Framework for assessing sustainability levels in Belgium agricultural systems - SAFE

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Université catholique de Louvain, Katholieke Universiteit Leuven

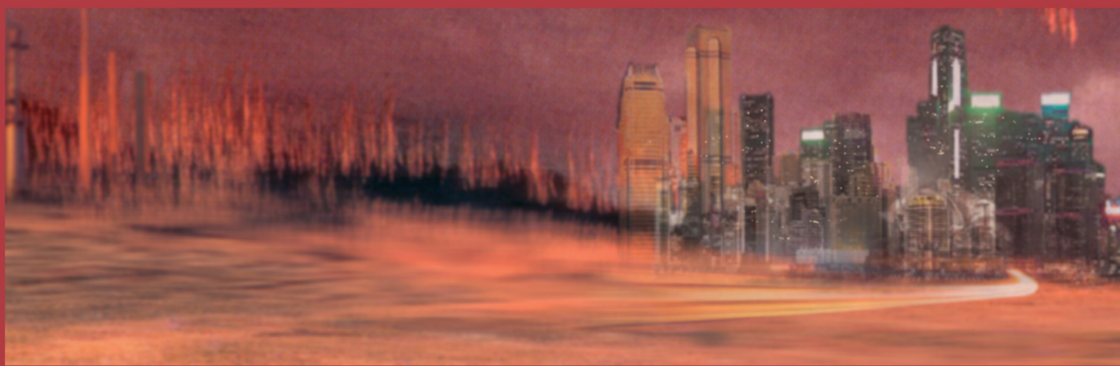
June 2005

SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY

SPSD II

FRAMEWORK FOR ASSESSING SUSTAINABILITY LEVELS IN BELGIAN AGRICULTURAL SYSTEMS (SAFE)

A. PEETERS, C. BIELDERS, M. HERMY, E. MATHIJS, B. MUYS, M. VANCLOOSTER



PART 1

SUSTAINABLE PRODUCTION AND CONSUMPTION PATTERNS

GENERAL ISSUES

AGRO-FOOD

ENERGY

TRANSPORT

SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY
(SPSD II)

Part 1:

Sustainable production and consumption patterns

FINAL REPORT

FRAMEWORK FOR ASSESSING SUSTAINABILITY LEVELS IN BELGIAN AGRICULTURAL SYSTEMS - SAFE

CP/28

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June 2005

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I INTRODUCTION

Throughout history and especially during the last century, mankind has made use of technological innovations (e.*g.* machinery, chemicals, genetic improvement) to increase levels of agricultural production. However, negative impacts of these developments were rarely considered. Nowadays, sufficient evidence exists that the actual production mode may not be sustainable, that is that farming systems may loose their production function in the long term. Indeed, there is legitimate concern that intensifying agricultural practices, but also successive European Common Agriculture Policy and World Trade Organisation reforms may have long term consequences on the expected level of goods and services provided by the agricultural sector, the economic viability of farms and the availability and quality of natural resources. Therefore, sustainability is now regarded as a crucial property of agricultural systems and its evaluation has become a main challenge for scientists, policy makers and farmers.

In the last decade, different sets of indicators have been designed both at national and international levels (*e.g*. Smith & Dumanski, 1994; Piveteau, 1998; NRC, 2000; MAFF, 2000; Wascher, 2000; OECD, 2001; Delbaere, 2002; de Angelis, 2002). Meanwhile, more practical environmental impact assessment (EIA) tools have been developed at the farm level (*e.g*. EP (Mayrhofer *et al*., 1996); EMA (Lewis & Bardon, 1998); SOLAGRO (Pointereau *et al*., 1999); ECOFARM (Peeters & Van Bol, 2000); AEI (Girardin *et al*., 2000); PROP'EAU SABLE (Lambert *et al*., 2002); MESMIS (Lopez-Ridaura *et al.*, 2002)). However, none of these indicator sets can be used at both levels. Further, most of these initiatives focus only on environmental aspects of sustainability and do not take socio-economic aspects into consideration. Indicator selection does not always fit in a consistent and comprehensive framework, although there is a strong need to integrate sustainability indicators in order to facilitate comparison and assessment. Finally, few of these works relate to Belgian agriculture, which up til now lacked a tool for assessing the sustainability of its farms.

