AgBioForum, 16(3): 194-206. ©2014 AgBioForum.

How Distorting Policies Can Affect Energy Efficiency and Sustainability: The Case of Biogas Production in the Po Valley (Italy)

Giulio Mela
Centro ricerche economiche sulle filiere suinicole (Crefis), Italy

Gabriele Canali
Università Cattolica del Sacro Cuore, Italy

Similarly to other EU countries, Italy began subsidizing electric energy production from renewable sources such as biogas. This proved to be an inefficient way of using available resources. In the Po Valley—the most productive agricultural area in Italy—the share of corn area used for biogas production increased from 0.4% in 2007 to more than 10% in 2012, reaching 18.2% in Lombardy. This, in a framework of declining acreage due to Common Agricultural Policy (CAP) reform, increases demand, competition for land, and agricultural prices, therefore pushing up production cost for livestock and, consequently, famous Italian quality products. Italy has started reforming its energy policy by incentivizing the construction of small manure-based biogas plants but more can and has to be done to promote a more efficient utilization of biogas, which, for example, can be upgraded into biomethane (with relatively low energy requirements) and injected into the natural gas grid.

Key words: biogas, green energy, energy policy, biofuels, Italy, Po Valley, biomethane, sustainability, energy crops.

Introduction

In recent years the use of renewable resources for energy production has been increasingly supported by governments to reduce CO_2 emissions from fossil fuel use and related negative effects on the climate, and to lower (economic and political) energy dependency from countries with a large endowment of these non-renewable resources.

In Europe, and especially in Italy, biogas has become one of the most important forms of renewable energy thanks to its versatility, since it can be used to generate heat, steam, electricity, and vehicle fuel. In Europe, biogas is produced in more than 10,000 plants, the majority of which are located in Germany. Biogas is produced during anaerobic digestion (AD) of organic substrates such as manure, sewage sludge, the organic fraction of household and industrial waste, and energy crops. At 20-40°C, biogas consists of 50-70% methane (CH_4), 25-45% carbon dioxide (CO_2), 2-7% water (H_2O), 2-5% nitrogen (N_2), 0-1% ammonia (NH_3), and 0-6,000 ppm hydrogen sulfide (H_2S; Akbulut, 2012).

The production process takes place in both large- and small-scale digesters located in single farms. Biogas can also be obtained from anaerobic degradation in landfills (European Biogas Association [EBA], 2011), but this technology is not very common in Italy.

Bigger plants typically almost only use energy crops, while small- and medium-sized plants use a mixture of animal slurry, agro-industrial residues, and energy crops. Whether the use of energy crops for energy production allows a reduction in greenhouse gas (GHG) emissions has been the object of many studies, often yielding conflicting results (see Mela, 2013, for an extensive literature review); for sure their employment raises some ethical issues, especially in a period characterized by high and volatile food prices. The use of corn and other agricultural commodities for energy production can also increase competition for land especially in areas with an intensive livestock production. The overall effect on livestock production can be, therefore, very important.

Biogas started to be subsidized—even though indirectly—as a possible tool to reduce GHG emissions and environmental problems caused by residues from livestock farms and agro-industries. It also lessens problems due to the presence of pathogens in animal sludge that alternatively would be directly spread on land (since anaerobic digestion kills them). The so-called digestate—that is, residues from anaerobic digestion—can be applied to land as a fertilizer to increase the level of organic matter in the soil (after specific treatment aimed at reducing nitrogen content).

Biogas can be employed in three ways. It can be burned directly in a boiler to produce thermic energy (efficiency of about 85%) to be used *in situ* or nearby the plant for heating. It can be also used to feed engines for electric energy production (efficiency of around 35%) or to produce both heat and electricity (cogeneration) with an efficiency, in terms of electric energy, of 35% and an efficiency in terms thermic energy of 40-

45% (Centro Richerche Produzioni Animali [CRPA], 2008a).

Most biogas facilities in Italy produce only electric energy (without cogeneration) since economic incentives have been high enough to support it, even though cogeneration would allow a more efficient utilization of biogas (CRPA, 2008a).

Biogas can also be upgraded—refined in order to reach a methane concentration of at least 95%—and injected into the natural-gas grid. The upgraded biogas is called biomethane. According Strauch, Krassowski, and Umsicht (2012) and Strauch, Krassowski, and Singhal (2013), there are already more than 200 biomethane plants in Europe in operation, meaning that technology is now mature and is no longer to be regarded as a limiting factor. Biomethane production is particularly developed in countries like Sweden, the Netherlands, Germany and Switzerland. Conversely, according to the report, just two biomethane plants were in operation in Italy in 2012. In Germany, the share of biogas upgraded and injected into the natural gas grind increased from 0.3% to almost 10% from 2007 to 2011. This can represent an interesting opportunity for Italian biogas—mostly produced from energy crops and animal slurry—since Italy is endowed with the most advanced and widespread natural-gas grid in Europe (Annesini, Augelletti, Fabriani, Murmura, & Turchetti, 2012).

Natural-gas consumption has increased in the last 30 years due to the progressive reduction in the use of coal for energy production. It has been forecasted that natural gas will account for more than 40% of the world's energy production by 2030. According to Nielsen and Oleskowicz-Popiel (2008), biogas produced from energy crops, animal manure, and industrial organic waste can supply nearly half of the European natural-gas consumption in the coming decades. Moreover, an increased substitution of liquid fuels with natural gas can also contribute to reducing emissions of toxic compounds like nitrogen oxides and reactive hydrocarbons.

Italy's annual gas consumption is slightly less than 80 billion m^3, and since the country is a net importer, it also represents one of the world's biggest markets for natural gas. One-third of Italy's electricity production is obtained from natural gas. Cars and trucks running on compressed natural gas (CNG) number more than 760,000 in Italy (one of the highest figures in the world), and roughly 850 filling stations offer CNG as a vehicle fuel.

