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The agroecological transition of agricultural systems in the Global South

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Chapter 12

Assessment of trade-offs between environmental and socio-economic issues in agroecological systems

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The concept of sustainable development as proposed in 1987 by the UN in its report 'Our Common Future' highlights the notion of inter- and intra-generational solidarity by affirming that 'sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland Report, WCED, 1987). Consequently, it becomes necessary to take into account the social, environmental and economic dimensions of human activities (or 'People, Planet, Profit', see Elkington, 1997).

Each of these dimensions includes countless factors of sustainability, which can act in synergy or in antagonism. It is therefore not possible to measure in absolute terms the sustainability of a particular way of exploiting nature. All we can do is to compare different options and, at the same time, accept that this comparison is not entirely free of subjectivity, as found in any 'model', i.e. in all the methods for studying complex systems.

Moreover, the specific objectives of the assessment can be very varied: it could be meant to inform public decision-making processes to enhance the sustainability of production methods, or to help practitioners or others who wish to evaluate their own actions. The assessment often encompasses several types of actors, with differing objectives and viewpoints, with the aim of creating a common vision of the issues within which the different points of view will eventually be identified and recognized as legitimate. The desire to understand the complexity of the problem in all these cases, and consequently to arrive at certain standards that can guide as large a number as possible of them, led to a sustained 20-year effort by the scientific community to devise methods.

At present, there is an abundance of these 'multi-criteria assessment methods'. How to navigate amongst them? Which ones are the most suitable to inform decision-making by actors of development of sustainable agriculture? And more specifically, in the case of family farming in the countries of the Global South? What kind of research is needed to improve our collective capacity to assess agricultural sustainability? This chapter attempts to provide answers to these questions.

The challenges of multi-criteria assessment of sustainability of agriculture in the countries of the Global South

The sustainable development approach based on its three dimensions (social, environmental and economic) has been widely accepted and implemented in different ways. Nonetheless, contrary to the initial holistic spirit of sustainable development, this approach has also led to various rifts between actors concerned by each of these dimensions according to their specific priorities on the basis of the exigencies of a place or time. This is a situation that has largely arisen due to the difficulty of incorporating the necessary trans-disciplinarity in the design and implementation of sustainable development. Indeed, this dimensional rift underlies the difficulty of taking the interactions between these dimensions into account and of their integration. Beyond the complexity of assessing these interactions in their totality, this approach also emphasizes the need for trade-offs rather than for the pooling of services across dimensions (Gibson, 2006). The three-dimensional approach to sustainability is, therefore, not unbiased. It results from different priority-based choices, and inevitably introduces biases in the integration of results.

In industrialized countries, where the concept of sustainability originated and where few environments remain untouched by human activity, the environmental dimension has always been at the forefront from an early stage, with the historic issues of resource scarcity sparking the first interest in the topic. Other societies, where resource scarcity is not as alarming an issue in comparison to their socio-economic development, do not recognize the essence of the three dimensions of sustainability a distinct. This is especially the case in various developing countries in the tropics. Thus, a study of the perception of sustainability by family farmers in Indonesia showed that they did not perceive the three dimensions of sustainability as distinct, but as intrinsically interwoven, non-separable and thus, non-overlapping (Bessou *et al.*, 2017). For these actors, for example, a forest is an environmental, cultural and social common good, as well as an individual source of material, income and other services. This resource is not perceived in terms of biodiversity protection that would oppose economic growth, but as a multi-dimensional whole.

The definition of sustainability, and therefore the need to safeguard future generations, only makes sense when it is considered in a global perspective. In order to reconcile local and global perspectives, it seems necessary to effect a change of scale in the conception of sustainability and sustainable development. This change of scale is understood, at the same time, in geographical terms as a change in the resolution of perceptions, and, in systemic terms, as the taking into account of different levels of organization at different scales (Macary, 2013). This problem of scale is thus intrinsically linked to a problem of inter-disciplinarity and, together, they represent basic challenges for assessing sustainability. As a result, recent conceptual development models address sustainability through the prism of the study of complex systems (Capra and Luisi, 2014; Capra, 1996, 2002) but do not provide a multi-criteria assessment method.

Consequently, there exists no single theory of sustainable development, nor is there any consensus on the relationship between sustainability and sustainable development. Some authors view sustainable development as a means of achieving sustainability (e.g. Diesendorf, 2000), while others interpret sustainability as a prerequisite for sustainable development (Sartori *et al.*, 2014). In any case, sustainable development is not a neutral concept. Assessment methods and sustainability indicators thus incorporate moral and normative conceptions (Thiry and Cassiers, 2010). As a result, despite the urgent need for methods and tools, a researcher involved in multi-criteria assessment must understand that sustainable development is not yet an established discipline; many questions remain unanswered and an awareness of underlying values is of utmost importance.

Standardizing sustainability assessment?

That said, significant efforts have been devoted to create reference methods applicable over as wide a range as possible, thus allowing a comparison of a very large number of farming systems to help inform decision-making by the citizen, consumer or public policymaker. These efforts have resulted in popular and frequently used tools, especially when only the environmental dimension of sustainability is considered.

