Manuscript Details

Manuscript number	RURAL_2017_35
Title	Knowledge networks and their role in shaping the relations within the Agricultural Knowledge and Innovation System in the agroenergy sector. The case of biogas in Tuscany (Italy)
Article type	Research Paper

Abstract

This paper presents an analysis of the knowledge retrieval networks behind the adoption of farm biogas in an area of Mediterranean Europe featuring arable farming systems. The overarching objective of the analysis is to help and understand the interplay between biogas adopters and the stakeholders of the Agricultural Knowledge and Innovations System (AKIS). Specifically, the paper proposes an application of social network analysis that aims at bringing out the influence of knowledge exchanged within the system on adopters' business decisions, as well as adopters' contribution to knowledge upgrading. Social network analysis focuses on the estimation of three network attributes (cohesion, knowledge co-creation, and brokerage) using primary data, collected in 2015 via questionnaire to plant adopters. Self-education, upstream industry, agronomists, farmer/biogas unions, university, public-funded projects, and public research centers are AKIS' stakeholders, which adopters turn to when seeking for information and/or know-how. Upstream industry is the most influential node and the one that can help knowledge diffusion across adopters, regardless of their background. Self-accessible resources are major providers of information at the adoption-decision stage. The networks are centralized on self-education tools, while upstream industry and the Research Center on Animal Productions are the brokers. Policy intervention aimed at improving AKIS in the biogas sector should involve the upstream industry in decision-making, while considering the duality of self-accessible information vs. physical advisors. This paper shows evidence from a region where public incentives have allowed biogas diffusion, despite the region not being intrinsically suitable for it. Study findings may be useful for policy-makers and researchers who deal with the prevention, or mitigation, of the negative externalities of land use change via the promotion of informed technology diffusion.

Keywords	AKIS; SNA; agroenergy; biogas adoption; knowledge; bioeconomy
Taxonomy	Alternative Energies Economics, Agricultural Business

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To the Editorial Board of the Journal of Rural Studies,

Dear Editors,

Please find enclosed a reviewed version of the paper below, to be considered for publication on the Journal of Rural Studies:

RURAL_2017_35

Title: Agricultural Knowledge and Innovation System and business models in the biogas sector. The case of Tuscany (Italy)

Authors: Oriana Gava[a], Elena Favilli[a], Fabio Bartolini[a], Gianluca Brunori[a]

Authors' affiliation: [a]University of Pisa – Department of Agriculture, Food and Environment, 80 Via del Boghetto, 56124 Pisa, Italy

Please note that the paper comes under a new title, following the suggestion of one anonymous reviewer; the **new title** is as follows:

"Knowledge networks and their role in shaping the relations within the Agricultural Knowledge and Innovation System in the agroenergy sector. The case of biogas in Tuscany (Italy)".

Authors and Authors' affiliation are unchanged.

All Authors are grateful to the Editors for giving us the possibility to improve our manuscript an submit a revised version of it.

I hereby confirm that the paper has not been published elsewhere in this form, that it is not under consideration for publication elsewhere, that its publication has been agreed by all named Authors and that the materials contained in the manuscript do not infringe on other copyright material.

I confirm that there are no known conflicts of interest associated with this publication and that no financial support for this work has influenced its outcome.

On behalf of all Authors,

Oriana Gava

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To the Editorial Board of the Journal of Rural Studies,

Dear Editors,

Please find enclosed the response to reviewers' comments to the paper below:

Title: Knowledge networks and their role in shaping the relations within the Agricultural Knowledge and Innovation System in the agroenergy sector. The case of biogas in Tuscany (Italy)
Former title: "Agricultural Knowledge and Innovation System and business models in the biogas sector. The case of Tuscany (Italy)"

All Authors are grateful to both anonymous reviewers and have much appreciated the work they did. We did our best for improving the paper by integrating all reviewer suggestions into the text. Paper structure was reorganized and paragraphs 1 through 3 thoroughly rewritten. English language was also doublechecked. The individual replies to reviewers' comments (marked in red) are set out in detail in Annexes 1 (Reviewer 1) and 2 (Reviewer 2).

On behalf of all Authors, I hereby confirm that the paper has not been published elsewhere in this form, that it is not under consideration for publication elsewhere, that its publication has been agreed by all named Authors and that the materials contained in the manuscript do not infringe on other copyright material.
I confirm that there are no known conflicts of interest associated with this publication and that no financial support for this work has influenced its outcome.

Annex 1

Reviewer 1

(1) While the 3 research questions are understandable, it would be useful if the text explicitly stated why this study is of analytical use (because it will give guidance to future funding at national and EU level etc.) at the beginning of the text and before the literature review. Otherwise the RQs point more or less to a descriptive text and not an analytical one (to study factors and barriers etc.). In the text after the 3 RQs there is an answer to this question but it would be better if it was formulated more clearly and to highlight that the aim is to see the local and sector specificities that differentiate biogas plants from the other rural/agricultural activities.

The new introductory paragraph makes explicit the way how this research might be of analytical use and reformulates the research questions into a more articulated objective. Specifically (page 3, lines 18-28):

"Against that background, the overarching objective of this paper is to give evidence about the networks of knowledge retrieval behind policy-driven biogas adoption in a region that features arable farming systems. Specifically, this study depicts the AKIS that has delivered that knowledge and helps and understand the interplay between biogas adopters and AKIS stakeholders. Operationally, we have pursued that objective by carrying out a social network analysis of primary data collected in 2015 via questionnaire to biogas adopters in Tuscany. We turned to social network analysis, because it has proved to be a useful, but underused, tool for studying knowledge flows within the AKIS (Spielman et al., 2011). Acknowledging the suggestion of Spielman et al (2009), this paper aims at providing recommendations to policy-makers in the act of designing support mechanisms at the micro-level, by adopting the perspective of biogas' adopters."

(2) My personal and non-binding opinion – in the literature review, I feel it will be clearer if the conclusion is stated before describing the researched case, in this way it is clearer to the reader what the main points of the literature review are.

The literature review underwent complete rewriting to meet papers' aims more closely. The new paragraph 2 (page 4, line 8, through page 7, line 12) is centered on the of Agricultural Knowledge and Innovation Systems in the agroenergy sector.

(3) SNA is a known enough method to allow for a shorter presentation of it in the Methodology section. By shortening it, more words can be allocated to the conclusion (see recommendation 4)

The "research method" section of the paper s be reduced to the essential elements for the reader to understand the analysis. This means we shrank the introductory part of the paragraph (the one before the description of network indexes) into what follows (page 10, lines 9-21):

"Social network analysis is a widespread tool for investigating systems (networks) of interconnected individuals and evaluate the extent to which individuals and individual-individual connections contribute to system performance, in terms of selected indexes. This allows ranking network elements, which improves the communication of research results (see e.g. Lamb, 2015). The present analysis is based on the calculation of three indexes, i.e. cohesion, knowledge co-creation, and brokerage, over a set of two-mode networks. Two-mode networks are graphs where edges represent the relation that maps actors of mode one to actors of mode two (Borgatti and Halgin, 2011). In this study, edges display the relation of adopters' knowledge (information and know-how) retrieval from AKIS' stakeholders. Many academic books guide researchers throughout network metrics and their empirical applications. The reader may refer to the exiting literature for methodological details – Scott (1991) and Wasserman and Faust (1994) are probably the most popular handbooks. Here, we report about the three indexes that make up the core of this study."

(4) Despite the acknowledged limitations, the text would benefit from an elaborated second paragraph of the conclusion – how exactly the upstream industry could be involved, how do self-accessed information and expert advisers differ in efficiency etc.

Paper conclusions have been reformulated and supplemented with an elaborated second paragraphs that goes beyond study limitations and provides clues on how to use research findings (page 27, line 29, through page 28, line 28):

"The research presented in this paper may facilitate decision-makers' choice of their preferred knowledge sources in the early stages of the adoption-decision process, this may help timely decisions, being the acquisition of relevant knowledge a time-consuming activity. AKIS stakeholders in the biogas sector and, more generally, decision makers in the bioeconomy should consider the increasing independence of biogas adopters as knowledge-seekers. For example, boosting online services for planning investments may reduce uncertainty and thus adoption delays, as well as proving guidance towards the more suitable innovation to be introduced on farm. Online services may be more effective for gathering the needed information for deciding upon the investment: e.g., funding opportunities, return on investment, land requirements, existing regulations, selection of suitable crop breeds, among the others. Targeted services may also facilitate the participation of plant operators to public-funded projects, which proved to be useful for improving biogas viability. Online services are not as targeted as those provided by physical actors, but offer prospected investors an overview of their potential choices. Most farmers who are keen on investing in the bioeconomy hold Master's degree and can solve some of the issues associated with cultivation or daily plant management. Still, innovation adopters need guidance by physical stakeholders, especially in adoption-confirmation and after plant adoption, being key for problem solving during daily plant operations. Technical problems in plant management are frequent and need to be fixed properly and quickly for guaranteeing continuous energy production. CRPA is among adopters' preferred knowledge sources; it also uses real world data originating from farmers with whom it is in contact for carrying or research and adapt plant solutions available from plant dealers to the local characteristics of the agricultural sector. AKIS' stakeholders, particularly in the upstream industry, hold that know-how. Further improvements in the regulation about state support to farmers in the bioeconomy should facilitate access to services of technical support and updated training. Upstream industry has also supported later decision-making, by delivering maintenance services and training, organizing visits to operating plants, sponsoring conferences, and participating to fairs. Agroenergy adoption implies 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 take on the that risk. The integration of agroenergy production on existing farms may improve the long-run sustainability of biogas installations."

(5) From a technical aspect, there are a few typos in the beginning of the text (even in the abstract, then on p. 1 etc.). There are quite a few omitted prepositions, many missed "to"s as part of an infinitive, and small technical mistakes in the text, so I would recommend a thorough language editing.
(6) On p. 15, in the phrase "from four to 29" – use either words or numbers
(7) In the introduction to paragraph 4 – when introducing the subparagraphs, there is no need to mention their numbers, otherwise the text becomes too difficult to read.

Thank you for that. We doublechecked orthography and language consistency throughout the text (e.g., omitted prepositions, words/numbers, etc.), and we cut redundant words, such as those, in brackets, referring to sub-paragraph numbers.

Annex 2

Reviewer 2

(1) The title is not completely in line with the main body of the article. The title should reflect more on the relevance and influence that knowledge networks have on the adopters of this innovation system and as a consequence the business models derive - I think. The focus is currently on the business models, but actually I do not find this as the innovative aspect of the article nor the main point of discussion. It is more the role played by the knowledge networks in shaping the relations within the system – so the way the actors organize their models.

Paper title was modified to bring out knowledge networks as the main element of research. The new title is as follows:

"Knowledge networks and their role in shaping the relations within the Agricultural Knowledge and Innovation System in the agroenergy sector. The case of biogas in Tuscany (Italy)".

(2) The structure of the paper could be better re-arranged to follow coherently the aim of the article.

