A Choice Experiment Study on the Farmers' Attitudes toward Biogas and Waste Reuse in a Nitrates Vulnerable Zone

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Summary

The present study aims at assessing dairy farmers' preferences over different technological options related to the anaerobic digestion technology. A Choice Experiment study was conducted in Arborea, a NVZ dairy district located in Sardinia, Italy. The results show that profitability of the investment is a general driver of the choice. Heterogeneity of preferences is observed, especially as regards the options of investment on-farm or off-farm. Farmers who are especially interested in an investment on-farm are characterized by higher awareness of energy issues; while farmers with excess waste load would prefer an off-farm investment. Digestate treatment options have practically been ignored in our choice experiments: farmers do not seem aware of the opportunities offered by further processing of the digestate to improve management of the farm waste. New regulations associated with the Circular Economy EU package could increase the farmers' perception of economic benefits associated with the adoption of anaerobic digestion technologies.

Keywords: choice experiment; random parameter logit; anaerobic digestion; nitrates directive

JEL Classification codes:
Q16 R&D, Agricultural Technology, Biofuels, Agricultural Extension Services
C35 Discrete Regression and Qualitative Choice Models, Discrete Regressors, Proportions
Q42 Alternative Energy Sources

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1. INTRODUCTION

On December 2015 the European Commission launched a Circular Economy Package (COM 2015/614), which encompasses a series of actions and legislative proposals with measures covering the whole cycle from production and consumption to waste management and the market for secondary raw materials. The proposed actions will contribute to "closing the loop" of product lifecycles through greater recycling and re-use, reducing land and water pollution and atmospheric emissions, and thereby enhancing environmental quality standards and health. Economic benefits are also envisaged, due to improvements in security of supply of raw materials, increased competitiveness and innovation, leading to the creation of new jobs and economic growth. However, it is also recognized that the change will impose some financial burden, due to structural adjustment both in the agricultural and industrial sectors; and that substantial modifications will be required in consumer behavior, in business, as well as in regulation and governance models.

In particular, agriculture, along with the entire food-chain, depends on the conservation of ecosystems, with a continual circulation of resources. The circular economy principle is consistent with fundamental pillars of EU environmental regulation, such as the Water Framework Directive (2000/60), the Nitrate Directive (91/676) and the Waste Directive (2008/98). The Water Framework Directive aims at improving water quality through the management of polluting activities with a "combined approach" of emission limit values and quality standards at a river basin level, comprising the design of measures to achieve load reduction of pollutants. An instrument to achieve quality standards set within the Water Directive is the Nitrate Directive, aimed at preventing nitrate pollution from agricultural sources in ground and surface waters, promoting use of good farming practices. EU Member States are required to identify polluted or at risk of pollution water bodies, and, where applicable, designation of Nitrate Vulnerable Zones (NVZs); and establish action programs to be implemented by farmers within NVZs on a compulsory basis. These programs must include: measures included in Codes of Good Agricultural Practice, which become mandatory in NVZs, such as a minimum storage capacity for livestock manure and slurry; and other measures, such as limitation of fertilizer application (mineral and organic) and maximum amount of livestock manure to be applied (corresponding to 170 kg nitrogen/hectare/year). The Nitrate Directive impose to livestock farms, and especially dairy farms, a binding constraint on the number of cattle per hectare of available agricultural land; while the Waste Directive imposed further regulation related to waste management, recycling, recovery. The Directive lays down some basic waste management principles: it requires that waste be managed without endangering human health and harming the environment, and in particular without risk to water, air, soil, plants or animals, without causing a nuisance through noise or odors, and without adversely affecting the countryside or places of special interest; it explains when waste ceases to be waste and becomes a secondary raw material (so called end-of-waste criteria), and how to distinguish between waste and by-products.

The Circular Economy action plan promotes the adoption of the technology of anaerobic digestion, which uses the by-products and waste from agriculture and food industries for biogas production and extraction of biochemicals. Anaerobic digestion is a process that produces biogas and heat from biomass. Biogas can be used to produce heat and electricity in cogeneration plants, or upgraded to biomethane. Livestock manure and slurries are an excellent feedstock for anaerobic digestion, and they may lead to new added value for the farm, if the biomass is used to produce energy and/or biomaterials. The material remaining after extraction of biogas is the "digestate", which still contains nearly all its major mineral elements (Nitrogen, Phosphorous, Potassium and other 'trace elements'), used as ingredients in agricultural fertilizers. The production of bio-fertilizers based on secondary raw materials could be an opportunity for livestock farmers, and especially those located in NVZs. Under the current regulation, the digestate obtained from manure and slurry is equivalent to the row feedstock and therefore subject to the same Nitrates Directive constraints. Further processing of the digestate, from the simplest mechanical separation through more complex biochemical processing, would allow a more efficient management of the surplus waste produced in the farm, which could be more easily stored and/or sold in the market. Promoting a EU wide market for fertilizers based on organic waste materials and reducing the need for mineral based fertilizers in agriculture is a fundamental action to sustain a circular economy system. In order to achieve these objectives a revision of the 2003 regulation on fertilizers is required: a proposal has been launched on March 2016, to set limits for the presence of heavy metals and contaminants in mineral fertilizers, to define rules for biowaste transformed into compost and digestate (so-called 'end-of-waste' criteria for the manufacturing of fertilizing products), and to introduce the CE marking for biofertilizers.

The discussion above has highlighted the merits of anaerobic digestion and related biofuels/biomaterials technologies in agriculture, as a means to "close the loop", enhancing environmental quality and increasing revenues. Of course there is not such a thing as a free lunch, and adoption of these technologies on farm requires financial cost, management changes, learning efforts. Thus, it seems worth investigating such issues as: what are the farmers' preferences and perceptions regarding these technologies? What the pros and cons they associate with such an investment? How different economic, attitudinal, cultural factors influence the preferences and the probability of adoption? How relevant is the perception of public benefits associated with the adoption of the technology in shaping the preferences?

The present research aims at addressing these issues. In particular, we focus on the preferences of dairy farmers with respect to the adoption of the anaerobic digestion technology, as a means to generate energy (cogeneration or biomethane) and biofertilizers. A case study has been carried out in Arborea (Sardinia, Italy), a leading dairy cattle farming district, and the only NVZ designated in the Region. A Choice Experiment was designed in order to understand which are the farmers' preferences over different biogas technologies, different treatments of the digestate, different scales of biogas production; and to identify the factors that influence these choices.