'Environmental' Life Cycle Assessment

The key example is that of 'environmental' Life Cycle Assessment (LCA). Environmental LCA consists of assessing the potential environmental impacts of a product or service from the stage of the extraction of the raw material needed for its manufacture to its end of life, through all the stages of its journey in the value chain (production, transport, distribution, consumption). Introduced in the 1980s, LCA quickly became an international methodological reference. For example, its use is mandatory in various decision-making frameworks such as the European Renewable Energy Directive (2009) and the European environmental information tool called Product Environmental Footprint. The interest in LCA arises from the extent of the system analysed, i.e. the entire value chain, as well as from its multi-criteria approach based on several environmental impacts (for example climate change, eutrophication, depletion of fossil resources, toxicity, etc.). This makes it possible to identify and potentially control 'impact transfers'[1], when comparing several production scenarios of the same product or when comparing two products performing the same function. This is essential for improving production systems, where less comprehensive approaches may only result in the shifting of problems. That is why this approach has mobilized a large international community, leading to the emergence of specific ISO standards[2] and continuous updating and improvement of the method. In addition, a growing community is also working on proposals for socio-economic indicators in the context of a so-called 'social LCA'.

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1. An impact transfer can occur when a process belonging to one production stage of the value chain is improved, but to the detriment of another process belonging to another stage of the chain. Similarly, an environmental impact may be reduced by improving a process, but it may exacerbate another environmental impact. If the analysis does not take all the stages and impacts into account, these transfers may not be identified and the assumed improvements could result in counter-productive effects.
2. ISO 14040 and 14044 (2006).

The ISO standards, which govern the implementation of LCA, define the method's stages of implementation and the modalities of publishing the results. Thus, when correctly applied, these standards ensure a transparent and reproducible assessment procedure. It follows that the existence of such a standard represents *a priori* the hope of arriving at a consensus between decision-makers as well as between consumers. Products and production systems based on this consensus need to be encouraged in order to reduce the negative impacts of human activities on the environment.

The ecological footprint

The concept of the ecological footprint is another example, but it has not been formalized by an ISO standard. This concept is promoted by an independent organization, the Global Footprint Network, which defines and adapts the standard and offers suggestions for the implementation of the concept with the help of experts. The ecological footprint is an indicator expressed in terms of the 'bio-productive' soil surface area required to sustainably meet the consumption of a given population and to absorb the waste generated, as well as greenhouse gas emissions. Applied at the scale of the entire planet, this indicator serves to mark the point beyond which global consumption is no longer 'sustainable', with a global ecological footprint expressed in number of planet Earths greater than 1, and the Earth Overshoot Day, the date – currently occurring earlier each year – on which global consumption exceeds the planet's annual regeneration capacity. The symbolic significance of the concept is convincing and has made it popular, which in turn has encouraged its use as a tool to compare the impact of populations on their environment in different countries. The concept has more recently been extended to the environmental assessment of products and organizations.

A certain relativity of methods

These two approaches to assess environmental impacts are very different and provide results that are difficult to compare. There are very many ways to assess the environmental impacts of human activities and each method requires some simplification of the complex systems under study. The standardization of a sustainability assessment method does not therefore mean that the method is the only way to assess sustainability or that its results are absolute. The assessment remains relative, depending in particular on the objectives of the study, and the knowledge and data available at the time of the assessment.

The objective of standardizing methods is also constrained by the difficulty of defining certain quantities in a mutually acceptable manner. For example, how to quantify the value of a forest as a recreational space? At what scale of time and space should the services provided by a complex agroforestry system be assessed? Can a rural society in crisis, faced with the short-term imperative of survival, and compelled to 'adopt whatever means necessary' to do so, be compared to a relatively wealthy society that has the luxury of being able to spare resources on the basis of long-term goals? How can a broad consensus on these issues be arrived at if it is only the 'experts', very likely lacking any real experience of extreme poverty, who participate in the search for a consensus (Cheyns *et al.*, in press)? Another, perhaps more abstract, example is: Should the value of biodiversity be assigned only on the basis of its contribution to ecosystem services? Or does it not, in a spiritual perspective, also represent a value for humanity that transcends such a narrow view, and is therefore both universal and eminently dependent on individuals?

Recognizing the role of subjectivity in multi-criteria assessments

A large number of methods and approaches explicitly recognize that the assessment of sustainability depends largely on the concerned actors' perspectives. Such methods propose general methodological principles, leaving ample room for case-by-case adjustments, which can be decided jointly by all the actors involved in the assessment, co-constructing in this way a common vision of a system's sustainability.

Many French scientists assume that a multi-criteria sustainability assessment necessarily mobilizes the implementation of what mathematicians call 'multi-attribute hierarchies'. These approaches are based on the identification of a certain number of indicators of the economic, social and environmental performance of the systems being compared, the assignment of values to these indicators for each of these systems, and the application of weighting and aggregation rules to classify different sustainability criteria (for example, see Sadok *et al.*, 2008) (Figure 12.1). All these elements of the method can be decided on a case-by-case basis. The general principles of the methods that make up this group are relatively simple to understand, and easy to implement and discuss (for example, see the MASC method[3]). However, the large number of possible variations in the methods for aggregating criteria and classifying the elements assessed are subtle and complex to grasp, and are the focus of many specialist debates. Indeed, these variations can have a considerable impact on the classifications obtained. More generally, the main criticism directed at these methods is that the classifications they generate are very sensitive to the particular method's parameters, with many threshold effects which also makes it difficult to assess their robustness.

