Assessing the role of the research in the transition to organic farming by using the Actor Network Theory: lessons from two case studies in France and Bulgaria

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Abstract: *This paper explores the potential of Actor Network Theory (ANT) in understanding how the process of interaction and translation between human and non-human actors contribute to the development, adoption and diffusion of science-based innovations linked to the transition to organic farming. The study relies on two case studies, the French Camargue case covering a range of technical and social innovations, and the case from Bulgaria focusing on the development of a technical and product innovation, i.e. a veterinary product for organic beekeeping. The paper shows the limitations of classical approaches in studying innovations since they underestimate the role of heterogeneous actors, their status, and how they interact with each other. We argue that focusing on actors' interactions helps to better understand the so-called "uncertainties" and "turning points" in the innovation development, as well as to interpret them as natural elements. Moreover we argue that challenges to tackle should be problematized to increase the success of research programs. We also stress the importance of opinion leaders during the implementation and diffusion phase of the innovation.*

Keywords: *Actor-Network-Theory, evaluation, science-based research, innovation process*

1. Introduction

During the last two decades, evaluation issues have gained importance through the development of public impact evaluation studies, in the context of both repeated financial and economic crisis, as well as of the diminishing role of the states, the demand of transparency, and the accountability expressed by citizens. Moreover, the importance of evaluation also increased because of the so-called "European paradox", i.e. the perceived failure of European countries to translate scientific advances into marketable innovations (European Commission, 1995). Recent studies shows that this "paradox" is not yet mitigated (Radicic et al. 2016). The European Commission (EC) and international organizations have led this movement and required provision of evidences for the effects of research and development programs. Two main objectives of evaluating impacts[1] of research are to measure the efficiency of interventions for accounting (CGIAR, 2000) and to bring out improvements in research policies and programs (Mackay and Horton, 2003). Additionally, the growing public awareness on main challenges for a sustainable planet calls for more accountability of firms and research organizations, in particular in the agricultural sector that accounts for biodiversity erosion, health problems, pollution, and for 24% of the GHG emissions worldwide (IPCC, 2014). The concern of actors for sustainability questions the role of research in supporting innovations towards a more sustainable world (Fischer, 2000).
In the case of the conversion to organic farming, Lamine et al. (2009) underlined the importance of extension services, collective actions and learning processes to impulse practices changes and transition trends among farmers. Social and technical innovations towards sustainable farming are complex and figure out a "black box" where research and

[1] The OECD (2002) defines impacts as the effects produced by outcomes in a long-term perspective, and that can be either intended or unintended.

innovation are supporting processes of change at individual, collective and institutional levels.
Several approaches have been developed in the literature to ex-post evaluate impacts of research programs, but these methods usually fail at highlighting the “black box”, i.e. the complex process occurring between research investments on the one hand and adoption and impacts of the innovation on the other (Quiedeville et al. 2017; Penfield et al. 2013). They are often of quantitative nature, including econometric models, non-monetary approaches, as well as multi-criteria and cost-benefit analyses. Those approaches focus on final results, trying to establish a link between funding on the one hand and social and economic changes on the other; but they fail at explaining the process of transformation. Qualitative approaches seem more suitable for the purpose of understanding the pathway to impacts. They are more operating in reflecting the complex learning interactions as well as the composite and causal underlying mechanisms (Hall et al. 2003, Colinet et al. 2014). These methods include for example the SIAMPI approach, and the Participatory Impact Pathway Analysis (PIPA).
More recently, three specific qualitative methods, which apply for agricultural research impacts, have been developed. These are the ASIRPA (Gaunand et al. 2015; Joly et al. 2015), IMPRESS (Temple et al. 2016) and IMPRESA[2] approaches (Stigler et al. 2014; Schmid et al. 2016; Quiedeville et al. 2017). The above methodologies have in common to seek to identify the pathway of the research although they differ in their terms, e.g. in re-constructing the pathway, and in analyzing precise actors’ contribution and the role of other factors. These recent approaches unsatisfactorily investigate the specific contribution of the research actors during innovation process.
In this paper, we ex-post evaluate the impacts and contribution of the research in two case studies, which have been performed in the EU-funded IMPRESA project. Our objective is to highlight and discuss the role of knowledge and learning processes through the Actor-Network-Theory (ANT).
The paper is structured as follows. Firstly, we highlight the evolution from a linear to a more interaction-based approach of innovation as well as the main features of ANT relevant to the evaluation. A subsequent part focuses on methods and data. Results are then presented, followed by a discussion on the main findings and by conclusion elements.

