ENDURE

European Network for Durable Exploitation of crop protection strategies

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Preliminary list of sustainability criteria for crop protection

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Summary

This deliverable provides a preliminary list of criteria for assessing the sustainability of crop protection strategies. It has been set up by (i) analyzing existing tools and selecting those criteria already proposed in such tools which are most relevant to ENDURE purposes and (ii) taking advantage of RA3 first outputs on multi-criteria assessment.
28 criteria are being proposed so far: 9 environmental criteria, 9 social criteria and 10 economic criteria. This number might be reduced in subsequent tasks to focus on those criteria which are most relevant to crop protection purposes.

1. Introduction

As for the assessment of sustainability of agriculture, several approaches and tools have been developed in the last ten years (e.g., risk assessment tools, life cycle analysis). They often differ in terms of criteria that are taken into account and these criteria usually focus on specific aspects of sustainability, mostly environmental aspects but rarely combined the various dimensions of sustainability, including economic, social en environmental criteria. ENDURE aims at providing a multi-criteria assessment framework which would not only combine a wide range of criteria but also be able to consider science-based knowledge as well as expert-based knowledge. Indeed, some criteria might be difficult to assess but they should not be left out for that single reason. In addition, to anticipate future changes (climate change, regulation, scientific breakthroughs), ENDURE aims at assessing the potential impact of speculative technologies or situations.

In this framework, ENDURE is being implementing the overall following approach:

- Design of innovative candidate crop protection strategies, based on emerging knowledge and technologies and including new cropping systems (based on existing or speculative components such as new ideotypes, new plant architecture, etc);
- Ex ante description of their characteristics and behaviour in terms of sustainability and its various components (technical, environmental, ecological, economic and social); both quantitative models and expertise will be used (see RA3);
- Ex ante assessment of their overall performances under various contexts or scenarios through a multi-criteria hierarchical analysis;
- Testing of the most promising ones through long-term experimentation and/or transfer to the practice.

Deliverable DR2.1 is the first component produced by RA2.4 to help setting up this approach.

2. Material and methods

Assessing sustainability requires the integration of economic, social and environmental criteria as well as the handling of the variability of preferences among those actors involved indecision-making processes. This can be viewed as a typical decision-making problem based on multi-criteria assessment tools. Several multi-criteria decision-making (MCDM) methods have already been developed, practical tools have been implemented and numerous indicators for assessment sustainability have been proposed. However, the approaches are mostly focusing on ex-post assessment of sustainability and restricted to some areas of sustainability.

The first goal of RA2.4 has been to choose an ex-ante Multi-Criteria Decision-Making tool and to set up a preliminary list of sustainability criteria relevant to crop protection issues.

As several past and ongoing projects have been dealing with similar objectives, the approach undertaken within RA2.4 has been to take advantage of existing activities in the same field through networking. In order to set up a preliminary list of criteria for an ex-ante assessment, the following steps were performed:

- Discussion of the scope of the sub-activity, presentation and discussion of past or ongoing projects dealing with assessment of sustainability, analysis of their findings regarding ENDURE objectives:
    - EU FP6 HAIR project (HArmonised environmental Indicators for pesticide Risk, Coord. B. Luttik, RIVM, NL)[1];
    - EU FP6 ECOGEN project (Coord. P.-H. Krogh, NERI, DK)[2];
    - French ANR ADD project Discotech "Innovative Design Methodologies for Sustainable Cropping Systems" (Coord. T. Doré, INRA);
- Comparison of multi-criteria assessment methods and selection of a Multi-Criteria Decision-Making Tool. This first step led to the choice of Dexi.
- Compilation of criteria which would be relevant to crop protection assessment: this has been done by using the sustainability criteria used by Discotech to assess cropping systems (as implemented in the MASC tool[3]) and by adapting them to the specific crop protection area and by making them consistent and compatible with the ex-post assessment approach carried out in RA3, e.g., Life Cycle Analysis approach (SALCA[4]).
- A first list of criteria was discussed with stakeholders through face-to-face interviews. About 12 people were interviewed: Environmental NGOs, Farmer organisations, ministries.

Three specific meetings were held:

- Kick-off meeting in February 2007 to discuss the scope and existing multi-criteria methods[5];
- Presentation of sustainability criteria as selected in various projects (November 2007);
- Discussion of a first list of criteria and interaction with RA3 (January 2008).

