

Designing agroecological farming systems with farmers: a review

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Abstract (278 words): Agroecology is a new paradigm that aims at redesigning sustainable farming systems. The implementation of its principles engages farmers in a radical transformation in the way they reason their farming systems, which requires a situated learning process of new techniques, norms and organizational practices. As the most important players in the transformation of farming systems, farmers and their advisers are now frequently invited to participate in research projects on the design of innovative farming systems. However, the role they play in these projects is rarely made explicit and can range from simple knowledge providers to co-designers. Here we review the role of farmers and other stakeholders in these participatory research projects and its impact on their learning and their engagement in the transformation of farming systems. Using a framework based on design theories, we analyzed thirty-nine papers on the design of innovative farming systems in which farmers were involved. We identified five main co-design approaches to the design of agroecological farming systems: De-novo design, Case-study design, Transition theory design, Co-innovation, and Activity centered design. Despite this diversity, we still point to the need for collectively and locally designed set-ups to support farmers and other stakeholders in the redesign of their own local activity systems. This learning process implies designing and experimenting locally methods that ensure continual back and forth between design and action. Such an approach should combine “design to design” methodologies, where co-design aims at producing artefacts that can be directly used by farmers to redesign their own activity, and step-by-step design, where the designer and users of artefacts are considered to be part of the same dialogical activity, so that individual and collective learning are favored.

Keywords: Co-design, Sustainability, Participatory research, Change management

Introduction

Developing sustainable agriculture requires reducing the use of chemical inputs to control the production environment. Agroecology tackle this problem by restoring and managing the natural regulation of the agroecosystem which will limit the use of chemical to support agricultural production (Francis et al., 2003). Referring to the Efficiency / Substitution / Re-design framework developed by (S. B. Hill & MacRae, 1996), agroecology falls under redesign since it implies the transformation of farming systems to (i) better match production methods at the farm scale with the local ecological, economic and social potentialities and (ii) to restore and maintain a functional agroecosystem (Darnhofer et al., 2012). Unlike sustainable development, which is based the on efficiency of the current practices or the substitution of chemical inputs by organic ones, agroecological redesign involves a profound change in farmers' reasoning. It requires a situated learning process of news technics, norms and organizational practices, to move from a logic in which the environment is perceived as a source of disturbance of an artificialized system and where production is supported by adequate inputs, to a logic of steering socio-ecological processes of the local agroecosystem which can support production. This means that useful knowledge to enable them to change comes from local confrontation to the choices and practices of their peers, from experiment conducted in their own situation (Cristofari et al., 2018), and from their own mobilization of a diversity of knowledge to act in their situation (Toffolini et al., 2017), rather than generally applicable recipes provided by outsiders. While agricultural modernization has attempted to reduce farmers to simple performers, the transition to more agroecological farming systems means restoring their roles as pilots of their farming systems that innovate and produce relevant knowledge to change directly in their own situation.

Researchers who work on designing more sustainable farming systems are aware of this change and are developing participatory approaches to include farmers and other

stakeholders in their work. From the perspective of development of agroecology, what we need to know is whether these participatory approaches support a change in the farmers' modes of reasoning and favour situated learning processes. This requires characterizing the expected role of participants as providers of knowledge, targets for learning or co-innovators?

To characterize the role of farmers in participatory research, in 1995, Pretty produced a typology that ranged from manipulation by the researchers, consultation, interaction, up to self-mobilization by the farmers themselves. The challenge of participatory research is the co-production of knowledge to inform a problematic situation. Taking a design perspective makes the relationship between knowledge production and action to transform that situation more explicit. In fact, Hatchuel et al. (2013) define "Design" as the "simultaneous generation of knowledge and objects" with the aim of achieving "an unknown desire" (Hatchuel et al., 2013). This process can be organized according to different ways of articulating knowledge production and transformational goals, for example: the extraction of knowledge objectified in a model that will serve to define public policies, design driven by researchers that invites farmers to engage in a learning process, co-design in which farmers and researchers work together to find solutions (Asaro, 1999).

Clearly, these different strategies do not imply the same level of engagement and learning for the participants. Making these aspects more explicit should allow researchers to better choose their own strategy to enable farmers to participate in the design of sustainable farming systems as a function of the scientific and transformative goals at stake.

In this paper, we refer to design theories to analyze the place given to farmers and other stakeholders involved in farming system management in the design of sustainable farming systems. We first build an analytical framework based on the literature on design theory concerning co-design, to highlight the dimensions of a co-design situation which need to be analyzed to qualify the link between this specific situation and its effects on co-

designers daily work situation. We use this framework to analyze 39 participatory research projects on the design of agroecological farming systems. We characterize different approaches based on how the farmers and other stakeholders are involved in the design process and with what effect on their own situation of change and learning. Finally, we identify the conditions for a design approach likely to best support the transformation of local farming activities toward agroecological ones.

Materials and methods

Analytical framework

Analysing design theory, we identified four relevant dimensions to analyze the link between a co-design situation and its transformational effects (Table1): who participates and who is considered to be a designer in the design process, what is the object of the design, the spatio-temporal dimension of the design process, and lastly, how to implement the design, mainly in terms of knowledge management during the design process (referred as “who”, “what”, “where and when”, “how” in Table 1).

“Who designs and who participates in co-design?” is a question that dates back to the origins of co-design in the 1970s. From a utilitarian point of view, co-design is seen as a way to develop technologies faster and better suited to consumer needs. The participants to be involved in the process are considered as consumers or “end-users”. The designers were those who led the process, taking the consumers’ needs and potential uses into account by involving “lead users” as expert representatives (Von Hippel, 1986) and by developing ethnographic approaches to better understand potential uses (Blomberg et al., 1993). Following a democratic idealism (Gregory, 2003), co-design aimed at producing operational technologies to improve workers’ daily work by sharing decisions between workers, designers and managers about which technologies should be designed and for what uses (Kraft & Bansler,

1994; Schuler & Namioka, 1993). It leads to considering that the workers are designers, rather than only participants who express their opinion during the process of designing new technologies or practices they would then merely adopt. According to Engeström (2001) workers permanently re-design objects, instruments and practices in their work. Therefore co-design calls for freedom at work and a rearrangement of the work place to enable the workers to better express their creativity (Mumford, 1987). The development of co-design approaches and methodologies in more complex and open fields (e.g. socio-ecological transitions or natural resources management where boundaries of problems and situations to transform are fuzzy, and where there are no clear hierarchical relations between participants) transformed the question of who is co-designer into the question of who should take part in and transform its practices through a collective design process (Couix, 1997; Grove et al., 2015)