2. Interaction-based approach of innovation and interest of ANT

The understanding of the innovation concept and evaluation approaches has changed over time, from a linear view to a more complex notion. The linear model of the Technology push was developed in the 50s and remained the mainstream approach during the 20th century (Badillo, 2013). In the 60s, Jacob Schmookler (1966) considered that innovation is rather triggered by the demand (Demand pull model). At the same time, the theory of diffusion of innovation by Rogers (1995) stressed that the process of adoption is a linear sequence where innovation is first adopted by so-called innovators, accepting to take risks, followed by the early adopters, early majority, late majority, and the laggards.
These approaches were criticized for their linearity. Kline and Rosenberg (1986) underscored that innovation development and new scientific knowledge are linked in a too simple and direct way. They have proposed, as one potential alternative, the so-called *Chain-linked model* which considers innovations as dynamic processes (other alternatives are, e.g. the different helix models). This model is composed of successive sequences being interactive to each other. However, the chain-linked model faces the same limitations as the approaches described above since it underestimates the role and status of actors and how they interact within the innovation process. In this paper, we attempt to overcome these limitations while analyzing innovation processes.
The Actor Network Theory (ANT) was developed in the 80s in the field of sociology of sciences and technologies by a group of Parisians sociologists: Michel Callon, Bruno Latour,

[2] Impact of the research on EU agriculture, http://www.impresa-project.eu

Madeleine Akrich and other researchers at the Mines ParisTech Center for Sociology of Innovation. Its main Anglo-Saxon theoretician is John Law, but also Arie Rip, Susan Leigh Star, Geoffrey Bowker. The key authors of ANT share the view that innovation is a novel combination of knowledge and a non-linear and interactive process in which the actors are transformed during translations (Latour, 2005). Moreover, ANT is based on the principle of "symmetry", giving to human and non-human actors equal analytical priority (Akrich et al, 2006). ANT is largely explored for studying innovations because of the attention it pays to unpredictable ends and on the development process, through focusing on the creation of heterogeneous actors' associations. In effect, a given social situation can only be explained by and through following players acting in association (Callon, 1984; Law, 2009).
The translation process is the core concept of ANT. It starts by the emergence and formation of an idea before it is transformed into useful knowledge through actors' relationships building (Latour, 1988). However, the interest of actors in being involved in the network should be aligned to increase chances of success of the translation process (Chen and Hung, 2016). As the notion of translation states, "actors are not brought into association with each other unchanged, [rather], they are displaced, redefined, and transformed, often in ways that are not readily apparent" (Lockie, 2007). There are four phases of translation: Problematization, Interessement, Enrolment, and Mobilization (Akrich et al. 2006). The first phase (Problematization) consists in identifying and formulating a problem and is led by a focal actor that seeks to become an "obligatory passage points" (OPP) along the process (Callon, 1986). In other words, the different actors will have to pass through this focal actor to take part of the network. The focal actor then imposes or stabilizes the identity of the other involved actors (Goulet, 2008), which is the second phase of the translation, i.e. the Interessement. The new entrants accomplish during the Enrolment phase the activities that were scheduled in the Problematization and previously agreed. Translating the interests of a sufficient number of enrolled actors will lead them to support and preserve the network (Walsham and Sahay, 1999). Finally, the Mobilization consists in ensuring that all actors are represented by spokespersons in the network (Callon, 1986).

ANT gained popularity in the area of innovation research (Hoholm and Araujo, 2011; Du Preez, 2012) and has been broadly utilized so far to assess transitions towards better sustainable food systems (e.g. Lockie and Kitto, 2000; Trauger, 2009).
ANT investigates the way networks of actors and social effects come into being and develop, the process of actors' enrollment, how the mechanisms of persuasion and influence act over these networks (Mouritsen et al. 2001), as well as how technology favors the organization of the actions undertaken (Chen and Hung, 2016). Economic agents' interactions stabilize the knowledge network by the means of "boundary objects", e.g. codes of practice (Šūmane, 2010). This process of stabilization, also known as process of translation, is not simple given the different actors' interests that need to align (Arnaboldi and Spiller, 2011).
Under ANT "neither human actions nor technologies are assumed to exert direct causal impacts" (Markus and Robey, 1988; Rhodes, 2009). Rather, impacts are resulting from different factors that, combined together, are contributing to the creation, development and transformation of knowledge (Markus and Robey, 1988). This perspective in terms of contribution analysis can avoid omitting non-obvious variables at first sight, which could also explain the innovation process development.
Furthermore, the principle of symmetry highlights how social arrangements are being constructed. It helps identify factors of network building, which are not necessarily obvious at first sight (Star, 1990). It also contributes in giving a realistic view of how the social come to be by integrating all its effects and uncertainties (Latour, 2000). Also, the generalized symmetry allows dichotomies like humans vs. non-humans or social vs. technical to be avoided (Cressman, 2009). The translation process is not pre-determined by a theoretical pathway, and by principles or beliefs. Instead, ANT focuses on data gathered from observable events or various documents, which appear as a result of the complex actors' interactions and negotiations in the network. The innovation is studied through understanding

actors' relations. ANT also allows to comprehend technological innovation processes, emphasizing how networks are created and how they remain or collapse (Latour, 1988).
However, describing the reasons of why things happen is a challenging task. ANT can contribute in helping explanations and provide elements to facilitate interpretations but usually fails at providing evidences that can be empirically verified (McLean and Hassard, 2004). Another critic often addressed to ANT is the heuristic stance made between humans and non-humans, which are treated on an equal footing (Murdoch, 2001). This was criticized by Hacking (1999), affirming it cannot be assumed that objects have the same characteristics as humans, e.g. in terms of communication. Law (1992) answered that being treated to the same level of importance is not identical as being equal by essence.

