cost tc, and depends on specific features of nearby agricultural systems like amount and distribution of arable land, its biomass yield and the extent of biomass already allocated to biogas production.

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

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

Where $\pi_{c,s}$ is the operational profit per year while I_s are total investment costs.

Under the profit maximising function (2), given exogenous input prices w, the model yield the optimal input demand d in each region c as an aggregation of each plant demand:

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

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

Function (2) is maximised iteratively, placing the first plant in the region having lower input transportation costs. After each iteration, available biomass input diminishes and consequently additional plants incur in higher transportation costs that make the ROI to decrease progressively.

The iteration process continues until ROI falls below a predefined interest rate threshold or the input biomass is out of stock. The model specification is defined below (Delzeit et al. 2009b) as key objective function, indices, parameters, decision variables and side conditions.

Objective function:

$$\max ROI = \sum_{s\,\in S}\ \sum_{p\,\in P} \frac{r_s - v_s - \eta_{sp} - f_s}{I_s} -$$

$$-\sum_{s\,\in S} \sum_{c\in C} \sum_{k\in K} \sum_{f\in F} \left(\frac{tm_{sck} * z_{sc}}{I_s} + \frac{tr_{sck} * x_{sc}}{I_s} + \frac{tn_{sck} * y_{sc}}{I_s} \right) \quad (4)$$

Indices / Sets

$s \in S$	current plant capacity (size)
$p \in P$	current input prices (maize)
$c \in C$	current region
$k \in K$	Regions

Parameters

r_s: sum of revenues (€/year)
v_s: sum of variables costs (€/year)
η_{sp}: per year input costs (maize demand times maize price)
f_s: sum of fixed costs (€/year)
I_s: costs for investments (€)
tm_{sck}: input (maize) transportation costs (€/t)
tr_{sck}: digestate transportation costs (€/m^3)
tn_{sck}: input (manure) transportation costs (€/m^3)
α_s: maize transportation costs for first km (€/t)
β_s: maize transportation costs for each additional km (€/t per km)
δ_s: manure and residues transportation costs for first km (€/m^3)
λ_s: manure and residues transportation costs for each additional km (€/m^3)
km_{sck}: driving distance (km)
b_{cp}: maize available (tons)
d_s: maize needed per plant size (tons)
dm_s: manure needed per plant size (tons)
dr_s: digestate per plant size (tons)
s_s: Share of maize on total feedstock blend for each plant size category (tons maize/tons feedstock; dimensionless parameter)
fz: output/input coefficient (m^3 digestate /tons maize)
fm: output/input coefficient (m^3 digestate /tons manure)
$tkout_{ck}$: distance between regions (km)
$tcin_{sc}$: driving distance within each region (km)
$tc0_{sc}$: transportation costs at first interaction each region
$tc1_{sc}$: transportation costs increase due to rising input (maize) use.
e_c: Maize yield (tons/hectare)
$share_c$: arable land/total land
$dens_c$: manure density (m^3/km^2)

Decision variables

z_{sc}: quantity of maize transported (tons)
y_{sc}: quantity of manure transported (m^3)
x_{sc}: quantity of digestate transported (m^3)
ROI: Return on Investments

Side Conditions:

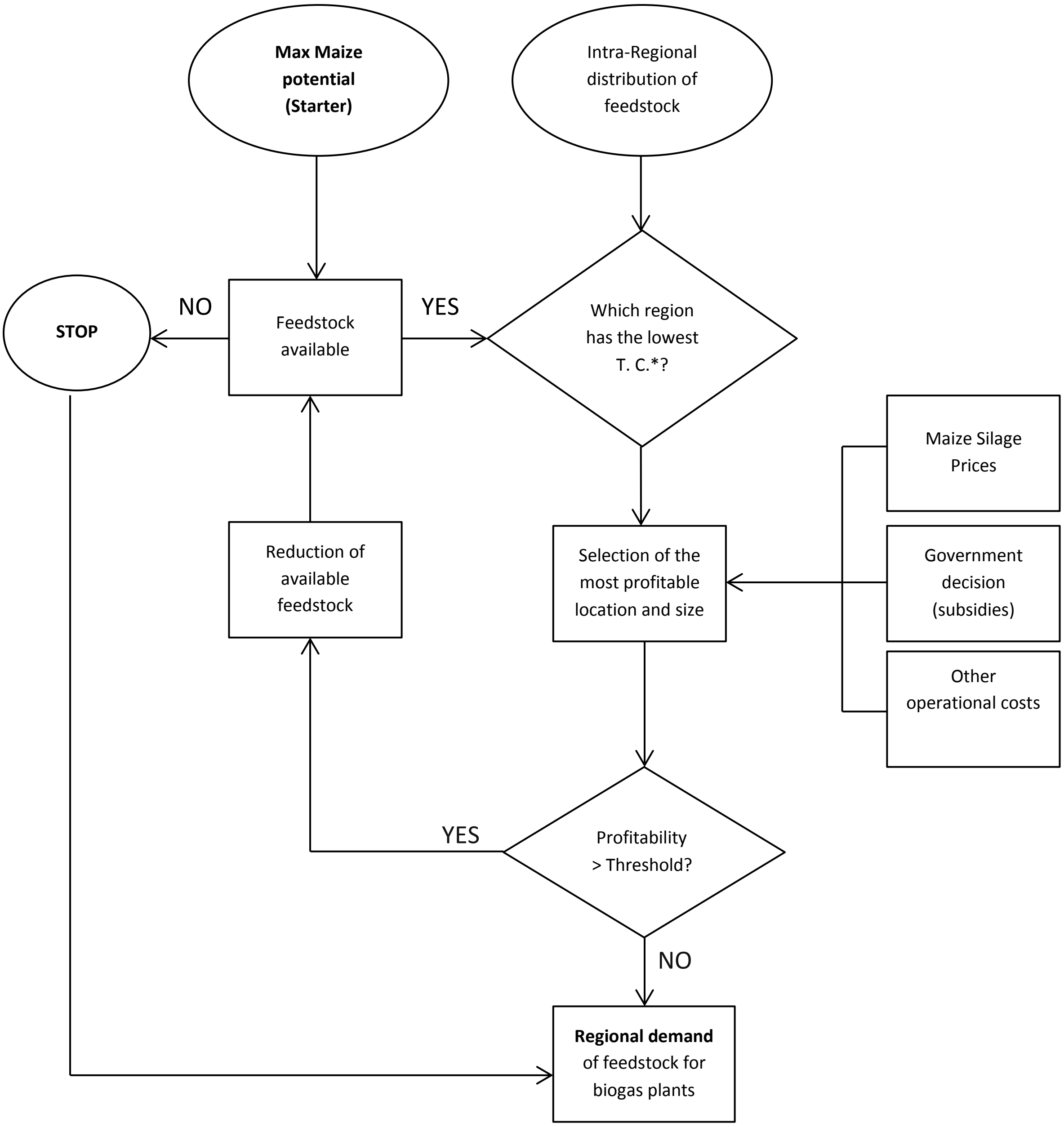
5) $\sum_{s\in S} z_{sc} \leq b_{cp}$ $\quad \forall\, p \in P, c \in C$
6) $\sum_{c\in C} z_{sc} = \sum_{s\in S} d_s * s_s * 1.08$ $\quad \forall\, s \in S$
7) $\sum_{c\in C} y_{sc} = \sum_{s\in S} dm_s * (1 - s_s)$ $\quad \forall\, s \in S$
8) $\sum_{c\in C} x_{sc} = \sum_{s\in S}(z_{sc} * f_z + y_{sc} * fm)$
9) $z_{sc} \geq 0$ $\quad c \in C, s \in S$
10) $x_{sc} \geq 0$ $\quad c \in C, s \in S$
11) $y_{sc} \geq 0$ $\quad c \in C, s \in S$
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) $tm_{sck} = (tc0_{sck} + tc1_{sc}) * 1.33$

