ENDURE

European Network for Durable Exploitation of crop protection strategies

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Presentation of DEXiPM arable crops

A qualitative multi-criteria model for the assessment of the sustainability of pest management systems

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Dissemination Level	
PU Public	
PP Restricted to other programme participants (including the Commission Services)	**X**
RE Restricted to a group specified by the consortium (including the Commission Services)	
CO Confidential, only for members of the consortium (including the Commission Services)	

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Glossary

ENDURE	European Network for Durable Exploitation of crop protection strategies
TFI	Treatment Frequency Index
IPM	Integrated Pest Management
AOC	Appelation d’Origine Contrôlée
UF	Utility Functions (DEXi models)

Summary

This documents aim at describing a first prototype of the DEXiPM tool, which has been developed for the assessment of sustainability of current and innovative crop protection systems. This first prototype has been designed for arable crops systems and should support the system case studies to propose scenarios limiting the use of pesticides. The model will be improved according to feedback from its use by system case studies. A tutorial of DEXiPM for arable crop systems is also available in a separate document (DR2.14b). This deliverable was written by the designers of DEXiPM (INRA). DEXiPM can be used by all partners of arable crop system case studies (maize and winter crops), and is being adapted to orchard systems. Details on hierarchical trees as well as the organisation of criteria per hierarchical level are presented in appendices. Tables presenting details on input criteria and utility functions are also presented in appendices. More details on DEXi models are presented in the companion deliverable (DR2.14b).

*Authors remind the users that **the model DEXiPM for arable crop systems is under development**. The prototype (DR2.14c) is made available together with its tutorial (DR2.14b) and with a description of the model (DR 2.14a). It will evolve according to feedback from arable crop system case studies and a new version of the model will be released at M42. **Authors ask the users to carefully report all their remarks** (criteria and hierarchy of criteria, choice of qualitative classes for criteria, utility functions, i.e. weights and aggregation rules, reports on assessments of systems) **and to send them to** Elise.Pelzer@grignon.inra.fr. DEXiPM will also be adapted to orchard systems.*

1. Context and aim of DEXiPM

Environmental and social sustainability become new challenges for modern agriculture beside economic performances and food safety. Crop protection which relies mainly on chemical control should be put in question, whereas alternative control methods (genetic, cultural, biological and physical) have proved to be efficient when applied appropriately. In this context, alternative or innovative protection strategies exploring the potential of new approaches (landscape ecology, habitat management, cropping systems) or new technologies (DNA-based tools, new traits, etc.) are studied within the ENDURE EU project, for various cropping systems (arable crops and orchards). Before being tested in fields, these innovative systems need to be assessed for their sustainability in order to select the most promising ones. This assessment should also consider those innovative systems which may not be feasible or efficient today, but which might be sustainable “tomorrow” (under a different regulatory context or because of new outcomes of research). In principle, all innovations can be proposed for the assessment step. The field test step (Figure 1) will not be dealt with in ENDURE, but often leads to exclusion of “too innovative” systems, because of the cost and constraints linked with experiments.

1.1. Definition of systems in ENDURE

Various levels of the agricultural production environment can be considered and form a coherent system:

- **The cropping system level:** a cropping system is defined as ‘*a set of management procedures applied to a given, uniformly treated area, which may be a field or a group of fields*’ (Sebillotte, 1990). Cropping system includes the crop sequence and the crop management (including cultivar choice) on each crop and between crops. There is a coherence between choice of variety, sowing date and density, nitrogen fertilisation and application of growth regulators, herbicides, insecticides and fungicides;
- **The farming system level**: coherence between intensive crop management, work organisation and available machinery;
- **The advisory system level:** coherence between the intensity of cropping systems, sources of technical advice and the content of the disseminated technical information;
- **The agro-industry level:** e.g., coherence between intensive cropping systems and susceptibility of varieties to diseases;
- **The market level:** effects of commodity prices and “consumer demands”;

Three types of systems have been defined within ENDURE and will be described in each system case study (SCS):

- **The current systems (CS)**, that characterize the most common systems observed in fields of farms in various European regions (intensive systems for arable crops). Quantitative data from the ENDURE case studies on apple orchards and winter wheat are available for these systems.

- **The alternative or advanced systems (AS).** These systems already exist in fields in a non-negligible proportion, but remain less common than current systems. The example of organic farming systems in arable crops can be cited, as well as IPM systems for orchard in Switzerland. The surveys on case studies can provide some data for these systems. Constraints (economical, regulation, feasibility…) can be taken into account for the proposition of these systems.
- **The innovative systems (IS)** do not occur in fields, or in a really low proportion. They can be on the one hand, an innovative combination of existing practices or an innovative crop succession for arable crop systems (IS1), and on the other hand, systems that include new technologies or practices (IS2). These systems should be first designed and proposed without any economical, regulation, feasibility or acceptance constraints, in order to allow proposition of really innovative systems. The multi-criteria assessment will then give clues about the conditions in which the system becomes viable, feasible and acceptable.

Table 1. Distinction of systems within ENDURE.

Systems		Examples	Approach	RA
Current systems **CS**	**Most common systems observed in fields**	**Intensive system**	**Quantitative**	**3.1**
Alternative or advanced systems **AS**	**Exist in fields in a non-negligible proportion, but less common than current systems**	**Resistant cultivar**	**Quantitative if possible/ qualitative (expertise)**	**3.1 /2.4**
		IPM, organic systems		
Innovative systems **IS**	**New combination of existing practices, innovative crop succession** **IS1**	**Cultivar/species mixture**	**Quantitative if possible/ qualitative (expertise)**	**2.4**
		Spatial distribution of crops/cultivars		
		Rotation with unusual crops (alfalfa, Triticale…)		
	New technologies **IS2**	**New resistance gene/GM crops**		
		Insurance		
		New biological control agent		

1.2. General issues for DEXiPM design

1.2.1. A hierarchical qualitative multi-criteria model[1]

One of the goals of ENDURE is to propose crop protection strategies that limit the use of pesticides. In order to be assessed with DEXiPM, these alternative strategies are described within a cropping system, as defined by Sebillotte (1990)[2] but taking into account the landscape[3], as well as context elements concerning upper levels of the system (farm,

[1] More details on this type of models and their components (criteria/attributes, utility functions, etc.) are given in the deliverable DR2.14b.

[2] '*A set of management procedures applied to a given, uniformly treated area, which may be a field, part of a field or a group of fields*'. Cropping system includes crop sequence and crop management on each crop and between crops.

[3] Some criteria such as habitat management are therefore taken into account

advices, market etc.). However, most of the criteria of DEXiPM deal with the cropping system scale. The extrapolation to farm or landscape/regional scale is not really considered at the moment.

DEXiPM is a hierarchical qualitative multi-criteria model supported by the software DEXi. It consists in a decomposition of the overall sustainability into more and more specific criteria (starting with environmental, social and economic sustainability). A tree of criteria is defined, as well as utility functions, or aggregation rules (if-then rules to determine the value of a criterion depending on the values of the immediate descendant criteria). Qualitative classes for each criterion have also to be fixed, some being highly dependent on the context of assessment[4]. Basic criteria (or attributes) are inputs of the model, describing the system as well as the context of the assessment (Figure 1). Aggregated criteria are estimated based on qualitative decision rules described in utility functions. The importance of each criterion is characterized by weights.

The tree has been designed to be as generic as possible and to allow *ex ante* and *ex post* assessment of systems. Differences in trees will occur between arable crops and perennial systems. DEXIPM will not only be used to estimate a final score for the assessed system, but also, and most important, as a « dashboard » to show the value of all criteria (to "open the black box"). Both outputs (final score and assessment of each criterion) are valuable, and allow a feed back on the diagnosis of the system (what can be improved?). It is therefore important to be exhaustive, even if this can lead to redundancy of some criteria description[5].

Two major points have been kept in mind for the design of the model:

- **Which criteria are influenced by crop protection strategies?** This determines which criteria have to be detailed, and which one can be simplified. In practice, only few criteria will be directly impacted by the assessed system. The others can be left at a value of a reference system (that will depend on the context).
- **Which criteria can be estimated in an *ex ante* assessment?** When quantitative data are available (*ex post* assessment), criteria can be quantitatively calculated and aggregated (Figure 1), using methods such as SALCA (e.g. Nemecek and Erzinger, 2005) or INDIGO (Bockstaller and Girardin, 2008). For *ex ante* assessment, most of criteria, for which no quantitative data is available, will be qualitatively estimated and aggregated with utility functions. It will not be always possible to estimate the qualitative value of input criteria. However, DEXi software can deal with blank or missing data. Moreover, one important point is that it is possible to "enter" into the tree at any level[6].

[4] For example, the classes for the yield or gross margin criteria in the following description of DEXiPM
[5] For example the energy criterion and the CO_2 emissions criterion
[6] This option is not so easy to implement in the current version of the DEXi software. In order to enter criteria at upper levels, the lower part of the tree has to be deleted. This "pruning" should be the same for all strategies described in the case of comparison of strategies. The pruning technique can be implemented only for applications evaluating alternatives without comparisons between these alternatives.

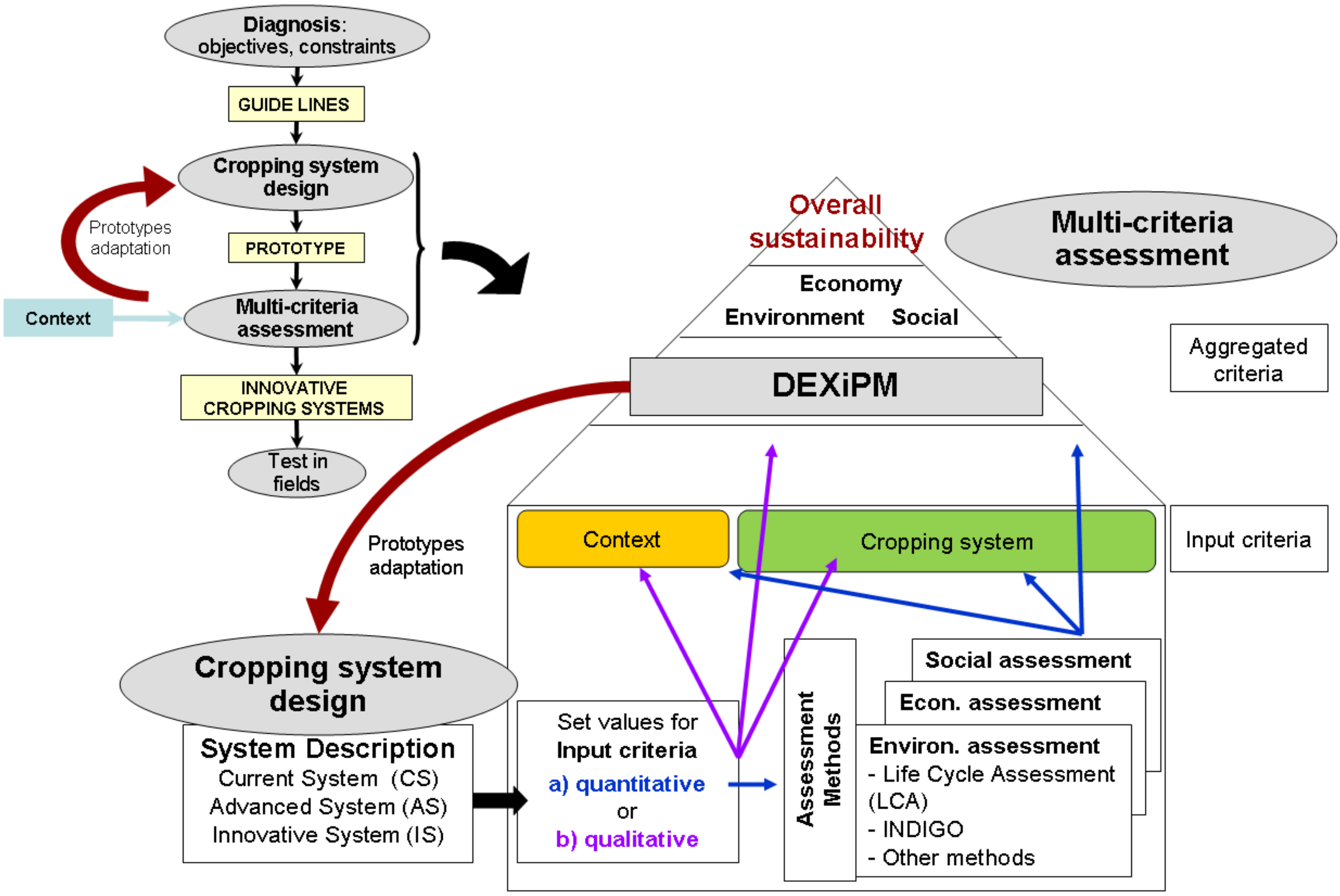


Figure 1. Schematic representation of systems assessment with DEXiPM

1.2.2. Inputs of DEXiPM

We call context inputs (figure 1) all inputs that concern the context of the system and that will influence the results of the assessment: climate, soil, market, public policies… Some context inputs are independent from the system (for example the climate or the soil[7]) whereas other depends on the system (requirement for specific agricultural equipment, delivery constraints…). Cropping system inputs group all technical inputs that describe the system (crop sequence and crop management: tillage, fertilizing, pesticide amount, etc.).

The context of the assessment is very important and will have to be taken into account, with inputs but also with adaptation of utility functions (UF) or qualitative classes of some criteria (yield, gross margin…).

1.2.3. Possible uses of DEXiPM

The two groups of inputs (context and system) are equally important and allow two major uses of DEXiPM.

1. First, it is possible to compare in a given context several systems (or protection strategies). In that use, the context inputs are considered fixed (current context for example) and several systems are compared. DEXiPM is used as a « dashboard » to highlight all the impacts and differences between systems, and not only to compare the final score of each system. For example, the introduction of a resistant cultivar

[7] Note that the system is not totally independent from these context elements. For example, not all strategies are possible in a given type of soil.

against aerial diseases for one crop of the crop sequence of the current system (see examples described in section 4) will lead to a modification of the cost of seeds and therefore of other economical criteria, but also of the amount of pesticide use, which has an impact on several criteria in environmental, social and economical sustainability. Because of the subjectivity of some input criteria, compared systems description should be carried out by the same user/group of user, and choices should be explicitly described in order to render the results of the assessment transparent. The choice of threshold for qualitative classes of inputs criteria (wide or more restricted range of values) will impact on the discrimination between systems assessed. For example, a wide range of values of input criteria will not discriminate between a current system and a current system with a resistant cultivar for one of the crop, whereas a choice of more adapted classes could allow a better highlighting of the differences between both systems. Discrimination between systems therefore depends on qualitative classes as well as weights attributed to criteria.

2. Another use, particularly for assessment of innovative systems, is to assess which changes in the context (taxes, regulation, subsidies, supply chain organisation, etc.) could render an innovative system acceptable or profitable for the farmer, while this system is not acceptable or profitable under the current context. In that use, the system inputs are left fixed, but the context inputs would vary. For example, in the examples described in section 4, the innovative system proposes a crop sequence with two years of alfalfa that is known to have beneficial agronomic properties. This system becomes profitable and therefore acceptable for the farmer only if the context of the farm allows the selling of this crop (proximity of cattle livestock, biofuel production…). The implementation of a system at a large scale in a region can have impact on the context (prices, new organisation of collecting firms…) but these induced effects are not explicitly considered by DEXiPM.

DEXiPM is an analytical tool which cannot deal with all interactions occurring within a complex system but aims at dealing with the major effects of crop protection strategies under various contexts.

1.2.4. Link with other assessment methods

As pointed out before, some DEXiPM criteria (whatever the level) can be calculated with SALCA or other quantitative methods such as INDIGO (Bockstaller and Girardin, 2008), for *ex post* assessment. We also added other criteria taken into account in DEXi approaches for assessment of innovative cropping systems (such as MASC, Sadok et al. 2009, ECOGEN, Bohanec et al. 2008), that can be assessed qualitatively even in an *ex post* assessment, whenever their calculation is not possible. In that way, DEXiPM is well adapted to *ex ante* assessment.

2. Proposal of a tree for DEXIPM for arable crops

This chapter describes the criteria that are considered in DEXIPM as well as their hierarchical organization. Figures of trees are presented in appendices, and input criteria are also detailed[8].