This project aims at providing a **framework for assessing sustainability levels in Belgian agricultural systems (SAFE)** that overcomes the deficiencies mentioned above. This is achieved by:

1. Considering the concept of *agricultural sustainability in a holistic manner* – SAFE accounts for all three pillars of sustainability (environmental, economic & social).
2. Developing (a) a *consistent approach for defining sustainability principles and criteria* and (b) a *core list of sustainability indicators* identified through a standardized selection procedure. The 'SAFE selection procedure' is a *flexible scientific process* that builts on knowledge and experience of *numerous experts*.
3. Ensuring that the tool remains *as easy as possible to interpret and thus to use,* thanks to the integration procedure of sustainability indicators and the graphic expression of the results.
4. Building on a *generic methodology*. Though the set of selected indicators presented in this report is specific to the Belgian agricultural context, the method developed for the construction of the SAFE tool can be transferred for assessing sustainability levels in other geographical (Europe, world, …) and sectorial contexts. In particular, principles and criteria defined in SAFE have a universal value.
5. Taking action at *three spatial levels*, depending on the scale of application: (1) parcel (2) farm or (3) watershed for surface water-related issues, landscape/ecosystem for some soil and biodiversity-related issues, and administrative units (region, state) for some environmental as well as for some socio-economic issues.

In this project, in parallel to the theoretical construction of the tool, four farms with different production systems and agricultural practices were chosen as test sites. These farms served as a support for the development and the testing of the SAFE tool and methodology: each was monitored during two years and the collected data was used as input for *case-studies***.** Whereas indicator results in these test sites are presented and commented in this report, they cannot be used for comparing different management types: these four farms are most definitely not a representative sample of Belgian agriculture, in part because some used innovative agricultural practices.

SAFE offers **a sound scientific tool for decision making in agriculture considering sustainability concerns.** It will notably help in the identification, development and promotion of locally more appropriate agricultural techniques and systems, which is a prerequisite for the development of policy measures that will lead to more sustainable agriculture at the local/regional level.

II THE SAFE HIERARCHICAL FRAMEWORK

In this section, the ***boundaries of the agricultural system*** *as it is considered in SAFE are underlined. Next, the* ***structure of the hierarchical framework*** *of Principles, Criteria and Indicators ('P,C & I') is introduced. This framework is used in SAFE in order to facilitate the formulation of sustainability indicators. Finally, the* ***content of the 'P, C & I'*** *table is described. It reflects the multifunctional character that an agricultural system, if sustainable, should reach.*

II.1 Definition of agricultural sustainability

In the framework of this project:

> "**Sustainable agriculture** is the management and utilization of the agricultural ecosystem in a way that maintains its biological diversity, productivity, regeneration capacity, vitality, and ability to function, so that it can fulfil -today and in the future- significant ecological, economic and social functions at the local, national and global levels and does not harm other ecosystems" (Lewandowski *et al*., 1999).

II.2 System boundaries

II.2.1 Product life cycle

The agricultural system considered in SAFE is restricted to *on-farm activities* of the **production cycle**. Down-stream activities (e.g. transport, food transformation and packaging, …) are not taken into account (Figure 1). Up-stream activities (e.g. fertilizer or biocides manufacturing and fossil fuel or phosphate extraction, …) are also excluded, except for the calculation of energy indicators and indirect carbon dioxide emissions. Including these input-related issues is important because they reflect the impact on sustainability of the farmer's choices of external resource inputs.

II.2.2 Spatial component

The **horizontal dimension** of the system depends on the user-defined scale of application. Indeed, selected sustainability indicators are defined for one or more of the following levels (Figure 1):

Lowest ↓ Highest spatial level

- The *parcel* is uniform with respect to management practices (except for the margins)
- The *farm* is the management unit including a set of human, man made, social and natural resource capitals (i.e. fields, buildings, machines, livestock)
- The highest spatial level depends on the issue to be analyzed: *watershed* for surface water-related issues, *landscape / ecosystem* for some soil and biodiversity-related issues, and *administrative units* (region, state) for some environmental as well as for some social and economic issues.

The **vertical dimension** is limited to the biosphere[1]. Effects on higher layers of the atmosphere (e.g. CO_2 emissions) or the geosphere (e.g. nitrate leaching to groundwater) are considered through the fluxes across the system boundaries (Figure 1).