The object of design could be an artifact that needs to be improved to fulfill a clearly identified function, or an entirely new artifact that fulfills a previously unknown function, for example, the case of the development of an environmentally friendly and economic car within the R&D service of European car manufacturer (Elmqvist & Segrestin, 2009). The object could be the design process itself, for example the design of an enabling platform to sustain social innovation (Seravalli, 2011). The different natures of the object led to different forms of cooperation with different actors involved in co-design processes. Product design aims to create a tangible artifact to fulfil a function that is clearly identified at the beginning of the design process. The aim of having the users participate is thus to ensure a better match between the artefact and the intended function. The users are chosen for their ability to test the artefact and contribute their experiential knowledge to the design process. The function and the artifact could be both the object of design that uses creative methods, such as innovative design (Le Masson et al., 2010). The co-designers are then selected for their creativity, which is based on their whole culture and experience. They could tackle what Sanders calls the

fuzzy front ends of innovation (Sanders & Stappers, 2008). Several authors showed that the process of design continues in the situation in which designed artifacts are put to use (Garud et al., 2009; H. A. Simon, 1997). As pointed out by Ehn (2008) “envisioned use is hardly the same as actual use, no matter how much participation there has been in the design process”. Users adapt artifacts and/or create new functions for them. Acknowledging the extension of the design process to its use situation gets designers to work on unfinished artifacts that can be customized and completed by the users to better match their own needs, for example the possibility to customize a pair of shoes to your taste in terms of size, color, etc. before making the purchase (Daaboul et al., 2011). In its most radical form, this awareness has led to the entangled concepts of “Design to design” and “Metadesign”. “Design to design” (also referred to as continuous design, redesign, unfinished design, collective resource approach, etc.) is to design set ups that help people to design what they want by themselves (Ehn, 2008).

Time and places for the co-design process differ, in particular, according to how the relationship between design and use is handled. Co-design can be managed as a process in which several people with different competencies and perspectives co-design something at the same time and in the same place, or alternatively, as a process in which different designers have a part to play but at different times and in different places. What is more, both cases may apply at different stages in the co-design process (Couix, 2002). For example, during the design of common working procedures to prevent forest fire by forest managers of the Cevennes region in France, managers had to reach a common understanding of the problem to coordinate themselves and to develop new working procedures in their own individual activity (Couix, 2002). All design processes converge at a certain point, and action and experimentation continues during practice and use, which make design partly an individual experience users/workers encounter in everyday practice. Béguin (2007) mentions the synchronized development of artefacts and activity and the need to see work places and

everyday practice as places where part of the design takes place. Other authors focused on the definition and characterization of collective places to stimulate reflexivity and coordination between actors, as motors of creation and of the development of individual and collective innovation (Albaladejo et al., 2010; Cantù et al., 2012; Couix, 2002; Gorli et al., 2015; Nevens et al., 2013; Voogt et al., 2015). Co-design could then be best represented as the articulation of collective thinking and production of artefacts, and individual action and experience. According to Darses et al. (2000), this articulation calls for the organization of two types of synchronization at the collective level: cognitive synchronization (to agree on ends) and operational synchronization (to agree on means). Avenier refers to an iterative and never ending-process, in which adjustment and new discussion of means and ends should constantly recur, and which should integrate unpredictable events and findings in the co-design process (Avenier, 2010).

“How” to implement co-design in terms of knowledge management requires thinking about the relevant types of knowledge to produce or to inject into the design process and what are the transformation goals of co-design (only knowledge production, the production of artefacts, practical changes, learning, etc.) According to the classical view of industrial design, in which designers design things for users’ uses, designers consider that the appropriate knowledge about the objects to be designed is technical and scientific and that they are experts on their uses (Midler & Lenfle, 2014; Muller et al., 1991; Von Hippel, 1986). To take a more social view of design, for example, for the co-design of urban transition, the focus is more on building a consensus among the participants on what change should be targeted. These types of approaches consider the building of a shared view among the participants as the first step in being able to engage in practice transformation (Cantù et al., 2012; Nevens et al., 2013). In that perspective, some researchers propose to mobilize actors’ experience as a source of professional development and learning in a particular enterprise or sector (Béguin et

al., 2012; Engeström, 2001; Gorli et al., 2015), while others suggest involving a wide range of competences and perspectives in co-design processes, to stimulate creativity, learning, coordination and intersubjectivation (Couix, 2002; Couix & Hazard, 2013; Steyaert et al., 2016). Some authors points out that the real challenge is not to reach a consensus but to constructively deal with conflicts (Dewey, 1927) to overcome contradictions and allows us to think of the two aspects simultaneously (dialectical logic). Finally, in action and work centered design approaches, the question is not only what knowledge should be mobilized, but how to create the conditions for practice learning, both at collective and individual levels. To be able to design new individual and collective action, we need to learn about one's own practices and about those of others (Avenier, 2010).

Choice of articles

Thirty nine papers illustrating the diversity of the participatory design of agroecological farming systems were selected (Table 2). First, in October 2017, we identified 923 papers published in scientific journals or conference proceedings by searching Google Scholar using the following algorithm: ("co-design" or "participatory design" or "co-innovation") and "farming systems" and "sustainability". We chose "sustainable" as it was more inclusive than "agroecology" which appeared too restrictive with respect to the range of co-design methods implemented to improve the sustainability of the systems. Next, the titles and abstracts of all these articles were analyzed to keep only the papers on farming systems that addressed issues at the farm level and developed a design approach with an explicit transformative agenda. Last, since several papers may be published concerning a single research project, we selected what we considered to be the most detailed and relevant paper per research project with respect to our inquiry.

Literature coding and analysis

We represented the different step of the analysis we performed on the 39 papers (Figure 1). First, we performed a semi-structured analysis of content (Fereday & Muir-Cochrane, 2006). The encoding process was based on the categories of our analytical framework: for each paper, we qualified each category of our framework (“who”, “what”, “where and when”, “how”, see Table 1) using an iterative encoding process with N-Vivo Software (Bazeley & Jackson, 2013). We obtained a node tree with three levels of branches: the two first corresponded to our framework and the last corresponded to the occurrences we found as a result of encoding the papers (Table 3).