2.1. Economical sustainability

Several criteria have been proposed within ENDURE and have been compared with those taken into account in MASC (Sadok et al. 2009), or in Bohanec et al. (2008), to propose the tree of DEXiPM. Two criteria are taken into account, the "profitability", and the "viability" of the farm (medium and long term viability, as the "profitability" characterizes the short term viability).

2.1.1. Profitability

This criterion takes into account the "gross margin", the "labour cost", the "subsidies" (direct subsidies linked with environmental aspects and other subsidies), and the "production risk". Cost of pesticides, fertilizers (N, P, K), fuel (deep tillage, total number of treatment operations, superficial tillage between crops and in the crop and fuel consumption at harvest), irrigation, seeds (depending on the sowing density and on the cultivar) are taken into account for the calculation of the gross margin, in the "production cost" criterion. We consider that other costs (buildings and material maintenance) are secondary, not reducible and not directly linked to crop protection strategy. The "production value" depends on the "yield" and on the "selling price". The "selling price" depends on the "average market price" that could increase or decrease because of "valuation or devaluation". "Valuation/devaluation" criterion takes into account the crops of the crop sequences, and the compliance with quality and/or certification requirements. Penalty can be due for example to low level of aesthetical or technological quality, to non-respect of regulation or certifications constraints etc. On the contrary, premium can be due to certification, in a context where IPM is valuated. The "yield" is described based on Bohanec et al. (2008): potential yield, depending on the climate and soil, independent from the system, and yield reductions. Reductions are due to "weed state", "pest state", "nutrition deficiency" and other causes linked with the system, such as the cultivar or the delay of sowing dates. It is difficult to estimate the yields at the system scale. Each crop should be considered, leading to a potential yield estimated globally for the crop sequence (resulting from the estimation for each crop of the crop sequence). The yield is typically a criterion where the boundaries for qualitative classes can not be fixed but will depend on the regional context of the assessment.

The criterion "weed state" corresponds to the "weed abundance" criterion detailed in the aerial biodiversity part, but classes are defined in the inverted order, as abundance of weeds is favourable to the aerial biodiversity, but unfavourable to the yield. "Pest state" is characterized by the "pest pressure" and by the "level of control", including all control methods (chemical and other). Even if this criterion is redundant with other input criteria, it has to be estimated here but should be in accordance with all control methods described in the tree (pesticides, cultivar, *etc*.). The "nutrition deficiency" depends on the "water stress" and the "risk of Nitrogen stress". The input criterion "water stress" should be in accordance with the climate, the crop requirement, the irrigation and the type of soil, described in other parts of the tree. Similarly, the mineral nutrition depends on the "coverage of crop Nitrogen

[8] RA24 had already discussed a first list of sustainability criteria (see DR2.1). This preliminary has been amended when designing DEXiPM.

requirement" that should take into account the amount of N fertilizers, the requirement of the crop and the yield.

The "labour cost" balances the gross margin: a system can have a high gross margin but necessitate a high cost of labour to be applied (lot of people for example for a protection strategy that would need a lot of surveillance, or need for the employment of a specialist that will be paid more). This has to be taken into account. The "production risk" will also be taken into account to balance the gross margin. This criterion characterizes the fluctuation of yield due to the tested system (not only due to reduction of pesticides), and the fact that the awaited gross margin could not be reach. For example, the efficiency of mechanical weeding depends on the climate, and the risk of such weeding of being not efficient at all has to be taken into account.

2.1.2. Viability

The "autonomy" criterion considers the economic "independency to subsidies" (calculated or estimated as the ratio between direct subsidies and the gross margin), the "economic efficiency" (calculated or estimated as the ratio between the gross margin and the production value), the "pesticide dependency" (calculated or estimated as the ratio between the pesticide cost and the production value), and the "specialization" (calculated or estimated as the ratio between the gross margin part due to the main crop in the system and the total gross margin). The "economic independency", "pesticide dependency" and "specialization" also characterize a notion of risk linked to transition towards an innovative system. "Subsidies" are separated in "direct subsidies linked with environmental aspects" (that can be modified to incite farmers to adopt a strategy, *e.g.* based on environmental performances) and "other subsidies".

In the "investment" criterion, the "requirement for agricultural equipment" is linked to the system being assessed, whereas the "financial security of the farm" is a qualitative estimation of the possibility of the farmer to invest in new equipments, linked to the context.

2.2. Social sustainability

We propose three criteria for the social criterion: one criterion characterizing the "likelihood of adoption of the protection strategy" by farmers, one characterizing the "social durability of the system", and one characterizing the "interactions between the system and the society". Note that the social trend is not taken into account in DEXiPM (*e.g.* something that was not acceptable few years ago can be acceptable today or *vice versa*). More generally, the relative dynamics of assessment is not considered: for example, a TFI of 3 would not have the same meaning if its value was 4 the year before or if it was 2), but it is not the purpose of DEXiPM. A global criterion could be added in the social tree to characterize the evolution of the farm.

2.2.1. Likelihood of adoption

The "likelihood of adoption" depends on the "possibility of access to market" (supply chain, possibility to sell products), but also on "support of farmers", on the "access to relevant technologies" necessary to adopt the innovative system and on the "potential reluctance of farmers to adopt the strategy" (*e.g.* if there is a risk of a decrease in yield or of non-selling of production). "Access to technologies" (financial and geographical) includes for example access to seeds of resistant cultivars if the innovation is the use of a new resistant cultivar, or access to GM crops, access to monitoring equipments or other specific equipment (*e.g.* tool for precision weeding), etc.

The "market access" depends on the possibility to sell the product at proximity of the farm, represented by the criterion "delivery constraints". It also depends on the compatibility of the production with certifications constraints and technological requirements for arable crops (protein content, sugar content, forage quality, etc.) or aesthetical requirements for orchards systems (fruits colour, spots, size, etc.). These criteria characterize the fact that quality imposed by the mass marketing, the supply chain, the certification or the regulations can be an obstacle to the adoption of the innovative system. "Technological or aesthetical requirements" are linked to the distribution network. A distribution network with fewer intermediates often leads to fewer requirements in the quality (but this is not always true). In the social tree, we only consider the certification as a potential obstacle to the adoption. For example, the AOC certification guidelines for vineyards in France only allow some cultivars; this can hinder the introduction of new resistant cultivars in cropping systems. Another example is the « pain normand (bread from Normandy) » certification for a traditional and local bread, for which the cultivar Camp Rémy is mandatory (susceptible cultivar), preventing the use of resistant cultivars (Lamine *et al.*, 2008). The certification favouring the adoption of a new protection strategy (valuation of IPM products for example) is considered in the economical tree, as premium for the selling price. "Market access" also depends on "product quality compliance with health requirements" (pesticide residuals in the products, due to pre-treatments, and mycotoxins)[9].

The "support" includes the "affiliation to a farm support network" (farmer groups…) that has to be in accordance with the strategy to adopt, and the "availability of a relevant advice" to help the farmer to adopt strategy: advice should be adapted to the strategy and independent from input selling and type of system (extension services could be opposed to non-independent advice associated to input selling). For example, the more the advice is independent from firms, the more the adoption of an IPM strategy is possible (an advisor linked with pesticide firms will tend to advice for treatments rather than alternative options). For orchard system, the specialization of the advice has also to be taken into account, with the hypothesis that a specialized advice adapted to the strategy helps the adoption. This is not true in arable crop systems.

2.2.2. System

The durability of the system itself includes "workers' health risk due to pesticides", "operational difficulties" and "adaptability". The criterion "adaptability" characterizes the capacity of the system to adapt itself to context modifications. The diversity (non-specialization) is supposed to favour the adaptability of the system, but this can be discussed. The adaptability depends above all on the "farmer and employees' knowledge and skills" (capacities to face a context modification). This criterion takes into account the educational background of farmer and employees, as well as its capacity and interest to mobilize diversified advices. The criterion "workers' health risk due to pesticides" considers the exposure of workers to pesticides during their application. Only the quantity of pesticides applied is taken into account. Other aspects such as the toxicity for human health, the duration of applications, the application method and the wearing of protections will not be considered, as it only attenuates or emphasizes the results due to the quantity (without changing the trend). Finally, the criterion "operational difficulties" takes into account the "work hardness" and the "complexity of the system". "Work hardness" includes "physical difficulty and disturbance" (noise, repetition of a task…) and "work intensity" (number of hours worked, including surveillance time). "Complexity" takes into account the "number of crops", the "risk of simultaneous operations due to a limited number of suitable days" (including specific operations linked with innovative systems), and the "farmer and employees' knowledge and skills". For orchard systems, the level of permanent work has also to be considered in this criterion, as farmer knowledge and skills are less efficient if the farmer or worker is only

[9] Dietetical quality could be added to this criterion but is not taken into account in the current version of DEXiPM: for example, grape or tomato cultivar with higher polyphenol content could be valuated but in contradiction with a protection strategy based on the use of a resistant cultivar.

punctually present on the farm. The “number of crops” and the “risk of simultaneous operations” increase the “complexity”, whereas the “farmer and employees’ knowledge and skills” decrease the “complexity”.

2.2.3. Interaction with society

This group of criteria takes into account really subjective criteria (except for the “contribution to employment”). The criterion “societal value of landscape” estimates how the system improves the landscape from the point of view of the society. The “societal value of landscape” is a very subjective criterion that deals for instance with diversity of crops, colours, unusual crop (e.g., flax in some regions), non-productive areas, 3-dimension perception… Today for instance, a landscape with a high proportion of natural elements will be better perceived by society (but it has not always been the case). This criterion is very subjective and could be difficult to estimate. However, it is important to consider in order to highlight that the adoption of new systems could raise such issues. The criterion “acceptance”, estimates how people perceive the innovation (for example if the innovation is a GM crop) and is also very subjective. It was kept for the same reasons. The criterion “social accessibility” characterizes how the system eases or renders more difficult the access to the product (price differences between current and innovative systems). Innovative systems could lead to higher prices, thus hindering part of the population to access to the products. The “contribution to employment” resulting from the system is also taken into account.

2.3. Environmental sustainability

We propose to decompose this part in three groups of criteria: “resource use”, “environmental quality”, and “aerial and above soil biodiversity” (organisms living in the soil, as worms or microorganisms, are not taken into account).

2.3.1. Resource use

2.3.1.1. Energy use

Both criteria “energy consumption” and “energy efficiency” were considered. These criteria are not redundant as a system with a low level of energy consumption could also have a bad efficiency in the use of this energy. We propose for the energy efficiency to calculate or estimate the production (yield, converted in energy equivalent) per unit of energy used.

As commonly done (ECOGEN, Bohanec et al. 2008, SALCA, Nemecek and Erzinger, 2005, INDIGO, Bockstaller and Girardin, 2008), we distinguished the direct and indirect energy for the “energy consumption”. The “direct energy consumption” includes electricity and fuel, used in machinery, buildings, irrigation and professional vehicles, whereas “indirect energy” takes into account fertilisers and pesticide manufacturing, seeds and machinery production (Bonny, 1993; Pervanchon et al. 2002). The energy for seeds production is negligible (Bonny, 1993; Pervanchon et al. 2002), whereas the energy used for machinery production and the electricity used in buildings are non-reducible for farmers, and not dependent on the crop management (Pervanchon et al. 2002). Even if irrigation is not directly linked to protection strategies, it represents 15 % of the total energy consumption in average, taking into account systems with no irrigation (Pervanchon et al. 2002). We therefore chose to consider only machinery use and irrigation for direct energy, and pesticide and fertilizer manufacturing for indirect energy (Pervanchon et al. 2002).

For the “direct energy consumption”, the fuel consumption depends on the size, power, speed of the tractor. Similarly, the energy use linked with irrigation depends on the water volume, the power and flow of the pump, the area of the irrigated field… Calculation of I_{En} of INDIGO could be done to estimate the range of values taken by these criteria, for various equipments. In DEXiPM, this was simplified by taking into account the “deep tillage” (every year, more than ½ year, less than ½ year, no), the “superficial tillage” (in the crop, mainly mechanical weeding, 2 or more per year, 1 per year, none, and between crop, including false seedbed, 4 or more per year, 1-3 per year, none)[10], the “total number of treatment operations” (fertilizers and pesticides, 8 or more per year, 4-7 per year, 3 or less per year), and the “fuel consumption at harvest” (can be very important for some crops (sugarbeets…), leading to a non-negligible impact when introducing such crops in the crop sequence).

For the “indirect energy”, the consumption linked to the production of fertilizers represents 30 to 70 % of the total energy use, depending on the study and system (Bonny, 1993; Pervanchon et al. 2002). Fertilizers are not directly linked to protection strategies, but can be influenced by a change in rotation for example. For this part, we will consider the quantity of mineral fertilizers (N, P, K). Even if the part of energy use due to the production of pesticides is low, it is important to consider this as this is directly linked to crop protection. The amount of pesticides used is expressed in TFI commercial product and not in TFI active substance[11]. Five qualitative classes based on TFI have been fixed: 0, [0-2[, [2-4.5[, [4.5-7[, >7. these classes are based on European data (average, minimum, maximum) for wheat, barley and rape, and on French data (average, 3rd decile, 7th decile) for other crops (potatoes, sugarbeet, sunflower…), and range of TFI were estimated for several usual crop sequences, leading to the five classes. Concerning arable crops in North of Europe, France is mainly in the [4.5-7[class, Denmark in the [2-4.5[class, and Great Britain in the [4.5-7[or >7 class. The same classes are used each time the “total Pesticide TFI” input appears. Classes for fungicides, herbicides and insecticides have been estimated with the same method. Note that seed treatments are not explicitly considered in the DEXiPM tree. Their environmental impact (water, soil quality, and volatilisation) is not well known but is probably negligible in comparison with sprayed pesticides. The impact on cost (economical part) can be taken into account in the estimation of the additional seed cost. The impact on energy consumption is not taken into account.

2.3.1.2. Water use

The “water use” description is derived from Sadok et al. (2009). Water use is due to “irrigation” but the impact is not the same during dry periods, or periods when rain is abundant. Similarly, the impact of irrigation depends on the water that is available for irrigation (ground water, proximity of a river…). The “risk linked to dry period” (represented by the proportion of summer crops in the crop sequence) as well as the “local availability of water for irrigation” (low to high) has therefore to be taken into account. The irrigation depends itself on the crop requirement (maximal evapotranspiration of crops) and crop water availability (rain), but is estimated directly as an input criterion.

2.3.1.3. Mineral fertilizers use

This criterion groups P and K elements. To simplify these criteria that are not directly linked to the protection strategies (except if the fertilization is modified due to a change of the rotation), we will only consider the quantity of mineral fertilizers supplied. Note that sulphur is not taken into account but could be added if necessary.

2.3.1.4. Land use

This criterion has been proposed for example in Brentrup et al (2004). It is characterized by the “availability of arable lands” (free lands not already use for agricultural production) as well

[10] Minimum tillage systems are considered by the estimation of the three criteria deep tillage (that should be none, superficial tillage between crops and superficial tillage in the crop.
[11] The TFI is maybe not the best indicator for pesticide amount, as it does not take into account some products such as pheromones, as well as seed treatments

as by the “intensity of occupation of land” (production per surface unit). This criterion seems important to be taken into account, for example to consider the impact of more extensive systems. These systems necessitate more land to produce the same quantity, which can be problematic in regions where arable land availability is limited, leading to removal of non-productive area. For this criterion, intensification of systems (in terms of productivity) is sown as positive for sustainability (the more intensive the system, the less the land necessary)

2.3.2. Environmental quality

This criterion takes into account the “water quality”, “soil quality” and “air emissions” (Sadok et al. 2009).