2. BACKGROUND

The Nitrate Directive regulation of the fertilizer application has proved effective in enhancing environmental and health quality either at farm level and at ecosystem level (Barnes et al., 2009). Successful regulation is likely to favor acceptance of further policies aimed at improving the environmental quality: Reimer et al. (2012) and McCann et al. (2015) point out that direct observation of the results obtained after implementing environmental policy actions is fundamental to build farmers' consensus and participation. Most studies show that, generally, farmers do demonstrate an understanding of what measures can be applied to reduce problems of nitrogen loss from the farming practices, however they do not acknowledge their actual contribution to water pollution (Mac Gregor e Warren, 2006; Barnes et al, 2009; Gathoni Gachango et al., 2015) and are not comfortable with the government regulations for controlling pollution from agricultural sources (Macgregor and Warren, 2006; Popp et al., 2007; Buckley, 2012). Common obstacles to implementing such measures are costs and time (Bratt, 2002; McDermaid, 2005; Hayman and Alston, 1999), lack of information on water quality at catchment level (Gathoni Gachango et al. 2015) and on the motivations behind the designation of NVZs (Barnes et al., 2009). This induces a perception of discriminatory treatment, since farmers in NVZ have to comply with stricter rules than others (Barnes et al., 2009), and a sense of distrust in the regulatory institutions (Mac Gregor and Warren, 2006). The latter authors comment (p. 113): "...it was clear that the farmers were not likely to be proactive in adjusting. This implies, perhaps, that a 'stick' (in the form of further legislation, for example) may prove to be a more effective motivator of change than a 'carrot'...". Farmers' low propensity to adopt voluntary approaches to control nitrate leaching has been observed by Mac Gregor and Warren (2006) and Gathoni Gachango et al. (2015), who find also a scarce propensity to adopt anaerobic digestion technologies that were proposed as an instrument to control farm waste; the same result was found by Glenk et al. (2014).

The decision to adopt a new technology is in fact influenced by many factors: for example, profitability (Griliches, 1957), affordability (Feder and Umali, 1993), human capital endowment (Benhabib and Spiegel, 2005), knowledge and attitude (Rogers, 2003). In general there seems to be a wide consensus over the fact that, coeteris paribus, an agricultural innovation is adopted only if it is profitable for the farm: see Prokopy et al. (2012), Tey and Brindal (2012), McCann et al. (2015). The economic benefit may be in terms of increased cost efficiency in the production process (Gathoni Gachango et al., 2015), or production innovations aimed at income diversification (Brudermann et al., 2013). However, the latter strategy is deemed acceptable only if its opportunity cost is low with respect to the main (dairy) farming activities (Mac Gregor and Warren, 2006; Reimer et al., 2012); if it is not perceived as too complex (McCann et al., 2015), or time consuming (Gedikoglu and McCann, 2012). The perception of risk associated with an innovation is one of the main hinders to the adoption of new technologies, so that incremental innovations are preferred to radical innovations (Giovanopoulou et al., 2011; Prokopy et al. 2012; Glenk et al., 2014; Gathoni Gachango et al., 2015; Nguyen et al., 2016).

Bishop et al. (2010) find that the farmers' propensity to adopt a biogas technology is associated with manure load management costs, which depend on opportunities of using and/or disposing of the manure. When farmers have few acres to apply manure, they face greater costs finding disposal sites. Interestingly, they find that also social costs have an effect in influencing the investment decision: for example, farmers who are closer to urban centers are more willing to control external costs of manure and slurry management (odors, etc.). Another factor is what they define as “innovation readiness”, i.e. a human capital factor, which is measured in terms of respondents’ sources of information: communication with other farmers, trade publications, seeing a digester in operation, and communication with digestion experts, and if the respondent had researched digestion technology extensively. The role of information, especially if coming through social networks, in driving the innovation diffusion is also highlighted by Prokopy et al. (2012).

3. METHODS

3.1. Choice Experiment Models

The CE approach draws from the Lancaster’s theory of value (Lancaster, 1966) and the Random Utility Model framework set up by McFadden (1974). If a decision maker *i* has to choose among *n* alternatives, deriving a given amount of utility from each of possible choices, he or she will choose the alternative that provides the greatest utility, so that individual *i* chooses alternative *j* among *n* alternatives if and only if $U_{ij}>U_{in}$. But since it is not possible to directly observe all the determinants of individual utility, the utility function is built up with two components: an observable or deterministic part and a stochastic or random component, and can be written as follows:

$$\mathrm{U_{ij}} = \mathrm{V_{ij}} + \varepsilon_{\mathrm{ij}}, \tag{1}$$

where $\mathrm{V_{ij}}$ is the observable component and $\varepsilon_{\mathrm{ij}}$ represents the random component. Therefore, since the decision process of the (assumed utility maximizer) individual involves unobservable pieces of information, it is necessary to model the decision in probabilistic terms. Assuming for simplicity, as presented above, that the error component is defined as the difference between the true utility, $\mathrm{U_{ij}}$, and the observed utility $\mathrm{V_{ij}}$, the probability that individual *i* prefers alternative *j* over alternative *n* can be expressed as follows:

$$\mathrm{P}\left[\left(\mathrm{V_{ij}} + \varepsilon_{\mathrm{ij}}\right) > \left(\mathrm{V_{in}} + \varepsilon_{\mathrm{in}}\right)\right] = \mathrm{P}\left[\left(\mathrm{V_{ij}} - \mathrm{V_{in}}\right) > \left(\varepsilon_{\mathrm{ij}} - \varepsilon_{\mathrm{in}}\right)\right], \tag{2}$$

The probability that individual *i* chooses *j* instead of alternative *n* is equal to the probability that the utility provided by option *j* is greater than the utility provided by the other alternative; in other words alternative *j* is preferred over *n* if the difference between the deterministic components is greater than the difference between the random components. Estimation of (2) entails some assumptions about the random component. Assuming that the error terms are independently and identically distributed (IID) with a Gumbel distribution leads to the multinomial logit model, sometimes also called conditional fixed effects logit model. Under this assumption, the probability that individual i chooses alternative j, in a choice set made up of n alternatives, is given by:

$$\mathrm{P}\left(\mathrm{U_{ij}} > \mathrm{U_{in}}\right) = \frac{\exp\left(\mu \mathrm{V_{ij}}\right)}{\sum_{\mathrm{n}} \exp\left(\mu \mathrm{V_{in}}\right)}, \tag{3}$$

where μ is a scale parameter, inversely related to the standard deviation of the error term. The deterministic component $\mathrm{V_{ij}}$ can be written as:

$$V_{ij} = \beta x_{ij}, \tag{4}$$

where x is a vector of attributes (in different levels), while β is a vector of utility parameters to be estimated. Moreover it is possible to include into the *x's* vector various socio-economic characteristics and respondents' attitudes, as interactions with the attributes.