The structure of the paper (especially paragraphs 1 through 3) was systemized into a series of paragraphs that reflect the background, rationale, objectives, and theory behind the paper. An overview of the revised paper is as follows:

1. Introduction
2. Literature review
3. Theoretical framework
4. Case study
5. Research method
6. Results and discussion
    - 6.1 The biogas sector in Tuscany
    - 6.2 The AKIS: network and brokers
    - 6.3 The networks of retrieval of information and know-how
    - 6.4 Network's cohesion and potential for knowledge co-creation
    - 6.5
7. Conclusions

(3) In the introduction section (1.), the research questions seem to follow more the structure of a "thesis" than not an article. I would suggest to argument them with more literature and more scientific soundness. Also, please refer to references when there is a real connection with what You want to say (e.g. Pascucci and DeMagistris, 2011 are referred to after the expression "traditional AKIS's stakeholders", but in what does this reference support Your argumentation?

The "Introduction" underwent complete rewriting. This applies to papers' objectives (former "research questions") as well, to give the article a more scholarly style. The use of citations was doublechecked throughout the text. Especially, citations are used for supporting the theoretical grounding of the study and lists of names are avoided. The new introductory paragraph (page 2, line 1, through page 3, line 31) follows:

"The lack of specific and reliable knowledge may be a stumbling block in farm-level innovation towards the bioeconomy (Kovacs, 2015). Flaws in the Agricultural Knowledge and Innovation System (AKIS), such as missing stakeholders, missing links between relevant stakeholders or ineffective knowledge transfer, may hinder farmers' ability to build their knowledge-base (EU SCAR, 2015). This is especially true for agroenergy, being the sector of the bioeconomy that relies more on inter-industry relations and knowledge networks (Golembiewski et al., 2015). Acknowledging AKIS' crucial role in the sustainable transition towards a bioeconomy, the European Commission empowers member states to effectively support and re-organize regional AKIS via their Bioeconomy Action Plans (European Commission, 2012; EU SCAR, 2013) – the Italian Bioeconomy Action Plan was released in 2016 (Italian Government, 2016). AKIS-specific measures are also included in the rural development policy 2014-2020 (e.g., public-private partnerships in agricultural research and agribusiness), which in Italy is implemented at the regional level. The EU has committed itself to AKIS' improvement and, with that aim, has invested in research (Moreddu and Poppe, 2013) to help evidence-based policy at the member-state level (Knierim et al., 2015). Here, we provide evidence about how the AKIS has allowed biogas adoption in a region[1] of Mediterranean Europe, i.e. Tuscany, Italy. Biogas is a popular and well-established biomass-to-energy technology (Raven and Verbong, 2004), and the most widespread in Italy (GSE, 2015).
Financial incentives included in Common Agricultural Policy's direct payments and rural development programs and national feed-in-tariff schemes have reduced market risk and ensured biogas competitiveness (Lee and Zhong, 2014; Liu and Zeng, 2017), thereby encouraging plant adoption on arable farms (Scarlat et al., 2015; Bangalore, 2016). However, the literature has not

[1] The twenty Italian regions are level 2 areas under the EU Nomenclature of Territorial Units for Statistics, i.e. NUTS 2.

addressed the concerns about land use shift from food/feed to energy cropping yet (Dauber et al., 2012; Kirkels et al., 2012; Lewandowski, 2015).
To date, the literature about AKIS in the biogas sector has mostly focused on northern climates (e.g., Hekkert and Negro, 2009; Markard et al. 2009). However, more varied evidence is needed from across the Union, being the EU a system of differentiated integration (Leuffen et al., 2013: 10), where the features of local agricultural systems are key for the diffusion of innovations (Capitanio et al., 2010; Hermans et al., 2015). This is especially true for Italy, where social, structural and institutional factors heavily affect innovation adoption in agriculture (Avolio et al., 2014). Knowledge retrieval from AKIS' stakeholders is critical for farmers' decision towards biogas adoption (Lundvall, 2007) and improved knowledge exchange across the system may encourage the involvement of Italian stakeholders and farmers in biogas-to-energy systems (Hodgson et al., 2106). Potential adopters would need different knowledge compared to the adopters of traditional agricultural innovation (Varis and Littunen, 2010), embedding elements from both the agricultural and energy spheres. Then, the AKIS in the Italian biogas sector is likely to differ from traditional AKIS, as, e.g., those described by Materia (2012) or Pascucci and De Magistris (2011). Lastly, recent research has called for studies that pinpoint the peculiarities of local agroenergy systems in Italy (Magnani et al., 2017).
Some Authors offer neo-institutional perspectives on the evolution of the biogas sector and on the success of some biogas business models (Carrosio 2013, 2014), as well as on the factors that helped or hindered the establishment of community agroenergy chains in rural areas. Other Authors describe the role of Energy Service Companies in biogas diffusion (Pantaleo et al., 2014), and assess the cost-effectiveness of public-private partnerships in agroenergy for the public sector (Fantozzi et al., 2014) to deliver guidelines for helping partnership success (Manos et al. 2014). However, at time of writing, we are not aware of published research about the AKIS in the Italian biogas sector.
Against that background, the overarching objective of this paper is to give evidence about the networks of knowledge retrieval behind policy-driven biogas adoption in a region that features arable farming systems. Specifically, this study depicts the AKIS that has delivered that knowledge and helps and understand the interplay between biogas adopters and AKIS stakeholders. Operationally, we have pursued that objective by carrying out a social network analysis of primary data collected in 2015 via questionnaire to biogas adopters in Tuscany. We turned to social network analysis, because it has proved to be a useful, but underused, tool for studying knowledge flows within the AKIS (Spielman et al., 2011). Acknowledging the suggestion of Spielman et al (2009), this paper aims at providing recommendations to policy-makers in the act of designing support mechanisms at the micro-level, by adopting the perspective of biogas' adopters."

(4) Literature review (2.). The literature review is split into two parts. Paragraph 2.1 is not clear not focused on the real aim of the paper. Often, sentences are incomplete (e.g. "This is known as

(Lundvall, 1985)"), or not clear (e.g. "AKIS stakeholder can control.........stakeholder relations (ties)": what does this mean?). I would suggest to recall also literature on the application of AKIS on a sectoral level, which is what the article actually intends to do. This paragraph needs consistent re-editing to clarify concepts on which the paper is based (innovation functions, assessing AKIS performance – performance is not your aim, why to present this issue?). Paragraph 2.2. seems to be there only to justify why SNA is used as a method. The literature review does not have a core of the analysis, it seems currently more as a list of papers which applied the same methods to not-always-similar aims (e.g. role of extension services, knowledge sharing, adoption of innovation...). It would be useful and informative to adopt one perspective (e.g. how farmers get the knowledge and information) and develop a literature review around it (so extension services can enter into play). Moreover, it is too long, and could be split into at least two parts, one with evidence from developing countries, one on developed ones. However, what do the experiences in developing countries say about your case? Is this part needed? Although it is certainly relevant to explain what indications to policy makers have been derived from each referred paper, to what extent this is what Your paper intends to achieve and deliver as a message? Is this a paper for policy makers? Why don't You refer to these recommendations when discussing your results?

(5) I am also wondering whether the case study (3.4) could be better introduced before the analysis. This is the value added of the paper, I would present it before the methodology in order to introduce the specific problem and case and in this way explaining the reason of the study. In this way, the business models would have more relevance as *supportive* of our study (although not the core of your study). This would make also clearer the explanation of the method applied and the indexes used, strictly connected to the actors and the problem analysed, and would clarify also the selection of the sample. So to say, paragraph 3.4 could be before the methodology, and many elements in the methodology and data collection be clearer and consistent with the case.

(6) The business model section (4.1) is now into the results section, why? Your results are more about the interactions among the actors defining then these business model, but the literature review 4.1. in my opinion should be into the introduction, not in your research results. the results are indeed the ones form the questionnaires.

The following text replies to reviewer 2's comments number (4), (5), and (6). The literature review was heavily edited. The new paper has a "literature review" and a "theoretical framework" paragraphs. The literature review provides an overview of the literature about AKIS in the agroenergy sector in Europe and includes a paragraph about research about Italy. The latter deals mainly with business models. The theoretical framework provides a sound background for the analysis that follows and concentrates on what helps explaining our methodological approach. Coherently with the new organization of the paper, the "case study" section is now between the "theoretical framework" and “research method” sections. We do not copy-paste here the improved paragraphs, because the text would be too long going from page 4, line 10 (paragraph 2. Literature review), to page10, line 8 (paragraph 4. Case study).

(7) Figures. Can you explain the meaning of the scores identifies in the graphs? How does self-education enter the list of actors involved (e.g. figure 1)?

This is the new caption to figure 1 (page 22, lines 7-10):
“**Figure 1.** Two-mode aggregated graph of adopters (black circles) by AKIS’ stakeholders (white squares) matrix. Source: Authors’ own elaboration.

Node size is proportional to the betweenness centrality of AKIS’ stakeholders. Width (and weight) of edges represents the share of Farmers or ESCos that retrieve knowledge from the stakeholder to which they are connected. “

We have explained the reason why we decided to include self-education among AKIS actors in sub-paragraph 2 (page 20, lines 1-5), as follows:

“Self-education is a way for acquiring information via books, technical magazines, participation to multi-professional events (fairs, conferences) and the web. Recently, self-accessible scientific and anecdotal literature have massively increased, particularly among entrepreneurs, who need build their knowledge base around investment opportunities (Bouhnik and Giat, 2015) also in rural areas (Reidolf, 2016).“

(8) Conclusion section. I think that the two broad issues that informed your research as presented on page 29 are actually not your core. On the one hand, you could stress even more the relevance of agro energy since the beginning of the paper; on the other hand, you do not deal with sustainability.
(9) Finally, in the limitations lots is said about how weak is the method and the sample. Why to stress this? I ask then myself “why did you do this knowing that it is so weak?”. Please stress what is this method useful for and how in the future it can be better supported otherwise I might wonder why this article should be published when the Authors themselves know since the beginning that it is weak to defend. Is this the first study on this topic with this method? Then this would justify and help more.

The conclusions have been supplemented with a discussion of the work we did that goes beyond study limitations. The text is now structured towards research findings, their usefulness for different types of readers, and provides some suggestions for further improvements. The new paragraph 7 follows (page 27, line 8, through page 29, line 15:

"The study of the rearrangement of Agricultural Knowledge and Innovation Systems (AKIS) towards the bioeconomy is in EU's agenda and is an open field of research. The paper uses social network analysis (SNA) for tracing the downstream flow of knowledge from AKIS' stakeholders to biogas operators, with the purpose of evaluating stakeholders' importance in driving biogas adoption and diffusion across arable farming systems. The research anchors on biogas, as for agroenergy technology, and on a case study area in Mediterranean Europe, i.e. Tuscany, Italy. That area was selected because it features arable farming systems, and agroenergy adoption is strictly dependent on public support. Data originate from semi-structured interviews with experts and network questionnaire to biogas adopters in Tuscany (2015). Research findings from Tuscany might be useful for tailoring policy and interventions to improve AKIS' ability to drive agroenergy innovation on farm in other Mediterranean areas.