3. Methods and Data

Two case studies, which were part of the IMPRESA project, are investigated by applying the ANT approach. The first is the transition to organic rice farming systems in the French Camargue, covering a broad range of technical and managerial innovations. The second one represents the development of a technical innovation, the anti-varroa product Ecostop, developed in Bulgaria for both organic and conventional beekeeping. The use of case studies to draw lessons is increasingly popular in the literature and allows investigating particular situations in-depth (Eisenhardt and Graebner, 2007).
These cases are selected in first instance for their focus on agro-ecological systems, with one case tackling a set of technical innovations and the other one only a new product. In addition, these cases concern radical innovations for the transition to organic farming, which a priori necessitate strong supports from the complex network and research system (EU SCAR, 2012). This particularity increases the interest of studying how the network, composed of diverse actors and composite interrelationships, impacts the development, adoption and diffusion of science-based innovations linked to the transition to organic farming.
These cases are also selected given their diversity in terms of networks configuration, local contexts, and research systems. The Camargue is a rather "conflicting territory" where several relational problems did occur among farmers over the last decades, especially in terms of cooperation building (Bassenne et al. 2014; Quiédeville et al. 2016). The Bulgarian case seems to be faced with fewer challenges in terms of cooperation building and conflicts at first glance, but the analysis will try to confirm this and explores related consequences on innovations development and impacts achievement. Still, the research system in the Camargue case is mostly composed of public institutions while the research efforts in the Bulgarian case are of private nature with the involvement in particular of two independent veterinarians. This diversity will allow studying the interest of ANT for different situations associated to the transition to organic farming in Europe, and will therefore facilitate drawing more comprehensive and general conclusions.

In both of the case studies, we mobilized qualitative data from explorative in-depth and semi-structured interviews with various actors, as well as qualitative and quantitative data from focus groups and stakeholders' workshops conducted in the frame of the IMPRESA project. The data were also gathered from the observations made in different situations (workshops, factories, and other organizations), as well as from the literature and different surveys completed. Data were collected at different stages in 2014 and 2015 during crucial periods for the application of innovations (e.g. spring application of Ecostop into hives) and in periods with fewer agricultural activities.
Data on same research aspects were collected in many different manners (qualitative – quantitative) among diverse and contradictory interviewees, in order to triangle them, and test their veracity. Some of conclusions and the key statements were discussed with representatives of all stakeholders during workshops at diverse stages of the research process (beginning and end) to inform them, build trust, and get their feedback. This approach contributes to insure the integrity both of the primary data and their interpretation.

Table 1: Data collection process in the Camargue and Bulgarian case

	Camargue case (FR)		Ecostop case (BG)	
Methods	Number of interviews / Attendance	Actors / Documents & surveys	Number of interviews or surveys / Attendance	Actors / Documents & surveys
Explorative in-depth interviews	21	Organic rice traders: Madar, SARL Thomas, BIOSUD and Biocamargue Research institutes: INRA[3] and CFR[4] Farmers	4	Researchers First organic beekeepers in the country
Qualitative semi-structured interviews	14	Partially-organic and organic farmers 1 key researcher from INRA (interviewed 2 times)	10	Beekeepers Researchers Owners of veterinarian pharmacies
Workshops	2 workshops (respectively 11 and 20 attendants)	Conventional and organic farmers Researchers from INRA and the CFR Respondents from the private traders SARL Thomas and Biocamargue	2 workshops (10 attendants in each)	Researchers Beekeepers Representatives of organic beekeeping association
Survey among users			116	Beekeepers who visited the most important exhibitions for beekeeping in the country and who attended the lectures on bee health
Secondary data and literature		Publicly available documents (Mouret et al. 2004, 2005, 2009, 2012; Bayot et al. 2009; Delmotte et al. 2011, 2013; Barbier et al. 2013)	1200	Regional representative survey among beekeepers (North-western region of Bulgaria)

4. Results

4.1. The Camargue case (France)

The Camargue is a small territory located in the South-East of France. Rice is the main crop production being farmed in the Camargue, which leads to specific environmental issues. In effect, rice systems are rather of intensive nature, and the flooding of paddy fields contributes to increasing the level of pollution of the Rhône stream. That is because the fresh water introduced in paddy fields accumulates chemical molecules before it is drained off into the Rhône stream during the season. However, rice helps to reduce the rate of salt in soils (capillarity effect with the fresh water introduced) and therefore facilitates cultivation of crop productions in the territory. Organic farming has developed in the 1980s through the initiative of pioneer producers. The territory counted 35 organic farmers out of 215 (16%) in 2014, where 10% of the total rice area was produced organically. The organic rice traders are the company SARL Thomas, the firm BIOSUD, the company Madar, and Biocamargue. BIOSUD was created in 2003 by the SARL Thomas and the cooperative SudCéréales (minor organic rice trader) with a view to organizing the organic value chain around a unique and specialized trader. In 2000, INRA (French National Institute of Agronomic Research) together with partners, i.e. the CIRAD (International Agricultural Center for Development), FranceAgriMer, and the CFR (French Rice Center), initiated a research program to develop

[3] French National Institute of Agronomic Research.
[4] French Center of Rice.

organic agriculture in the Camargue, composed of several research activities (Mouret et al. 2005, 2009, 2012; Bayot et al. 2009, Barbier et al. 2013).