Input biomass is splitted in maize (as energy crop) and manure. Constraint (5) limits the amount of input maize used to the maximum biomass production in the region. Constraints (6) and (7) impose equality between quantities of input biomass (maize and manure, respectively) transported to and demanded by plants, assuming a 8% loss of maize. Condition (8) imposes an input-residue (digestate) relation. Non-negativity constraints are set in conditions (9)-(12). Parameters from (13) to (16) describe the computation of transportation costs for maize and digestate. Figure 3 provides a flow-chart of ReSI-M.

Figure 3 – Overview of ReSI-M.



**T.C. = Transportation Costs*

Source: Readapted from Delzeit (2010).

3.2.2 The Agricultural Model (MAORIE)

Such model is an adaptation of the MAORIE model (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 and the sub-models are than assembled in a staircase structure. The model simulates farmer choices in terms of crop mix and land allocation (Rozakis et al., 2001; Kazakçi et al., 2007). Each farmer f optimizes a profit function (17) under various constraints set in relations (18)-(22). The model specification is defined below as key objective function, indices, parameters, decision variables and side conditions.

Objective function:

$$\max \sum_{f \in F} \sum_{y \in Y} g_{y,f} xf_{y,f}^{j} + \sum_{f \in F} \sum_{d \in D} (p_d^j \gamma_{d,f}^j - c_{d,f}) xe_{d,f}^j \quad (17)$$

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)
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

p^j_d: grid j of energy crop d selling price parametrically imposed (€/ton)

$xf^j_{y,f}$:non-energy crop y area in farm f (ha) under a grid of j exogenous prices

xe^j_{df} : energy crop d area in farm f (ha) under a grid j of parametrically imposed prices

Side conditions

Land availability:

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

Sugar-beet quota:

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

Agronomic constraints:

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

Non-negativity constraints:

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

The model yields the gross margin maximising quantity q^{j}_{d} to be produced at each level of exogenous price j of energy crop d:

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

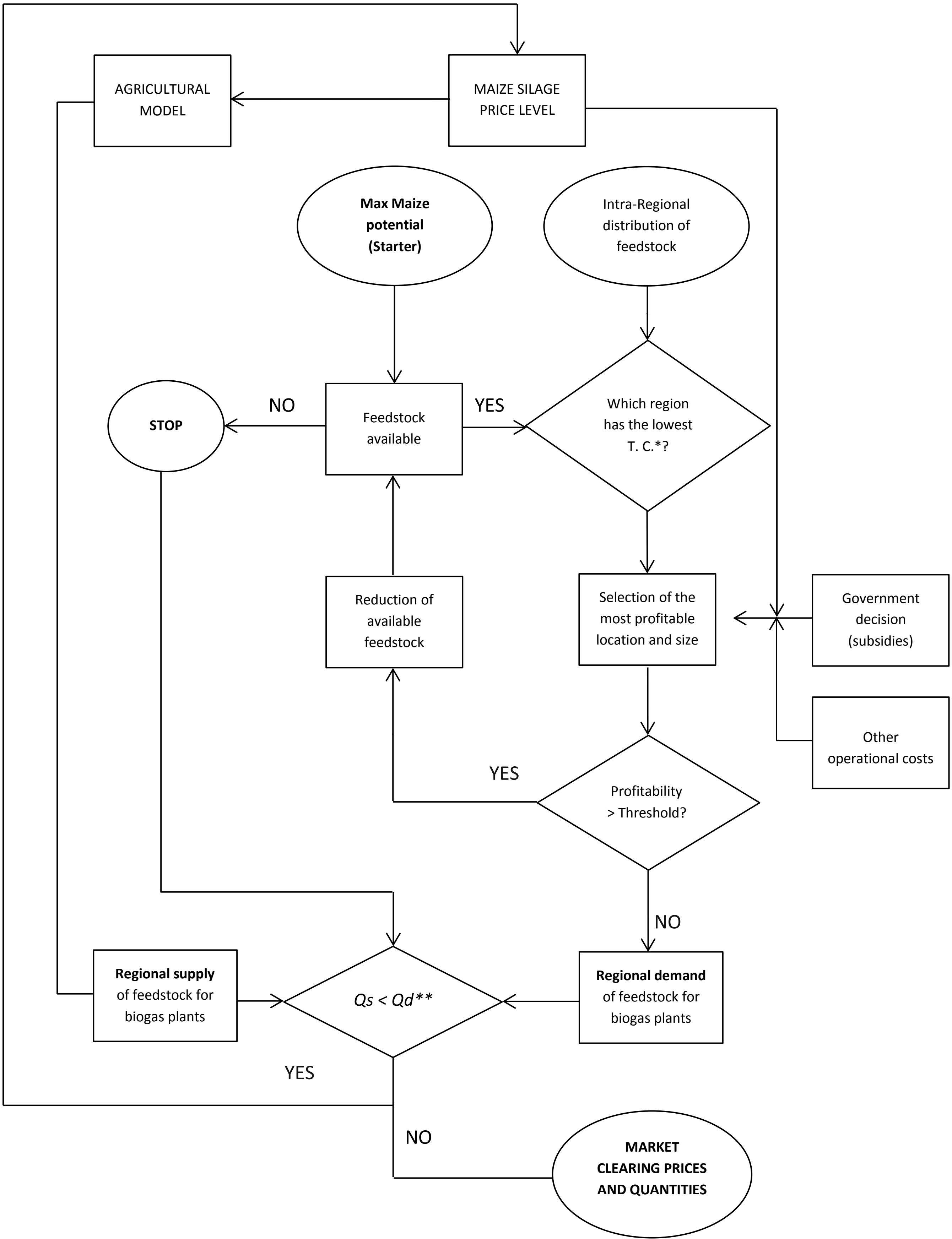
Output of the agricultural model is the optimal crop mix distributions supplied by farms at each level of predefined grid of exogenous prices.

3.2.3 The Integrated Model

Maize silage market for biogas production is simulated integrating the two model described above with a partial equilibrium approach. The model implementation has been done using General Algebraic Modelling System (GAMS) software, designed for modelling and solving linear, non-linear and mixed-integer linear mathematical optimization functions

Assuming a grid of all possible maize prices (p maize = {30…70 €/ton}, see Chapter 4) 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 Figure 4.

Figure 4 – Multi level model flowchart.



**T.C. = Transportation Costs*
*** Qs = Quantity supply; Qd = Quantity demanded*

Chapter 4

Data and Model Specifications

In this chapter 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 Lombardy.

4.1 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 (Table 3). Size class segmentation reflects differences in output prices (energy sold by biogas plants) according to the current legislation (see Section 3.1). We apply

ReSI-M modelling framework described in 3.2.1. in Brescia (BS) and Cremona (CR), assuming a grid of exogenous input (maize) prices (p maize = {30…70 €/ton}). 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 simplification has been necessary for a matter of model tractability and may induce a slight overestimation in maize silage demand.

Table 3 – Feedstock mix of biogas plants for power classes in Lombardy region (reference year 2012).

Power (kWe)	Maize Silage (t/year)	Manure (t/year)	Residue (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.

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 (ECO-BIOGAS project) funded by Lombardy Region to assess the economic and environmental impact of biogas on agri-food supply chains, (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) have been considered not suitable for biogas production, as a consequence of both landscape planning laws and low agricultural input availability. Density and distribution of arable land and manure, within each NUTS 3 region, have been used to estimate regional transportation costs of feedstock. 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 2). Further assumptions on plant efficiency and operating hours per year are also taken from Frascarelli (2012). Transportation costs for maize are extracted from Delzeit (2010). Data on the amount of manure available for biogas production have been taken from the Decision Support System ValorE (Acutis et al., 2014) and Regione Lombardia (2013) data.