Unfortunately, in many countries (including Italy), policies incentivizing biogas production are focused on the production of electricity rather than its direct use as a replacement for natural gas. The Italian renewable electricity support scheme is one of the most supportive in Europe even though support has been reduced with the last reform, which entered into force in January 2013. Policymakers have been subsidizing a scarcely efficient electricity production technology, which translates into an inefficient use of public resources. Moreover, the fact that "renewable" energy production would be subsidized regardless of the biogas production technique (energy crops, wastes, organic residues, etc.) failed to provide an incentive to farmers (who are the most important biogas producers) to choose the most sustainable organic substrate. The large majority of Italian biogas facilities are located in the Po Valley in Northern Italy; many of these facilities are fed with corn silage and cropped on land that alternatively could be used to produce food for animal or human consumption. The increased use of corn and other agricultural commodities for energy production (not only biogas but also biofuels) alters markets by increasing demand, which faces a rigid supply; this contributes to increasing prices.

This article aims to estimate the impact that biogas production—incentivized by the Italian government—has been having in terms of areas cropped in the Po Valley of Northern Italy (namely in the Piedmont, Lombardy, Veneto, and Emilia-Romagna regions), which is also an area characterized by a high degree of urbanization and agriculture intensity (see Appendix I for figures on the Northern Italian agriculture). The article also aims to provide evidence to spur a major shift in energy policies toward a more efficient use of resources.

The Policy Framework in the EU and Italy

Biogas, similarly to many other forms of renewable energy, began to be subsidized because its production would help countries respect their commitments in terms of GHG emissions reduction and would represent a way to increase farmers' income. Furthermore, the development of an efficient bioenergy system could represent a good opportunity for other sectors of the economy, i.e., those providing goods and services for the bioenergy sector.

In Italy, bioenergy was seen as a good opportunity for the Italian agricultural sector, especially in a framework characterized by a declining degree of protection by the Common Agricultural Policy (CAP) of the European Union (EU)—the last one being the one promoted by Agriculture Commissioner Fischler in 2005 and entered into force in 2005-2007; this meant a higher degree of market openness and therefore an increased level of competition to which European (and Italian) farmers were not accustomed.

The EU began promoting the production of electricity from renewable energy sources (including biogas) with Directive 2001/77/EC. The directive stated that Member States had to take 'appropriate steps' to encourage a greater consumption of electricity produced from renewable energy sources, in accordance with national energy targets. The Italian government implemented EU Directive 2001/77/CE on the production of renewable electric energy with the Legislative Decree 387/2003 and the Ministerial Decree of October 24, 2005. According to this legislation, producers of energy from renewable sources would obtain "green certificates" (*certificati verdi*) for the amount of energy produced if they can show they emitted less GHGs than energy production from fossil sources would have. They then can sell those to electric energy providers that have to produce a certain quantity of energy from renewable sources but either choose not to or cannot do it by themselves. Such providers were mandated to convey to the national grid increasing quantities of energy from renewable sources (7.55% in 2012) that they could either produce by themselves of buy on the market through green certificates. Money obtained by sellers of green certificates provided an incentive to sustainable energy production.

Green certificates changed over time. At the beginning they were given to producers of energy from renewable sources for a period of 12 years, irrespective of the type of energy produced. Beginning in 2008, the length of green certificates was extended to 15 years and the number of them given to producers was linked to the type of renewable source. Also beginning in 2008, small producing facilities could opt for an alternative incentive system in which green certificates were substituted by payments for the amount of electricity conveyed to the national grid.

Electric energy produced from biogas derived from agricultural products or residues was, together with tidal and wave energy, the energy source characterized by the highest multiplicative coefficient (1.8) for the computation of the number of green certificates to be awarded (Gestore Servizi Energetici [GSE], 2010). The number of green certificates grew steadily with time, implying a strong decrease in their price. For this reason, the Gestore dei Mercati Energetici (GME)[1] could buy certificates expiring in the year at the average price of the year before.

For production facilities built after December 31, 2007, and with less than 1 MW of power, it was possible to benefit from an all-inclusive tariff for the electric energy released into the national network. Such tariffs encompassed both incentives and the remuneration for the energy produced. Producers could benefit from them for 15 years, after which they would have to sell the energy at market prices. In this case, the tariff for biogas was amongst the highest. As an alternative to green certificates, small producers could opt (paying some administrative fees) for the so-called "dedicated withdrawal" (*ritiro dedicato*), a simplified procedure. Under this regime, the GSE[2] pays the producer the market price of the electric energy in the area where the plant is located.

Later, the EU changed its energy policy with Directive 2009/28/EC (Renewable Energy Directive [RED]), according to which EU Member States committed themselves to reach a 20% share of energy from renewable sources and a 10% share of renewable energy specifically in the transport sector by 2020.

Concerning biogas, the RED specifically states that the use of agricultural material such as manure, slurry, and other animal and organic waste for biogas production has significant environmental advantages in terms of heat and power production and its use as biofuel. Biogas production facilities can also, as a result of their decentralized nature, contribute significantly to sustainable development in rural areas and contribute to raising farmers' income.

In 2010 the Italian government developed a national action plan (*Piano d'azione nazionale*) for renewable energy; it contained directives to meet the objectives set by the RED. The Ministerial Decree of July 6, 2012 implemented the Legislative Decree 28 of March 3, 2011, which in turn implemented the RED. The decree defines the incentives for biogas plants that start producing in 2013 and onwards. The most important news is that all-inclusive tariffs will be decreasing with plant size, and a national registry in which producers have to enroll in order to access the incentives will be established. The registry allows for the construction of new biogas facilities for a maximum of 170 Megawatts electric (MWe) in 2013 and 160 MWe in 2014 and 2015.

1. *The GME is the governmental body that regulates the energy market in Italy.*
2. *The GSE is the governmental body that promotes the use of renewable energy and allocates subsidies to renewable energy producers in Italy.*

The decree also states that facilities of 100 kilowatts electric (kWe) or less can be built without enrollment in the registry, and facilities under 600 kW of electric power in farms have the priority. This means that the Italian government wants to spur the construction of small- and medium-sized facilities fed with waste and residues and, at the same time, reduce the subsidy level.

The Decree of July 6, 2012 sets an upper limit for the subsidies to be awarded every year (5.8 billion Euros), and the subsidy (in the case of biogas) depends on the type of feedstock used for biogas production and the power of the facility. Incentives range between €85 and €236/kilowatt hour (kWh). All facilities up to 100 kW can access the incentives, while facilities up to 5,000 kW have to enroll in a special registry and can access the subsidies through auctions.