Table 2: Projects constituting the research program for organic farming systems in Camargue

Years	Projects	Objectives of the different projects
2000-2004	CEBIOCA project (Organic Cereals in the Camargue)	Making an agronomic diagnosis
2005-2006	Experimentation in farming plots	Developing techniques against weeds and improving practices of fertilization
2008	"ORPESA Table" (Organic Rice Production in Environmentally Sensitive Areas) This project was conducted by INRA	Trainings sessions among research and farmers
2011	Experimentation of crop management techniques (new testing conducted by INRA and its partners)	Developing techniques to combat weeds
2011	International conference on rice (held in Montpellier)	Easing international relationships
2012-	Experimentation by CIRAD	Focusing on the interest of harrows, hoes and rotavators to control weeds

Initial problematization and Interessement

Before the research program on the transition to organic farming in the Camargue was launched, different local researchers, especially from INRA, recognized the severe environmental problems the Camargue territory was being faced. But the significance of the environmental damages caused by rice farming was undervalued. Negative effects on the natural resources (soil, water, biodiversity) have been however increasingly documented by the scientific community. This situation has led a key scientist from INRA to reroute his research from conventional to organic rice farming systems. In fact, the idea of developing organic farming in the Camargue was first raised by the Internal Committee for Organic Farming (CIAB) of INRA. This committee, which was created in 2000, and composed of representatives from all INRA research departments as well as from external persons, initiated a first call for tenders in the year 2000, with a view to creating knowledge on organic farming issues. The key INRA's researcher submitted a proposal, the CEBIOCA project, which was accepted and founded. This project intended to make an agronomic diagnosis on the current situation, as well as identifying the opportunities and challenges with respect to the transition to organic rice production in the Camargue. This interdisciplinary project benefited from previous knowledge developed on organic rice farming systems in the Camargue. Indeed, the key INRA's researcher already explored this topic in the year 1998 with the implementation of eight test plots dedicated to organic rice. This underlines the importance of publishing the "new knowledge", even limited and emergent, in leaflets, scientific articles, and various other documents.

First Enrollment and Mobilization of allies

As a result of the stages of Problematization and Interessement, INRA's partners and farmers have been increasingly tackling challenges in relation to organic farming transition. This movement has sustained in the Enrollment and Mobilization stages. To make the CEBIOCA project successful, the key INRA's agronomist did spend extensive time to convince his hierarchy about the rationale of switching to organic rice in this particular region, but also researchers from other institutions by the help of physical meetings. The main obstacle was the general skepticism about the role of organic farming as a solution for the future of agriculture. Through many efforts for developing his personal network in the region, he established trustful relationships with all stakeholders. Then, the Tour du Valat (private research center in Camargue), the CFR (French Rice Center), and the CIRAD decided to participate in the CEBIOCA project by doing genetic research as well as trials on weed management. Furthermore, relationships between researchers and farmers also have developed. The Interessement process led by the INRA's researcher relied on evidence-based results, showing the research was in line with farmers' needs. Interestingly, no formal agreement was established between INRA and farmers for these on-farm trials, and farmers did not get funded either. Farmers were rather interested to host these trials to observe and assess experimentations by themselves and for establishing a direct communication link with INRA's researchers.

Re-problematization and new wave of interessement

The CEBIOCA project was successfully implemented by INRA together with CIRAD and the CFR. A new phase of Problematization came into being from the CEBIOCA project. It was demonstrated the crucial importance of controlling weeds to reach an acceptable level of yield. This outcome was utilized by INRA in order to convince CIRAD and the CFR to participate in further projects dealing with the issue of organic rice farming. The initial scientific experimentations (2005-2006), which followed the CEBIOCA project, were initiated by INRA and supported by CIRAD and the CFR.

Enrolment and Mobilization of allies

Weeds have successfully been enrolled into the problematic since their importance was recognized by the results of the CEBIOCA project. Clearly, the transition to organic rice farming systems in the Camargue is not possible without "negotiating" with the non-human actor "weed". Weeds compete with rice and the other crop productions constituting the rotation for water and nutritive elements, but are more problematic in organic systems compared to conventional for two main reasons: (1) yields of crop organic productions are lower, leaving more resources to weeds and (2) chemical herbicides are forbidden according to organic regulations. The researchers defined different strategies to try dealing with weeds. These strategies were tested by the means of scientific experimentations. The best ways of "negotiating" with weeds appeared to be as follows: (1) allowing weeds developing when rice is not cultivated, and to combat them once they significantly have developed (false-seed bed techniques), (2) extending the time between two crop production cycles (when the soil is bared) to facilitate weeds' development while allowing, later, the rice to grow more rapidly through higher temperatures (the date of sowing is deferred), and (3) increasing the diversity of the species of weeds while reducing their density, by extending and diversifying crop rotations. Such rotation systems can cut cycles of weeds (and pests). By extending crop rotations, human actors have to "negotiate" not only with "rice" but also with the other cultures constituting the rotation (e.g. alfalfa and durum wheat). The cultures themselves need to deal with each other with respect to how they are combined together, i.e. which culture should be consecutive to the previous one.