4.2 Supply-side Agricultural Model

We apply to Lombardy Region the bottom-up farm level model described in 3.2.2. Only maize silage is considered as energy crop for biogas and its selling price is parametrically imposed within the same grid imposed at the demand-side biogas industrial model (p maize = {30…70 €/ton}).

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 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).

As the sharp growth of biogas plants installation began in 2009 (see Chapter 3, Figure 2), 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 4.3).

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, on average, 10 crop processes) and 300 constraints.

The farm sample include the following crops (more representative): maize grain, soft wheat, soya bean, durum wheat, maize silage, alfalfa and other grain legumes.

Following Rozakis et al. (2013), data used at farm and crop level are: Utilised agricultural area (hectares), prices (€/ton), yield (ton/hectare), subsidies (€/hectare) and variable costs (€/hectare). The latter include all costs directly attributable to each 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. Therefore, in order to investigate the extent to which the regional biogas sector can grow without incurring in significant 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 Chapter 1 by estimating the market clearance price of maize silage purchased by biogas plants.

4.3 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. We introduced three scenarios to better explain such multiple impacts of biogas production under different policy incentive systems (*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

€/ton) 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 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 2). Farm supply and biogas industry demand are derived assuming different exogenous prices (from 30 € to 70 €) for maize silage.

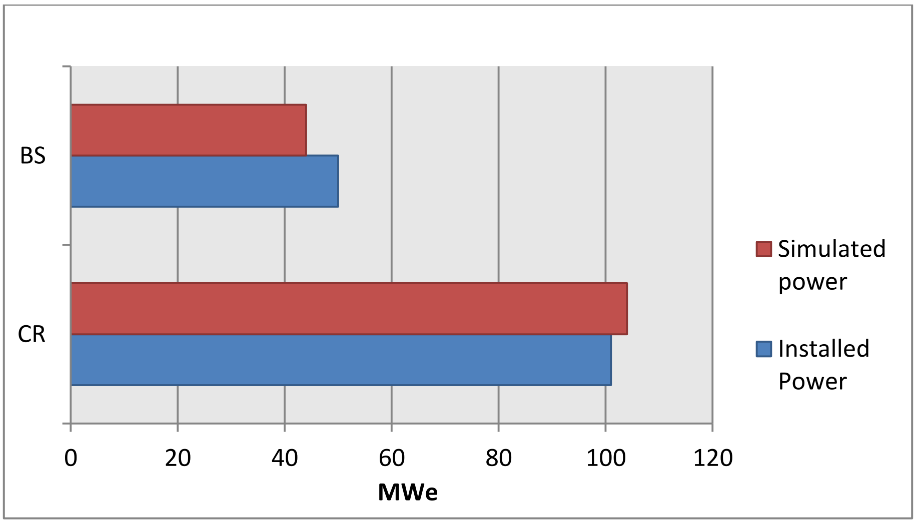
- **Scenario_2**: In this scenario we simulate silage maize market, from 2013 onward, under the new incentive system (post 2013 policy), still accounting for the maize demand from plants surveyed at the end of 2012, but, assuming that biogas plants receive FITs according to the new post 2013 policy framework. Plants are constructed with a planning horizon of 20 years (see Table 2). 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 Chapter 5, tables 6 and 7).

4.4 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 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 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 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 - 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.

Figure 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 maximisation model, ReSI-M chooses the plant typology that maximises ROI (999 kWe, more efficient but using more maize), minimising 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 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 LP supply model with the observed ones (2008). The LP supply model allocates, for each crop (*k*) the level of arable land (hectares) that maximise 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).

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

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

Absolute deviations between observed and predicted land allocation shown in Table 4, 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., 2012).