A number of practitioners and researchers prefer not to use the term 'multi-criteria', choosing instead to speak of the integrated assessment of farming systems, thus emphasizing the systemic nature of the approach and complexity of the system studied. Until recently, studies advocating integrated assessment tended to rely less on multi-attribute methods, using instead so-called constrained optimization methods. A key assumption in these methods is that farms represent enterprises that have their own objectives and are managed by rational decision-makers whose role is central to agricultural sustainability. Models have been constructed to simulate the decision of farmers who have to select production techniques from amongst several options, on the basis of their objectives and constraints. These models describe mechanisms that determine the economic and environmental performance of farms in order to

3. Multi-attribute Assessment of the Sustainability of Cropping systems, http://wiki.inra.fr/wiki/deximasc/package+MASC/?language=en (retrieved on 30 January 2018).

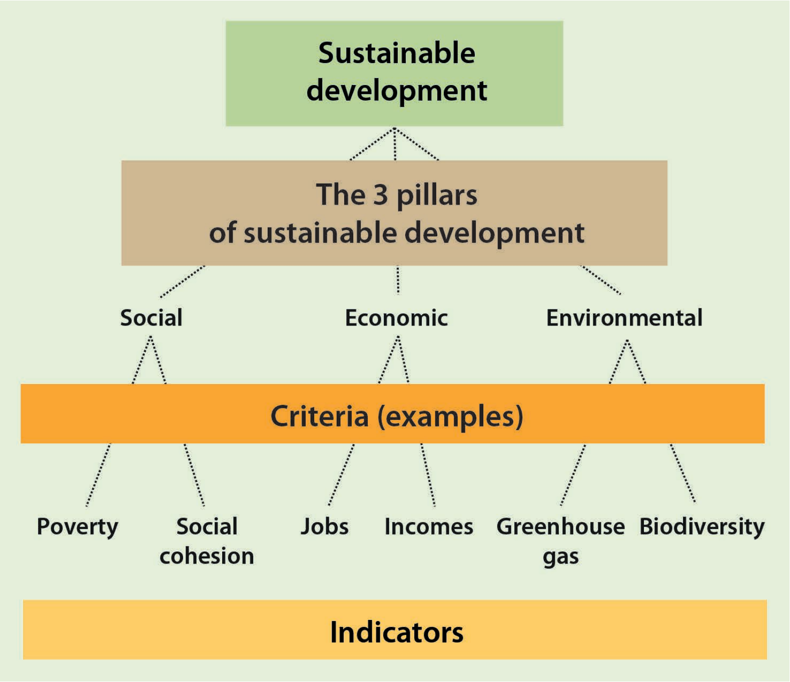

Figure 12.1. Example of a multi-attribute hierarchy representing sustainable development presented as a tree with multiple aggregation levels.

predict deviations as a function of variations in their biophysical, economic and social environments. These models operate in a highly variable and often complex manner, such as changes in scale between the cropping/livestock systems and the production system, or between the farm and the region or the market. These methods are part of the same mathematical domain as multi-attribute hierarchies, or 'operational research', and pose problems that are similar in nature regarding the assessment of their robustness, or the transparency of the methodological choices that arise from the countless possible variants.

This similarity between multi-attribute methods and constrained optimization methods seems to be increasingly accepted by specialists of both methods, who recognize, for some years now, that both methods use optimization techniques and are based on multiple criteria.

However, there are several important differences, and in comparison to multi-attribute hierarchies, it is more difficult to present methods based on mathematical programming to non-specialists and, *a fortiori*, involve them in the implementation of these methods. This approach is sometimes severely criticized for its dependence on an assumption of farmer rationality, especially when it is translated (often abusively) as a reduction of a farmer to a '*homo economicus*' driven solely by the goal of maximizing his income. These methods, however, do allow the taking of the highly varied objectives of producers into account (e.g. see Lozano Vita *et al.*, 2017; Berbel and Rodriguez-Ocaña, 1998; Flinn *et al.*, 1980).

Importantly, many examples have shown the usefulness of these methods in assessing agroecological systems in their economic and social dimensions for family farming (Affholder *et al.*, 2010; Naudin *et al.*, 2014; Alary *et al.*, 2016; Belhouchette *et al.*, 2011). They make it possible to identify clearly the conflict between the short-term economic objectives of farmers and the objectives of maintaining or strengthening long-term ecosystem services other than the service of supply, including for complex farms, with very diverse activities and where simple economic indicators fail to capture the interactions between the various activities that contribute to income generation.

More specifically, it is often possible to use these methods to quantify the optimal trade-offs between the different dimensions of sustainability, using an estimate of short-term income losses of producers who implement agroecological processes, and thus to assess the level of remuneration that should be associated with environmental services in order to reconcile, in an effort to maintain producers' income, their short-term economic objectives and those specific to these environmental services. This function of the method is especially valuable in the context of poor family farms in the countries of the Global South, where producers are constantly confronted by the immediate reality of ensuring their families' survival. When farm income is less than one Euro per worker per day – and this figure includes home consumption – and when each working family member must support two or three unproductive ones (the very young or the aged), as is the case in the overwhelming majority of farms in sub-Saharan Africa, it is especially important to ensure that an agroecological alternative to existing practices does not reduce this income, even marginally, in the short term, irrespective of the promise of an increase in income in the long term if agroecological practices are adopted.