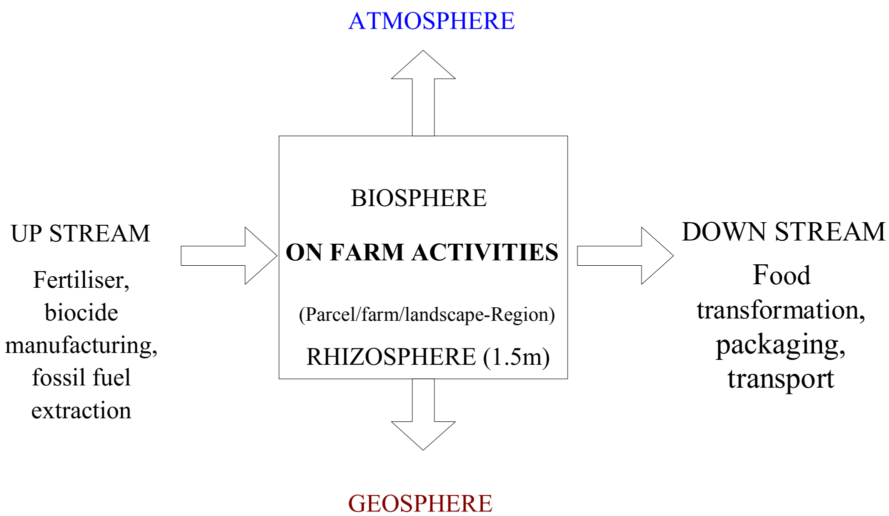


Figure 1. Product life cycle and spatial component of the system boundaries.

II.2.3 Time component

Sustainable agriculture is about maintaining the ability of agriculture to perform significant social, environmental and social functions for present and future generations. However, it is illusory to pretend being able to assess whether an agricultural system will still be active in several centuries. Rather, the scope of a sustainability assessment applies to the coming two or three generations.

The agro-ecosystem is highly dynamic while indicators are often intrinsically static, being a snapshot measurement. In SAFE, the time scale over which to calculate sustainability indicators is set to one year. Yearly values are derived from single yearly measurements for slowly changing variables or from time integration of repeated measurements in the case of more rapidly fluctuating variables. These yearly indicators should then be monitored over several years in order to detect trends. Because of the cyclic behaviour of some indicators or differing responsiveness to climatic and other variation sources of the agro-ecosystem, it is sometimes adviseable to integrate indicator values over years.

II.3 Structure of the P, C & I hierarchical framework

The SAFE analytical framework defines hierarchical levels to facilitate the formulation of sustainability indicators in a consistent and coherent way. The structure of the hierarchical framework is shown in Figure 2 (adapted from Lammerts van Bueren & Blom, 1997). The general aim of the framework is to evaluate sustainability in agriculture and this aim is progressively reached by defining successively 'Principles', 'Criteria' and 'Indicators':

[1] Thin layer at the earth surface, colonized and influenced by organisms. It includes the soil profile as the actively rooted zone (1.5m), the plant canopy and the atmosphere between and above the canopy (birds & flying insects included).

1. **Principles -** The first hierarchical level relates to the *multiple functions of the agro-ecosystem*, which go clearly beyond the production function alone (de Groot *et al*., 2002) and encompasses the three pillars of sustainability: environmental, economic and social.

2. **Criteria** – The *resulting states* of the agro-ecosystem when its related Principles are respected. Criteria are more concrete than Principles and thus easier to link to indicators.

3. **Indicators** - Variables of any type that can be assessed in order to *measure compliance with a Criterion*. A set of indicator values should provide a representative picture of the sustainability of agricultural systems in all its environmental, economic and social aspects.

4. **Reference values -** The desired level of sustainability for each indicator. They give users guidance in the process of continuous improvement towards sustainability (Mitchell *et al*., 1995; Girardin *et al*., 1999; Wefering *et al*., 2000; Piorr, 2003).