We then explored the tree using the analytical functions of N-Vivo to see which occurrences in our node tree often encoded the same sources (Diagram Tree Function of N-Vivo, see Bazeley & Jackson, 2013). This analysis sorted the occurrences into five groups as a function of their proximity during coding. It means that if two occurrences were often encoded together to the same paper, they had more chance of being close in the final diagram tree and to be part of a group of occurrences associated to specific papers. This allowed us to determine five main approaches within research projects as a function of their main characteristics in our analytical framework (Table 4).

Results

Using the analytic framework (Table 1), the papers on the participatory design of agroecological farming systems were categorized in five approaches: De-novo design (12 papers), Case-study design (10 papers), Transition theory design (4 papers), Co-innovation (12 papers), Activity centered design (4 papers) (see Table 4). Three papers were common to two different approaches.

De-Novo Design

De-novo design refers to a group of French researchers at the French National Institute for Agricultural Research, whose work is mainly rooted into the C-K theory of innovative design (Le Masson et al., 2010), and whose aim is to design innovative cropping systems.

In de-novo design, researchers create out of the scratch ideotypes or models of farming systems with the help of farmers and other stakeholders. Participants are chosen by the researchers for their expertise and for being innovative themselves so they are not too conservative in the process. The level of involvement in the process of the participants varies. In its lowest level, they are invited to evaluate the design ideotypes (Reau et al., 2012). In a few cases, they participate to the creation of the evaluation tools (Barcellini et al., 2015). In a more participatory way, they can be consulted to define objectives for the prototype to achieve or to evaluate the scenarios (Navarrete et al. 2010), to share their knowledge with researchers at the different steps of the process when building the model (Moraine et al. 2015), or to help researchers to create new combinations of practices that are relevant from their point of view (Lefèvre et al., 2014; Penvern et al., 2012).

The way farmers implement and adapt what they learn on their own farm is not considered to be part of the design process (Clément Murgue et al., 2015), nor usually, is the use situations of evaluation software (Cerf et al., 2012). The design process ends when the model designed is considered to have achieved the goals the researchers laid down for the design (Lefèvre et al., 2014).

Regarding knowledge management, the aim of De-novo design is to produce knowledge that is relevant for developing innovative prototypes and models. Most of the projects seek to produce original knowledge and references about potential innovative farming systems to inform policy and decision makers. Learning and transformation are

considered more as a side effect of the work rather than as a desired result (Murgue et al., 2015).

Case-study Design

In case-study design, the aim is to invite farmers and other stakeholders to examine a case study that involve the re-design of farming systems. This exercise is supported by modeling. The aim is to simulate the possible impact of the decisions they may take (Martin, Felten and Duru, 2011; Sautier et al., 2017) and/or to facilitate collective learning among them by representing their view of a situation (Barnaud et al., 2008; Gouttenoire et al., 2013).

Models of farming systems management and functioning are designed by researchers(Martin et al. 2011; Sautier et al. 2017). These models are used in simulation workshops in which the farmers are invited to play their roles and take virtual decisions. The objective is to evaluate the impact of different decision scenarios on changes in farming systems. Some authors argue for the need to build the model in collaboration with the actors, as a way of building a shared view of the boundaries of a problem and of empowering people in the design of scenarios of change (C. Simon & Etienne, 2010) or of promoting collective thinking (Gouttenoire et al., 2013). However, aggregation, decisions and representation rules of the model are mostly decided by modellers, who, in the majority of cases, are the researchers.

The models and scenarios may be designed at the farm or regional scale. At the farm scale, this allows farmers and their advisors to test and discuss the consequences of different scenarios of change, under conditions that are close to their own conditions (Martin et al., 2011; Sautier et al., 2017). At regional scale, it creates a common understanding of a problematic situation and helps stakeholders envisage brakes and levers to improve a conflicting situation (Barnaud et al., 2008). When researchers organize collective workshops with farmers and other stakeholders, they play a role of facilitators.

Most of the collective work is organized by researchers through indoor workshops (Sautier et al., 2017; Gouttenoire et al., 2013). These workshops could be organized on the participants farms or in their villages (Barnaud et al., 2008; Martin et al., 2011), whereas in other projects, there is no mention of where the workshops take place. Modelling process by researchers and collective workshops with farmers are generally separated in time and in space (Martin et al, 2011; Sautier et al., 2017), except in the few cases where designing the model is part of the collective process. In those cases, they are iterations between the workshops where the model is co-designed and the lab where the modelling and IT development takes place.

The aim of interacting with the farmers is extracting knowledge that is useful for the modellers' work. However, in most cases, the researchers hope that the farmers and their advisors learn from the workshop sessions. They hope that reaching a consensus on best options and scenarios for change in the workshops will trigger the re-design of farming systems or the creation of territorial synergies. Nevertheless, there is little information in the papers on how the participants implement what they learn and on the impact of the workshop in the real world.

Transition Theory Design

The transition theory design is an approach led by a group of researchers located in the Netherlands (Bos et al., 2009). They developed a methodology called reflexive interactive design (RIO) to design innovations at farm scale, for instance, an innovative farm building to improve animal welfare. Their work is rooted in transition studies and socio-ecological theories (Geels & Schot, 2007). This design process aims to produce niche innovation products at farm or market level.

The design process follows different steps in which the object of design differs: first, the socio-economic system representation, in which the innovation design process will take

place, is defined. Defining the socio-economic system is a way of getting a clear idea of who the actors of the dominant and alternative regimes are (Geels & Schot, 2007) and of how they interact. Then, the importance of achieving new rearrangements of this system is underlined, which means new practices of cooperation and interactions between actors. The process ends when the new rearrangements lead to a niche innovation in the socio-ecological system.

According to the authors, achieving niche innovations (Geels and Schot, 2007) is hard because of the difficulty of keeping people involved from the beginning to the end of the process, which is very time demanding. The design process is iterative and ends when a prototype of the product is installed on a farm, but the way this innovation transforms the farmer's activity, or the way he adapts his practices and the new innovation is disseminated to other farms is not considered as part of the design process (Elzen & Bos, 2015). The process mainly relies on indoor workshops.