In these integrated assessments, the 'farm models' calculate the aggregate income of different farm activities by taking into account the flow of resources between activities (e.g. organic matter from livestock is used as crop fertilizer). This helps explain how a transition to an agroecological system of a given farm activity is constrained by the changes it induces in the flows of biomass, labour and cash between activities, as well as in the use of the animal traction or mechanized work, with an impact also on the farm's other activities. For example, using mulch to protect the soil from erosion can result in lower livestock productivity since less straw will be available for use as fodder. Or an agroecological practice could result in higher land productivity but lower labour productivity (or vice versa) than with the 'conventional' method, with highly variable consequences on the farmer's income depending on whether the farm is constrained by land or by labour. Multi-attribute hierarchies generally do not explicitly consider these interactions between activities and their impact on farm income in the economic indicators they use.

There thus seems to be some contradiction between the objective of helping the common man understand the assessment of sustainability and the objectives of robustness, consistency and rigour that must be satisfied for such an assessment to be more than merely one point of view (even collective) out of many. Indeed, bringing assessment within the reach of the inexperienced common man involves using methods that are simple to explain and implement, which would require disregarding the complexity of the problem to be tackled and ignoring key interactions between the elements of the system to be assessed.

Assessing agroecology

There does not exist as yet any widely applicable comprehensive and systematic assessment that would allow the comparison of the sustainability of agroecology with that of conventional agriculture. The main difficulty in designing such an assessment is to arrive at a mutually agreeable classification of agricultural practices belonging to agroecology and those belonging to 'conventional' agriculture, from among the myriad practices that exist in sufficiently diverse environments across the planet.

However, when focusing on low-capital family farms in the countries of the Global South, a number of robust facts can be derived from the numerous assessments we already have, even though they may be partial or local in scope. This is especially true for conservation agriculture, which can be seen as a major ideotype of agroecology, particularly adapted in the tropics to climates ranging from the semi-arid to the sub-humid where annual crops rather than perennial ones tend to dominate.

Prevalence of socio-economic issues in family farms in the Global South

It should be noted that poor and very poor family farms in these climatic regions represent the overwhelming majority of the world's agricultural systems, accounting for a very significant portion of its cultivated areas (Hyman *et al.*, 2008; Dixon *et al.*, 2001). While there may be many exceptions, social and economic sustainability is not guaranteed in the majority of these agricultural systems. Indeed, the population that depends on them for a living is most often below the poverty line and is growing so rapidly that if the value of the production does not increase, and the next generation does not find other means of subsistence away from the land farmed by previous generations, and therefore mainly in non-agricultural jobs, poverty will worsen further.

As far as environmental sustainability is concerned, a variety of patterns exist of the use of inputs exogenous to the local ecosystem. Cotton, for example, is widely cultivated by poor farmers in Africa, but with the use of substantial amounts of pesticides, thus posing long-term threats to the environment and people's health. On the other hand, there also exists a majority of cases in which the producers' practices could be described as agroecological, since they make very little use of inputs exogenous to the farm ecosystem, even if this is more due to a lack of finances to procure these inputs than by conscious choice (Feintrenie and Affholder, 2015). These practices are very interesting to assess in their environmental dimension, precisely because they often use the most subtle agroecological levers such as the optimization of nutrient cycles by recycling of livestock effluents and transfers between plant species in association, or the regulation of pests and diseases by rotations and associations of diversified species. But these non-input agricultural systems can have negative environmental impacts, typically in the form of soil erosion, which becomes particularly problematic when demographic pressure results in cultivation expanding to vulnerable soils.

Agronomic and environmental performance of conservation agriculture

Even if there still are, as we shall see, many knowledge gaps to be filled, we have today a certain benefit of hindsight concerning the level of agronomic and environmental performance of conservation agriculture. This form of agriculture can be seen as a way of reconciling increased productivity and environmental sustainability, through the least possible disruption of the soil, enhancement of soil protection using a vegetal cover of dead or living plants, and promotion of rotations and associations of different species. Rather than presenting a battery of indicators with their values and ranges of variation for this kind of agriculture in comparison with current practices of the dominant form of agriculture, we propose, in what follows, to draw a progressive portrait based on published syntheses, starting from the processes implemented in the cultivated ecosystem and leading to a holistic view of its sustainability (Scopel *et al.*, 2013; Giller *et al.*, 2011; Giller *et al.*, 2009; Rusinamhodzi *et al.*, 2011; Pittelkow *et al.*, 2015; Ranaivoson *et al.*, 2017).

Conservation agriculture has proved to be effective, almost everywhere that it is practised, in greatly reducing or even halting soil erosion. It can also be highly efficient in terms of water and nutrient use and in pest control. However, this efficiency is rarely achieved simultaneously for all these functions. And for each of them, what is actually possible to achieve is highly variable, depending on the local environment and the particular conservation agriculture practices used. For example, while a soil cover of mulch residues allows more water to percolate into the soil, thus reducing water runoff, it does not always translate into reduced water stress on crops, as it may lead to an increase in water drainage below the soil zone colonized by the roots, which is likely to increase the loss of nutrients carried away by this water. Only a fairly detailed analysis of rainfall distribution during the cropping season can predict whether or not mulch can help increase yields by reducing water stress (Scopel *et al.*, 2004; Bruelle *et al.*, 2017).