The study identifies two types of adopters and three business models in the biogas sector of Tuscany. Adopters are people with farming background and energy service companies (ESCos). The three business models are multifunctional farms, entrepreneurial farms, and ESCos (most farms). The outputs of social network analysis suggest that self-education tools, farmer/biogas unions, upstream industry, and the Research Centre on Animal Productions (CRPA) are key AKIS' elements, by improving network cohesion, allowing knowledge co-creation between adopters and AKIS' stakeholders, and by brokering knowledge sources towards (potential) adopters. Both farmers and ESCos are informed, "updated", and cost-effective knowledge seekers, and diversify their knowledge sources. The networks are centralized on self-education tools, with two brokers, i.e. the upstream industry and the CRPA.

The research presented in this paper may facilitate decision-makers' choice of their preferred knowledge sources in the early stages of the adoption-decision process, this may help timely decisions, being the acquisition of relevant knowledge a time-consuming activity. AKIS stakeholders in the biogas sector and, more generally, decision makers in the bioeconomy should consider the increasing independence of biogas adopters as knowledge-seekers. For example, boosting online services for planning investments may reduce uncertainty and thus adoption delays, as well as proving guidance towards the more suitable innovation to be introduced on farm. Online services may be more effective for gathering the needed information for deciding upon the investment: e.g., funding opportunities, return on investment, land requirements, existing regulations, selection of suitable crop breeds, among the others. Targeted services may also facilitate the participation of plant operators to public-funded projects, which proved to be useful for improving biogas viability. Online services are not as targeted as those provided by physical actors, but offer prospected investors an overview of their potential choices. Most farmers who are keen on investing in the bioeconomy hold Master's degree and can solve some of the issues associated with cultivation or daily plant management. Still, innovation adopters need guidance by physical stakeholders, especially in adoption-confirmation and after plant adoption, being key for problem solving during daily plant operations. Technical problems in plant management are frequent and need to be fixed properly and quickly for guaranteeing continuous energy production. CRPA is among adopters' preferred knowledge sources; it also uses real world data originating from farmers with whom it is in contact for carrying or research and adapt plant solutions available from plant dealers to the local characteristics of the agricultural sector. AKIS' stakeholders, particularly in the upstream industry, hold that know-how. Further improvements in the regulation about state support to farmers in the bioeconomy should facilitate access to services of technical support and updated training. Upstream industry has also supported later decision-making, by delivering maintenance services and training, organizing visits to operating plants, sponsoring conferences, and participating to fairs. Agroenergy adoption implies 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 take on the that risk. The integration of agroenergy production on existing farms may improve the long-run sustainability of biogas installations.

A follow-up questionnaire involving non-adopters might help identifying differences and overlaps between the two AKIS. Those farmers should be managing similar farms, which approximates for having the same likelihood of adopting the technology based on profit maximization. Besides, having network data over more time periods would help evaluate the way how the raise of the biogas sector affected the AKIS. Indeed, the implementation of participatory methods may improve network building and SNA outputs. For example, the current results of SNA might be discussed and improved after a workshop with a sample of biogas adopters, a sample of non-adopters, and AKIS' stakeholders. The most critical steps in analyses such the one presented here are identifying the study population and designing the questionnaire. Particularly, in two-mode networks (i.e. when relationships exist between individuals owing to different sets, but do not exist within each set), it is crucial to define the horizontal boundary of the population, viz. the set of individuals to which individuals from the other set would report to have ties. Maybe, the major drawback of this study is the provision of a static picture an emerging sector. Indeed, further work on the same study area would improve the overall output of the research. Further work may focus on the strengths and weaknesses of agroenergy's AKIS in arable systems and evaluate the costs and benefits of the public support system. The multilevel perspective of socio-technical transitions may allow highlight the current potential and the existing barriers for agroenergy to get mainstream. Additionally, a natural experiment, based on data from both adopters and non-adopters, would provide a more dynamic view of the biogas sector."

(10) I am not expert in the methodology applied though, so I would ask for a check on it from experts.
(11) A substantial check of the English (grammar and style) is necessary before the article can be published.
(12) Please, also check the rules on how to cite scientific references (e.g. Spielman and Colleagues (2011) should be Spielman et al. (2011).

Thank you for that. We doublechecked the methodology, the use of English language, and the consistency with citation rules

Highlights.

- Improving knowledge networks may help the adoption of innovation in the bioeconomy.
- A social network analysis of the Agricultural Knowledge and Innovation System of biogas is proposed.
- Upstream industry is a relevant producer of knowledge, self-information is key for deciding upon adoption, the Research Centre on Animal Productions can act as a broker.
- Policy to improve AKIS should involve the upstream industry.

Knowledge networks and their role in shaping the relations within the Agricultural Knowledge and Innovation System in the agroenergy sector. The case of biogas in Tuscany (Italy)

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Knowledge networks and their role in shaping the relations within the Agricultural Knowledge and Innovation System in the agroenergy sector. The case of biogas in Tuscany (Italy)

Abstract. This paper presents an analysis of the knowledge retrieval networks behind the adoption of farm biogas in an area of Mediterranean Europe featuring arable farming systems. The overarching objective of the analysis is to help and understand the interplay between biogas adopters and the stakeholders of the Agricultural Knowledge and Innovations System (AKIS). Specifically, the paper proposes an application of social network analysis that aims at bringing out the influence of knowledge exchanged within the system on adopters' business decisions, as well as adopters' contribution to knowledge upgrading. Social network analysis focuses on the estimation of three network attributes (cohesion, knowledge co-creation, and brokerage) using primary data, collected in 2015 via questionnaire to plant adopters. Self-education, upstream industry, agronomists, farmer/biogas unions, university, public-funded projects, and public research centers are AKIS' stakeholders, which adopters turn to when seeking for information and/or know-how. Upstream industry is the most influential node and the one that can help knowledge diffusion across adopters, regardless of their background. Self-accessible resources are major providers of information at the adoption-decision stage. The networks are centralized on self-education tools, while upstream industry and the Research Center on Animal Productions are the brokers. Policy intervention aimed at improving AKIS in the biogas sector should involve the upstream industry in decision-making, while considering the duality of self-accessible information vs. physical advisors. This paper shows evidence from a region where public incentives have allowed biogas diffusion, despite the region not being intrinsically suitable for it. Study findings may be useful for policy-makers and researchers who deal with the prevention, or mitigation, of the negative externalities of land use change via the promotion of informed technology diffusion.

1. Introduction

The lack of specific and reliable knowledge may be a stumbling block in farm-level innovation towards the bioeconomy (Kovacs, 2015). Flaws in the Agricultural Knowledge and Innovation System (AKIS), such as missing stakeholders, missing links between relevant stakeholders or ineffective knowledge transfer, may hinder farmers' ability to build their knowledge-base (EU SCAR, 2015). This is especially true for agroenergy, being the sector of the bioeconomy that relies more on inter-industry relations and knowledge networks (Golembiewski et al., 2015). Acknowledging AKIS' crucial role in the sustainable transition towards a bioeconomy, the European Commission empowers member states to effectively support and re-organize regional AKIS via their Bioeconomy Action Plans (European Commission, 2012; EU SCAR, 2013) – the Italian Bioeconomy Action Plan was released in 2016 (Italian Government, 2016). AKIS-specific measures are also included in the rural development policy 2014-2020 (e.g., public-private partnerships in agricultural research and agribusiness), which in Italy is implemented at the regional level. The EU has committed itself to AKIS' improvement and, with that aim, has invested in research (Moreddu and Poppe, 2013) to help evidence-based policy at the member-state level (Knierim et al., 2015). Here, we provide evidence about how the AKIS has allowed biogas adoption in a region[1] of Mediterranean Europe, i.e. Tuscany, Italy. Biogas is a popular and well-established biomass-to-energy technology (Raven and Verbong, 2004), and the most widespread in Italy (GSE, 2015).

Financial incentives included in Common Agricultural Policy's direct payments and rural development programs and national feed-in-tariff schemes have reduced market risk and ensured biogas competitiveness (Lee and Zhong, 2014; Liu and Zeng, 2017), thereby encouraging plant adoption on arable farms (Scarlat et al., 2015; Bangalore, 2016). However, the literature has not addressed the concerns about land use shift from food/feed to energy cropping yet (Dauber et al., 2012; Kirkels et al., 2012; Lewandowski, 2015).

To date, the literature about AKIS in the biogas sector has mostly focused on northern climates (e.g., Hekkert and Negro, 2009; Markard et al. 2009). However, more varied evidence is needed from across the Union, being the EU a system of differentiated integration (Leuffen et al., 2013:

[1] The twenty Italian regions are level 2 areas under the EU Nomenclature of Territorial Units for Statistics, i.e. NUTS 2.

10), where the features of local agricultural systems are key for the diffusion of innovations (Capitanio et al., 2010; Hermans et al., 2015). This is especially true for Italy, where social, structural and institutional factors heavily affect innovation adoption in agriculture (Avolio et al., 2014). Knowledge retrieval from AKIS' stakeholders is critical for farmers' decision towards biogas adoption (Lundvall, 2007) and improved knowledge exchange across the system may encourage the involvement of Italian stakeholders and farmers in biogas-to-energy systems (Hodgson et al., 2106). Potential adopters would need different knowledge compared to the adopters of traditional agricultural innovation (Varis and Littunen, 2010), embedding elements from both the agricultural and energy spheres. Then, the AKIS in the Italian biogas sector is likely to differ from traditional AKIS, as, e.g., those described by Materia (2012) or Pascucci and De Magistris (2011). Lastly, recent research has called for studies that pinpoint the peculiarities of local agroenergy systems in Italy (Magnani et al., 2017).

Some Authors offer neo-institutional perspectives on the evolution of the biogas sector and on the success of some biogas business models (Carrosio 2013, 2014), as well as on the factors that helped or hindered the establishment of community agroenergy chains in rural areas. Other Authors describe the role of Energy Service Companies in biogas diffusion (Pantaleo et al., 2014), and assess the cost-effectiveness of public-private partnerships in agroenergy for the public sector (Fantozzi et al., 2014) to deliver guidelines for helping partnership success (Manos et al. 2014). However, at time of writing, we are not aware of published research about the AKIS in the Italian biogas sector.

Against that background, the overarching objective of this paper is to give evidence about the networks of knowledge retrieval behind policy-driven biogas adoption in a region that features arable farming systems. Specifically, this study depicts the AKIS that has delivered that knowledge and helps and understand the interplay between biogas adopters and AKIS stakeholders. Operationally, we have pursued that objective by carrying out a social network analysis of primary data collected in 2015 via questionnaire to biogas adopters in Tuscany. We turned to social network analysis, because it has proved to be a useful, but underused, tool for studying knowledge flows within the AKIS (Spielman et al., 2011). Acknowledging the suggestion of Spielman et al (2009), this paper aims at providing recommendations to policy-makers in the act of designing support mechanisms at the micro-level, by adopting the perspective of biogas' adopters.

The paper is structured towards seven paragraphs, including this introduction. Next paragraph delivers a review of the relevant European literature about AKIS in agroenergy. After that, we present the selected case of biogas diffusion in arable farming and provide a theoretical basis for our analysis. The following paragraph is about the data collection procedure. The results and discussion paragraph depicts and comments the outputs of data processing under the selected methodological framework. In the conclusions, we pinpoint key research findings, deliver policy recommendations, and suggests improvements and directions for further research.