Learning about other participants' views, opinions and expectations, as well as building a consensus on how to improve the sustainability of the systems are clearly targeted in the process. Actors are also invited to participate because of their expertise on specific aspects or elements of the systems. However, the papers provide little feedback about how individuals use what they learned during the collective process to transform their own practice.

Co-innovation

Co-innovation aims at producing practice-led innovations to support farmers' empowerment for sustainable transition through participatory action research. Two streams can be distinguished within this approach with respect to the object of design on which researchers focus. The first stream focuses on the design and management of innovation platforms or training centres, as a physical location for meetings, discussion and co-innovation with farmers and other stakeholders (Pound & Posthumus, 2016; Tittonell et al.,

2012). The second stream focuses more on the design and management of farmer's networks as an immaterial system of co-innovation (Botha et al., 2014, 2017; van Dijk et al., 2017). In both cases, the final goals are the empowerment and action capacity building of the stakeholders, and the production of practice based or organizational innovations.

The researchers formulate and lead the project, although the goals for change are open to discussion right from the beginning (Botha et al., 2014). Farmers and other stakeholders get together and discuss innovative solutions within the framework designed and managed by the researchers. The researchers organize reflexivity about the management of the collective process among interdisciplinary action research teams. In some projects, researchers organize the facilitation and animation by hiring facilitators for the co-innovation process between stakeholders (van Dijk et al., 2017).

In these approaches, co-innovation is acknowledged to be a never-ending and non-linear process. However, sustaining the process over time may prove to be difficult for researchers: the project is usually not funded for long enough for changes in farmers' practices to be observed, and, under these circumstances, it is difficult to maintain and extend farmers' participation and empowerment (Pound and Posthumus, 2007).

The aim is clearly to produce knowledge that will be useful for farmers to enable them to adopt new practices and techniques in their own context, and to guide them in their understanding and use of it. Farmers' learnings are clearly targeted by researchers. However, projects usually focus one aspect of farm activity and do not promote collective discussion about the type of farming system to be achieved: for example, a project about conservation agriculture where the use of pesticides is not part of the collective discussion, even though it represents an additional cost for farmers and pesticides could affect their health in the long run (Dabire et al., 2017). The co-innovation process is successful if changes are achieved in the specific aspect of farm activity which is targeted for change. Some researchers highlight

the relevance of such approaches to reach new local arrangements between farmers or between farmers and advisers (Botha et al., 2017; Triomphe et al., 2008).

Activity-centered design

The activity-centered design was developed by a Finnish team and is based on the activity theories (Engeström, 2001). Here, the researchers aim to help local groups of farmers or a farming sector to solve a structural problem related to their activity; for example, a problem of illegal labour in the apple industry in New-Zealand (R. Hill et al., 2007) or a problem of pest management within a group of farmers (Vänninen et al., 2015). Researchers help re-design by mediating a transformative agency process within local activity systems (farming practices, but as well normative system of references, norms and instruments farmers use to design their own actions and make their own choices in their work situations). A transformative agency process is a process where individuals develop their capacity to act independently and make free choices to (Engeström, 2001).

The object of design is at the same time individual and collective activities. What are designed are new rules, instruments, or arrangements for farming activities. To this end, researchers start from a local farmer's demands. In collaboration with the farmers, they develop a Change Laboratory process. This process takes place directly within farmers and other stakeholders work environment and the focus is on contradictions in views and ideas within individual and collective practices. By helping participants expressing and sharing these contradictions, researchers facilitate the creation of new rules and instruments to help participants improve individual and collective practices themselves (Hill et al., 2007) For example, one of the outcome of the change laboratory process with horticultural producers facing a pest management problem is the creation of a new collective vision of the pest management problem at the scale of the local community and the set-up of protocol rules to implement new integrated management technics at the local scale. In this approach, farmers

and other stakeholders of the activity system need to be at the origin of the demand and willing to engage in the process of change of their own practices. Among the limitations of this approach is the fact that it can be hard to get stakeholders from the same activity system but with very different perspectives and interests together around the table, and may require organizing different Change Laboratory arenas to be able overcome conflicts and power games (Vänninen et al., 2015).

The design process is considered as never ending as long as the farmers consider their problem is not yet solved and the object of design is discussed throughout the process. Design is considered to take place both during collective meetings in dedicated collective work spaces and within individual workplaces on informal occasions. In that sense, the process is iterative and should continue until the tensions in the system are resolved.

Controversial elements within the activity system and their expressions are central to the development of this kind of process. However, limiting the system to the activity system can exclude from debates and changes stakeholders who are interested in the farming activity but who are not actually workers in the sector concerned, for example consumers or environmental associations, who may be interested in participating in local discussions about farming system transformations, but are not considered as farmers' peers. The process is action oriented in the sense it directly induces changes in participants' practices and organizations, mainly through learning by doing, experience sharing and reflexive discussions about their own individual and collective contradictions.

Discussion

Participatory design involving both researchers and farmers is considered as a way to improve both the relevance of the scientific knowledge produced and the efficiency of farmers' innovation processes. However, this analysis highlights the fact that the relationship between the goal of participation and the way it is implemented is seldom discussed in

401 scientific articles, as well as the transformative goals of the work. There is little doubt,
402 however, that the goal of researchers working on the design of sustainable farming systems is
403 transforming existing systems. This transformative goal is only explicit in articles referring to
404 Co-innovation and Activity-centered design. These are the only two streams to explicitly
405 target situated learning of participants, in and through practice and organizational
406 experiments.

407 In De novo-design, the work is oriented by the production of scientific knowledge.
408 However, it is conducted following a logic similar to that of a lead user innovation (von
409 Hippel, 1986). The farmers involved in the process of co-design are considered as innovators,
410 already advanced in the implementation of innovative practices on their farm and interested in
411 working with scientists. Empowerment and learning are not explicitly sought.

412 In Case-study design, the goal is to engage farmers in reflexive activity on a case
413 study that may be theirs. From a scientific point of view, this makes it possible to better
414 understand farmers' reasoning and to judge the relevance of the models and scenarios
415 produced by researchers. From a transformative point of view, the idea is that this reflection
416 will encourage farmers to question their practices when they return home. However, in this
417 approach, the impact on effective changes in farms is not part of the research project. There is
418 therefore no evidence for this impact or feedback likely to be reused in the design work.

