ENDURE

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Report on the robustness of DEXIPM (preliminary evaluation of the sensitivity)

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PP Restricted to other programme participants (including the Commission Services)	
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
UF	Utility Functions
SCS	System Case Study
TFI	Treatment Frequency Index

Definitions

Attributes: in DEXi, attributes are criteria taken into account to assess the sustainability of cropping systems. They are characterized by their name, a description, and a **scale**, *i.e.* possible **qualitative values or classes** for the attribute (discrete values described as words rather than numbers). Attributes are either **basic** (attributes that the user will describe when entering an option) or **aggregated** (resulting from an aggregation or utility function in DEXi, based on values of immediate descendant attributes).

Utility functions: utility functions (UF) determine the aggregation of attributes in the tree. They consist in a table of **"if-then" aggregation rules** to fix the value of an aggregated attribute depending on the value of the immediate descendant attributes. UF are summarized by **weights** allocated to attributes. Rules of UF can either be fixed by the user, or automatically fixed by the software based on weights indicated by the user.

Cropping system: 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.

Summary

DEXiPM is a model for qualitative, multi-criteria assessment of systems sustainability, allowing *ex ante* assessment of innovative arable crops cropping systems. It is a hierarchical tree of attributes that have been chosen for their relevance in term of sustainability assessment. The tree is divided in environmental, economical and social sustainability.

The aim of this deliverable is to test the robustness of DEXiPM by showing an example of assessment of two cropping systems and by analysing and discussing the results in view of limits of DEXiPM and possible improvements. Feedbacks from SCS are also discussed, as well as planed steps to improve the model. However, DEXiPM as it stands can already be used as a tool to help for the design of innovative cropping systems with a limited use of pesticides.

1. DEXiPM

Agricultural systems are complex, with various and sometimes contradictory goals, such as the productivity or profitability versus the quality of products or the limitation of environmental impacts. There is therefore a necessity for multi-criteria assessment of sustainability of agricultural systems.

DEXiPM is a hierarchical and qualitative multi-attribute model (or multi-criteria model) allowing evaluation of cropping systems according to several and sometimes conflicting goals. It allows *ex ante* assessment of innovative arable cropping systems proposed by system case studies within ENDURE. It is a hierarchical tree of attributes that have been chosen for their relevance in term of sustainability assessment. The overall sustainability is decomposed into smaller and less complex problems, characterized by attributes (or criteria) that are organized hierarchically into a decision tree. DEXiPM has been implemented within the DEXi decision support system (Bohanec et al. 1999) already used for agricultural sustainability assessment (Bohanec et al. 2008, Sadok et al. 2009).

In DEXi, attributes are characterized by their name, a description and a scale, i.e., possible qualitative values for the attribute (discrete values described as words rather than numbers, e.g., 'low, medium, high'). Even if scales are qualitative, some can be based on quantitative values (e.g., the amount of fertilisers or pesticides). Attributes are rather basic (attributes that the user will describe when entering an option) or aggregated (resulting from an aggregation of immediate descendant attributes, aggregation rules being described in utility functions). Three main steps are necessary for the design of a DEXi model:

- The first step is the choice of attributes taken into account (including basic attributes) as well as their hierarchy in the decision tree. For DEXiPM, the question underlying this step was: "what does sustainability mean for agricultural systems involving protection strategies with a limited use of pesticides?" The choice of attributes has been validated based on expertise from various disciplines including, for instance, agronomy, weed science or sociology.
- The second step is the definition of qualitative classes for attributes (basic and aggregated attributes), based on expertise (i.e., experts with a wide range of skills and knowledge linked with issues identified as important) and/or system of references (i.e., data from experiments and/or biotechnical models).
- The third step is the choice of utility functions (UF) determining the aggregation of attributes in the tree. They consist in "if-then rules" to fix the value of an aggregated attribute depending on the value of the immediate descendant attributes. For example, if an aggregated attribute Y, with three qualitative classes high, medium and low, depends on two attributes X1 and X2, also with three qualitative classes, a decision rule could be: "If X1=low and X2=medium, then Y=Low". UF are summarized by weights allocated to attributes. In DEXiPM, aggregation rules are either fixed (by the designers, based on expertise and/or system or references) or adaptable by the user depending on its priorities and on the context (the latter are more subjective). The choice of UF is important and should be explicit and traceable, as it explains a large part of the results of the assessment.

