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This paper contributes to the ongoing debate on the sustainability of agroenergy. We propose an empirical model to simulate the diffusion of farm biogas installations and estimate a set of indicators covering the economic, environmental, and social dimensions of sustainability at the regional level. Model results show that agroenergy production can help farmers stabilise their income and keep viable rural areas, despite some trade-offs among socioeconomic and environmental indicators. Major drawbacks are environmental risks associated with farming intensification.

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Biogas and EU's 2020 targets: Evidence from a regional case study in Italy

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***Highlights**

- The paper assesses socio-economic and environmental impacts of farm biogas at the regional level.
- Trade-offs between socio-economic and environmental indicators are observed.
- Biogas adoption on farm is a strategy to maintain the viability of rural areas.

Biogas and EU's 2020 targets: Evidence from a regional case study in Italy

Abstract

The provision of renewable energy by agriculture—so-called agroenergy—is a key element of the Europe 2020 Strategy and has sparked public and research debates on the bio-based economy. Hot topics involve direct and indirect land use change and the ability of agroenergy to foster or hinder food and energy security. Worldwide research has dealt with these and other issues associated with the sustainability of the diffusion of agroenergy generation systems, but the subject is still open.

This paper contributes to the ongoing debate on the sustainability of agroenergy. We propose an empirical model to simulate the diffusion of farm biogas installations and estimate a set of indicators covering the economic, environmental, and social dimensions of sustainability at the regional level. Model results show that agroenergy production can help farmers stabilise their income and keep viable rural areas, despite some trade-offs among socioeconomic and environmental indicators. Major drawbacks are environmental risks associated with farming intensification.

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Biogas and EU's 2020 targets: Evidence from a regional case study in Italy

1. Introduction

The European energy strategy towards 2020 builds on a set of binding community-wide targets aiming to reduce the European Union's (EU) dependence on imported fossil fuels and boosting new energy technologies (Renewables Directive 2009/28/EC). In the EU, the share of renewable energy among overall energy consumption should reach 20% by 2020; each member state is called to contribute with at least 5.5%: Italy, for example, is committed with 17%. The Renewables Directive recommends EU nations to increase the use of biogas as a fuel for energy plants and for transports due to its reduced greenhouse gas emissions compared to fossil fuels. Biogas is generated through the bacterial processing (digestion) of biomass in oxygen-free containers (anaerobic digesters). In addition to the useful output (biogas), the digestion delivers a by-product (i.e., the digestate, a sludge with application as fertiliser). Biomass includes residues, by-products, and waste from forestry, fishery, aquaculture, crop and livestock farming, food processing, management of urban green, the timber processing industry, energy crops and the biodegradable fraction of municipal solid waste.

The agricultural sector may help the EU meet the energy target by providing agroenergy from biogas.

In Italy, the number of farm-based biogas installations has recently increased tremendously. Three interdependent global crises at the energy, environmental and agricultural level may have contributed to biogas success (Carrosio, 2013). Geopolitical trends, with rising political and social instability in fossil-fuel-producing countries and the emergence of state-owned energy champions, contributed to the global increase of traditional fuel prices until 2008 (Umbach, 2010). This upward trend of fuel prices, which raised production costs at the farm level, and adverse meteorological conditions linked to climate change had pushed up agricultural commodity prices globally (FAO-HLPE, 2013). In addition, farmers are more and more committed to climate change mitigation requirements (Nelson et al., 2009). Biogas is a viable bottom-up solution to face the crisis, by delivering clean and renewable energy, reducing fossil fuel imports, and providing a new stream of income to farmers (Ausilion et al., 2009). Given their decentralised nature and the regional investment structure, biogas plants can also contribute significantly to rural development (Carrosio, 2013).

Two major interdependent determinants of on-farm biogas diffusion in Italy are the public support system and the prospect that production diversification may help income stabilisation by preventing farmers' reliance on the commodity market. Small on-farm biogas plants (up to 999 kWh rated power) have benefited from feed-in tariffs since 2009 (DM 18-12-2008): each unit of electricity plugged into the national grid was remunerated with €0.28/kWh for 20 years. Tariff eligibility involved two major constraints: (i) self-supply constraint (i.e., the farmer needed produce at least 51% biomass on farm) and (ii) out-sourcing constraint (i.e., purchased biomass had to come from within 70 km from the plant). The former constraint aims at ensuring that biogas depends on a farm's agricultural activities, while the latter is meant for limiting greenhouse emissions from transports, in compliance with EU's Renewables Directive.

Against this background, this paper aims to answer the following research questions: "To what extent can the diffusion of farm biogas help meet EU's 2020 energy targets at the regional scale?" and "What are the potential socioeconomic and environmental impacts of that diffusion on the region under study?" To answer these questions, we take the Italian province of Pisa as a case study. The province of Pisa is an administrative division of the region Tuscany, one of the 20 regions of Italy. The European Nomenclature of Territorial Units for Statistics (NUTS) classifies Italian regions as level-2 units (NUTS 2) and provinces as level-3 units (NUTS 3). The agricultural sector of Pisa is a heterogeneous set of small and medium farms, which jointly contribute to rural development, local diversity, and cultural heritage and have a prominent role in ensuring food nutrition security. Pisa is located in the northern Mediterranean area, and agricultural systems are rather extensive and the agri-food industry is weak. Abandonment of rural areas and farm exit are current issues: in the last decade, utilised agricultural areas and farm numbers have decreased by 10% and 50%, respectively. In terms of 2020 energy targets, the province of Pisa is committed with 7056 MWh energy from biogas by 2020 (Provincia di Pisa, 2012). In Italy, on-farm biogas has followed regional patterns of diffusion, based on the prevailing farming systems. That heterogeneity makes estimating the impacts at the national level tricky; instead, scaling modelling approaches down to the regional level delivers more accurate estimates, although results would not be generalisable. The regional approach to sustainability assessment may allow greater planning efficiency in agriculture and related activities towards 2020 targets. Those assessments may help policy makers and environmental planners focus on key dependencies and processes with local relevance rather than scattering their efforts to face phenomena with unmanageable scopes (Vermeulen et al., 2012). Trainers in biogas technology should also know more about biogas impact at the regional level to adjust their courses to address local needs.

