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Diverging and Converging Pathways

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Workshop Theme 3: Pathways towards sustainable agri-food systems – tensions or synergies?

Workshop 3.1: Sustainability of food chains: contested assessments

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In the last two decades the corporate-based food system has been shaken by a loss of reputation, due to concerns about its sustainability. To respond or to anticipate an increasing demand for information about sustainability of products and processes, food businesses have addressed the sustainability issue seriously, investing in technologies, measurement tools, certification schemes and social reporting. This effort has put some pressure on 'alternative food chains' that have introduced the issue among consumers by highlighting the vulnerability of the existing food system, and given consumers the opportunity to choose alternative products and processes with a high sustainability reputation. An increasing number of scholars have developed sustainability assessment of food chains, and, surprisingly, a growing number of studies show that the superiority of local food chains with regard to sustainability is not to be taken for granted. Methodologies with a high reputation for scientific rigour, such as LCA, tend to confirm these limits. However, there is more than a suspicion that existing sustainability metrics are not appropriate to the characteristics of alternative food chains, and that when using them as instruments to influence consumers or policy makers they alter the balance of power in favour of corporates. This workshop aimed to address these issues in relation to European as well as international contexts, and accepted papers from researchers, NGOs and business actors built around the following questions:

- How is the sustainability performance assessment of food systems evolving?
- How do assessments evolve in relation to the evolution of the meaning of sustainability? What is the impact of sustainability assessment on the governance of food chains?
- What are the methodological differences implied in measuring sustainability of local and global food chains?
- Can 'alternative food networks' propose 'alternative sustainability assessment' metrics?
- Are there avenues for collaboration between food movements and global players in creating a level playing field? What can alternative food networks learn from global players? What can global players learn from alternative players?
- How can policies accompany the efforts of actors in the food chains to improve their sustainability performance?

On the use of LCA indicators for the environmental assessment of food systems: the case study of the Mediterranean Diet

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Abstract: The broad recognition of Life Cycle Assessment (LCA) as a science-based methodology for environmental assessment of products has paved the way toward extending it into a framework for sustainability analysis. This work analyses the applicability of the method to environmental sustainability questions posed from different points of view. The case study of the Mediterranean Diet is considered, as it allows formulation of options under two different perspectives on food system sustainability. The approach is inspired by conceptual modelling and focuses on analysis of the modelling paradigms of LCA. Our findings confirm hypotheses expressed in the literature that not all perspectives on sustainable food systems can be captured by such modelling paradigms.

Keywords: Life Cycle Assessment, Mediterranean Diet, conceptual model, Input-Output Analysis, measurement theory, multi-criteria

Introduction

Nowadays environmental, social and health objectives bring into the policy agendas the need to look for novel pathways for the food system, which depart from economy of scale objectives. Within this multi-objective policy landscape, sustainability assessments are expected to play a benchmark role for food system reforms (iPES FOOD, 2015). The tools based on LCA are becoming increasingly popular in informing policy makers about sustainability performance of food systems. LCA methods have gained particular relevance in the European policy arenas especially after the publication of the Product and Organisational Environmental Footprint methods (EC, 2013), whose aim is to "*develop an approach that could be used in existing and new EU policies"* (Galatola, 2014). The heart of LCA is the system-based thinking, called "Life Cycle Thinking" (LCT) determined by product life cycle perspective, when assessing products' performances. Today it is considered a sound base in extending LCA to encompass other dimensions of sustainability, to broaden the object of analysis on meso and macro-scales and to deepen modelled relations and mechanisms (Guinée et al., 2011).

Even if LCA is considered a mature instrument based on science and mathematical rigour, there are few works in the literature which analyse its conceptual structure and properties of the underlying modelling paradigms and the corresponding assumptions and conditions under which it can be correctly applied. The focus is mainly on procedural elements, which explain how to build life cycles and how to compute them with the help of software instruments. The main objective of the present study is to link the "world-views" at the base of LC-thinking to the way footprint numbers are computed by means of LCA. The aim is to further disclose the conceptual model of LCA, which determines the way economic systems are represented for subsequent analysis.

The Mediterranean Diet has been selected as a case study for the analysis of LCA since it allows for identification of options under two different perspectives. The modelling paradigms of LCA are examined in relation to system characteristics considered relevant by each point of view. The study builds upon epistemological analysis of LCA (Heijung, 1997), mathematical modelling employed in computation of LC inventories (Heijungs & Suh, 2002; Suh & Huppes, 2005) and analyses of the way LCA is being used (Freidberg, 2014; Garnett, 2014; Heiskanen, 2000). Our findings confirm the hypothesis expressed in (Garnett, 2014) that not all perspectives on sustainable food systems can be captured within the modelling paradigms of LCA.

Approach

The approach followed within this study starts from the assumption that there can be different points of view about food system sustainability (Galli et al., 2016). Such differences could arise from considering as relevant not completely overlapping sets of food system characteristics.

We adopt the three perspectives on framing food systems sustainability identified in Garnett (2014): efficiency; demand-restrained; and system transformation perspectives. It is important to recognise that there could be more perspectives than these three, but for the purpose of the present study, they provide a sufficient base for analysis. All three perspectives bear ideological components even though options prioritised by each of them are based on scientific findings. The efficiency perspective prioritises technological innovation, demand-restrained – nutrition science evidence linking nutrition and health, and system transformation - knowledge based systems and ecological management of farms (Wezel et al., 2009). While LCA seems to be a useful tool in assessing environmental performances of food systems from efficiency and demand-restraint points of view, its adequacy in capturing system transformation perspective is questionable (Garnett, 2014).

The modelling paradigms on the base of LCA are analysed with the help of techniques from the discipline of conceptual modelling. Conceptual modelling deals with concepts and relations between them with the aim of facilitating communication and understanding among actors involved in the model development and use processes (Wilmont et al., 2013). Its focus is on characteristics of a problem domain considered relevant and captured in models. Conceptual models facilitate linking mental models and perspectives to formal modelling tools implemented within software systems. Figure 1 illustrates how food system perspectives are linked with LCA modelling instruments. In the subsequent sections a more detailed analysis of the LCA conceptual model will be presented. In addition, some problems arising with the system transformation perspective will be discussed through a case study of the Mediterranean Diet.

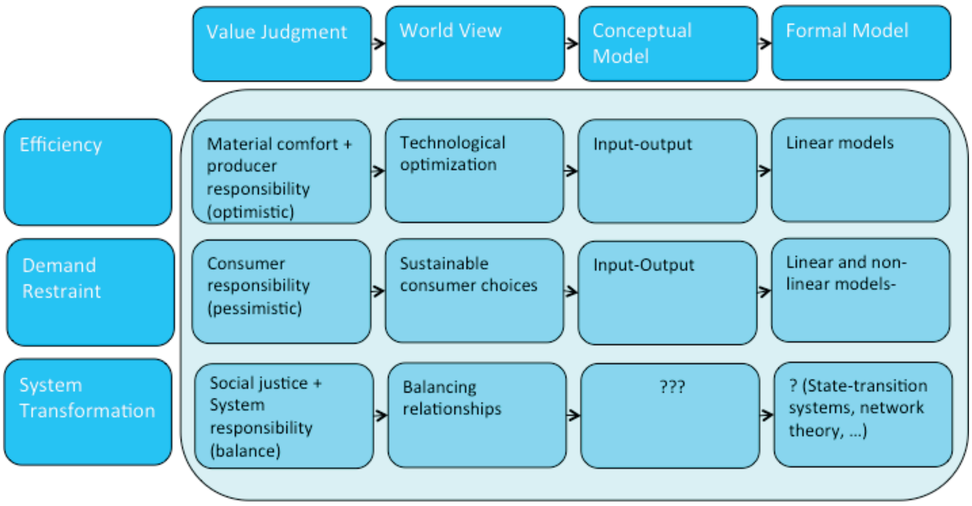

Figure 1. Linking perspectives to models. ***Source : FAO (2015) p. 182 (Ianetta and Stefanova, 2015)***

Conceptual modelling

"Conceptual modelling" is a term and a discipline in its own right, which reflects needs, shared by a number of separate disciplines, for understanding and communication in the processes of model development and use (see Brodie, 2009; Geofrion, 1987). Understanding is conceived on the base of a multi-level interpretation system, which is focusing on the conceptual level and which links aligned mental models (or worldviews) of modellers and users of a model with the formal constructs into which the model is eventually expressed. Formal representations of the models could be on several levels, i.e. expressions recorded in a mathematical notation or in computer code (Figure 2).

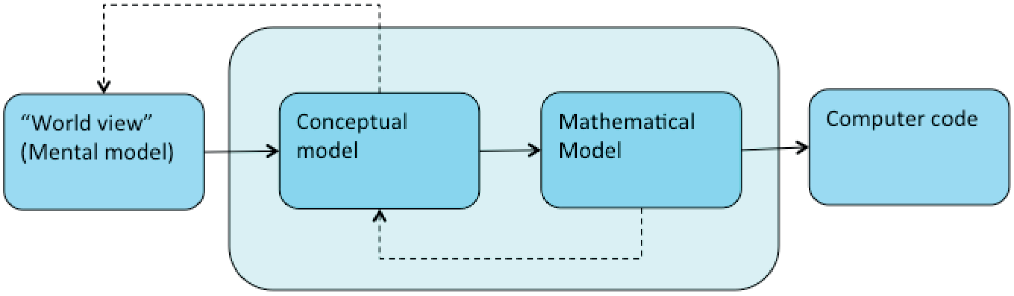

Figure 2. Relations between world-views, conceptual models, mathematical models and software

As a discipline conceptual modelling is strongly influenced by linguistics, cognitive science, philosophy and formal logic. To the authors' knowledge, the linguistic notion of "worldview" (Underhill, 2009) is universally assumed. Some scholars, influenced by constructive logic theories[1], accept also the Sapir-Whorf hypothesis that thought is language-dependent, which has profound consequences for the type of tools designed in order to help communication and understanding (see Partrige et al., 2013 for a discussion, and see Wilmont et al., 2013 and Chekland, 1995 for examples). The paper follows this latter current.