Given (4) we can rewrite (3) in this way, dropping out for simplicity the scale parameter:

$$P(U_{ij} > U_{in}) = Pr_{ij} = \frac{\exp(\beta_1 x_{i1j} + \beta_2 x_{i2j} + \dots + \beta_k x_{ikj})}{\sum_{n=1}^{N} \exp(\beta_1 x_{i1n} + \beta_2 x_{i2n} + \dots + \beta_k x_{ikn})}, \tag{5}$$

Once the coefficient estimates have been computed it is possible to compute the marginal rates of substitution between the attributes. Given the utility function (4), if a cost or monetary attribute has been included, the WTP for a change of level of another attribute is calculated as follows:

$$WTP = -\frac{\beta_{\text{non monetary attribute}}}{\beta_{\text{monetary attribute}}} \tag{6}.$$

The conditional logit model assumes independence of irrelevant alternatives (IIA) and taste homogeneity across respondents. The former follows from the assumption of independent error terms and it postulates that adding or removing any alternative from the choice set will not change the relative probability of the choice made by individual *i* over any other alternative. In pair-wise choices this is not an issue, even though panel effects may arise because of repeated observations for the same individual. The utility parameters are estimated as fixed coefficients, hence the homogeneity restriction; however, it is possible, through interaction-terms with socio-economic characteristics or other covariates, to take account of some (observed) source of heterogeneity. Other models have been proposed in order to relax the homogeneity assumption across respondents to account for unobserved heterogeneity: two examples are the Random Parameter Logit model (RPL) and the Latent Class model (LCM).

Both the RPL and the LCM models address the issue of heterogeneity, since in these two models we do not assume $\beta_{ik} = \beta_k$ for each individual i as postulated in the Conditional Logit model, allowing instead for some degree of variation among individuals. The difference between RPL and LCM is that the former assumes a continuous distribution for the parameters vectors, while for the latter the distribution is discrete, with individual parameters clustered in classes.

Going now into details, considering the RPL specification first, we have that the utility for individual *i* opting for alternative j, in a context with k attributes and n alternatives, depends now also on a random component introduced in the parameters:

$$U_{ikj} = \tilde{\beta}_{ik} x_{ikj} + \varepsilon_{ij}, \tag{7}$$

and $\tilde{\beta}_{ik} = \overline{\beta}_k + z_i{}'\delta_{ik} + \sigma_k \tau_{ik}$, (8)

where $\overline{\beta}$ stands for the population mean and δ_{ik} is an error term with distribution $f(\delta_{ik})$ characterized by zero mean and variance φ^2 which account for observed heterogeneity, and τ_i is an error term which accounts for specific individual unobserved heterogeneity. This is the reason why β is random, following a certain distribution to be specified by the researcher, such as normal, lognormal or triangular. Furthermore it worth noting that it has to be established how many parameters are believed to be random too; given this, the unconditional choice probability is the weighted average of all possible $\tilde{\beta}$: this leads to a multidimensional integral that does not have a closed form, so that simulation techniques, such as maximum simulated likelihood, are needed in order to carry out estimation. The integral takes this form:

$$P_{ij} = \int L_{ij}(\beta) f(\beta;\theta) d\beta \tag{9}$$

Where $L_{ij}(\beta)$ is the kernel logit, as in eq.(5), of individual *i* choosing alternative *j*, evaluated at parameters *β*, and $f(\cdot;\theta)$ is a density function, with parameters θ over the population, chosen by the modeller. In the random parameters model, one or more individual preference parameters can be modelled as random variates, with possibly different distribution functions, in order to account for preference heterogeneity across individuals. As demonstrated by McFadden and Train (2000), the RPL model can approximate any discrete choice model at any desired level of accuracy. All the econometric models described above are usually estimated through maximum likelihood (ML) or maximum simulated likelihood (MSL).

Once coefficients have been estimated it is possible to compute the marginal rates of substitution between attributes; in this regard the willingness to pay is again given just by the ratio between non monetary attributes and the monetary attribute, when we assume a linear utility function. In the case of random parameters, if all are assumed to be such, the WTP is given by the ratio of two random variables; if the cost attribute is held constant is then given by the ratio of a random and a non random variable: in both cases the WTP is a random variable. In the latter case its distribution follows the same distribution of the random coefficient.

Moving to the LCM, in this case β_k can take up to a finite number of values, depending on which class the individual belongs to, with respective membership probabilities: in fact we now have $\beta_{k|s}$, meaning that each segment *s* has, for each attribute *k*, its particular parameter estimate β_k. The unconditional probability of individual *i* choosing alternative *j* is again a weighted average of all the $\beta_{k|s}$:

$$\Pr_{ij} = \sum_{s=1}^{S} h_s \Pr_{j|s}, \tag{10}$$

where $\Pr_{j|s}$ is the probability of choosing *j* conditional on membership in class *s*, that takes an analogous form of equation (5) and (9), being:

$$\Pr_{ij|s} = \frac{\exp(\beta_{i1|s}x_{i1j} + \beta_{i2|s}x_{i2j} + \cdots + \beta_{ik|s}x_{ikj})}{\sum_{n=1}^{N} \exp(\beta_{i1|s}x_{i1n} + \beta_{i2|s}x_{i2n} + \cdots + \beta_{ik|s}x_{ikn})} \tag{11}$$

Finally $h_1 \ldots h_s$ are the segment membership probabilities; these are unknown but can be computed by means of a multinomial logit model. It is also possible to condition h on covariates such as socio-economic variables and/or psychometric variables, available in this study.

So h_s can be thought to be given by:

$$h_s = \frac{\exp(\gamma_s z_k)}{\sum_{s=1}^{s} \exp(\gamma_s z_k)}, \tag{12}$$

where $\mathrm{Z_k}$ is a vector of k covariates and γ_s is the respective coefficient: these covariates can help us characterize the groups, something that is not possible in the RPL context.