Even though Legislative Decree 28/2011 stated that biomethane production must be subsidized, there was no practical instruction until December 2013 when the Italian government set the incentives to inject biomethane into the national natural-gas grid or to use it as vehicle fuel. If biomethane is to be injected into the gas grid, the producer can benefit (for a maximum of 20 years) from a tariff premium equal to two times the price of natural gas in 2012 minus the current monthly price of natural gas if biomethane is directly sold into the market. The tariff is increased by 10% for small production plants (less than 500 standard m^3/hour) and decreased by the same percentage for big plants (more than 1,000 standard m^3/hour). Small plants can also opt for the "dedicated withdrawal" at twice the natural gas price in 2012. In case plants are fed with by-products only, the incentive is increased by 50%. In case biomethane is used as vehicle fuel, producers can benefit for 20 years, and like any other biofuel producer, from certificates for the production and marketing of biofuels. In case biomethane is produced from byproducts or waste, the number of certificates awarded is doubled. Incentives (a 50% increase in the number of certificates for 10 years) are awarded also to producers that decide to market directly their biomethane by building a gas station at their expenses.

The Italian government also introduced incentives for electric energy produced from biomethane, which is more efficient than producing it from raw biogas. The incentive is equal to the tariff for electricity production from biogas net of the amount of energy needed for the conversion process. In the case of biomethane, producers will not have to take part in auctions to purchase production quotas and will not have to enroll in the producers' registry.

Literature Review of Biogas Production Efficiency and Biomethane

It has been claimed that electric energy and heat produced from biogas—in turn obtained from animal sludge, landfill materials, or energy crops—can represent a way to reduce GHG emissions and to enhance soil fertility using the so-called digestate as a fertilizer. However, biogas effectiveness in reducing GHG emissions depends on many factors, and evidence in this respect is mixed. At the same time, many studies highlight the high potential of biomethane production in efficiency terms; some studies also criticize the EU's Renewable Energy Directive.

Using a life-cycle approach, Berglund and Börjesson (2006) analyzed the energy performances of different biogas production systems. Results are significantly affected by the system design and the raw materials digested, including raw materials transportation; it is also possible that the overall energy balance turns negative.

The Intergovernmental Panel on Climate Change, however, states that the combined action of reduced waste generation and the exploitation of energy from waste (including anaerobic digester biogas) can produce an indirect reduction of GHG emissions through the conservation of raw materials, improved energy and resource efficiency, and fossil fuel avoidance (Bogner et al., 2008).

Tilche and Galatola (2008) investigated the potential contribution of anaerobic digestion in terms of GHG-emission reduction for the 27 EU countries on the basis of their 2005 Kyoto declarations using life-cycle data. They considered two possible biogas applications—electricity production from manure waste and upgraded methane. The authors show that biogas may considerably contribute to GHG-emission reduction in particular if used as biofuel: biogas has the potential of covering almost 50% of the 2020 biofuel target of the EU without implying land-use changes.

Pöschl, Ward, and Owende (2010) evaluated the energy efficiency of various biogas and production pathways. They consider single and co-digestion of multiple feedstocks and different biogas utilization pathways. The analysis is based on the three main feedstock material flows, agricultural waste, energy crops, and municipal solid waste and residues from the food industry. Results also show that, whereas the upgrading of biogas to biomethane for injection into the natural-gas grid potentially increases the primary energy input for biogas utilization by up to 100%, the energy efficiency of the biogas system is improved by up to 65% when natural gas is substituted with electricity.

Blengini Brizio, Cibrario, and Genon (2011) also used life-cycle assessment to evaluate the environmental and economic sustainability of various types of biogas facilities in Piedmont (Northern Italy). They analyze biogas plants using dedicated crops (corn, sorghum, triticale, and miscanthus) and manure to produce biogas that is in turn used for either heat or power generation. In terms of GHG emissions, savings depend on many factors and are heavily influenced by the non-renewable energy of reference to be substituted. The authors also found that, when used as fertilizer, the digestate can increase the risk of acidification and eutrophication of water and that particulate-equivalent emissions were found to be very large in comparison to modern natural-gas power plants.

Also, Boulamanti, Maglio, Giuntoli, and Agostini (2013) point out the fact that biogas production does not necessarily mean a reduction in GHG emission since the carbon footprint of biogas is strongly influenced by several factors, especially the choice of feedstock and operational practices regarding the digestate. Corn has higher yields, but 28-42% of total GHG emissions of the whole process for producing energy come from its cultivation. On the contrary, manure usage reduces the amount of electric energy that can be produced but lowers the fossil energy required to produce it since it is a residue of the livestock activity. Using manure is also more efficient from a carbon point of view since the storage and spread of manure on the fields avoids emissions.

Manninen et al. (2013) calculate climate-change impacts of biogas production with two alternative life-cycle assessment approaches: the one outlined in the RED and the one compliant to the ISO 14040 standard. The aim was to determine whether the production system achieves the saving targets (60%) for GHG emissions as set by the RED. Since the RED enables different interpretations of its calculations rules, the authors created four case studies. Emission estimates vary between 16.9 to 47.7 g CO_2/megajoule (MJ), allowing emission savings from 42% to 80%.

Uusitalo et al. (2014) study—always through life-cycle assessment methods—the GHG emissions from biowaste, wastewater treatment plant sludge, and agricultural-biomass-based biogas use as a transportation fuel and compare the transportation use with the electricity and heat production and composting feedstock. They find that the use of biogas in the transportation sector can reduce GHG emission by 49-84% compared to fossil transportation fuels. Also, converting biogas into electricity and heat production can reduce GHG emissions as compared to composting of feedstock, but reductions are not as high as in transportation use in most cases, even though GHG savings heavily depend on local energy systems.

Data and Methodology

This work aims to provide an estimate of the land needed to grow energy crops (corn for corn silage) for biogas production in the Po Valley using data available from the Italian National Statistics Institute (Istat) and the literature. In addition, we estimate the energy gains that are possible to achieve by upgrading biogas into biomethane instead of using it to produce electric energy.

Data used in this study are from Fabbri, Labartino, Manfredi, and Piccinini (2013). The database contains data on the number of operational biogas plants and installed electric power by region and by substrate used for feeding the digestors. In 2012 in Italy, 994 biogas plants were in place, 744 of which are in the four regions under study: Piedmont, Lombardy, Veneto, and Emilia-Romagna, where agriculture intensity levels are very high.