2. Literature review

Traditionally, the AKIS concept refers to those institutional set-ups where knowledge organizations operate and interact (Röling and Engel, 1991; Edquist, 2005; World Bank, 2006). To enter the age of the bioeconomy, that definition has been updated to introduce more heterogeneous, less formal and more autonomous ways of knowledge diffusion, which suggest a more complex interaction between stakeholders of the knowledge triangle (research, education, extension) and potential adopters of innovation in agriculture (Esposti, 2012). For one, the strictly agricultural perspective has opened to a system of innovation that encompasses all sectors now converging into the bioeconomy (Manos et al., 2014; Bauer et al., 2017; Hansen and Bjørkhaug, 2017). For example, diverse upstream industries (e.g. energy, chemical, pharmaceutical) take part in technology development and provide key competences and resources to enable farm competitiveness on the market (Hellsmark et al., 2016), besides firms producing seeds, fertilizers, agricultural machinery, and precision agriculture technologies. Then, those more complex systems of innovation include participation, experimentation, training, learning by doing, and AKIS-adopter interaction, while benefiting from informal institutions (Wirth et al., 2013) and e-science[2] (Esposti, 2012; Moreddu and Poppe, 2013). For example, in Italy, local environmental conditions, institutional landscape, and informal social resources underlie the local characteristics of agroenergy systems (Carrosio, 2013, Wirth, 2014;

[2] E-science refers to the global infrastructure made of ubiquitous high-end computers, storage, network, and web technologies, that has increasingly supported research in many areas of science and allowed synergistic activities between different scientific disciplines (Yang et al., 2009).

Magnani et al., 2017). E-science has received special attention by institutions, being able to improve access, exchange, and co-creation of knowledge (EU SCAR, 2015). Research findings support the political interest (e.g., Reidolf, 2015), though highlighting the need to integrate e-science with conventional (physical) AKIS (Klerkx and Proctor, 2013; Materia et al., 2015). Better knowledge integration may also mitigate the decreasing legitimacy of agroenergy systems (Markard et al., 2016).

The literature about AKIS in the agroenergy sector is expanding. Research has primarily considered regions of center-north Europe, where agroenergy, especially biogas, has a longer tradition compared to southern regions. Basically, there are two analytical strands, i.e. the AKIS' functions framework (Andersson and Jacobsson, 2000; Jacobsson and Bergek, 2004; Hekkert et al., 2007) and the technological innovation systems perspective (Markard and Truffer, 2008). The former involves assessing the proper (or improper) functioning of an AKIS by evaluating the functions the system should be carrying out. The functions are seven, (i) entrepreneurial activities, (ii) knowledge development, (iii) knowledge diffusion through networks, (iv) guidance of the search, (v) market formation, (vi) resource mobilization, (VII) creation of legitimacy (Hekkert et al., 2007). The latter is related to the study of technological transitions (Geels, 2002; Hoogma et al., 2002) and involves considering the reciprocal relationships across all stakeholders in the system from a micro (niche) perspective. This approach allows the researcher to highlight the factors (landscape) that influence the innovative performance of firms, including the behaviour of prospected adopters, the coexistence with established technologies and production systems (regimes), and the overlap of interest groups (Markard and Truffer, 2008).

Under the AKIS' functions framework, Negro et al. (2007) argue that irregular function fulfillment by AKIS stakeholders underlies the slow diffusion of biogas technology in the Netherlands. No system function has shown continuous build up over the 30 years under study, perhaps because short periods of enthusiastic entrepreneurial activities by pioneers and policy change have prevented the system from gaining critical mass to overcome technological issues. Negro et al. (2008) observed positive feedback loops among the functions of biomass gasification systems in the Netherlands. However, policy change, especially market liberalization and restrictions on emissions from processing plants, hindered entrepreneurial activities, knowledge development, and guidance of the search. Based on a set of case studies in the Netherlands and Germany, Hekkert and Negro (2009) highlight that AKIS should be able to align stakeholders' needs within the system (creation of legitimacy) and to mitigate investor uncertainty, by facilitating resource mobilization (e.g., public funds), market creation, knowledge development and guidance of the search.

In the literature on technological innovation systems, Markard et al. (2009) identify three successful business models in Switzerland, i.e. the farmer, waste company, and utility models. Both the farmer and waste company models involve direct plant operations, but process different types of biomass, i.e. agricultural waste and/or dedicated crops, and municipal (organic) waste, respectively. The utility model, instead, is structured towards a utility company that stipulates contracts with farmers or waste companies, who take care of biomass procurement and plant operations. Wirth and Markard (2011) show that stakeholders' interaction among different technological innovation systems can contribute to creation of successful integrated business models in the biomass gasification sector in Switzerland, including, e.g., large utility companies, gas suppliers, and local owners of forests and sawmills. Success might be associated to models' ability to handle the complexity that comes along with plant financing, supply and operation.

Concerning successful business models, Carrosio (2013) offers a neo-institutional perspective on the evolution of the sector in northern Italy and depicts four key operating patterns of biogas-hosting farms, which mainly differ for size, mission, and type and origin of biomass. Multifunctional farms adopt biogas for reaching the maximum possible vertical integration and autonomy from the market; they supply energy resources, while maintaining food/feed production systems. Plant size is set coherently with farm's potential in terms of biomass supply; then, plants are usually small (around 100 kWh rated power). Entrepreneurial farms pursue the objective of continuous scale enlargement (van der Ploeg, 2008), they adopt biogas to increase profit margins via supply diversification and ecological upgrade. Farms are large (500-1000 ha), at least for the Italian context, and livestock-based. Biogas allows increase the number of livestock units, while complying with the Nitrates Directive. Plant is sized to maximize the returns from electricity sale and does not depend on farm's productive capacity[3]. In Author's view, this is the major business model in Italy. Entrepreneurial bioenergy farms have completely shifted from food/feed production to energy cropping. Plant size is decided under a profit maximization logic. Some of those farms have established of joint enterprises with industrial organizations that take over the investment and arrange contracts with plant-host farmers; the latter just deal with biomass production and processing within the plant. Those industrial organizations (Energy Service Companies or ESCos) are enterprises that operate diverse renewable energy plants. Like other EU countries (cf. Hannon et al., 2013), ESCos have quickly widespread in the Italian biogas sector, following the release of the feed-in tariff scheme. Recently, Pantaleo et al. (2014) have published a detailed overview of ESCos' development and current operating models worldwide. The last, and more innovative, business model is the community bioenergy farm, which is currently observable just in some marginal areas (Wirth, 2014; Magnani et al., 2017). The plant is integrated within the local community, which, in turn, supplies biomass and benefits from excess heat production via a private distribution grid. Plant size depends on the supply capacity of the area under community management.

3. Theoretical framework

Innovation in agriculture is a systemic event (Fagerberg 2005; EU SCAR, 2012), being the result of social and economic processes of regional rural development (Ward and Brown, 2009), and of the interactions among innovation adopters and knowledge organizations (Smits et al., 2010). The latter can influence innovation even more than traditional production factors (land, labor, capital) (Marshall, 1920; Hermans et al., 2002; Radosevic, 2010). Besides financial motives, farmers' ability to build a proper knowledge-base is the first and unavoidable step of the process of innovation-adoption (Rogers, 2003). Non-physical knowledge sources (non-physical stakeholders, such as e.g. media channels) are extremely important in early knowledge acquisition, while physical sources (physical stakeholders, such as the providers of extension services) are more important in later stages (Rogers, 2003). That knowledge-base is made of specific enough information and know-how, to influence the perceptions of potential adopters towards innovation's successfulness and sustainability (Padel, 2001). In principle, potential adopters should be aware of the benefits and disbenefits of the innovation they are going to adopt, and know how to utilize it. This is particularly important when it comes to innovation in the bioeconomy, because high production and transaction costs and social opposition can lead to suboptimal (when not counter-productive) operating conditions (Carneiro and Ferreira, 2012; Soland et al., 2013; Pantaleo et al., 2014). AKIS' stakeholders may help potential innovation adopters when building their knowledge-base, by involving them in a network of relationships that provides access to different sources of information and know-how. The ability to build networks or connect to existing networks is recognized as one of the fundamental conditions for innovation (Knickel et al., 2009; Moshiz et al., 2015).

Research about knowledge flows within the AKIS – but also within other systems (Phelps et al., 2012) – relies significantly on social network analysis, or SNA, (Spielman et al., 2009; Klerkx et al., 2010). SNA is just one of the available analytical tools for AKIS' evaluation (Klerkx et al., 2012). Researchers may decide upon adopting other methodologies that would turn to into more informative results, depending on various issues, viz. type and availability of data, geographical scope of the enquiry, and specific research question (e.g., Hunt et al., 2014; Hermans et al., 2015; Läpple et al., 2015, 2016). Reviewing those approaches is beyond the scope of this paper; the reader can refer to Klerkx et al. (2012) for an overview. Rather, we set out a theoretical grounding for our research, drawing from social network studies of the AKIS.

Spielman et al. (2011) examine the interplay between farmers and AKIS' stakeholders and highlight that public organizations are the core of the innovation system, while market and civil society are more peripheral. Matouš et al. (2013) stress the importance of informal knowledge exchange among peers in the network. Isaac (2012) observes that effective flow of agrarian information between producers and public/private organizations is bi-directional, mainly thanks to farmers' training programs. In Cadger et al. (2016), extension services turn to be knowledge hubs and help farmers' affiliation to public projects, which improves the diversification of farmers' knowledge and their willingness to innovate. According to Aguilar-Gallegos et al. (2015), the higher the number of farmer connections within the AKIS (especially with extension services), the greater and more heterogeneous the set of information they can access and the higher the rate of innovation, with improved yields and increased income. Reed and Hikey (2016) show that brokerage and knowledge sharing are positively associated with knowledge diffusion about agricultural innovations. Developing communication strategies for creating contacts between peripheral farmers and external sources of knowledge may help innovation adoption on farm. According to Hermans et al. (2013), the rate of participation of AKIS's stakeholders in environmental projects is an indicator of network's knowledge co-creation potential; the rate of participation in project meetings approximates for knowledge upscaling, and organizations' ability to affiliate participants is a measure of brokerage (Moore and Westley, 2011). Lubell et al. (2014) call for the synergic integration of social, technical, and experiential learning pathways, via the promotion of boundary-spanning partnerships (brokerage activities), i.e. organizations made of groups of people with different backgrounds that co-produce knowledge meant to boost innovation. Smedlund (2008) and Klerkx and Proctor (2013) evaluate advisory networks in terms of their centralization, distribution, and decentralization patterns. Centralized networks operated within close-knit communities of practice (same organization), where few individuals can create bridges with the outside. Problem solving in centralized networks is an issue. Knowledge is retrieved from the web, professional magazines, books, and education stakeholders. Distributed networks include advisors (same organization) that rely on informal exchange with peers for retrieving knowledge about technical issues, problem-solving, best-practice, and mentoring. Within those networks, the exchange of formal and/or informal knowledge among advisors and scientific experts takes place via face to face (e.g., at conferences) or remote (e.g. via the web) interactions. Innovation brokers, or inter-professional and cross-sector collaboration, are needed for creating connections outside the own organizations.