DEXiPM has 74 basic attributes and 85 aggregated attributes along the decision tree. Basic attributes are a technical description of the cropping systems (based on quantitative data) and a description of the context of the assessment, whereas aggregated attribute are qualitative indicators of sustainability. Most of the attributes are at the cropping system scale (e.g., pesticide use, mineral N fertilisation). Basic attributes have therefore to be estimated at this scale and not at the usual field or annual scales. However, because the cropping system can have consequences on attributes defined at larger scales, some basic attributes describing the practices or the context as well as some aggregated attributes deal with other levels such as the landscape scale (e.g., habitat management) or the farm scale (e.g., requirement for agricultural equipment). Various time scales are also explored with attributes, from short to long term assessment (e.g., gross margin and economical viability respectively) in order to address sustainability issues. DEXiPM is based on the MASC model (Sadok et al. 2009) modified and improved to meet the defined aim: additional attributes are accounted for, from other models such as Bohanec et al. (2008) or SALCA (e.g., Nemecek et al. 2008) and from other studies (e.g., le Roux et al. 2008). It has been developed by three agronomists and one sociologist, and then been submitted for appreciation by experts from various fields (e.g., weed scientists) in order to validate the choice and hierarchy of the attributes.

The cropping system as well as the context of assessment is described as inputs of DEXiPM by a vector of values of basic attributes (Figure 1). The description of the cropping system includes the crop sequence and the crop management on each crop and between crops. Forty two basic attributes characterize the cropping systems. They are grouped in crop sequence, pesticide applications, fertilisation applications, tillage, irrigation and harvest (with some attributes characterizing the quality of product). The "context" of the cropping system is also described as it will impact the results of the sustainability evaluation. Context basic attributes (32) are grouped in soil and climate, regional context and landscape (e.g., open fields), economical context (including subsidies), farm context (including material, support), and farmer and societal perception of the system. The context of the assessment is very important and will have to be taken into account for the adaptation of utility functions: for instance, depending on the pedoclimatic and regional context, the weights attributed to the water use, land use, energy use and mineral fertiliser use to explain the resource use can vary. The context of the assessment will also impact some qualitative scales of attributes (yield, gross margin, etc.). Outputs of the model are the qualitative estimation of each attribute of the tree as well as estimation of the overall sustainability of the cropping system.

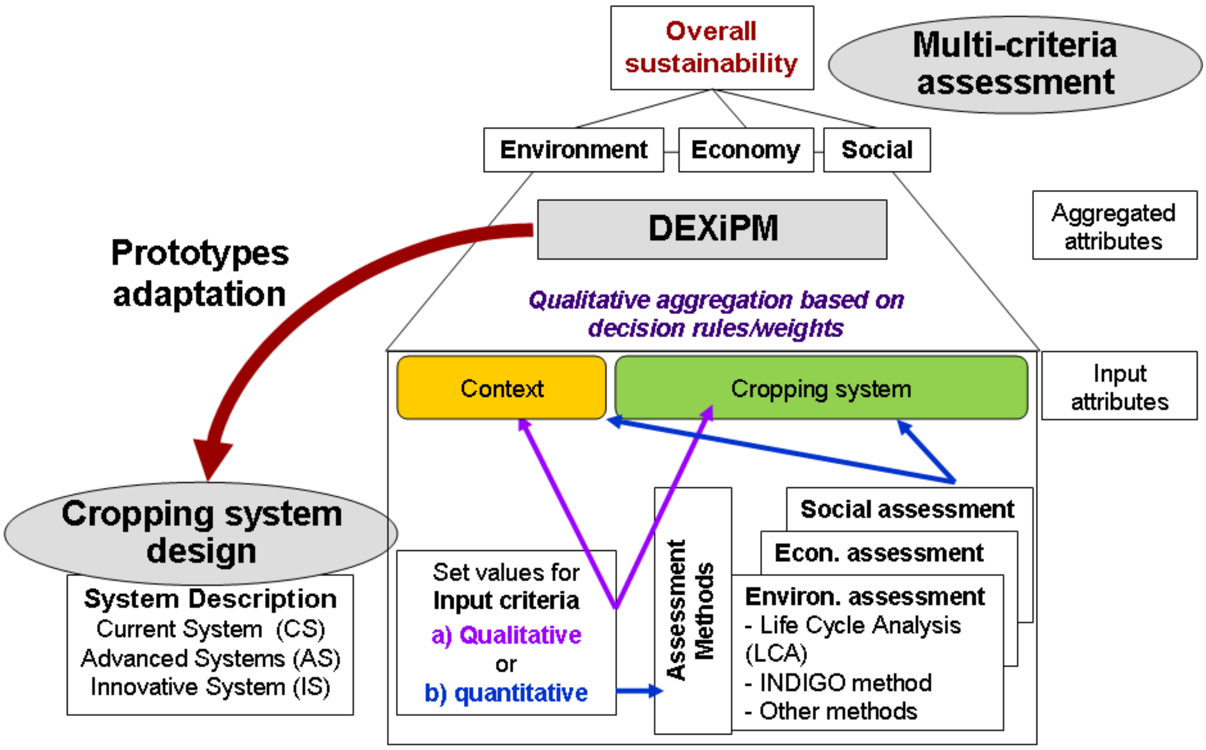

Figure 1. Schematic representation of systems assessment with DEXiPM

In order to have further details on DEXiPM, the delivrable DR 2.14 is already available:

- DR2.14a: presentation of DEXiPM, trees, justification of choice of attributes and aggregation rules (UF)
- DR2.14b: tutorial, tables for basic attributes estimation and aggregation rules
- DR2.14c: DEXiPM in DEXi

2. Example of an assessment of cropping systems with DEXiPM: advantages and limits

In order to test the robustness of DEXiPM, we describe here the assessment of two cropping systems and analyse and discuss the results in view of limits of DEXiPM and possible improvements.

2.1. Current and innovative systems assessed

Both systems are described in detail in the DR 2.16.

2.1.1. Context of the assessment

Assessments of one current and one innovative system are performed in the context of the French region Bourgogne, on limestone plateau with shallow soils. There are some cattle farms in this region, allowing the use of feed crops.

2.1.2. Current system

The crop sequence of the current system is winter oilseed rape-winter wheat-winter barley. The crop protection strategy is mainly based on pesticides (TFI=7.1.ha^{-1}.year^{-1}, Guichard et al. 2009). The main pest risks in this region with this system are: autumn emergence weeds (all crops), weevil, pollen beetle (WOSR), aphids (WW). The expected yield is medium to high.

Crops are sown at a high density, and at usual sowing dates. There is no superficial tillage aiming at weed control (mechanical weeding or false seedbed), as well as no deep tillage (specificity of the farm where the system is assessed). High amount of mineral fertilizers are used.

2.1.3. Innovative system

This system has been proposed to improve the control of the main pests mentioned above. The crop sequence is winter oilseed rape-winter wheat-spring barley-alfalfa-alfalfa-winter wheat-(Mustard)-sunflower-triticale. Spring crops and crops with high competitiveness against weeds have been introduced.

Crops are sown at a lower density, and sowing dates are adapted in order to control:

- Weeds: false seedbed on wheat sown later, competitiveness of WOSR sown earlier
- Disease: e.g. WOSR sown earlier is less susceptible to phoma
- Insects: e.g. autumn aphids are limited on wheat sown later
- Slugs: limited on WOSR sown earlier

The use of pesticide is very low (estimated TFI=0.4.ha^{-1}.year^{-1}). Mechanical weeding and false seedbed are used, and deep tillage occurs once in the crop sequence after alfalfa. Resistant cultivars are also used. Straws are exported, limiting slugs. Contans® (biological control) is used against sclerotinia. The amount of N fertilizer is lower than for the current system (due to the alfalfa and the intermediate crop after winter wheat). Some landscape managements are performed: flowering strips for pollinators, refuges for natural enemies (hedges, others), turnip rape on WOSR margins (pollen beetle).

Table 1. estimated TFI (.ha^{-1}.year^{-1}, Guichard et al. 2009) for the current system and the corresponding innovative system. WOSR: Winter Oilseed Rape, WWh: Winter Wheat, WB: Winter Barley, SB: Spring Barley, Sf: Sunflower, Tr: Triticale, Al: Alfalfa

Region	***Bourgogne***	
System	**Current system**	**Innovative system**
Crop sequence	WOSR-WWh-WB	WOSR-WWh-SB-Al-Al- WWh -(Mustard)-Sf-Tr
TFI Herbicide	2.2	0.2
TFI Fungicide	2.1	0
TFI Insecticide	1.7	0.2
Total TFI	**7.1**	**0.4**

2.1.4. Other aspects accounted for in DEXiPM

Other positive or negative impacts of the innovative system are accounted for in DEXiPM. The effect of the intermediate crop on nitrogen applications and on the reduction of NO_3 leaching is taken into account, as well as the limitation of green house gases emissions due to a lower amount of nitrogen fertilizers. The landscape management and the diversification of rotation also impact positively the biodiversity. On the other hand, the mechanical weeding or superficial tillage between crops can have a negative impact on energy and time consumption. The late sowing of cereals leads to a risk of unsuitable sowing conditions, as well as reduction of yield. The diversification of rotations implies a lower frequency of cash crops, and can lead to problems of delivery for some crops (alfalfa, triticale). No growth regulator is used in the IS. This can cause lodging leading to lower yield (but N fertilisation is decreased). Exported straws limit soil organic matter content and finally, there can be a reluctance of farmers for landscape management.