3.2. Principal Component Analysis

The Principal Component Analysis (PCA) is a statistical technique used to reduce data dimensions, while finding meaningful patterns in the data. It is often used in the analysis of data resulting from multiple Likert-scale like questions.

Let X be a vector of *n* data values with corresponding population variance-covariance matrix $\sum$. By the Spectral Decomposition theorem, $\sum$ can be written as follows:

$$\sum = \sum_{i=1}^{n} \lambda_i e_i e_i', \tag{13}$$

where λ_i are the eigenvalues and e_i are the corresponding eigenvectors. The principal components are defined as the following linear combinations:

$$Y_1 = e_{11}x_1 + e_{12}x_2 + \cdots + e_{1n}x_n \tag{14}$$

$$Y_2 = e_{21}x_1 + e_{22}x_2 + \cdots + e_{2n}x_n$$

...

$$Y_n = e_{n1}x_1 + e_{n2}x_2 + \cdots + e_{nn}x_n$$

If all the n components are taken, there will be no amount of variance unexplained, but also no data reduction; however, if the *X* variables are correlated, a good proportion of variance can be explained with only $k<n$ components, and data dimensionality can be reduced.

In order to find the principal components the eigenvectors are selected so that $\mathrm{Var}(Y_i)$ is maximized, subject to two constraints: the sum of squared eigenvectors must add to 1 and the covariance between the component Y_i and all the previously defined components must be equal to zero, so that the components are unrelated.

The selection of components is based on statistical criteria: eigenvalues greater than a certain threshold, additional variance explained by an extra component (the amount of variance explained is decreasing in the number of principal components).

4. THE CASE STUDY

The Arborea district was classified as pre-desert area, with salt pools and marshland bordering the seaside, until 1937, when the land was reclaimed for cattle breeding and agricultural use. Nowadays, more than 150 livestock farms are settled there and produce for the diary sector: the 3A Cooperative, created in 1956 to associate all dairy farms in the area, is currently the fourth cow's milk producer in Italy, with an annual volume of more than 191 million liters. The other side of the coin is that highly intensive cow farming and the uncontrolled agronomic use of livestock manure and slurry caused severe environmental consequences, hindering achievement of EU water quality standards in the area. The water ecosystem in the Arborea district is classified as extremely vulnerable: the groundwater and the wetlands are susceptible to contamination from the fertilizers (manure and slurries, but also chemical fertilizers) that farmers apply to the sandy soil of their farm fields. The quality of freshwater and groundwater in the area is classified as "very low" in the 2015 Regional Plan for the quality of the water (based on the requirement of the Water Framework Directive): achievement of a good quality level is now forecasted by 2027 (initially the compliance term was 2015).

After implementation of the Nitrate Directive the environmental situation has improved, but the handling of such large amount of organic material poses serious management problems to the farmers, increasing production costs and imposing a constraint to the herd size, which depends on the farmer's endowment of agricultural land where the slurries can be spread. The anaerobic digestion technology may be useful to convert costs related to storage of farm wastes into a value: cogeneration of heat and electricity (the latter delivered at subsidized prices to the national grid); or further transformation of biogas into biomethane, that can be used as a fuel for vehicles. In our study we investigate on the farmers' preferences between the cogeneration technology and the upgrading technology. In addition, we study the potential interest to invest on their own biogas plant, or rather they would prefer joining a consortium and externalize the biogas processing. Another technological element analyzed in our study regards the treatment of digestate. As explained in the introduction, the digestate has better characteristics than raw manure and slurry, in terms of reduced pathogens and odors, and increased fertilizing power; however, the untreated digestate poses the same management issues as slurries, in terms of storage requirements and limitations in the agricultural use. In our study we assess the potential interest of farmers toward treatments of the digestate that would reduce the handling burden: either a simple separation of liquid and solid components, or further processing to produce biofertilizers that could be stored and/or marketed.

5. SURVEY DESIGN

A thorough qualitative phase of the study, which involved several in-depth interviews with various stakeholders (farmers, agronomists, biogas plant installers), and a focus group with farmers, informed the experimental design and the construction of the questionnaire. The questionnaire contains a first section focused on the collection of farm data (plot size, herd size, production, costs, etc.) and on the adoption of new technologies (both energy and farm technologies); the second section contains questions on the production and management of manure and slurries; the third section is devoted to issues related to market strategies after change in CAP milk policies and an analysis of risk perception (based on Schaper et al., 2010); then, a series of questions investigates on the farmer's attitudes toward the Biogas technology. Finally, a choice experiment exercise was proposed; the scenario consisted in 5 attributes (Table 1).

Table 1: Attributes and levels of choice experiments (Investment scenarios).

Attributes	Levels
Technology	Cogeneration (electricity/heat); biomethane upgrading
Agronomic use of digestate	Raw digestate; separated digestate; marketable biofertilizers
Plant size	On-farm or collective (off-farm) plant
Payback period	5 years, 7 years, 10 years
Farm income increase	3%, 6%, 12%, 18%

The structure of the exercise is very simplistic, and obviously cannot resemble a real investment situation: for example, we are not explicitly considering the financial risk associated with the investment, suggesting that in any case there will be some income increase after the adoption of the technology. Our study was principally aimed at analyzing the preferences toward the first three attributes: energy technology options, digestate management options, and private vs collective investment options. The last two attributes are economic/financial characteristics, which in our analysis mainly serve the purpose of controlling for consistency and "rationality" of the responses.

6. RESULTS

The survey has been conducted in the period March – October 2015. The whole sample was made by 97 farmers: 92 farmers in Arborea, which account for 60% of the Arborea dairy farmers population; plus 5 farmers outside the ZVN area. A summary of the sample characteristics is reported in Table A.1 in Appendix. Each respondent faced 6 choice exercises, where it was possible to select either an Investment Scenario A or an Investment Scenario B, or to choose the Status Quo (No investment) option. After removal of observations because of missing or inconsistent responses, we are left with a sample of 82 individuals. The Status Quo option was chosen in all exercises by 5 individuals; while 2 farmers selected this option 2 times , and one 1 time.