Installed power was 756.4 MW in 2012, 10% of which in Piedmont, 35.8% in Lombardy, 14.3% in Veneto, and 14.6% in Emilia-Romagna. Almost 75% of total installed power was located in the Po Valley.

Biogas plants that use only animal slurries as substrate represented 3.2% of total installed power; plants that process animal slurries, agro-industrial wastes, and energy crops constitute 11.8% of installed power; plants using animal slurries and energy crops total 38.2%; plants employing animal slurries and agro-industrial wastes represent 24.4%; and plants fed with only energy crops total 22.4%. These percentages referred to Italy as a whole, but they have been judged representative of the situation in the Po Valley (which represents 75% of installed power) and therefore applied to compute the amount of corn needed to produce biogas in the various regions (Table 1).

Normally, small plants (up to 500 kW of installed power) tend to use more animal slurry than energy crops (they are often attached to livestock farms), while big plants (more than 1 MW) use energy crops as primary feedstock. Professionals and employees of the regional governments indicated that energy crops (typically corn silage) also are widely used in plants that declare to employ animal slurries only.

Table 1. Typologies of biogas plants in Italy and relative share on total installed electric power (EP) in 2012.

Plant type by substrate	EP (MW)	% on total EP installed
Animal slurries only	24.2	3.2
Animal slurries, agro-industrial (a.i.) residues, and energy crops	89.3	11.8
Animal slurries and energy crops	288.9	38.2
Animal slurries and a.i. residues	184.6	24.4
Energy crops only	169.4	22.4
Total	756.4	100.0

Source: Own elaborations on CRPA data

The amount of electric energy generated in 2012 both in MWh and terajoules (TJ)—assuming plants work for 90% of total available time—has been calculated. Biogas typically has a thermal value of about 23 MJ/m^3. Since 1 kWh equals 3.6 MJ, it is possible to produce 2.14 kWh of electric energy from a cubic meter of biogas (Swedish Gas Centre, 2012). This conversion coefficient was used to estimate the amount of biogas needed to produce all the electric energy generated in 2012.

The amount of substrate needed to obtain the biogas produced in 2012 has been calculated using other conversion coefficients from the literature (CRPA, 2008b, 2008a; Fabbri, Soldano, Moscatelli, & Piccinini, 2012). It was assumed that it is possible to obtain 25 m^3 of biogas from 1 ton of animal slurry, 200 m^3 of biogas from 1 ton of corn silage, and 170 m^3 of biogas from one ton of agro-industrial residues. It was further assumed that all cereal silage employed was corn silage. The conversion coefficient from agro-industrial residues to biogas is the average of all conversion coefficients of the main residues employed.

It was assumed that all feedstock used in digestors fed with energy crops was corn silage. It was more difficult, however, to make an assumption about the quantities of corn silage used in digestors also fed with animal slurry and agro-industrial residues. It eventually was decided to assume that 25% of feedstock used in plants running on animal slurries "only" was corn silage; 60% in plants using both animal slurries and energy crops; and 25% in plants employing animal slurries, energy crops, and agricultural residues. However, since the composition of the substrate varies substantially depending on the size of the biogas plant and local conditions, it was decided—as a sensitivity analysis—to employ a different hypothesis on the share of corn silage used in plants running on both animal slurry and corn silage. These percentages range between 50% and 60% in plants using both animal slurries and corn and between 0% and 25% in plants that declare to use animal slurry only.

Finally, the area needed to grow the corn for biogas production was computed assuming a corn silage yield of 60 tons/ha.

After estimating the area cropped with energy crops for biogas production, the efficiency of energy conversion from biogas to electric energy and from biogas to biomethane (assuming that all other stages of biogas production and digestate management remain the same) was computed, even though the energy balance of the whole process also depends on the type of substrate used, the efficiency of the cogenerator, and on whether substrates have to be transported for long distances.

If the biogas is used to provide heat, then little further processing is required: the gas is burned in a boiler and converted to heat at 85% efficiency. If only electric energy is produced, the efficiency of the conversion from biogas to electricity is about 35%. If the biogas is consumed in a cogeneration or combined heat and power (CHP) unit, then a minimal amount of gas scrubbing (upgrading) might be required to remove excess H_2S. Then, the gas is converted to electricity at 35% efficiency and heat at 55% efficiency: approximately 85% of the energy value of the biogas is therefore transformed into either electricity or heat (Berglund & Börjesson, 2006). Conversely, in order to be suitable for injection into the natural-gas grid, biogas must be "upgraded" to pure methane (by eliminating H_2S and CO_2) and compressed.

To upgrade biogas to biomethane (typical methane content of biogas is 60-70%, while at least 95% purity is required for injection into the natural-gas grid), several technologies are available, including water scrubbing, organic physical scrubbing, amine scrubbing, pressure swing adsorption (PSA), and membrane technology. Investment and operational costs are not very different among the different technologies and decrease with plant size. However, membrane technology tends to be the cheapest option in terms of investment costs. The electric energy demand for biogas upgrading is 0.46 kWh/m^3 for water scrubbing, 0.46-0.67 kWh/m^3 for organic physical scrubbing, 0.27 kWh/m^3 for amine scrubbing, 0.46 kWh/m^3 for PSA, and 0.25-0.43 kWh/m^3 for membrane technology. The optimal solution depends on the farm characteristics, size, and location (European Commission, Intelligent Energy Europe,

Table 2. Italy—Biogas plants, installed EP, and produced in 2012.

Regions	Plants	Installed EP (MW)	EP produced MWh	EP produced TJ	Share on national total (%) Plants	Share on national total (%) Installed and produced EP
Piedmont	106	75.4	594,454	2,140	10.7	10.0
Lombardy	374	271	2,136,564	7,692	37.6	35.8
Veneto	151	107.8	849,895	3,060	15.2	14.3
Emilia-Romagna	143	110.2	868,817	3,128	14.4	14.6
Total Po Valley regions	774	564.4	4,449,730	16,019	77.9	74.6
Italy	994	756.4	5,963,458	21,468	100.0	100.0

Source: Own elaborations on data from Fabbri et al. (2012)

Table 3. Estimation results: Quantity of substrate needed to produce biogas in 2012 (thousand tons).