In the Mediterranean area, agriculture is facing environmental (e.g., global change), economic (e.g., market fluctuations, maintenance of agricultural income) and social (e.g., abandonment of rural areas, job and labour creation) challenges. The diffusion of local agroenergy chains may help sustain those rural areas.

The following section overviews the literature on the impacts of farm biogas on the economy, society and the environment. The next one provides the theoretical framework of this study. Then, we detail the steps we followed for delivering this analysis and discuss the results of the model we proposed. We conclude by summarising our findings and delivering policy recommendations. We also discuss the strengths and weaknesses of this study.

2. Sustainability issues associated with the diffusion of farm biogas

The sustainability of biogas is still debated within the scientific community (see Kirkels, 2012, for a review). Here, we propose a brief review of the academic literature that points out the hot topics concerning the sustainability of farm biogas. Far from depicting the complete picture, we aim at framing relevant opportunities and threats to the environment, economy and society associated with the adoption and diffusion of farm biogas-to-energy plants.

Biogas offers agricultural systems the opportunity to mitigate some of their externalities on the environment (Ausilion et al., 2009), particularly in terms of climate change potential, contamination of underground water, and fertiliser use intensity. For example, replacing natural gas with biogas for fuelling electricity plants saves around 90% greenhouse gas emissions (Bachmaier, 2010). In addition, using biogas for processing manure and slurry in animal farming abates climate-altering emission (Clemens et al., 2006), nitrogen leaching into underground water, which help farmers in the EU to comply with the Nitrates Directive (91/676/EEC), as well as as pathogen and odour spreading (Yiridoe et al., 2009) from livestock waste compared with other treatment processes. Particularly, odour reduction may facilitate the coexistence of livestock farms with residential areas in the countryside (Massé et al., 2011), thereby contributing locally to economic and social stability, thanks to job creation (Faaij and Domac (2006). In addition, the diffusion of biogas-to-energy plants in rural areas helps the distributed generation and allows host farms reach energy security (see Chicco and Mancarella, 2009; Sovacool and Mukherjee, 2011 for an overview), which is particularly important for remote communities (Faaij and Domac, 2006). However, the NIMBY (not in my back yard) syndrome has slowed down the diffusion of farm plants (Capodaglio et al., 2016), as has the high start-up costs and daily management costs (Massé et al., 2011), at least in the EU, including Italy. The allocation of Common Agricultural Policy (CAP) funds to farm plant building and member states' support of electricity production from renewable sources boosted the adoption rate (Wilkinson, 2011). The CAP is structured towards two pillars. Pillar I entails direct payments to farmers and is entirely covered by EU funds. Direct payments are a lump sum payment per hectare (ha) of utilised agricultural area (including energy crops), and farmers received around €174/ha of farmland (Frascarelli, 2014). Pillar II is the rural development policy and is cofounded by member states. Member states deliver their Rural Development Programmes (RDPs) at either the national or subnational level. RDPs follow EU regulation, but might differ in terms of funding priorities and activated measures. Italian RDPs are delivered at the regional level (NUTS 2). Both pillars could contribute to the diffusion of agroenergy production systems by ensuring liquidity, raising the incentive to invest in agriculture (Pillar 1), and by cofunding investment costs (Pillar 2). See, for example, Bartolini and Viaggi (2012), Bartolini et al. (2015), and Bartoli et al. (2016) for a discussion of policy measures that may affect propensity to adopt renewables.

Capital-risk investors have driven the diffusion of farm biogas plants in Italy, following the release of the first feed-in tariff scheme (e.g., Cannemi et al., 2014). The recent literature, however, suggests that the profitability of biogas plants is so dependent on states' incentives (e.g., Capodaglio et al., 2016) that changing the tariff could hinder further investments (Chinese et al., 2014). In Italy, the incentive scheme has driven a process of structural isomorphism, with entrepreneurial agroenergy farms hosting plants with over 900 kWh rated power being the dominant model (Carrosio, 2013).

Concerning landscape, biogas installations have a visual impact. Such plants are not necessarily associated with livestock farming; in that case, odours increase, especially during digestate spreading. Basically, biogas adopters prefer the digestate to a purchased fertiliser for economic reasons. For example, in Demark, digestate spreading saves 100% phosphorus and up to 80% nitrogen fertilisers (Holm-Nielsen et al., 2009). Digestate spreading may also reduce farm reliance on chemicals, such as herbicides and phytopharmaceuticals (Sapp et al., 2015).

Biogas plants hardly rely on a single type of biomass, as co-digesting different animal- and plant-based substrates improves the processing conditions and allows year-long production. Although the use of by-products from the agri-food industry is rising, energy crops are widespread biomasses, particularly where arable farming systems prevail and where the food-processing industry is not well developed. Silage corn is the most widespread cultivated biomass, given the high yield of high-quality biogas (Walla and Schneeberger, 2008). Corn cropping for energy purpose is generally nutrient-intensive and rarely entails crop rotation, thus bringing environmental pressures such as reduced fertility, water retention potential of soils (May, 1975) and loss of biodiversity on farmland (e.g., Sauberei et al., 2014). However, double-cropping systems (e.g., the rotation corn-triticale) are more suitable for areas where yields are suboptimal; those rotations are less intensive than the monoculture of silage corn and more efficient in terms of water and nitrogen use (Heggenstaller et al., 2008). Major potential drawbacks of mainstreaming farm biogas are direct land and water use change from food to energy supply and indirect land and water use change from unmanaged land to cropland (Taheripour et al., 2013).