In the same way, the contribution of organic matter rich in carbon from this mulch can paradoxically but not unfrequently provoke nitrogen deficiency in plants; the population of soil microbes – which increases thanks to this carbon source – uses up soil nitrogen, then said to be 'immobilized', at the expense of the crop that has barely enough for its requirements. In general, however, such organic matter inputs lead to a gradual build up of soil nitrogen and carbon stock, albeit in very variable proportions that are not solely dependent on the quantity of biomass returned to the soil, but also on the nature of the soil (its sand and clay content in particular) and the climate (Maltas *et al.*, 2007; Corbeels *et al.*, 2018). The very fact of reducing, or even eliminating, tillage operations is sufficient to promote biological activity, and this is further stimulated by the return of biomass to the soil (Blanchart *et al.*, 2007). This enhanced biological activity, compared to that in 'conventional' cropping techniques, creates a macroporosity that contributes to improved water infiltration (and, consequently, the reduction of erosion).

On the other hand, the other favourable effects often expected from this enhanced biological activity in the soil, such as an increase in soil water storage capacity, mechanisms of soil pest regulation, or improved availability of nutrients during the cropping season have not been convincingly demonstrated. Indeed, we often observe the negative effects on crop growth and yield, at least over a period of a few years following the conversion of the plot to conservation agriculture, because of a relative proliferation of pests that find a favourable environment in mulch. More specifically, the pressure of weeds on the crop is relatively high when the quantity of mulch used is large enough (a threshold of 7 tonnes/ha has been identified, for example, in Southeast Asia). Species associations and rotations do provide the expected benefits in terms of a reduced pressure from pests and, notably, from weeds, when compared to monoculture or continuous cropping, but this advantage is not very significant when the cultivated species – such as maize and other high straw-producing cereals – is itself highly competitive against weeds. For more sensitive species, such as rainfed rice, which are often grown in rotation in a conventional manner precisely for this reason, the advantage of the cultivated diversity through rotations or associations is offset in conservation agriculture by the difficulties in planting the crop across the straw mulch covering the soil. Relay crops have shown they can reduce nutrient losses and pollution from leaching. Nitrogen transfers between legumes and non-nitrogen-fixing plants have been observed, in associations and rotations, with or without conservation agriculture, but again this is a potential that cannot easily be achieved, and one that current simulation models fail to predict reliably (see, for example, Baldé *et al.*, forthcoming; Baldé *et al.*, 2011).

We also note that species associations and relay crops pose risks of competition for access to resources between the cultivated species, which is also difficult to predict accurately as it results from numerous interactions. Any reduction of this competition requires great precision in managing the cropping calendar (see, for example, Silva *et al.*, 2019), often requiring investments in equipment or a large amount of manpower to ensure this precision.

Economic performance of conservation agriculture

The foregoing reveals some conflicts between different environmental criteria, and between these criteria and economic sustainability criteria. Indeed, when we take the processes defined above into account, we understand why reducing erosion through conservation agriculture necessitates, in many cases, a corresponding increase in the use of synthetic nitrogen fertilizers in order to reduce the risk of nitrogen immobilization, if the yield and, more importantly, the economic return to land has to be maintained. This added fertilizer may represent a water pollution risk comparable in impact to that due to erosion, and plays a role in farm economics in a way that runs counter to the effect of the elimination of tillage. And in the same vein, the implementation of conservation agriculture also often leads to the use of additional herbicides to control weeds, this time with greater environmental risks and a corresponding negative economic impact. The alternative of a thick mulch, effective against weeds, would certainly have a better environmental effect but it is, in fact, very rarely used. Indeed it makes little economic sense since straw residues are often more beneficially used in the short term for feeding livestock rather than for constituting a mulch expected to bring long-term positive effects on production through improved nutrient stocks and weed control. An additional factor is the equipment and specific labour-consuming interventions required to produce such a biomass (Naudin *et al.*, 2014).

At the farm level, such conflicts between environmental and economic indicators are generally reflected in a short-term assessment that is clearly unfavourable to the adoption of conservation agriculture by the poorest farmers who have little cash reserves to procure herbicides or urea, and who use biomass more beneficially as fodder, fuel or building material. This is the main reason they do not adopt conservation agriculture (Affholder *et al.*, 2010; Giller *et al.*, 2009) or indeed most other ecological intensification options currently known (Affholder *et al.*, 2015a). And it is also such conflicts that leads wealthier farmers (for example, large family business farms in central Brazil) to implement only some of the principles of conservation agriculture, with relatively little ground cover, high inputs of chemical fertilizers, with rotations with relatively low crop diversity, and with a heavy use of herbicides to control weeds (and often Roundup Ready GMO maize or soya bean). These farmers thus obtain a favourable environmental assessment in terms of erosion and greenhouse gas emissions (thanks to the elimination of motorized tillage), but their practices are *a priori* actually harmful (although, to our knowledge, this has not been quantitatively demonstrated) to the quality of surface water and groundwater, and possibly to biodiversity. They also obtain a rather favourable – albeit only marginally – economic assessment, which is again thanks to the elimination of tillage that generates savings that offset the additional costs of herbicides and fertilizers, even though specific direct seeding equipment must also be acquired (Freud, 2005). Finally, socially, the farmers of family business farms of the central plateau of Brazil – and there exists a similar situation in France (Goulet and Vinck, 2012) – have used conservation agriculture to improve their image with the rest of society, by playing up its agroecological character. It is also possible that this aspect played a key role in convincing family business farms to adopt these practices, by compensating in a certain way the inherent risks assumed by the farms in adopting a technique that is difficult to master, and which is radically new in comparison with their existing expertise.