Including the status quo alternative in the econometric model gave rise to unstable estimates and/or convergence problems: therefore we remove those 5 individuals who always selected the No Investment option, and estimate a model with only two alternative project options. After removal of observations because of missing or inconsistent responses, we are left with a sample of 82 individuals. The panel is unbalanced, with 6 choices for all farmers but one with 5 choices, and three with 4 choices.

As a first step, we estimate a Multinomial Logit model to check whether, on average, the signs of the Payback period and Income coefficients are consistent with the expectations. This seems to be the case: both coefficients are significant, and the negative sign indicates that longer periods for the return of the investment are less preferred, while the positive sign indicates that higher increases in income are preferred. The coefficient of the dummy Collective plant is significant and positive, indicating that on average the farmers would prefer not to manage a biogas plant on their own; however we will see that the MNL model masks a relevant heterogeneity of farmers with respect to this attribute. The proposed technologies for the treatment of the digestate are not attractive for the farmers: the coefficient of the attribute Raw is not significant, i.e. this treatment is valued just as the other proposed options, Separation and BioFertilizer (which in this specification are lumped so to save degrees of freedom); in other terms, this attribute is ignored. Finally, the coefficient on the attribute Biomethane is negative (electricity cogeneration would be preferred to Biomethane), but not significant: yet, the P-value is not far from the 10% level, and it will be seen that a different model specification provides more significant estimates for this attribute.

The MNL results show that income is a significant determinant of the choice: this is in line with other studies that show that direct economic benefits are main drivers of innovation in agriculture (Mac Gregor and Warren, 2006; Tey and Brindal, 2012, McCann et al., 2014); even those who are concerned about environmental impacts (Gedikoglu and McCann, 2012) will not adopt a practice if they believe it is not profitable. In a study dealing with organic farming, Lapple and Kelley (2013) found that economic incentives are a driver in the choice of organic farming, conditional on environmental awareness.

Table 2. Econometric estimations, choice models.

	Multinomial Logit model	Latent Class model: Utility parameters in latent class - 1	Latent Class model: Utility parameters in latent class - 2	Random Parameters Logit Model (Base model)	Random Parameters Logit Model (Extended model)
Variables	Coefficients (St. Dev.)				
Biomethane	-0.093	**-0.138****	**-0.138****	-0.158	-0.169
	(0.059)	(0.068)	(0.068)	(0.124)	(0.126)
Raw	0.037	**0.042**	**0.042**	**0.079**	**0.078**
	(0.050)	(0.058)	(0.058)	(0.077)	(0.077)
Collective plant	0.084*	1.561***	-0.226***	0.163	0.626**
	(0.050)	(0.295)	(0.068)	(0.131)	(0.259)
Payback period	-0.045*	**-0.067****	**-0.067****	**-0.086****	**-0.094****
	(0.025)	(0.029)	(0.029)	(0.041)	(0.041)
Income	0.052***	**0.074*****	**0.074*****	0.106***	0.148***
	(0.009)	(0.011)	(0.011)	(0.022)	(0.033)
Class probability model					
Environmental risk prob		-1.161**			
		(0.516)			
Energy_att		-1.353***			
		(0.503)			
Manure/acreage		1.228**			
		(0.546)			
Constant		-2.132			
		(1.401)			
Standard Deviations					
Biomethane				0.686***	0.732***
				(0.179)	(0.173)
Collective off-farm				0.859***	0.790***
				(0.159)	(0.163)
Income				0.103***	0.098***
				(0.026)	(0.025)
Heterogeneity in mean					
Collective*Environ risk prob					-0.382***
					(0.147)
Collective* Energy_att					-0.383**
					(0.153)
Collective* Manure/acreage					0.547**
					(0.240)
Income*Financial factors					-0.038*
					(0.022)
Average class probabilities		0.232	0.768		
N. obs	485	485		485	485
N. individuals		82		82	82
Log Likelihood	-313.272	-277.271		-282.763	-271.189
Adj. Pseudo R2	0.048	0.158		0.145	0.173

Level of significance: *** at 1%; ** at 5%; * at 10% - Bold figures are constrained parameters

The second model is a Latent Class specification. Different models have been tested, also to check heterogeneity in ignoring attributes, and model selection has been based on criteria (AIC, AIC3, CAIC, BIC), or, where applicable, likelihood tests. In particular, we select a specification where the coefficients of Biomethane, Raw, Payback period and Income are constrained to be the same across classes, while the other coefficient (collective plant) is unconstrained. The results confirm the MNL estimates, in terms of sign and significance, for both the Payback period and Income; and the coefficient of Raw is confirmed to be decidedly not significant for both classes. The Biomethane coefficient is negative and significant: it means that cogeneration is the preferred technology. Farmers are more attracted by the electricity cogeneration technology, maybe because it is more mature, and information is available on the technical and economic aspects, including subsidies on the electricity price, and presumably observable in existing applications; while the Biomethane technology at farm level is still in its early stages of diffusion and not as well known. This result is coherent with literature, where “observability” of the innovation and its performance is an important determinant of manure management technologies (Reimer et al., 2012; McCann et al., 2015).

The estimates show that a majority (77%) of farmers are actually interested in a Biogas plant at farm level, while the 23% of farmers in Class 1 show a strong preference (as indicated by the level of the coefficient) for the solution outside the farm. The Class probability model gives some insights on the characteristics of the farmers pertaining to either class. Farmers with a more binding constraint on the emissions (ratio manure/acreage higher than 75) are more associated to Class 1: collective, off-farm level. This variable captures the per-cow ‘‘pressure’’ on the land: farmers who face binding constraint on the management of slurry and manure will be interested in placing their waste off-farm (an efficient waste disposal strategy). Bishop et al. (2010) found a similar positive influence of such a structural characteristic on the farmers’ propensity to adopt the anaerobic digestion technology (which anyway should require further processing of the digestate to reduce the volumes). Farmers characterized by a higher perception of Environmental risks, e.g. climate change and animal health issues (see Tables A.2 and A.3 in Appendix) are more probably willing to invest in a Biogas technology on-farm. We interpret this concern in terms of awareness about the risks posed on farming activities, rather than an altruistic, pro-environmental attitude, in accord with Mac Gregor and Warren (2006, p. 115): “the farmers tend to focus only on what occurs within the boundaries of their farm. This is not to say that they lack concern for environmental integrity but that, for them, its value is strongly associated with production motivations. What occurs off the farm seems to be over-looked or ignored partly because there is little incentive to minimize off-site impacts” (see also Barnes et al., 2009 for similar considerations). Also the attitudinal component Energy_att (i.e. people interested in self-consumption of energy, in CO2 reductions, in imitating other farmers who have installed biogas plants) is associated with Class 2. As explained by Bruderman et al. (2013) in a study dealing with photovoltaic technology, “farming is energy-intense and owning a PV plant may be seen as a first step towards energy autarky and independence from energy companies. It is often regarded as a safe and meaningful investment, or even a private pension plan in unsecure times”. Furthermore, the observability of the technology is confirmed to be a strong predictor of farmers’ behavior (see previous comments). It is remarkable that such a large percentage of farmers would choose an individual rather than a collective solution (though this is at least in part explained considering that our experimental scenarios did not include downside risk). In a study dealing with participation in a collective agri-environmental measure, Villanueva et al. (2015) found that different behaviors among farmers are likely due to different perceptions of transaction costs related to collective participation, and of the expected disutility related to losing some control in the management of their farm. In the qualitative phase of our research, some farmers stated they would not trust other farmers’ behavior in waste treatment, and that a cooperative plant would involve excessive monitoring costs.