3. Theoretical framework

This paper simulates the *ex-ante* impact of biogas diffusion in the province of Pisa (NUTS 3 level). Several methodologies are available for assessing the *ex-ant*e impact of technology diffusion. In a review of agricultural and environmental studies, Manos et al. (2013a) identifies 15 different integrated assessment tools for simulating the complexity of the diffusion of new technologies. The approaches, based on modelling and on the measure of physical indicators, outnumber all other methodologies, given their ability to incorporate multiple dimensions (economy, society, environment) and being suitable to different contexts. Those tools are robust and allow one to draw a causal inference about impact pathways (Sterman, 2000; Buysse at al., 2007) in *ex-ante* analyses. Causality is relevant in case of potential spatial spillover, which requires one to simultaneously account for synergies and trade-offs among the dimensions of sustainability (Pfau et al., 2014). Modelling approaches belong to both econometrics and mathematical programming (Feder and Umali 1993; Janssen et al., 2010). Econometric modelling of official or primary data consider the pathway from technology adoption or diffusion (treatments) to observed impacts on selected outcome variables as cause–effect relationships. Existing methods encompass several alternatives that are classified based on the applied model (regression or propensity score), the typology of treatment (binary or continuous), and the level of the measured outcome variable (farm-level, territorial level, spillovers). Most methods rely on (spatial) regression or counterfactual methods. The former estimate elasticities of an outcome variable with respect to diffusion or adoption using a set of covariates that includes participation or diffusion. The latter estimate impacts in two steps. Firstly, a matching is performed to create pairs of treated and counterfactual observations. Secondly, a quantification of difference in performance on selected outcome is measured; these procedures are collectively known as estimations of treatment effects (Wooldridge, 2010). See Demartini et al. (2016) or Emman et al. (2013) for examples of regression model applied to impact estimation of biogas diffusion on the land market, employment in rural areas, use of productive factors, and land prices. Examples of biogas impact assessments via counterfactual analysis can be found in Spicka and Krauser (2013), Neupane et al.

(2015), and Gava et al. (2015). These researchers aim to assess the impact at the farm or regional scale on outcomes such as farmers' income and labour and health or environment. Gava et al. (2015) also investigate the impacts of biogas diffusion on neighbouring areas to assess spillover effects. Provided that these models generally estimate elasticity, such value can be used to predict changes in outcome variables assuming increasing values of participation or diffusion and *inter alia* constant condition. Despite a growing diffusion in recent years (also due to increasing data availability), these methods involve mainly *ex-post* exercises, with limited possibility to create future scenarios that diverge from the observed ones (Buysse et al., 2007).

Mathematical programming models, instead, estimate impacts of new technology simulating profitability or utility associated with the decision of adopting a new technology. The main assumptions of those models are rational behaviour and (quasi) perfect access to information (Abadi-Ghadim, and Pannell, 1999; Kallrath and Britz, 2012). Compared to econometric models, mathematical programming models are more flexible and allow design of new and complex policy scenarios, which is a useful feature when past data are poor and when trade-offs or conflicts affect the decision process (Bartolini et al., 2007). Hence, the mathematical programming model is largely applied to *ex-ante* analyses of new technology impacts (Buysse et al., 2007).

Earlier works on new technologies have described innovation diffusion as an S-shape function (Rogers, 1962), where the new technology is first introduced by a group of innovators, then followed by other groups that Rogers (1962) has identified as Earlier Adopters, then by Early and Late Majority, and finally by Laggards. Belonging to one of these categories depends on several variables that could be grouped into farmers' behaviour toward risk; human capital such as age, experience, and educational level; or other constraints such as purchasing power, access to credit, and access to, use, and quality of information (Sunding and Zilberman, 2001).

Most *ex-ante* models that simulate farmers' attitudes towards innovation or new technology adoption are farm-level models (Janssen and van Ittersum, 2007) because those models better simulate farmers' behaviour as enable to details both characteristics of innovation and the farmers' preferences and attitudes (Janssen and van Ittersum, 2007). In normative terms, mathematical programming modelling encompasses three different elements of farmers' decision making: operation choice, sequential to the crops mix and rotation, and strategic decisions (Bouma et al., 1999).

Investment in new technologies that deeply affect faming systems or farm structures (e.g., biogas) are generally regarded as a strategic decision and simulated through profit maximisation or farmer/ household's utility. Some authors estimate farmers' utility, while simultaneously considering their economic, social, and environmental goals (see Manos et al., 2013b) or risk attitude (see Hardaker et al., 2014). Most authors, however, apply capital budgeting techniques and analyse the net present value (NPV) of the cash flow following technology adoption (Marra et al., 2003), and then new technology is adopted when profitable. Some authors extend NPV maximisation to a farm household by including, for example, household consumption patterns or the utilities generated by different labour allocations between on- and off-farm activities (Taylor and Adelman, 2003). Farm household models tend to be more accurate than farm models when the investment decision affects the household in terms of consumption patterns, stream of income, and labour (Viaggi et al., 2011). Applications of capital budgeting techniques to the analysis of the choice to adopt biogas on a farm can be found in Bartolini and Viaggi (2012), Bartolini et al. (2015), and Bartoli (2016).

4. Methodology

In this paper, we simulate the behaviour of farmers deciding whether to adopt a biogas plant on plant by applying a mathematical programming model to representative farm types. We aim to assess the impact of farmers' decisions at the territorial level, taking an Italian province (NUTS 3) as a case study. The empirical analysis covers the province of Pisa and uses micro-data on about 1852 farms, from the latest Italian census of agriculture (2010).

The methodology involves three consecutive steps: identification of representative farms, simulation of farmers' behaviour, and sustainability assessment.

Identification of representative farms

The objective of this step is to apply a non-hierarchical cluster analysis (Aldenderfer and Blashfield, 1984) to the dataset to achieve a manageable number of representative farm types (Bernhardt et al., 1996). Cluster analysis allows us to identify homogeneous groups of farms based on their relative similarity over a set of parameters. We selected four parameters that can discriminate farms with different profiles in the region under study: (i) utilised agricultural area (UAA), (ii) single farm payment per year over the period 2005–2010, (iii) hired labour per year, and (iv) household labour per year. Among the different farm specialisations included in the dataset, we selected arable, horticulture, and livestock specialisations suitable for simulating an investment in biogas. We run the clustering procedure[1] over those three farming specialisations.

