Introduction

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Abstract Impact of agriculture on environment and human health, energy crisis and climate change enjoin policy-makers and farmers to rethink the model of agricultural production. One way is to promote a strong ecologisation of agriculture reducing inputs using ecosystem services at field, farm and landscape level and new managements. Designing and implementating such agricultural model needs to deeply change the management of farming systems, natural resources and food–chain while dealing with a wide range of environmental and societal changes. To accompany this change agricultural actors and researchers require new tools. Based on the concept of ecological transition, the TATA-BOX project will propose a methodology and a set of methods and tools to help local agricultural stakeholders to develop a vision of the desirable transition of local agricultural systems and to steer it. As part of the adaptive and transition management paradigms, the project will propose an epistemological move to better match current needs of participatory research (hybridization between hard and soft sciences). The case-study will be the Tarn river watershed where water and biodiversity resources are at stake and where some collective dynamics toward agroecology have already started.

After World War, the productivist model of agriculture led to the standardisation of production methods and consequently to a decrease in the specific cognitive resources necessary to implement them. It also contributed to the specialisation of territories as a function of their comparative advantages (Lamine 2011). In the 1990s, the development of the concepts of sustainability and multifunctionality challenged the monolithic logic of the productivist model. Objectification of the environmental impacts of agriculture, social awareness linked to media coverage of it, and redefinition of the objectives of agriculture due to agricultural policies have

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J.-E. Bergez et al. (eds.), *Agroecological Transitions: From Theory to Practice in Local Participatory Design*, https://doi.org/10.1007/978-3-030-01953-2_1

been the sources of two forms of ecological modernisation of agriculture (Horlings and Marsden 2011). The first one, which stems from the productivist model, corresponds to "a weak Ecological Modernisation of Agriculture" (weak-EMA). It is based on an increase in resource-use efficiency (e.g., water), the recycling of waste or by-products (Kuisma et al. 2013), and the application of good agricultural practices (Ingram 2008) and/or of precision-agriculture technologies (Rains et al. 2011). It can also correspond to new off-the-shelf technologies, such as organic inputs (Singh et al. 2011) or genetically modified organisms. Since it primarily aims to reduce the main negative environmental impacts, it is often called "ecological intensification". The other one is a real departure from the productivist model. It corresponds to "a strong Ecological Modernisation of Agriculture" (strong-EMA). Compared to weak-EMA, strong-EMA needs a paradigm shift in the conceptualisation of the link between environment and production. Along with the principles of resource recycling and flow management, it includes the use of biodiversity to produce "input services" that support production (e.g. water availability, fertility, pest control) and regulate flows (e.g. water quality, control of biogeochemical cycles) (le Roux et al. 2008). These services depend on the practices implemented at field and farm scales, as well as at the landscape scale (Kremen et al. 2012). Strong-EMA allows agricultural production and management (conservation, improvement) of natural resources (Griffon 2006) to be reconciled. This form of ecological modernisation of agriculture founded on ecological concepts is also called "ecologically intensive" (Bonny 2011). While weak-EMA is essentially based on off-the-shelf technologies and/or agricultural practices that render the environment artificial, the goal of strong-EMA is to apply agricultural practices that can capitalise on functional complementarities between organisms, or on services that agro-ecosystems can render.

Strong-EMA requires the implementation of agricultural practices that can exploit functional complementarities between diverse species and genotypes in resource use and biological regulations at multiple spatial and temporal scales (Ostergard et al. 2001; Kremen et al. 2012). Biggs et al. (2012) identify seven general key principles to maintain or increase the production of ecosystem services within an agro-ecosystem, along with their resilience to social and environmental changes. They distinguish three system properties to manage, all of which concern the biophysical and social dimensions of the system, and four attributes for its governance.