Previous studies have shown that a major factor preventing farmers from adopting more sustainable practices is the perception of a technology as complicate, expensive and time-consuming or incompatible with the needs of farm/current farming system (Mac Gregor and Warren, 2006; Reimer et al., 2012; Gedikoglu e McCann, 2012; MacCann et al., 2015); however, this attitudinal factor proved not significant in our application.

Finally, we estimate two Random Parameter models: a "base" model and an extended model with heterogeneity in mean estimation. We select a specification with non random coefficients on Raw and Payback period. In both RPL models, the Payback period and Income coefficients are significant and with the expected signs. In the extended model, the Collective level is significant with a positive sign, but the attitudinal component Energy_att and the perception of Environmental risks have a negative effect on the coefficient (on-farm investment preferred to collective investment); while farmers with higher costs (manure/acreage) are associated with a higher coefficient (collective plant). The interpretation of these covariates effects is the same as in the Latent Class model, so we do not discuss it further. Another factor explaining heterogeneity of preferences is the farmer's perception of financial fragility: these farmers require a higher increase in income (higher benefits) in order to choose a specific investment option.

Table 3. Selection model tests.

	CL	LC	RPL	RPL_HM
Log-lik	-313.272	-277.271	-282.763	-271.189
AIC	-636.544	-574.542	-581.526	-566.378
AIC3	-641.544	-584.542	-589.526	-578.378
CAIC	-662.465	-626.383	-622.999	-628.588
BIC	-657.465	-616.383	-614.999	-616.588

Table 3 reports the values obtained from the model selection criteria AIC, AIC3, CAIC and BIC. All criteria indicate that the models with heterogeneity fit the data better than the simple CL model. The AIC and AIC3 criteria select the "richer" RPL_HM model, while CAIC and BIC point to the more parsimonious RPL model; the LC model is ranked second by all criteria.

7. CONCLUSIONS

Anaerobic digestion is an efficient way to recycle farm waste, generating biogas to produce heat and electricity in cogeneration plants, or upgraded to biomethane. The digestate remaining after the digestion process can be used as a fertilizer and amendment. The production of bio-fertilizers based on secondary raw materials could be an opportunity for livestock farmers, and especially those located in NVZs. Under the current regulation, the digestate obtained from manure and slurry is equivalent to the row feedstock and therefore subject to the same Nitrates Directive constraints. Further processing of the digestate, from the simplest mechanical separation through more complex biochemical processing, would allow a more efficient management of the surplus waste produced in the farm, which could be more easily stored and/or sold in the market.

The present study has been aimed at assessing dairy farmers' preferences over different technological options related to the anaerobic digestion technology. The results of our case study show that dairy farmers are interested in the Biogas technology, if the investment is profitable (and profitability may be dependent on subsidization of electricity or biomethane produced). Farmers who are especially interested in an investment on-farm are informed of the benefits of renewable energy, and interested in energy autonomy. However, other interesting features related to the anaerobic digestion technology are overlooked by farmers: in particular, the good properties of the digestate for agronomic use and the possible options offered by further processing of the digestate to improve management of the farm waste. The attribute related to the digestate treatment has been practically ignored in our choice experiments.

However, a change in European legislation aiming at implementing the Circular Economy strategy could improve awareness of the benefits of the anaerobic digestion technologies, including the digestate treatment. The New Fertilizer Regulation is pointing to the creation of a common European market for bio-based fertilizer in order to decrease dependence from imported mineral fertilizers, thereby reducing contamination from cadmium and other heavy metals.

From the farmers' point of view, this is a viable solution form manure management problems and valuable way to integrate and diversify the main farming income. From the public point of view, it is an efficient way to "close the loop", fostering more sustainable agriculture practices and enhancing the environmental quality in the ecosystem.

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REFERENCES

Barnes, A.P., Willock, J., Hall, C. and Toma, L. (2009). Farmer perspectives and practices regarding water pollution control programmes in Scotland. *Agricultural Water Management* 96: 1715-1722.

Benhabib, J. and Spiegel, M. (2005). Human Capital and Technology Diffusion. In Aghion, P., and Durlauf, S., (eds.), *Handbook of Economic Growth*, vol. 1, Part A. Elsevier, 935-966.

Bishop, C.P., Shumway, C.R. and Wandschneider, P.R. (2010). Agent heterogeneity in adoption of anaerobic digestion technology: Integrating economic, diffusion, and behavioral innovation theories. *Land Economics* 86(3): 585-608.

Bratt, A. (2002). Farmer's choice: management practices to reduce nutrient leaching within a Swedish catchment. *Journal of Environmental Planning Management* 45(5): 673–689.

Brudermann, T., Reinsberger, K., Orthofer, A., Kislinger, M. and Posch A. (2013). Photovoltaics in agriculture: A case study on decision making of farmers. *Energy Policy* 61: 96-103.

Feder, G., Umali, D. (1993). The adoption of agricultural innovations. A review. *Technological Forecasting and Social Change* 43: 215-239.

Gathoni Gachango, F., Morch Andersen, L. and Pedersen, S.M. (2015). Adoption of voluntary water-pollution reduction technologies and water quality perception among Danish farmers. *Agricultural Water Management* 158: 235-244.