	Animal slurries "only"		Animal slurries, a.i. residues, & energy crops			Animal slurries & energy crops		Animal slurries and a.i. residues		Energy crops only
Regions	Slurries (75%)	Corn silage (25%)	Slurries (50%)	Corn silage (25%)	Residues (25%)	Slurries (40%)	Corn silage (60%)	Slurries (55%)	Residues (45%)	Corn silage
Piedmont	255.2	10.6	627.4	39.2	46.1	1,624.8	304.7	1,427.0	171.7	297.7
Lombardy	917.3	38.2	2,254.9	140.9	165.8	5,839.9	1,095.0	5,129.0	617.1	1,070.1
Veneto	364.9	15.2	897.0	56.1	66.0	2,323.0	435.6	2,040.3	245.5	425.7
Emilia-Romagna	373.0	15.5	917.0	57.3	67.4	2,374.8	445.3	2,085.7	251.0	435.2
Total Po Valley regions	1,910.3	79.6	4,696.3	293.5	345.3	12,162.5	2,280.5	10,682.0	1,285.3	2,228.7
Italy	2,560.2	106.7	6,293.9	393.4	462.8	16,300.0	3,056.3	14,315.9	1,722.5	2,986.9

Source: Own elaborations on data from Fabbri et al. (2012)

2012). To calculate the energy gains that are possible to achieve by injecting upgraded biogas into the natural-gas grid instead of using it to produce electric energy, it was assumed that—regardless of the upgrading technique used—an energy requirement of 0.5 kWh/m^3 is required.

Results

Table 2 shows the estimated amount of electric energy produced from biogas (from agriculture) in Italy in 2012.

Po Valley regions represented 74% of total electric energy produced in Italy for a total of almost 4.45 million MWh or 16,019 TJ. Among Po Valley regions, Lombardy was characterized by the highest electric energy production (7,692 TJ, 35% of total national production); this is the region with the most intensive and productive agriculture and the one where the livestock sector is more developed.

Biogas facilities that employ animal slurry and energy crops produce 38% of total electric energy generated; 24% was generated in facilities fed with animal slurry and agro-industrial residues; 23% in facilities using energy crops only; 12% in plants fed with animal slurry, residues, and energy crops; just 3% in plants using animal slurry only.

Biogas needed to produce all the electric energy generated in 2012 totaled 1.99 billion m^3 in the Po Valley regions. Table 3 reports the estimated quantities of animal slurry, agro-industrial residues, and energy crops (corn silage) used to produce biogas in 2012 in Italy and in the Po Valley regions.

Our estimates indicate that about 6.5 million tons of corn silage were used for biogas production in Italy in 2012, 4.9 million of which was in the Po Valley regions. Corn silage use was highest in Lombardy (2.3 million tons), while biogas plant typologies that employed most corn silage were those fed with animal slurry and energy crops (3.1 million tons).

Assuming a corn silage yield of 60 tons per hectare in the Po Valley, it is possible to compute the area needed to produce the corn silage to be used for biogas production. Results are shown in Table 4.

In 2012, more than 81,000 ha were cropped with energy crops—namely corn—for biogas production in the Po Valley regions. In Lombardy, the area cropped

Table 4. Estimation results: Area needed to grow corn for biogas production in 2012 (ha).

Regions	Animal slurries "only"	Animal slurries, a.i. residues, & energy crops	Animal slurries & energy crops	Energy crops only	Total	Share of corn area for biogas on total corn area (%)
Piedmont	177.2	653.5	5,077.6	4,962.4	10,870.7	5.6
Lombardy	637.0	2,348.9	18,249.7	17,835.7	39,071.3	18.2
Veneto	253.4	934.4	7,259.5	7,094.8	15,542.0	5.8
Emilia-Romagna	259.0	955.2	7,421.1	7,252.7	15,888.0	14.0
Total Po Valley regions	1,326.6	4,891.9	38,007.9	37,145.6	81,372.0	10.3
Italy	1,777.9	6,556.1	50,937.6	49,781.9	109,053.5	11.2

Source: Own elaborations on data from Fabbri et al. (2012)

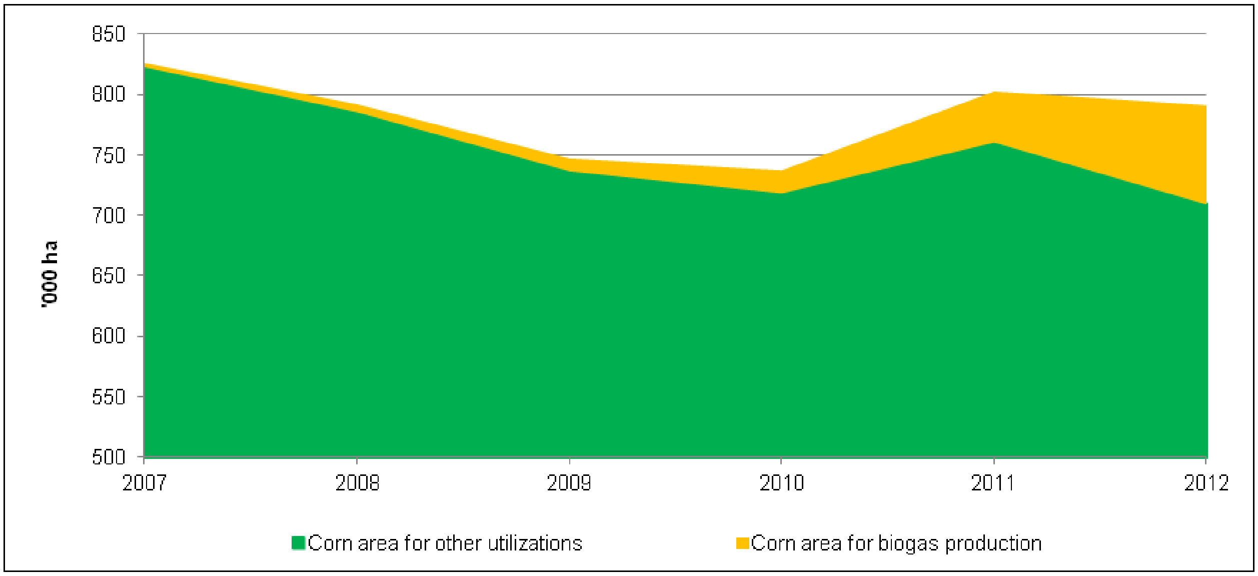

Figure 1. Changes in total corn area and corn area for biogas production in the Po Valley, Italy.
Source: Own elaborations on Isat data

with corn for biogas production reached 39,071 ha; in Emilia-Romagna and Veneto, this totaled about 15,500 ha each; and totaled 10,900 ha in Piedmont. This means that about 10.3% of total corn area in the Po Valley regions was used for biogas production in 2012, a share that reached 18.2% in Lombardy and 14.0% in Emilia-Romagna. These figures acquire even more relevance if compared to those of the last few years: in 2011 just 5.2% of the corn area was used for biogas production in the Po Valley, 2.6% in 2010, and 0.4% in 2007 (Figure 1).