2.3.2.1. Water quality

This part is divided in “eutrophication potential”, “aquatic ecotoxicity” (considered in LCA analysis) and ground water quality (as in Bohanec et al. 2008). The same processes are involved for the NO_3 reaching superficial or ground water. The fact that NO_3 can reach ground water only depends on the permeability of soil layers. We therefore consider the same criterion “NO_3 leaching” for “ground water quality” and “eutrophication potential”. The “eutrophication potential” depends on nitrogen and phosphorus. Both N and P surplus are considered, as well as the way elements reach water: erosion risk for P and leaching risk for NO_3. The “P surplus” is estimated as an input. The “N fertilizers” (indirectly linked to crop protection strategies if rotations are modified or for the impact on crop architecture) together with the crop requirements are important to determine the “N surplus” that can be leached. The date of application of fertilizers (in relation with the development stage of the crop determining the absorption) impacts the leaching risk of NO_3. Moreover, two period of risk can be distinguished (INDIGO, Bockstaller and Girardin, 2008): spring and after harvest. However, for simplification reasons, the “N surplus” is estimated by the user with the “coverage of crop Nitrogen requirement” criterion (deficiency, balanced, surplus). A deficiency could be tolerated for some reasons, or occur because of a mistake in the doses supplied, whereas a surplus could occur in a situation where high protein content is required for example. This criterion should take into account the amount of N fertilizer and the crop requirements (depending on the yield). The “capacity of the crop sequence to uptake N during the leaching period”, mainly autumn and winter, is also estimated. It depends on the frequency of bare soil periods, the occurrence of catch crops or volunteers, the nature of volunteers, and also on the duration of non-uptake period (starting from the flowering of crops). The effect of stubble can also be considered: the date of stubble breaking and the C/N ratio of stubble impacts on the N available for leaching (the higher the ratio, the higher the amount of N necessary for stubble decomposition, and the lower amount of N available for leaching). However, this effect is secondary. The “leaching risk” is estimated as an input and is linked to the soil type and depth, and to the climate. It could be estimated by the drainage indicator (rain/soil water stock, CORPEN, 2006).

“Field erosion risk” and “runoff risk” both determine the “erosion risk” (Bockstaller, 2007). These criteria have been simplified, and depend on the “context” (erodibility or sensibility of the soil to drops’ ripping, and topographical risk for field erosion, soil type and sensibility to battance for runoff), the “soil cover” (limiting the erosion), the “deep tillage” (enhancing erosion risk) and the “superficial tillage” (increases the field erosion risk when the risk is low but decreases the runoff risk when it is high) (e.g. Boiffin et al. 1988, Papy and Boiffin, 1988).

The “ground water quality” is considered, as it determines the quality of drinkable water. NO_3 and pesticides are taken into account. The “pesticide leaching” includes “total Pesticide TFI” (TFI commercial product), “mobility”, and “leaching risk”. Finally, we only consider the pesticides (amount and eco-toxicity[12] for the environment, defining the pesticide profile risk) and heavy metals (estimated as an input criterion) for the "aquatic ecotoxicity". There is no risk of contamination in arable crops systems, except when wastewater sludge is supplied (more risk occurs in vineyards when copper is applied). "Runoff risk" is considered as the way pesticides and heavy metals reach water.

The ammonia deposition impacts on eutrophication and aquatic ecotoxicity, as well as on biodiversity. NH_3 is therefore considered in the "air emission" criterion. The acidification, considered in LCA analysis, concerns only some lakes and does not touch groundwater and rivers. It also affects terrestrial natural area like forest. However, this is not a problem in arable lands and is not taken into account in DEXiPM. NO_x deposition is not considered in DEXIPM, as NO_x emissions due to agriculture are negligible in comparison with other activities (as S_2O).

2.3.2.2. Soil quality

This criterion has been divided in "physical", "chemical" (Sadok et al. 2009), and "biological quality" (soil biodiversity in Bohanec et al. 2008). The "physical quality" of soil depends on the "compaction risk" and on the "erosion risk" (Sadok et al. 2009). The "compaction risk" depends on the climate (rain during late-harvests) and on the "proportion of autumn-harvest crops" in autumn (sugarbeets, maize) that increases the risk. The "erosion risk" criterion is detailed in the water quality part. The "chemical quality" depends on "organic matter" and "phosphorus fertility" (Sadok et al. 2009). "Organic amendment", "exportation of crop straws or burning", and "deep tillage" define the "organic mater" content, whereas "P fertility" depends on "P surplus" (estimated as an input criterion). The impact of pesticides is considered in the "biological quality" of the soil, in the "chemical disturbance" criterion. The "soil cover" limits the impact of pesticides on soil. In "biological quality", the "physical stress" is also taken into account, depending on "deep tillage" (climatic effect could also be considered but in extreme situations), as well as the "soil fertilisation intensity" (Bohanec et al. 2008).

2.3.2.3. Air emissions

This criterion considers "greenhouse gases", "ammonia" and "pesticide volatilization". According to Brentrup et al. 2004 or Mouron et al. 2006, emissions of nitrogen oxides or volatiles organic compounds (from engine exhaust gases) impacting on ozone layer due to agricultural activity are negligible in comparison with other activities. They are not taken into account in DEXiPM

"NH_3 emission" deals with large spatial scales whereas "pesticide volatilization" is more limited. "Pesticide volatilization" impacts the human health but also other living organisms. However, this criterion is not taken into account in the social part of the tree, but is considered here in the environmental part. The quantity of pesticides is considered, as well as the "risk of pesticide drift due to material" used for the application that determines part of the air losses. Concerning "NH_3 emissions", the form of organic and mineral N fertilizers (liquid or not) impact the volatilisation: the volatilisation of liquid product is much higher, particularly if applied in dry conditions. The type of application of fertilizers (buried by tillage or not) as well as the type of soil (limestone or not) also impact the volatilisation (Bockstaller and Girardin, 2008). However, the effect of tillage is observed only if tillage operation is applied just after the application of fertilizer (as the volatilisation is a fast phenomenon). For simplification reasons, we will only consider the "quantity of fertilizers" applied (but the form of fertilizer should be kept in mind).

[12] See the toxicity by products on http://e-phy.agriculture.gouv.fr/ or by active ingredient on http://www.dive.afssa.fr/agritox/php/fiches.php. Other features of pesticides are also given.

The “greenhouse gases emissions” include “CO_2” and “N_2O”. Methane emissions are negligible in crops (except for rice). In INDIGO (Bockstaller and Girardin, 2008), N_2O emissions depends on the type of soil (humus and calcium content, hydromorphic or not), on the tillage (ploughing after application of fertilizer) and on the application of organic fertilisers (incorporated or not). To simplify the criterion, we will only consider the “hydromorphic soil state” and the “quantity of fertilizers” applied. “Direct” and “indirect CO_2 emissions” are described as “direct” and “indirect energy consumption”: the hypothesis here is that energy consumption due to various causes (machinery, fertilizer manufacturing…) is proportional to CO_2 emissions.

2.3.3. Aerial and above soil biodiversity

In SALCA-BD (Jeanneret et al. 2006), indicator organisms have been chosen and their diversity and abundance is considered. The link of organisms with the agricultural activity as well as the representation of various compartment of the agricultural systems (soil, natural elements…) were taken into account. The chosen organisms were: birds, small mammals, amphibian, mollusc, spiders, carabidae, butterfly, pollinators, grasshoppers, flora of the fields, flora of pastures. The effect of all practices on groups of species is inventoried according to the habitat: arable crops, meadows, semi-natural habitats and area dedicated to the environmental protection (with details for each type: nature of arable crops…). The level of intensification of each habitat is also taken into account. The inventory of impacts is based on bibliographical studies and on experiments set up in Switzerland. The system is assessed according to its impact on the different groups of species. Several limits can be raised for a qualitative and *ex ante* approach in the European context. The method is complex to use and represent in a hierarchical tree. Concerning the choice of organisms, organisms such as natural enemies should be considered in the framework of ENDURE. The impacts have been estimated according to the literature but also to experiments carried out in Switzerland. The method is only valid for Switzerland and need to be adapted to other European contexts. The SALCA approach is relevant from a conceptual point of view, as it directly links a practice with organisms. However, it would be necessary to propose a more exhaustive list of organisms, to integrate the impact of innovative technologies (for *ex ante* assessment), to enlarge the method to other European contexts and to adapt the method to other crops than arable crops. This necessitates a huge bibliographical and experimental work.

In Bohanec et al. (2008), two criteria are taken into account: the soil biodiversity, corresponding to the soil quality described above (environmental quality), and the aerial and above soil biodiversity. Several groups of species are considered, from the food chain point of view: pollinators, predators, herbivores, weeds, parasitoïds, on which the type of crops and crop protection level have an impact.

Given the difficulties to assess the impact of cropping systems on biodiversity from the species point of view, MASC (Sadok et al. 2009) proposed simple indicators. Several indicators have been mentioned during the construction of MASC, such as field size (a landscape with smaller fields should favour the biodiversity), crop diversity (species and cultivars), non-productive areas (non-cropped, meadows…), weed diversity and pressure from chemical treatments. In the last version of MASC, only the crop diversity and the chemical pressure are considered.

The main practices that seem to impact the biodiversity (Le Roux et al., 2008) are the tillage (direct effect on macro-fauna, indirect effect on micro-fauna *via* modification of trophic conditions and micro-climate, direct effect on weeds), the pesticide use (insecticides on arthropods, fungicides on soil fauna, herbicides on flora, and indirect effect on animals *via* the trophic chain, effect on soil microbial community and resistance development), and the rotation (a more complex rotation is generally considered positive for the biodiversity). Mineral fertilisation also impact biodiversity (direct effect on soil microbial community and flora, indirect effect on animals *via* plants, effect on aquatic ecosystems *via* eutrophication risks, and on other ecosystems *via* N deposition). Some of these impacts are already taken into account in the other criteria of the environmental tree. Practices can have an opposed effect on diversity and abundance. This is the case for fertilisation that has globally a positive effect on abundance but a negative effect on diversity. Similarly, pesticides in orchards have no effect on diversity (because of the resilience of such systems) but a negative effect on the abundance of insects. Heterogeneity of landscape is considered to have a positive impact on both diversity and abundance.

We propose a mixed approach for DEXIPM, where the fauna and flora are characterized by groups of species, on which the agricultural practices have an impact. The chemical pressure is taken into account, as well as crop sequence and tillage that are the main practices impacting the biodiversity. Other practices are considered as secondary. The proportion of non-productive areas (including meadows and semi-natural areas such as hedges) is also taken into account, as well as habitat managements that improve this proportion, or the nature of plants in non-productive areas.

2.3.3.1. Fauna

For the “fauna”, we chose to consider the “pollinators” (for their function in agriculture), the “soil natural enemies” (mostly carabidae and spiders), and “flying natural enemies” (such as ladybugs), that are predators of pests but also other natural enemies. Other species could be taken into account, such as birds, that are also predators of some pests. Worms or microbial organisms are taken into account implicitly in biological soil quality. The impact of pesticides on soil natural enemies is small compared with deep tillage or habitat (Le Roux et al. 2008). We chose however to keep this criterion, as this impact is not null. The “habitat network” depends on the occurring landscape (proportion and connectivity of “non-productive areas”), but also on the quantitative and spatial “habitat managements” that can improve the proportion or connectivity. The connectivity is particularly important for insects living on soil (Le Roux et al. 2008). On the contrary, “chemical pressure” has a great impact on “flying natural enemies” and “pollinators”, particularly in simplified landscape (with low proportion and connectivity of non-productive areas, Le Roux et al. 2008). The “effect of crops” on pollinators is also taken into account, as some crops (*e.g.* oilseed rape) are more favourable to pollination than other. The effect of the landscape on flying insects is taken into account through the “flora” criterion. The impact of pesticides on fauna includes insecticides and fungicides.

2.3.3.2. Flora

The “flora” is described with “natural or semi-natural flora” (in non-productive areas) and “weeds” (fields flora), as in SALCA-BD. The “natural/semi natural” criterion depends on the “quality of margin”, and on the “chemical pressure”, as herbicides could reach field borders and damage flora. The “margin flora quality” depends itself on the “habitat network” (proportion and connectivity of non-productive areas), but also on “habitat management quality” (which species are sown in borders). The flora profile (soil and climate that impacts the species that can grow) is not taken into account: species are indeed different when soil or climate change, but there is no flora profile that really increase or decrease the number and abundance of species, except for extreme conditions, that do not occur in cultivated areas in Europe. Impacts on “weeds” have been decomposed in two criteria, concerning “abundance” and “diversity”. A diversified crop sequence increases the diversity of weeds. According to Fried et al. (2008), Munier-Jolain (pers. Com.) and Bohan (meta-analysis on FSE data, pers. Com.), the season of crop sowing impacts on weed diversity and abundance. We chose to defined 4 “types of crops”: winter crops, spring crops, summer crops and perennial crops (more than one year implantation, such as alfalfa). The crop sequence is supposed less favourable to diversity when there is only one type of crop in the rotation (whatever the type), whereas it is more favourable when there is several types of crops. On the contrary, a more diversified crop sequence decreases the abundance of weeds. The more favourable class for abundance is the occurrence of one type of crops in the crop sequence. According to Fried et al. (2008), some weed species disappear in more intensive agriculture. This is taken into account in the “regional intensification context” criterion. The “margin flora quality” has a small impact on field flora (seedbank, proximity of natural flora in field borders…) but is nevertheless taken into account. The “chemical pressure” has a small impact on weed diversity but a great impact on weed abundance. The “false seedbed”, “inversion tillage” and “mechanical weeding” are supposed to have no impact on weed diversity, but an impact on weed abundance. The impact of tillage depends on the occurrence of an inverting operation.

3. Proposal of weights and decision rules for utility functions for DEXiPM arable crops

We propose here utility functions for the aggregation of the criteria. In DEXiPM, some utility functions are fixed, whereas other are left to the choice of the user, if they depend highly on the context or on the priorities of the user. This distinction between fixed and adaptable would be more important if the model was spread at wider scale than ENDURE. The occurrence of thresholds imposed for some criteria in UF can be discussed. What is important is to explicitly describe the choice of weights in UF[13], in order to render the assessment results as transparent as possible. Utility functions are summarizes in appendices.

3.1. Economical sustainability

By default, weights of "profitability" and "viability" are equal (50%) but can be adapted according to the context, with a minimum value of 30% for each criterion. The "gross margin" should have a higher weight than "production risk" and "production cost" in order to explain the "**profitability"**. If the "gross margin" is very low, the "profitability" is low or very low, except when other criteria are at the higher value. Decision rules have been fixed accordingly, and this leads to 40% weight for "gross margin", 20% for "production risk", "subsidies" and "labour cost". These weights can be adapted, with a minimum weight of 20% for "gross margin", and 10% for risk and "labour cost".

For the "**subsidies"**, weights attributed to "direct subsidies linked with environmental aspects" and to "other subsidies" are equal. This can be adapted. The "**labour cost"** depends on the "number of hours" and on the "hourly wage", with the same weight for both criteria. The "**gross margin"** is a balance between "production value" and "production cost". The utility function has been fixed, resulting from simulations with 4 realistic values of "production value" and "production cost", corresponding to the four qualitative classes of both criteria. This leads to 60% weight for "production value", and 40% for "production cost". The weights for the "**production cost"** are derived from the AGRESTE 2006 surveys and the results of the ADAR French project "systèmes innovants". Weight for the irrigation cost is derived from the results of a French farm representative of the French region Centre, and from Levy et al. (2005) who estimate the part of the cost of irrigation at 20% of the total costs, but taking into account only irrigated crops. Weights are 27% for "pesticide" and "fertilizer cost", 18% for "seeds" and "fuel costs", and 10% for "irrigation". For the "**cost of fuel"**, the same weights are attributed to "deep tillage", "superficial tillage", "total number of treatment operations" and "fuel consumption at harvest" than for the energy use criteria (15%, 30%, 30%, 25% respectively), as well as for "**cost of fertilizers"** (70% N, 15% P and 15% K). The "**cost of seeds"** is a result of the "potential additional price of the cultivar" and of the "density of sowing". The same weight is attributed to both criteria. The "cost of irrigation" depends on the irrigation input criterion.

The "**production value"** depends on the "selling price" and the "yield". Both criteria have the same weight. The utility function has been fixed as follows. The "**selling price"** is based on the "average market price". It is unchanged if there is no "valuation or devaluation", a penalty decreases the price of one class, a premium increases the price of one class. This leads to equal weights. The "**yield"** is described with "potential yield" and "yield reduction". When the potential yield is very low, the yield remains very low, whatever the yield reduction. For other cases, the yield has the same value of the potential yield for low or very low yield reduction, and is decreased of one class if yield reduction is high and of two classes if yield reduction is

[13] The discussion around the standard and choice of weights is often very rich.

very high. This leads to 50% weight for "potential yield" and 50% for "yield reduction". As in Bohanec et al. (2008), a higher weight is attributed to the "nutrition deficiency" than to the "pest" and "weed state" (for the **"yield reduction"**). However, a higher weight is attributed to the "yield reduction due to other cause" than nutrition or pests and weeds, as delay in sowing dates or lower yield target lead systematically to a yield reduction, whereas weeds, pests and nutrition deficiency (at least nitrogen) are more accidental than systematic. Weights are fixed at 45% for "yield reduction due to other cause" than nutrition or pests and weeds, 25% for "nutrition deficiency", and 15% for "weeds" and "pest state". The "**pest state"** is very low when there is no "pressure", and low (no or low control) or very low (control high and very high) when the "pressure" is low. This leads to 70% weight for "pressure," 30% for "control". The "**nutrition deficiency"** depends on the "water stress" and the "N mineral nutrition deficiency", but in case of water stress, nitrogen can not be assimilated by the crop. Utility functions have been fixed accordingly and this leads to higher weight (60%) for "water stress" than for "mineral nutrition deficiency".