The three system properties are: diversity and redundancy; connectivity; and the state of slow dynamic variables. (i) Diversity and redundancy: diversity (taxonomic and functional), and biological (genes, species, ecosystems, spatial heterogeneity) and social (individual, social groups, strategies, institutions) equilibriums, and their levels of redundancy, define the potential for adaptations, innovations, and learning about the system. (ii) Connectivity defines the conditions and level of circulation of material and cognitive resources and actors in the system that determine the exchange capacity among system components and thus the system's performance level. (iii) The state of slow dynamic variables: the dynamics of complex systems are determined by the interaction between slow dynamic variables (e.g. farm size, soil organic matter, management agencies and social values) and fast dynamic variables (e.g. water withdrawals, authorisation to access to resources). The way of middle- or long-term management of the former determine the conditions under which the latter occur and, most often, the ecosystem services of regulation.

The four key management and governance principles are: (i) understand the system as a complex adaptive one, i.e. characterised by emergent and non-linear behaviour and a high capacity for self-organisation and adaptation based on past experiences and ontological uncertainties; and accordingly consider that governance and adaptive management are structurally necessary; (ii) encourage learning and experimentation as a process for acquiring new knowledge, behaviour, skills, or preferences at the individual or collective levels, ultimately to support decisions and actions in situations of uncertainty; experimentation, particularly in the framework of adaptive management, is a powerful tool for generating such learning; (iii) develop participation: the participation of system actors in governance and management processes facilitates collective action, as does the relevance, transparency, legitimacy, and ultimately acceptability of social organisations, decisions, and actions within the system; (iv) promote polycentric subsystems of governance that structure debate and decision-making among different types of actors, at different levels of organisation, and of different forms (e.g., bureaucratic, collective, associative, informal). The basic principle of polycentric governance is to organise governance systems at the spatial scale at which the problems to manage emerge.

The implementation of strong-EMA to ensure the expression of ecosystem services faces various difficulties (Duru et al. 2015):

(a) Strong-EMA requires a redesign of the agricultural systems (Meynard et al. 2012);
(b) Strong-EMA assumes that actors coordinate with one another, particularly for the arrangement of landscape structures, spatial crop distribution, and exchanges of matter (Brewer and Goodell 2010);
(c) The development of new cropping systems based on crop diversity (e.g. crop associations) and a decrease of inputs may cause problems for production and marketing chains (Fares et al. 2011);
(d) Incomplete information during implementation of practices (difficulty in observing ecosystem states, or difficulty in predicting the effects of actions) leads to risk-taking by farmers (Williams 2011);
(e) Given the decidedly local character of production methods to be implemented to take advantage of biological regulating services (Douthwaite et al. 2002), the process of innovation must also be localised (Klerkx and Leeuwis 2008);
(f) Steering strong-EMA at a territorial level will not happen without changes in the mode of production of knowledge and socio-technical systems (Vanloqueren and Baret 2009). An effective integration of societal concerns into scientific practice may require more fundamental changes in the nature of scientific inquiry, and a move towards truly trans-disciplinary research strongly involving external stakeholders in the research process (Pahl-Wostl et al. 2013).

Considering the key challenges of strong-EMA, three conceptual frameworks are potentially suitable to support its implementation: the farming system framework to analyse the organisation and dynamics of production systems, the social-ecological system framework to analyse the management of natural resources locally, and the socio-technical system framework to understand the dynamics of activities, especially transitions in production methods.

Farming systems (FS) range from simplified to more diversified and integrated (Hendrickson et al. 2008). The simplest ones generally have a limited number of crops and pre-planned management. Their dynamics are grounded in plant and animal genetic improvement and the acquisition of high-performance equipment. Innovation on such farms is mostly linear and top-down. In contrast, diversified systems include multiple crops or subsystems that interact dynamically in space and time, which allows them to benefit from multiple synergies emerging from interactions between components. These production systems are managed dynamically, to make the best use of opportunities by performing annual or seasonal adjustments. Innovation on such farms is generally based on the development of coordination between actors to co-produce knowledge and technologies, sometimes assisted by participatory and transdisciplinary research (Knickel et al. 2009). While this type of approach enables us to analyse the structure and dynamics of farming systems, it has three main limits: (i) it does not really consider the risks of implementing specific agroecological practices, due to knowledge gaps; (ii) the social system considered is often reduced to the farmer; and (iii) the impact of farmers' practices on the state of natural resources at the local scale is barely considered or assessed, if at all.