The initial scientific experimentations were done with success in terms of collaboration between INRA and its partners. However, both the CFR and CIRAD thereafter have stopped collaborating with INRA on organic rice experimentations. This rupture was due to the completion of another project, the so-called ORPESA, which was succeeding the CEBIOCA project and the first scientific experimentations. The ORPESA project concerned the organization of a set of training sessions between farmers and researchers on how to convert to and maintain organic farming, especially for weed management. In the end of the ORPESA project, the participants agreed on the conduct of advanced experimentations based on knowledge generated in discussions and on the different findings. The CFR was asked to contribute to the advanced experimentations but has not answered positively. No reason was provided for their non-participation. Regarding CIRAD, the situation was slightly different as in the meantime their botanical expert had retired. The study of weeds was the main activity of CIRAD so far on organic rice in the Camargue. Still, this underlines the importance of the non-human actor "weed" during the process. That said, CIRAD started to develop organic rice experimentations independently in 2012 instead of collaborating closely with INRA. Our hypothesis concerning the disengagement of CFR is that the ORPESA project has been brokering their keenness. Evidences were gathered that at least a few local actors had not particularly appreciated the ORPESA project. An important Camargue organic trader considered this project was too radical in the way it pushed forward the conversion to organic farming. This critic was linked to the supposed high expectations of INRA regarding the transition speed towards organic farming. In fact, it seems that this organic trader was concerned by the fact that a too rapid development of organic farming might have weakened the organic rice market with the appearance of a disequilibrium between the offer and demand. A few farmers also have criticized this project because they considered it was not relying on robust scientific results. Here, we see that the transition process towards organic farming is by essence very long, and local actors should not be "brutalized" or enrolled too quickly in advanced stages of the process like for the implementation of participatory learning sessions on how to produce organically.

With respect to the ORPESA project, it was financed and initiated by the means of a complex process of actors' negotiations. INRA was being in contact with scientists from the Ebre Delta, in Spain, where rice is a major culture. The key INRA's agronomist visited that region some years before the ORPESA project was initiated, where he distributed leaflets presenting how weeds are or could be controlled in the context of Camargue rice farming systems. More recently, the LEONARDO EU-funded program, of which the ORPESA project came out, was designed by a society from the Ebre Delta. This enterprise was looking for an interesting case study and contacted INRA to propose taking the case of the Camargue organic rice as one of the objects of analysis. Interestingly, the process of enrollment was not initiated here by INRA but was resulting from their previous efforts, that is, when communicating broadly on the problematic tackled through physical meetings, leaflets, and scientific publications. Additionally, the ORPESA project enrolled other farmers although none of them have become "opinion leader". They were either not interested in leading this role or facing with a lack of legitimacy in the whole actor network, particularly in relation to conventional farmers.

Challenges

The CFR was intended to communicate INRA's results on organic rice experimentations. However, the trust between researchers from these two institutions appeared not to be sufficient. Also, no contract was signed by the CFR on communication issues and for the diffusion of the scientific results. These reasons most probably explain why there was a failure for farmers in receiving relevant scientific information and knowledge on Camargue organic systems. The CFR left available in their building the leaflets created by INRA instead of actively spreading the new knowledge. This fact bears witness to the relatively poorness of the Interessement stage during the initiation & invention phase but also later during the implementation, with no clear interest shown for CFR to actively participate and with no defined monitoring nor enforcement procedures to ensure the CFR would actually contribute.

Impacts

The surface under organic rice in the Camargue steadily increased during the time span of the project, although this evolution was mainly explained by external factors to the research, especially economic drivers like direct payments and selling price for organic rice (Quiedeville et al. 2017). The surface of organic rice in 2003 was of around 600 ha. It increased up to 1000 ha in 2007 and 1400 ha in 2014.
The conversion to organic by farmers was rendered possible by adopting several technical and managerial innovations. Our survey by producers show that main innovations concern the introduction of alfalfa and temporary pastures in the rotation, which is lengthened, as well as the implementation of false-seed bed techniques by the help of disc harrows and comparable materials. They also include a later sowing date, an increased level of and better

management of water in paddy fields, and an increased crop/seeding rate. All of these innovations are intended to control weeds. The latter are distinctly identified as an "undesirable" type of object to be combatted by the help of "support objects" (e.g. leaflets) and "solution objects" (the mentioned innovations).

4.2. Ecostop case (Bulgaria)

This case study focuses on the development of the product Ecostop in Bulgaria, for commercialization at national and international level. Ecostop is a veterinary medicinal product for the control of the varroa destructor, which causes varroatosis, i.e. the most widespread disease that affects the honey bees worldwide. Effective treatment of varroatosis has challenged researchers since 1990s. In 1994, two scientists have founded the private company Primavet in which alternatives to existing conventional solutions were developed. Ecostop was developed by this company between 1999 and 2006, and was commercialized in 2007. Ecostop offers an exclusive technology that allows controlling the evaporation of essential oils (thymol and mint oil) by applying a single treatment composed of entirely natural substances. In 2014, the adoption rate of Ecostop by beekeepers in Bulgaria has reached around 20-25% while in 2010 it was only between 2 and 3%. In 2015 and 2016, the adoption share has increased up to 40% (source: quantitative survey among beekepers). Ecostop is available on the market in more than 10 countries in Europe, Asia, and Latin America.