The same weight has been attributed to the "autonomy" and to the "investment" in the "**viability"**, but this can be adapted according to the context, with a minimum of 30% per criterion. By default, the same weights are attributed to the "pesticide dependency", "efficiency", "independency" and "specialization" for the "**autonomy"** criterion, but this can be adjusted according to the context, with a minimum of 10% per criterion. The same weight is attributed to the "requirement for agricultural equipment" and "financial security of the farm". The weights attributed to "pesticide cost" is higher (60%) compared with "production value" for the "**pesticide dependency"**. The weight attributed to "gross margin" for the "**economic efficiency"** is higher (60%) compared with the "production value". The weight attributed to "subsidies" is higher (60%) compared with "gross margin" for the "**economic independency"**.

3.2. Social sustainability

A higher weight is attributed to "likelihood of adoption" and "durability of the system" in comparison with "interaction between the system and the society", but this can be adapted according to the context. A minimum of 20% weight is required for "system" and "likelihood of adoption".

For the "**likelihood of adoption"**, in the current version, if the "market access" is difficult, the "likelihood of adoption" is low or very low, even if the "support" and "access to technologies" are favourable. This leads to a higher weight (45%) for the "market access" compared with "support" (30%), "access to technologies" (15%) and "reluctance/reservation of the farmer to adopt the strategy" (10%). However, this can be adapted depending on the context. The weights for criteria should not be less than 10%. The decisions rules were fixed for the "**support"**, leading to a slightly higher weight for "availability of relevant advice" (55%). This can be adapted to the context, with a minimum of 10% weight per criterion. For the "**market access"**, the possibility to sell the product at proximity of the farm ("delivery constraints") seems more important, followed by the "product quality compliance with health requirements". The "compatibility with the aesthetical or technological requirements" can also be a serious obstacle to the market accessibility. Weights are 30% for the "delivery constraints", 25% for the "product quality compliance with health requirements", 25% for the "compatibility with aesthetical/technological requirements" and 20% for the "certification constraints". However, these weights can be adapted according to the context, with a minimum threshold of 20% for "product quality compliance with health requirements". "Certification constraints" can be null. The "delivery constraints" can also not be problematic at all. In "**product quality compliance with health requirements"**, the same weight has been attributed to "risk of mycotoxins" and "risk of pesticide residuals" (50%).

Concerning the “durability of the **system”**, weights for “workers’ health risk due to pesticides”, “operational difficulties” and “adaptability” are equal by default, but can be adapted according to the context and farmer priorities or feelings, with a minimum of 15%. In the “**operational difficulties”**, the weights for “complexity” and “work hardness” are equal by default, but can be adapted, with a minimum of 20% per criterion. Weights are equal for “physical hardness” and “work intensity” in the “**work hardness”**. Weights of criteria (“number of crops”, “risk of simultaneous operations”, “farmer and employees’ knowledge and skills”) are also equal for the “**complexity”**. The “**adaptability”** depends above all on the “farmer and employees’ knowledge and skills”, and a higher weight has been attributed to this criterion (80%).

Finally, for the “**interaction with the society”**, because of the subjectivity of the “societal value of landscape” and the “acceptance” criteria, a lower weight has been attributed to both criteria, leading to 35% for the “contribution to employment” and the “social accessibility”, and 15% for the “societal value of landscape” and the “acceptance”. Weights can be adapted by the user, with a minimum of 10%.

3.3. Environmental sustainability

The same weights have been attributed to “resource use”, “environmental quality” and”aerial and above soil biodiversity”. However, these weights are not fixed and can be adapted by the user according to the context. A minimum of 20% should be given to each of the three descendant criteria.

3.3.1. Resource use

The weights of “land use” and “water use” are highly dependent on the region where the assessment is done. By default, the same weight (30%) has been attributed to “energy use”, “land use” and “water use”, and a smaller weight to “mineral fertilizer use” (10%), but weights have to be adapted by the user. Weight of “energy use” should not be smaller than 25%, and weight of “mineral fertilizers” should be equal or smaller than other. Weights of “land” or “water use” could be higher than weight of energy: for instance, agriculture can be responsible for ground water depletion, whereas it is never the activity responsible for the higher energy consumption in a region (compared to industrial activity). In order to avoid compensation, when the “energy use”, the “water use” or the “land use” criteria are very high, “resource use” is either very high, or high (depending on the other criteria). When these criteria are high, “resource use” can not be very low.

3.3.1.1. Energy use

For the “**energy use”** criterion, given the aim of this model (assessment of the overall sustainability of systems) a higher weight is given to the “energy consumption”. However, this would be different in another context (assessment of systems with crops devoted to biofuel production for example). This function and all the functions of the descendant criteria of energy use are fixed.

The “**energy efficiency”** criterion estimates the production (yield) per unit of energy used. If data are available; it can be calculated as a ratio between “yield” (converted in energy equivalent) and “energy consumption”. UF has been fixed, and weight for “energy consumption” is slightly higher (60%) than weight for “yield”.

The “direct energy consumption” includes “machinery use” and “irrigation”, and the “indirect energy” includes “pesticide” and “fertilizer manufacturing”. Pervanchon et al. (2002) defined three contrasted crop management in terms of “**energy consumption”** (high, medium and low energy consumption, corresponding to intensive, integrated and extensive systems in arable crops). In average, the part of direct energy represents 60% of the total energy consumption (40% in the medium crop management). In contrast, Bonny (1993) compared three crop managements (intensive, rational and extensive) for wheat, and the part of direct energy varies between 25 and 28% of the total energy consumption. However, the irrigation is not taken into account. Given these results, we chose to attribute a slightly lower weight to the “direct energy consumption” (45%) in comparison with “indirect energy consumption”.

Consumption linked to the manufacturing of fertilizers represents 35 to 70 % of the total energy use. If we only consider “**pesticide” and “fertilizer manufacturing”** in the “**indirect energy”**, Bonny (1993) and Pervanchon et al. (2002) agree that the part due to pesticide manufacturing represents only 10%. Weights to **N, P and K fertilizers** have been attributed according to the quantity applied and to the energy necessary for their respective production. Weights are 80 for N fertilizers, and 10 for P and K fertilizers (Bonny, 1993).

Concerning part of “irrigation” in the “**direct energy consumption”**, we only have data in Pervanchon et al. (2002), for the intensive crop management (other systems are not irrigated. For this crop management, irrigation represents 30% of the direct energy consumption (70% for the machinery use). However, because the lack of data and because the consumption due to irrigation was supposed high, the decision rules were fixed, the worst between “irrigation” and “machinery use” determining the value of the “direct energy consumption” (leading to equal weights for irrigation and machinery use). Concerning the “**machinery use”** criterion, we considered “deep tillage”, “superficial tillage”, “total number of treatment operations” (fertilizers and pesticides) and “fuel consumption at harvest”. Clements et al. (1995) give data about energy consumption for different tillage or mechanical weeding tools, as well as for a treatment operation. Energy necessary for tillage varies between 130 $MJ.ha^{-1}$ for rotary hoe and 557 $MJ.ha^{-1}$ for mouldboard ploughing. The energy necessary for superficial tillage is lower (130 $MJ.ha^{-1}$ for rotary hoe or 160 for inter-row cultivator), and energy required for spraying operation is 90 $MJ.ha^{-1}$. However, these operations are more frequent than deep tillage. Given this data, energy consumption due to machinery use was calculated for each combination of qualitative classes. This led to weights of 15% to “deep tillage”, 30% to “superficial tillage”, 30% to ”total number of treatment operations” and 25% to “fuel consumption at harvest”.

3.3.1.2. Water use

The “**water use”** is due to “irrigation”, the “risk linked to dry period” as well as the “local availability of water for irrigation”. Weights have been fixed at 55% for “irrigation”, 15% for “risk” and 30% for “local availability of water for irrigation”, but could be adapted according to the context. However, the weight attributed to “irrigation” could be higher. Moreover, there is no impact of the “risk” when other criteria are favourable, and when there is no “irrigation”, the “local availability of water” has no impact.

3.3.1.3. Land use

A slightly higher weight is attributed to “availability of uncropped lands” compared to “land intensity”. Again, the choice of qualitative classes for the yield, that estimates the land intensity, has to be done according to the regional context of the assessment.

3.3.1.4. Mineral fertilizers use

In general (see for instance the cropping systems described in the ADAR project “Systèmes de culture innovants”), the quantity of K and P fertilizers applied is equivalent in rotations that are not too diversified. The weights for both criteria are therefore equal.

3.3.2. Environmental quality

The same weight is attributed to “water quality”, “soil quality” and “air emissions”. This can vary according to the region where the assessment is done. However, the weights for each criterion should not be less than 20%.

3.3.2.1. Water quality

The same weight is attributed to “aquatic ecotoxicity”, “ground water quality” and “eutrophication potential”. However, it can be adjusted by the user, with a minimum weight of 20% for each criterion.

Concerning **NO_3 leaching**, a slightly higher weight (40%) is attributed to the risk to reach water (leaching risk) than to the capacity of crop sequence to uptake N during leaching periods (35%) and to the N surplus (25%).

For the “**eutrophication potential”**, according to results of Nemecek et al. (2008), a higher weight could be attributed to “NO_3 leaching” compared to the “phosphorus”. However, this is highly dependent on the context, and by default, an equal weight is attributed to both criteria, but this could be adapted by the user. “**Phosphorus”** (or NO_3) reaching water is due to “P (N) surplus” but also to “erosion” (or “leaching risk”), allowing elements to reach water. A higher weight is attributed to the risk to reach water than to the surplus itself (also true for NO_3 leaching), and when there is a very low “erosion risk”, the “phosphorus” is very low, whatever the P surplus. This leads to 75% for “erosion risk” and 25% for “P surplus”.

For “**ecotoxicity”**, a lower weight is attributed to “heavy metals” as pesticides have more impact on water ecotoxicity in agricultural systems (particularly in arable crop systems where the risk occurs only when wastewater sludge are supplied). Again, a higher weight is attributed to the “runoff risk” that allows heavy metals and pesticides to reach water: when the “runoff risk” is low, the “ecotoxicity” is low or very low. Weights are 45% for “runoff risk”, 35% for “pesticide profile” and 20% for “heavy metals”. The “**pesticide profile risk”** takes into account the “total Pesticide TFI” and “eco-toxicity”[14]. When the amount or the toxicity are null, the “pesticide profile risk” is very low, leading to 41% weight for amount and 59% for toxicity.

The “pesticide leaching” and “NO_3 leaching” are taken into account for the “**ground water quality”**. The maximum between NO_3 and pesticides determines the value of the above criteria “ground water quality” (leading to equal weights). The “**pesticide leaching”** takes into account the “leaching risk”, the “total Pesticide TFI” (TFI commercial product) and the “pesticide mobility”. If the amount of pesticides or the mobility are null, the “pesticide leaching” is very low, and if the amount is low, the “pesticide leaching” is low or very low. The “pesticide mobility” and “leaching risk” determine the possibility for pesticides to reach water. If we stick on our rules for NO_3 and Phosphorus, their cumulated weight should be higher than the amount of pesticides. Weights are 35% for the “total pesticide TFI”, 43% for the “mobility” and 22% for the “leaching risk”.

3.3.2.2. Soil quality

The “biological” and “chemical qualities” are more resilient than “physical quality”. A lower weight has been attributed to these criteria. On the contrary, the “physical quality” has the higher weight as its degradation is irreversible. Weights can be adapted depending on the region where the assessment is performed. However, “physical quality” should have a higher (or equal) weight than others.

[14] See the toxicity by products on http://e-phy.agriculture.gouv.fr/ or by active ingredient on http://www.dive.afssa.fr/agritox/php/fiches.php. Other features of pesticides are also given.

In "**physical soil quality**" the same weight is attributed to "erosion risk" and "compaction risk". However, this depends on the region where the assessment is performed and can be adjusted, with a minimum weight of 20% for "compaction risk" ("erosion risk" can be null). The "**erosion risk"** is also highly dependent on the context. The worst between "runoff" and "field erosion" determines the value of the "erosion risk" (it leads to 50% weights). The "field erosion risk" and "runoff risk" are both dependent on the "context risk", the "deep tillage", the "soil cover" and the "superficial tillage". Decision rules for the "superficial tillage" have been fixed as follows (e.g. Boiffin et al. 1988, Papy and Boiffin, 1988). Concerning the "**field erosion"**, the frequent "superficial tillage" (higher class) has a negative impact and increases the "field erosion risk" when it is low or very low. On the contrary, the frequent superficial tillage (higher class) has a positive impact and decreases the "**runoff risk"** when it is high or very high. Other decisions rules (tillage, soil cover, and context) have been fixed. This leads to 27% for "deep tillage", "soil cover" and "context" and to 19% for "superficial tillage". The same weight is attributed to "climate" and "proportion of autumn-harvest crops" for the "**compaction risk"**.

In "**biological soil quality"**, a lower weight is attributed to "soil fertilization intensity" (20%) than to "physical stress" and "chemical disturbance". For the same reasons than for "soil quality" (irreversibility of physical degradations of soils), a higher weight is attributed to "physical stress" (45%) than to "chemical disturbance" (35%). In "**chemical disturbance"**, the weight of the impact of "pesticides" is higher (70%) than the impact of "soil cover" (that balances the negative impact of pesticides).

In "**chemical soil quality"**, a higher weight has been given to "organic matter" in comparison to "P fertility". However, this is dependent on the context and can be adjusted, with a minimum of 25% for each criterion. The "**organic matter"** depends on "deep tillage", "organic amendment" and "stubble/straw management" (exported or burnt, or not exported). Decision rules of the utility function have been fixed and lead to 45% for "organic amendment", 30% for "deep tillage", and 25% for "stubble/straw management". The "**P fertility"** depends only on the "P surplus": the higher the P surplus, the higher the fertility.

3.3.2.3. Air emissions

A higher weight is given to "NH_3" and "green house gases" than to "pesticide volatilization", as the impacts of NH_3 deposition are multiple (biodiversity, eutrophication, acidification…) and as the global warming due to green house gases is a major issue. These weights are fixed.

Nemecek et al. (2008) assessed several cropping systems with or without legumes crops, using LCA analysis. According to their results, the weight associated with "N_2O" for "**greenhouse gases"** is 60% (compared to 40% for "CO_2"). For "**N_2O"**, the "hydromorphic state of soil" has a great impact on N_2O emissions (Bockstaller and Girardin, 2008), and a weight of 60% has been attributed to this criterion compared with "N fertilizers" criterion. As for energy consumption, impact of "direct **CO_2**" emission is lower than "indirect CO_2" emission. Only the "N fertilizer amount" is taken into account for the **NH_3** emissions (even if the form of fertilizer, liquid or not, has a great impact on the emissions). The maximum amount between organic and mineral N fertilizers is considered for the above criteria "**N fertilizers"**, leading to 50% weights for both criteria. Finally, for "**pesticide volatilisation"**, a higher weight (60%) is attributed to "pesticide quantity" than to "risk of pesticide drift" due to material.

3.3.3. Aerial and above soil biodiversity

The same weight is attributed to "**Fauna**" and "**Flora"**, but it could be adjusted, for example in a region where a specific fauna or flora species is protected. However, the weight attributed to "fauna" or "Flora" should not be less than 30%. Similarly, the same weight is attributed to the three groups of fauna species and to natural/semi natural flora and weeds, but this could be adapted by the user, with a minimum value of weight of 20% for the fauna species types and 30% for the flora species types.