3. Choice of a Multi-Criteria Decision-Making tool

In the last 15 years, various Multi-Criteria Decision Methods (MCDM) have been designed to address decision problems. Most MCDM methods provide numeric evaluations of alternatives that are themselves described with numbers. Operations in these models are arithmetic, usually weighted sums. Alternatively, decision problems can be described qualitatively, using non-numeric variables and 'if–then' rules. This is especially useful for problems that are not well formalized and innovative cropping systems are a typical example of such problems. Within ENDURE, we decided to use the qualitative methodology called DEX[6]. A multi-attribute DEX model is characterized by the following:

- the model consists of hierarchically structured variables called attributes;
- all these attributes are qualitative rather than numerical: they can take only a finite (and usually a small) number of discrete symbolic values;
- aggregation of values in the model is defined by rules.

[1] HAIR web site : http://www.rivm.nl/rvs/overige/risbeoor/Modellen/HAIR.jsp
[2] ECOGEN web site : http://www.ecogen.dk/
[3] Sadok et al., 2008. MASC: a qualitative multi-attribute decision model for ex ante assessment of the sustainability of cropping systems. Submitted to ASD.
[4] Nemecek et al.,
[5] Sadok et al. (2008). Ex ante assessment of the sustainability of alternative cropping systems: implications for using multi-criteria decision-aid methods. A review. Agron. Sustain. Dev. 28 1 (2008) 163-174 Doi : 10.1051/agro:2007043
[6] Bohanec, M., Rajkoviˇ c, V., 1999. Multi-attribute decision modeling: industrial applications of DEX. Informatica 23 (4), 487–491.

For each attribute, DEX requires a definition of a set of corresponding qualitative values. These are usually descriptive and the aggregation of values is carried out according to aggregation rules, which are usually given in tabular form.
The DEX methodology is implemented through the software DEXi[7]. DEXi is easy to use and allows very fast and convenient model construction. It facilitates the development of attribute trees, definition of aggregation rules, evaluation of options (crop protection strategies or systems in our case), 'what-if' analysis and graphical output. Furthermore, INRA has already used DEXi for various agronomic applications[8] and the MASC tool runs under DEXi.
DEXi will thus be used to develop an ENDURE prototype for assessing the sustainability of crop protection. This prototype should be able to assess Current or Advanced Systems (ex-post analysis) as well as Innovative Systems (ex-ante assessment).

4. List of criteria

Environmental, economic and social criteria are described below. Hierarchical attributes have been proposed in order to be further aggregated into a multi-attribute decision tree though the DEXi software. The current structure is tentative and may evolve upon discussion. Indeed, there is certain redundancy or interactions between criteria and it should be possible to reduce their number. Nevertheless, at this stage, it is worth keeping a wide range of criteria in order to stimulate discussion within ENDURE members and with external projects. Only the higher levels of attributes are described, the final implementation of hierarchical attributes will be defined once aggregation rules and calculation procedures have been defined in subsequent RA2.4 tasks.

Preliminary exchanges on criteria have highlighted confusion between indicators about impacts and indicators on practices. For example, implementing areas of environmental regulation or limited use of pesticide are generally considered as beneficial to biodiversity and one might want to include them as criteria. However, our objective is to describe, as far as it is possible the relationship between practices (crop protection practices, cropping system management) and impacts. This is not always possible and this is why we sometimes have included "practices" as a criterion (e.g., crop diversity within biodiversity).

4.1. Environmental Impact

4.1.1. Resource management

This first family of criteria deals with the impact of crop protection systems on resources.

4.1.1.1 Energy use (ENV-R-EU)

This criterion represents the total amount of energy used by the option considered:

- Direct use of energy by technical operations (fuel consumption by machinery);
- Indirect use of energy (energy cost of fertilizers and pesticides)

Whenever it is possible, this could be calculated by the Life Cycle Analysis developed in RA3.4. Alternatively, a qualitative assessment will be provided (Innovative Systems).