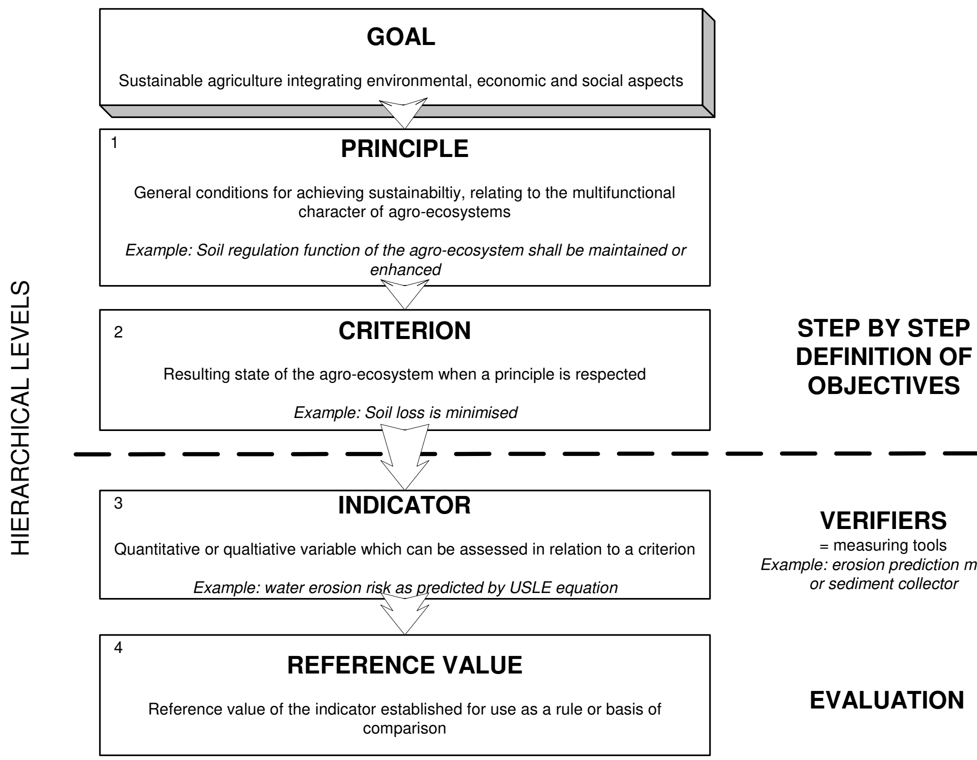


Figure 2. Structure of the SAFE hierarchical framework (Adapted from Lammerts van Bueren & Blom, 1997).

II.4 Reference values typology

The holistic approach adopted in the SAFE framework allows both relative and absolute assessment (von Wirén–Lehr, 2001) (Figure 3). Absolute assessment relies on the existence of previously defined reference values. Relative assessment is based on the comparison of different systems among each other.

Fixed values include **scientific** and **legal** reference values. Scientific values are brought forward by scientists as the result of reflection on state-of-the-art knowledge in combination with the precautionary principle. Legal values are also called norms and their compliance is compulsory. They are typically the result of negotiations, for instance between policy makers, farmer representatives, advisory organisms and scientists. Fixed values can also be divided into target and threshold values. *Target values* identify desirable conditions (Mitchell *et al.*, 1995), while *threshold values* may be expressed either as minimum or maximum levels or ranges of acceptable values, which should not be crossed. As shown in Figure 3 both target and thresholds values can have a scientific source. Legal norms are typically represented by thresholds, although they can constitute targets in some cases.

For some Criteria, e.g. economic Criteria, it is meaningless to define (fixed) reference values at a local spatial scale. The most adequate reference value established for them is at larger spatial scales such as the **group average** (e.g. regional). Relative assessment can also be based on **comparison between sectors**. For other Criteria, the definition of static indicators and reference values does not make much sense. In such cases indicators and reference values should be defined to evaluate a desirable **trend**. Assessing changes in time may be achieved by presenting the time course of the system state variable from which trend indicators and reference values can be inferred. Trends may be very useful for instance to describe insect or plant diversity. The above-mentioned types of reference values may be applicable to different scales such as the parcel, the farm or the landscape/watershed/administrative unit scale.

Space and time dependency increases going down in the hierarchy. Whereas **Principles are universal**, **indicators and reference values will change** according to the geographical, cultural and temporal context of application.