The analysis returned 18 clusters: seven (F1 to F7) are arable, three (F8, F9, F10) horticultural, and eight (F11 to F18) in livestock farming. Within each farming system, clusters mainly differ for their UAA and livestock clusters for the number of animals as well. Energy cropping and biogas plants are rare in all clusters (see Annex 1 for details).

Simulation of farmers' behaviour

This step involves farm-household modelling; the methodology draws on Bartolini and Viaggi (2012) and Bartolini et al. (2015). The simulation of farmers' behaviour relies on four basic assumptions: (i) farmers behave rationally and can allocate their productive factors between off-farm and on-farm activities; (ii) farmers face a binary choice about biogas adoption and a discrete choice about available plant size; (iii) biogas adopters decide between self-supplying all the needed biomass to feed the plant or self-supplying 51% biomass and outsourcing the rest within 70 km (in adherence with the Italian regulatory framework); and (iv) the investment in biogas is irreversible and is spread over a multi-annual plan (Blyth et al., 2007)—that is, adopters invest in year *t* and keep the investment in the fund for the loan term. Rationality allows farmers to choose the optimal business strategy based on the maximisation of discounted cash flows:

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[1] Non-hierarchical cluster analysis is based on the k-means method; the criteria for identifying the optimal number of clusters is the highest pseudo-F. Farms with less than 2 ha utilized agricultural area, and farms mainly producing for household self-consumption are excluded from the analysis.

$$\max NPV = \sum_{t=1}^{n} \frac{cf_t^*}{(1+i)^t}$$

s.t.

$$cf_t = \Pi_{onfarm}^t + \Pi_{offfarm}^t + s^{t-1} \geq C'$$

$$\Pi_{onfarm}^t = \pi_c^t + \pi_m^t + \S \pi_e^t + BP^t + GP^t + AECP^t + Loan^t - C_l^t - (1 - \S) C_{eb}^t - \S k^t - \S\, kfeed$$

The objective function is to maximise the NPV (max NPV) of cash flows (cf_t^*) for 20 years (i.e., the period covered by the incentive scheme). The discount rate *i* is 1%; we chose a low discount rate to consider farmer preferences over time, while avoiding overestimating late revenues. The first constraint guarantees that each year the optimal cash flow would at least compensate the farmer for the overall energy consumed by farm activities (C`), where Π_{onfarm}^t and $\Pi_{offfarm}^t$ are the incomes generated on-farm and off-farm, respectively, and s^{t-1} are the savings originated in year (*t-1*). The second constraint is a definitional constraint that defines profit generated by on-farm activities as equalling the sum of the incomes from selling farm products—crops (π_c^t), milk (π_m^t), and energy surplus (π_e^t)—plus the payments from EU's support scheme—basic payment (BP^t), greening payment (GP^t), and agri-environmental climate payment ($AECP^t$)—plus the loan to cover the investment in the plant ($Loan^t$), minus the costs for hired labour(C_l^t), minus missed profits due to energy auto-consumption (C_{eb}^t), minus the cost of the investment in the plant (k^t)—the overall monetary value of the plant paid in year *t*, including the annual cost of credit—and minus the market price of purchased biomass (*kfeed*); § indicates a favourable decision towards biogas adoption.

Most farm biogas installations in Italy can potentially supply over 900 kWh electricity, but smaller plants are operating and are worth being analysed; thus, we solve the profit maximisation problem for five plant sizes (B1 to B5, smaller to bigger), differing for rated power (108 to 972 kW/h), needed quantity of biomass, investment cost, annual cost for planned maintenance, needed quantity of labour, and quantity of energy used for self-consumption (see Annex 2 for details). Model outputs would indicate the optimal plant size per farm type.

We considered the changes in indicator values and farmers' behaviour towards biogas adoption in four scenarios, each simulating a different feed-in tariff:

1. S0: control scenario, simulating that biogas technology does not exist; this scenario allows one to evaluate the impact of biogas adoption;
2. S1: baseline scenario; the feed-in tariff is € 0.28/kWh (i.e., the tariff provided by the Italian government at the time of plant building [2010]);
3. S2: the incentive is € 0.35/kWh (i.e., 125% baseline);
4. S3: the incentive is € 0.42/kWh (i.e., 150% baseline).

We performed this scenario analysis to evaluate the extent to which raising the level of public support drives technology adoption and then leads to technology diffusion over a region. In this study, farmers' behaviour towards biogas adoption is associated with the introduction of energy cropping over a share of farm UAA and to the selection of the optimal plant size, which in turn determines a farm's electricity output.

Impact estimation

To answer the research question, we estimated the values of eight broad socioeconomic and environmental indicators at the cluster level to be used as proxies of impact. We chose that set of indicators to match the provision of an overview of the main opportunities and threats of biogas diffusion with data availability from official sources.

The five socioeconomic indicators are as follows:

(i) firm's NPV (i.e., a measure of the expected profitability of the investment in biogas);

(ii) share of payments received under EU's support scheme over NPV (i.e., a measure of the importance of CAP payments in investment decisions);

(iii) quantity of electricity generated (i.e., a measure of the extent to which biogas helps comply with 2020 targets locally);

(iv) labour demand (i.e., a measure of biogas ability to create jobs or to keep existing jobs locally);

(v) farmland allocated to energy cropping over UAA (i.e., a measure of the extent to which biogas diffusion can create land and water use competition between food/feed and energy cropping).

Altogether, the values of socioeconomic indicators allow us evaluate the extent to which biogas diffusion helps the viability of rural areas by generating new streams of income and employment (Bartolini and Viaggi, 2012) and drives changes in terms of productive factors and crop mixes. Productive factors and land use changes are worth addressing because of the associated social concerns about the competition between food/feed and energy cropping (Schubert, 2009).

