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Designing coupled innovations for the sustainability transition of agrifood systems

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A B S T R A C T

Numerous signs underline an urgent need for innovation in the current agriculture and food industries. However, even though the components of the agrifood systems are all strongly interconnected, the design processes to improve their sustainabilities are still mostly managed separately. This frequently leads to innovating in one domain in order to adapt to the constraints or specifications of the other, such as tweaking the farming systems to address processing issues, or the other way round. The objectives of this paper are first to show the limits of such an organization, and second to provide a heuristic framework to organize the design of coupled innovations, by reconnecting the dynamics of innovation in agriculture and food, with a view to improving the whole agrifood system.

Our framework highlights that working at this level requires designing in raw production, exchange, processing, and consumption, while taking into account synergies or antagonisms between upstream and downstream. Thus, the innovations are not only technological – *e.g.* concerning cropping systems or processing – but also organizational and institutional. Based on several examples, in the cereal, linseed, legume, and market-gardening productions, at the junction of agriculture and food sciences, we also show that this perspective of designing coupled innovations calls for a renewed research agenda. Three main domains are thus questioned. First, coupling requires an innovative design process for radical innovations, challenging the coordination of exploration in both domains. Second, the development of "innovation niches" outside the dominant sociotechnical regime, in order to bypass the lock-in from the dominant system, faces the difficulty of favoring the building of renewed networks of actors, which were used to working separately so far. Third, the necessity to share expectations and knowledge, and to design together innovations that suit all sides, leads to making several recommendations for the governance of the design process. Finally, we conclude that the need for innovation in the agrifood systems requires going beyond the historical specialization of skills, and the usual forms of coordination between designers.

1. Introduction

This paper aims to explore the following question: instead of working to increase the sustainability of agriculture and food separately, is it possible to benefit from a reconnection between the innovation dynamics in both domains, by working at the scale of the agrifood system?

The agrifood system (also called food system) is "*the way in which people organize themselves, in space and in time, to obtain and consume their food*" (Malassis, 1994). According to FAO (HLPE, 2014), "*a food system gathers all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food and the outputs of these activities, including socio-economic and environmental outcomes*". The concept of food system refers to numerous interactions between these different activities, as well as between ecological, social, economic and technological dimensions (Rundgren, 2016). For example, in the 2nd part of the XXth century, without the huge increase in cereal yield (which has more than doubled at global scale, Tilman et al., 2002), allowed by the use of fertilizers and pesticides, and by genetic progress, the price of meat could not have decreased so much, and its

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consumption could not have become so popular in developed countries (Pollan, 2006). Today, agrifood systems are strongly managed throughout global exchanges: animals from European livestock being mainly fed by soya meals from South America, the development of soybean-based cropping systems in Argentina or Brazil is enhanced by the development of the cattle industry and the decline of crop-livestock mixed farming in Europe (Lassaletta et al., 2014).

Today, all the components of the agrifood systems are concerned by a huge need for innovation to reach sustainability (Tilman and Clark, 2015). There are numerous reasons for this: increase in food demand (linked to the increase in the human population), but also serious damage to the ecosystem and human health due to current agrifood systems (Baroni et al., 2007). Innovations are required in agriculture, with the aim of saving energy resources, strengthening biodiversity, improving soils and water quality, and decreasing pesticide applications, whose detrimental effects on human health have been clearly shown (Wilson and Tisdell, 2001). Innovations are also required in the ways of eating, with the aim of preventing both nutritional deficiencies and obesity, and in adapting food to particular population needs (young children, pregnant women, the elderly…). Innovations are also required in processing in order to improve the nutritional value of food (for instance: less sugar, less lipids, more omega 3 fatty acids…), in reducing waste (produced and not consumed) and in decreasing the environmental costs of food manufacturing and distribution. However, because both the stakeholders and the researchers are specialists in one or other of these segments, the innovation process in agriculture is today carried out separately from the one in processing or nutrition (Spiertz, 2012). Yet, more and more authors insist on the necessity to act on the whole agrifood system to meet the challenges that apply to agriculture as much as food. For example, Francis et al. (2003) proposed to enlarge the concept of agroecology to the study of the whole food system, admitting that it is impossible to design future agroecological systems, focusing only on the production aspects, on short-term economics, and on local environmental impacts. Similarly, FAO adopts a global view of the food system, both for reducing food losses and waste (HLPE, 2014) and for improving resource use efficiency (FAO-UNEP, 2013 sustainable food system program). Moreover, Lamprinopoulou et al. (2014) argue for enlarging the Agricultural Innovation System approach to the level of the whole agrifood sector. Rundgren (2016) adds "*The rethinking of food as a right, of farming as a management system of the planet and the food system as a common will lead us to develop new institutions that complement the roles of the market and the state*". This calls for considering innovation dynamics in the sustainability transition of agrifood systems, defined as "*a change (in terms of the co-dynamics of technologies, institutions, organizations and social and economic subsystems) of systems towards environmental and social sustainable alternatives, which (…) can be directed to a certain extent*" (Lachman, 2013).