Gedikoglu, H. and McCann, L. (2012). Adoption of win-win, environment-oriented and profit-oriented practices among livestock farmers. *Journal of Soil and Water Conservation* 67(3): 218-227.

Giovanopoulou, E., Nastis, S.A. and Papanagiotou, E. (2011). Modeling farmer participation in agri-environmental nitrate pollution reducing schemes. *Ecological Economics* 70: 2175–2180.

Glenk, K., Eory, V., Colombo, S. and Barnes, A. (2014). Adoption of greenhouse gas mitigation in agriculture: An analysis of dairy farmers' perceptions and adoption behavior. *Ecological Economics* 108: 49-58.

Griliches, Z. (1957). Hybrid corn: an exploration in the economics of technological change. *Econometrica*, 25(4): 501-522.

Hayman, P.T., Alston, C.L. (1999). A survey of farmer practices and attitudes to nitrogen management in the northern New South Wales grains belt. *Australian Journal of Experimental Agriculture* 39(1): 51–63.

Lancaster, K. (1966). A new approach to consumer theory. *Journal of Political Economy* 74: 132-157.

Lapple, D. and Kelley H. (2013). Understanding the uptake of organic farming: Accounting for heterogeneities among Irish farmers. *Ecological Economics* 88: 11-19.

Macgregor, C.J. and Warren, C.R. (2006). Adopting sustainable farm management practices within a Nitrate Vulnerable Zone in Scotland: the view from the farm. *Agriculture, Ecosystems and Environment* 113: 108–119.

McCann, L., Gedikoglu, H., Broz, B., Lory, J. and Massey, R. (2015). Effects of observability and complexity on farmers' adoption of environmental practices. *Journal of Environmental Planning and Management* 58(8): 1346-1362.

McDermaid, K., 2005. *Social Profile: La Moine River Ecosystem Partnership*. University of Illinois working paper. Available at: http://www.uwex.edu/ces/regionalwaterquality/Publications/LaMoineReport.pdf (accessed 25/05/2016)

McFadden, D., 1974. Conditional logit analysis of qualitative choice behavior. In P. Zarembka, ed., *Frontiers in Econometrics*. New York: Academic Press.

Nguyen, T.P.L., Seddaiu, G., Virdis, S.G.P., Tidore, C., Pasqui, M. and Roggero, P.P. (2016). Perceiving to learn or learning to perceive? Understanding farmers' perceptions and adaptation to climate uncertainties. *Agricultural System* 143: 205-216.

Popp, J. and Rodriguez, G. (2007). The role of stakeholders' perceptions in addressing water quality disputes in an embattled watershed. *Journal of Environmental Monitoring and Restoration* 3: 225–263

Prokopy, L.S., Floress, K., Klotthor-Weinkauf, D. and Baumgart-Getz, A. (2008). Determinants of Agricultural Best Management Practice Adoption: Evidence from the Literature. *Journal of Soil and Water Conservation* 63(5): 300-311.

Reimer, A.P., Weinkauf, D.K. and Prokopy, L.S. (2012). The Influence of Perceptions of Practice Characteristics: An Examination of Agricultural Best Management Practice Adoption in Two Indiana Watersheds. *Journal of Rural Studies* 28: 118-128.

Revelt, D. and Train, K. (1998). Mixed Logit With Repeated Choices: Households' Choices Of Appliance Efficiency Level. *The Review of Economics and Statistics* 80(4): 647-657.

Rogers, E.M. (2003). *Diffusion of Innovations*. New York: Free Press

Schaper, C., Lassen, B. and Theuvsen, L. (2010). Risk management in milk production: A study in five European countries. *Acta Agriculturae Scandinavica, Section C – Food Economics* 7(2-4): 56-68

Tey, Y. S. and Brindal, M. (2012). Factors influencing the adoption of precision agricultural technologies: a review for policy implications. *Precision Agriculture* 13: 713-730

Villanueva, A.J., Gomez-Limon, J.A., Arriaza, M. and Rodriguez-Entrena, M. (2015). The design of agri-environmental schemes: Farmers' preferences in southern Spain. *Land Use Policy* 46: 142-154

Appendix

Table A.1. Sample characteristics.

Variable	Mean or Percentage	Standard Deviation
Age (mean)	47.64	11.05
Primary School (%)	6.10	
Junior high school (%)	70.73	
High school (%)	23.17	
Acreage (mean)	39.62	27.69
Cattle size (mean)	207.27	118.72
Manure production (mean)	4017.73	2731.76
Manure/Acreage (mean)	121.34	
Farmers who have:		
- Installed a PV appliance in house or farm (%)	24.39	
- Adopted a technological innovation for shed (%)	39.02	
- Obtained the 3A Milk quality premium (%)	91.46	
- Obtained PAC subsidies (%)	92.68	
- Obtained Rural Development Plan (RDP) subsidies (%)	31.71	
- RDP subsidy to renovate farm structures (%)	73.08	
- Rented land outside NVZ to dispose of excess manure and slurries (%)	69.33	

Table A.2. Principal Component analysis: Attitudes toward Biogas farm plants.

	Worried about technology	Energy attitude	Worried about farm	Neighbors' complains
The maintenance of the plant would require too much dedication	**0.786**	0.081	0.081	0.195
Neighbors would complain if I install a biogas plant	0.129	-0.012	0.026	**0.847**
A biogas plant requires substantial changes in the farm structures	0.151	-0.003	**0.695**	-0.393
With a biogas plant I would reduce CO2 emissions	-0.070	**0.773**	0.131	0.088
A biogas plant would require significant changes in daily practices management	**0.703**	-0.077	0.118	-0.368
With a biogas plant I would be energetically autonomous	-0.200	**0.591**	-0.320	0.087
To manage a biogas plant I should acquire too much technical knowledge	**0.799**	-0.063	-0.117	0.118
You have to wait too long before recovering the cost of the investment	-0.105	-0.070	**0.801**	0.270
Knowing someone who has already installed a biogas plant in his farm could help me in the choice	0.188	**0.755**	-0.056	-0.177

Table A.3. Principal Component analysis: Perception of risks on farm management.

	Financial risk probability	Environmental risk probability	Market/Regulations risk probability
Sharp milk price decreases	-0.237	0.273	**0.694**
Unscheduled reduction in direct payments	**0.817**	-0.067	0.115
Increasing difficulties in credit availability	**0.842**	0.139	-0.079
Animal diseases	0.050	**0.841**	-0.061
Increasing climate change consequences	0.013	**0.748**	0.214
Low quality milk allowed in EU market	0.247	-0.070	**0.812**

Table A.4. Principal Component analysis: Perception of damages on farm management.