2.2. Results of the assessment

2.2.1. Overall sustainability

Few differences are observed for the overall sustainability between the two systems (Figure 2). This is firstly due to the compensation between attributes when assessing sustainability of systems, but also to the lack of sensitivity of DEXiPM, due to its qualitative nature and above all to its complexity. It is however necessary to analyse the attributes within the tree.

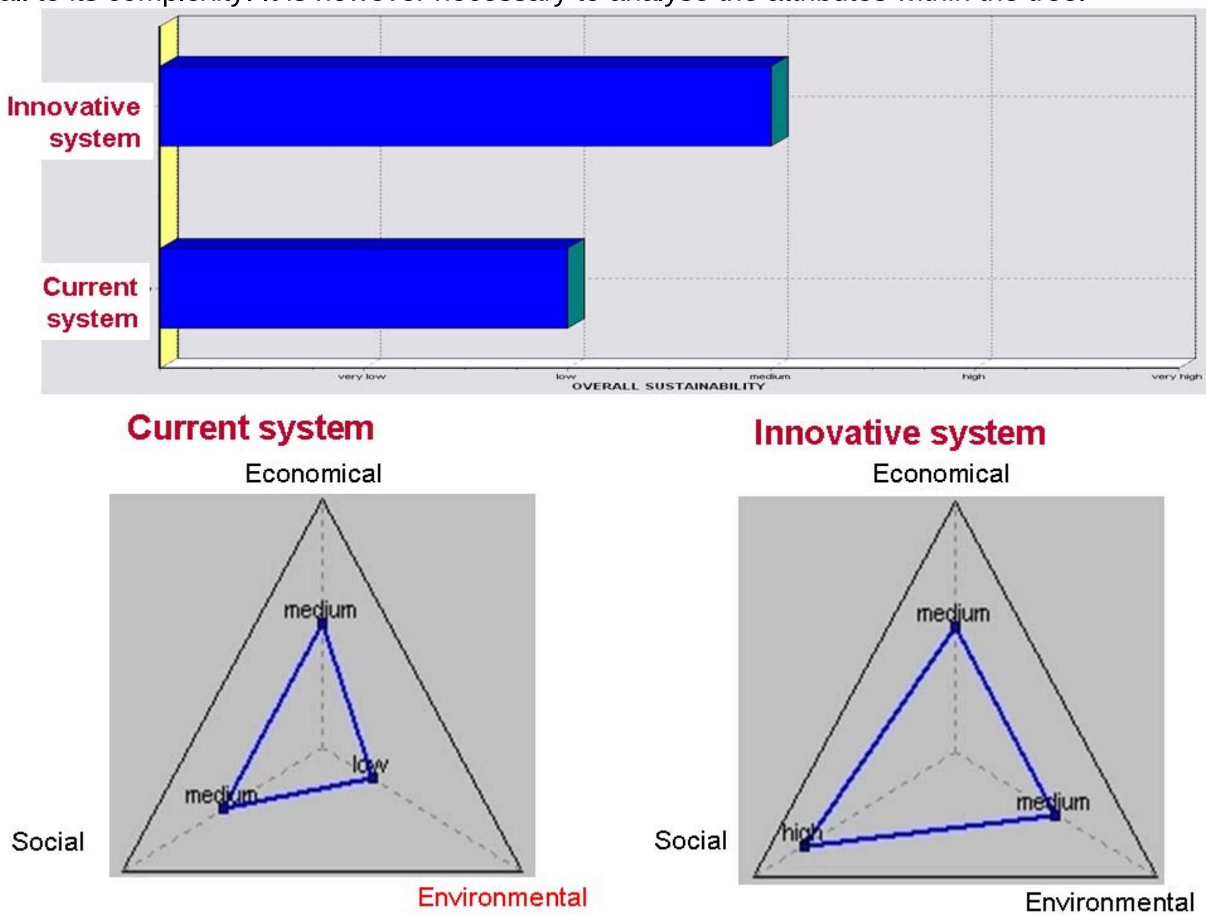

Figure 2. Overall sustainability assessment of the current and advanced system, resulting from the economical, social and environmental sustainability

2.2.2. Environmental sustainability

The environmental sustainability is low for the current system and medium for the advanced system: there is only one class difference between both systems (Figure 2). However, if we look at the three attributes aggregated, environmental quality (water, soil, air), aerial biodiversity (fauna and flora), and resource use (water, land, mineral fertilizers and energy), differences can be observed. The environmental quality is improved of one class, from low to medium, and the aerial biodiversity of three classes, from very low to high (Figure 3). The lower amount of pesticides used explains the differences in environmental quality, as well as the lower amount of N fertilizers, leading for instance to a lower risk of NO_3 leaching (also due to a better soil cover during leaching period), ad to a lower risk of N_2O emissions. The better aerial biodiversity is mainly due to the lower amount of pesticides used, the diversification of the crop sequence for the innovative system in comparison with the current system, as well as the landscape management. On the other hand, no difference is observed for the resource use attribute.