The question of innovation dynamics at the scale of the whole agrifood system is not lacking in scientific literature, but few studies have been developed in comparison with other sectors (Touzard et al., 2015). Studies mainly focus on innovation systems (Lamprinopoulou et al., 2014; Bitzer and Bijman 2015), or on governance of food systems (Sanz-Cañada and Muchnik, 2016; Duru et al., 2015; Rundgren, 2016), but rarely on design. Design, that can be defined as the process that leads to devising artifacts to attain goals (Simon, 1996), is a key point of the innovation process, during which the identity of the designed object is defined: what it will be, what it will do, or what it will make it possible to do. In order to make innovations in agriculture compatible with innovations in processing, in cooking or in consuming, their compatibility must be thought out as soon as they are designed. Yet, while design studies are numerous in agriculture (see synthesis in Meynard et al., 2012; Prost et al., 2016) or in food processing (see for example, Roos et al., 2015), the linkage between these two domains still remains highly limited, and thus questions the levers to be mobilized to steer sustainable innovations throughout the whole agrifood system.

The objective of this paper, written by agronomists, economists and food technologists engaged in design studies, is to specify the traits of an integrated approach to design in agriculture and food, taking the whole of the agrifood system into account. Our analysis is based on several case studies, where various actors worked to develop sustainable agrifood systems. In a first part of this paper, we analyze various ways of linking production, processing and consumption, during the design stage of the innovation process. In a second part, we question the ways of organizing the design within the sociotechnical system, which refers to the governance of change in agrifood systems. Our analysis, and the examples at their basis, mainly concern both the production and the processing of plants.

2. The need for coupling upstream and downstream innovations

2.1. Designing production strategies in order to satisfy downstream constraints

In general, downstream specifications linked to products or processes are imposed to upstream: requirements are transferred to the farmer from his customer. To optimize the processing procedure, the agrifood industry imposes standards of marketable quality to farmers (Allaire, 2010), or draws up contracts with precise specifications (Henson and Humphrey, 2012), thus configuring the raw material. In agriculture, the processing or distribution companies are generally far larger than the farms, and this often contributes to a balance of power detrimental to the farmer (Stuart and Worosz, 2012). Design of farming systems is thus a design under constraints: farmers and agronomists design techniques or cropping systems which make it possible to reach the quality desired by the processors. Its outputs can then take the form of rules for adapting the techniques to the environment, or for excluding some cropping systems. These rules can be transmitted to farmers as advice, but also, in some cases, as orders: the manufacturers impose some rules for adapting practices, or some practices as specifications in contracts (for example, the canning industry imposes irrigation on farmers for the production of vegetables). Moreover, from the manufacturer to the farmer, the process requirements are simplified so as to be easily measured and negotiated at storage and field scales. For example, for a baker, the quality of flour for bread making is linked to the properties of proteins, their extensibility and strength, impacting the final bread aspect. It is translated to the farmer by a minimum grain protein content threshold, and a list of wheat cultivars accepted by the milling industry.

Methods for designing cropping systems have been adapted to this situation. In model-based design, largely practiced by agronomists (Meynard et al., 2012), different methods of multi-criteria sorting identify, among the wide range of technical solutions simulated by the model, the combinations that will best satisfy a hierarchical set of criteria (Bergez et al., 2010). Some of them refer to the farmer's needs, others to those of his industrial customer, and others to societal requirements, such as environment protection. For example, in order to design wheat management plans for diverse outlets, Loyce et al. (2002a) proposed a design support tool, combining an agronomical model to explore various solutions, with a multi-criteria method, based on a non-totally compensatory aggregation to sort them. For ethanol wheat, compared to bread wheat, this tool provided low input crop management plans associated with varieties highly resistant to diseases, based on the following criteria (Loyce et al., 2002b):

1. for the farmer: semi-net margin (to be maximized) and cost per ton of grain (to be minimized);
2. for the environment: energy balance/ha (to be maximized); losses of nitrogen and pesticides used (to be minimized);
3. for the distillers: grain protein content (more than 11.5%, to produce protein-rich draff, and less than 13.6% because excessive protein content can cause draff to stick during drying); hardness of the grain (soft varieties are preferred).