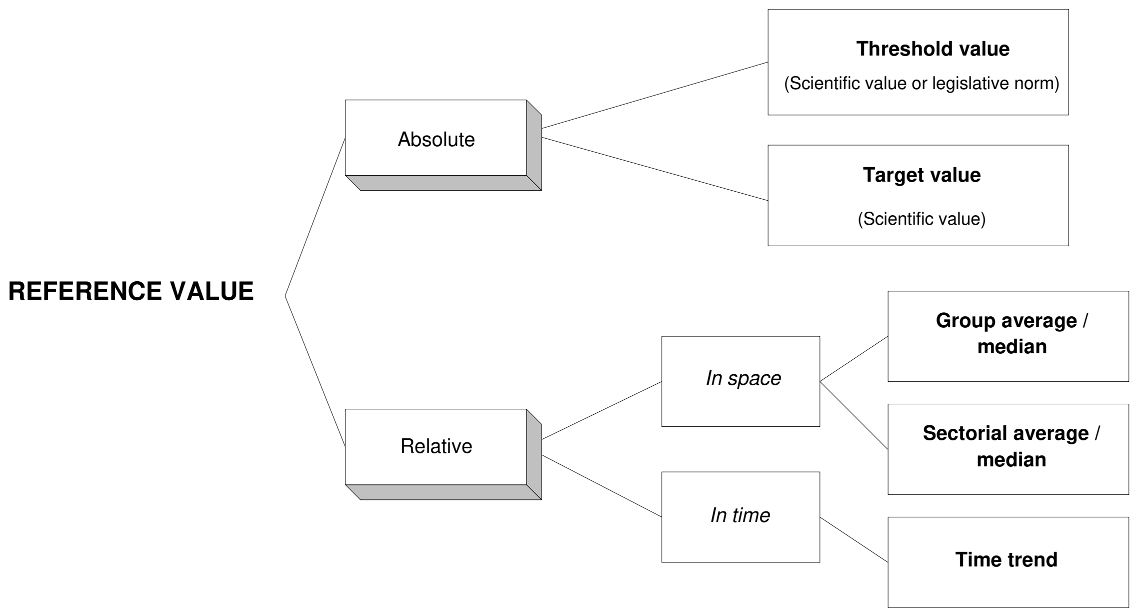


Figure 3. Classification of reference values.

II.5 Principles & Criteria definition

The Principles and Criteria of the SAFE framework are presented in table 1. They are related to the multi-functions of an agro-ecosystem (de Groot *et al*., 2002) and to the three Pillars of sustainable agriculture:

Table 1. The SAFE hierarchical framework: Principles & Criteria.

PRINCIPLES	CRITERIA
ENVIRONMENTAL PILLAR	
AIR	
Supply of quality air function [1]	Air quality is maintained/enhanced
Air flow buffering function [1]	Wind speed is adequately buffered
SOIL	
Stock of soil function [1]	Soil loss is minimized
Stock of quality soil function [1]	Soil chemical quality is maintained/increased
	Soil physical quality is maintained/increased
WATER	
Supply of water function [1]	Adequate amount of surface water is supplied
	Adequate amount of soil moisture is supplied
	Adequate amount of ground water is supplied
Supply of quality water function [1]	Surface water of adequate quality is supplied
	Soil water of adequate quality is supplied
	Groundwater of adequate quality is supplied
Water flow buffering function [1]	Flooding and runoff regulation is maintained/enhanced
ENERGY	
Supply of energy function [1]	Adequate amount of energy is supplied
Energy flow buffering function [1]	Energy flow is adequately buffered
BIODIVERSITY	
A. Biotic resources	
Stock of biotic resources function [1]	Planned biodiversity is maintained/increased
	Functional part of natural/spontaneous biodiversity is maintained/increased
	Heritage part of natural/spontaneous biodiversity is maintained/increased
B. Habitats	
Stock of habitat function [1]	Diversity of habitats is maintained/increased
Stock of quality habitat function [1]	Functional quality of habitats is maintained/increased
ECOSYSTEM INTEGRITY	
Ecosystem stability regulation function [1]	Resistance and resilience of the ecosystem is maintained/increased

ECONOMIC PILLAR	
VIABILITY	
Economic function [1]	Farm income is ensured
	Dependency on direct and indirect subsidies is minimised
	Dependency on external finance is optimal
	Agricultural activities are economically efficient
	Agricultural activities are technically efficient
	Market activities are optimal
	Farmer's professional training is optimal
	Inter-generational continuation of farming activity is ensured
	Land tenure arrangements are optimal
	Adaptability of the farm is sufficient
SOCIAL PILLAR	
FOOD SECURITY AND SAFETY	
Production function [1]	Production capacity is compatible with society's demand for food
	Quality of food and raw materials is maintained/increased
	Diversity of food and raw materials is maintained/increased
	Adequate amount of agricultural land is maintained
QUALITY OF LIFE	
Physical well-being of the farming community function [1]	Labour conditions are optimal
	Health of the farming community is acceptable
Psychological well-being of the farming community function [1]	Education of farmers and farm workers is optimal
	Equality in the man-woman relation is acceptable
	Family access to and use of social infrastructures and services is acceptable
	Family integration in the local and agricultural society is acceptable
	Farmer's feeling of independence is satisfactory
SOCIAL ACCEPTABILITY	
Well-being of the society function [1]	Amenities are maintained/increased
	Pollution levels are reduced
	Production methods are acceptable
	Quality and taste of food is maintained or increased
	Equity is maintained/increased
	Stakeholder involvement is maintained/increased
CULTURAL ACCEPTABILITY	
Information function [1]	Educational and scientific value features are maintained/increased
	Cultural and spiritual heritage value features are maintained/increased

Legend. 1 = each function/Principle "of the agro ecosystem shall be maintained/enhanced".