Overall, the values of environmental indicators would help in understanding the potential pressures of biogas diffusion. Those indicators are as follows:

(i) water intensity (i.e., a proxy for farming system's water saving [or wasting] potential); the indicator is measured in volume input water per unit UAA;

(ii) nitrogen intensity (i.e., a proxy for a potential farming system's ability to pollute underground water); the indicator is measured in weight input nitrogen per unit UAA;

(iii) Shannon diversity index (i.e., a proxy for a potential farming system's ability to threaten agro biodiversity). The indicator is a modified version of the Shannon index (Desjeux et al., 2015) that approximates for crop diversity. The adjusted Shannon index (*H*) is the ratio between the UAA cultivated with a certain crop i (N_i) and at the overall UAA (*N*) (i.e., $H=-NiN\cdot\ln NiN$). Given a set of *i* crops suitable for cultivation in the region under study, the maximum possible diversity occurs when the farmer dedicates equal shares of land to all suitable crops; instead, monoculture ($i = 1$) delivers the minimum possible diversity on farmland.

We extended indicators' measures to the regional (NUTS 3) scale. Firstly, we used the clustering weight to adjust the values of each indicator; secondly, we calculated the frequency of each cluster within the province and used them for aggregating indicators' values at territorial level; finally, we add the adjusted values per each indicator.

In addition, the assessment considers energy supply under all scenarios to evaluate the potential contribution of biogas towards reaching 2020 energy targets at the regional level.

5. Results and discussion

This paragraph describes simulations' results both at the farm type and at the regional level. Five tables display the outputs of software elaborations: Tables 1 to 4 show farm level results per scenario (S0 to S3), and Table 5 shows impact aggregation at the regional level.

Scenario S0 simulates a control situation, in which biogas technology does not exist (see Table 1 below).

TABLE 1 ABOUT HERE

The estimates of indicators are heterogeneous across farm types. NPV is systematically higher for livestock than for arable and horticultural farms, and EU's financial support accounts for a significant share of NPV (10% to 30% income). This latter result confirms previous analysis (European Commission, 2013, 2014) and highlights that the farming income, and particularly of arable farming, depends largely on public support. In our model, public support consists of direct payments to farmers under Pillar 1 of CAP 2014-2020. Starting from the harvest year 2015, farmers would get a payment per unit UAA based of the value of entitlements in 2014, which would be subject to yearly adjustments up to 2019. That last payment would turn into a flat rate after 2019. Compared to arable and horticultural farming, livestock farming is more demanding in terms of productive factors, needing more labour for daily operations, such as feeding animals, cleaning, and milking. The number of livestock units per farm is set by the Nitrates Directive.

Concerning environmental pressures, the intensity of both nitrogen fertilisation and watering are similar across farm types; instead, the Shannon index is higher for arable farms, presumably because farmers diversify their marketable outputs for reducing risk exposure towards market price fluctuations (Hardaker et al., 2004).

The introduction of biogas and of the payment associated with its adoption drive some structural changes at the micro-level (Table 2).

TABLE 2 ABOUT HERE

Under S1, farmers get €0.28 per each kWh electricity plugged into the national grid. In most cases, that price is not enough to motivate farmers to adopt. Just two livestock farm types (F11, F14) would install B1 plant—the smallest of the simulated plants, rated at 108 kWh electricity. Adopting biogas requires reorganising farm activities, including farmland allocation to different crops, and affects the demand for land and labour. The self-supply constraint forces adopters towards energy cropping. In the region under study, silage corn mono-cropping is not economically convenient because irrigation is mostly unfeasible; in addition, land sloping and soil quality make crop yields generally suboptimal. Then, biogas adopters in that region turn to corn-triticale double-cropping. Compared to S0, land demand nearly doubles, presumably due the self-supply constraint (see Emmann et al., 2013), as biogas adopters allocate over one-fifth UAA to energy cropping. Larger UAA also benefits from higher CAP payments, thus the share of those payments over NPV increases. Berndes and Hansson (2007) highlighted that the introduction of energy production on farms may boost the demand for rural labour; here, however, labour demand varies only slightly, with about 2% increase in F11 and about 2% decrease in F14. Moving to environmental indicators, overall quantity of both nitrogen and water applied on farmland rises, given the increased UAA. Nitrogen intensity (quantity per unit UAA) also rises, while water intensity decreases. That pattern may be due to farmers having shifted from multiannual (4 to 6 years) rotations for feed production, involving winter grains and fodder (see Annex 1), to the biannual corn-triticale rotation: energy cropping is more nitrogen demanding than producing feed; however, energy cropping in the region under study relies on dryland farming, while feed production may require some watering. As expected (see also Pedroli et al., 2013), reducing the number of cultivated crops lowers the Shannon index. That decrease in the Shannon index might also be due to a shrinking of the UAA dedicated to pasture, which generally allows greater biodiversity than intensive energy cropland (Reidsma et al., 2006).

Two further scenarios (i.e., S2 [Table 3] and S3 [Table 4]) simulate increased feed-in tariffs compared to baseline (S1) scenario.

TABLE 3 ABOUT HERE

TABLE 4 ABOUT HERE

The government's decision to pay €0.35 per each kWh electricity plugged into the national grid (S2) leads to four adoptions (F11, F14, F15, F18), all within the livestock sector and involving B1 plants. If farmers' revenue per unit electricity reaches €0.42/kWh (S3), three more livestock (F13, F16, F17) and two arable farms (F1, F3) would install the plant. Among the nine adopters under S3, two arable and four livestock farms (F1, F3, F14, F16, F17, F18) would decide on B1 plant and the three remaining livestock farms (F11, F13, F15) on B2 plant, rated at 254 kWh electricity. Encouraging adoptions, higher energy prices in S2 and S3 drive the same sort of structural change and impact at the farm level as in S1, thereby emphasising the observed values of the indicators.