	Market factors	Financial factors	Regulation
Increasing regulation	-0.002	0.010	**0.917**
Unscheduled reduction in direct payments	0.124	**0.770**	0.186
Increasing difficulties in credit availability	0.038	**0.788**	-0.144
Increasing climate change consequences	**0.752**	0.093	-0.271
Low quality milk allowed in EU market	**0.791**	-0.022	0.044
Increasing fuel price	**0.685**	0.233	0.312

Figure A.1: Principal Component Analysis. Likert scale on on-farm biogas attitudes.

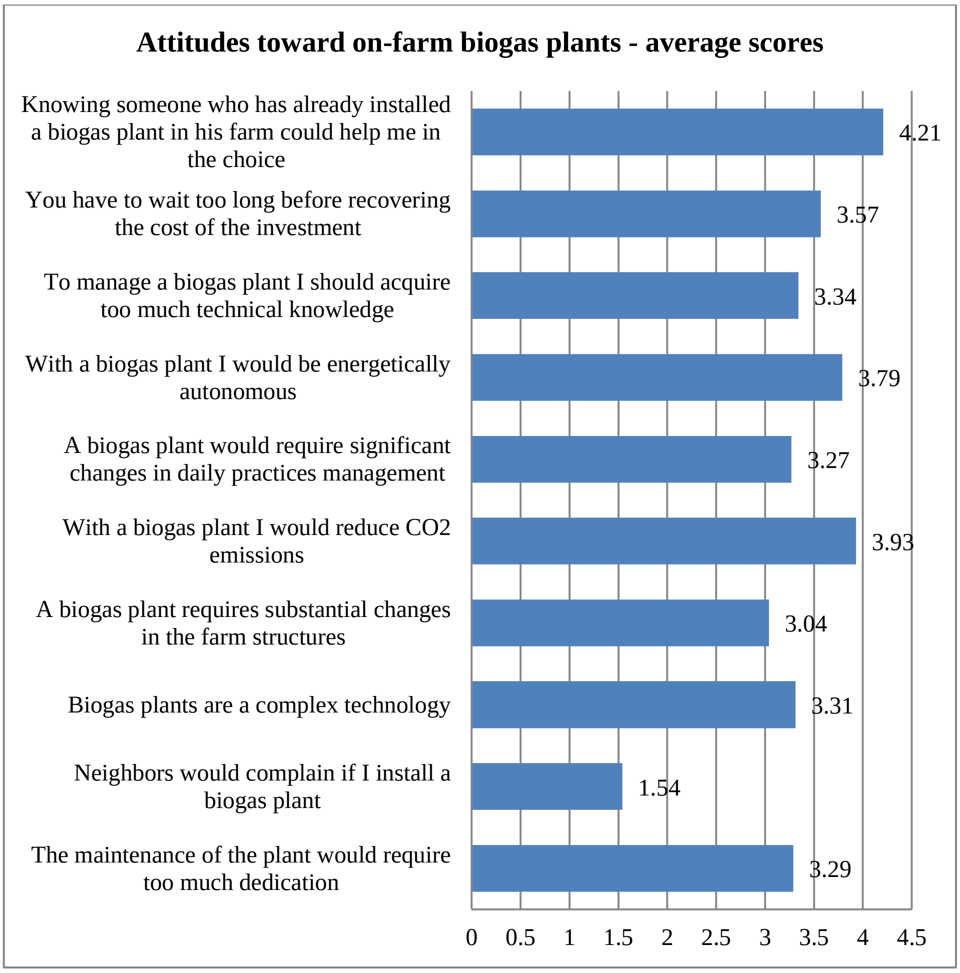

Figure A.2: Principal Component Analysis. Likert scale on perceived damages related to some events.

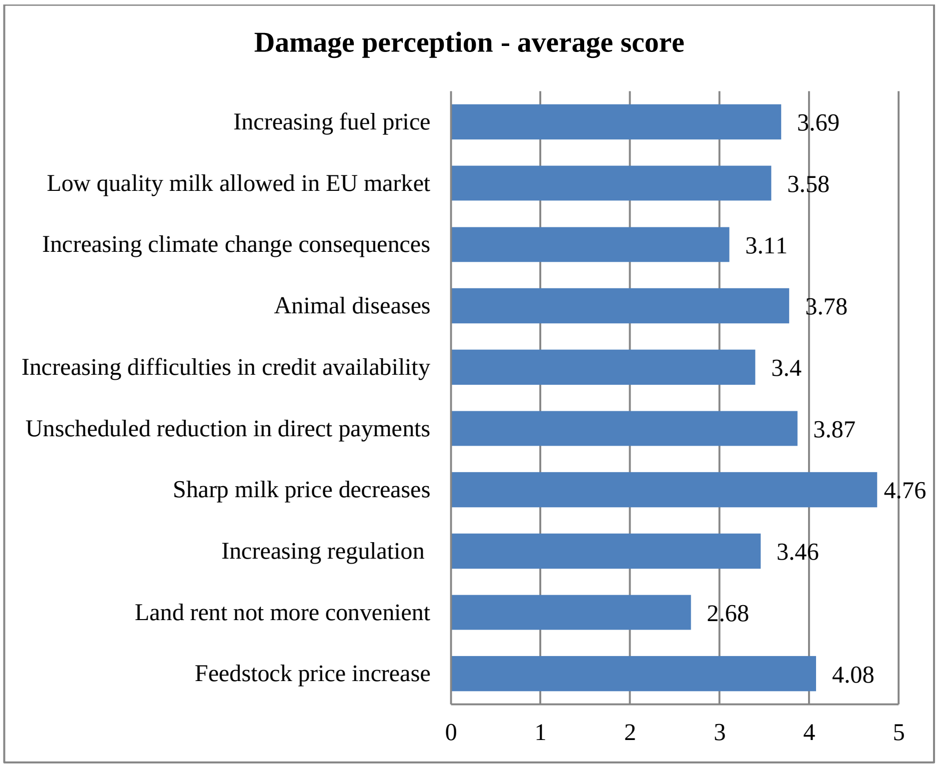

Figure A.3: Principal Component Analysis. Likert scale on events probability.