As outlined in the 'data and methodology' section above, as a sensitivity analysis, estimations have been carried out again, varying the share of corn silage that was assumed biogas plants running on a mixture of animal slurries and silage would employ, since it might vary considerably according to farm location, corn silage availability, and the period of the year.

Looking at the figures shown in Table 5, it is possible to see how the corn area needed for biogas production, ranges from 73,711 ha to 87,707 ha according to the assumptions made on the quantity of corn silage employed. This means that, according to the various scenarios, the share of corn area used for biogas production on total corn area in 2012 ranges between 9.3% and 11%, percentages only marginally different than that computed in the baseline scenario.

Even though our calculations (due to lack of data) are based on assumptions and have to be regarded as estimates, it is nevertheless clear that the expansion of the biogas sector in the last few years has been exponential, while total corn area has been decreasing despite increased prices. This probably has to do with the last reform of the CAP (from Fischler, implemented 2005-2007), which fully decoupled subsidies from production. This means that, in a framework of progressively declining corn (and cereal) production, an increasing

Table 5. Corn area used for biogas production in the Po Valley in 2012 according to different scenarios in terms of corn silage used in plants fed with a mixture of slurries and corn silage.

		Animal slurries "only" (2 corn silage use options)	
Po Valley total		**0%**	**25%**
Slurries and energy crops (3 different corn silage use options)	50%	73,711	75,037
	60%	74,816	81,372
	70%	86,380	87,707

Source: Own elaborations on data from Fabbri et al. (2012)

share of it is being used for non-food purposes. This—similarly to what has been happening in the United States in the case of ethanol production—might have had negative repercussions on price levels and, more importantly, on feed availability. The role of policy in agricultural price spikes of recent years is key: de Gorter et al. (2013) argue that biofuels' impact on food markets is all due to policy, and that, even though several other factors might have played a role, prices would not have increased to that extent in absence of biofuel policies. The United States and other Organisation for Economic Co-operation and Development (OECD) countries' environmental and renewable energy policies not only have established a new link between food and biofuel prices but also created the premise for the price spikes of last years.

In recent years, the profitability of the livestock sector in Italy has been declining due to lack of supply coordination and scarce valorization of quality products (especially on foreign markets) but also due to increased feed cost. For this reason it should be avoided by the government to promote alternative uses for agricultural commodities that could be alternatively employed for animal feed.

Table 6 shows the estimated efficiency gains, in terms of energy produced, that would be obtainable if all biogas used for electric energy production was upgraded and injected into the natural-gas grid instead, other things (starting from the substrate used to digestate-management techniques) being equal.

From biogas produced in Italy in 2012, it was possible to obtain 21,468 TJ of electric energy with an energy efficiency of about 35%. If all that biogas were upgraded to biomethane, the energy that would be possible to obtain (in the form of biomethane and net to the energy spent for the upgrading process [0.5 kWh/m^3]), would be about 53,884 TJ—1.25 times more than the electric energy produced instead.

Table 6. Efficiency of different biogas utilization pathways in Italy.

Total biogas produced (million m^3)	2,666.9
Total electric energy generated (TJ)	21,468.4
Total biomethane obtainable (million m^3)	1,600.1
Potential biomethane energy content (TJ)	55,204.6
Energy needed for biogas upgrading (TJ)	1,320.1
Effective biomethane energy content (TJ)	53,884.5
Energy gain (%)	125.9

Source: Own elaborations on data from Fabbri et al. (2012)

It is possible, through the so-called cogenerators, to recover almost 55% of the energy contained in biogas in the form of heat. Nonetheless, heat cannot be stored and must be used immediately and in the place of production. It is very unlikely that small- and medium-sized farms are able to use all the heat generated in the cogeneration process since even big farms that need heat for transforming their products, like dairy farms with attached cheese factories, would struggle); this is especially true during the summer when the energy requirements for domestic heating are almost zero.

Conclusions and Policy Recommendations

This article assessed the impact of policies stimulating the production of electric energy from renewable energy sources—specifically biogas—in the Po Valley, the most productive agricultural area in Italy. The aim was to show that policies in favor of "renewable energy" might lead—due to bad design, implementation, and monitoring—to unwanted effects.

Electric energy production from biogas in Italy started to take off in 2007 thanks to a very favorable policy framework—one of the most generous in Europe. In a few years, the number of agricultural biogas plants grew exponentially, and installed power increased from 24 MW in 2007 to 564 MW in 2012 in the Po Valley regions (Piedmont, Lombardy, Veneto, and Emilia-Romagna). Even though digestors producing biogas can be fed with any kind of organic matter—among which is animal slurry—almost all of them also employ energy crops (typically corn silage) to increase the biogas yield and stabilize the digestion process. The highest share of energy crops is used in large-scale plants.

Our estimates show that in 2012 some 1.9 billion m^3 of biogas were used for electric energy generation in the Po Valley; this was generated from 4.9 million tons of corn silage. This means that more than 80,000 ha were cropped with corn to be used for biogas production, representing 10.3% of total corn area; this share reached

18.2% in Lombardy and 14.0% in Emilia-Romagna. The growth has been exponential: in 2011, just 5.2% of total corn area was used for biogas production in the Po Valley regions, as compared to 0.4% in 2007. Sensitivity analysis showed that results are robust to different assumptions regarding the quantity of corn silage employed in plants running on both animal slurries and corn silage.