4. Case study

The case study area is Tuscany, one of the twenty administrative regions of Italy. Tuscany is the only region of central-southern Italy where the introduction of the feed-in tariff scheme has driven relevant adoption of farm biogas. The number of operating plants had increased from 4 to 29 between 2011 and 2014 (Fabbri et al., 2011; ARPAT, 2015). However, the biogas sector in Tuscany is still in its infancy (Fabbri et al., 2011; Fabbri et al., 2013), contrary to the regions of northern Italy, towards which research have been mostly addressed so far (Gava et al., 2016). In fact, 90% of the roughly 1000 biogas plants that are currently operating in Italy are in the north and mostly associated to intensive dairy and pig farming (Fabbri, 2013). In those farming systems, getting rid of excess livestock waste is a priority, for preventing environmental damage and complying with the Nitrates Directive (91/676/EEC). Instead, farming systems in central and southern Italy are mainly arable, thereby missing excess polluting waste to be used as biogas input, which means that plant adoption needs structural change on farm, to rearrange productive activities. This has somewhat prevented biogas from spreading, despite the availability of profitable feed-in tariffs since 2009 (DM 18-12-2008). Pedo-climatic and topographic differences between northern and central-southern Italy might be additional reasons for the uneven distribution of biogas plants across the country. Research has shown that adopting biogas in some sub-regions of Tuscany could improve farmers' income, push the supply of rural labor, and help meeting 2020 energy targets (Bartolini et al., 2015; Bartolini et al., forthcoming). However, biogas diffusion in Tuscany has fed a debate around potential plants' sustainability and the impacts on land and water use across the region.

5. Research method

Social network analysis is a widespread tool for investigating systems (networks) of interconnected individuals and evaluate the extent to which individuals and individual-individual connections contribute to system performance, in terms of selected indexes. This allows ranking network elements, which improves the communication of research results (see e.g. Lamb, 2015). The present analysis is based on the calculation of three indexes, i.e. cohesion, knowledge co-creation, and brokerage, over a set of two-mode networks. Two-mode networks are graphs where edges represent the relation that maps actors of mode one to actors of mode two (Borgatti and Halgin, 2011). In this study, edges display the relation of adopters' knowledge (information and know-how) retrieval from AKIS' stakeholders. Many academic books guide researchers throughout network metrics and their empirical applications. The reader may refer to the exiting literature for methodological details – Scott (1991) and Wasserman and Faust (1994) are probably the most popular handbooks. Here, we report about the three indexes that make up the core of this study.

Cohesion. We calculate two complementary measures: density and centralization (Freeman, 1979; Scott, 1991). Density is the proportion of pairs of nodes that have ties out of the maximum possible number ties in the two-mode network (Borgatti and Everett, 1997). Density is inversely correlated with the ease of knowledge exchange. High density may lead to trusty relationships (Bodin and Crona, 2009), which can hinder the entrance of new knowledge within the network. Given the generally weak relationships among adopters, efficient downstream flow of knowledge from AKIS' stakeholders and self-accessible sources to adopters is crucial within policy-driven-innovation networks (van der Valk et al, 2011; Isaac, 2012). Centralization measures the extent to which edges are evenly distributed among nodes, viz. the extent to which density is organized around focal points (Scott, 1991). Focal points turn to be the most influential nodes, i.e. the ones to whom most individuals owing to the other set of nodes turn to for seeking knowledge (Scott, 1991). Centralized networks are for routine problem solving and updating. Distributed networks are for more complicated problem solving and informal exchange of tacit knowledge. Decentralized networks are for complex problem solving, knowledge exchange with the outside, and developing service innovation. We highlight network areas with different cohesion, by fitting a core/periphery model to our data. The core/periphery algorithm calculates a "coreness" value for each node based on density and degree centrality, and defines node-node distance based on coreness similarity (Comrey, 1962; Borgatti and Everett, 1999).

Knowledge co-creation. We use two interdependent indexes: degree centrality (Freeman, 1979) and adopters' affiliation rate to AKIS' stakeholders (Hermans et al., 2013). Degree centrality is the ratio between the number of edges a node is involved in and the maximum possible number of edges in the network. In a two-mode network, degree centrality is calculated for each set of nodes. Here, we focus on AKIS' stakeholders. Degree centrality allows to evaluate network dynamism (Freeman, 1979). In innovation systems, adopters collaborate and co-create knowledge with a variable set of AKIS' stakeholders. This dynamism helps innovation, especially when different types of network individuals have different backgrounds (Van de Ven, 1999), as for example in projects with multiple partners (Hermans et al., 2013). The index for knowledge co-creation *tout court* is adopters' affiliation rate to AKIS' stakeholders, i.e. the degree centrality of AKIS' stakeholders divided by the number of adopters. The lower the index, the greater the opportunities for AKIS' stakeholders to learn, develop new ideas, and convey those ideas to the upstream industry and policy makers (Moore and Westley, 2011; Hermans et al., 2013).

Brokerage. We use a qualitative criterion, i.e. boundary-spanning relations (Lubell et al., 2014), and an index, i.e. betweenness centrality (Freeman, 1979). Following Lubell et al. (2014), we identify nodes with boundary-spanning relations among AKIS' stakeholders. Nodes with boundary-spanning relations play multiple roles, supply multiple types of knowledge, and have reciprocal exchange of knowledge with innovation adopters. Betweenness centrality measures the extent to which a node allows shortest paths among network nodes. Here, we calculate the index for AKIS' stakeholders. Betweenness centrality is a key concept in the study of knowledge flow (Freeman, 1979). Nodes with high betweenness can control the flow of knowledge through the network; those nodes are gatekeepers, as they bridge providers and seekers of knowledge (Barzilai-Nahon, 2008). Here, we use betweenness centrality for ranking AKIS' stakeholders, based on their gatekeeping potential.

5. Data

The tools for primary data collection are face-to-face semi-structured interviews and questionnaires. The level of analysis is the farm, notably biogas-hosting farms in Tuscany. The unit of analysis is the person in charge of plant operations management on farm. We distinguish between two main knowledge needs, i.e. information (coded knowledge, such as e.g. technical details and funding opportunities) and know-how (tacit knowledge, such as e.g. management practicalities or plant-specific training) (Kogut and Zander, 1992).

Data collection includes three-steps: (i) identification of the study population; (ii) network questionnaire; (iii) coding and completing the network with perceived relations (Burt, 2010).

Step 1. The study object is biogas adopters' network of knowledge retrieval from AKIS' stakeholders. Self-accessible sources are among AKIS' stakeholders (cf. Sutherland et al., 2017). There are two sets of individuals, i.e. seekers (biogas adopters) and suppliers (AKIS' stakeholders) of knowledge. The study population has two vertical and horizontal boundaries. (Burt, 2010). Biogas adopters in Tuscany define the vertical boundary. The regional authority for environmental protection of Tuscany (ARPAT) helped us contacting all biogas adopters in Tuscany (technical features and geographical location of plants are available online (ARPAT, 2015)). AKIS' stakeholders and self-accessed knowledge mentioned by plant adopters define the horizontal boundary of the population. We drafted a preliminary list of AKIS' stakeholders via interviews with experts. The list was refined after questionnaire administration to adopters. Expert interviews followed a draft with two sections. Section one addressed the dynamics of biogas diffusion in Tuscany. Section two was meant for pinpointing the institutions, enterprises, and private practitioners that have had a role in the process of knowledge diffusion across potential biogas adopters (name generator). We interviewed eight experts, which we identified via a snowball procedure starting from two research agronomists from a public university in Tuscany, with expertise on energy cropping. The remainder interviewees were as follows:

- the person in charge of biogas plants' census at ARPAT;
- a freelance agronomist providing consultancy to biogas adopters in Tuscany;
- a researcher with over twenty-year expertise in the field of agroenergy, working for the Research Centre on Animal Production (CRPA), i.e. the major public research and extension organization that deals with farm biogas in Italy;
- two officers of the Regional Government of Tuscany with over ten-year expertise in rural policy planning in Tuscany;
- an energy engineer who manages biogas plants' in behalf of an ESCo.

The combination of the eight name generators originated the roster to be used within network survey to farmers.

Step 2. A network questionnaire was administered to the persons in charge of investment decisions on farm, for collecting relational data. The relations under study are those involving seeking information and know-how from AKIS' stakeholders. The questionnaire included three sections. Section one addressed respondent and farm details, with questions ranging from education, to land use change on farm and labor supply due to plant establishment. Section two had (closed-end) network questions, notably flexible roster-recall tables (Wasserman and Faust, 1994), which respondents could integrate with missing elements. Questions were of the following two types: (i) "To whom did you turn when you needed to decide on biogas adoption?"; (ii) "Why did you turn to that specific actor? [(A) for gathering technical and economic information about the plant (e.g., plant sizing, land requirements, return on investment, funding opportunities; (B) for learning how to manage the plant or the farm, including problem solving]". Section three included open-ended questions about knowledge exchange relations with other biogas adopters, and type of relationship with listed AKIS' stakeholders. Respondents could name missing stakeholders. Eventually, we ended up with an improved list of AKIS' stakeholders that included self-education through books, the web, and attendance to fairs and conferences.

Step 3. We coded the list of institutions, enterprises, and private practitioners to the categories of AKIS's stakeholders in Italy (Materia, 2012; Caggiano, 2014); we also coded the list of respondents to two homogeneous categories, based on the outcomes of section one of the questionnaire.

The collection of network data from plant adopters occurred across spring and summer 2015. We collected valid questionnaires for 13 out of the 29 operating farm biogas plants in Tuscany (ARPAT, 2015).

6. Results and discussion

This paragraph is based on the results from questionnaires and SNA. Subparagraphs depict the biogas sector and the associated AKIS, focusing on stakeholders' role within the network (brokerage), the types of knowledge that biogas adopters are interested in, the patterns of knowledge retrieval, as well as network's cohesion and potential for knowledge co-creation.

The software for SNA elaborations is UCINET® (Borgatti et al., 2002). Index values are standardized from 0 to 1. All network layouts are based on a spring embedding algorithm, which defines nodes relative position based on the average shortest path between node pairs and degree: the higher the degree the more central the node.

6.1. The biogas sector in Tuscany

Table 1 summarizes respondents' and farms' characteristics.

Table 1. Summary of respondent and farm characteristics. Source: Authors' own elaboration.