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[1] *As opposed to classical logic, constructive logic theories rely on the conception of "relative truth", with subsequent implications in the way syntax and semantics of formal languages are dealt with, which has far reaching consequences in practical applications.*

Recalling the seminal definition of M. Minski, in the field of Artificial Intelligence (Minski, 1968): "*an object A is a model of an object B for a modeller C if the modeller C can use A in order to answer questions that interest him about B"*, it follows that a model is not an absolute entity, it is subjective and reductionist in a sense that it expresses the "world-view" of the modeller on the problem domain of which B is an entity. It is the modeller who decides how to represent entities to be modelled and which of their characteristics are relevant for his purposes. In this definition the modeller is a collective role, comprising both model developers and users. In an ideal situation, model developers and users share a common "worldview" on a problem domain, which assures that, on the one hand, the relevant user characteristics of B are being captured in A and on the other, that the model user understands the model A and applies it correctly for the purpose it serves. In practice, such ideal situations are rather rare, especially when modelling instruments are being developed and used by many people. The aim of conceptual modelling is to provide tools for learning and reflection, which help model developers and users to align and share "worldviews" about a domain. Such tools are used in a continuous and interactive process, in which mental models are "written" down, shared, and constructed back in the mind by interpreting descriptions and so on, until a shared view is achieved.

A conceptual model of a problem domain can be regarded as a declared or written "worldview". It can be thought of as a language, in terms of which specific models of domain entities can be expressed. In this sense, concepts are analogous to word classes (or parts of speech), while relations between concepts correspond to grammatical rules. Two cognitive processes are central to the model development and use: abstraction and relational reasoning (Wilmont et al., 2013). These processes help in constructing or understanding concepts and relations between them by relating them to a vast body of concrete knowledge and/or experiences about the problem domain. They are used in the continuous and interactive process of meaning formation and learning resulting in "writing" and "reading" of representations and in constructing, aligning and adjusting "mental models" of a domain (Johnson-Laird, 1983).

In the present paper, natural language in combination with mathematical notations will be used, in order to describe the conceptual model of LCA. It is important to note that LCA guidelines and case studies often make use of a convenient graphical notation, aiding the process for representation of economic systems. However, such notation as a language does not have enough expressive power to capture our analysis assumptions.

Conceptual model of LCA

There are three main types of actors involved in the process of modelling and use of the LCA methodology: the LCA expert; the final user (i.e. the client of the LCA expert); and a specialised software system. Footprint numbers are co-produced by the LCA expert and the software system: the LCA expert retains tacit expert knowledge and skill, while codified knowledge and routine calculation tasks are delegated to the ICT system (Collins, 2012). All actors involved need to align their "worldviews" in order to engage with an LCA study. The "worldview" of the ICT system is precisely and explicitly codified, in the course of another similar modelling process in which developers of LCA methodology, mathematical modellers and software developers needed to align to a shared "worldview". The conceptual model of LCA is this latter "worldview".

The codified "worldview" of the ICT system cannot be changed in the course of an LCA study, so it is the LCA expert and his client who need to adapt their "worldviews" to the one codified in the software. Various guidelines and scientific papers in the literature provide useful input in order to help LCA experts in adapting their “worldviews” to those codified in software and in various standards. However, LCA literature is often limited to intuitive explanations, which make explicit only some of the relations between concepts used in the underlying modelling paradigm.

The main concepts employed in LCA are those of economic systems and their configurations to satisfy exogenous demands (these configurations, as we shall see later, are exactly what is meant by “product life cycles”).

LCA literature traces back the origins of LCA to energy analysis, which in its turn is influenced by economic theory, most notably by Input Output Analysis (IOA). The origins of the ideas behind IOA can be traced back to applications of centralised planning of an economy (ten Raa, 1990). Even though LCA as a tool is not intended for planning applications, the process of configuring an economic system to exogenously given (unconstrained) demand levels is central to the calculation of footprints. Such a calculation process certainly bears planning elements, and it is not surprising that literature often reports alternative uses of LCA as a tool for governance of entire supply chains (Freidberg, 2014).

Economic systems

The composite concept of economic system is central to LCA. It is conceptualised through the relation of other simpler concepts of products, flows and processes.

Economic systems are represented as a set of interconnected processes, defined in terms of input and output commodity and environmental flows (Heijungs, 1997; Heijungs & Suh, 2002). The basic assumptions behind the LCA conceptual model are the same, as in the open model for IOA (Christ, 1955), that is:

1. Constant proportions between levels of output and input flows, i.e. single observation in time is sufficient to obtain estimation of all parameters in the process representations;
2. Each product is determined uniquely by a process which produces it. In other words, if a process produces more products, then they are in constant proportion and one of them can be identified as the primary product, while the other products must be primary products of other distinct processes.

These assumptions lead to (a) a condition of non-substitutability of inputs – a change in input proportions of a process leads to the “creation” of a distinct product and its corresponding production process and (b) the level of primary output determines uniquely the level of all inputs and other outputs of a process.

More precisely, an economic system S[2] can be defined by means of ordered sets C, E and P of respectively n products (i.e, names of commodities or services), m environmental interventions (i.e. names of environmental flows) and n processes. Each product and environmental intervention is associated with a unique measurement unit, which allows expression of levels of flows of the corresponding types. Each process $\overline{p_i}$ is represented as an ordered $n + m$ tuple of numbers, standing for commodity or environmental flows:

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[2] *In the sequel, tuples of numbers will be denoted by over-lined letters; scalars and names – by small letters, more complex structures and sets – by capital letters.*

$$\overline{p_i} = \langle c_1^i, \dots, c_n^i;\ e_1^i, \dots, e_m^i \rangle,$$

where:

- Positive numbers indicate output flows (i.e. levels of produced products or emissions to the environment). Negative numbers indicate input flows;
- The primary commodity output of $\overline{p_i}$ is the i-th product p_i and the flow $0 < c_i^i \leq 1$ denotes a fraction of its primary unitary output flow, which is not used within the process itself as input;
- $c_j^i < 0\ (i \neq j)$ are constant efficiency coefficients expressing levels of input commodities necessary for the production of a unit of the primary output;
- $c_j^i > 0\ (i \neq j)$ are constant ratios of secondary outputs produced together with a unit of the primary output;
- e_k^i are constant ratios between so-called environmental interventions and the unitary primary output.

A detailed account of how the above conceptual structures relate to both methodological and computational/mathematical issues about LCA can be found in (Stefanova & Iannetta, 2016)[3].

Demand-centric configuration of economic systems

Demand for a particular product or mix of products is another concept central in both the contexts of LCA and IOA. In LCA, quantities of two or more products of the system can be equalised on the base of the same level of demand for a function. Such demand levels are expressed in terms of functional units, defined exogenously. The central problem of the LCA inventory analysis is: given a demand level for a product and a representation of an economic system find a configuration of the system which satisfies the demand level of the product (Heijung & Suh, 2002). Life Cycles of a product are exactly these demand-centric configurations of economic systems. In such configurations the intermediate commodity outputs are adjusted in such a way as to satisfy the demand level for the product by following backwards the output-input links. Life Cycles are possible to compute, only under the assumptions discussed in the previous section. More precisely, the life cycle of a product p_i with respect to an economic system S and a functional unit f is a n-tuple:

$$LC_f^S(p_i) = \langle o_1 \times \overline{p_1}, \dots, o_n \times \overline{p_n} \rangle,$$

where o_j are the levels of primary outputs of each process in the system scaled-up to match the external demand level for p_i (for complete details see Stefanova & Iannetta, 2016). Processes of S, which do not participate in the life cycle of the product p_i will be null-valued process tuples.

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[3] *Available upon request from the authors.*

Environmental performance

In LCA a system perspective is adopted for measuring environmental performance. In fact, for each impact category LCA makes use of conjoint measurement functions with additive composition rule, which have the following form:

$$I_f^S(p_i) = \sum_{j=1}^{n} o_j \times I(\overline{p_j}),$$

where $I(\overline{p_i})$ are the impact measurement functions per unit primary output flow for each process in the system.

Mediterranean Diet and LCA

This section discusses the conceptual model of LCA in connection with two conceptions of the notion for Mediterranean Diet. In the first case, LCA can be used in analysing options under the demand-restrained perspective, and the consequences of such options on land use or trade intensity patterns. The second conception of the Mediterranean Diet refers to a model of relations characterising the peasant way of farming (van der Ploeg, 2008) and can be adopted in analysing options under the system transformation perspective.

Conceptions of the Mediterranean Diet

The notion of Mediterranean Diet can be perceived in two ways.

First, it is associated with a healthy nutritional model, successfully disseminated across the world through the Mediterranean Diet pyramid (Bach-Faig et al., 2011). The term itself had been coined by the American physiologist Ancel Keys, in order to capture typical dietary habits occurring among poor rural populations in the 1960s in several ecological zones from the Mediterranean Basin (Trichopoulou et al., 2014). The *traditional* Mediterranean diets have been expiring case studies for understanding numerous relations between nutrition and health. Such studies employ the dietary pattern concept, which, abstracting from spatio-temporal contexts and the corresponding food systems, allows capture of such characteristics of a diet which are of interest to health and nutrition professionals. For this reason, specific dietary patterns often need to be updated in order to accommodate changes in other food system characteristics which can impact health (Trichopolou et al., 2014).