It is hard to imagine that this sudden increase in biogas production—due to a very favorable policy framework—did not have any consequence on the local agricultural production structure and on agricultural prices, since government subsidies are granted only if the organic matter used to feed the digestors is from an area within 70 km of the plant. The increase in the area covered with energy crops took place in a period characterized by declining total cereal area due to changes in the CAP: in 2005, the complete decoupling of CAP subsidies from production triggered a progressive decline in cropped area and an increased exposure of farmers (especially livestock producers) to fluctuations of world agricultural commodity prices and to higher prices. Italy is a net-importer of cereals and other agricultural commodities, therefore the increased competition for land generated by biogas expansion has been having negative consequences for the Italian livestock sector (concentrated in the Po Valley), which suffers from increased production cost (namely feed cost) and quality products (Parmigiano Reggiano, Prosciutto di Parma, Grana Padano, etc.).

It is possible that biogas expansion represented by the Italian agricultural sector (and, to a certain extent also by EU's) is equivalent to what ethanol expansion has been representing for US agriculture. In the United States, the policy-driven expansion of the ethanol sector (which uses up more than 40% of total US corn production) triggered an exponential increase in the demand for agricultural commodities, fostered competition for land, and contributed to a strong increase in agricultural commodity prices and agricultural commodity price volatility domestically and abroad. The existing literature contains many works illustrating how biogas' and biofuel's effectiveness in reducing GHG emissions must not be taken for granted since it depends on many (sometimes even farm-specific) factors and assumptions that are difficult to take into account during the policy-making process. The substantial lack of foresight of Italian (and European) policymakers created a sustainability paradox or "sustainability trap": policies aimed at increasing sustainability (of energy production in this case) revealed themselves as not sustainable or, at least, of limited effectiveness.

Biogas can be "upgraded" to biomethane (by eliminating impurities) and then injected (after being compressed) into the natural-gas grid. The upgrading process and gas compression require energy, but our estimates indicate that, even taking that into account, transforming biogas into biomethane rather than into electricity allows a 126% gain in energy efficiency.

The new Italian policies in favor of electricity production from biogas (entered into force in January 2013) move in the right direction—even with some years of delay with respect to other European countries—by favoring small biogas plants operated by livestock farms fed with animal slurry and by recognizing that biomethane production can represent a valid alternative use for biogas produced in the Po Valley. What lacked for many years was the political will of reforming the sector and a proper *ex-ante* evaluation of sustainability of biogas policies and their proper monitoring after implementation. Even when Italian policymakers recognized that reforming biogas policies was a priority, it took some years for the new measures to be approved and implemented due to the historically slow and inefficient Italian policy-making process. Moreover, it is still not clear whether the new biogas policies will be valid retroactively or if old incentives will remain in place until their original expiration date.

This article provided a critical analysis of renewable energy policies in Italy and highlighted their scarce effectiveness in promoting the most efficient and sustainable use of available resources. It was difficult to obtain the data needed for the analysis since—to date—there is no national database of installed biogas plants, nor an active and efficient monitoring program. Data had to be collected from multiple sources and double-checked with operators and local policymakers; and even so, many assumptions had to be made. The lack of precise information on a phenomenon that deeply affects Italian agriculture undermines the credibility of Italian energy policies and gives a measure of the great room available for improvement.

References

Akbulut, A. (2012). Techno-economic analysis of electricity and heat generation from farm-scale biogas plant: Çiçekdagi case study. *Energy*, *44*, 381-390.

Annesini, M., Augelletti, R., Fabriani, I., Murmura, M., & Turchetti, L. (2012). *Analisi tecnico-economica del processo di* upgrading *del biogas mediante* pressure swing adsorption [Techno-Economic Analysis of the biogas upgrading process through pressure swing adsorption]. Roma: Sapienza University of Rome, Itailian National Agency for New Technologies, Energy, and Sustainable Economic Development (ENEA).

Berglund, M., & Börjesson, P. (2006). Assessment of energy performance in the life-cycle of biogas production. *Biomass and Bioenergy, 30,* 254-266.

Blengini, G., Brizio, E., Cibrario, M., & Genon, G. (2011). LCA of bioenergy chains in Piedmont (Italy): A case study to support public decision makers towards sustainability. *Resources, Conservation and Recycling, 57,* 36-47.

Bogner, J., Pipatti, R., Hashimoto, S., Diaz, C., Mareckova, K., Diaz, L., et al. (2008). Mitigation of global greenhouse gas emissions from waste: Conclusions and strategies from the Intergovernmental Panel on Climate Change IPCC, fourth assessment report. Working group III (mitigation). *Waste Management & Research*, *26*(1), 11-32.

Boulamanti, A., Maglio, S., Giuntoli, J., & Agostini, A. (2013). Influence of different practices on biogas sustainability. *Biomass and Bioenergy, 53*, 149-161.

Centro Ricerche Produzioni Animali (CRPA). (2008a). *Energia dal biogas—Prodotto da effluenti zootecnici, biomasse dedicate e di scarto* [Energy from biogas—Produced from animal slurries, dedicated biomass and residues]. Legnaro, Padua, Italy: Associazione Italiana Energie Agroforestali (AIEL).

CRPA. (2008b, April). *Biogas: l'analisi di fattibilità tecnico-economica* [Biogas: Techno-economic feasibility analysis] (CRPA Notizie 4/2008). Legnaro, Padua, Italy: AIEL.

de Gorter, H., Drabik, D., & Just, D.R. (2013). Biofuel policies and food grain commodity prices 2006-2012: All booom and no bust? *AgBioForum*, *16*(1), 1-13. Available on the World Wide Web: http://www.agbioforum.org.

European Biogas Association (EBA). (2011). *Biogas—Simply the best*. Budapest: Author.

European Commission, Intelligent Energy Europe. (2012). *Introduction to the production of biomethane from biogas—A guide for England and Wales*. Brussels: Author.

Fabbri, C., Labartino, N., Manfredi, S., & Piccinini, S. (2013). Biogas, il settore è strutturato e continua a crescere [Biogas sector is structured and keeps growing]. *Informatore Agrario, 11*, 11-16.