Plant			Farm pre-exists plant	Type of enterprise	Business model(*)	Respondent's education		Respondent's professional experience		UAA	Rented land	Energy cropping	Other land uses	Potential alternative innovation	ESPC	Self-supplied biomass	# hired workers after plant est.
ID	year	kWh				Level	Ac. major	Past	Current	ha	% UAA	% UAA				% total	
B1	2009	999	Yes	ESCo	ESCo	MSc	Engineering	Operations manager - RE plants	Operations manager - RE plants	400	0	63	Cop	[Just biogas]	BTS	51	0
B2	2009	999	Yes	ESCo	ESCo	MSc	Engineering	Operations manager - RE plants	Operations manager - RE plants	490	0	67	Cop	[Just biogas]	BTS	51	0
B3	2012	300	Yes	Farm	Multifunctional farm	High school	-	Bank	Farmer	120	0	92	Tree crops	Organic farming; land rental	BTS/CPL-Concordia	100	0
B4	2012	990	Yes	Farm	Entrepreneurial farm	MSc	Agriculture	Farming; building sector	Farming; building sector	1000	0	40	Cop; fodder crops, game forest	Organic farming; construction sector	-	85	1
B5		716	Yes	Farm	Entrepreneurial farm	MSc	Agriculture	Farming	Farming	2000	0	20	Cop; tree crops; forest	Photovoltaics	UTS	100	0
B6	2010	999	No	ESCo	ESCo	MSc	Engineering	Operations manager - RE plants	Operations manager - RE plants	260	100	100	-	Syngas (agroenergy)	ENVITEC	51	1
B7	2010	999	No	ESCo	ESCo	MSc	Engineering	Operations manager - RE plants	Operations manager - RE plants	300	100	100	-	Syngas (agroenergy)	ENVITEC	51	1
B8	2011		No	ESCo	ESCo	High school	-	Operations manager - RE plants	Operations manager - RE plants	220	23	100	-	Syngas (agroenergy)	BTS	51	1
B9	2011	999	No	ESCo	ESCo	High school	-	Operations manager - RE plants	Operations manager - RE plants	185	27	100	-	Syngas (agroenergy)	BTS	51	1
B10	2012	999	Yes	ESCo	ESCo	High school	-	Operations manager - RE plants	Operations manager - RE plants	250	0	100	-	Syngas (agroenergy)	AGB	51	0
B11	2011	249	Yes	Farm	Multifunctional farm	MSc	Agriculture	Farming	Farming	490	0	20	Cop; fodder crops; livestock; game forest	Photovoltaics	EISENMANN	85	0
B12	2006	999	Yes	Farm	Entrepreneurial farm	MSc	Agriculture	Farming	Farming	700	0	57	Cop; fodder crops	[Just biogas]	BTS	100	
B13	2012	999	No	ESCo	ESCo	MSc	Engineering	Operations manager - RE plants	Operations manager - RE plants	350	100	100	-	[Just biogas]	ENVITEC	51	1

(*) cf. Carrosio (2013); ESCo: energy service company; UAA: utilized agricultural area; Cop: cereal, oil, and protein crops; ESPC: energy system provider company; RE: renewable energy

Like elsewhere in Italy (cf. Chinese et al., 2014), farm biogas in Tuscany is economically dependent on the feed-in tariff scheme (cf. Torquati et al., 2014): just one plant was operating before the release of the scheme (2008). More recent changes to the Italian feed-in tariff scheme have reduced investment profitability (Torrijos, 2016), thus no plant was built after 2012 (ARPAT, 2015). Biogas adopters share similar features with the adopters of other expensive technological innovations in agriculture (cf. Cavallo et al., 2014). For example, farms are over 100 ha arable land and respondents are highly educated. All respondents hold secondary education and most of them has a Masters' degree. They considered abundant and diverse information before deciding upon biogas adoption for differentiating their firm's activities (cf. Carrosio, 2013). Other features are more biogas-specific and split respondents into two groups. Group one includes individuals that were farmers before adopting biogas and still own and manage the farm, beside and the plant (hereinafter biogas-farms). Group two includes ESCo employees (hereinafter "ESCOs"), with no farming background; they just deal with plant operations management; farming activities are delivered to hired labor.

Biogas-farms (B3, B4, B5, B11, B12) have integrated biogas within their existing family business and rearranged farmland to be almost self-sufficient in terms of biomass production: just two plants (B4, B11) need outsource 25% biomass. Before plant installation, biogas-farms were already diversified. All of them included ago-tourism; B3 cultivated olive trees and embedded an olive processing plant for oil production; B4 hold a wildlife and hunting reserve; B5 was a winery; B11 reared pigs; B12 was a joint enterprise made of four arable farms, each one cultivating both food/feed crops. Respondents of four out of five biogas-farms hold a MSc in agriculture. The respondent of the fifth biogas-farm (B3) has a background in banking. The average high-level education of interviewees is among the drivers of innovation adoption (Feder and Slade, 1984). Presumably, the high state incentives induced biogas-farms with available capital to take on the risk of installing the plant and thus improving the economic viability of their farm in the long-run. Additionally, biogas adoption allowed farm's upgrade to a more modern business model (cf. Carrosio, 2014). None of the five biogas-farms has entirely switched to agroenergy production. Presumably, the diversified farm businesses, which farmers were already running before the introduction of agroenergy, have an option value for them (Bartolini and Viaggi, 2013). The feed-in tariff grants a fixed energy price for 15 years. After that and in case biogas would not be profitable anymore, adopters would still have the option to dismiss the plant and maintain other activities. The generation of agroenergy within a diversified farm might led to a more sustainable production of energy from biogas (Lewandowski, 2015). Overall, biogas-farms' profile recalls the "innovative-owner", depicted by Cavallo et al. (2014). Despite sharing similar personal and entrepreneurial characteristics, the five biogas-farms implemented two different business models: multifunctional farms (B3, B11) and entrepreneurial farms (B4, B5, B12). The decision upon plant sizing accounts for the difference between the two models: multifunctional farms host smaller plants as they set plant rated power based on their actual potentials in terms of biomass supply; entrepreneurial farms adopted bigger plants and adjusted cropping patterns based on plant feeding requirements. ESCo is the major biogas business model in Tuscany (E1=B1+B2; E2=B6+B7; E3=B8+B9+B10; E4=B13), though with different operational patterns. For example, one ESCo (E1) have internalized two arable farms (B1, B2). The ESCo takes on the financial risk, leaving biomass production to the farm. In the remainder six cases, ESCos are also responsible for biomass production. Pantaleo and Colleagues (2014) acknowledge this vertically integrated organizational pattern among widespread ESCo business models: the company rents enough land for complying with the self-supply requirement and hire full-time workers (one per farm), who would carry out daily routine activities after specific training. A possible drawback of this model is that unfamiliarity with farming may prevent correct land management (Dauber et al., 2012). Despite this difference, the four ESCos are alike. The company counts on a working team with technical skills in the field of renewable energy generation (cf. Bolton and Hannon, 2016). Most respondents hold a MSc in energy engineering and have experience in plant operations management. ESCos installed the biggest possible plant 750-999 kWh rated power) and hold enough land to produce 51% biomass. The remainder 49% biomass is outsourced via supply contracts with neighboring farms and/or food processors– within 70 km from plant sire. The feed-in tariff is the only source of agricultural income on farm. After 15 years from plant establishment, ESCo's eligibility for the incentive scheme would expire. Both the plant and the farm would be likely dismissed in favor of other investments.

6.2. The AKIS: network and brokers

Table 2 lists the nodes resulting from social network questions with the associated codes.

Table 2. Coded survey outputs. Authors' own elaboration.

Code	Nodes	Description	Mode (role)
ESCos	B1, B2, B6, B7, B8, B9, B10, B13	Plants operated by ESCos (Energy Service Companies)	Plant adopter (respondent)
	E1, E2, E3, E4	ESCos: E1 operates B1 and B2; E2 operates B6 and B7, E3 operates B8, B9, B10; E4 operates B13	
Farms (Biogas-farms)	B3, B4, B5, B11, B12	Plants operated by farmers	Plant adopter (respondent)
Self-education	Web/Books; Fairs/Conferences	Information available through books, technical magazines, the web, participation to sectoral fairs, and scientific/technical conferences	
Upstream_industry	ESPC (Energy System Provider Companies): ESPC_bts, ESPC_uts, ESPC_envitec, ESPC_agb, ESPC_eisenmann, ESPC_cpl	Private enterprises that supply biogas plants, training and service contracts, and carry out R&D	AKIS's stakeholder
Agronimists	Freelance agronomists	Practitioners who provide advice and guidance for agronomic issues	AKIS's stakeholder
Farmer/Biogas_unions	CONFAGRICOLTURA (farmers'union); CIB (biogas producers' organisation)	Confagricoltura is a farmers' union; it provides advice to farmers about technological, economic, and social issues, and coordinates research and demonstration projects funded by the MIPAAF CIB is the union of biogas producer; it is the representative body of biogas producers; it groups producers and stakeholders from the biogas supply chain	AKIS's stakeholder
CRPA	Research Centre on Animal Productions (CRPA)	Quasi-private regional research and extension center focusing on the livestock and agroenergy sectors	AKIS's stakeholder
University	Faculty_AgriculturePisa; Faculty_EngineeringFlorence; Faculty:EngineeringNaples	University departments are public tertiary education and research center, owing to the University, which is financially dependent of the Ministry or University and Research; departments can directly access money from the European Research Fund, in case they participate to EU-funded research projects	AKIS's stakeholder
MIPAAF_Projects	MIPAAF_AgroenergyProject; MIPAAF_BiomassProject	Research and demonstration programs funded by the MIPAAF; project partners are farmers and stakeholders of the biogas supply chain; projects provided funding to investments in plants and created networks of stakeholders with different expertise to provide support and advice to biogas adopters	AKIS's stakeholder

Self-education is a way for acquiring information via books, technical magazines, participation to multi-professional events (fairs, conferences) and the web. Recently, self-accessible scientific and anecdotal literature have massively increased, particularly among entrepreneurs, who need build their knowledge base around investment opportunities (Bouhnik and Giat, 2015) also in rural areas (Reidolf, 2016).

Upstream industry involves plant dealers (Energy System Provider Companies or ESPCs), which also, provide, maintenance services, training, and visits to operating plants, as well as sponsoring conferences, participating to fairs, and being members of the Italian union of biogas producers (or CIB). Three ESPCs are German (ESPC_uts, ESPC_envitec, ESPC_eisenmann) and three Italian. ESPCs embed R&D about the core biological technology (fermenting bacteria). Electricity generators are based on German technology and distributed by and American group. ESPCs integrate all plant components into one facility and provide customers with a package of services, including one-year maintenance and start-up training. ESPCs keep in touch with their customers, and uses the plant for field visits. Plant visits allow some exchange of information, but not of know-how, across potential adopters. The acquisition of know-how occurs after biogas adoption.

Agronomists are private consultants that got skilled in energy cropping. Despite the availability of tertiary agricultural education, agronomists needed gather specific knowledge, mainly via the web and specific courses on energy cropping. Interviewed experts reported to have contacted more experienced colleagues in northern Italy. Land management in arable cropping for biomass production resemble that of any other arable cropping. The issue is sowing proper breeds. Most energy crops' breeds were originally selected for cultivation in northern Italy and are not suitable for pedo-climatic features of Tuscany. Agronomist worked together with farmers for identifying proper crop breeds and crop rotations. Biogas-farms are run by agriculture graduates, who selected crop breeds themselves. Then, agronomists have reciprocal relations with ESCos and biogas-farms carry out some functions that pertain to agronomists (boundary-spanning relations).

Farmer/Biogas unions are the largest farmers' union (CONFAGRICOLTURA) and the only biogas producers' union (CIB) in Italy. CONFAGRICOLTURA participates in various multidisciplinary research and extension programs, funded by the Ministry of Agriculture (MIPAAF). Those projects generally include market (e.g., industry) and non-market (e.g., university) partners. Farmers' association organizes training workshops, courses, and events, that are popular across farmers. CIB is a representative body made of biogas-host farms, ESPCs, CRPA, and other institutions. Adopters were willing to join the Union, which, however, could not offer significant service. The relationship between farmer/biogas unions and adopters do not seem to be reciprocal.