The Social Ecological System (SES) framework allows us to analyse interactions between a social system composed of users, managers, and institutions using technologies and infrastructures to manage resources and a complex ecological system generating these resources (Anderies et al. 2004; Sibertin-Blanc et al. 2011). Through this framework the dynamics of complex systems is analysed through the concepts of resilience, adaptation, and transformation (e.g. Folke et al. 2011). In many situations, the problems of managing natural resources are associated with a failure in governance due to an underestimation of the changing nature and complexity of the SES concerned (Pahl-Wostl et al. 2010). The challenge is therefore twofold: (i) to strengthen the adaptive capacities of governance systems for sustainable management of natural resources; and (ii) to implement adaptive management that aims for continual improvement in policies and practices for the management of natural resources. The application of management strategies is then considered as part of a system for experimentation and learning. Here management methods correspond to an adaptive, deliberative, and iterative decision-making process that is often associated with the organisation of social learning, whose main objectives are mutual understanding, sharing of viewpoints, collective development of new adaptive management strategies for resources, and the establishment of "communities of practice" (Armitage et al. 2008; Newig et al. 2008). While analysis of the social-ecological system allows us to decipher their structure and dynamics, it poorly takes into account (i) the agronomic and organisational constraints of farming systems and (ii) the necessary changes in agricultural supply chains.

The Socio Technical System (STS) framework allows us to analyse the dynamics of innovations and ways of producing goods within economic sectors or production chains as the result of interactions between three levels of organisation (Geels 2002): (i) production niches (an unstable configuration of formal and informal networks of actors in which radical innovations emerge); (ii) socio-technical regimes (a relatively stable and dominant configuration associating institutions, techniques, and artefacts, as well as regulations, standards, and norms of production, practices, and actor networks); and (iii) the global context (the set of factors outside regimes that “frame” interactions among actors: cultural values, political institutions, environmental problems, etc.). Its dynamics are addressed by analysing the adoption and dissemination of the innovations that niches bring, and the transformation of one or more dominant socio-technical regimes under the pressure of niche development and incentives, and regulatory changes from the global context (Geels 2005; Smith and Stirling 2010). Currently, the dominant socio-technical regime is the weak-EMA model (Vanloqueren and Baret 2009). Niches correspond to alternative production models of varying structure, which coexist in a complementary or competitive manner. Analysis of STS allows us to highlight both how regimes adapt when they are threatened, along with the obstacles that prevent regime changes (Schiere et al. 2012); and conditions for the emergence and stabilisation of niches or their access to the status of a regime. However, the STS approach, like the social-ecological approach, has some limitations for dealing with strong-EMA. It fails to consider the stakes and constraints of: (i) the collective management of natural resources; and (ii) farming systems.

To deal with the limitations of these three approaches to implement strong-EMA, Duru et al. (2014, 2015) built a unified framework (DTF-Framework, Fig. 1). They