In all three scenarios (S1, S2, S3), livestock farmers are more willing to adopt biogas than arable and horticultural farmers. Some arable farmers may decide to install a plant just in the highest-price scenario (S3), while no horticultural farmer would take on the risk associated with such an investment; being intensive, horticultural farming is profitable. Within the framework of CAP 2014–2020, farmers in the EU would receive direct farm payments based on their UAA, with larger farms benefiting from higher payments. This can explain the slight increase of the share of those payments over NPV (Bartolini et al., 2015) in S1, S2, and S3 compared to S0. Regardless of the feed-in tariff level, all adopters rent land to widen their UAA for cultivating energy crops. Besides complying with the self-supply commitment, cultivating is more convenient than purchasing biomass. In the case study region, the market price of biomass is around €130/t, while cultivating it on rented land costs around €80/t, with around €20 farmer surplus[2]. Those results support de Wit and Faaij (2010) by suggesting that the

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[2] Production costs refer to the rotation corn-triticale and are based on "silage maize equivalents," which express the quantity of a certain biomass (here, silage corn and triticale) in terms of the quantity of silage corn that

biomass market has little potential. Nitrogen intensity increases, given the significant yield response of corn to nitrogen fertilisation. Water intensity decreases because of wider dryland farming (see comment to Table 2). The Shannon index decreases as farmers shift from 4-year or 6-year to 2-year crop rotations, thereby reducing the number of cultivated species from four or six to two.

Moving to regional-level assessment, we add farm-level estimates adjusted for their respective clustering weights (Table 1). Table 5 displays the regional-level aggregation of simulation's results.

TABLE 5 ABOUT HERE

Changing the feed-in tariff affects the rate of biogas adoption, which in turn drives structural change in the agricultural sector of the region under study. This process has diverse effects on the sustainability indicators.

The simulation returns positive values for economic indicators. Raising the price of energy helps biogas diffusion in the region under study by boosting farmers' profits: compared to S0, NPV increases with 7.39%, 8.65%, and 28.75% in S1, S2, and S3, respectively. The feed-in tariff provides additional income to biogas adopters, thereby mitigating their reliance on direct payments from the EU. The self-supply constraint drives the increase in the demand for cropped biomass to be produced on-farm, which in turn explains the higher demand for agricultural land: compared to S0, UAA rises with 8.64%, 8.50%, and 30.44% in S1, S2, and S3, respectively.

The share of energy cropping over UAA reaches 13% in the highest incentive scenario (i.e., S3). This result suggests that even government's decision to raise the baseline feed-in tariff with 50% would not significantly shrink the surface of land allocated to food and feed production in the province of Pisa.

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releases an equivalent volume of biogas. Data are relative to harvest year 2011 and are sourced from the Italian National Institute of Agricultural Economics (INEA, from the Italian acronym), which also provides rental costs. Biomass market price is valid for central Italy and is sourced from Bologna Commodity Exchange.

Those increases can somewhat counterbalance the recent rate of farmland abandonment in the region under study. The increased demand for land may also increase rental rates, as farmers are more willing to pay for agricultural land for cultivating biomass.

Despite wider UAA, daily activities on biogas host farms require roughly the same quantity of working hours (see Emman et al., 2013). Being highly mechanised, energy cropping is undemanding in terms of working hours, thus allowing the farm household to deal with most activities. However, an employment effect of biogas diffusion may occur in R&D, as suggested by Moreno and Lopez (2008).

Increased feed-in tariffs raise the electricity supply from biogas: the potential energy output per year is 1685 MWh under S1, 3370 MWh under S2, and 9524 MWh under S3.

Raising the price of energy can affect biodiversity, with the Shannon index falling with 3.03% under S2 and 9.09% under S3, compared to S1. Land use change may explain the loss of cropland biodiversity.

Concerning the remaining environmental indicators, the simulation highlights a marginal decrease in both nitrogen and water inputs.

6. Conclusions and Policy Implications

This paper estimates the impact of biogas diffusion at the regional level. We carried out the analysis using farm-level data from the last Italian census of agriculture (2010), relative to the Italian province of Pisa (NUTS 3), and implemented the empirical model on representative farm types belonging to the three main farm specialisations of that province: arable, horticulture, and livestock. We simulated three levels of energy price: (i) baseline (i.e., feed-in tariff in force in Italy in 2010), (ii) 125% baseline, and (iii) 150% baseline. We also simulated a control situation in which technology does not exist. Simulation's results suggest that farmers are averse to biogas adoption, mainly due to the low endowment of productive factors in the region under study. The introduction of the baseline feed-in tariff (€0.28/kWh) drives just two adoptions—in the livestock sector—over the 18 representative farms under study. Increasing that baseline price with up to 50% is not enough to make biogas profitable for most farms: 25% increase drives four adoptions all in the livestock sector, while 50%

increase allows six adoptions in the livestock sector and three in the arable sector. Livestock farmers are more willing to invest in biogas than arable or horticultural farmers, presumably because they require less structural change for complying with the self-supply commitment (51% biomass must be self-produced on farm) and because livestock waste yields high-quality biomass, which needs treatment anyway. Regardless of farm specialisation, the self-supply constraint contributes to the increased demand for land following biogas diffusion, which may affect the price of land and rentals rates. The relevance of the effect on land demand is clearer if considered in the light of the reduction in the operated land, with abandonment of marginal land, that has recently occurred in the region under study. Again, the self-supply commitment explains adopters' allocation of extra farmland to biomass cropping (mainly the rotation corn-triticale), which also frees farmers somewhat from the volatility of commodity prices, while providing differentiate biomass that is anyway required for optimal plant operation. Cultivating energy crops is less labour-intensive than rearing livestock; thus, biogas adopters prefer to meet the self-supply constraint by introducing biomass cropping rather than increasing the number of livestock units to have higher margins on electricity sale. Few arable farmers would adopt the technology just under the highest price scenario. The highest of the simulated tariffs is enough to encourage some farmers to invest in larger plants; however, most farmers do not adopt the technology, and adopters choose small plants due to high investment costs.