Fabbri, C., Soldano, M., Moscatelli, G., & Piccinini, S. (2012). Biomassa, come si calcola il suo valore economico [Calculating the economic value of biomass]. *Informatore Agrario*, *40*, 13-17.

Gestore Servizi Energetici. (2010). *Guida agli incentivi per la produzione di energia elettrica da fonti rinnovabili* [A guide to the incentives for electric energy production from renewable sources]. Rome: Author.

Manninen, K., Koskela, S., Nuppunen, A., Sorvari, J., Nevalainen, O., & Siitonen, S. (2013). The applicability of the renewable energy directive calculation to assess the sustainability of biogas production. *Energy Policy, 56,* 549-557.

Mela, G. (2013). *Assessing the economic, environmental and social sustainability of biofuel policies*. Unpublished doctoral dissertation, Università degli Studi di Padova, Padua, Italy. Available on the World Wide Web: http://paduaresearch.cab.unipd.it/5366/.

Nielsen, J., & Oleskowicz-Popiel, P. (2008, December 11). The future of biogas in Europe: Visions and targets until 2020. Paper presented at the European Biomass Association's (AEBIOM) annual workshop 'Biogas—A promising renewable energy source for Europe,' Brussels, Belgium.

Pöschl, M., Ward, S., & Owende, P. (2010). Evaluation of energy efficiency of various biogas production and utilization pathways. *Applied Energy*, *87*, 3305-3321.

Strauch, S., Krassowski, J., & Singhal, A. (2013). *Biomethane guide for decision makers—Policy guide on biogas injection into the natural gas grid*. Brussels: European Commission.

Strauch, S., Krassowski, J., & Umsicht, F. (2012). *Overview of biomethane markets and regulations in partner countries*. Intelligent Energy Europe—Green Gas Grids.

Swedish Gas Centre. (2012). *Basic data on biogas*. Malmö: Author.

Tilche, A., & Galatola, M. (2008). The potential of bio-methane as bio-fuel/bio-energy for reducing greenhouse gas emissions: A qualitative assessment for Europe in a life cycle perspective. *Water Science and Technology, 57*(11), 1683-92.

Uusitalo, V., Havukainen, J., Manninen, K., Höhn, J., Lehtonen, E., Rasi, S., et al. (2014). Carbon footprint of selected biomass to biogas production chains and GHG reduction potential in transportation use. *Renewable Energy, 66*, 90-98.

See next page for Appendix.

Appendix. Structural Data on the Agricultural Sector in the Po Valley and in Italy.

Table A1. Number of agricultural holdings by utilized agricultural area (UAA) and average UAA per holding in 2010.

	Holdings ('000)				UAA ('000 ha)				Average UAA			
Region	<50 ha	50-100 ha	>100 ha	Total	<50 ha	50-100 ha	>100 ha	Total	<50 ha	50-100 ha	>100 ha	Total
Piedmont	62.5	2.9	1.7	67.1	473	177	361	1,011	7.6	61.4	208.8	15.1
Lombardy	48.9	3.3	2.1	54.3	415	209	363	987	8.5	62.4	172.4	18.2
Veneto	116.8	1.7	0.9	119.4	538	102	172	811	4.6	59.9	186.2	6.8
Emilia-Romagna	67.8	3.8	1.8	73.5	563	208	294	1,064	8.3	54.1	162.1	14.5
Others	1,267.2	24.2	15.2	1,306.6	5,086	1,326	2,570	8,983	4.0	54.8	169.6	6.9
Italy	1,563.2	36.0	21.7	1,620.9	7,075	2,021	3,760	12,856	4.5	56.2	173.1	7.9

Source: Own calculations on Istat data

Table A2. Number of agricultural holdings and UAA by land use in 2010.

	Holdings ('000)					UAA ('000 ha)				
Region	Arable crops	Perm. Crops	Grazing land	Energy crops	Total	Arable crops	Perm. Crops	Grazing land	Energy crops	Total
Piedmont	41.0	33.8	29.7	0.1	67.1	543.2	94.6	371.4	2.2	1,010.8
Lombardy	35.2	14.7	21.8	0.2	54.3	715.3	36.5	234.6	4.7	986.8
Veneto	91.9	47.2	21.9	0.3	119.4	569.3	109.6	130.5	1.9	811.4
Emilia-Romagna	56.5	36.8	13.8	0.3	73.5	830.6	129.60	102.6	4.6	1,064.2
Others	603.8	1,059.6	187.3	0.4	1,306.6	4,351.0	2,010.5	2,595.0	3.6	8,982.8
Italy	828.4	1,192.1	274.5	1.4	1,620.9	7,009.3	2,380.8	3,434.1	17.0	12,856.0

Table A3. Number of agricultural holdings with livestock and livestock population in 2010.

	Holdings ('000)					Heads ('000)				Heads per ha of UAA			
Region	Cattle	Sheep	Pigs	Chickens and turkeys	Total	Cattle	Sheep	Pigs	Chickens and turkeys	Cattle	Sheep	Pigs	Chickens and turkeys
Piedmont	13.2	1.5	1.2	1.7	19.7	816	93	1,112	10,669	0.8	0.1	1.1	10.6
Lombardy	14.7	1.7	2.6	2.4	22.1	1,485	106	4,759	26,513	1.5	0.1	4.8	26.9
Veneto	12.9	0.5	1.8	2.9	20.0	756	52	798	46,187	0.9	0.1	1.0	56.9
Emilia-Romagna	7.4	1.0	1.2	1.0	12.6	557	63	1,247	28,247	0.5	0.1	1.2	26.5
Others	76.0	46.4	19.4	15.9	143.0	1,979	6,469	1,415	55,896	0.2	0.7	0.2	6.2
Italy	124.2	51.1	26.2	24.0	217.4	5,593	6,782	9,331	167,512	0.4	0.5	0.7	13.0

Table A4. Holdings with renewable energy plants in 2010.

	Number of holdings					
Region	**Wind**	**Biomass**	**Biogas**	**Solar**	**Hydro**	**Other**
Piedmont	3	97	40	1,429	33	158
Lombardy	9	299	142	1,640	18	178
Veneto	19	139	41	1,569	12	308
Emilia-Romagna	17	93	38	1,369	20	95
Others	380	1,397	71	11,286	400	1,674
Italy	428	2,025	332	17,293	483	2,413