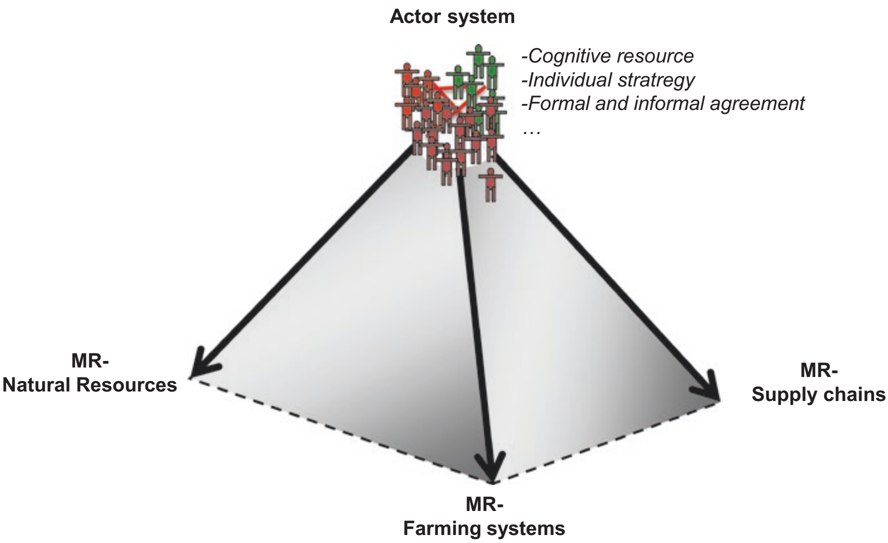

Fig. 1 The DFT framework

use this framework to describe the nature of the complex system concerned by the agroecological transition (AET) of agriculture. The framework is supposed to help thinking on and to organise the transition towards a strong-EMA of local agriculture. It is also used to assess current agricultural production methods and define the types of management and governance systems that promote a strong-EMA. Integrating key concepts of FS, SES and STS approaches, the DTF-Framework represents local agriculture as a system of various actors whose behaviour is determined by formal and informal norms and agreements that interact, via technology, with the material resources specific to farms, supply chains, and natural resource management. Two main types of managed resources are distinguished: material resources (with a biophysical dimension) and cognitive resources. The latter are intangible assets corresponding to the knowledge, beliefs, values, and procedures that actors use to define their objectives, devise their own strategies or alliances, and drive their actions. This framework distinguishes three main systems of material resources (MR) associated with the three management processes: (i) the MR system of the farm (MR-F), used by the farmer for agricultural activities; (ii) the MR system used by actors of each supply chain for collection, processing, and marketing activities (MR-PC); and (iii) the MR system used by actors for management of the natural resources of local agriculture (MR-NT). These MR systems include components that interconnect or interact, such as fields, planned biodiversity (crops, domestic animals), associated biodiversity, machinery, buildings, water resources, and labour for the MR-F system; transportation, storage, and processing equipment and roads for the MR-PC system; and water, soil, and biodiversity (including associated) resources and landscape structures (hedgerows, forests, hydrological network) for the MR-NT system. The three systems of material resources are interdependent, if not interlocked. Material resources, more particularly natural resources, are considered as a social construct and not as an intrinsic characteristic of biophysical objects that become resources for actors. The dimensions and properties that qualify a biophysical object as a resource depend directly on the management process considered. Each management process is based on, and determined by, technologies that are specific to it and used to act upon the concerned resource system. Importantly, within these technologies, information systems determine the methods for characterising resources, the knowledge that actors have about the state of material resources over time, and consequently their actions for managing them in time and space, and ultimately, their ability to meet their performance objectives. Following New Institutional Economics (Williamson 2002) and the Sociology of Organised Action (Crozier and Friedberg 1977), the DTF-Framework considers that formal norms do not completely determine the behaviour of actors. Thus, having limited rationality, actors have a certain degree of freedom and autonomy in their choices and actions.

This integrative conceptual framework can be used to analyse and characterise current forms of agriculture called “Agricultural Systems in a Territory” (ASaT) and to design a future “Territorial AgroEcological System” (TAES) corresponding to a strong-EMA of current ASaT. A key characteristic of the TAES is to organise interactions at the local level between the production systems, in order to take advantage of their complementarities whether they be biophysical (best use of differing soil and/or climate characteristics and/or of access to some natural resources of the farms) and/or production-oriented (e.g. organisation of crop-livestock interactions at the local scale) (Moraine et al. 2017).

Duru et al. (2015) also present a generic transdisciplinary methodological framework for designing, at the local scale, an AET to foster a strong-EMA and allow stakeholders to develop a Territorial AgroEcological System (TAES). This methodology is sketched in Fig. 2.

To support local stakeholders in the design of such transitions, they identified three key methodological challenges:

1. designing, developing and steering a multi-level, multi-domain participatory approach dealing explicitly with trade-off issues;
2. developing boundary objects (conceptual model, computerised-model, indicators, dashboard, etc.) used in the different participatory workshops by stakeholders and enabling trade-off analysis and multicriteria representations;
3. characterising adaptive governance and management enabling stakeholders to locally steer the AET.