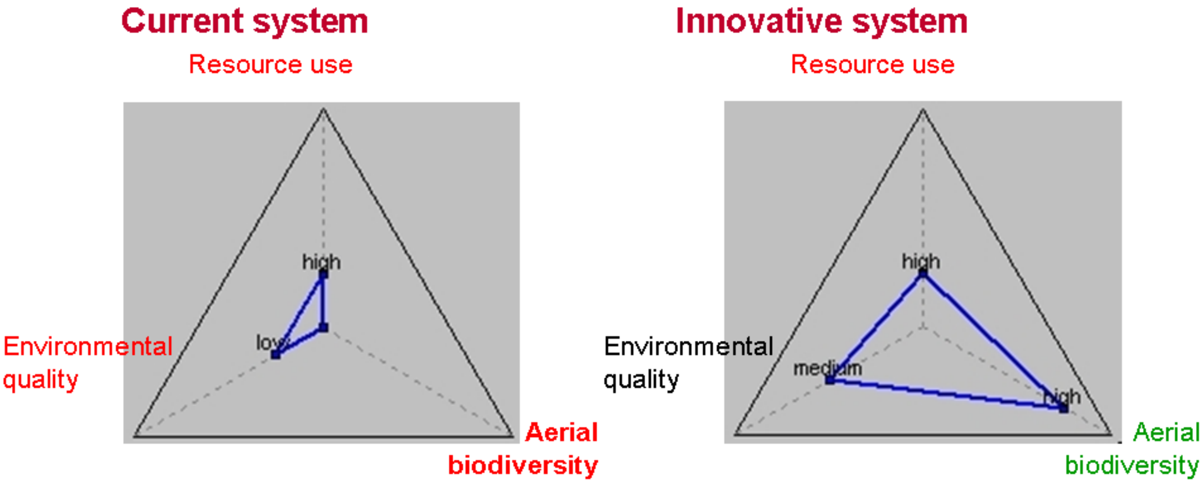

Figure 3. Environmental sustainability assessment of the current and advanced system, resulting from the resource use (water, land, mineral fertilizers, energy), environmental quality (water, soil, air) and aerial biodiversity (fauna and flora)

The attribute resource use results from the water use, the land use, the P and K mineral fertilizer use and the energy use (Figure 4). There is no difference in water use between both systems, as they are not irrigated so the water use is very low. The same amounts of P and K fertilizers are applied to both systems, leading to the same value of the attribute. The sustainability of the innovative system regarding resource use could be improved by decreasing these amounts: this possibility has to be discussed with experts. The land use is explained by the availability in uncropped land, which depends on the regional context (the same for both systems) and on the land intensity, explained by the yield.

The yield can take five qualitative values in DEXiPM, from very low to very high, and there is one class difference between the current system (medium) and the innovative system (low). On the other hand, the land intensity can only take four values, very low, low to medium, medium to high and very high. The land intensity is therefore low to medium for both the current and innovative systems, despite differences in yield. For the land use, the sensitivity of the model to the yield is lost due to this transition from an attribute explained by 5 qualitative classes to an attributes explained by four. A solution could be to increase the number of classes for the land intensity to five, but there will then be a disequilibrium with the other attribute explaining the land use (availability in uncropped land) presenting only four classes. Another problem of increasing the number of qualitative classes for an attribute is that it also increases the number of aggregation rules to fix. The lost of sensitivity of the model due to the number of classes for attributes should however be investigated.