419 In Transition theory design, it is up to the researchers to co-produce an intelligibility
420 of the problematic and complex situation they wish to transform with the actors of the
421 situation. Collective work produces a shared interpretation that serves the researchers who
422 analyze these situations and the actors who can then act with a better understanding of their
423 problematic situation. To achieve rearrangement within the socio-economic system or a niche
424 innovation, the challenge is to maintain the collective in the long term and to trigger the new
425 actors' arrangements that favor innovation. The authors recognize that these outcomes are

very hard to achieve. In fact, they point to the risk of spending too much time and giving too much importance to the definition of the socio-economic system, because it can become a “fixist” view of the system, whereas the objective of the co-design process is to produce rearrangements (Elzen and Bos, 2015).

The link to action and the interplay between design and action are explicit in the last two approaches: Co-innovation and Activity-centered design. These stand out by organizing the co-design process directly in the situation to be transformed (on farms, locally, in regions or agricultural sectors where farmers want change). In these approaches, farmers and other stakeholders are part of the process right from the beginning and co-design aims at directly transforming their farming systems and practices. However, the way reflexivity is organized to benefit all participants remains unclear. For example, during Co-innovation, even if farmers are co-designers, researchers are the ones who lead the projects. The place where they organize, analyze or reflect on the design remains separate from the place where farmers think, organize and implement changes.

The different approaches presented here are not exclusive: it might be possible to articulate them. For example, Transition theory design can be seen as a first step to bring local actors of farming systems together round the table to discuss the future and the stakes of their own situation. Co-design of models can be a way to hybridize practitioners’ knowledge and scientific knowledge and to imagine innovative solutions and desired states for transition. However the outcomes of these first stages should not be seen as the end of the co-design process. Articulating this type of work with approaches that organize the co-design process directly in the activity and organizations to be changed (Activity centered design, Co-innovation) would make it possible to address both the redesign of farming activity as a whole and the local co-design of goals, tools and arrangements to facilitate redesign locally. We suggest that it requires considering co-design as a dialogical activity in which the results of

designers' work fertilize the work of the users and vice versa (Beguin, 2013) and in which the aim is to produce artefacts that can be directly used by farmers to redesign their own activity (Ehn, 2008).

In fact, in most approaches, we identified a clear separation between both the place and the time of design and implementation, i.e., between the collective work organized by researchers and the changes implemented by the farmers on their farms. Moreover, farmers' goals and the concrete problems with which they have to cope in their activity are rarely taken into account from the beginning of the process. This means that researchers cannot observe the changes produced by the co-design process or facilitate farmers' real practices, or at least they do not consider them as interesting feedback to continue the co-design process. However, it should be noted that only analyzing published scientific papers likely introduced a bias in our conclusions: farmer-led projects undoubtedly exist and some of them probably involve researchers as co-designers but they did not lead to scientific publications that were picked up by our algorithm. Moreover, the fact that scientists rarely report the changes in the papers they write does not necessarily mean they never observe them, or take them into account in future work. However, this literature review shows there is a room to develop local participatory projects in which the co-design process, involving both researchers and farmers, aims at producing artefacts that can be directly used by farmers to re-design their own activity, and in which dialogue is organized between the different times and locations of the design and use of these artefacts, so individual and collective learning are favored.

This dialogical activity would make it possible to interconnect different arenas in which farming system transformation is at stake: the first arena is the farm, where farmers redesign their own activity. Coquil et al. refer to the professional transformation of farming activity (X. Coquil et al., 2017). The second arena is farmer peer groups, where new rules and arrangements for local changes in farming activities can be defined collectively from an

agroecological perspective. The third arena is a group of stakeholders involved in local farming and food systems management, in which different stakeholders of agricultural sectors, including farmers and their advisers, can collectively define the local farming sector stakes and the problems to be tackled, share their views on the different activities and competences of each stakeholder, and coordinate actions to produce tools and resources to support changes into farming activity systems. This means organizing the collective design processes locally, within existing working places of participants, and helping them to develop their autonomy in search of their own solution, as the developed by the Scandinavian school of co-design (Ehn, 2008; Gregory, 2003; Mumford, 1987).

Certainly, one of the future avenues for research would be to better define the relevant working places that are at stake when talking about re-designing farming systems. Exploring farming system as an activity system, like some recent research works propose (X. Coquil, Dedieu, & Beguin, 2017; Vänninen, Pereira-Querol, & Engeström, 2015b), may be a possible path to do it. In fact, supporting farmers' changes locally would also mean enrolling their advisers and other local farming system stakeholders as co-designers. In such perspective, the most engaging stance regarding learning and changes in farmers' reasoning is to involve all the participants of the activity system (farmers, local stakeholders and researchers) as co-designers. This implies that, at the very least, the farmers should be involved in the definition of the objectives of change right from the beginning, even initiate and carry out their own projects for change. Projects should also include the changes they produce on their own farms and articulate them with collective work to design local resources and set-ups to support that change. As a consequence, the farm, the local network of farmers, the local food system, etc. would be better integrated in the co-design process as the workplaces to be transformed.

Finally, this leads us to ask what it means for a researcher to be a co-designer. What would a researcher's attitude be in a design set up in which the aim is to help people to

achieve autonomy to solve their own problems in their own working situation? It calls on researchers to work on the problems that people face in real life, to let them lead their own projects and to help them search for their own solutions. The researchers could facilitate, participate, and monitor the collective process of inquiry to produce both scientific knowledge on the situation they accompany and to help formulate warranted assertions to guide the actions of farmers and other stakeholders (Martela, 2015) during the design processes.

Conclusion

This analysis, informed by the literature on design theory, allowed us to identify five main approaches to participatory projects to design agroecological farming systems: De-novo design, Case-study design, Transition theory design, Co-innovation, Activity centered design. When it comes to promoting changes in farmers' reasoning to support the development of agroecology, we identified several methodological approaches that aim to collectively and locally design set-ups to support farmers in the re-design of their own farming systems. This implies designing and experimenting methods that ensure continual back and forth between the different arenas where farming systems are discussed and redesigned (at the individual level on the farm, between peers for professional transformation, and at the level of the territory to discuss local stakes and projects). For local stakeholders, this means working together on a new organization of local development. For researchers, developing these types of design practices with farmers and other stakeholders means putting themselves in the position of the participants and accompanying the co-design process. Such a design approach would be the most suitable for the agroecological transition, in which innovation needs to be produced locally, and collective work should support farmers and other stakeholders' learning and experimentation of new modes of reasoning.