II.5.1 Environmental Pillar

Environmental functions are connected with the management and conservation of natural resources as well as fluxes within and between these resources. **Natural resources** provided by ecosystems are water, air, soil, energy and biodiversity (habitat and biotic resources). Except for habitat, all natural resources can be characterised by **stocks and flows (or supply)**, whether or not they are part of a natural cycle. The decision to express a given Principle in terms of stock or flow is largely arbitrary but is based on the relative importance of flows and stocks in the agro-ecosystem. In addition, all resources can be evaluated in terms of their **quantity or quality**. Consequently, **two sets of agro-ecosystem functions** are considered in SAFE:

1. To ensure an adequate supply of the various resources for use by all living organisms, the resource having to be of adequate quality

2. To ensure that the fluxes are sufficiently buffered so as to minimise damaging effects to the agro-ecosystem, e.g. wind and flood regulation function

The first set of functions can be expressed equally as a stock regulation function or as a flow regulation function. In the first case (stock regulation), the emphasis is on conservation and, in some cases, enhancement of the existing quantity of a resource. In the second case (flow regulation), the emphasis is on regulating flows such that at any time a sufficient amount of resource is available for use. For instance, "soil loss is minimised" and "soil mass is maintained" are equivalent but refer to flow regulation and stock regulation, respectively, the end result being the same in both cases (conservation of soil mass). Except for habitat that exists only as a stock, the choice between the two ways of expressing ecosystem functions is therefore largely arbitrary. In SAFE, the choice between one or the other way of expressing the functions was made on the basis of the relative importance of the stocks versus the flows. Table 2 presents the selected functions for the various environmental resources.

Table 2. Principal functions of the agro-ecosystem's natural resources.

Natural resource		**Stock**		**Flow**		
		Retention function		**Regulation function**	**Supply function**	
		quantity	**quality[1]**		**quantity**	**quality[1]**
Air	Atmosphere	/	/	yes	no	yes
	Soil air	/	/	na[2]	yes	yes
Water	Surface water	/	/	yes	yes	yes
	Soil water	/	/	na[2]	yes	yes
	Groundwater	/	/	na[2]	yes	yes
Soil (solid)		yes	yes	/	/	/
Energy		/	/	yes	yes	na
Biodiversity / biotic	Planned	/	/	na	yes	na
	Functional	/	/	na	yes	na
	Heritage	/	/	na	yes	na
Biodiversity / habitat	Planned	/	/	na	yes	yes
	Functional	/	/	na	yes	yes
	Natural / spontaneous	/	/	na	yes	yes

na = not applicable
[1] physical and chemical quality only; biological quality is taken into account under biotic diversity.
[2] because flow rates never reach damaging levels

II.5.1.1 Air

The supply of air is considered constant. Hence, with respect to air, the agro-ecosystem serves two main functions:

1. To **regulate wind speed** so as to minimize its damaging effects (*regulation function*).

2. To ensure an adequate **supply of quality air** (*supply function*)

Concerning air quality, four main categories of emissions are considered: (1) Greenhouse gases, e.g. N_2O, CH_4 and CO_2, (2) Emissions provoking acidifying or euthrophicating depositions, e.g. NH_3[2] from animal effluents stocking, manipulation and application, (3) Emissions of ecotoxic pollutants' e.g. biocides and (4) Emissions of particulate matter, e.g. dust production during tillage operations or wind erosion and particlesemissions from diesel engines.

II.5.1.2 Soil

The soil component in the framework refers to the solid phase of the soil, the air and water components being considered as part of air and water resources.

The agro-ecosystem has a double function with respect to soil: to maintain a sufficient **stock of soil** and to maintain **the quality of that stock**. Soil functions are defined here in terms of stocks and not of flows. This is an arbitrary choice, depending on which process one wants to emphasize, as stocks and flows are complementary.

There is one Criterion associated with the soil stock function: soil loss is minimized, i.e., soil loss by water, wind, tillage and harvest erosion and soil loss by mass movements need to be minimised, both in order to conserve the soil resource and to prevent damaging off-site effects (e.g., muddy floods). Since the soil buffering function would deal with water and wind erosion and mass flow, it is clear that redundancy would be created if the buffering function would have been included. For soil quality, both soil physical (e.g. bulk density or water holding capacity) and chemical quality (e.g. pH, adsorbed pollutants, or nutrient content) are taken in consideration[3].