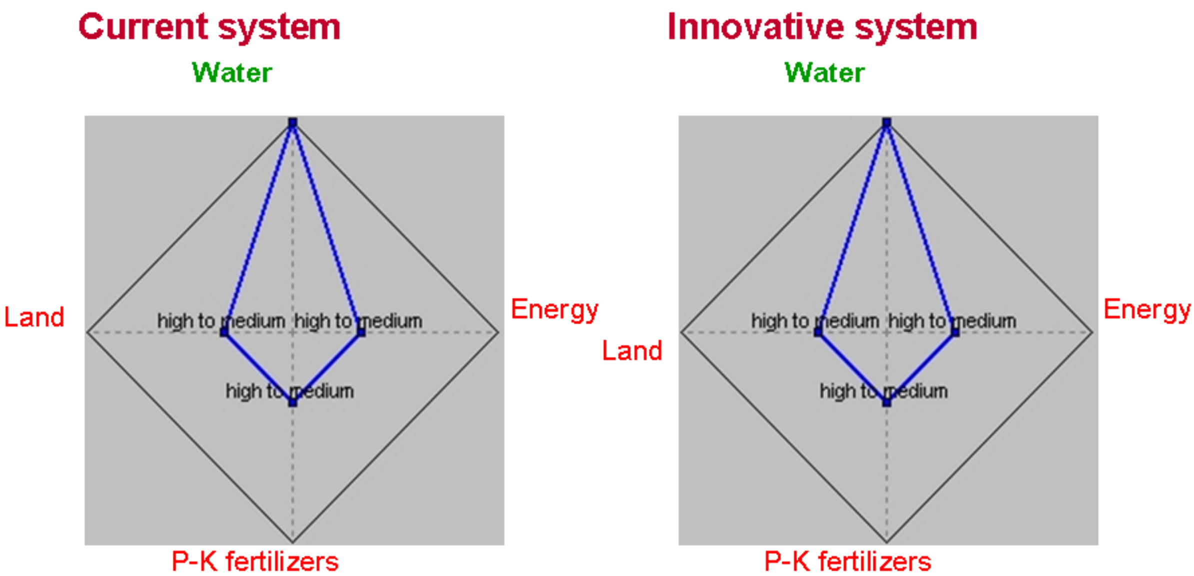

Figure 4. Resource use assessment of the current and advanced system, resulting from the water use, the land use, the P and K mineral fertilizer use and the energy use.

The energy use was also the same for both systems, high to medium. However, looking at some of the attributes explaining the energy use, we can notice that some are improved for the innovative system in comparison with the current system whereas some are negatively affected (Figure 5). For example, the number of spraying operation is improved, from 7 or more per year for the current system to less than four per year for the innovative system, essentially due to the decrease in pesticide use. On the other hand, the energy consumption linked with the superficial tillage (mechanical weeding and superficial tillage between crops) is higher for the innovative system due to the mechanical weeding (in average 1-2 per year for the innovative system and less than one per year for the current system). The overall energy use remains the same for both systems due to compensation between attributes, and these compensations could hardly be avoided.

Despite the fact that the average number of superficial tillage operations between crops is increased in the innovative system in comparison to the current system due to the occurrence of false seedbed operations before wheat sown later, no difference for this attribute occurs between system due to the choice of the intervals for the qualitative classes: both systems present an average number of superficial tillage operations between crops between one and five per year. Again, there is a lack of sensitivity due to the qualitative nature of the model that could only be improved if the number of qualitative classes was increased.

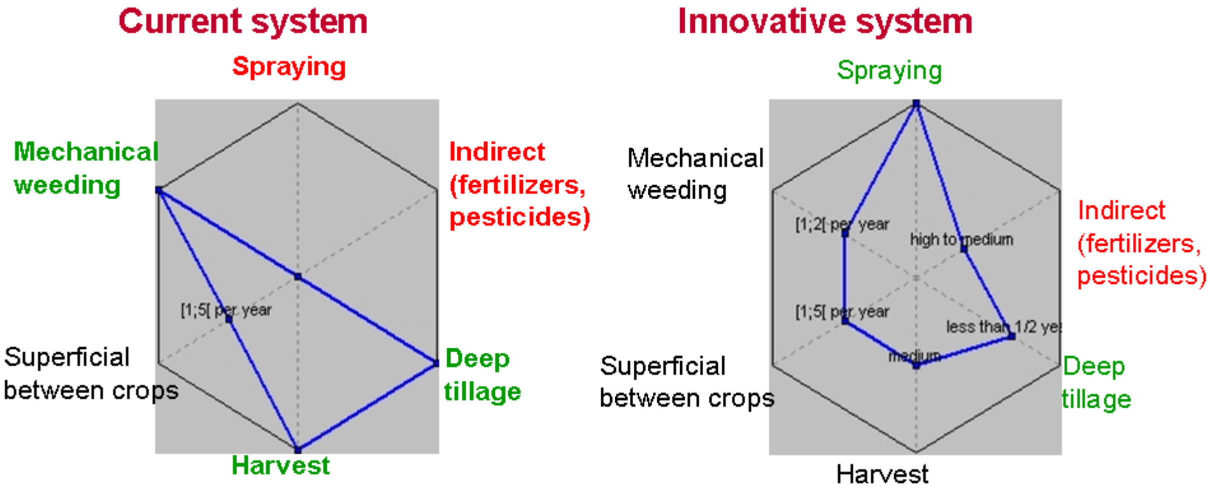

Figure 5. Some of the attributes explaining the energy use assessment.