Problematization and Interessement

At the very end of the 1960s, beekeeping state cooperatives in socialist Bulgaria discovered the emergence of a new disease in the country – the varroatosis. In the 70s a group of researchers from the Academy of Sciences in Bulgaria developed the first synthetic substance against varroatosis (Coumaphos). The product received an international patent that was then bought by the company Bayer. On the basis of Coumaphos, Bayer has developed one of the most spreaded anti-varroa products – Perizin, but the varroa destructor has developed resistance to it.
Since then, there have been numerous attempts worldwide to find effective treatments, but two problems remained: (1) the varroa mite developed resistance to synthetic anti-varroa medicinal products (VMPs), and (2) until the end of 90s almost all known VMPs were based on synthetic chemicals (e.g. Coumaphos, Tau-Fluvalinate, etc.), which could not be used during the honey collection (residues could remain in the honey and other bees products).
In 1994, two Bulgarian scientists (different from those who developed Coumaphos), both veterinarian and fellow student, founded the private company Primavet. In 1998, this company launched on the market its first anti-varroa product for bees, i.e. the synthetic medicine Varostop (with the active substance Flumetrin), which was very well received by beekeepers worldwide although it developed resistance because of its synthetic origin.
Two main purposes guided the two veterinarians to start developing a new product Ecostop (entirely natural and based on thymol and methyl) from 1996 to 1998): (1) new scientific challenges to address, i.e. how to develop an anti-varroa product based on natural substances without any risks of resistance development, and (2) how to guarantee economic sustainability of their start-up through the development of a new product without any risks of resistance. Both of these problems can be reduced to a single one: how to "negotiate" with the varroa destructor and the development of resistances to it. Negotiations between scientists and the mite through synthetic substances (Varostop) appeared possible, but in a temporary (because of resistance problems) and fragile manner in economics terms. The only guaranteed way of negotiation between scientist and the mite was through dealing with essential oils (Ecostop).

Enrolment and Mobilization of allies

Natural substances like mint oil and thymol were well known by beekeepers. The problem is that oils are volatile, evaporate too fast, and have therefore only a limited effect on the varroa mite. The process of development of Ecostop started by trying first to negotiate with the volatility of the oils and then to deal with the mite. One of the veterinarians, specialized in pharmacology, tried different combinations with oils, with the purpose of reducing their volatility. The other veterinarian, specialized in bio mineralogy, started to explore different materials (carrier) on which oils can be impregnated, and that are able to slow down and control the evaporation process. The challenge was to find the type of material (e.g. minerals, plastics, and wood) having the best qualities regarding the control of essential oil evaporation. Two other actors joined the small group of scientists in that initial period, the mite, as well as the essential oils and carriers. Articles from scientific journals exposed the debate on natural oils and their potential as effective anti-varroa treatment, as well as the beekeepers' traditional practices on the application of essential oils into hives. This ensured further advancements in terms of interactions between oils, minerals, and the mite, which the scientists tried to develop.

Two other actors also joined the group and started to support its activities. The first one is a former engineer who started to practice beekeeping and to resell the products of Primavet. At the same time this person becomes an editor in chief of the most popular newspaper among beekeepers, *Bee and hive*. He also imported for the first time in Bulgaria the concept of organic beekeeping. In 2002, he established a very active organic beekeeping association. This beekeeper was the first one to try the very prototype of Ecostop. He found that the mineral carrier was too crumbly and the packaging not very well developed, and that beekeepers faced with difficulties to remove and attach it into hive. His profession of engineer helped him to develop a trial diary where he noted down very precisely all about the behavior of bees, mite and other pests he observed in the apiary. This person has become a vital part of the core research team during the development phase of the prototype. In addition to this, he started to publish on the usefulness of essential oil and to alert on the development of the new product. Moreover, trying to develop the idea of organic beekeeping, he used Ecostop as a key while convincing beekeepers to convert to organic beekeeping. That time Ecostop was the only existing VMP suitable for organic beekeeping in Bulgaria. The prototype was difficult to be applied but was received well by the beekeepers who tested it. This means that the “negotiations” with the varroa mite through the mineral carrier and essential oils have been successful and that the mite disappeared. The engineer-beekeeper helped scientists to improve the quality of the prototype, i.e. to successfully negotiate with end-users in the future. Finally, he helped scientists to identify a new niche which appeared on the market, i.e. the organic niche. Scientists have become “focal points” for the development of Ecostop network but this engineer-beekeeper has become an “opinion leader”, ensuring the introduction of the product and its technology of application through beekeeping community.

The second human actor who joined the Ecostop group was a veterinarian from the National Veterinary Institute, who in collaboration with other colleagues and with the support of Primavet, conducted a series of independent trials. She concluded that the quality of the product is comparable and even more efficient (94-96%) than existing anti-varroa products. Also, it is suitable for both conventional and organic beekeeping (Gurgolova and Zhelyazkova, 2004). This observation has helped the product to be registered for commercial use.