Table 4 – 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 4.2

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 the two products. The agriculture supply model is therefore enough representative of farmers' behaviour concerning land allocation for crops of interest for the present analysis. Optimal land allocation presented in Table 4 is referred to the sample; the model extends such results to the universe of farms represented in such sample (see Section 4.2) in Brescia e Cremona, yielding the maize silage production from which are computed the hectares potentially available for biogas production (see Table 5).

Chapter 5

Results

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 5).

Table 5 – Scenario_0: Simulated hectares of maize silage potentially available for biogas production and their incidence on Utilised 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 4.2

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 6 and 7). 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 6 and 7). Maize silage demand is therefore estimated under such upper and lower bounds (figures 6 and 7).

5.1 Scenario_1

Figure 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 €/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),[10] 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). Table 6 reported the amounts of land required to produce market clearing quantities of maize silage: 44,793 ha (25.6% of UAA) in Brescia and 30,421 ha (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 6).

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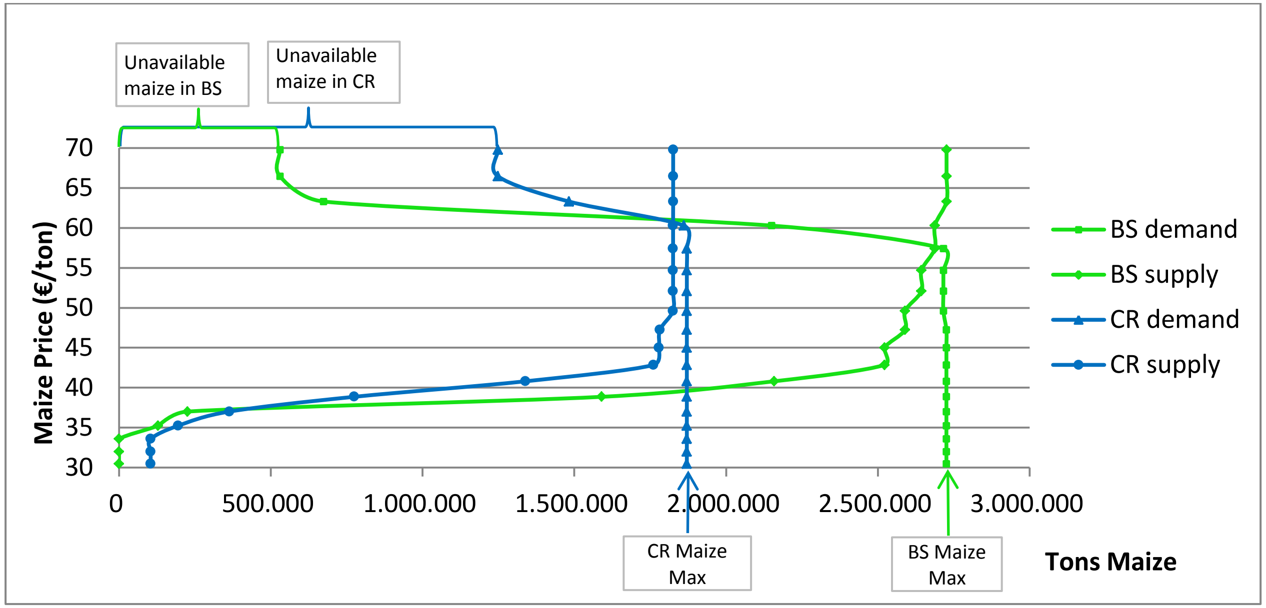
[10] Average values obtained from data of Camere di Commercio, Industria, Artigianato e Agricoltura della Lombardia (Lombardy Chambers of Commerce, Industry, Agriculture and Handicraft).

Figure 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 Chapter 3.

Table 6 – 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 Chapter 3.

5.2 Scenario_2

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 7 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 3).

Table 7 – 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 Chapter 3.