Roughly considering electricity as the only energy form, the baseline feed-in tariff (S1) would allow the province of Pisa to comply with the 24% target; raising the baseline price to 25% would help the province reach 48% target; and raising the price to 150% baseline (€0.42/kWh) would allow Pisa to comply with the target, while delivering an electricity surplus of 2468 MWh per year. The potential impacts of agroenergy chains on economy, society, and the environment are current issues within the academy and policy debates around the bio-based economy. The results of our simulation point out the extent to which different rates of biogas adoption may affect the three dimensions of sustainability. Major trade-offs concern the impacts on economy and the environment. Biogas diffusion can boost farmers' income, with positive effects on the viability of rural areas, but may also increase the environmental risk by driving the expansion of nitrogen-spread areas and negatively affecting farmland biodiversity. A key issue in the assessment of biogas sustainability is land and water use change from food and feed to energy cropping. The results of our simulation suggest that such a use change would involve a relatively low share of utilised agricultural area in the region under study, even in a case of the introduction of a high subsidy policy. Yet, building biogas plants in marginal areas may improve the sustainability of land and water use change, thereby preventing land abandonment and providing ecosystem services. Biogas adoption requires deep structural change at the farm level and high investment costs; the low endowment of productive factors is a barrier towards adoption, with just few farmers being likely to assume that risk. Simulation's outputs also suggest that biogas diffusion cannot significantly affect the farming systems' structure in the case study area. This paper suggests that supporting the diversification of farm activities helps the viability of rural areas, mainly through increased income, though a slight rise in the demand for labour occurs. Considering the land market, the proposed example warns about the potential increase in rent and selling prices, given the increased land demand for energy cropping. The results of this study are likely to be extended (*mutatis mutandis*) to other Mediterranean areas that share similarities with the province of Pisa.

Our results highlight that EU's 2020 targets somewhat mismatch. For example, simultaneously attempting shifting towards a bio-based economy, limiting the loss of biodiversity, guaranteeing food security, and promoting the sustainable intensification of agriculture at the EU level may not be straightforward given the issues associated with policy implementation at the regional level. Decision makers should address the issues of policy design complexity and lack of coordination among economic instruments to add value to local potentialities to improve the provision of ecosystem services by agriculture. The climate deal reached at the COP 21 conference in Paris (2015) supports EU's top-down approach towards reducing greenhouse gas emissions and agrees on the promotion of agroenergy. That agreement may aggravate policy inconsistency with actual farmers' ability to drive climate change mitigation at the regional level.

This study is not without limitations. Focusing on the changes at the cluster level, the model does not consider the interactions among farmers or clusters, thereby delivering a coarse analysis of the patterns of change at the farm level, with a rough quantification of impacts. The scarcity of productive factors would increase their price to farmers, with partial mitigation impacts. In this respect, further research based on a (spatial) equilibrium model may improve the simulation by including factor market analysis, which in turn would deliver a more realistic picture.

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Table(s)

Table 1. Results of the simulation under scenario S0 (biogas technology does not exist).

		Cluster weight	NPV	FP /NPV	UAA	LSU	Labour demand	Nitrogen use	Nitrogen intensity	Water use	Water intensity	
Farm type	Specialisation	%	€		ha	#	h/year	kg	kg/ha	m^3	m^3/ha	H
F1	Arable	2.54	1,897,400	0.13	145.55	-	3,044	11,554	79.38	14,118	96.99	0.51
F2	Arable	1.46	2,747,313	0.19	165.81	-	3,579	8,289	49.99	12,983	78.30	0.27
F3	Arable	5.23	1,361,658	0.21	143.34	-	1,791	9,757	68.07	13,203	92.11	0.39
F4	Arable	0.59	114,170	0.11	35.83	-	373	2,611	72.87	3,089	86.20	0.09
F5	Arable	16.68	337,691	0.18	27.5	-	433	1,096	39.84	2,342	85.15	0.39
F6	Arable	42.47	51,513	0.18	54.08	-	117	1,022	18.90	3,197	59.11	0.38
F7	Arable	8.26	865,136	0.15	31.92	-	1,503	2,675	83.80	1,686	52.82	0.37
F8	Horticulture	0.65	506,241	0.13	70.94	-	1,143	5,369	75.68	21,030	296.45	0.28
F9	Horticulture	5.45	44,732	0.07	56	-	200	4,604	82.21	14,967	267.27	0.2
F10	Horticulture	1.24	188,491	0.15	30.79	-	634	2,878	93.47	8,061	261.81	0.18
F11	Livestock	0.43	20,225,947	0.05	147.27	190	12,238	6,654	45.18	5,624	38.19	0.24
F12	Livestock	8.09	72,729	0.01	70.96	11	2,307	2,905	40.94	5,664	79.82	0.18
F13	Livestock	1.3	3,185,463	0.04	23.37	47	4,511	976	41.76	960	41.08	0.22
F14	Livestock	0.22	21,101,226	0.07	189.24	248	13,783	6,352	33.57	4,299	22.72	0.28
F15	Livestock	0.65	5,026,697	0.05	82.41	83	5,338	3,648	44.27	3,725	45.19	0.2
F16	Livestock	1.89	3,047,662	0.04	74.35	107	3,446	3,457	46.50	2,031	27.32	0.26
F17	Livestock	0.10	425,075	0.07	83.5	47	2,646	3,254	38.97	2,921	34.98	0.13
F18	Livestock	2.75	1,781,085	0.09	59.27	36	3,243	2,078	35.06	4,092	69.04	0.17

NPV: net present value; UAA: utilised agricultural area; FP: farm payments under the CAP 2014-2020; LSU: livestock units; H: Shannon index.

Table 2. Simulation’s results under scenario S1 (incentive = € 0.28/kWh): percent change with respect to S0; introduction of energy cropping; size of adopted biogas. Unchanged results are omitted.