It is probably also a general property inherent to agroecology, since it is also found in the case of agroforestry, and which emerges from all the rigorous multi-criteria assessments available: from the moment we seek to facilitate relationships between living organisms – the essence of agroecology being to increase resource-use efficiency in ecosystems – we also seem to run the risk of creating competition between species for access to these resources, and that this competition occurs at the expense of production functions. The essence of managing agroecological farming systems will specifically be to attempt to prevent the system from 'tipping' towards competitions that are too disadvantageous for production... and this tipping is especially difficult to anticipate as it is sensitive to the dynamic equilibrium between variables that are in constant interaction.

Avenues to improve multi-criteria assessments

Quantitative knowledge of farming systems

A conceptual difficulty in the assessment of agroecology lies in the need to assess ecosystem functions. To be able to do so, it is necessary either to mechanistically model the processes, or to directly assess the results of these processes assuming that we ignore their determinism. In both cases, the assessment is very complex.

Despite the promise of information technology and the revolution of quantitative systemic approaches over the last half-century, we are far from having models that can provide reliable estimates, of all the variables of the functioning of cultivated ecosystems for all types of agriculture in diverse contexts.

We can assume that, at the scale of cropping systems, we can predict reasonably well the dependence of the yields of primary crops on solar radiation, temperature and rainfall (or irrigation). The prediction of variations in yield based on soil nitrogen availability is however very uncertain, except for major cereals (maize, wheat, rice) in temperate regions. However, the effects of other macro-nutrients (phosphorus, potassium) are currently poorly predicted irrespective of the climatic context. In general, it is easier to predict the agronomic and environmental performance of agriculture in an environment that is highly artificialized through chemical inputs exogenous to the ecosystem, than of agroecological systems that are often dependent on tenuous interactions between living organisms. As such, efforts to model cropping systems in the countries of the Global South, which are often agroecological in nature given the lack of access to inputs, could well lead the way to the modelling of the performance of future agroecological systems in the countries of the Global North. In any case, current modelling efforts at the field scale focus on:
– the long-term prediction of soil nitrogen and carbon stocks as a function of cropping systems, efforts motivated in particular by the challenge of sequestrating carbon in soils to reduce net emissions of greenhouse gases;
– the estimation of nutrient and pesticide fluxes outside the root zone in the soil profile, indicators of water pollution risks;
– the modelling of synergies and competitions between plant species in multi-species systems (agroforestry, associated crops) or for taking the impact of weeds on yields into consideration;
– the relationship between crop species and invasive pests (insects, bacteria, fungi, viruses, etc.), which could require adopting a landscape-scale outlook and focusing on other ecosystem services such as regulation services (Chapters 8 and 11).

At farm scale, we know how to build models capable of modelling farmers' decision-making (in terms of the production system) and, consequently, their incomes and a fairly good number of economic and social indicators, when farms are acutely constrained by their biophysical and economic environment, as is most often the case in the Global South. These models are more difficult to develop and calibrate when producers have more room to manoeuvre in line with their various goals. The development of experimental economics is helping fill this gap, most notably by proposing promising methods for identifying producers' goals (Ward *et al.*, 2016; Jaeck and Lifran, 2014; Louviere *et al.*, 2015). However, the reliability of these models anyway largely depends on the quality of the data representing the performance of cropping and livestock systems, and therefore of the underlying biophysical models (Affholder *et al.*, 2015b).

At the territorial scale, improved hydrological models are now able to predict the flow of dissolved substances such as pesticides (Mottes *et al.*, 2015). In addition to a methodological renewal, we are observing the emergence of a landscape agronomy based on the ecology of the countryside (Chopin *et al.*, 2015; Baudry *et al.*, 1990) that aims to better understand and estimate the interactions between living organisms at this scale, especially relevant for assessing the impacts of changes in agricultural systems on biodiversity. The development of multi-agent models and spatial modelling tools is contributing to this evolution and is also improving our ability to take into account the interdependence of producers and other territorial actors, and thus better assess the social dimension of sustainability (Bousquet *et al.*, 1998).

Finally, irrespective of the scale considered, the processing of big data is opening up new perspectives. The explosion in data being recorded by various sensors, their universal accessibility, and the development of powerful algorithms to connect such data and perform hugely multivariate analyses is offering the hope of identifying simple ways to estimate some variables based on others, without having to undertake new, laborious experiments or the time-consuming route of developing models and comparing them with experimental data. One of the limitations of such approaches is the risk of making serious prediction errors, when the relationships identified are extrapolated by assuming the correlations observed between variables as evidence of causality when it is not. We must also note that farming in the countries of the Global South generates far less big data than in those of the Global North, and that these methods show very distinct biases in favour of phenomena that are important in the contexts of the latter, even though they may not be so for the contexts of the former.