Accordingly, 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 7), to levels closer to actual price in 2012 (36.9 €/ton) and in line with the actual maize silage market price in Lombardy (ca. 40 €/ton in 2014).[11]

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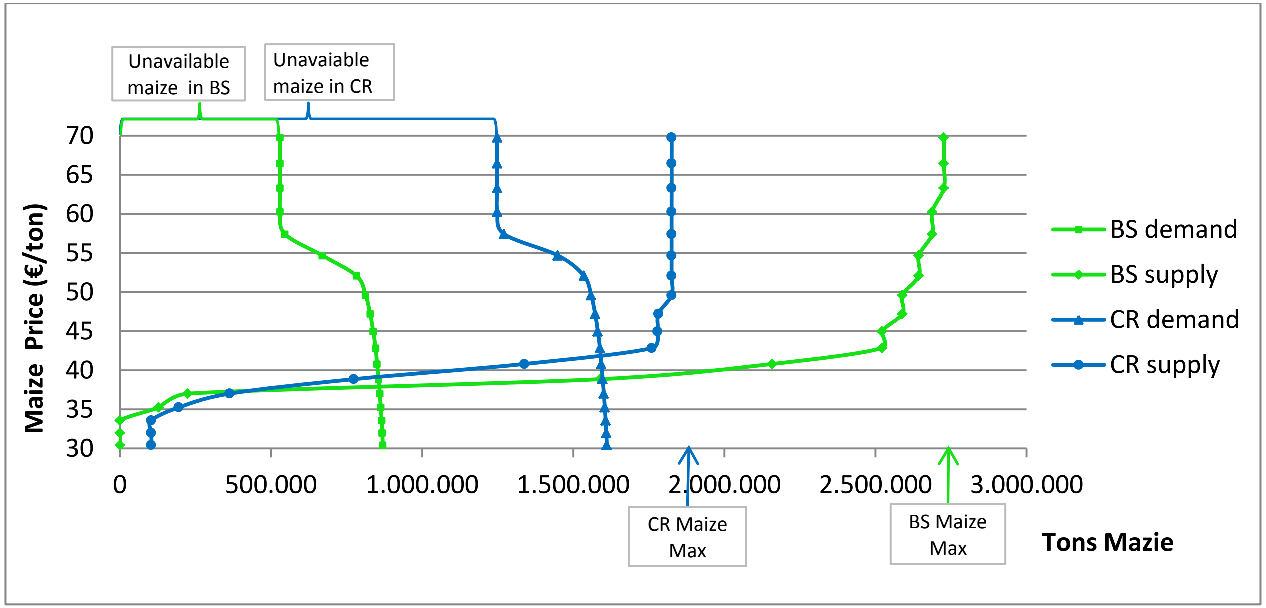
[11] Average values obtained from data of Camere di Commercio, Industria, Artigianato e Agricoltura della Lombardia (Lombardy Chambers of Commerce, Industry, Agriculture and Handicraft).

Figure 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 Chapter 3.

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, far lower with respect to Scenario_1 (Table 8-9). 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.

Table 8 – Comparison between scenarios 1-2 in terms of market clearing price, installed power and land use change in Brescia (BS)

	BS/S1	BS/S2	**BS diff. (S1 -S2)**
Market clearing price (€/ton)	57.6	37.9	**-19.7**
Market clearing quantities (tons)	2,687,584	857,915	**-1,829,669**
Total Installed Power (MWe)	170	93	**-77**
Land required for maize (ha)	44,793	14,299	**-30,494**
Share of land for maize (% Total UAA)	25.62	8.18	**-17.44**

Source: Authors elaboration on results of partial equilibrium model described in Chapter 3.

Table 9 – Comparison between scenarios 1-2 in terms of market clearing price, installed power and land use change in Cremona (CR).

	CR/S1	CR/S2	**CR diff. (S1 -S2)**
Market clearing price (€/ton)	60.6	42.0	**-18.6**
Market clearing quantities (tons)	1,825,283	1,590,005	**-235,278**
Total Installed Power (MWe)	133	145	**+12**
Land required for maize (ha)	30,421	26,500	**-3,921**
Share of land for maize (% Total UAA)	22.59	19.7	**-2.92**

Source: Authors elaboration on results of partial equilibrium model described in Chapter 3

The simulated (new) plants are smaller (130 kWe) and the demand for maize silage (used maize[12]) decreases, compared to Scenario_1, from 2,157,623 to 327,963 tons (–1,829,660 tons, -85%) in Brescia and from 577,017 to 341,739 tons (–235,278 tons, -41%) in Cremona.[13] 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). The new incentive system would consequently 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).