The “**soil natural enemies”** are little affected by the pesticides compared with “deep tillage” or “habitat” (Le Roux et al. 2008). A lower weight (15%) was therefore affected to this criterion. The highest weight was attributed to “deep tillage” (50%) followed by the “habitat network”, including proportion of “non-productive areas”, and their connectivity (that has a great impact on soil insects, Le Roux et al. 2008). These weights can be adjusted, with a minimum of 20% for “deep tillage” and “habitat”, and 5% for “chemical pressure”. On the contrary, “chemical pressure” has a great impact on “**flying natural enemies”** and “**pollinators”**, particularly in simplified landscape (with low proportion and connectivity of non-productive areas, Le Roux et al. 2008). The same weight is attributed to the impact of “chemical pressure” and the impact of “Flora”. However, the balance between those two criteria varies according to the landscape complexity (the impact of pesticides is attenuated in complex landscapes, Le Roux et al. 2008), and can therefore be adapted depending on the context. A smaller weight is attributed to the “effect of crops on pollinators”. The effect of the landscape on flying insects is taken into account through the “flora” criterion. Concerning the impact of “**pesticides on fauna”**, the impact of “insecticide” is much greater than the one of “fungicides”. The “**habitat network”** depends on the actual landscape (proportion and connectivity of “non-productive areas”), but also on the quantitative and spatial “habitat managements” that can improve the proportion or connectivity. The occurring landscape has however a higher weight (70%).

For the “**natural/semi natural flora”** criterion, a lower weight (40%) is attributed to “chemical pressure”, as margin flora is indirectly reach by herbicides applied in fields. The “**margin flora quality”** depends itself on the “habitat network” (proportion and connectivity of non-productive areas), with the highest weight, but also on “habitat management quality” (which species are sown in borders). These weights are fixed.

The same weight is attributed to the “diversity” and “abundance” for the “**weeds”** criterion. The “**weed diversity”** mostly depends on the variety of “crop types” in the crop sequence. A higher weight (50%) is attributed to this criterion. “Weed diversity” also depends on “intensification context” and “chemical pressure” (20%), and on the “margin flora quality” (10%). The “**weed abundance”** mostly depends on the “chemical pressure”, and a higher weight (30%) is attributed to this criterion. It also depends on “crop type” and on the occurrence of “false seedbed” practices. A 20% weight has been attributed to both criteria. The “mechanical weeding” is supposed less efficient, and a lower weight is attributed to this criterion (15%). Finally, the “tillage” (inversion or not) has also a smaller impact on weed abundance (15%). These weights could be fixed.

References

Bockstaller, C., Girardin, P., 2008. Mode de calcul des indicateurs agri-environnementaux de la méthode INDIGO.

Bockstaller, C., 2007. Proposition de construction d'un modèle mixte pour l'évaluation des risques de ruissellement et d'érosion. Document de travail.

Bockstaller, C., Girardin, P., 2008. Mode de calcul des indicateurs agri-environnementaux de la méthode INDIGO.

Bohanec, M., Messean, A., Scatasta, S., Angevin, F., Griffiths, B., Krogh, P.H., Znidarsic, M., Dzeroski, S., 2008. A qualitative multi-attribute model for economic and ecological assessment of genetically modified crops. Ecological Modelling 215, 247-261.

Boiffin, J., Papy, F., Eimberck, M., 1988. Influence of cropping systems on concentrated flow erosion risk. I. Analysis of the conditions for initiating erosion. Agronomie 8, 663-673.

Bonny, S., 1993. Is agriculture using more and more energy? A French case study. Agricultural Systems 43, 51-66.

Brentrup, F., Kusters, J., Kuhlmann, H., Lammel, J., 2004. Environmental impact assessment of agricultural production systems using the life cycle assessment methodology: I. Theoretical concept of a LCA method tailored to crop production. European Journal of Agronomy 20, 247-264.

Brentrup, F., Kusters, J., Lammel, J., Barraclough, P., Kuhlmann, H., 2004. Environmental impact assessment of agricultural production systems using the life cycle assessment (LCA) methodology. II. The application to N fertilizer use in winter wheat production systems. European Journal of Agronomy 20, 265-279.

Brown, J., 2008. Biotechnologies: breeding for disease resistance as an integral component of crop protection. Proceedings of the first ENDURE International conference, Diversifying crop protection, La Grande Motte, France.

Clements, D.R., Weise, S.F., Brown, R., Stonehouse, D.P., Hume, D.J., Swanton, C.J., 1995. Energy analysis of tillage and herbicide inputs in alternative weed management systems. Agriculture, Ecosystems & Environment 52, 119-128.

CORPEN, 2006. Des indicateurs Azote pour gérer des actions de maïtrise de pollutions à l'échelle de la parcelle, de l'exploitation et du territoire. Rapport du Commité d'Orientation pour des Pratiques Agricoles Respectueuses de l'Environnement.

Fried, G., Norton, L.R., Reboud, X., 2008. Environmental and management factors determining weed species composition and diversity in France. Agriculture, Ecosystems & Environment 128, 68-76.

Jeanneret, P., Baumgartner, D., Freiermuth, R., Gaillard, G., 2006. Méthode d'évaluation de l'impact des activités agricoles sur la biodiversité dans les bilans écologiques. SALCA-BD. Rapport Agroscope.

Lamine, C., Carpentier, A., Meynard, J.M., 2008. Diffusion des couples Variétés rustiques de blé / Itinéraires techniques à bas niveaux d'intrants. GeDuPIC - WP1 - Livrable D1.2.

Le Roux, X., Barbault, R., Baudry, J., Burel, F., Doussan, I., Garnier, E., Herzog, F., Lavorel, S., Lifran, R., Roger-Estrade, J., Sarthou, J.P., Trometter, M., 2008. Agriculture et biodiversité, valoriser les synergies. Rapport d'expertise collective INRA.

Levy, J.D., Bertin, M., Mazodier, J., Combes, B., Roux, A., 2005. Irrigation durable. Rapport du Conseil Général du Génie Rural, des Eaux et des Forêts.

Mouron, P., Nemecek, T., Scholz, R.W., Weber, O., 2006. Management influence on environmental impacts in an apple production system on Swiss fruit farms: combining life cycle assessment with statistical risk assessment. Agriculture, Ecosystems & Environment 114, 311-322.

Mouron, P., Scholz, R.W., Nemecek, T., Weber, O., 2006. Life cycle management on Swiss fruit farms: relating environmental and income indicators for apple-growing. Ecological Economics 58, 561-578.

Nemecek, T., Erzinger, S., 2005. Modelling representative life cycle inventories for Swiss arable crops. International Journal of Life Cycle Assessment 10, 68-76.

Nemecek, T., Richthofen, J.S.v., Dubois, G., Casta, P., Charles, R., Pahl, H., 2008. Environmental impacts of introducing grain legumes into European crop rotations. European Journal of Agronomy 28, 380-393.

Papy, F., Boiffin, J., Douyer, C., 1988. Influence of cropping systems on the risk of concentrated flow erosion. II. Evaluation of control possibilities within farms. Agronomie 8, 745-756.

Pervanchon, F., Bockstaller, C., Girardin, P., 2002. Assessment of energy use in arable farming systems by means of an agro-ecological indicator: the energy indicator. Agricultural Systems 72, 149-172.

Sadok, W., Angevin, F., Bergez, J.E., Bockstaller, C., Colomb, B., Guichard, L., Reau, R., Messéan, A., Doré, T., 2009. MASC: a qualitative multi-attribute decision model for ex ante assessment of the sustainability of cropping systems. Agronomy for Sustainable Development In press.

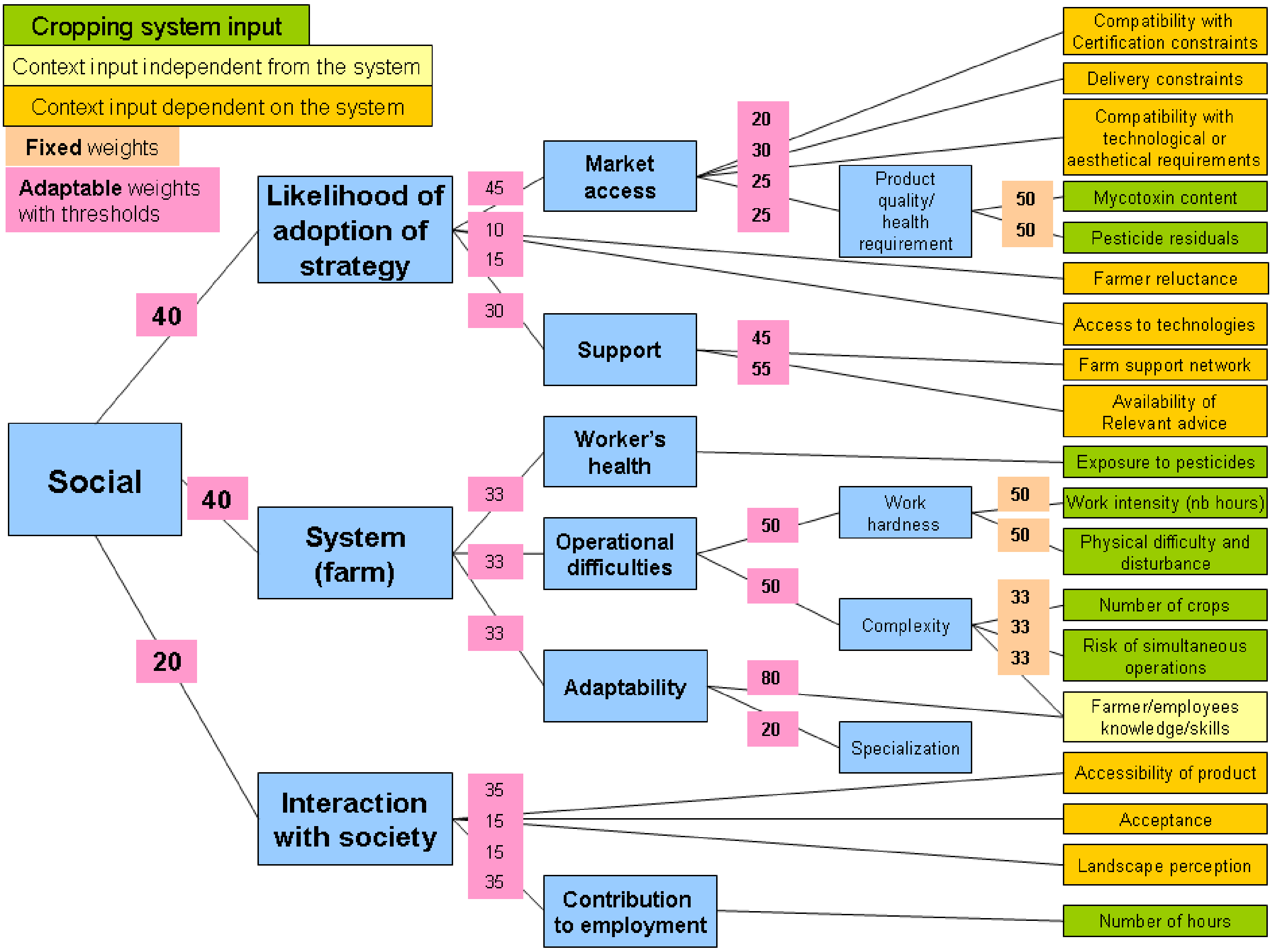
Sadok, W., Angevin, F., Bergez, J.E., Bockstaller, C., Colomb, B., Guichard, L., Reau, R., Landé, N., Coquil, X., Messéan, A., Bohanec, M., Doré, T., 2007. An indicator-based MCDA framework for *ex ante* assessment of the sustainability of cropping systems. Proceedings of the FSD congress, Catane, Italy.

Sebillotte M. (1990) Système de culture, un concept opératoire pour les agronomes, in : Combe L., Picard D. (Eds.), Un point sur les systèmes de culture, INRA éditions, Paris, pp. 165-196.

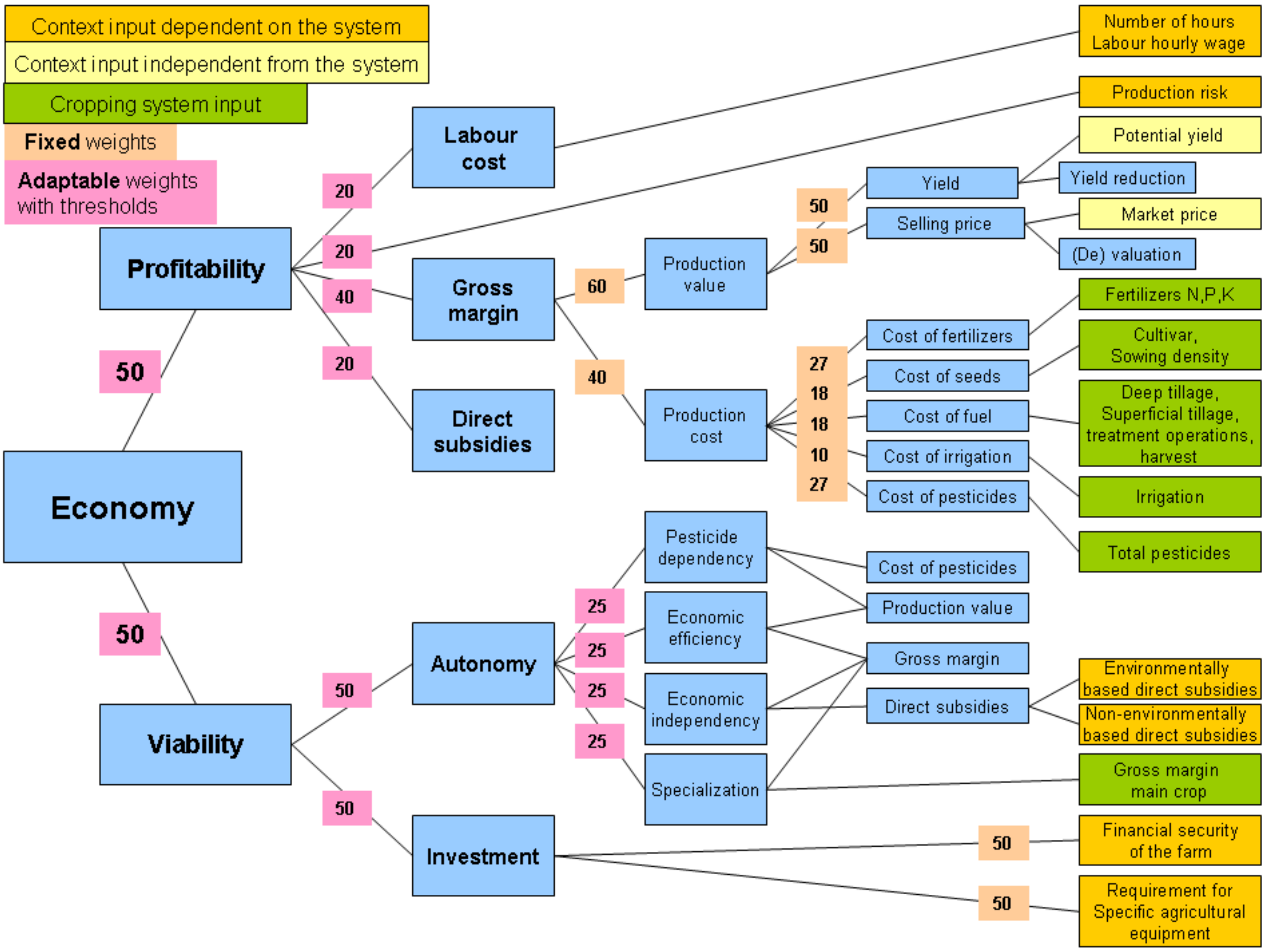
Appendices

The trees and the organisation of criteria per hierarchical level are presented in the following figures. **Weights** are also proposed, either fixed (salmon-pink colour), or adaptable with thresholds or rules (pink). Tables presenting details on input criteria and utility functions are also presented.