II.5.1.3 Water

Three Principles describe the functions of an agro-ecosystem related to water. First, surface water, soil water and groundwater have to be **present in an adequate amount** and second, **of satisfying quality**. Third, in the agro-ecosystem, the **surface flow of water has to be buffered**. An adequate amount of water implies that (i) intra-annual variations of surface water have to be reasonable; (ii) the quantity of soil moisture has to permit a continuous occupation of the soil; and (iii) the use of groundwater should not exceed the recharge rate. The physical and chemical properties that must be considered for water quality include (i) load of agro-chemicals, (ii) load of nitrates for surface and groundwater, (iii) load of phosphates for surface water, (iv) sediment load, and (v) load of pathogen micro-organisms in water. Other living organisms living in water are considered under biotic biodiversity. The habitat function of water is considered under biodiversity/habitat.

II.5.1.4 Energy

For the sake of comprehension, the term "energy" instead of "exergy" is used in this context, although the latter, referring to useful energy able to do work, would be more appropriate (Dewulf *et al*., 2000; Cornelissen and Hirs, 2002).

The agro-ecosystem serves two main functions with respect to energy:

1. To **provide sufficient energy** for the agro-ecosystem to perform its other functions (*supply function*)

2. To **regulate energy flow**, mainly through the energy consumption of the agro-ecosystem (*regulation function*)

[2] The risks for human health related to the concentration of ammonia in livestock buildings are considered in the social Pillar under the Criterion "acceptable production methods".
[3] Soil biological quality is included under biotic biodiversity. The habitat function of soil is considered under biodiversity / habitat.

II.5.1.5 Biodiversity

The concept of biodiversity in agriculture can be defined at three main levels: the genetic diversity within individual species, the number of species within a community and the diversity of communities in the local environment. For each of these three levels, planned and natural/spontaneous biodiversity can be identified:

- *Planned or agricultural biodiversity* (Vandermeer *et al*., 1998; Maljean and Peeters, 2001) at the gene level measures the diversity of plant varieties and animal breeds, or even strains of micro-organisms, which are deliberately used by the farmer. At the species level, it considers the diversity of cultivated plants or livestock species. At the community level, it characterises the diversity induced by the different land cover types, plot sizes, the presence of hedgerows, distinct field margins, orchards, etc.

- *Natural/spontaneous biodiversity* consists of genes, wild species and community diversity that appear spontaneously within production systems. It can be called associated biodiversity (Vandermeer *et al*., 1998). Some of these species play a decisive role for the farming system functioning, forming what is known as functional or para-agricultural biodiversity (Altieri, 1999; Maljean and Peeters, 2001). They include:

    1. *Functional or para-agricultural biodiversity:* species with a positive effect on production, such as photosynthetic organisms that produce fodder, micro-organisms that play a role in decomposition or nitrogen fixation, parasites, parasitoids and predators of crop enemies, pollinators and earthworms. Other functional species, such as weeds, diseases and pests, have a negative effect on agricultural production. At community level, functional biodiversity is mainly provided by the presence of hedgerows, field margins and woodland strips.

    2. *Heritage or extra-agricultural biodiversity*: other spontaneous taxa and communities, linked to varying degrees with the farming system, but with a less important role in its functioning (Maljean and Peeters, 2001). Many species in this category have a major heritage value. Species include higher plants (e.g. orchids), insects (e.g. butterflies, dragonflies), birds, mammals… At the community level, this type of diversity includes elements that are less important from a functional point of view, such as copses, ponds and wetlands.

For the definition of the Principles, a distinction is made between **biotic (or genetic) resources** on the one hand and habitats on the other hand. The latter serve as carriers for adequate development of the genetic patrimony. Analogue to the biotic resources, the quantity as well as the quality of habitats is considered. Habitats include the atmospheric (air), aquatic (water) and terrestrial (soil, land) part of the environment on which organisms depend, directly or indirectly, in order to carry out their life processes. Habitats also include corridors, whose main function is to sustain the flow of biotic resources. When it comes to the **quantity of** habitats, the diversity, the number and the total area are important as well. The **functional quality of habitats** refers to the area of core habitat and the degree of connectivity between habitats.

II.5.1.6 Ecosystem integrity

In addition to stock and flow regulation functions of individual resources, there exists a higher level of organisation at which regulation takes place: the level of the ecosystem itself. This is defined as ecosystem integrity and can be seen as an integrative component of the ecosystem.

Ecosystem integrity includes all aspects related to the control the ecosystem has over energy and material flows (Müller *et al*., 2000); it is a measure of the **ecosystem resistance and resilience to natural and anthropogenic perturbations**. Ecosystem resistance is the capacity of the system to resist disturbances. The resilience of an ecosystem represents the capacity of the system to recover its initial state after disturbance.