Farm type	NPV	FP/NPV	UAA	Labour demand	Nitrogen use	Nitrogen intensity	Water use	Water intensity	H	Energy cropping	Energy cropping /UAA	Adopted plant	Electricity supply
	% change	% change	% change	% change	% change	% change	% change	% change	% change	ha			MWh per year
F11	26.21	-20.00	113.03	2.18	181.02	31.92	68.41	-20.94	-50.23	28.79	0.09	B1	842.4
F14	10.52	-14.32	104.23	-1.79	89.21	-7.36	31.45	-35.64	-47.86	15.8	0.04	B1	842.4

NPV: net present value; FP: farm payments under the CAP 2014-2020; UAA: utilised agricultural area; LSU: livestock units; H: Shannon index.

Table 3. Simulation’s results under scenario S2 (incentive = € 0.35/kWh): percent change with respect to S0; introduction of energy cropping; size of adopted biogas. Unchanged results are omitted.

Farm type	NPV	FP /NPV	UAA	Labour demand	Nitrogen use	Nitrogen intensity	Water use	Water intensity	H	Energy cropping	Energy cropping /UAA	Adopted plant	Electricity supply
	% change	% of change	% change	% change	% change	% change	% change	% change	% change	ha			MWh per year
F11	28.16	-20.05	113.03	2.18	181.02	31.92	68.41	-20.94	-50.23	29.82	0.09	B1	842.4
F14	14.1	-14.32	95.01	-0.6	89.21	-2.99	31.45	-32.6	-47.86	17.28	0.05	B1	842.4
F15	9.01	-40	43.46	5.2	25.12	-12.71	-0.14	-30.3	-32.67	11.86	0.1	B1	842.4
F18	48.13	-33.33	231.21	3	12.34	-66.08	-0.08	-69.83	-41.82	17.77	0.09	B1	842.4

NPV: net present value; FP: farm payments under the CAP 2014-2020; UAA: utilised agricultural area; LSU: livestock units; H: Shannon index.

Table 4. Simulation’s results under scenario S3 (incentive = € 0.42/kWh): percent change with respect to S0; introduction of energy cropping; size of adopted biogas. Unchanged results are omitted.

Farm type	NPV	FP /NPV	UAA	Labour demand	Nitrogen use	Nitrogen intensity	Water use	Water intensity	H	Energy cropping	Energy cropping /UAA	Adopted plant	Electricity supply
	% change	% change	% change	% change	% change	% change	% change	% change	% change	ha			MWh per year
F1	97.23	-10	29.12	0.18	4.32	-19.21	-15.43	-34.50	-6.95	35.85	0.23	B1	842.4
F3	2.45	-14	33.1	0.14	28.15	-3.72	-12.45	-34.22	-22.12	49.54	0.21	B1	842.4
F11	75.7	-60	113.03	0.08	158.23	21.22	59.24	-25.25	-54.5	68.85	0.22	B2	1489.8
F13	19.11	-25	245.12	0.27	196.44	-14.10	71.99	-50.17	-23.43	80	0.99	B2	1489.8
F14	23.72	-71.42	143.25	-0.05	29.37	-46.82	72.61	-29.05	-58.66	21.13	0.05	B1	842.4
F15	40.73	-80	41.1	-0.05	25.76	-10.88	-13.24	-38.50	-1.43	27.72	0.26	B2	1489.8
F16	26.8	-0.25	69.42	0.18	44.39	-14.78	1.11	-40.33	-22.82	106.38	0.84	B1	842.4
F17	59.45	-57.12	130.76	0.17	81.74	-21.24	22.67	-46.84	-45.76	111.87	0.58	B1	842.4
F18	77.47	-88.89	116.87	0.01	90.51	-12.16	41.23	-34.88	-2.17	22.43	0.17	B1	842.4

NPV: net present value; FP: farm payments under the CAP 2014-2020; UAA: utilised agricultural area; LSU: livestock units; H: Shannon index.

Table 5. Regional-level estimates (province of Pisa, Italy, a NUTS 3 region): values and percent change with respect to S0 and S1 of sustainability indicators, introduction of energy cropping, and electricity generation.

Sustainability indicator / Propensity towards adoption	Unit	Scenario			
		S0	S1	S2	S3
NPV	Million €	2,369	2,544	2,574	3,050
	% change (S0)	-	7.39	8.65	28.75
	% change (S1)	-	-	1.18	19.89
FP/NPV	Index	0.095	0.092	0.092	0.088
	% change (S0)	-	-3.16	-3.16	-7.37
	% change (S1)	-	-	-0.00	-4.35
UAA	ha	99,093	107,656	107,517	129,260
	% change (S0)	-	8.64	8.50	30.44
	% change (S1)	-	-	-0.13	20.07
Labour demand	h/year	2,791,749	2,791,964	2,797,108	2,798,358
	% change (S0)	-	0.01	0.19	0.24
	% change (S1)	-	-	0.18	0.23
Nitrogen use	t/year	4848	5261	5265	5830
	% change (S0)		8.52	8.60	20.26
	% change (S1)		-	0.08	10.82
Nitrogen intensity	kg/ha	48.93	48.87	48.77	45.10
	% change (S0)	-	-0.12	-0.33	-7.83
	% change (S1)	-	-	-0.20	-7.71
Water use	Thousand m^3	7620	7741	7741	7637
	% change (S0)	-	1.59	1.59	0.22
	% change (S1)	-	-	0.00	-1.34
Water intensity	m^3/ha	76.90	72.91	72.00	60.08
	% change (S0)	-	-5.19	-6.37	-21.87
	% change (S1)	-	-	-1.25	-16.56
H	Index	0.35	0.33	0.32	0.30
	% change (S0)	-	-5.71	-8.57	-14.29

	% change (S1)	-	-	-3.03	-9.09
Energy cropping /UAA	ratio	-	0.01	0.03	0.13
	% change (S1)	-	-	200	1200
Electricity generated	MWh per year	-	1685	3370	9524
	% change (S1)	-	-	100	465

NPV: net present value; FP: farm payments under the CAP 2014-2020; UAA: utilised agricultural area; H: Shannon index