A second interpretation is connected with the recognition of the Mediterranean Diet as a cultural heritage by UNESCO. "*The Mediterranean Diet – derived from the Greek word díaita, way of life – is the set of skills, knowledge, rituals, symbols and traditions, ranging from the landscape to the table, which in the Mediterranean basin concerns the crops, harvesting, picking, fishing, animal husbandry, conservation, processing, cooking, and particularly sharing and consuming the cuisine"* (Unesco, 2013). In this conception the Mediterranean diet encompasses more than just food, it makes reference to the entire food system which delivers it and it puts emphasis on social interaction. As mentioned above, *traditional* Mediterranean diets are the diets of poor rural communities from the past (Trichopoulou et al., 2014). As such they are connected with the peasant mode of farming, whose distinguished characteristics are tightly connected with the presence of difficult conditions in the social context of peasantry, in which such a way of farming becomes a "*necessary institution*" (van der Ploeg, 2008, p. 35).

Mediterranean Diet and demand-restrained perspective

Recent studies on the environmental impacts of livestock-based products, has brought attention to the potential environmental impact reductions associated with diets low in animal-based products. There are many LCA studies in the literature, carried from a demand-restraint perspective, which aim to identify synergies between environmental and health outcomes of food systems (Heller, et al., 2013). Many of these studies consider the Mediterranean dietary pattern as an option for environmental assessment (see the first conception discussed above).

This sub-section discusses five studies from the literature, which employ LCA indicators to measure the environmental performance of Mediterranean dietary patterns (Duchin, 2005; Pairotti et al., 2015; Tilman, 2014; Tukker et al., 2011; van Dooren & Aiking, 2015; van Dooren et al., 2015). In LCA dietary patterns are represented with the help of mixing processes with an output - the mix-product, and inputs - the product components of the pattern. Changes of proportions in the mix of products results in the creation of a new process and a commodity representing a different dietary pattern mix of the same product groups. Synergies between health and environmental outcomes are not always reported, because sometimes a reduction in the contribution of the most impacting food-stuffs in a product-mix (i.e. animal-based products) can be offset by the increased contribution of other food-stuffs (see for example Tukker et al., 2011). As a general rule, various product mixes by means of which Mediterranean dietary patterns are represented result in lower environmental impacts, due to the lower share of animal-based products.

As a general rule, all LCA studies assessing diets take as a reference the global production context. Diversely, the consumption context can be national, regional or global, according to the purpose of the study. For example, studies aiming to define nutritional guidelines recommending healthy and environmentally friendly dietary choices often target national or regional consumption contexts (van Dooren et al., 2014 and 2915; Pairotti et al., 2015). Other studies are more concerned about the consequences of dietary change on the agricultural sector and shifts in land use patterns. Such kinds of studies propose to consumers less drastic changes in diet (which, most likely, are also less healthy), but take into account also industrial interests (Duchin, 2005). For example, the Mediterranean dietary pattern in Tukker et al. (2009) is defined in terms of the current average dietary patterns of several countries from South-East Europe (Bulgaria, Romania, Greece and Italy), which is less impactful on the life-stock sector than the Mediterranean patterns recommended by health professionals (Bach-Faig et al., 2011). Further studies explore regional differences in technological efficiencies in the production of the same products and consider impacts on trade flow intensities (Tilman & Clark, 2014). The consumption context of such studies is global. Duchin (2005) defines a modelling framework which allows assessment in a consistent way of the options for change in technological efficiencies, consumption demand (diets), and trade intensities between regions on a global scale.

Mediterranean Diet and system transformation perspective

According to the second conception above, the Mediterranean Diet can be regarded as a model of relations characterising the peasant-mode of farming and induced by its market and consumption relations (van der Ploeg, 2008). As such it could be regarded as an idealistic reference model for guiding food system transitions in the Mediterranean Region. Such idea-based models are useful artefacts in studies, where modelling is employed for the purpose of re-design of systems of human activities (Checkland, 1995). This kind of modelling puts more emphasis on alignment of concepts and relations between the actors involved, since empiric observation is possible only for the present state of the systems. In fact, involved actors must understand which are the important characteristics of real-world systems to be empirically observed and modelled when making reference to a “desired-to-be-future”.

Peasant production mode is characterised by (a) co-production with nature and self-controlled resource base, (b) learning and (c) social interactions (van der Ploeg, 2008, p. 26). This section assumes that these characteristics are considered relevant under the system transformation perspective. The aim is to show that they pose a representational challenge to the assumptions of a primary output and fixed coefficient ratios adopted within the conceptual model of LCA.

Each production cycle in peasant-mode production is built upon resources (natural and social) that are produced and re-produced during previous cycles. This feature alone is challenging in terms of LCA, as change in efficiencies or substitution in inputs can be represented only by introducing distinct processes and products (see previous section on Conceptual model of LCA). From a purely pragmatic point of view it seems unfeasible to add a distinct process for each production cycle in this type of farming.

Secondly, representation of peasant farming inputs in terms of LCA is also problematic. The main types of inputs here are from nature (i.e. ecosystem services) and from humans (labour and knowledge) (van der Ploeg, 2008). In the modelling framework of LCA, only marketable inputs from other production processes (or sectors) are considered and that is why the assumption of fixed coefficient ratios to primary output can seem plausible. Applying it to inputs from nature and to knowledge inputs does not look easy; our knowledge of both nature and humans is not so precise to be expressed in so simple a way.

Thirdly, representation of outputs is problematic too. The outputs of this type of farming are not only marketable products and undesired outputs to nature, but also desired outputs to nature and knowledge, as well as construction of a style of farming which determines the relationships with markets and consumers (van der Ploeg, 2008, p. 26). In particular, reproduced production factors and outputs, not delivered to the market, are variable and cannot be handled by extending the framework of fixed ratios of secondary outputs to primary commodity output (van der Ploeg, 2008, p. 44). Furthermore, it is difficult to identify a unique primary output in such farming modes of production.

Finally, the concept of exogenous demand, adopted in LCA by making reference to functional units, is also problematic. Peasant-mode of production is characterised by limited resource base per unit of product. This clearly poses a constraint on the demand to a system, and the concept of a life cycle being a configuration of a system to an exogenous unconstrained demand needs re-consideration.

Discussion

We are far from claiming a complete analysis of the traditional Mediterranean model for production and consumption. As shown in the previous section, assessing options under the system transformation perspective could be extremely challenging in terms of LCA. This section therefore discusses some fundamental assumptions about empirically observable systems, implied by the performance measurement functions of LCA and the conditions defining relations between concepts within its conceptual model. On the base of this and the analysis in the previous section, a generalisation of the performance measurement functions is proposed, which avoids some of the identified representational problems.

Independence assumption

The additive composition rule (see Environmental performance section above) implies preferential independence assumption among components (phases) of the observable economic systems (Krantz et al., 1971). Note that such independence can only be assumed and not validated through empiric observations. In fact, economic system representations in LCA are cognitively related to observable systems of human activities, but unlike models used in classical sciences, footprints calculated out of them cannot be experimentally validated (Heijungs, 1997). Therefore a preference relation between observable systems cannot be empirically established in order to check whether or not preferential independence condition holds (see Krantz et al., 1971).

Independence is a very strong assumption, which is often hard to demonstrate empirically and enters often into debates of correctness in using additive aggregation rules in MCDA (see Nardo et al., 2005). What does it mean, in a LCA setting? A subset of two or more phases from the observable economic system are assumed to remain in the same preference order with respect to their e.g. climate impacts, whatever the corresponding impacts of the rest of system stages. That is, no matter how we improve and optimise the agricultural phase of a food chain, the rest of the phases can be ordered for their impacts in the same way as before optimisation happened at farm level.

The independence assumption at empirical level is tightly connected to both the use of LCA and to the way concepts are related in its conceptual model. In fact, even if each LCA-study adopts a live-cycle perspective, options compared by it concern only single system stages. The rest of the system remains the same, while corresponding flows are adjusted to satisfy a new level of production due to a change in technological efficiencies.

The additive composition and independence assumption also imply a compensatory logic and the existence of trade-offs between processes participating in the life cycle of a product (Nardo et al., 2005). That is, if for example a phase in a food chain is very efficient (e.g. distribution or large-scale industrial production), it can offset inefficiencies at other phases (e.g. agricultural phase). Such inefficient phases can be identified by performing LCA for hot-spot analysis. Thus, consecutive substitutions of single processes with more efficient options can result in an optimisation process, facilitated by the use of LCA, which aims at **trade-offs minimisation**. Offsetting disadvantages and compensatory principles are also applied when the goal is to identify optimal product mixes (as in the cases discussed in the section on Mediterranean diet and demand-restrained perspective).

The independence assumption is incorporated in the conceptual model too in the form of two assumptions: (a) primary output products and (b) fixed ratios of other inputs and outputs to primary output. That is, if two processes deliver comparable products with different efficiencies, substitution of one of them in the corresponding life cycle does not lead to change of input/output ratios in other processes (only corresponding quantities are adjusted). The argument extends also to situations of input substitutions, as for example in the case of organic and conventional agriculture. In this case we have a number of processes affected, which are independent of the rest (see Nardo et al, 2005, p. 75).

These two conditions at the level of conceptual model (as the section on the Mediterranean diet and system transformation perspective shows) are problematic when considering options under the system transformation perspective.

Generalised performance measurement functions

Based on the analysis in the previous section and identified representation gaps within the conceptual model of LCA, this subsection proposes a generalised form for the performance measurement function. It is generalised in two ways. Firstly, by allowing assumptions of interdependencies between system parts. Secondly, the modelling paradigms can be chosen according to characteristics considered relevant for the purpose and consistent with "desired-to-be-futures". In fact, the term sustainability is carrying a reference to the future, which makes it both ambiguous and difficult to measure (Chekland, 1995).