Challenges

Ecostop is on the market since 2007. It must be underlined that at the first stage of marketing it did not achieve significant market share and only brought between 1 and 3% of the annual profit of the company between 2008 and 2010. The combination of two main barriers hindered the diffusion of Ecostop at this first stage: (1) the social conservativeness of the beekeeping community and (2) the price of Ecostop which was considered too high by beekeepers.

Ecostop was included into the list with VMPs, application of which is subsidized by the National Beekeeping Program[5]. The State refunded to beekeepers up to 80% of the price of VMPs included in the list. This financial support played a key role for the diffusion of Ecostop. In two years, the market share of Ecostop increased from 3 to 25 %. Due to the efforts of the whole actor network, the Ecostop product is being replaced Varostop, which helps the company Primavet to maintain its position on the market and even to enlarge its market share but also to "negotiate" with the varroa mite and to reduce or limit the resistance to it.

Impacts

The diffusion phase of Ecostop started even before the registration of the product and before it was launched on the market. The beekeepers who participated in the development of the product have become 'opinion leaders', spreading information and distributing free samples of the product among the beekeepers' community (source: qualitative interviews by beekeepers and workshops). Two researchers and entrepreneurs also participated in this phase through organizing information campaigns, publishing in specialized newspapers, etc. In addition, scientists from the National Veterinary Institute also started to play a role of 'opinion leader', through giving lectures on anti varroa treatments and answering questions. The mineral carrier also played a substantial role: beekeepers started to reuse it either to fight ants and other pests or to re-impregnate the same used carrier, with essential oils, by themselves.

5. Discussion

Problematization is a crucial stage since it underpins the whole innovation processes during the initial and implementation phase of the innovation.

- In the Camargue case, problematizing environmental challenges has led to the first idea of developing a specific research program aiming at easing the transition to organic rice farming systems in the territory. Later on, it was identified that controlling the object "weed" is key to the problem investigated.
- In the Bulgarian case, the problematizing has led to the conceptualization of the product Ecostop by recognizing the danger and resistance problem of exiting synthetic pesticides to combat the varroa mite.

Problematization is the moment where humans and non-humans enter into durable interactions, start to recognize each other while changing their mode of interaction and through this the surrounding world. Matt et al. (2017) also discovered the importance of the phase of Problematization within the pathway leading to impacts on the basis of 32 cases of agricultural innovations conducted by INRA.

Innovations were initiated and developed only by a very few actors, very committed for personal reasons, during the first phases of the respective innovations.
The importance of only a limited number of such pioneers, who have become "focal points" in triggering the development of agricultural innovations, was also recognized for example by Flinterman et al. (2013) in the case of adopting practices in relation to care farming in the Netherlands. These authors explain this particularity as part of the process of a niche development. The latter is then expected to destabilize the exiting regime (set of norms and routines). The limited number of actors related by close and long date relationships shows that science-based innovation figures out a kind of "secret", but behind this we discover the full uncertainty and unpredictability of the relationships between humans and non-humans.

[5] The NBP is a public financial instrument in support of beekeepers (purchase of hives, colonies, medicines and communication activities). The NBP does not fund R&D activities. It started in 2006 and it runs in 3-year periods.

This character of the innovation needs silence, confidence, concentration and continuous interactions, i.e. “things” which cannot be explicated and articulated ex-ante. Their inner and tacit logic of rationalization cannot be subordinated to the external one. This character of the innovation explains the absence of written contracts between actors in both cases. The process is driven by an unpredicted and unarticulated logic of continuous relationships guided by the idea to change the mode of interactions between humans and non-humans, i.e. to fight weeds and resistance of the mite.

Role played by specific “coalitions” between humans and non-humans in the innovation network is a key booster of innovation. We refer here to specific combinations of humans’ interactions which cannot be redeployed somewhere else for an equivalent or superior benefit.

- In the Camargue case, when the botanical expert from CIRAD had retired, the Camargue innovation network did face with disturbances. The tie between INRA and CIRAD, in relation to organic rice farming issues, was considerably weakened.
- In the case of Ecostop, in which beekeepers actively participated to the development of the product Ecostop, some of these beekeepers have become opinion leaders. The latter started to diffuse innovations thanks to their reputation into the community. Those beekeepers have been sharing the new technology to fight the varroa mite as well as offering free samples of the product to other farmers. However not every beekeepers can become opinion leader. To do so, the first necessary step is to gain confidence among the community through experimenting personally the job of beekeeper to develop knowledge and experiences (e.g. on bees products, selling prices), and to develop a good reputation in the network. The force of opinion leaders is to use the confidence they have to create trust in the new product and technology in order to fight the varroa mite. They form a “coalition” with the innovation itself, which significantly helps the process of diffusion and adoption. The interaction between those actors has been transforming veterinarians into pharmacologists and bio mineralogists, and has turned the mite and oils into subjects of control through trials. This was crucial for the development of the innovation in helping the problem to be identified as well as diffusing a solution for solving it.

Several recent studies also have highlighted the importance of opinion leaders in diffusing innovations and/or technologies (e.g. Lamine et al. 2012; Blythe et al. 2017). It is recognized that opinion leaders possess more knowledge on the innovation and/or technology, are more innovative, and are less receptive to norms (Eck et al. 2011). However, these “classical” studies do not consider “coalitions” of humans and non-humans, which in fact a priori explain the success and failure of innovation and help draw the frontier of their impacts.