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1- “Who” → Who participates? Who designs?
1.1. Who is considered to be the designer?
1.2. Who participates?
1.3. Who formulates the demand?
1.4. Is the demand discussed?
2- “What” → What is the object of design?
2.1. The design object: a technology / a place to facilitate exchange / a new workplace / a new design practice
2.2. Unpredicted output of design / what transformation is targeted in the real world?
2.3. Is the object of design discussed?
3- “Where and When” → Space and time dimension
3.1. Where does co-design take place? (in one or several places?)
3.2. Is the co-design considered as an ending process / an unending process?
3.3. Is the co-design considered as an ending process / an unending process?
4- “How” → Design implementation in terms of knowledge management
4.1. What is considered as useful knowledge for the co-design process?
4.2. What place is given to a prototype / models / predictive tools?
4.3. What place is given to experiential knowledge/practical knowledge/sensitive knowledge?
4.4. Is learning an expected effect of design? (Action oriented design)
4.5. What is the role of consensus?
4.6. Is space allowed for unexpected findings / controversies / debate?

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Table 2. Table listing the 39 papers selected for the analysis.

	Authors / Years	Title	Affiliation of the scientist	Concepts
1	(Blazy et al., 2009)	A methodological framework that accounts for farm diversity in the prototyping of crop management systems. Application to banana-based systems in Guadeloupe	France, INRA/CIRAD	Pototyping with expert, Sustainable Farming Systems
2	(Le Gal et al., 2009)	A modelling framework to support farmers in designing agricultural production systems	France, INRA/CIRAD	Participatory design, Sustainable Farming Systems
3	(McCown et al., 2003)	A new role for hard science in soft Farming Systems Research: Learnings from ten years of facilitating farmers' experimenting using a cropping systems simulator.	CSIRO, Australia	Participatory experiments Design, Sustainable Farming Systems
4	(Moraine et al., 2017)	A social-ecological framework for analyzing and designing integrated crop–livestock systems from farm to territory levels	France, INRA	Participatory Design, Sustainable Farming Systems
5	(Murgue et al., 2014)	Agricultural viability in a water-deficit basin: can participatory modelling and design activities trigger collaboration between water management and agriculture stakeholders?	France, INRA	Participatory Design, Sustainable Farming Systems
6	(Albicette et al., 2017)	Co-innovation in family-farming livestock systems in Rocha, Uruguay: A 3-year learning process	INIA, Uruguay	Co-innovation, Sustainable Farming Systems
7	(Delma et al., 2016)	Conception participative d'innovations et accompagnement des projets d'élevage familiaux au Burkina Faso : explorer, expérimenter et évaluer	France, Cirad; IRD, Burkina Faso	Participatory Design, Sustainable Farming Systems
8	(Barcellini et al., 2015)	Designers' and users' roles in participatory design: What is actually co-designed by participants?	France, INRA	Participatory Design, Sustainable Farming Systems
9	(Dabire et al., 2017)	Operationalizing an innovation platform approach for community-based participatory research on conservation agriculture in Burkina Faso	CIRAD, France	Co-Innovation, Farming systems, Agroecology
10	(Navarrete et al., 2010)	Elaborating innovative solutions with experts using a multicriteria evaluation tool: the case of soil born disease control in market gardening cropping systems	INRA, France	Participatory Design, Farming Systems
11	(Bellec et al., 2012)	Evidence for farmers' active involvement in co-designing citrus cropping systems using an improved participatory method	France, Cirad/INRA	Co-design, Sustainable Farming Systems
12	(Coquil et al., 2014)	Experiencing organic mixed crop dairy systems: a step-by-step design centered on a long-term experiment	France, INRA	Step-by-Step Design, Sustainable Farming Systems
13	(Sautier et al., 2017)	Exploring adaptations to climate change with stakeholders: A participatory method to design grassland-based farming systems	France, INRA	Participatory Design, Sustainable Farming Systems
14	(van Dijk et al., 2017)	Facilitating practice-led co-innovation for the improvement of animal welfare	United Kingdom, Bristol University	Co-innovation, Sustainability, Farming Sector
15	(Lefèvre et al., 2014)	Farmers and agronomists design new biological agricultural practices for organic cropping systems in France	France ISARA/INRA	Participatory Design, Organic Farming Systems
16	(Moraine et al., 2014)	Farming system design for innovative crop-livestock integration in Europe.	France, INRA	Participatory Design, Farming Systems, Agroecology
17	(Martin et al., 2011)	Forage rummy: A game to support the participatory design of adapted livestock systems	France, INRA	Participatory Design, Farming Systems, Climate Change
18	(Vänninen et al., 2015)	Generating transformative agency among horticultural producers: An activity-theoretical approach to transforming Integrated Pest Management	Finland, University of Helsinki/Natural Resources Institute; Brazil, Federal University of Sergipe	Co-innovation, Activity Theory, Farming Systems, Integrated pest management
19	(Reau et al., 2012)	Les ateliers de conception de systèmes de culture pour construire, évaluer et	France, INRA	Collective Design of Prototypes