Suppose an economic system can be defined in terms of n components $p_1, \dots, p_n$. A general form for impact measurement function can be expressed by:

$$I(\langle p_1, \dots, p_n \rangle) = F\left(I_1(p_1), \dots., I_1(p_1)\right).$$

The measurement function above generalises LCA in two ways: first, it is not necessary to define the measurement functions of each system component in terms of the same modelling paradigm; and second, in order to calculate system performance, it is not necessary to use additive composition rule. For example, a function for sustainability performance for Mediterranean Diets from different agro-ecological zones, using geometrical mean composition functions have been proposed in Iannetta (2012). While the challenge of finding appropriate measurement functions in order to consider and asses options prioritised under the system-transformation perspective remains open, the generalised measurement function can be useful in two ways. Firstly, the scientific base of LCA can be better clarified (in terms of conditions, properties and assumptions), if examined in relation to measurement theory (Krants et al., 1971). Secondly, reference to well- developed theoretical frameworks could provide a further step in the development of approaches for sustainability analysis, which differentiate between subjective assumptions and objective procedures based on them, thus allowing consideration of multiple stakeholders' perspectives.

References

Bach-Faig, A., Berry, E.M., Lairon, D., Reguant, J., Trichopoulou, A., Dernini, S., Medina, F.X., Battini, M., Belahsen, R., Miranda, G., & Serra-Majem, L. (2011). Mediterranean diet pyramid today. Science and cultural updates. Public Health Nutrition 14(12A): 2274-2284.

Brodie, M. (2009). John Mylopoulos: sowing seeds of conceptual modelling. In A.T. Borgida et al. (Eds) Conceptual Modelling: Foundations and Applications. Springer Berlin Heidelberg.

Collins, H.M. (2012). Expert systems and the science of knowledge. In Bijker et.al. (Eds) The Social Construction of Technological Systems, New Directions in the Sociology and History of Technology. Cambridge, Massachusetts; London, England: The MIT Press.

Checkland, P. (1995). Systems theory and management thinking. In Ellis et al. (Eds) Critical Issues in Systems Theory and Practice. New York: Springer Science+Business Media.

Christ, C.F. (1955). A review of Input-Output Analysis. In: Input-Output Analysis: an Appraisal. Princeton University Press. Available online: http://www.nber.org/chapters/c2866 (accessed on 27 03 2016).

Duchin, F. (2005). Sustainable consumption of food: a framework for analysing scenarios about changes in diets. Journal of Industrial Ecology 2: 1-2.

EC (2013). Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organizations. PEF and OEF guides.

FAO (2015). Proceedings of an International workshop: Assessing Sustainable diets within the Sustainability of Food Systems, 14th September 2014, FAO, Roma. Available online: http://www.fao.org/3/a-i4806e.pdf (Accessed on 05 03 2018).

Freidberg S. (2014). Footprint technopolitics. Geoforum 55: 178-139.

Galatola, M., & Pant, R. (2014). Reply to the editorial “Product environmental footprint—breakthrough or breakdown for policy implementation of life cycle assessment?” written by Professor Finkbeiner (Int J Life Cycle Assess 19(2): 266–271). International Journal of Life Cycle Assessment 19: 356-1360.

Galli, F., Bartolini F., & Brunori, G. (2016). Handling diversity of visions and priorities in food chain sustainability assessment. Sustainability 8(4): 305. doi: 10.3390/su8040305.

Garnett, T. (2014). Three perspectives on sustainable food security: efficiency, demand restraint, food system transformation. What role for Life Cycle Assessment? Journal of Cleaner Production 73: 10-18.

Geoffrion, A.M. (1987). An introduction to structured modelling, Management Science 33(5) 547-588.

Guinée, J.B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Ekvall, T., & Rydberg, T. (2011). Life Cycle Assessment: past, present, and future. Environmental Science and Technology 45: 90-96.

Heijungs, R. (1997). Economic drama and the environmental stage: formal derivation of algorithmic tools for environmental analysis and decision-support from unified epistemological principle. Ph.D. Thesis, Rijskuniversiteit te Leiden, Leiden, the Netherlands.

Heijungs, R., & Suh, S. (2002). The Computational Structure of Life Cycle Assessment. Dordrecht/Boston/London: Kluwer Academic Publishers.

Heiskanen, E. (2000). Managers' interpretation of LCA: enlightenment and responsibility or confusion and denial? Business Strategy and the Environment 9: 239-254.

Heller, M.C., Keoleian, G.A., & Willet, W.C. (2013). Toward a life cycle-based, diet-level framework for food environmental impacts and nutritional quality assessment: a critical review. Environmental Science and Technology 47(22): 13632-13647.

iPES FOOD (2015). The new science of sustainable food systems. Overcoming barriers to food systems reform. Report 01, International panel of experts on sustainable food systems. Available online: http://www.ipes-food.org/reports (accessed on 03 12 2015).

Krantz, D.H., Luce R.D., Suppers P., & Tversky, A., (1971). Foundations of Measurement, Volume1 Additive and Polynomial Representations. New York and London: Academic Press.

Iannetta, M. (2012). Expert system for evaluating the sustainability of Mediterranean diets by an integrated product index (IPI-SMeD) in a specific agro-ecological zone. Options Méditerranéennes, Series B: Studies and Research, No. 70. CIHEAM.

Iannetta, M., & Stefanova, M. (2015). On the Use of Environmental Life Cycle Indicators for Sustainability Assessment of Mediterranean Diets. In FAO (2015).

Johnson-Laird, P. (1983). Mental Models: Towards a Cognitive Science Of Language, Inference, and Consciousness. Cambridge: Cambridge University Press.

Minski, M.L. (1968). Matter, Mind and Models. In M.L. Minski (Ed.) Semantic Information Processing. MIT Press. Available online: http://web.media.mit.edu/~minsky/abstracts.html (accessed on 22 December 2015).

Nardo, M., Saisana, M., Saltelli, A., & Tarantola, S. (2005). Knowledge Economy Indicators, Input to Handbook of Good Practices for Composite Indicators' Development, FP6, CIS8-CT-2004-502529 KEI, Deliverable 5.2.

Pairotti, M.B., Cerutti, A.K., Martini, F., Vesce E., Padovan D., & Beltramo, R. (2015). Energy consumption and GHG emissions of the Mediterranean Diet: a systemic assessment using hybrid LCA-IO method. Journal of Cleaner Production 103: 507-516.

Partridge, C., Gonzalez-Perez, C., & Henderson-Sellers, B. (2013). Are conceptual models concept models? In W. Ng et al. (Eds) Conceptual Modelling ER 2013, LMCS 8217.

Stefanova, M., & Iannetta, M. (2016). Food system transformation: can LCA help? TR BIOAG-P000-001, ENEA-Bologna.

Suh, S., & Huppes, G. (2005). Methods for Life Cycle Inventory of a product, Journal of Cleaner Production 13: 687-697.

Ten Raa, (1990). National accounts, planning and prices. Nieuw Archief voor Wiskunde (Serie IV), 8(3): 375-385.

Tilman D., & Clark, M. (2014). Global diets link environmental sustainability and human health. Nature (515): 518-522.

Trichopoulou, A., Martinez-González, M.A., Tong, T.Y.N., Forouhi, N.G., Khandelwal, S., Prabhakaran, D., Mozaffarian, D., & de Lorgeril, M. (2014). Definition and potential health benefits of the Mediterranean Diet: views from experts around the world, BMC Medicine 12: 112.

Tukker, A., Goldbohm, R.A., de Koning, A., Verheijden, M., Kleijn, R., Wolf, O., Pérez-Domiguez, I., & Rueda-Cantucge, J. (2011). Environmental impacts of change to healthier diets in Europe. Ecological Economics 70: 1776-1788.

UNESCO (2013). Mediterranean Diet. http://www.unesco.org/culture/ich/en/RL/mediterranean-diet-00884 (accessed on 25 March, 2016).

Van der Ploeg, J.D. (2008). The New Peasantries. Struggle for Autonomy and Sustainability in an Era of Empire and Globalisation. FiSH Books.

van Dooren, C., & Aiking, H. (2015). Defining a nutritionally healthy, environmentally friendly, and culturally acceptable Low Lands Diet. The international Journal of Life Cycle Assessment Volume 21(5): 688–700. doi: 10.1007/s11367-015-1007-3.

van Dooren, C., Marinussen, M., Blonk, H., Aiking, H., & Vellinga, P. (2014). Exploring dietary guidelines based on ecological and nutritional values: a comparison of six dietary patterns. Food Policy 44: 36-46.

Wezel, A., Bellon, S., Dore, T., Francis, C., Vallod, D., & David, C. (2009). Agroecology as a science, a movement and a practice. A review. Agronomy for Sustainable Development 29: 503-515.

Wilmont, I., Hengeveld, S., Barendsen, E., & Hoppenbrouwers, S. (2013). In W. Ng et al. (Eds) Conceptual Modelling. ER 2013, LMCS 8217.

Long-term sustainability assessment of market-gardening farms involved in short supply chains: a case study in the South of France

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Abstract: In France, one market-gardening farm in two is nowadays involved in short supply chains (SSC). Involvement in SSC has been proved to be a driver of farming system modifications and can therefore affect farm sustainability. Impacts of SSC at farm scale have been however little assessed at medium and long term. Our study aimed therefore at analysing why and how market-gardening farms involved in SSC evolved over time, and at assessing current farm sustainability. Comprehensive interviews were conducted from April to July 2015 in 28 market-gardening farms located in two areas of South of France to describe and analyse their evolution trajectories from the time when they were first involved in SSC up to the present day. Current functioning was analysed as well and combined with a sustainability assessment. We found that farm strategies and evolution trajectories differed mainly in the intensity of SSC use, the complexity of the marketing strategy, the level of crop diversity and the intensity of input use. Farms that were most involved in SSC displayed the better agro-ecological sustainability and a higher contribution to local economy and life. The economic assessment resulted in contrasting scores depending on farm types and sustainability components but the available farming income was a shared issue within the surveyed farms. The social assessment highlighted mediocre working conditions but life quality was assessed as correct to good by the farmers. We highlighted a high diversity of situations regarding evolution trajectories and current farm functioning, and this diversity affected sustainability assessment results.