CRPA (Italian acronym of Research Centre on Animal Production), is a quasi-public regional research and extension center. CRPA is not located in Tuscany, but in a the most livestock-intensive region of Italy, i.e. Emilia Romagna, which shares a boarder with Tuscany. Emilia Romagna was the first Italian region to host farm biogas in the 1970s. CRPA has been the leading Italian institution involved in the production of energy on farm, since its establishment in early 1970s. It carries out research and monitoring activities, and is a key institution for knowledge and technology transfer and for communication with international research institutes. In recent years, CRPA has implemented a service desk providing technical advice to small and medium enterprises interested in biogas-to-energy chains. CRPA provides public goods to the agricultural sector in the form of information services, which range from support to investment decisions to best management practices. Geographical proximity between Tuscany and Emilia Romagna had facilitated the use of CRPA's services by farmers in Tuscany. CRPA benefits from the collaboration with farmers, via data acquisition. CRPA-farmers relationships helped the adaptation of plant solutions available on the market to the characteristics of the local agricultural sector, thereby encouraging biogas adoption.

University includes the faculties of agriculture and engineering located in and outside Tuscany. The faculty of agriculture is interested in cropping, while that of engineering deals with facilities. University depends on the Ministry of Research and University (MIUR). Research funds can originate from within MIUR itself, from MIPAAF, and from the EU (European Agricultural Fund for Rural Development or EAFRD). Contact with faculty members depend on the network of acquaintances that famers have built while studying. University can deliver advice on crop or plant management/operation in exchange for data, thereby allowing reciprocity.

MIPAAF projects are multi-year, multi-disciplinary, and cross-sector research and demonstration programs, funded by MIPAAF. The interviews pinpointed the names of two such projects, i.e. the Agroenergy project and the Biomass project. Interviewees who participated in either project gave it great importance. Projects included funds, exchange of know-how and information across partners, organization of open dissemination events, publication and distribution of program results, training sessions, and project meetings. Then, MIPAAF projects have reciprocal relations with partnering adopters.

Figure 1 shows the network of biogas' AKIS in Tuscany.

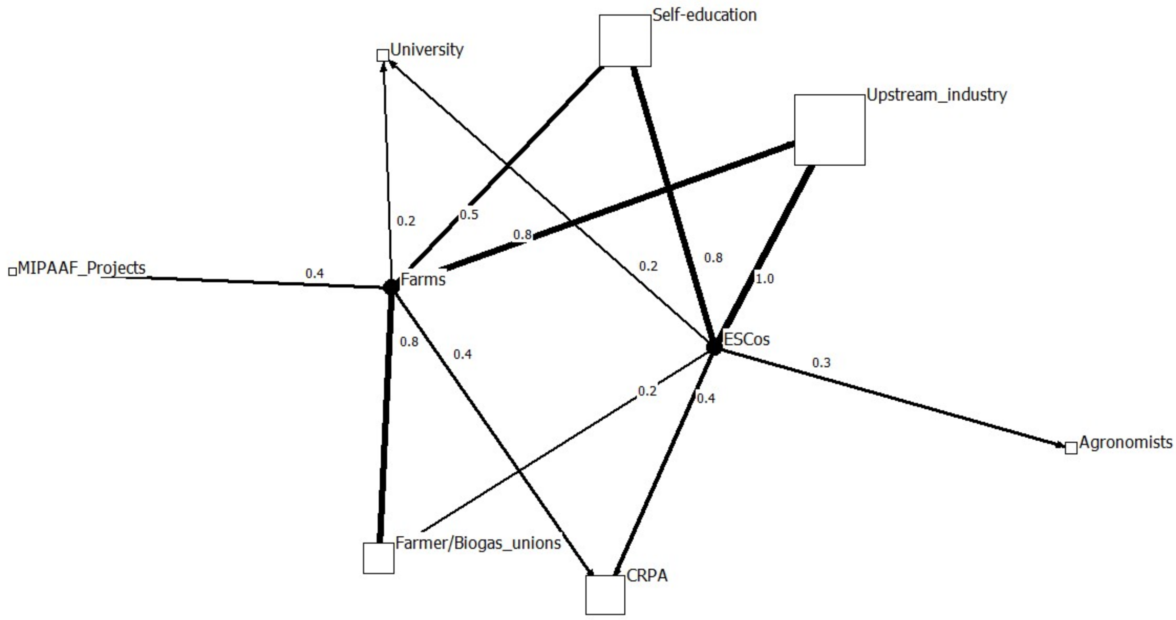

Figure 1. Two-mode aggregated graph of adopters (black circles) by AKIS' stakeholders (white squares) matrix. Source: Authors' own elaboration.
Node size is proportional to the betweenness centrality of AKIS' stakeholders. Width (and weight) of edges represents the share of Farmers or ESCos that retrieve knowledge from the stakeholder to which they are connected.

Two nodes are peripheral (MIPAAF projects and agronomists), while five are equally connected with plant adopters (university, CRPA, farmer/biogas unions, self-education, and upstream industry), though with different tie strength, i.e. proportion of adopters who span that tie. Then, betweenness centralities (gatekeeping positions) are heterogenous. MIPAAF projects and agronomists are marginal because they are accessed by just one of the two adopters' groups. This finding does not reduce the importance of MIPAAF projects for biogas-farms or that of agronomists for ESCos. Instead, this points out that stakeholders' ability to negotiate vary depending on the types of adopters they are dealing with (Moore, 2011). Upstream industry turns to be the most influential node (cf. Arora, 2012) and the one that can help knowledge diffusion across adopters, regardless of their background. The evaluation of boundary-spanning relations strengthens this finding. CRPA and university also showed reciprocal relationships with adopters. However, the number of adopters from both groups involved in those relations is lower compared to those with upstream industry. Self-education is important (cf. Reidolf, 2016) and can broker different adopters' groups, despite still missing reciprocity. Willing-to-innovate farmers have benefited from self-sourced information (e.g. Cavallo, 2014). When it comes to irreversible and burdensome investments, such as biogas plants, prospected adopters still prefer double checking their understanding by asking physical people within the AKIS. This behavior is for mitigating uncertainty (Berkhout, 2006; Meijer et al., 2007; Läpple et al., 2016), particularly when policy is likely to change (Bartolini et al., 2015).

6.3. The networks of retrieval of information and know-how

Figure 2 displays the networks through which biogas adopters in Tuscany retrieve information (Figure 2A) and know-how (Figure 2B).

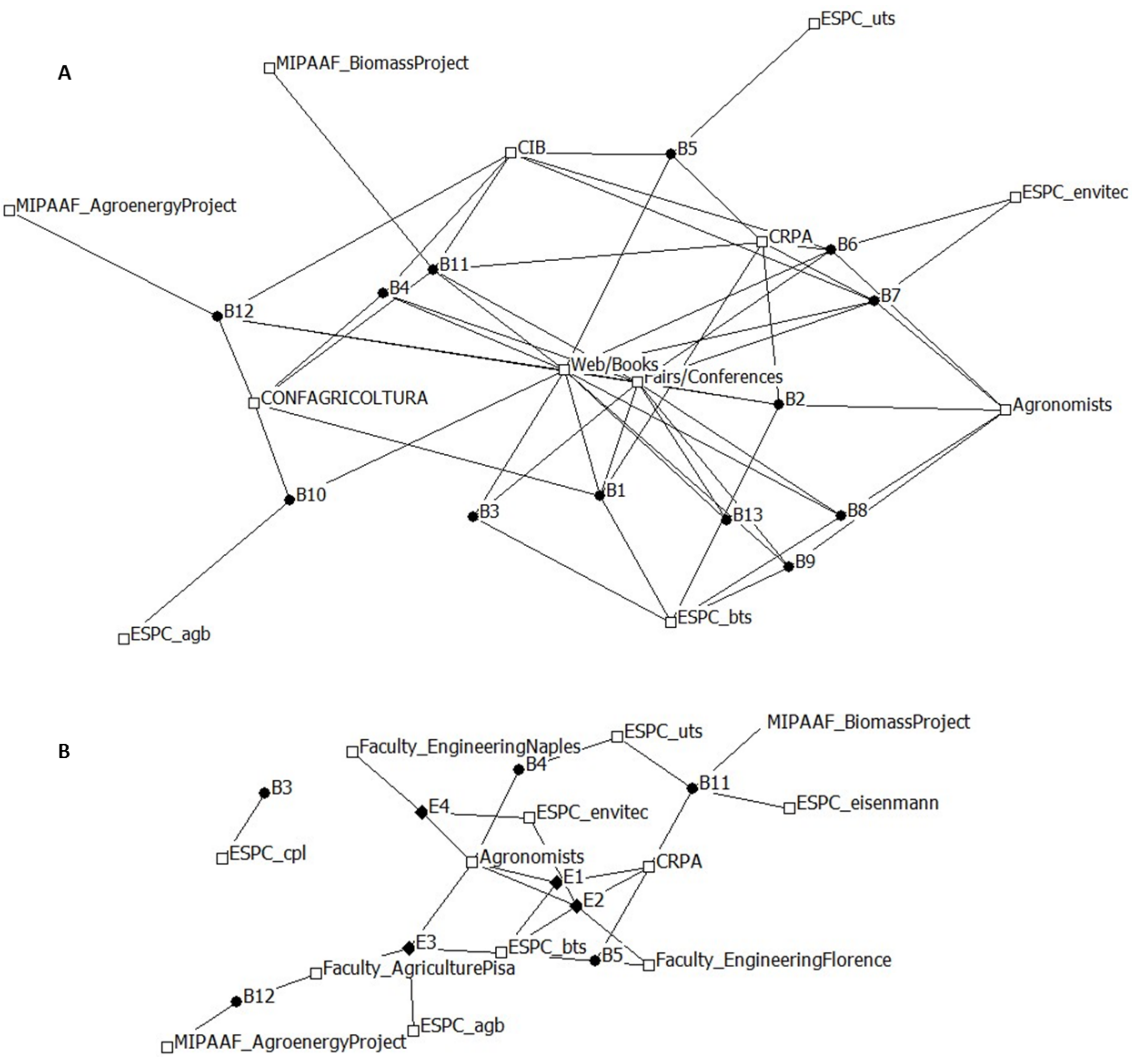

Figure 2. Two-mode information (**A**) and know-how (**B**) networks. Source: Authors' own elaboration.
Black nodes are plant (circles: farmers; diamonds: ESCos); white squares are AKIS' stakeholders.

Adopters' patterns of knowledge acquisition depend on knowledge type (cf. Isaac, 2012). Both networks have core/periphery structures, but the information network is overly more complex compared to the know-how network. This might due to information being retrieved before deciding on plant adoption and know-how after. After adoption, knowledge retrieval may be more targeted towards familiar sources, while before individuals need access more varied sources (cf. Isaac, 2012). The information network is mainly centralized on two nodes (web/books and fairs/conferences); CRPA is another centralizing node. Adopters from both groups are equally affiliated to web/books and almost equally to fairs/conferences. CRPA, instead, attracts famers that will decide to associate to an ESCo more than those who will run the plant independently. We may suppose that those farmers were already keen on establishing a partnership with an ESCo and try to understand whether CRPA could help them in their decision. The know-how network aggregates the plants that turned to be associated with ESCos. The same ESCo usually run more than one plant in Tuscany and, generally, has other associated plant outside of Tuscany. Figure 2B shows that biogas-farms are more relaxed than ESCos in terms of knowledge seeking intensity, when it comes to problem solving during plant management. This may be due to higher familiarity with farming, to higher propensity to learning by doing, and to higher self-sufficiency attitude. The most accessed sources of know-how are agronomists and CRPA. With this respect, CRPA is central in both information and know-how networks, which makes it a broker under the boundary-spanning perspective.