A typology of actors helps to better understand the interest of actors and their positions within the interaction process.

- In the Camargue case, with respect to the transition to organic, which is the specific focus of the two case studies investigated, three types of non-human actors have been identified: (1) the “undesired objects”, (2) the objects representing the “solutions”, and (3) the objects supporting the adoption of the identified solutions. The combination of these three types of objects seems to be specific to innovation processes related to the transition to organic farming. Three main reasons can explain this: (1) the complexity and radicalism of the organic production mode that requires adopting several technical and managerial innovations (Bellon and Penvern, 2014), (2) the limited number of knowledge brokers specialized on organic farming issues which make using other types of supports very valuable to help diffuse the knowledge and enroll international research actors, and (3) the non-use of chemical products making non-human actors like “weeds” more important and problematic (Bond and Grundy, 2001).
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The “undesired objects” are crucial as other actors need to negotiate with them for problem-solving purpose.

- In the Camargue, human actors need to “negotiate” with weeds regarding the period weeds should be controlled. The “solution objects” are a set of technical and managerial innovations: introduction of new crops in the rotation such as alfalfa and temporary pastures, and adapted use of materials like disc harrows to combat weeds (e.g. increased number of passages and adaptation of the application dates to soil conditions). A third type of object, the so-called “support”, is identified as necessary to help develop these innovations and increase their rate of adoption. Leaflets and scientific articles, in which the new knowledge is represented, were important in Camargue to share this knowledge as well as to raise funding and enrolling relevant international partners. Coalitions of opinion leaders and “solution actors” have become the most important channel to diffuse and adopt the innovation.
- In the Bulgarian case, this applies for the resistance of the varroa mite and the volatility of essential oils. The “solution objects” in the Bulgarian case is the combination between essential oils and carrier, which is represented by the product Ecostop on market.

To sum up, and as main conclusions that enhance the general state-of-the art in the field of evaluating the contribution of knowledge co-produced by research in the agricultural innovation processes, we have shown that

- ANT helps to understand (1) the reasons for which and how an innovation is being initiated, implemented and diffused and (2) why and in what way actors’ interests are changing during innovation processes.
- ANT brings substantial additional and useful elements compared to the recent participatory IMPRESA approach proposed by Quiédeville et al (2017).
- ANT shows clearly (1) how crucial the phase of Problematization is, (2) the key role played by close and small networks of actors as well as by “coalitions between humans and non-humans” during the implementation and diffusion phases of innovation, (3) the key factor of “trust” at the beginning of the process to allow a suitable enrollment of the actors, and (4) the interest of the “support objects”, i.e. the leaflets and scientific articles to raise funding and enroll international partners.

Limitations of the ANT are several. In the agricultural context, technical lock-ins and scales are “barriers to innovate” that ANT addresses weakly, and a more systematic review of technical factors would improve the approach, which is very centered to social factors of innovations. From the social point of view, the contribution of research to innovation processes should not be limited to the understanding of the actors and their interactions in terms of knowledge building and sharing, but should include more the processes of up-scaling and out-scaling of the innovation. Furthermore, the combination of ANT with other approaches and tools seems to be necessary to better understand the role of broader institutional and economic context. Moreover, ANT could also be combined with qualitative approaches such as IMPRESS (Impact of Research in the South) (Temple et al. 2016) or ASIRPA (Joly et al. 2015), which have in our view similar deficiencies as the IMPRESA approaches in terms of understanding the contribution of interpersonal humans and non-humans interrelationships during innovation processes. A deepening of the knowledge on those elements allows increasing the understanding of the process leading to impacts.

6. Conclusion

We have shown the interest of the Actor Network Theory to identify the contribution of actors during innovation processes in relation to agro-ecological transition as well as shedding light on the interaction process among these actors.

We underlined the importance of the phase of Problematization to better understand the challenges and define suitable strategies accordingly. This phase should not be omitted when planning and implementing research programs. Opinion leaders are seen as fundamental actors. Actors may only become opinion leaders in the course of the innovation process, but current and potential ones should be identified in early stages. Close contacts should then be established to involve them more in both the design of the research program and the problem addressed. Then, it was stressed the crucial role played by the closeness of the network actors at the beginning of the process. We advocate that, when investing into a research program based agricultural innovation, those closely related actors, which are interested in the same problem but differently, should be identified in order to enroll them and reinforce their competences. Furthermore, given their importance to the process, "specific assets", either human or non-humans, should be identified in all phases of the innovation in order to build strategic answers in case one of them would leave the network. Moreover, the "trust" among stakeholders should be created in the very early stages of the innovation process. Contracts and/or enforcement procedures should only be signed if the "trust" established is insufficient or cannot be substantially ameliorated. Also, the potential contribution and role of objects, e.g. leaflets and publications, as well as of the public authorities and markets, should always be reflected when planning research programs and during its implementation in order to take appropriate decisions and be able to amend them. Finally, it would be interesting to validate our results for other innovations linked to organic farming conversion, and under different socio-economic contexts.

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