Keywords: Short supply chain, market-gardening, farm sustainability, assessment, evolution trajectory, crop diversity, input use

Introduction

Short supply chains (SSC), defined as chains based on no to one intermediary between the producer and the consumers, have seen a significant development over the past fifteen years and represent, depending on the source, 6 to 15% of food purchases today in France (Allain, 2015; Chiffoleau, 2016). One farm in five is today involved in SSC and this share reaches one in two regarding market-gardening farms (Rosenwald, 2012). In addition, one market-gardening farm in three markets at least three quarters of its production through SSC (Rosenwald, 2012). Social and economic sustainability at the territorial scale are generally emphasised (Traversac & Kébir, 2009; Kneafsey et al., 2013): a higher multiplier effect on local economies is described, as well as impacts on maintaining local employment. On the other hand, environmental sustainability remains under discussion; for instance, local appears not to be a sufficient feature to ensure a reduction in greenhouse gas emissions (Redlingshöfer, 2008; Kneafsey et al., 2013). Impacts at farm scale remain under discussion as well. For example, SSC are said to allow retention of a higher share of value added, whereas higher labour inputs and possible higher production costs are described (Chiffoleau, 2008; Traversac & Kébir, 2009; Kneafsey et al., 2013). Moreover, involvement in SSC has been proved to be a driver of farming system modifications and therefore affects farm sustainability (Navarrete, 2009; Aubry et al., 2011; Lamine et al., 2014; Navarrete et al., 2015). Producers involved in SSC combine different activities (at the least production, marketing and promoting) and often combine different marketing chains (including long and short supply chains) (Kneafsey et al., 2013) making farm management more complex and increasing workload. In addition, in market-gardening farms, a growing involvement in SSC is said to go hand in hand with crop diversification in order to provide a range of products fitting consumer requirements (Navarrete, 2009; Aubry et al., 2011). Such a crop diversification also adds complexity to farm management but can result in crop management simplification (Aubry et al., 2011). Besides, marketing standards are said to be more flexible regarding cosmetic standards but more demanding regarding taste, which can foster changes in crop management (Bressoud, 2010). Combined with crop diversification, this has been described in some cases as leading directly or indirectly to input use reduction (Navarrete, 2009; Bressoud, 2010; Aubry et al., 2011; Petit, 2013). All these observations remain scattered and were not assessed at medium and long term: there is a lack of baseline and horizontal data to discuss thoroughly the benefits and drawbacks of SSC at different scales (Kneafsey et al., 2013). Our studies aimed therefore (i) at analysing why and how market-gardening farms involved in SSC evolve over time and (ii) at assessing their current sustainability.

Materials and Methods

Data collection: surveys on market-gardening farms in the South of France

Comprehensive surveys were conducted from April to July 2015 in 28 market-gardening farms located in two areas of the South of France which represented different dynamics: (1) the Roussillon plain, located around Perpignan (urban area of about 305,900 inhabitants), and (2) the peri-urban area around Toulouse (urban area of 1,270,800 inhabitants). The Roussillon plain, located in the Eastern Pyrenees plain used to be a major market-gardening production basin in France and hosts the Saint Charles international hub for marketing, transport and logistics of fruits and vegetables. The production basin is however nowadays in decline. The peri-urban area of Toulouse is influenced by the presence of a major urban area and by the presence of a national wholesale market. Farms were sampled according to the following criteria: (i) market-gardening represented a significant share of the farm income generating activity (at least 50% of the revenue); and (ii) farmers managed the farm for at least five years. In addition, the sample was built to cover a range in marketing strategies (SSC with no intermediary, SSC with one intermediary, long supply chain (LSC)) and in crop management styles (conventional, low input, organic farming). Farm sampling in the Roussillon plain benefited from surveys carried out in 2006 (Godard, 2006) or 2010 (Demarque, 2010).

Figure 1. Location of the studied areas: (1) the Roussillon plain, (2) the Toulouse peri-urban belt. *(Source: © Geoportail)*

Table 1. Main characteristics of the sampled farms

	1: Roussillon plain	**2: Toulouse peri-urban belt**
Average farm size		
Total	9 ha	15.5 ha
In market-gardening	2.9 ha	4.8 ha
Under shelters[1]	1.1 ha	0.4 ha
Number of workers (Annual Work Unit AWU)	3.6 AWU	2.9 AWU
Other farming activity	Arboriculture (73%) Viticulture, Livestock - poultry, pigs; Plantlet production; Aromatic plants	Grain crops (38%) Arboriculture Plantlet production Horticulture
Crop management style		
Organic farming	8	6
Low input	0	3
High input	7	5
Marketing chains		
Direct SSC	10	12
SSC with one intermediary	7	9
LSC	9	5

[1] *Unheated high plastic tunnels or multispan plastic greenhouses with soil cultivation*

The interviews were semi-structured in order to collect both quantitative and qualitative data. They lasted from 1 to 2.5 hours and were recorded. We characterised the current functioning regarding farming systems, labour organisation, and marketing outlets with factual data. We also examined farmers' reasons for the current situation and characterised how and why the farm evolved since SSC were first used. Four main topics were questioned: (i) the overall characteristics of the farm were describe - general history, objectives, family, main activities; (ii) the various marketing chains were described by their type, relative importance and distinctive features (e.g. number of intermediaries, location, standards, use of resale, etc.); (iii) the market-gardening cropping systems were described by the cropped species, the spatial and temporal organisation and the crop technical management. Pest and disease management was recorded in more detail because it is a major bottleneck of market-gardening with a focus on four species: tomato, cucumber, melon and lettuce; and (iv) production means, including land, equipment and labour were questioned: information on labour included the number and types of workers and labour organisation. In addition, specific questions were asked to assess current farm sustainability regarding (i) working conditions: workload, peak work periods and satisfaction at work, and (ii) economic results: current farmer income, satisfaction regarding treasury and financing ability. Farmers were questioned as well about the main difficulties they faced (technical, economic, organisational, etc.) and about their projects for the farm (regarding production, commercialisation, equipment, etc.).

Analysis of farming systems and farm sustainability assessment

Analysis of farming systems

We built a farm typology to characterise current farm functioning (Landais, 1998; Alavarez et al., 2014). Based on the surveys, each farm was portrayed through three set of variables describing (i) the marketing strategy, (ii) the agronomic strategy, and (iii) the farm production means and other structural characteristics. The marketing strategy described the marketing chain or the combination of marketing chains used in the farm, as well as the main features of the chains. The agronomical strategy was defined with a focus on the market-gardening activity by the nature of the crop, their organisation in time and space and their management. Farm production means included labour, land and equipment. Three successive multiple correspondence analysis (Baccini & Besse, 2004) were performed using R software (R version 3.1.2, package FactoMineR; R Core Team, 2014) to identify the variables that discriminate farms the most. The first analysis allowed identification of the discriminant variables regarding marketing strategy. The second analysis allowed the same regarding agronomic strategy. The third and final analysis used the previous analysis results to include variables from the three sets (Table 2). Based on the selected variables, theoretical types were identified and described.

Table 2. Variables used to describe farm functioning

	Variable	Variable description
Marketing strategy	Share of SSC	1 : SSC in minority, only direct sale 2 : average share of SSC 3 : SSC dominant, combined with LSC 4 : only SSC
	Combination type	1 : only one SC 2 : from 2 to 4 SC, combining SSC and LSC 3 : from 2 to 4 SSC 4 : more than 5 SC, short and long
	Use of resale	0 : no, 1 : yes

Agronomic strategy regarding MG[1] crops	Crop diversity	Weak : 2 to 5 species Average : 6 to 17, seasonal difference High : 15 to 30, all year long Very high : more than 30
	Crop spatial organisation	Balanced, With niches, Specialised
	Use of crop rotation	None, Only for specific crops, Occasional, Systematic
	Crop protection[2]	1 : chemical pesticide only, used systematically or after detection 2 : chemical pesticide and biological control products, used systematically or after detection 3 : biological control products only, used systematically or after detection 4 : biological control products used only after detection or no intervention
Structural characteristics	MG[1] area / total farming area	1 : 0 to 30% 2 : 31 to 60% 3 : 61 to 100%
	Sheltered crop area / MG[1] area	1 : 0 to 10% 2 : 0.11 to 0.30% 3 : 0.31 to 100%
	Other farming activity	None, Grain crops, Perennial crops, Diverse

[1]Market-gardening; [2:] Focus on tomato, cucumber, melon and lettuce

Farm sustainability assessment

To our knowledge, no existing assessment methods account for the specific features of market-gardening farms (e.g. diverse production systems including protected crops, high crop diversity, lower field and farm size, diverse marketing chains, labour intensive systems , etc.). We therefore built a sustainability assessment framework based on existing French methods, namely the IDEA method (Zahm et al., 2007, 2008), the GEDEAB method (Favreau, 2013) and the RefAB framework (Fourrié et al., 2013). We also used the framework proposed by Navarrete et al. (2015) for market-gardening systems. Our assessment framework included three dimensions: the agro-ecological dimension, the economic dimension and the socio-territorial dimension; 10 components; and 28 indicators (as shown in Table 3). The components and the indicators (including the scoring system) were either directly or indirectly derived from the methods and frameworks cited hereinabove. When necessary, they were adapted to the studied farming systems and to the data available from the surveys. Each indicator was quantified with a numerical score and the scores of indicators belonging to the same component were added. Assessment results were analysed in two ways: (i) scores were computed for each component and each farm; and (ii) for each farm type of the functional typology.