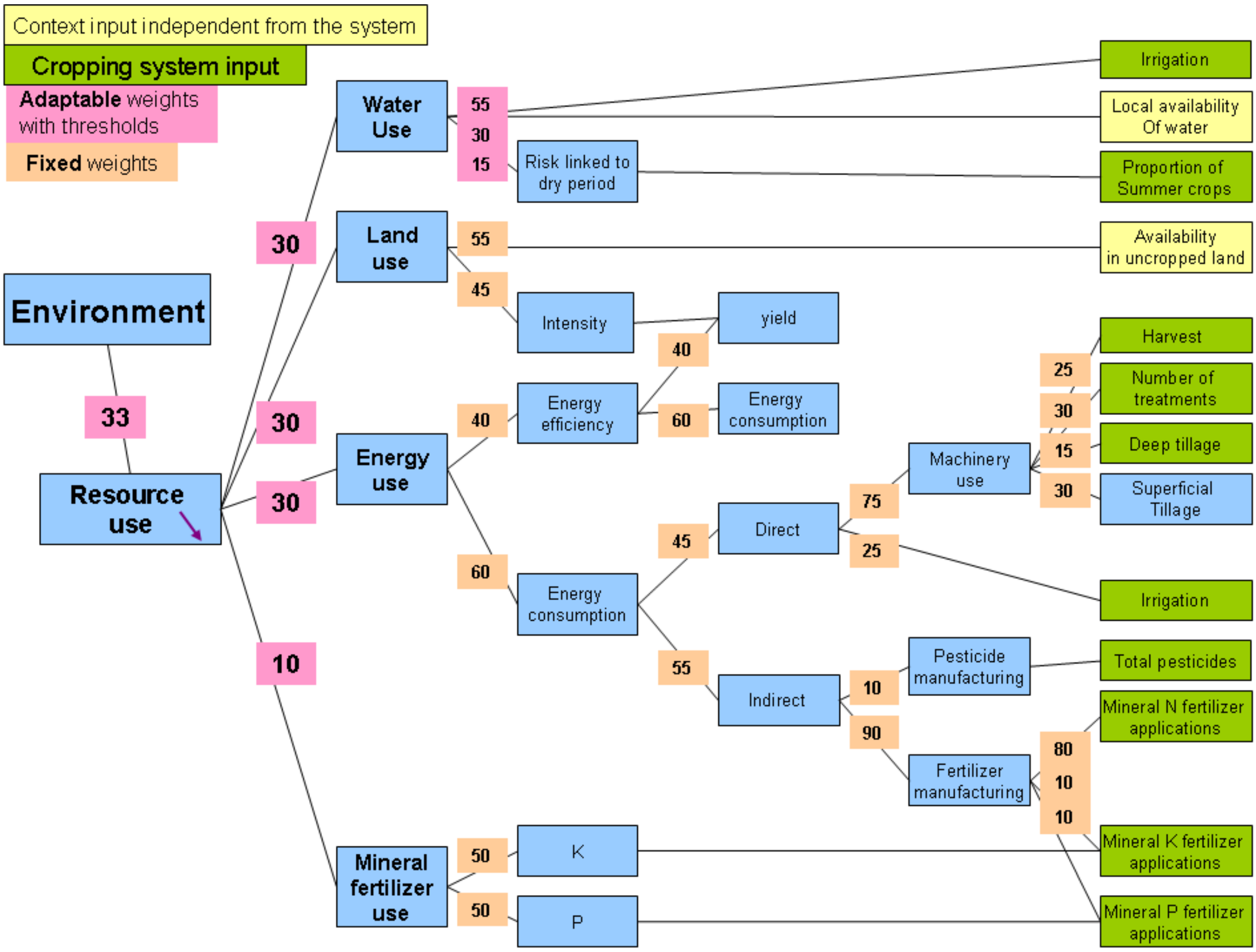
Social tree



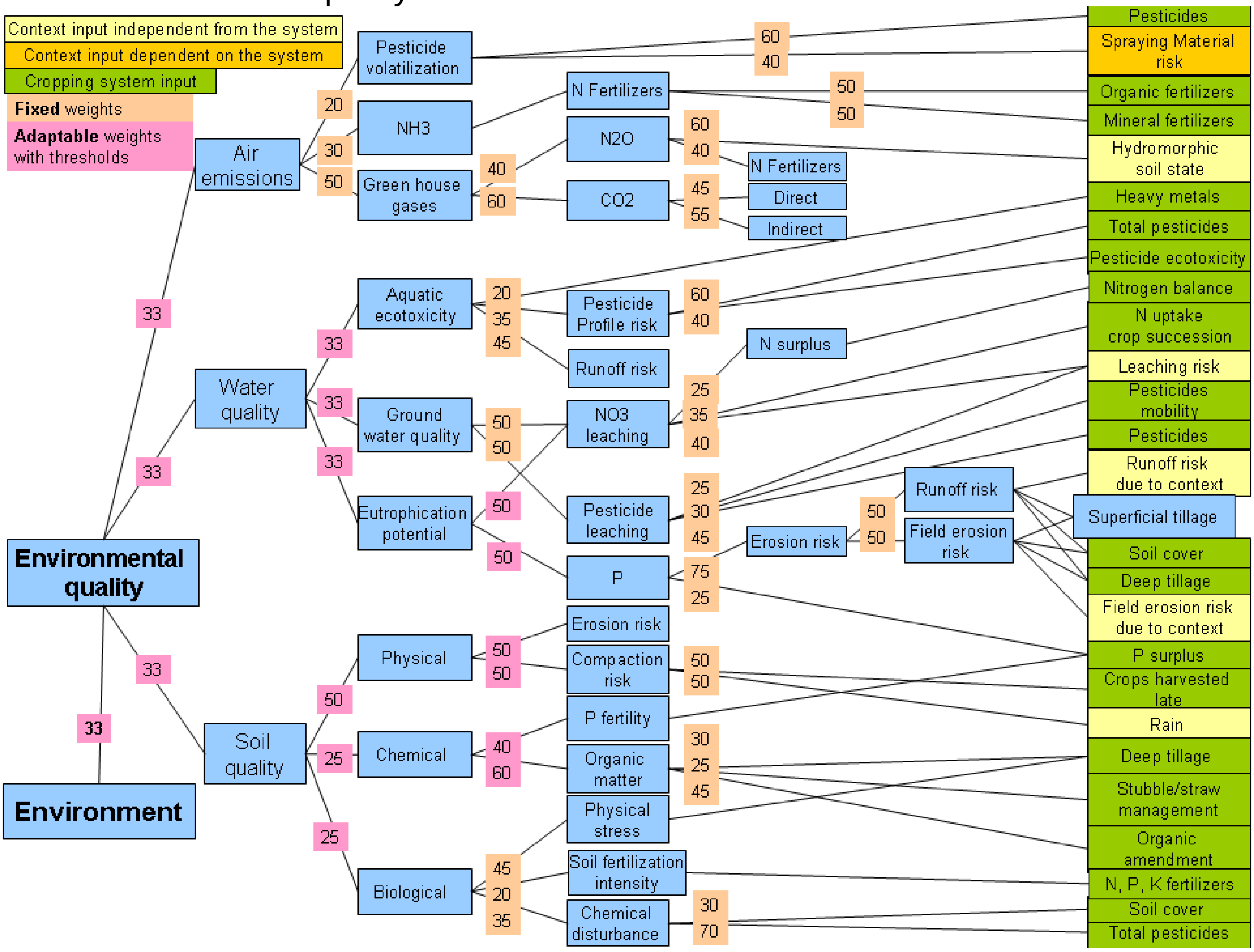
Economical tree



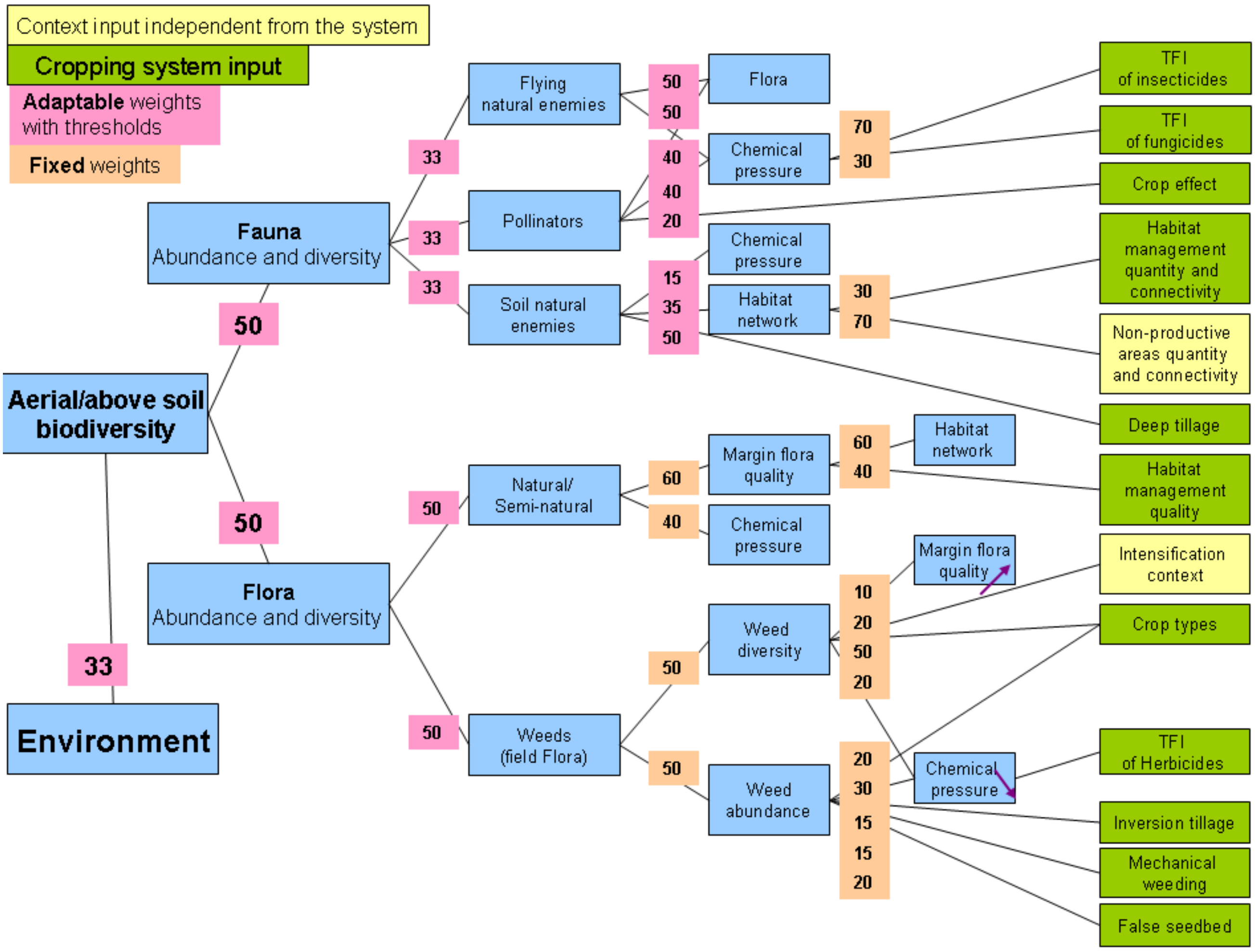
Environmental trees
Resources use



Environmental quality



Aerial and above soil biodiversity



List and description of input/basic attributes of DEXiPM

Inputs	Corresponding pillar	Short description and observations (correlation with other inputs)	Qualitative classes[15]
Context inputs independent from the system (fixed in the case of comparison of systems)			
Soil and climate			
Leaching risk (soil and climate)	Environment	Effect of soil type and depth, climate, etc. on the risk of leaching. This may be estimated by the drainage indicator (rain during leaching period/soil water stock, CORPEN)	very high, high to medium, medium to low, very low ***See sheet 1, DR2.14b***
Runoff risk due to context	Environment	Surface runoff is considered water, from rain, snowmelt, or other sources, that flows over the land surface. It can pick up contaminants such as pesticides, or fertilizers. Another source not considered here is runoff due to water saturation of the soil profile. The amount of soil that can be lost due to runoff is considered in the following criterion Field erosion. It is linked to topographical risk (increases with the slope and with the slope length). Soil cover and effect of tillage are considered in other criteria.	high, medium, low
Field erosion risk due to context	Environment	Amount of soil lost from a field by runoff due to the action of rain drops on soil (In this context, it does not include soil losses due to wind erosion). It is linked to topographical risk (increases with the slope and with the slope length). Soil cover and effect of tillage are considered in other criteria. **Correlation with runoff risk due to context (low if runoff risk due to context is low)**	high, medium, low
Hydromorphic soil	Environment	A general term for soil state that develops under conditions of poor drainage, such as marshes, swamps, seepage areas and flats (clay soils are more hydromorphic than sandy soils). Hydromorphic soils are sources of denitrification (N_2O emissions). Well drained soils are not Hydromorphic.	yes, no
Potential yield	Economic	Overall assessment or the potential yield of all the crops of the crop sequence. It is important to note that potential yields should be estimated <u>independently from the system</u>. They mostly depend on pedoclimatic conditions	very low, low to medium, medium to high, very high
Regional context and landscape			
Regional intensification	Environment	Estimation of intensification at the regional scale. This criterion helps to estimate flora diversity. The proportion of non-cropped area in the region should be taken into account, as well as intensity of practices in fields of the region. The landscape does not favour biodiversity if it is mainly an open-field area, whereas it favours biodiversity if fields are at least partly surrounded or included in mixed-cropping–breeding systems that include hedges and both arable fields and meadows (French name '*bocage*'; Fried et al. 2008)	Not favourable to biodiversity, favourable to biodiversity

[15] Qualitative classes are proposals and can be modified if they are not adapted to the context (country) of assessment

Availability of uncropped land	Environment	Relative amount of uncropped land, not used for agricultural production. This criterion assesses the fact that extensive systems will require more land area to produce the same amount (population growth context), and land availability is a problem in most of the European regions	very low, low to medium, medium to high, very high
Non-productive areas	Environment	Proportion and connectivity of non-cropped areas adjacent to the fields (contrary to the previous attribute that deals with uncropped area in the region, not field border): hedges, field margins, etc. This criterion is used to estimate flora and fauna biodiversity.	low proportion, medium proportion but low connectivity, medium proportion and high connectivity, high proportion and connectivity
Economical context			
Average market price	Economic	Relative commodity price. This criterion assesses the market condition for agricultural production, independently from the type of crops (effect of cash crops in the crop sequence is estimated in the criterion “Valuation or devaluation of price due to crops in the crop sequence”) and from subsidies. This criterion highly depends on the country and it could raise problems when comparing countries.	very low, low to medium, medium to high, very high
Labour hourly wage	Economic	Level of wages for employees, used to estimate the cost of labour. The case of double employment is not explicitly taken into account neither for this criterion nor for the criterion number of hours.	very high, high to medium, medium to low, very low
Farm context			
Local availability of water for irrigation	Environment	Depends on availability of water (ground water availability, proximity of a river, water cisterns, restriction regulations, etc.) and on restriction frequency imposed by regulation	Low (restriction every year), medium (restriction 1/2 or 1/3 year), high (no restriction)
Financial security of the farm	Economic	Availability of financial resources for investment necessary for the cropping system, for example new tillage material for mechanical weeding, specific harvesters, etc.	low, medium, high
System inputs (crop sequence, crop management on each crop and between crops)			
Crop sequence			
Number of crops	Social	Number of different crops in the cropping sequence, including intermediate catch crops. This criterion is only used in social sustainability to estimate the complexity of the CS, not only in terms of techniques linked with the number of different crops, but also in terms of complexity linked with pest attacks. The more crops, the more complex, with the exception of monoculture, that is supposed more complex because of consequences in terms complexity linked with risk of pests, risk of soil structure damaging, risk of fertility loss, etc.	high (5 or more) or monoculture, medium to low (2-4)
Proportion of autumn-harvest crops	Environment	Crops that remains in field during the driest months (July-August), harvested after the end of September: sugarbeets, maize etc. **Correlation with "crop type"**	very high [75-100%], high to medium [50-75%[, medium to low [25-50%[, very low [0-25%[
Crop type	Environment	Variety of crops in the crop sequence (in terms of sowing season): winter crops, spring crops, summer crops or perennial crops	1 type (winter or spring or summer or perennial crop), 2 types, 3 types, 4 types (winter and spring and summer and

			perennial crop)
Crop effect on pollinators	Environment	Proportion of crops suitable for pollination (nectar plants). Wheat, barley, maize and most cereals are not attractive, oilseed rape, sunflower, pea or alfalfa, for example, are more attractive. Intermediate catch crops have to be considered for the estimation of this attribute.	not favourable, little favourable, favourable, very favourable
Additional seed cost of crop species or cultivars[16]	Economic	Additional seed cost linked to the crop species and cultivars grown (*e.g.* resistant cultivar), independently from the sowing density. Seed treatments can also be considered if it has a significant impact on the price. Intermediate catch crops have to be considered for the estimation of this attribute. **Correlation with "TFI fungicide"**	high, moderate, no
Sowing density	Economic	Assessment of the sowing density for all crops of the crop sequence. Estimation of density (high, medium or low) highly depends on the region of assessment: soil type and climate (frost risk) leading to seedling death. Sowing density should be in accordance with sowing date: higher density when early or late sowing, because of higher risk of seedling losses.	high, medium, low ***See sheet 2, DR2.14b***
Soil cover	Environment	Typical crop cover, average for the crops of the crop sequence, taking into account all crops in the crop sequence, as well as intercrop periods (bare soil, volunteers or intermediate catch crop). *The classes for this attribute could not be relevant some countries and can be adapted if necessary.* **Correlation with "proportion of summer crops", "crop type", "proportion of autumn-harvest crops", "soil cover at pesticide application"**	low (0-40%), medium (41-60%), high (61-100%) ***See sheet 3, DR2.14b***
Pesticide treatments			
TFI of insecticide	Environment	Average insecticide Treatment Frequency Index of commercial products (and not active ingredient) across all crops in the cropping sequence $TFI = \frac{1}{n}\sum_{t=1}^{t=T_I}\frac{DI_t}{DAp_t}$ with n: number of years in the crop sequence, T_I: total number of insecticide treatments, DI: applied dose in commercial product, DAp: approved/registered dose for the commercial product	High (>2), medium (]1-2]), low (]0-1], none
TFI of fungicide	Environment	Average fungicide Treatment Frequency Index of commercial products (and not active ingredient) across all crops in the cropping sequence $TFI = \frac{1}{n}\sum_{t=1}^{t=T_F}\frac{DF_t}{DAp_t}$ with n: number of years in the crop sequence, T_F: total number of fungicide treatments, DF: applied dose in commercial product, DAp: approved/registered dose for the commercial product	High (>2), medium (]1-2]), low (]0-1], none