[7] Bohanec, M., 2003. Decision support. In: Mladeni´ c, D., Lavra˘ c, N., Bohanec, M., Moyle, S. (Eds.), Data Mining and Decision Support: Integration and Collaboration. Kluwer Academic Publishers, pp. 23–35.
[8] Bohanec et al. (2008). A qualitative multi-attribute model for economic and ecological assessment of genetically modified crops, *Ecological Modelling*, *Volume 215, Issues 1-3, 10 July 2008, Pages 247-261*

4.1.1.2 *Energy efficiency (ENV-R-EE) or Land productivity (ENV-R-LP)*

This criterion may complement the previous one which may favor systems or strategies with very low levels of energy consumption but leading to limited production outputs. This could be addressed by considering the Energy efficiency or the Land productivity:

- The energy efficiency is the ratio between the total amount of production outputs and the amount of energy used in the production process;

- The Land Productivity may be expressed in terms of yield/ha.

4.1.1.3 *Non-renewable resources (ENV-R-NRR)*

This criterion includes Phosphorous and Potassium which are only indirectly affected by crop protection strategies and land occupation (some strategies may require more land to produce the same amount of production and this can be considered as an issue in some regions).

4.1.1.4 *Water use (ENV-R-WU)*

This criterion depends on the amount of water required by the option and can be mitigated by the level of dependency with respect to the water at the regional level. Indeed, a cropping system may need a lot of water or be rather inefficient, this would not be a major problem if water is widely available in the region. This criterion may be broken down in water consumption (mm) and level of water dependency or regional effect (qualitative).

4.1.1.5 *Global Warming Potential (ENV-R-GWP)*

This criterion will calculate the contribution to global warming through greenhouse gases emission (GHG). GHG are mainly made of CO2 emission (consumption of fuel, production of fertilizers and pesticides) and N2O emission (depends on soil, climate, fertilizer use and crop management practices). This Global Warning Potential (GWP) could be calculated through the LCA approach whenever possible.

4.1.2. Environmental Quality

This second group of criteria deals with the impacts on the soil, the air and the water.

4.1.2.1 *Water quality (ENV-Q-W)*

This criterion can be derived from an assessment of:

- Eutrophication potential
  - Nitrate leaching
  - Phosphorous losses (depending on slopes, erosion potential and distance to water).
- Acidification potential
  - Ammonia emission
  - Sulphur emissions
- Aquatic Ecotoxicity
  - Pesticides
  - Non-pesticides

4.1.2.2 *Air quality (ENV-Q-AIR)*

The air pollution due to ammonia (depending on the manure use – quantity and nature) as well the potential for ozone formation depend on agricultural practices (mainly operations, fertilizers) and could be calculated by LCA. In addition, pesticide presence in the air might be considered as well.

4.1.2.3 Soil Quality (ENV-Q-SOIL)

Soil quality can be described in terms of physical, chemical and biological properties. Physical properties are depending on:

- The soil structure;
- The cultivation intensity;
- The management of residues (left or not);
- The erosion risk.

Chemical properties can be estimated through the organic matter and the phosphorous fertility.

Biological properties depend on:

- The chemical disturbance due to pesticide management (amount, nature, frequency);
- The soil fertilization (quantity, timing nature);
- The physical stress due to crop management (soil tillage) and depending on the climate;

The Soil Quality attribute will be broken down into two or three sub-attributes. As for the soil biodiversity sub-attribute, the ECOGEN EU project proposed a hierarchical structure for assessing impacts on soil biodiversity which could be used here[9].

4.1.3. Biodiversity (ENV-BIO)

Impacts of agriculture on biodiversity are less documented than other topics. Indicators for flora and fauna could be provided by the LCA methodology (SALCA) whenever it is possible. Those are:

- Birds
- Small mammals
- Amphibian
- Mollusc
- Spiders
- Carabidae
- Butterfly
- Bees (Pollinators)
- Grasshoppers
- Flora of the fields
- Flora of pastures

Pollinators are a key indicator of biodiversity and are directly affected by crop protection strategies. In addition, flora could be broken down into natural biodiversity and cultivated biodiversity (mixed crops or varieties). Therefore, specific criteria could be considered. However the relationship between practices and impacts is not well-documented and

[9] Bohanec, M., Cortet, J., Griffiths, B., Znidarsic , M., Debeljak, M., Caul, S., Thompson, J., Krogh, P.H., 2007. A qualitative multi-attribute model for assessing the impact of cropping systems on soil quality. Pedobiologia 51 (3), 239–250.

qualitative expertise may be necessary. This would also be the case for other criteria and it might be necessary to use a global indicator to summarize the effect of cropping systems and crop protection practices on the overall biodiversity. Indicators of practices, such as Crop diversity or the number of doses of registered pesticides will be considered whenever it is useful.