Evolution trajectory analysis

Timelines were built for each surveyed farmer according to Moulin et al. (2008) to represent for each of the four questioned topics how the farming system changed, i.e. the evolution trajectory. Timelines displayed evolutions of the marketing strategy, of the agronomical strategy and of the production means. Interactions between marketing, agronomical and/or production means dimensions were shown as well. Coherence phases were defined on the timelines as periods where the marketing strategy and the agronomical strategy were relatively stable and consistent. Coherence phases referred therefore to a general coherence of farm organisation and management (Moulin et al., 2008). We hypothesised that the evolution of marketing strategies on one hand and of agronomic strategies on the other were key elements to analyse farming system evolutions. We therefore built an *a priori* typology of evolution trajectories based on these two items. In addition, we described the main characteristics of the farms representing each theoretical type including farm overall characteristics and farm production means. The speed of changes, either influenced by the external environment (climatic event, price evolutions, regulations, marketing opportunities, etc.) or internal to the farming system (technical or organisational issue, change regarding the household, etc.), were identified from the farmer speech and showed on the timelines.

Table 3. Farm sustainability assessment framework

Component	Indicator	Definition	Best score	Source
Agroecological dimension				
Diversity	Diversity of annual crops	Number of annual species cropped per year at farm scale	12	1*
	Diversity of perennial crops	Number of perennial species at farm scale	8	1**
Organisation of space	Practices in favour of biodiversity	e.g. plantation of hedges or flower strips, presence of fallow areas	6	1-4***
	Cropping pattern	Crop spatial allocation: specialised, with niches, balanced	7	1**
	Crop rotation	Type of crop rotation: none, for specific crops only, irregular, systematic	7	2-4**
Farming practices	Crop protection practices	Dependence on chemical pesticides: pesticide type, systematic use or not	12	1**
	Soil organic matter management	Frequency and type of organic matter inputs	8	1**
	Use of fossil inputs	Dependence to fossil inputs: fertilisers, plastic mulch (including recycling)	10	
Economic dimension				
Income	Farmer income	Available income per non salaried worker (compared to national legal minimum wage)	20	1**
Robustness	Production diversity	Share of the main crop	8	1
	Marketing chain diversity	Share of the main client, use of direct sale	6	1*
	Farm activity diversity	Presence of other activity/ies than market-gardening (including agri-tourism, commerce)	4	3**
Autonomy	Autonomy regarding inputs	Intensity of external input use (seeds and plantlets, fertilisers and manures, pesticides)	4	1-3***
	Autonomy regarding land	Share of land in property	2	
Independence	Treasury	Farmer satisfaction regarding the farm treasury	4	4***
	Financial ability	Farmer satisfaction regarding the farm financial ability	4	
Socio-territorial dimension				

Working conditions	Workload	Number of hours per week (compared to 40h)	10	3*
	Work intensity	Number of overloaded weeks per year (compared to 10)	10	1*
	Status of workers	Intensity of volunteer, family or seasonal work	5	3**
	Collective work	Use of collective equipment or services, involvement in professional networks	5	1*
Quality of life	Satisfaction	Estimation from farmer speech	10	1*
	Technical satisfaction	Estimation from farmer speech	10	
	Adaptation capacity	Farmer adaptation regarding weather or economical hazards, or other difficulties	2	3***
	Transferability perspectives	Probability of farm existence within 10 years	3	1*
Contribution to local economy and life	Contribution to employment	Land per worker; job creation for 5 years	8	1**
	Use of SSC	Share of SSC	8	2
	Multifunctionality	Presence of agri-tourism, pedagogical farm	4	1*
	Social involvement	Involvement in local professional networks, presence of on-farm direct sale	5	2*

(Source - 1: Zahm et al., 2007, 2008; 2: Favreau, 2013; 3: Fourrié et al., 2013; 4: Navarrete et al., 2015
**** indicates that the attribute targeted by the indicator was derived from previous work(s) whereas the indicator definition, calculation mode and parameters were created for our study; ** indicates that the indicator calculation mode and parameters were adapted for our study; * indicates that only the indicator parameters were adapted).*

Results

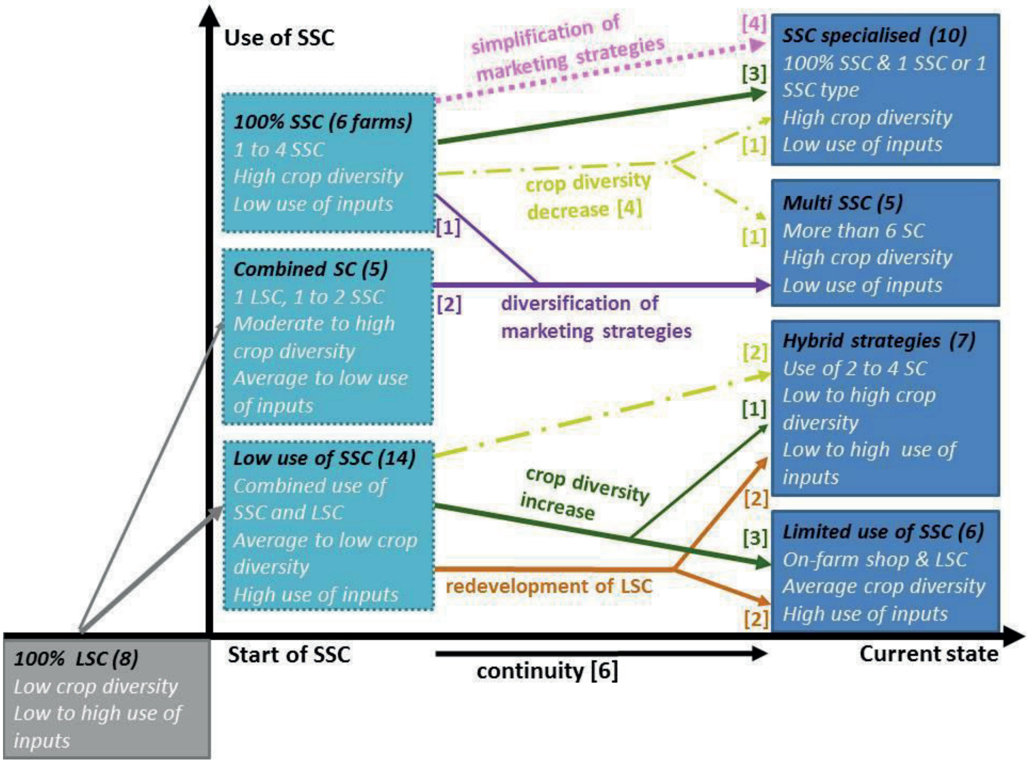

Figure 2. Evolution trajectories and current farm functioning of the 28 farms studied. *(Left boxes display theoretical farm types when they start to use SSC. Right boxes display current theoretical farm types. The number of farms per type is displayed between brackets. The six evolution trajectories are displayed between the boxes. The number of farms per trajectory is displayed between square brackets).*

Analysis of current farm functioning and of farm sustainability

The multiple correspondence analysis highlighted six discriminant variables. Two variables described the marketing strategy: the ‘combination type’ and the ‘share of SSC’. The others described the agronomic strategy with variables referring to the level and the organisation of crop diversity (crop spatial organisation, crop diversity, use of crop rotation) and the variable describing crop protection, which was used as an indicator of the level of input use. Four current farm types were built based on these variables (Figure 2). In addition to differences regarding marketing and agronomic functioning, they also differed regarding production means. They differed as well regarding sustainability assessment results (Table 4).

The first type, named **‘Limited use of SSC’**, grouped together six farms that combined on-farm sale with LSC. They were the biggest farms of the samples regarding the total farming area (median: 18 ha) and the number of workers (median: 6.2 annual work units AWU). The share of sheltered crops was low (<15%). Another farming activity was important regarding the dedicated area or the share within the revenue: arboriculture (three farms), grain crops (two farms) and aromatic plants (one farm). Crop diversity regarding market-gardening crops on one hand and regarding perennial crops on the other hand was low to moderate. These farms used on average a high input management style. One farm had recently converted to organic farming but still relied on a high use of organic inputs. As a consequence of the cited characteristics regarding crop diversity and input use, agro-ecological sustainability results were mediocre. Socio-territorial sustainability was contrasting. Working conditions were assessed as mediocre due to high workloads. On the other hand, the contribution to local economy was assessed as moderate and life quality was assessed as correct. Economic sustainability was contrasted as well. Autonomy was assessed as poor. On the other hand, results regarding income and economic robustness were average, and economic independence was assessed as correct.

The second type, named **'Hybrid strategies'**, grouped together seven farms that displayed a balanced combination of SSC and LSC since LSC appeared to be as important as SSC based on the farmer speech. SSC with one intermediary were frequently used and sometimes combined with direct sale (market or on-farm shop). Total farming area amounted to 3.2 ha and was lower than the sample median value. Market-gardening occupied on average 50% of the total area. The number of workers amounted to 2 AWU that corresponded to the sample median value. Assessment results were close to the one of the first group regarding agro-ecological and socio-territorial sustainability. As for economic sustainability, results were close regarding robustness and autonomy but lower regarding income and independency.

The third type, named **'Multi SSC'**, combined LSC and SSC as well but stood out since it grouped together five farms that combined various SSC including direct sale (on-farm shop, on-farm picking market) and SSC with one intermediary (grocer, collective producer shop, out-of-home catering). Total farming area (median: 11.4 ha) and number of workers (median: 4 AWU) were higher than the sample median values. The share of market-gardening area in the total farming was high and amounted to 70%. On the other hand, the share of sheltered crops was low (<10%). This type included four organic farms out of five and the fifth one used low inputs. Assessment results regarding agro-ecological sustainability were therefore good. Results regarding working conditions were poor and similar to the previous types whereas life quality and contribution to local economy were good and similar or better to the previous types. As for economic sustainability, robustness and autonomy were assessed as good but income and independency were assessed as mediocre.