[16] The origin of seeds is not considered in the seed cost whereas seeds that are produced in the farm (particularly in organic systems) are less expensive. This could be added in a future version of DEXiPM

		Correlation with "Additional seed cost of cultivar" (if use of resistant cultivar)	
TFI of herbicide	Environment	Average herbicide Treatment Frequency Index of commercial products (and not active ingredient) across all crops in the cropping sequence $TFI = \frac{1}{n}\sum_{t=1}^{t=T_H}\frac{DH_t}{DAp_t}$ with n: number of years in the crop sequence, T_H: total number of herbicide treatments, DH: applied dose in commercial product, DAp: approved/registered dose for the commercial product. For herbicides, the proportion of treated surface per field could be included in the calculation of the indicator to take into account localised treatments (*e.g.* on rows)	High (>2), medium (]1-2]), low (]0-1], none
Total Pesticide TFI	Economic, social, environment	Average pesticide Treatment Frequency Index of commercial products (and not active ingredient) across all crops in the cropping sequence, for fungicides, insecticides, herbicides, molluscicides, growth regulators and all other products used $TFI = \frac{1}{n}\sum_{t=1}^{t=T}\frac{D_t}{DAp_t}$ with n: number of years in the crop sequence, T: total number of pesticide treatments, D: applied dose in commercial product, DAp: approved/registered dose for the commercial product. Seed treatments are not taken into account as their impact compared to sprayed pesticides is not clear. *The classes for this attribute could not be relevant some countries and can be adapted if necessary.* **Correlation with "TFI fungicide", "TFI insecticide", TFI herbicide"**	Very high (>7), high to medium (]4.5-7]), medium to low (]2-4.5]), low (]0-2], none
Pesticide mobility	Environment	Pesticide mobility is taken into account to assess the risk of pesticides reaching water. Mobility depends on the plant protection product family. This can be estimated using the Ground water Ubiquity Score (GUS). In this case, across the crop sequence, a "worst case" can be applied, *i.e.* the most mobile pesticide has to be used to estimate the attribute.	High, medium, low, no pesticide ***See sheet 4, DR2.14b***
Pesticide eco-toxicity	Environment	Environmental toxicity of products depending on the active ingredients. In this case, across the crop sequence, a "worst case" can be applied, *i.e.* the most toxic pesticide has to be used to estimate the attribute	High, medium, low, no pesticide ***See sheet 4, DR2.14b***
Soil cover at pesticide application	Environment	The proportion of soil covered for the most risky pesticide application (see pesticide mobility and pesticide eco-toxicity attributes), often herbicide. **Correlation with "soil cover"**	Low (0-20%), medium (21-60%), high (61-100%) or no application ***See sheet 3, DR2.14b***
Fertilisation			
Mineral N fertilizer applications	Economic, environment	Average amount of mineral N applied per year. The form (liquid or not) impacts volatilization of NH_3 (no evidence for N_2O)	High (> 150 kg/ha), medium (50-150 kg/ha), low (0-50 kg/ha), none
Organic N fertilizer	Environment	Average per year. The form (liquid or not) impacts volatilization of NH_3 (no evidence for N_2O)	liquid manure or hen droppings,

applications[17]		**Correlation with "Organic amendments"**	solid manure or low amount of liquid manure/hen droppings, compost or low amount of solid manure, none
Organic amendments[17]	Environment	Average amount of organic amendments per year. **Correlation with "Organic N fertilizer applications"**	liquid manure or low amount of hen droppings, hen droppings or low amount of solid manure, solid manure or low amount of compost, compost
Coverage of crop Nitrogen requirement	Economic, Environment	Should take into account the amount of N fertilizers, the requirement of the crop and the yield. A deficiency could be tolerated for some reasons, or occur because of a miscalculation of the doses supplied, whereas a surplus could occur for example in a situation where high protein content is required. **Correlation with "Mineral N fertilizer applications", "Organic N fertilizer applications", "yield"**	Deficiency: less than – 25 kg N, balanced: - 25 to + 25 kg N, surplus: more than + 25 kg N ***See sheet 5, DR2.14b***
Mineral P fertilizer applications	Economic, environment	Average amount per year, expressed in P_2O_5. For information, 100 kg/ha of P_2O_5 = 44 kg/ha of P	High (> 100 kg/ha P_2O_5), medium (50-100 kg/ha), low (0-50 kg/ha), none
P surplus	Environment	Should take into account the amount of P fertilizers, the requirement of the crop, soil type, etc. **Correlation with "Mineral P fertilizer applications"**	high, medium, low, none
Mineral K fertilizer applications	Economic, environment	Average amount per year, expressed in K_2O. For information, 100 kg/ha of K_2O = 83 kg/ha of K	High (> 100 kg/ha K_2O), medium (50-100 kg/ha), low (0-50 kg/ha), none
Total number of treatment operations	Economic, environment	The summed number of applications made per year. This should take into account all pesticides and fertilizers. The lower class (3 or less per year) could correspond to a system with 0 pesticide and low amount of fertilizers (eventually crops without fertilizers, such as pluri-annual crops integrated for several years in the crop sequence). **Correlation with "Mineral N, P, K fertilizer applications", "Organic N fertilizer applications", "Total pesticide TFI"**	7 or more per year, [4-7[per year, less than 4 per year
Tillage			
Deep tillage[18]	Economic, environment	Frequency of deep tillage (with or without inversion) in the rotation. **Correlation with "Inversion tillage"**	Every year, 1 year out of two (or more), less than ½ year, no
Inversion tillage[18]	Environment	With or without inversion. This criterion is used to estimate weed abundance. The inversion has a great impact on weed abundance, whereas a deep tillage without inversion will have less of	With inversion, no inversion

[17] The amount of organic N should be taken into account, particularly if organic systems are assessed. This could be added in a future version of DEXiPM

[18] Minimum tillage systems are considered by the estimation of the three criteria deep tillage (that should be none, superficial tillage between crops and superficial tillage in the crop

		an impact. **Correlation with "Deep tillage"**	
Superficial tillage in the crop (mechanical weeding)[19]	Economic, environment	Average number of operations per year (combined tools should be counted several times).	2 or more per year, [1, 2[per year, [0, 1[per year
Superficial tillage between crops (including false seedbed)[19]	Economic, environment	Average number of operations per year (combined tools should be counted several times)/	5 or more per year, [1, 5[per year, [0, 1[per year
Irrigation			
Irrigation	Economic, environment	Amount of water used for the entire crop sequence, average per year. **Correlation with "crop type", "Proportion of summer crops"**	high, medium, low, none
Risk of water stress	Economic	Depends on rain, soil, crops requirements, irrigation. **Correlation with "crop type", "Proportion of summer crops", "Irrigation"**	High, medium, low, none
Harvest			
Fuel consumption at harvest	Economic, environment	Average consumption depending on the harvest tools for crops of the crop sequence (*e.g.* sugarbeet harvester consumes more than cereal harvester). Other fuel consumptions (tillage, fertilizers and pesticides applications) are estimated through other criteria.	High, medium, low
Stubble/straw management	Environment	This criterion impacts soil organic matter. The consequence of burnt stubble/straw is the same, in terms of organic matter, as exported stubble/straw	Exported or burnt, not exported
Global variables for the system description			
Capacity of crop sequence to uptake N during the leaching period	Environment	Leaching is mainly confined to autumn and winter. Depends on the frequency of bare soil periods, the occurrence of catch crops, the occurrence and nature of volunteers, and also on the duration of non-uptake period (sometimes starting before harvest of the previous crop and ending after emergence of the following crop). The effect of stubble (date of stubble breaking, C/N ratio) is secondary but can be taken into account. **Correlation with "crop type", "soil cover", "Stubble/straw management"**	very high, high to medium, medium to low, very low ***See sheet 6, DR2.14b***
Yield reduction due to system, other than nutrition and pests or weeds[20]	Economic	Yield reduction may be due to resistant cultivars, delaying of sowing dates, lower yield targets, etc. This has to be estimated relative to current systems, with highly productive cultivars, sown at usual dates.	High, medium, no
Habitat management	Environment	Sowing and spatial arrangement of adjacent newly non-cropped areas, leading to a higher proportion and better connectivity of non-productive areas.	none, low increase of % of non-productive areas, low increase

[19] Minimum tillage systems are considered by the estimation of the three criteria deep tillage (that should be none, superficial tillage between crops and superficial tillage in the crop

[20] The possible yield increase that could be associated with some practices (e.g. maize GM cultivars present higher yields) is not taken into account in DEXiPM and could be added in future versions

			of % and increase of connectivity, high increase of % and connectivity
Habitat management quality	Environment	Characterizes the type of species sown on newly non-cropped areas. None, if there is no habitat management. **Correlation with "habitat management"**	none, little favourable to flora, favourable to flora, very favourable
Pest control	Economic	This criterion summarizes all control methods, chemical and other, and should therefore be in accordance with other criteria describing the system. Even if it is redundant with other input criteria, it has to be estimated. **Correlation with all criteria impacting pest control: crop sequence, cultivars, TFI, N fertilizers, sowing density, etc.**	none, low, medium, high
Number of hours	Economic, social	Estimation of time necessary for all operations of the cropping system. Includes monitoring time, such as 'in the field crop surveillance', necessary for the protection strategy. Average per year for the entire crop sequence. **Correlation with all criteria describing practices**	very high, high to medium, medium to low, very low
Risk of simultaneous operations, due to a limited number of suitable days	Social	Concurrence in timing of operations, during some periods of the year, often due to diversification of crop sequence or practices. **Correlation with all criteria describing practices**	high, medium, low
Physical difficulty and disturbance	Social	Noise, repetition of a task, etc. for example, superficial tillage for mechanical weeding can be estimated as highly difficult (more generally, for tillage, the difficulty depends on the machinery and tool used). **Correlation with all criteria describing practices**	high, medium, low
Heavy metal contamination	Environment	Environmental quality. There is almost no risk of contamination in arable crop systems, except when slurry, sewage sludge or compost are supplied (more risks occur in vineyard systems when copper is applied). **Correlation with "Organic and mineral N fertilizer applications", "Organic amendment"**	high, medium to low, none
Product			
Proportion of gross margin due to main crop	Economic, social	Does the system economically rely on one or several crops of the crop sequence? (Specialization of the system). The main crop is the one that has the highest selling price per mass unit.	high: >50% of margin relying on the main crop(s), medium: 25-50% of margin relying on the main crop(s), low: <25% of margin relying on the main crop(s)
Risk of pesticide residuals in product	Social	Indicates the quality of production, in terms of pesticide contamination. This risk depends on the crops of the crop sequence (*e.g.* for maize, except for sweet corn, there is no late pesticide application and therefore no risk) but has to be estimated at the crop sequence scale. **Correlation with "Total pesticide TFI"**	Above the regulation threshold, below the regulation threshold, none

Risk of mycotoxin contamination	Social	Indicates the quality of production, in terms of mycotoxin contamination	Above the regulation threshold, below the regulation threshold, none
Context inputs dependent on the system (inputs linked to the context but that vary depending on the system)			
General			
Production risk	Economic	Uncertainty of yield. Overall assessment of the risk (climate, high pest attack, etc.)	high, medium, low
Soil and climate			
Pest pressure	Economic	Due to the pedo-climatic context and the system. Should take into account the effect of spatial distribution of crops/practices	high, medium, low, none
Quantity of rain during late harvest	Environment	For the estimation of risk of soil compaction. Concerns above all autumn harvests. **Correlation with "proportion of autumn-harvest crops"**	very high, high to medium, medium to low, very low
Material			
Requirement for agricultural equipment	Economic	Requirement for specific equipment needed by the farm for the system assessed (*e.g.* equipment for mechanical weeding, harvester if a new crop is included in the crop sequence, etc.). For current systems, requirement for specific equipment will be low-none. **Correlation with all criteria describing practices needing equipment**	high, medium, low-none
Risk of pesticide drift due to material	Environment	The risk of pesticide drift depends on the material as well as on the wind, but the weather (wind) should not be considered here. The risk of pesticide drift remains therefore low in arable crop systems as the material is safer than in orchards or vineyards.	high, medium, low
Support			
Farmer and employees knowledge and skills	Social	Estimation of the management capacity and skills of farmers and their employees to apply the strategy. Depends on both the educational level of the farmer and his/her ability to seek out appropriate advice. Innovative systems will be more easily adopted by farmers with high (or medium) skills. The level of permanent work should be considered in orchard systems, as farmers have often several activities and do not work full time on orchard (decreases skills).	low, medium, high
Affiliation to a farm support network	Social	Farmers groups, etc… For "good" support to be provided, the network has to be familiar with the strategy	no network or no affiliation to a network corresponding to the strategy, affiliation to a network corresponding to the strategy
Availability of relevant advice for the strategy	Social	An indication of availability of relevant advice to help the farmer to adopt strategy: advice adapted to the strategy and independent from input selling. The independency of advisors (independency for the type of system, and for the input selling) should therefore be taken into account (as well as the specialization of advice for orchards systems).	No, low to medium, high
Subsidies			
Environmentally based direct subsidies in support of the strategy	Economic	Direct subsidies based on environmental aspects of the system. Corresponds approximately to the second pillar of CAP. **Correlation with "habitat management", "non-productive area"…**	high, medium, low, none