2.2.3. Economical sustainability: gross margin

The gross margin is assessed very low for the innovative system and low to medium for the current system (Figure 6). The production cost was however decreased of one class (medium to low for the innovative system in comparison with high to medium for the current system), mainly because of the cost of pesticides and nitrogen fertilizers that was decreased due to lower amounts applied. Moreover, during the two years of alfalfa few tillage and fertilisation operations were performed, and no pesticides were applied, also decreasing the production cost. Nevertheless, the decrease of the production cost was not compensated by the decrease of the production value: from medium to high for the current system to very low for the innovative system. This decrease was due to the lower yields of the innovative system (low for the innovative system and medium for the current system): late sowing dates for cereals, lower sowing density, control of disease and insects supposed less efficient than pesticides. A lower selling price also lead to this significantly lower production value (low to medium for the innovative system and medium to high for the current system): cash crops were less frequent in the diversified rotation, and it was also supposed that they could be some difficulties to sell crops such as alfalfa or triticale.

Despite the differences in the gross margin, and in the profitability (resulting from the gross margin, the labour cost, higher for the innovative system, the production risk, higher for the innovative system and the subsidies, equal for both system), the overall economical sustainability of both systems was equal as the economical medium and long term viability of both systems was equal.

Concerning the results, the fact that the yields for the innovative system are lower is maybe not true, as some beneficial effects for the yield are not accounted for, such as the preceding effect of alfalfa (soil structure, nitrogen content of soil, etc.) or of mustard. Finally, by accounting for a possible penalty due to the crops of the crop sequence for the selling price, DEXiPM shows that the innovative system have to be implemented in regions where it is possible to sell alfalfa, i.e. regions with cattle farms (or in the close future, industries for second generation biofuel transformation). Without penalty due to the crop of the crop sequence, the gross margin of the innovative system becomes equal to the gross margin of the current system.

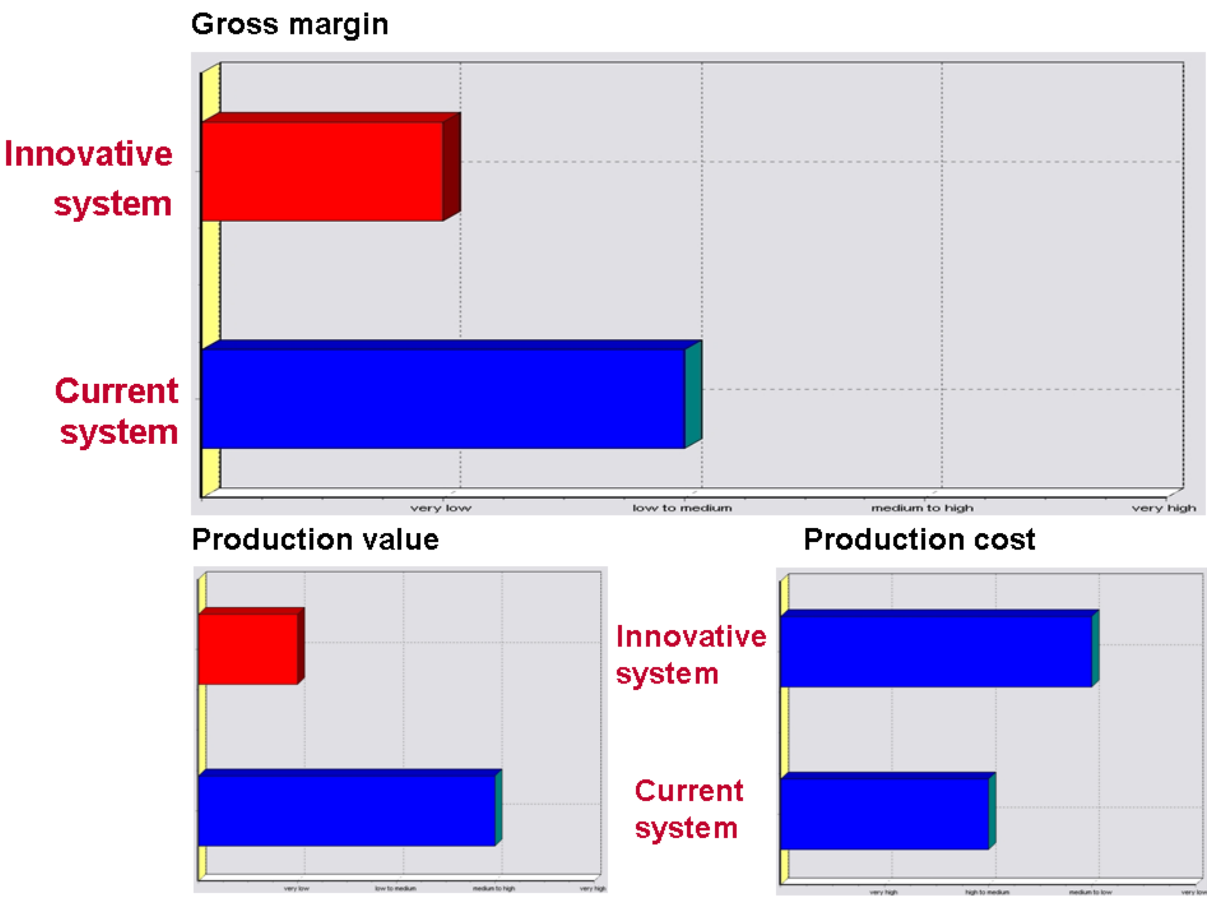

Figure 6. Gross margin assessment of the current and advanced system, resulting from the production value (yield and selling price) and the production cost (pesticides, fertilizers, fuel, seeds and irrigation).