The fourth type, named **'SSC specialised'**, grouped together ten farms that were involved only in SSC and that used either a unique SC based on direct sale (CSA (Community Supported Agriculture) network, on-farm shop) or only one type of SSC (CSA networks, grocers). Eight farms out of ten were involved in CSA networks. Except for one farm with a large area dedicated to grain crops, they were characterised by low farming areas (median: 3.1 ha). Market-gardening occupied 50% of the total area and the share of sheltered crops was average. The number of workers amounted to 2 AWU. This type included seven organic farms and two farms using low inputs to fulfil the CSA network standards. Four farmers began their activity between four to six years ago. A particular profile was included in this group. It was a farmer close to retirement who used to combine a LSC with an on-farm shop and who currently maintained the on-farm shop only but was involved at the same time in his son's business. Sustainability assessment results were close to the ones of the previous group. The most significant difference concerned economic independence, which was assessed as better and could be related to the important presence of CSA networks in this group.

Table 4. Farm sustainability assessment results. *Each score is relatively coloured from red to green based on the best scores defined for each component*.

	Agroecological dimension			Economic dimension				Socio-territorial dimension		
	Diversity	Organisation	Farming practices	Income	Robustness	Autonomy	Independence	Working condition	Life quality	Local
Best score	***20***	***20***	***30***	***20***	***18***	***6***	***8***	***30***	***25***	***25***
1-Limited SSC	6	5	8	9	9	2	6	9	17	12
2-Hybrid	6	4	11	5	7	3	3	7	14	13
3-Multi SC	16	13	23	6	15	5	3	8	17	17
4-SSC specialized	12	15	21	6	14	4	5	11	20	15

Evolution trajectories

We characterised six evolution trajectories (Figure 2). Examples for each trajectory are displayed in Figure 3. Three main change drivers were identified from the evolution trajectories: opportunities (access to new chains, farm extension), dissatisfaction regarding how SC worked, and difficulties regarding crop management or labour organisation.

Two trajectories depicted mainly changes related to the level of crop diversity. The most encountered trajectory (seven farms) depicted **an increase in the level of crop diversity** (example in Figure 2a). Two types of farms were concerned. The first type grouped together farms that used to market through LSC only before developing an on-farm shop. They diversified crops to supply the on-farm shop but the use of SSC in the farm remained on average limited. Crop management was based on a high use of inputs all along the trajectory. They belonged currently to the types ‘Limited use of SSC’ and ‘Hybrid strategies’. The second type grouped together farms dedicated to SSC that increased crop diversity to supply CSA networks or an on-farm shop as a unique marketing chain. In that case, crop management was mainly based on a low use of inputs all along the trajectory. They belonged currently to the type ‘SSC specialised’. On the other hand, four farm evolution trajectories were marked by **a reduction in the level of crop diversity** (example in Figure 2b). In these farms, SSC with one intermediary were present or dominant. They highlighted also total farming areas and market-gardening areas lower than the sample averages. In two farms, the reduction in crop diversity was related to the development of a resale activity combined with a production volume increase for the remaining crops. They belonged currently to three different types: ‘Limited use of SSC’, ‘Hybrid strategies’ and ‘Multi SSC’.

Regarding marketing, three trajectories were observed. First, four farms **simplified their marketing strategy** to supply one or two CSA networks and belonged currently to the type ‘SSC specialised’ (example in Figure 2c). In two cases, they went along with an increase in crop diversity and a reduction in input use to fulfil the CSA network standards. On the other hand, three farms **diversified their marketing channels** (example in Figure 2d): they were from the beginning significantly or entirely involved in SSC but increased the number of SSC types in their strategies and belonged currently to the type ‘Multi SSC’. They were also characterised by the use of SSC with one intermediary and/or of a LSC. They had the organic farming label or used little inputs. They highlighted total farming areas and market-gardening areas higher than the sample averages. Lastly, four farms depicted **a redevelopment of LSC** in their marketing strategy (example in Figure 2e) and currently belonged to the types ‘Limited use of SSC’ or ‘Hybrid strategies’. Two types of farms were concerned. The first type specialised in one crop (tomato, with several tomato types and varieties) or one crop type (aromatic plants) and took advantage of a commercial niche. Farming area was higher than the sample average. The second type had stopped the use of SSC for the moment due to personal issues.

Eventually, the trajectory named ‘Continuity’ grouped together the remaining six farms because no noteworthy changes except adjustments were visible. Two types of farms were concerned. Most of them combined SSC and LSC, highlighted high total farming area and had another farming activity (arboriculture, horticulture or viticulture). The others were recent farms specialised in market-gardening and using mainly direct sales (CSA, market, baskets).

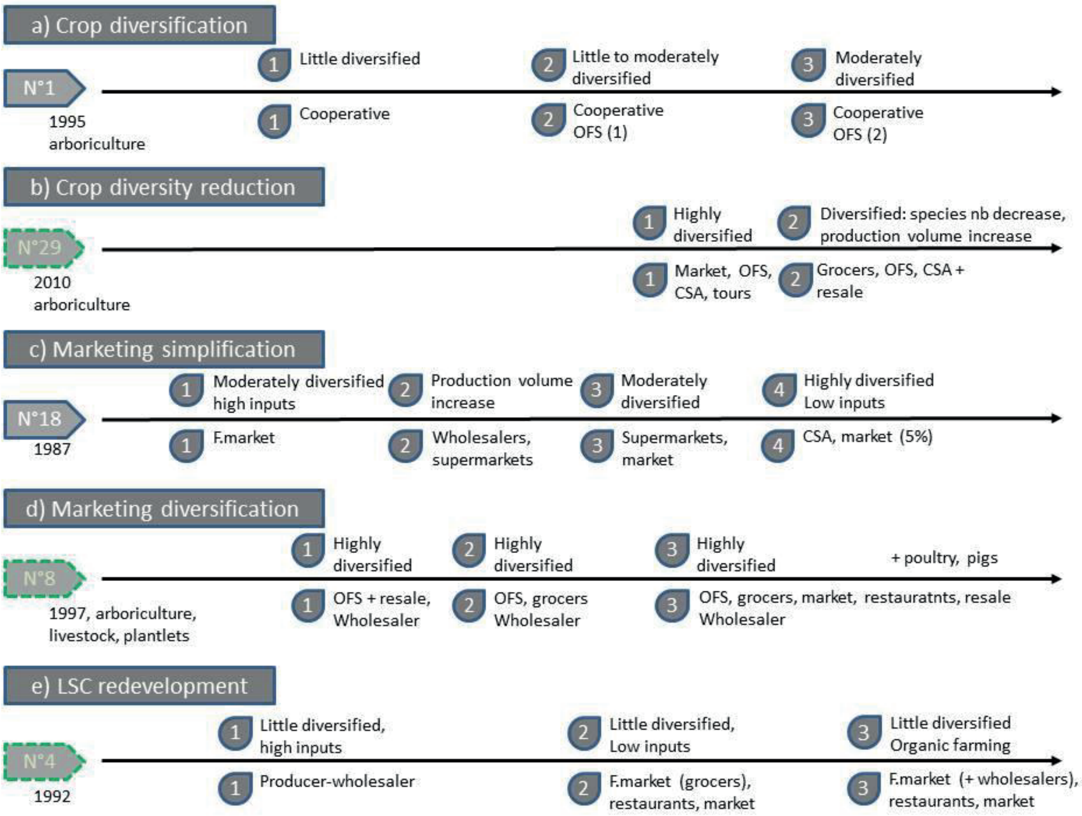

Figure 2. Examples of farm evolution trajectories. *Beyond the farmer number is the installation year. Green and dashed numbers indicate organic farming. Main traits of the marketing strategy and of the agronomical strategies are displayed respectively above and under the timeline. OFS: on-farm sale; CSA: Community Supported Agriculture; F.market: farmer market within wholesale market.*

Discussion and Conclusion

Our results highlighted a high diversity of situations regarding the evolution trajectories, the current farm functioning and the sustainability assessment results. We observed diverse configurations of involvement in SSC and in two farms out of three, one or several SSC were combined with LSC. We therefore observed a SSC-LSC continuum comparable to the local-global continuum highlighted by Brunori et al. (2016). Compared to the farms of the samples that used to be involved in LSC only, market-gardening farms involved in SSC were more diverse and more complex. However, the level of diversity and complexity differed strongly according to the farm profiles. Regarding marketing strategy, the less complex farms belonged to the type ‘Limited use of SSC’ and paradoxically also to the type ‘SSC specialised’, i.e. to opposite types regarding the involvement in SSC. Farms within these types also differed strongly regarding other criteria, with on one hand large farms with an important workforce and a limited crop diversity, and on the other hand small diversified farms with a limited workforce. Half of the farmers of the ‘SSC specialised’ type were involved in simplification trajectories regarding marketing or crop diversity, which was probably related to their limited means regarding land and labour. Farmers of the ‘Multi SSC’ type managed the most complex marketing strategies but they described their strategies as a way to limit risks. These farms could count as well on a transitional workforce compared to the other types.

We hypothesised that such a risk limitation was important for them since market-gardening occupied on average 70% of the farming area, which was relatively large. Regarding wine production, Touzard et al. (2016) observed as well at farm or cooperative level strategies mixing local and global chains that were justified by the reduction of local and global risks. ‘Hybrid strategies’ were actually hybrid regarding the marketing strategy and were transitional in our sample regarding the level of crop diversity and the level of input use. However, they were closed to the ‘SSC specialised’ type based on farm production means. It should be noted that four farmers chose to redevelop LSC, either as an economic choice, or for personal reasons. A fifth farmer went further and gave up SSC; he was therefore not included in the final sample. He was close to retirement and said that he wanted to make time for his family. There were in total five trajectories that pointed out how events from the personal and family life could affect marketing choices.