4.2. Economic impact

The list of criteria is most likely too long for assessing the specific impacts of crop protection strategies. It is used as a starting point and should be restructured when designing the assessment tool.

4.2.1. Profitability

4.2.1.1 Profitability of crop production (ECO-PRO-PRO)

This corresponds to the revenue R = (Yield × Price) – Production Costs when the assessment is carried out at the crop level. This can be extended at the farming system level.

4.2.1.2 Crop protection efficiency (ECO-PRO-EFF)

The profitability of crop production will be mitigated by considered the ratio of crop protection cost to the overall production costs which represents a kind of crop protection efficiency (Relative cost).
RC= Cost Protection Cost/Production costs

4.2.2. Autonomy

4.2.2.1 Level of economic independency (ECO-IND)

This criterion represents to what extent the farm depends on external subsidies to support its income: the lower the dependency on subsidies, the more sustainable.

4.2.2.2 Economic efficiency (ECO-EFF)

This criterion represents the efficiency of the inputs used to produce crops. EFF= (Product value – Input costs)/Product value. The higher the efficiency, the lower the dependency on external inputs, the higher the sustainability.

These two criteria can be combined to estimate the level of autonomy of the farm.

4.2.3. Investment

4.2.3.1 Needs for agricultural equipment (ECO-EQUI)

Qualitative estimation: does the crop protection system require specific investment?

4.2.3.2 Self-sufficiency (ECO-SELF)

Capability of the farm to support new investment.

4.2.4. Viability

4.2.4.1 Worker income (ECO-INC)

ECO-INC is the average income per worker

4.2.4.2 Economic viability (ECO-VIA)

ECO-VIA = (Gross Operating Profit – Financial Need)/number of person-year

4.2.5. Economic Risk

4.2.5.1 Production risk (ECO-RISK)

This criterion describes the potential risk linked to crop protection strategies in terms of variability of economic results (less pesticide may lead to higher variability in yields).

4.2.5.2 Economic specialisation rate (ECO-SPEC)

Specialized farming systems are considered as more susceptible to economic risk and this criterion can ne estimated by the percentage of the revenue due to the main crop in the farm.

4.3. Social impact

Several criteria have been identified so far. They are not necessarily linked to crop protection and some of them might be withdrawn in the subsequent steps of ENDURE. In addition, they would have to be structured into a hierarchy.

4.3.1. Contribution to employment (SOC-EMP)

4.3.2. Operational difficulties

4.3.2.1 Work hardness (SOC-HARD)

Impact of crop protection on the welfare of workers (noise, physical stress, etc)

4.3.2.2 Complexity (SOC-COMP)

This criterion can be estimated by taking into consideration the diversity of crops within the farming system (the more crops, the more complex) as well as the number of techniques required by crop protection strategies.
This complexity can be mitigated by considering the level of education of farmers and/or their experience in implementing integrated crop management or complex management.

4.3.3. Human health

4.3.3.1 Farmer health (SOC-WORKH)

Impact of crop protection strategies on worker health (qualitative estimation?).

4.3.3.2 Consumer health (SOC-CONH)

This criterion represents the human toxicity due to:

- Pesticides (can be estimated by combining the frequency of pesticide applications, the quantity of pesticides and their profile)
- Non-pesticides (e.g., heavy metals)

4.3.4. Working intensity (SOC-INT)

Impact of crop protection strategies or systems on working intensity (expressed as a qualitative indicator and/or a quantitative one – e.g., the number of vacation weeks of the farmer -)

4.3.5. Adaptability (SOC-ADAPT)

Impact of crop protection strategies or systems on the adaptability of the farm, i.e. its capacity to evolve, to adapt itself to external drivers, etc.

4.3.6. Market access (SOC-MARKET)

Impact of crop protection strategies or systems on market access. This might be difficult to asses as it highly depends on regional patterns and on supply chains.

Transmissibility of the farm might be considered but it is unlikely that crop protection strategies might be a major component of transmissibility.

4.3.7. Landscape perception (SOC-LAND)

This criterion represents the value given to the landscape by citizens.