A meta-analysis of the sustainability of organic farming compared to that of conventional agriculture (Seufert and Ramankutty, 2017) provides an example of this risk of bias. In this study, presented as having a global relevance, production systems of the countries of the Global South are practically absent, partly because of the paucity of data available in comparison with those from the countries of the Global North, and partly because the market for organic products is much less developed in the South. While we do find many farmers complying with organic farming specifications, it is not so much by choice as by a lack of access to any external inputs. As a result, there is a virtual lack of interest among producers to certify their products as originating from organic farming. If these production systems were included in the analysis, given the very low average yields that characterize them (Affholder *et al.*, 2013), the conclusions of this meta-analysis would have been, on an whole, extremely unfavourable for organic farming as far as the social and economic dimensions of sustainability are concerned – while, contrastingly, the conclusions of this study were, in fact, favourable in this respect. Indeed, there exists a significant contrast between farmers from the countries of the Global North and those from the Global South in terms of the opportunities opened up by organic farming specifications as they are currently framed, which would undoubtedly have been interesting to identify and discuss in this meta-analysis study.

Methodological research

The third part of this chapter has identified, as the main methodological challenge, the issue of reconciling rigour, transparency, robustness, and ease of implementation, in short a whole list of more or less opposing characteristics that all stem from a necessary reconciliation between recognizing there is a subjective angle of science and striving for maximum objectivity. This challenge seems unremarkable since it has concerned all of contemporary science ever since 20th-century epistemologists discarded the myth of a science that would gradually reveal a unique truth of the world, existing independently of people and their means to discern it (Chalmers, 1976, 2006). However, this epistemological revolution is far from complete, and the very organization of research is broadly inherited from the previous paradigm. Above all, the challenge in question takes on a certain dimension when science needs to be used immediately for collective action, as is the case for the multi-criteria assessment of sustainability. Thus, there exists a certain dynamism in methodological research on multi-criteria assessment.

One focus of such research activities is to compare the mathematical properties of operational research tools using sensitivity, uncertainty and robustness analysis. This is more clearly needed for multi-attribute hierarchies whose properties perhaps pose more problems than for mathematical programming, which formulates dependence indicators of its solutions for each variable considered.

Uncertainty

Uncertainty is the maximum error that can be made in assessing performance and impacts. It arises from an imperfect knowledge of socio-economic and biophysical processes, performance and impact measurement errors, and the variability of the characteristics of the systems being assessed.

The challenge is to quantify the uncertainty, and to take it into account when comparing assessed elements. Multi-criteria assessment methods today have a strong interest in identifying the variables that most influence the conclusions of the assessment in order to measure them more precisely and guide efforts to model the disciplines in which these variables are found. A sensitivity analysis of assessment methods can be undertaken by checking their ability to discriminate between two similar systems. However, the methods must also be robust, i.e. have the capacity to produce accurate results when minor changes take place in the conditions of their implementation.

Robustness and sensitivity

Robustness can be verified, for example, by ensuring that similar conclusions are obtained when the method is implemented in the same production system by different individuals or at different times of the year. Assessment methods that aggregate up to the 'contribution to sustainable development' may lack sensitivity and may have difficulty in differentiating between cropping systems (Craheix *et al.*, 2012). The designers of the MASC method, which is based on a multi-attribute hierarchy, thus carried out sensitivity analyses and identified the need to reduce the number of aggregation levels and balance the number of criteria in each organizational branch of the sustainable development tree considered in their approach.

The ergonomics and transparency of these methods for actors are also goals of research studies with a more specific objective to identify, in the broad range of this set of tools, the branches best adapted to the 'participatory' assessment of sustainability, and to produce overviews and guides to help actors choose a tool based on their objectives and constraints (Lairez *et al.*, 2015).

Integration of the social and economic dimensions

Another major area of research is the integration of the social and economic dimensions in approaches that have hitherto focused solely on the environmental dimension (with, for example, the development of the so-called 'social' LCA) and, more generally, a better taking into account of the multidimensional nature of sustainability.

In the case of poor farmers in the countries of the Global South, the challenge is, above all, to recognize the prevalence of the social and economic dimensions of sustainability, in the short term, in relation to environmental issues, in order to identify trajectories that do not simply add an injunction of environment conservation to the burden of poverty. The concept of the agroecological transition, originating in France and promoted by public actors, itself comes with risk, as long as it focuses solely on environmental issues, in contrast to the ecological intensification concept (Chevassus au Louis and Griffon, 2008; Cassman, 1999), which espouses the idea of reconciling the implementation of agroecological principles with increased agricultural production, seen as necessary to ensure global food security and as an opportunity to help farmers in the countries of the Global South break the cycle of poverty (Tittonell and Giller, 2013; Affholder *et al.*, 2015a).

It therefore seems necessary to create tools for designing agricultural policies that can resolve the conflict between the socio-economic and environmental dimensions of sustainability, for example by providing subsidies for adopting particular practices, for products originating from these practices, or for specific inputs used in these practices or, more generally, by paying for environmental services.

At the same time, if we accept the principle of such policies, we must question ourselves about policies that encourage agricultural intensification. Indeed, why not consider making payments for 'social services' which could result in alleviating poverty for millions in rural areas? Because if their lot does not improve, they may soon be flooding international migration routes in far greater numbers than they have done so far, leading to major social impacts in the rich democracies they land up in, which could even result in a regression of some democratic principles. This issue of support for agricultural development receded into the background during the 30-odd years of liberal globalization, which was finally called into question by international organizations following the global food crisis of 2007. Because the experience of industrialized countries has helped reveal the considerable biases of public policies supporting agriculture in general, we have to propose new tools for *ex ante* and *ex post* assessment of these policies in terms of their impacts on sustainability.