Non-environmentally based direct subsidies in support of the strategy	Economic	Direct subsidies based on non-environmental aspects of the system. Corresponds approximately to the first pillar of CAP	high, medium, low, none
Production and product			
Access to relevant technologies	Social	This criterion includes financial and geographical (proximity) access to technologies necessary to adopt the innovative system (*e.g.* seeds, specific equipment, etc.) **Correlation with "Additional seed cost of crop species or cultivars"**	very limited, limited, possible, easy
Delivery constraints	Social	Reliance on off-farm enterprises or collecting firms to sell the production (*e.g.* alfalfa crop can be sold only if there is cattle livestock at proximity of the farm)	high, medium, low, none
Compatibility with quality requirements other than health	Social	The compatibility could decrease because of the adopted strategy, leading to non-respect of requirements. For arable crops, quality other than health can be protein contents, dry matter level, etc. Aesthetical for orchards. Depends on the distribution network. Risk for health (mycotoxins, pesticide residuals) is considered elsewhere.	Low to no, medium, high or no technological/esthetical requirement
Compatibility with certification requirements	Social	Non-compliance with requirements due to the adopted strategy could occur (*e.g.* because of the cultivar)	Low to no, medium, high or no certification requirement
Valuation or devaluation of price due to crops in the crop sequence	Economic	Proportion of cash crops in the crop sequence. If the current system has one or several cash crops (such as onions), the criterion can be estimated at premium. For alternative systems, the user should estimate how this proportion evolves in comparison with current system (more/less cash crops). This attribute is difficult to estimate as it is estimated relatively to other systems. Be sure when comparing systems that the estimations are correct between systems, the current system being fixed at neutral if there is no specific cash crop.	penalty, neutral, premium
Valuation or devaluation of price due to quality and certification requirements	Economic	Devaluation due to lost quality or certification requirements, valuation due to certification of the adopted strategy (IPM). The estimation of this criterion for current systems depends on the occurrence of a certification of one or several crops of the crop sequence (neutral if no certification, premium if certification with the hypothesis that requirements are satisfied). For alternative systems, the user should estimate how it evolves in comparison with current system (neutral if no certification). This attribute is difficult to estimate as it is estimated relatively to other systems. Be sure when comparing systems that the estimations are correct between systems, the current system being fixed at neutral if there is no specific quality specificity. **Correlation with "Compatibility with technological/aesthetical requirements", "Compatibility with certification requirements"**	penalty, neutral, premium
Farmer/societal judgment			
Reluctance/reservation of the farmer to adopt the strategy	Social	Can be due to risk of yield decrease, non-possibility of product selling (downgrading of harvest), etc. for current system, the criterion is "none". **Correlation with "yield", "complexity", "production risk"**	Yes, none
Social accessibility of product for consumers	Social	How the system could prevent the accessibility to product for part of the society (too high prices for example). In the current context, there is no problem of accessibility for products cultivated intensively/conventionally (criterion is "accessible" for current system)	little accessible, accessible

		Correlation with "production cost" and "production value"	
Societal value of landscape	Social	How the system improves or degrades the perception of the landscape by the society: diversity of crops, colours, unusual crop in a given region, non-productive areas, 3-dimension perception etc. This criterion is highly subjective but interesting to keep in mind when assessing overall sustainability of cropping systems. The estimation for current systems is bad (*e.g.* monocrops) or indifferent. **Correlation with "crop type", non-productive areas", "habitat management", etc.**	bad, indifferent, good
Acceptability of the strategy by society	Social	Acceptability of product and production mode by the society (*e.g.* GM crops). For example, the acceptability of a current system with high amount of pesticides and fertilizers can be considered as low.	low, indifferent, acceptable

Summary of utility functions

Criteria	Rules	Weights	Proportion of fixed rules in the UF[21]
OVERALL SUSTAINABILITY	**Adaptable** According to user's priorities. If one out of three contributing attribute (social, economical or environmental) is low or very low, the overall sustainability can not be high or very high Minimum15% per criterion	Equal by default (social, economy, environment)	46/125
ECONOMICAL SUSTAINABILITY	**Adaptable** According to user's priorities Minimum 30% per criterion	Equal by default (profitability and viability)	4/25
Profitability	**Adaptable** Gross margin very low: profitability low or very low Minimum 20% for gross margin, 10% for other criteria	By default 40% gross margin, 20% production risk, 20% labour cost, 20% direct subsidies.	6/144
Gross margin	**Fixed** Resulting from simulations with 4 realistic values of production value and production cost, corresponding to the four qualitative classes of both criteria.	Leading to 60% production value, 40% production cost	10/16
Production value	**Fixed** by the designers	50% selling price 50% yield	20/20
Selling price	**Fixed** Based on the average market price. Unchanged if there is no valuation or devaluation, a penalty decreases the price of one class, a premium increases the price of one class.	Leading to 50% average market price, 50% valuation or devaluation	12/12
Valuation or devaluation of price due to the system	**Fixed** Penalty decreased of one class, premium increase of one class, neutral: no effect	Leading to equal weight for each criterion (Valuation or devaluation of price due to crops of the crop sequence, and due to quality and certification requirements)	9/9
Yield	**Fixed** Potential yield very low: yield very low Other cases: Yield has the same value of the potential yield for low or very low yield reduction	Leading to 50% potential yield, 50% yield reduction	20/20

[21] This is a good indicator to see if decision rules are mostly fixed by the designer or user, or if they are automatically fixed by DEXi based on weights entered by the designer/user

	Yield decreased of one class if yield reduction is high, of two classes if yield reduction is very high.		
Yield reduction	**Fixed** Based on Bohanec et al. 2008, adapted by designers of DEXiPM	45% yield reduction due to system, other than nutrition and pests or weeds 25% nutrition deficiency 15% pest state 15% weed state	23/192
Nutrition deficiency	**Fixed** N mineral nutrition is not taken into account when the water stress is high or medium	60% risk of water stress 40% risk of Nitrogen stress	8/8
Pest state	**Fixed** Very low when no pressure Low (no or low control) or very low (control high and very high) when pressure low	70% pest pressure 30% pest control	7/16
Production cost	**Fixed** Based on systems described in the French ADAR project “systèmes innovants”, on AGRESTE 2006 survey, on data from a French farm in region Centre, and on Levy et al. 2005	27% pesticides 27% fertilizers 18% fuel 18% seeds 10% irrigation	8/768
Cost of fuel	**Fixed** Based on Clements et al. 1995, for energy	15% deep tillage 30% superficial tillage 30% total number of treatment operations 25% fuel consumption at harvest	108/108
Cost of fertilizers	**Fixed** Based on Bonny, 1993, for energy	70% Mineral N fertilizers application 15% Mineral P and K fertilizers application	6/64
Cost of seeds	**Fixed** by the designers	50% Additional seed cost of crop species or cultivars 50% Sowing density	4/9
Labour cost	**Fixed** by the designers	50% number of hours 50% cost per hour	4/16
Direct subsidies in support of the strategy	**Adaptable** Based on user’s priorities Minimum 20% per criterion	By default, 50% Environmentally based direct subsidies in support of the strategy, 50% Non-environmentally based direct subsidies in support of the strategy	16/16
Viability	**Adaptable** According to user’s priorities Minimum 30% per criterion	By default 50% autonomy, 50% investment capacity	9/9
Autonomy	**Adaptable** According to user’s priorities	Equal by default (pesticide dependency, economic efficiency, economic independency, specialization)	10/81

	Minimum 10% per criterion		
Economic independency	**Fixed** by the designers	60% direct subsidies 40% gross margin	5/12
Economic efficiency	**Fixed** by the designers	60% gross margin 40% production value	16/16
Pesticide dependency	**Fixed** by the designers	60% pesticide cost 40% production value	12/16
Investment capacity	**Fixed** by the designers	50% requirement for agricultural equipment 50% Financial security of the farm	4/9
SOCIAL SUSTAINABILITY	**Adaptable** According to user's priorities Minimum 20% for likelihood of adoption and system.	By default, 45% likelihood of adoption and system, 10% interaction with society	8/125
Likelihood of adoption	**Adaptable** According to politic/socio-economic context Minimum 10% per criterion	By default, 45% market access, 30% support, 15% access to technologies, 10% reluctance/reservation of the farmer	17/36
Market access	**Adaptable** According to politic/socio-economic context Minimum 20% product quality compliance with health requirements, other can be null	By default, 30% delivery constraints, 25% product quality compliance with health requirements, 25% compatibility with aesthetical/technological requirements, 20% compatibility with certification constraints	30/144
Product quality compliance with health requirements	**Fixed** by the designers	50% risk of pesticide residuals in product 50% risk of mycotoxin contaminations	9/9
Support	**Adaptable** According to user's priorities Minimum 10% per criterion	By default 55% availability of relevant advice, 45% Affiliation to of a farm support network	6/6
Social durability of the system	**Adaptable** According to user's priorities Minimum 15% per criterion	Equal by default (workers' health risk due to pesticides, operational difficulties, adaptability)	6/80
Adaptability	**Fixed** by the designers With specialization disfavouring adaptability	20% specialization 80% farmer and employees' knowledge and skills	4/9
Operational difficulties	**Adaptable** According to user's priorities Minimum 20% per criterion	Equal by default (complexity and work hardness)	4/16
Work hardness	**Fixed** by the designers	50% physical difficulty and disturbance 50% work intensity	5/12
Complexity	**Fixed**	33% number of crops	10/18

	by the designers	33% risk of simultaneous operations 33% farmer and employees' knowledge and skills	
Interaction with society	**Adaptable** According to user's priorities Minimum 10% contribution to employment and accessibility	By default, 35% contribution to employment and social accessibility, 15% societal value of landscape and acceptance	2/72
ENVIRONMENTAL SUSTAINABILITY	**Adaptable** Minimum 20 % for each criterion	Equal by default.	12/125
Resource use	**Adaptable** According to the context Minimum 25 % for energy Weight of mineral fertilizers equal or smaller than other. Avoid compensations between criteria: High or very high when one of the criteria (except mineral fertilisers) is very high. Should be adapted to the context	By default, 30% to energy use, land use and water use, and 10% to Mineral fertilizers use	46/256
Energy use	**Fixed** by the designers	60% energy consumption 40% energy efficiency	8/16
Energy consumption	**Fixed** Based on Pervanchon et al. 2002, Bonny, 1993	45% direct energy 55% indirect energy	7/16
Direct energy	**Fixed** Maximum between irrigation and machinery use	50% machinery use 50% irrigation	16/16
Machinery use	**Fixed** Based on Clements et al. 1995	15% deep tillage 30% superficial tillage 30% total number of treatment operations 25% fuel consumption at harvest	108/108
Indirect energy	**Fixed** Based on Pervanchon et al. 2002, Bonny, 1993	90% fertilizer manufacturing 10% pesticide manufacturing	8/20
Fertilizer manufacturing	**Fixed** Based on Bonny, 1993	80% N fertilizers 10% P and K fertilizers	32/64
Energy efficiency	**Fixed** by the designers	60% energy consumption 40% yield	20/20
Water use	**Adaptable** According to the context Higher weight for irrigation No impact of the risk when other criteria are favourable, No impact of the context when no irrigation	By default, 55% for irrigation, 15% for risk linked to dry periods and 30% for local availability of water	6/48
Land use	**Fixed** by the designers	55% availability of uncropped lands 45% land intensity	4/16
Mineral fertilizer use	**Fixed**	50% Mineral P fertilizer applications	5/16

	Based on systems described in the French ADAR project “Systèmes de culture innovants”	50% Mineral K fertilizer applications	
Environmental quality	**Adaptable** According to the context and to user’s priorities Minimum 20% for each criterion	Equal by default (air, water, soil)	5/64
Water quality	**Adaptable** According to the context and to user’s priorities Minimum 20% ground water, 10% for other	Equal by default (ecotoxicity, ground water and eutrophication)	6/64
Eutrophication potential	**Adaptable** According to the context	By default, 50% NO_3 leaching, 50% Phosphorus	5/16
Phosphorus	**Fixed** by the designers low when erosion risk is low	75% erosion risk 25% P surplus	4/16
NO_3 leaching	**Fixed** by the designers	40% leaching risk 35% capacity of crop sequence to uptake N 25% N surplus	13/32
Ground water quality	**Fixed** by the designers Maximum between pesticides and NO_3 leaching	Leading to 50% for each criterion (pesticides and NO3 leaching)	17/20
Pesticide leaching	**Fixed** by the designers Amount of pesticides null or Pesticide mobility null (no pesticides): pesticide leaching very low Amount low: pesticide leaching low or very low	35% total pesticide TFI 43% mobility 22% leaching risk	48/80
Aquatic ecotoxicity	**Fixed** by the designers low when the runoff risk is low	45% runoff risk 35% pesticide profile 20% heavy metals contamination	9/60
Pesticide profile risk	**Fixed** by the designers. Very low risk when the amount of pesticides or eco-toxicity is null Low risk when the amount of pesticides is null	41% Total pesticides TFI 59% toxicity	14/20
Soil quality	**Adaptable** According to the context and to user’s priorities Physical higher or equal to others	By default, 50% physical, 25% chemical, 25% biological	11/64
Physical quality	**Adaptable** According to the context Minimum 20% for compaction, erosion risk can be null	Equal by default (compaction and erosion risk)	5/16
Compaction risk	**Fixed**	50% proportion of autumn-harvest crops	5/16

	by the designers	50% Quantity of rain during harvest	
Erosion risk	**Fixed** by the designers Worst between runoff and field erosion	Leading to 50% for each criterion	16/16
Field erosion risk	**Fixed** by the designers Frequent superficial tillage increases field erosion risk when it is low or very low	27% deep tillage, soil cover and context 19% superficial tillage	108/108
Runoff risk	**Fixed** by the designers Frequent superficial tillage decreases runoff risk when it is high or very high	27% tillage, soil cover and context 19% superficial tillage	108/108
Superficial tillage	**Fixed** by the designers (quantitative estimation)	30% superficial tillage in the crop 70% superficial tillage between crop	9/9
Chemical quality	**Adaptable** According to the context Minimum 25% per criterion	By default, 60% organic matter, 40% P fertility.	2/12
Organic matter	**Fixed** by the designers	45% organic amendment 30% deep tillage 25% stubble/straw management	15/32
Biological quality	**Fixed** Based on Bohanec et al. 2008	45% physical stress 35% chemical disturbance 20% fertilization intensity	10/60
Chemical disturbance	**Fixed** by the designers	70% Total Pesticide TFI 30% soil cover	6/15
Soil fertilisation intensity	**Fixed** by the designers	33% mineral N fertilizer applications 33% mineral P fertilizer applications 33% mineral K fertilizer applications	16/64
Air emission	**Fixed** by the designers	50% green house gases 30% NH_3 20% pesticide volatilisation	5/80
Greenhouse gases	**Fixed** Based on Nemecek et al. 2008	60% N_2O 40% CO_2	9/16
N_2O emissions	**Fixed** by the designers, based on Bockstaller and Girardin, 2008	60% hydromorphic soil 40% N fertilizers	7/8
CO_2 emissions	**Fixed** Based on the energy consumption criterion	45% direct 55% indirect	7/16
N fertilizers	**Fixed**	Leading to 50% for each criterion	11/16

	by the designers Maximum between organic and mineral fertilizers		
Pesticide volatilisation	**Fixed** by the designers	60% Total Pesticide TFI 40% Risk of pesticide drift due to material	6/15
Aerial and above soil biodiversity	**Adaptable** According to the context and to user's priorities Minimum 30% for each criterion	Equal by default (fauna and flora)	5/16
Fauna	**Adaptable** According to the context and to user's priorities Minimum 20% per criterion	Equal by default (pollinators, soil and flying natural enemies)	6/64
Soil natural enemies	**Adaptable** According to the context Minimum 20% deep tillage and habitat, 5% chemical pressure	By default, 50% deep tillage, 35% habitat network, 15% chemical pressure	7/64
Habitat network	**Fixed** by the designers	70% non-productive areas 30% habitat management	13/16
Flying natural enemies	**Adaptable** According to the context Less impact of pesticides in more complex landscapes Minimum 35% per criterion	By default 50% chemical pressure and flora	6/16
Pollinators	**Adaptable** According to the context Less impact of pesticides in more complex landscapes Minimum 25% per criterion, 20% crop effect (fixed).	By default 40% chemical pressure and flora, 20% crop effect	7/64
Chemical pressure on fauna	**Fixed** by the designers	70% TFI insecticides 30% TFI fungicides	8/16
Flora	**Adaptable** According to the context and to user's priorities Minimum 30% per criterion	Equal by default (natural/semi natural flora and weeds)	4/16
Natural/semi natural flora	**Fixed** by the designers	60% margin flora quality 40% chemical pressure	2/16
Margin flora quality	**Fixed** by the designers	60% habitat network 40% habitat management quality	4/16
Weeds	**Fixed** by the designers	50% weed diversity 50% weed abundance	6/16
Weed diversity	**Fixed** by the designers	50% crop types 20% intensification context 20% chemical pressure 10% margin flora quality	18/128

Weed abundance	**Fixed** by the designers	30% chemical pressure 20% crop type 20% superficial tillage between crops 15% superficial tillage in the crop (mechanical weeding) 15% inversion tillage	11/288