		identifier des prototypes prometteurs		
20	(Botha et al., 2014)	Lessons on transdisciplinary research in a co-innovation programme in the New Zealand agricultural sector	New Zealand, Ruakura Research Center/ The Netherlands, Wageningen University	Co-innovation, Agricultural system
21	(Groot Koerkamp & Bos, 2008)	Designing complex and sustainable agricultural production systems: an integrated and reflexive approach for the case of table egg production in the Netherlands	The Netherlands, Wageningen University	Reflexive and Integrated approach, Farming systems
22	(Gariépy et al., 2016)	Multi-scale modelling as a tool for sharing the perspectives of researchers , practitioners and farmers on beneficial management practices to be adopted in an intensive agricultural watershed	France, INRA; Canada, Quebec University	Participatory modelling and design, Agricultural Watershed management
23	(Dogliotti et al., 2014)	Co-innovation of family farm systems: A systems approach to sustainable agriculture	Uruguay, Facultad de Agronomía UDELAR; The Netherlands, Wageningen	Co-innovation, Farming systems
24	(Casagrande et al., 2015)	Participative design of conservation agriculture cropping systems in organic agriculture	France INRA	Participatory Design, Organic Farming Systems
25	(Mapfumo et al., 2013)	Participatory action research (PAR) as an entry point for supporting climate change adaptation by smallholder farmers in Africa	Zimbabwe, University of Zimbabwe; Ghana, University of Ghana; The Netherlands, Wageningen University	Co-design, Participatory Action Research, Farming Systems, Climate Change
26	(Naivinit et al., 2010)	Participatory agent-based modeling and simulation of rice production and labor migrations in Northeast Thailand	Thailand, Chulalongkorn University/Ubon Rajathani University; France, CIRAD/Université Paris-Ouest	Co-design, Companion modeling, Rice production systems
27	(Triomphe et al., 2008)	Participatory Cropping and Farming System Design among multiple stakeholders to contribute to sustainable agricultural production. Experiences and lessons with the Agrarian Reform Sector in the Brazilian Cerrados	France, INRA	Co-design, Agricultural Watershed Management
28	(Schaap et al., 2013)	Participatory design of farm level adaptation to climate risks in an arable region in The Netherlands	The Netherlands, Wageningen University	Participatory Design, Farming Systems, Climate Change
29	(Gouttenoire et al., 2013)	Participatory modelling with farmer groups to help them redesign their livestock farming systems	France, INRA	Participatory Modelling to help re-design; Farming Systems, Sustainability
30	(Bos et al., 2009)	Reflexive interactive design and its application in a project on sustainable dairy husbandry systems	The Netherlands, Wageningen University	Reflexive interactive design; Dairy system innovation; Sustainability
31	(Vall et al., 2008)	Role of partnership and experimentation for the co-design of sustainable innovations: the case of farming systems of the West of Burkina Faso	Burkina Faso, CIRAD/CIRDES; France, CIRAD/INRA	Co-design; Farming Systems, Sustainability
32	(McKee et al., 2014)	'Shift happens': Co-constructing transition pathways towards the regional sustainability of agriculture in Europe	Scotland, The James Hutton Institute; Portugal, Universidade de Evora	Interactive Design, Collaborative environment, Sustainable Agriculture
33	(Penvern et al., 2012)	Sustainable orchards' redesign: at the crossroads of multiple approaches	France, INRA	Participatory Modelling and Design, Redesign, Sustainable Farming Systems
34	(Tittonell et al., 2012)	Agroecology-based agroecology-conservation agriculture (ABACO): Targeting innovations to combat soil degradation and food insecurity in semi-arid Africa	France, CIRAD; Zimbabwe, University of Zimbabwe, UK, University of Greenwich; Madagascar, FOFIFA, Burkina Faso, CIRDES	Co-innovation; Cropping Systems, Agroecology
35	(Elzen & Bos, 2015)	The RIO approach : Design and anchoring of sustainable animal husbandry systems	The Netherlands, Wageningen University	Reflexive Interactive Design; Sustainable Production Systems

36	(Murgue et al., 2015)	Toward integrated water and agricultural land management: Participatory design of agricultural landscapes	France, INRA	Participatory Design, Sustainable Agricultural Landscapes
37	(Giller et al., 2011)	Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development	France, CIRAD	Participatory design, Simulation, Crop-livestock systems
38	(Botha et al., 2017)	Using a co-innovation approach to support innovation and learning: Cross-cutting observations from different settings and emergent issues	New Zealand, AgResearch; The Netherlands, Wageningen University	Co-innovation, Agricultural System Innovation
39	(Hill et al., 2007)	Workplace learning in the New Zealand apple industry network: A new co-design method for government “practice making”	New Zealand, Lincoln University/NZ Department of Labour and We Research of Wellington	Co-design, Activity Theory, Apple industry network