That said, the issue of designing a system at the scale of the cultivated plot, based on multi-criteria assessments at this scale and at higher ones, remains pivotal in the search for techniques corresponding to the most acceptable trade-offs between the environmental, economic and social issues at these different scales. Reasoning here in terms of 'ideotypes of agroecological systems', i.e. ideal agroecological systems, would probably lead to an overestimation of the cost of policies promoting ecological intensification and thus, very likely, delay their implementation. But farms in the countries of the Global South are often very diversified in their activities because it increases their resilience to all kinds of risks. These farms are also very different from one another, each adapted to the constraints of its own biophysical environment, while infrastructure and agricultural support policies in the rich countries greatly reduce the impact of such constraints on their farmers. This complexity and diversity of the production systems of poor farmers in the Global South are such that the individual indicators of productivity of the various activities they carry out are not able to accurately represent their aggregate farm income, its variability due to various hazards, or its dependence on the evolution of their practices, especially towards agroecological techniques. This therefore only reinforces the need to model the economic and social performance of these farms.

Furthermore, agriculture is constantly changing, in the countries of the Global North as well of the Global South, much like the world it is part of. These changes can be extremely slow but also take the form of real technical revolutions that lead to a radical change in a few years of all the variables characteristic of the functioning of the agrarian system. The Green Revolution was an example, and similar revolutions are underway in many countries, most notably in emerging ones that had been bypassed by the Green Revolution in the 20th century. How to avoid assessing agroecological prototypes of cropping or livestock systems that are appropriate for today's farming systems, but which will be of little use in the near future when these farming systems will have been replaced by others? How to design agroecological cropping systems quickly, based on ex ante assessments, when the growing demand for an agricultural product leads farms to rapidly adopt intensive conventional systems? Those intensive systems may indeed be financially more efficient in the short term to generate profits from this emerging demand, but it may make it then more difficult to subsequently transition towards more sustainable practices. Agroecological cropping systems developed by teams of researchers in the mountains of Vietnam, by taking into account the constraints of subsistence farming that existed in these regions at the start of the research and development programme, were found to be inadequate a few years later when production systems had been profoundly altered following an economic boom in this country and the integration of farms into a market that had become more attractive to farmers (Affholder *et al.*, 2008). Similarly, in Brazil, agroecological techniques proposed for maize cultivation that were well adapted to farms created by the agrarian reform (Alary *et al.*, 2016) lost much of their relevance following a considerable reduction of the surface area under maize. This happened because these farms became specialized in intensive dairy production and started buying livestock feed from the market to meet their animals' protein requirements.

Linking the assessment of sustainability with prospective approaches

So how can we avoid implicitly embracing the hypothesis that poor farmers will remain poor when we have to assess cropping or livestock systems? How to instead consider plausible scenarios to help them break out of the cycle of poverty, but which involve entirely different production systems, whose sustainability indicators to be estimated would differ radically from those of their existing farms? And taken to its extreme, the lack of deliberation on the dynamics of production systems will result in a static vision of sustainability, which does not really encourage actors to favour radical changes in production systems. In other words, by assessing agroecological systems for the poor while assuming they will continue to remain poor, do we not run a risk of favouring policies that, at the very least, miss opportunities to lift farms out of poverty and, at worst, help keep them there?

To avoid these major pitfalls, it is necessary to link the assessment of sustainability with prospective approaches in order to identify possible scenarios for the evolution of agrarian and production systems. And we must be able to reason out the choice of indicators, their weightage, and their methods of aggregation by taking these scenarios of evolution into account. For example, in the case of farms set in extreme poverty, which do not use fertilizers or pesticides, key indicators to assess their sustainability would need to pertain to income and food security. But if, within a decade, these farms become part of a market that remunerates agricultural labour well and they begin to use pesticides, the weightage of environmental indicators in assessing sustainability will have to become significantly higher compared to income indicators. If we have not invested in the meantime in estimating pesticide flows in the current setting, we will have to extrapolate from estimates made elsewhere, without any means of knowing how pertinent and accurate these estimates are, and thus be left with no means to ascertain if the relative rankings of sustainability of production systems which use more or less pesticide are reliable or not. In such a case, it will be difficult to convince actors to implement a given technique on the basis of increased sustainability!

More generally, this area of methodological research entails progressing in step with how the disciplines of biophysical sciences and social sciences collaborate, are collectively conscious of the part subjectivity plays in their analyses, and thus jointly subscribe to the results they produce. Contrary to popular belief, this is not particularly based on the amount of goodwill researchers have – which they usually have in ample measure –, but rather on the implementation of certain principles, some of which are simple and have been known for a long time (e.g. recognizing that if it is more difficult, more resources are needed; Naiman, 1999) while others are more subtle (assuming dissymmetry in between disciplines in power relations within a working group; MacMynowski, 2007), but most of which are somewhat constrained by existing modalities of organization and, above all, of the assessment by the research community – not sufficiently multi-criteria, or in any case in which the value of inter-disciplinarity is insufficently recognized!

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