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 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 (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 3.2).

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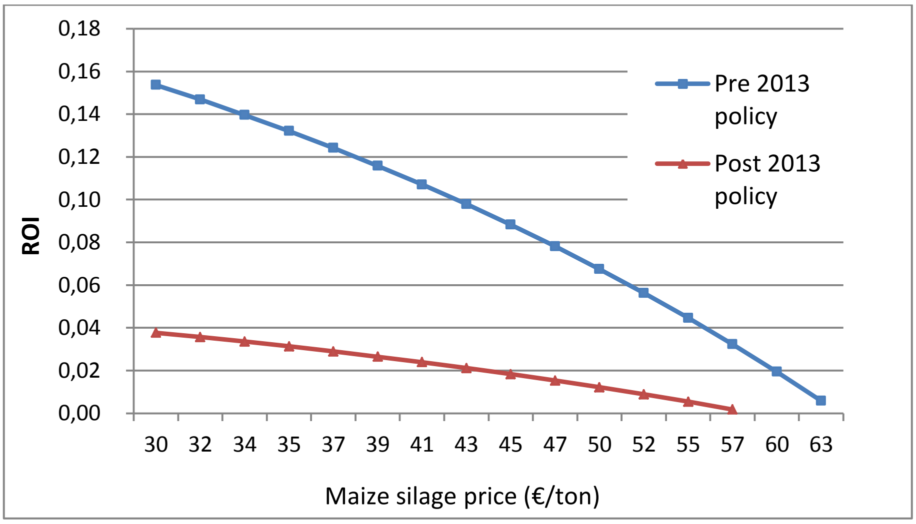
[12] As explained above, used maize is computed by subtracting unavailable maize for plants built until 2012 from market clearing quantities.

[13] 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).

Figure 8 – 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 Chapter 3.

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, despite using less maize, shutdown when the price of maize exceeds 55 €/ton.

Conclusions

The rapid growth in bioenergy production from energy crops has the potential to affect food and feed prices: Higher demand for energy crops can induce higher energy crop prices, providing greater incentives for farmers to increase their acreage. The more land that are converted to the production of such crops, the fewer land that are available for food and feed crops. This process can therefore generate competition for land between fuel and food/feed crops: Higher food prices can threaten food security in developing countries; higher feed prices can threaten the traditional agri-food supply chain, raising the opportunity cost of livestock feed. This potential impact of bioenergy support policy on food and feed prices, the related land use change effects, and the cost shouldered by the community in terms of the bioenergy incentive system, has sparked a lively debate and controversy about the effectiveness of these policies, both at the national and international levels.

This research investigates 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 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 run.

In comparison with the above mentioned policy option, the new incentive system (*post* 2013 policy), simulates different market conditions, with smaller plants (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 a 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 to counteract the ILUC effect and to accelerate the shift from the first to the second biofuel generation. The new legislation approved on 28 April 2015 reduces indeed from 10% to 7% the energy for transportation (at 2020) coming from biofuels; such lower level is intended for the first-generation biofuels, obtained using crop inputs from arable land. The rationale behind such decision is to reduce the competition for land between biofuel (or biogas) crops and food crops.

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 valorise the manure and by-products; key condition for the containment of plants operating costs. The likely effects of new incentive system are double-faced: On one hand it may discourage further investments on biogas sector, but, on the other it would mitigate distortive effects on maize market and agri-food supply chains.

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). A future potential extension would require to model explicitly also the behaviour of livestock farms by including them in the agricultural model. Such change would make the modelling 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 modelling (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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