The general goal of the TATA-BOX project was to deal with these three challenges through the operationalisation and application of the transdisciplinary methodological framework of Duru et al. (2015). For this, an operational participatory

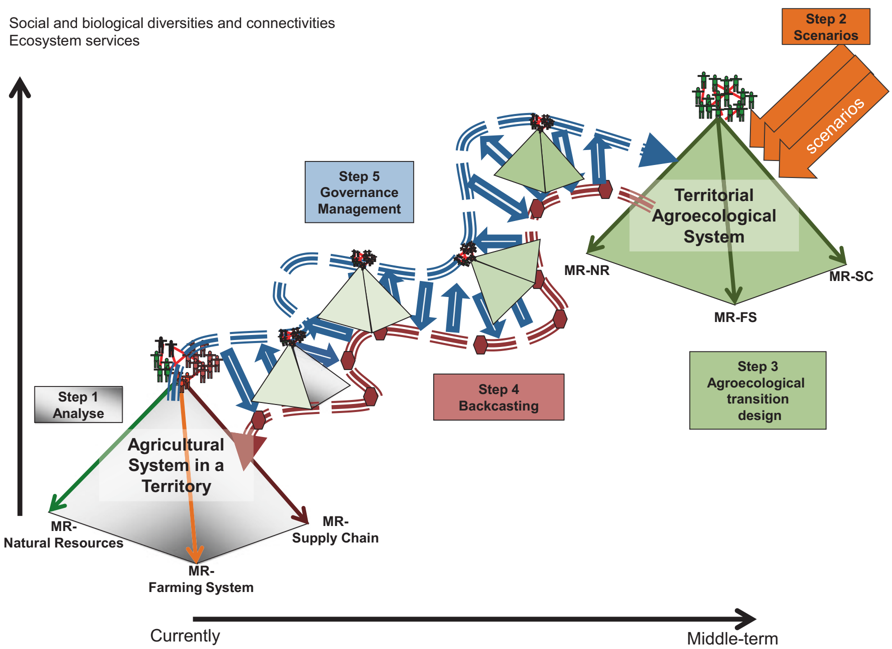

Fig. 2 The conceptual methodology for design and the agroecological transition of a territory

design approach was developed and applied in the Tarn River watershed (south-western France) where farming systems range from arable to livestock ones. In this area water and biodiversity resources are at stake and some collective dynamics toward agroecology already exist.

The TATA-BOX participatory design approach seeks to deal with the interdependences of technological, technical, social, economic and institutional innovations at the farm, supply chain and natural-resources management scales. It is based on the development and support of a "transition arena"; a relatively small group of innovation-oriented stakeholders who reached a consensus on the need and opportunity for systemic changes, and engaged in a process of social learning about future possibilities and opportunities (Foxon et al. 2009). An adhocratic organisation of this arena, based on an institutionalised dialogue involving all the partners and enhancing mutual and permanent adjustments, was organised and implemented.

This book gives some insights of the main outcomes of the TATA-BOX project. It is structured into three sections.

The first section deals with key concepts, challenges and stakes related to agriculture transition: (i) the socio-economic characterisation of the different agriculture models; (ii) the stakes of autonomies and sovereignties; (iii) the AET to a territorialised food system; (iv) the management of uncertainties in AET; (v) the governance of AET; and (vi) the role of actors in the AET.

The second section deals with methodological issues. It contains three chapters. The first describes the transdisciplinary methodology developed and the main outcomes of its application. The second chapter is an assessment of social impacts of the participatory methodology for designing AET developed during the project. The third chapter provides a reflective approach on the characteristics of a research project seeking to support stakeholders in AET design.

The third section opens the field studied during the TATA-BOX project. The first chapter is a foresight on the potential use of information and communication technologies (ICT) for an AET. In the second chapter we asked three other research groups to analyse and discuss outcomes of the TATA-BOX project.

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