Differences in farm functioning and strategies resulted in differences in sustainability assessment results. Farms belonging to the types ‘Multi SSC’ and ‘SSC specialised’ displayed on average the best results regarding agro-ecological sustainability, economic robustness, economic autonomy and contribution to local economy. It should be noted however that there was some heterogeneous results within the types. It should also be noted that the use of SSC caused a reduction of input use in only two cases and such a reduction was related to the standards of CSA networks. On the other hand, two farms converted to organic farming to get access to LSC. Most farms strongly involved in SSC did use organic or low input management styles but they did so from the beginning. We nuanced however our analysis since our surveys did not focus specifically on crop management style and were maybe too vast to track down every change regarding crop management. In any case, diversifying crops did not appear to allow directly an input reduction. Besides diversity and crop protection, differences were noticeable as well regarding soil fertility management (studied through soil organic matter management) and were in favour of the ‘Multi SC’ type. This type and the ‘SSC specialised’ type displayed better results regarding the use of fossil resources (studied through the use of chemical fertilisers and plastic mulch). Our analysis did not include logistic aspects and their impact on the use of fossil resources. However, in the surveyed sample, SSC were local chains as well based on a 100 km radius.

As for the other sustainability dimensions, farms belonging to the types ‘Multi SSC’ and ‘SSC specialised’ displayed as well on average the best results regarding economic robustness, economic autonomy and contribution to local economy. On the other hand, regardless of the types, most farms displayed similar sustainability issues regarding income and working conditions, although life quality was assessed as correct to good. This apparent contradiction pointed out the need to put assessment results in perspective with farmers’ global aspirations and with the means implemented to meet their aspirations. This is in accord with the proposition of Galli et al. (2016) to further develop the combination of hard, i.e. quantitative, and soft, i.e. qualitative indicators.

To go into the economic analysis in depth, our study would have benefited from an analysis of the economic efficiency but our survey targeted a static and a dynamic analysis carried out on complex farms and did not allow for inclusion of that dimension. However, the static and dynamic analysis complemented one another and the dynamic analysis brought a different perspective to the sustainability assessment. Analysis of the evolution trajectories in our samples showed that several farms came across difficulties due to internal (technical, organisational or personal issues) or external (e.g. extreme weather event, drop in prices, land pressure) issues. They proved however to be resilient since they were still in activity, although the future of at least one farm was seriously questioned. Yet the main change drivers identified from the evolution trajectories referred to two types of flexibility (Chia & Marschesnay, 2008). The motor named ‘opportunities’ (access to new chains, farm extension) referred to a proactive flexibility. On the other hand, the motors ‘dissatisfaction regarding how SC worked’ and ‘difficulties regarding crop management or labour organisation’ referred to a reactive flexibility. Within the observed trajectories, both type of flexibility frequently alternated, although some farmers could be qualified as more proactive based on the change drivers they cited. Combining the static and the dynamic analysis allowed identification in each type and following Darnofer et al. (2010): (i) farms involved in an exploitation strategy that were in a relatively stable phase; (ii) farms involved in an absorption strategy facing external changes without modifying strongly their functioning; (iii) farms involved in an adjustment strategy; and (iv) farms involved in a transformation strategy characterised by a major realignment of their resources. Being in an exploitation or in a transformation strategy affects very probably farm sustainability and it would have been valuable to further include this aspect in our analysis.

On the whole, our study highlighted the need to account for different sources of diversity in the assessment of short food chains, especially regarding farm functioning and farm evolution. Sustainability assessment methods would be improved by including more indicators reflecting these two aspects, to account for the systemic properties of farms on one hand, and for the evolutionary character of sustainability on the other. However, assessment tools and frameworks will always encounter limits. As pointed out by Brunori et al. (2016), sustainability assessment can be a tool for encouraging transition. The design of an assessment tool would therefore also be improved by including at the beginning the ability of the tool to facilitate transition towards sustainability.

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References

Alavarez, S., Wim, P., Descheemaeker, K., Tittonell, P., & Groot, J. (2014). Typology construction, a way of dealing with farm diversity. General Guidelines for Humid Tropics. CGIAR, Wageningen University, Wageningen, Netherlands.

Allain, B. (2015). Rapports d'information déposé par la commission des affaires économiques sur les circuits courts et la relocalisation des filières agricoles et alimentaires.

Aubry, C., Bressoud, F., & Petit, C. (2011). Les circuits courts en agriculture revisitent-ils l'organisation du travail dans l'exploitation ? In P. Béguin, B. Dedieu and E. Sabourin (Eds.) Le Travail en Agriculture : son Organisation et ses Valeurs Face à L'innovation pp. 19-36. L'Harmattan: France.

Baccini, A., & Besse, P. (2004). Data mining 1. Exploration Statistique. UniveLaboratoire de Statistique et Probabilités - UMR CNRS C5583 - Université Paul Sabatier, Toulouse, France.

Bressoud, F. (2010). Systèmes de culture et qualité de la tomate. Innovations Agronomiques 9: 107-114.

Brunori, G., Galli, F., Barjolle, D. et al. (2016). Are local food chains more sustainable than global food chains? Considerations for assessment. Sustainability 8: 449.

Chia, E., & Marschesnay, M. (2008). Un regard des sciences de gestion sur la flexibilité: enjeux et perspectives. In B. Dedieu, E. Chia, B. Leclerc, C.H. Moulin and M.Tichit (Eds.) L'élevage en Mouvement - Flexibilité et Adaptation des Exploitations d'Herbivores pp. 23-36. Versailles, France: Quae.

Chiffoleau, Y. (2008). Chapitre 1 - Les circuits courts de commercialisation en agriculture: diversité et enjeux pour le développement durable. In: Les circuits courts alimentaires - bien manger dans les territoires, Educagri edn. pp. 21-31. G. Maréchal (coord.), France.

Chiffoleau, Y. (2016). Systèmes alimentaires territorialisés: l'heure de la prolifération est venue ! Vegetable n°330. France.

Darnhofer, I., Fairweather, J., & Moller, H. (2010). Assessing a farm's sustainability: insights from resilience thinking. International Journal of Agricultural Sustainability 8: 186-198.

Demarque, F. (2010). Incidence du système de commercialisation sur le fonctionnement technique des exploitations maraîchères en plaine du Roussillon (66). Master thesis, Montpellier SupAgro, INRA - UE Alénya Roussillon, 76 pp. France.

Favreau, J.L. (2013). Durabilité des exploitations en agriculture biologique: une analyse de la diversité des situations et des trajectoires d'évolution en Midi-Pyrénées. PhD thesis, Université de Toulouse, 243 pp. France.

Fourrié, L., Cresson, C., Letailleur, F., Sauterau, N., Willot, M., Berthier, C., & Vallas, M. (2013). RefAB: Des références pour les systèmes agricoles biologiques: proposition d'un cadre méthodologique innovant. Innovations Agronomiques 32: 271-284.

Galli, F., Bartolini, F., & Brunori, G. (2016). Handling diversity of visions and priorities in food chain sustainability assessment. Sustainability 8(4): 305.

Godard, G. (2006). Etude du fonctionnement des exploitatoins maraîchères en vente directe des Pyrénnées Orientales. Master thesis, ENITA de Clermont-Ferrand, INRA - UE Alénya Roussillon, 92 pp. France.

Kneafsey, M., Venn, L., Schmutz, U. et al. (2013). Short Food Supply Chains and Local Food Systems in the EU. A State of Play of their Socio-Economic Characteristics. Joint Research Centre - European Commission.

Lamine, C., Navarrete, M., & Cardona, A. (2014). Transitions towards organic farming at the farm and at the local scales: the role of innovative production and organisational modes and networks. In S. Bellon and S. Penvern, INRA (Eds.). Organic Farming. Protoype for Sustainable Agricultures pp. 423-438. France: Springer.

Landais, E. (1998). Modelling farm diversity. New approaches to typology building in France. Agricultural Systems 58: 505-527.

Moulin, C.H., Ingrand, S., Lasseur, J., Madelrieux, S., Napoléone, M., Pluvinage, J., & Thénard, V. (2008). Comprendre et analyser les changements dorganisation et de conduite de l'élevage. In: L'élevage en Mouvement. Fléxibilité et Adaptation des Exploitations d'Herbivores p. 296. Paris (FRA): Quae.

Navarrete, M. (2009). How do farming systems cope with marketing channels requirements in organic horticulture? The case of market-gardening in Southeastern France. Journal of Sustainable Agriculture 33: 552-565.
Navarrete, M., Dupré, L., & Lamine, C. (2015). Crop management, labour organisation and marketing: three key issues for improving sustainability in organic vegetable farming. International Journal of Agricultural Sustainability, 13: 257-274.

Petit, C. (2013). Transitions des exploitations agricoles vers l'agriculture biologique dans un territoire: approche par les interactions entre systèmes techniques et de commercialisation.

Application aux aires d'alimentation de captages en Île-de-France. PhD thesis, AgroParisTech, 412 pp. France.

R Core Team (2014). R: A language and environment for statistical computing. Foundation for Statistical Computing. Vienna, Austria.

Redlingshöfer, B. (2008). L'impact des circuits courts sur l'environnement. In: Les circuits Courts Alimentaires - Bien Manger Dans Les Territoire., Educagri pp. 175-185. G. Maréchal (coord.), France.

Rosenwald (dir.), F. (2012). Commercialisation des produits agricoles - Un producteur sur cinq vend en circuit court. Agreste Primeur, 275.

Touzard, J-M., Chiffoleau,Y., Maffezzoli, C. (2016). What is local or global about wine? An attempt to objectivise a social construction. Sustainability 8: 417.

Traversac, J-B., & Kébir, L. (2009). Introduction - Les circuits courts au révélateur des problématiques du développement régional. In: Circuits Courts: Contribution au Développement Régional. Educagri, J.B. Traversac (coord.), France.

Zahm, F., Viaux, P., Girardin, P., Vilain, L., Mouchet, C., & Environnement, F. (2007). Farm sustainability assessment using the IDEA method. From the concept of farm sustainability to case studies on French farms. Sustainable Agriculture -From Common Principles to Common Practice 77-110.

Zahm, F., Viaux, P., Vilain, L., Girardin, P., & Mouchet, C. (2008). Assessing farm sustainability with the IDEA method-from the concept of agriculture sustainability to case studies on farms. Sustainable Development 16(4): 271-281.