6.4. Network's cohesion and potential for knowledge co-creation

Figure 3 and Table 3 presents the knowledge network and related metrics, respectively.

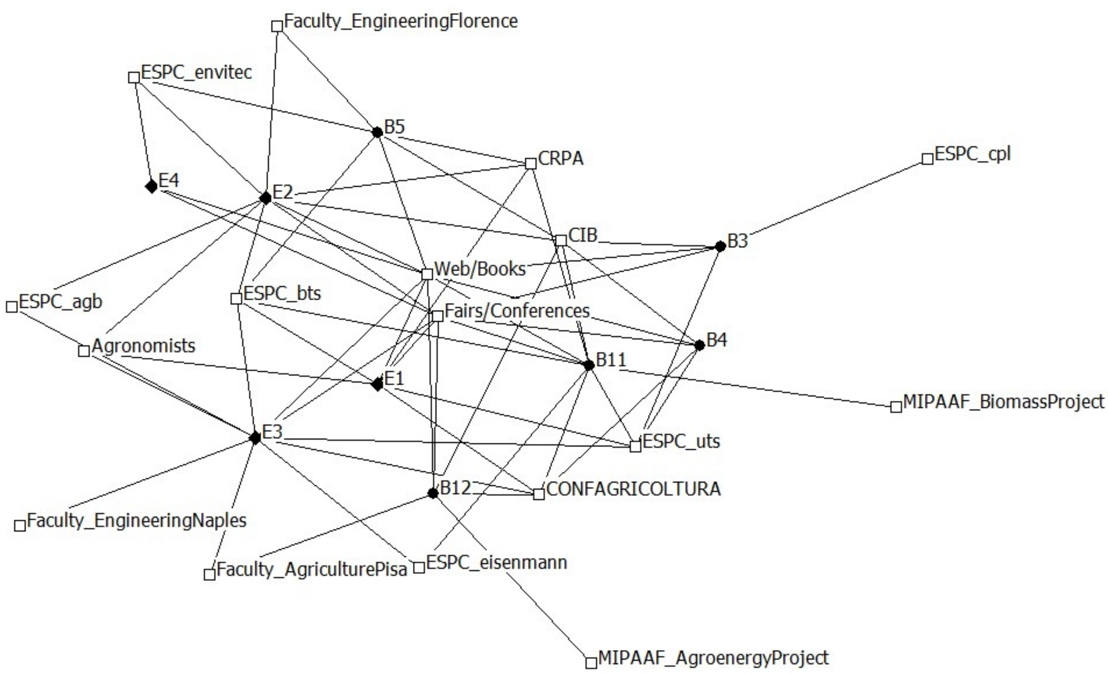

Figure 3. Two-mode graph of adopters (black circles: farmers; black diamonds: ESCos) by AKIS' stakeholders (white squares) matrix. Graph layout is based on a spring embedding algorithm, where more central nodes are those with the highest degree. Source: Authors' own elaboration.

Table 3. Degree centrality of AKIS' stakeholders; average network density and core/periphery density; core/periphery nodes. Source: Authors' own elaboration.

	Degree centrality	Density		Nodes
Web/Books	1.00	Average	0.39	
Fairs/Conferences	0.89	Core	2.31	E1, E2, E3, B11, web/books, fairs/conferences, CRPA, ESPC_bts
CRPA	0.44	Periphery 1	0.57	E1, E2, E3, B11, faculty of agriculture Pisa, faculty of engineering Florence, faculty of engineering Naples, agronomists, CIB, CONFAGRICOLTURA ESPC_uts, ESPC_envitec, ESPC_agb, ESPC_eisenmann, ESPC_cpl, MIPAAF AgroenergyProject, MIPAAF Biomass Project
Faculty_AgriculturePisa	0.22	Periphery 2	0.58	B3, B4, B5, B12, E4, web/books, fairs/conferences, CRPA, ESPC_bts
Faculty_EngineeringFlorence	0.22	Periphery 3	0.25	B3, B4, B5, B12, E4, faculty of agriculture Pisa, faculty of engineering Florence, faculty of engineering Naples, agronomists, CIB, CONFAGRICOLTURA ESPC_uts, ESPC_envitec, ESPC_agb, ESPC_eisenmann, ESPC_cpl, MIPAAF AgroenergyProject, MIPAAF Biomass Project
Faculty_EngineeringNaples	0.11			
ESPC_bts	0.56			
ESPC_uts	0.56			
ESPC_envitec	0.33			
ESPC_agb	0.22			
ESPC_eisenmann	0.22			
ESPC_cpl	0.11			
Agronomists	0.33			
CONFAGRICOLTURA	0.56			
CIB	0.67			
MIPAAF_AgroenergyProject	0.11			
MIPAAF_BiomassProject	0.11			

The network has a medium level density (0.4) and a core/periphery structure, with a small and denser group (core; density: 2.3) and three big and more disperse groups (periphery1, 2, 3; all densities below 0.6). Web/books, fairs/conferences, CRPA, and an ESPCs are within the core, together with three out of four ESCos and one biogas-farm (B11). Willing-to-innovate farmers have benefited from self-sourced information (e.g. Cavallo, 2014). When it comes to irreversible and burdensome investments, such as biogas plants, prospected adopters still prefer doublecheck their understanding by asking physical people within the AKIS. This behavior is for mitigating uncertainty (Berkhout, 2006; Meijer et al., 2007; Läpple et al., 2016), particularly when policy is likely to change (Bartolini et al., 2015).

The measure of degree centrality confirms the importance (Burt, 1982) of web/books and fairs/conferences in influencing adopters' decision to install the plant; that measure also highlights that farmers' and biogas unions may co-create knowledge with adopters (cf. Hermans et al., 2013). Other Authors have highlighted the growing importance of self-accessible knowledge and communication tools – particularly, the web – in rural enterprises (cf. Reidolf, 2016; Läpple et al., 2016) Two nodes from upstream industry also show relatively high degree centrality. Those two nodes are the most popular and widespread ESPCs in Italy.

MIPAAF projects turned to be peripheral, despite their importance for knowledge sharing and innovation brokerage (cf. Hermans et al., 2013).

7. Conclusions

The study of the rearrangement of Agricultural Knowledge and Innovation Systems (AKIS) towards the bioeconomy is in EU's agenda and is an open field of research. The paper uses social network analysis (SNA) for tracing the downstream flow of knowledge from AKIS' stakeholders to biogas operators, with the purpose of evaluating stakeholders' importance in driving biogas adoption and diffusion across arable farming systems. The research anchors on biogas, as for agroenergy technology, and on a case study area in Mediterranean Europe, i.e. Tuscany, Italy. That area was selected because it features arable farming systems, and agroenergy adoption is strictly dependent on public support. Data originate from semi-structured interviews with experts and network questionnaire to biogas adopters in Tuscany (2015). Research findings from Tuscany might be useful for tailoring policy and interventions to improve AKIS' ability to drive agroenergy innovation on farm in other Mediterranean areas.

The study identifies two types of adopters and three business models in the biogas sector of Tuscany. Adopters are people with farming background and energy service companies (ESCos). The three business models are multifunctional farms, entrepreneurial farms, and ESCos (most farms). The outputs of social network analysis suggest that self-education tools, farmer/biogas unions, upstream industry, and the Research Centre on Animal Productions (CRPA) are key AKIS' elements, by improving network cohesion, allowing knowledge co-creation between adopters and AKIS' stakeholders, and by brokering knowledge sources towards (potential) adopters. Both farmers and ESCos are informed, "updated", and cost-effective knowledge seekers, and diversify their knowledge sources. The networks are centralized on self-education tools, with two brokers, i.e. the upstream industry and the CRPA.

The research presented in this paper may facilitate decision-makers' choice of their preferred knowledge sources in the early stages of the adoption-decision process, this may help timely decisions, being the acquisition of relevant knowledge a time-consuming activity. AKIS stakeholders in the biogas sector and, more generally, decision makers in the bioeconomy should consider the increasing independence of biogas adopters as knowledge-seekers. For example, boosting online services for planning investments may reduce uncertainty and thus adoption delays, as well as proving guidance towards the more suitable innovation to be introduced on farm. Online services may be more effective for gathering the needed information for deciding upon the investment: e.g., funding opportunities, return on investment, land requirements, existing regulations, selection of suitable crop breeds, among the others. Targeted services may also facilitate the participation of plant operators to public-funded projects, which proved to be useful for improving biogas viability. Online services are not as targeted as those provided by physical actors, but offer prospected investors an overview of their potential choices. Most farmers who are keen on investing in the bioeconomy hold Master's degree and can solve some of the issues associated with cultivation or daily plant management. Still, innovation adopters need guidance by physical stakeholders, especially in adoption-confirmation and after plant adoption, being key for problem solving during daily plant operations. Technical problems in plant management are frequent and need to be fixed properly and quickly for guaranteeing continuous energy production. CRPA is among adopters' preferred knowledge sources; it also uses real world data originating from farmers with whom it is in contact for carrying or research and adapt plant solutions available from plant dealers to the local characteristics of the agricultural sector. AKIS' stakeholders, particularly in the upstream industry, hold that know-how. Further improvements in the regulation about state support to farmers in the bioeconomy should facilitate access to services of technical support and updated training. Upstream industry has also supported later decision-making, by delivering maintenance services and training, organizing visits to operating plants, sponsoring conferences, and participating to fairs. Agroenergy adoption implies 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 take on the that risk. The integration of agroenergy production on existing farms may improve the long-run sustainability of biogas installations.

A follow-up questionnaire involving non-adopters might help identifying differences and overlaps between the two AKIS. Those farmers should be managing similar farms, which approximates for having the same likelihood of adopting the technology based on profit maximization. Besides, having network data over more time periods would help evaluate the way how the raise of the biogas sector affected the AKIS. Indeed, the implementation of participatory methods may improve network building and SNA outputs. For example, the current results of SNA might be discussed and improved after a workshop with a sample of biogas adopters, a sample of non-adopters, and AKIS' stakeholders.

The most critical steps in analyses such the one presented here are identifying the study population and designing the questionnaire. Particularly, in two-mode networks (i.e. when relationships exist between individuals owing to different sets, but do not exist within each set), it is crucial to define the horizontal boundary of the population, viz. the set of individuals to which individuals from the other set would report to have ties. Maybe, the major drawback of this study is the provision of a static picture an emerging sector. Indeed, further work on the same study area would improve the overall output of the research. Further work may focus on the strengths and weaknesses of agroenergy's AKIS in arable systems and evaluate the costs and benefits of the public support system. The multilevel perspective of socio-technical transitions may allow highlight the current potential and the existing barriers for agroenergy to get mainstream. Additionally, a natural experiment, based on data from both adopters and non-adopters, would provide a more dynamic view of the biogas sector.

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