2.3. Discussion

The description of these results aims at showing how DEXiPM has to be used. Rather than a model to predict the overall biodiversity of systems or any of the attributes, DEXiPM is a dashboard for cropping systems, allowing a visibility on all aspects of sustainability. DEXiPM is a tool to raise discussions around cropping systems and their possible improvements in terms of sustainability. The results have therefore to be analysed within the tree, to try to explain the weak points in term of sustainability, linked to the cropping system or sometimes to the model that need to be improved.

We pointed some problems of sensitivity of the model, mainly due to its qualitative nature (number of classes per attribute) but also to its size and complexity. DEXi-PM presents 74 basic attributes (42 cropping system inputs and 32 context inputs) and 85 aggregated attributes along the decision tree. This can be a problem for the description of the cropping system and context, the analysis of results. Due to this complexity, the sensitivity of the model to basic attributes and weights is probably decreased, and this has to be further investigated.

We identified two possible uses of the model. DEXiPM allows comparisons of cropping systems in a given context, but also “What-if” simulations: e.g. what modifications of the context are necessary to render an innovation attractive (acceptable, profitable…): environmental subsidies associated to landscape management, cattle farms in the surrounding area, etc.

3. Improvement of DEXiPM according to system case studies feedback

Since September 2009, DEXiPM has been used by winter crops and maize based system case studies. Current, advanced and innovative systems for winter crop SCS have been assessed with DEXiPM. Remarks on basic attributes were already taken into account and included in the deliverable DR2.14. For instance, the tables describing the basic attributes and utility functions were improved. Modifications of classes for some attributes were also discussed (e.g. pesticide mobility and toxicity). It was noticed that qualitative classes of some attributes need to be adapted according to the context/systems (e.g. TFI for Denmark, that are low in comparison with other European countries). Some attributes were judged too subjective, particularly in the social part. Adjusting the qualitative scales to the local context could also allow a better segregation between systems

As pointed out before; a proper sensitivity analysis of DEXiPM should be carried out in order to identify where the necessary improvements are. The loss of sensitivity is probably due to the complexity of the model or to the qualitative estimation and aggregation of attributes. The tree has maybe to be simplified.

Again, the results shown above prove that DEXiPM should not be used to score systems but to analyse sustainability attributes in detail, not only those linked with pesticide use. The analysis of results of assessment includes discussion around hypotheses behind the results: estimation of basic attributes, modifications of aggregation rules that can be adapted according to the context or to the users' priority. These discussions about basic attribute estimation and aggregation rule choice have also to be reported. DEXiPM does not give "the truth" about cropping system sustainability but should reveal unexpected impact of systems.

Conclusion

To conclude, DEXiPM as it stands can already be used as a tool to help for the design of innovative cropping systems with a limited use of pesticides. However, some steps have been identified to improve the model

- A sensitivity analysis to basic attributes and weights has to be carried out
- A new version of DEXiPM more sensitive to "new technologies" (GPS, micro/localised treatments, etc.) could be proposed and would be more adapted to assess innovative systems not based on deep modification of crop sequence such as the one presented here.
- It is necessary to account for social sustainability in addition to economical and environmental sustainability. Another social tree will be proposed to analyse the social sustainability at a given moment rather than the transition from current to innovative system as it is accounted for in the attribute "likelihood of adoption of the system" in the current tree.

References

Bohanec, M., Rajkovic, V., 1999. Multi-attribute decision modeling: industrial applications of DEX. Informatica 23, 487-491.

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.

Guichard, L., Savini, I., Brunet, N., Debaeke, P., Delos, M., Guérin, O., Guindé, L., Mischler, P., Munier-Jolain, N., Omon, B., Rolland, B., Viaux, P., Villard, A., 2009. ECOPHYTO R&D, vers des systèmes de culture économes en produits phytosanitaires. VOLET 1, TOME II: Analyse comparative de différents systèmes en grandes cultures. Rapport d'expertise, INRA Editeur.

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 29, 447-461.

Sebillotte, M., 1990. Système de culture, un concept opératoire pour les agronomes. In Combe, L. and Picard, D. (Eds), Les systèmes de culture. INRA, Paris, 165-196.