Figure 1. Diagram of the encoding and analytical process of the literature

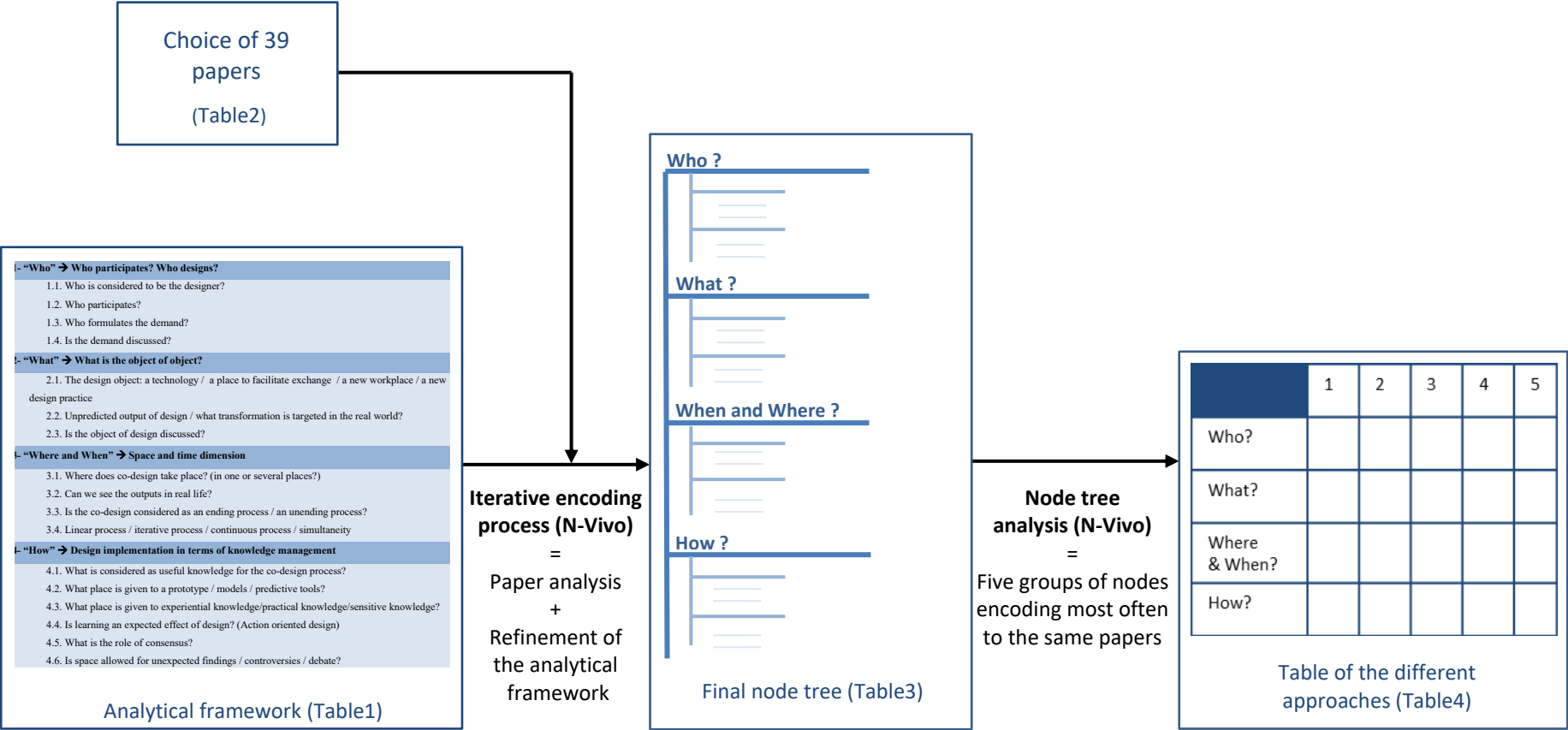


Table 3. Final node tree (Lines in blue corresponds to our framework, line in white are the occurrences we defined while encoding the papers).

1. Who design – Who participate?
1.1. Who is designer?
End-users
Practitioner
Researchers
Stakeholders
1.2. Who participate?
Future potential expert users
Practitioner as knowledge providers
Researchers facilitate the process
Stakeholders give their opinion
1.3. Who formulate the demand?
From where does the demand come from?
Farmers
No information
Society injunction
Who formulate the original demand?
Practitioners
Researchers
1.4. Is the demand discussed?
Iterations after researchers' proposal
Iterations from the beginning of the process
No discussion
2. What is the object of design?
2.1. Design Object
Agricultural practices-Cultural Techniques
Common representation of the socio-technical system situation
Farming system evaluation software
Farming system prototypes / ideotypes
Hybrid knowledge about farming systems
Innovation platforms – centres
Models of farming system functioning
Multi-stakeholder arenas – networks
Scenarios of change
Shared concepts
Working practices - Working rules
2.2. Transformation targeted in the real world
New organizational arrangements and rules
None
Practice innovation
Redesign of farming systems

Stakeholders empowerment
Technical innovations
2.3. Discussion of object
Discussion of researchers' proposals
No discussion
Permanent discussion of the object of design
3. Spatio-Temporal Dimensions
3.1. Where does co-design take place?
Indoor and Experimental stations
Indoor and Working places
Indoor only
3.2. Is the co-design considered as an ending process / an unending process?
Ending process
Research time
Unending process
3.3. Is the co-design considered as an ending process / an unending process?
Disjointed process
Iterative process
4. Knowledge Management
4.1. What is considered as useful knowledge for the co-design process?
Expert knowledge / Technical knowledge
Local constraints
Scientific knowledge
Socio-technical arrangements
4.2. What place is given to a prototype / models / predictive tools?
Scenarii are validated by stakeholders
Models are used to simulate changes
4.3. What place is given to experiential, practical, sensitive knowledge?
Experience sharing are important
Practitioners-Users Knowledge are important
Stakeholders knowledge about their territory are important
4.4. Is learning an expected effect of design? (Action oriented design)
Learnings are targeted with design
Action oriented design (more than knowledge oriented design)
4.5. What is the role of consensus?
Consensus is searched between researchers and stakeholders
4.6. Is space allowed for unexpected findings / controversies / debate?
Controversial elements (which bring debates) are important

Table 4. Tables of the different approaches we identified and their main characteristics with respect to our framework. Each approach corresponds to a specific combination of the occurrences for the criteria used in our conceptual framework. Some references were half way between two categories. Their numbers are in bold and they are sorted into two categories.

	De novo design Papers: 1, 4, 8, 10, 12 , 15, 16, 19, 24, 28 , 33, 36	Case-study design Papers: 2, 3, 5, 13, 17, 22, 26, 28 , 29, 37	Transition theory design Papers: 21, 30, 32, 35	Co-innovation Papers: 6, 7, 9, 11, 14, 20, 23, 25, 27 , 31, 34, 38	Activity-centered design Papers: 12 , 18, 27 , 39
What?	Innovative ideotypes of sustainable farming systems and evaluation tools to assess their sustainability.	Virtual consensual scenarios or optimized farming system models created with local actors to promote sustainable transformations in the real world.	Shared concepts and a common representation of the socio-technical system that help to create new socio-technical arrangements or niches for technical innovations	Sustainable agricultural practices through the creation of innovation platforms or multi-stakeholder arenas/networks.	Working practices and/or rules that could lead to a new organization of labor.
Who?	Researchers are the designers. As the end-users, the farmers are invited to evaluate the results of design. Depending on the project, their expertise can be sought at different stages.	Researchers led the process in the name of societal injunctions. Farmers are invited to participate in a few cases to design the model and in all cases to feed the model with their decisions.	The design is implemented by the researchers but their proposals are discussed with the stakeholders of the targeted socio-technical system. These stakeholders and the researchers are co-designers	The design is implemented by the researchers but their proposals are discussed with the farmers. Both farmers and researchers are co-designers. The researchers could play the role of facilitator.	The design is led by the practitioners with the help of researchers to facilitate the process.
Where and when?	Formal meetings whose timing is dictated by the research schedule. The process is ended by the researchers.	From one to several iterations in an indoor workshop style of interaction between researchers and farmers. Some workshops are held on farms.	Iterative process conducted indoors.	Iterative process with several indoor workshops. The process is virtually endless.	At the workplace, the process will last until the problems or tensions are solved.
How?	Practitioners are knowledge and feed-back providers for the modeling activity.	The process is to implement problem-based learning with farmers in which models help design sustainable solutions. Farmers' knowledge is extracted for research purposes. In the real world, Impacts rely on the belief that the farmers learn from the process and will change their habits.	Co-production of a shared understanding of the complex situation in the hope it will help the participants develop their own strategy and favor niche innovation.	Co-production of a common language, creation of conditions for cross-learning between the participants. The goal is the empowerment of farmers. The process is successful when changes are achieved in the specific aspect of farm activity targeted for change.	Learning by doing and collective organization of the reflexive activity