II.5.2 Economic Pillar

The economic function of the agro-ecosystem is to provide prosperity to the farming community and thus refers to the economic viability of the agro-ecosystem. It must be noted that **economic viability** is often a prerequisite for several aspects of the social Pillar as well (e.g. access to social activities depends on income level).

Basic farm economic activities cover three types of activities: (i) maintenance, production and product processing activities, (ii) marketing activities and (iii) financial activities. The combination of these activities results in the generation (or reduction) of income and financial capital.

Technical (or production) efficiency is achieved when the output is produced at minimum cost. This minimises the inappropriate use (and thus waste) of inputs, such as fertilizers, pesticides, animal feed, energy, water, mechanical work, buildings, labor, land and information.

Market activities should be efficient. Allocative efficiency, the efficient allocation of resources, or price efficiency is reached when marginal returns equal marginal costs for all inputs and outputs. However, as mostly price takership is assumed, this Criterion could be broadened with the condition that prices should be "fair" or "equitable". Sales can be realised in the spot market, on contract, through a marketing cooperative or directly to the final consumer, but the condition of the sale often depends on the relative bargaining power of the farmer, which is to his disadvantage. The same holds for inputs, and particularly for land.

Financial activities should be efficient, that is, the dependency on external finance through credit or subsidies should be optimal, resulting in an optimal debt/equit ratio (solvency) and optimal investment. Subsidies may create a strong dependency, thus inhibiting innovation. Subsidies may be direct (direct income support, second Pillar payments, etc.) and indirect (tax and VAT exemptions, indemnities for climatic and pandemic catastrophes, price support, etc).

When technical, allocative and financial efficiency are all met at the same time, the farm is said to be economically efficient. The sum of the return on labour, on own capital and the net farm result equals to family income.

Three aspects that cannot be captured by production, market or financial activities are added to the framework. First, a farmer supplies and invests in human capital which is used to manage the farm. In order to be economically efficient, the farmer's professional training should be optimal. Second, the activities of the farm are influenced by whether or not the inter-generational transfer of the farm is ensured, e.g. through a higher incentive to invest. Third, a farm should have the potential to adapt to changes in the market, institutional, and agro-ecological environment through effective changes in governing and production structures.

II.5.3 Social Pillar

The agro-ecosystem has several social functions, both at the level of the farming community and society level.

With respect to the former, farming activities should be carried out with respect to the quality of life of the farmer and his family. The agro-ecosystem needs to be organised in such a way that social conditions are optimal for the people who work there (that is, who perform an economic function). This refers both to the **physical well-being** (labour conditions and health) and the **psychological well-being** (education, gender equality, access to infrastructure and activities, integration into society both professionally and socially, feeling of independence) of the farm family and its workers.

Society's demands with respect to farming activities are realised at three levels. Arranged from basic necessities to luxury goods these include: food security and safety, socially acceptable farming practices and cultural goods. First, the most basic function of the agro-ecosystem is to **provide safe, sufficient and**

diverse food. Second, it should also **contribute to the well-being of society**. Positive externalities include amenities (landscape, hedges and attractive farm buildings namely) and quality, tasty food. Negative externalities include both odour and visual pollution, unacceptable production practices (e.g., animal welfare) and an unequal distribution of wealth. Finally, the agro-ecosystems may produce cultural goods **pertaining to its information function**: specific features may be of educational, scientific, cultural and spiritual value.

II.6 Discussion

Many indicator sets and frameworks for sustainable agriculture have already been presented in literature (e.g. Adriaanse, 1993; OECD, 1993; Hammond *et al*., 1995; Wascher, 2000). In an overview by Lenz *et al.* (2000) it was stated that "at the moment, three types of conceptual frameworks for indicator selection are widely accepted: the 'pressure-state-response' (PSR) framework used by the OECD (Hammond *et al*., 1995); the 'pressure-state-impact-response' (PSIR) framework used by UNEP and RIVM (Hardi and Zdan, 1997) and the 'driving force-state-response' (DSR) framework. The latter was adopted by the UN Commission on Sustainable Development (CSD) in 1995 as a tool for organizing information and indicators on sustainable development (Mortensen, 1997)." The 'driving force-pressure-state-impact-response' (DPSIR) used by the EU-EEA (EEA, 1999) is another variant on these frameworks. Frameworks can be either action or evaluation orientated or include both paths in sustainability (Madlener *et al*., 2003). This will have consequences on the types of indicators included in the framework.

Unfortunately, **most of these frameworks suffer from a series of drawbacks**. Frequently encountered weaknesses of existing frameworks are, first, partial coverage of sustainability issues, partial capture of the key factors and key processes, and partial reflection of the complex chain of causes and effects. Secondly, many existing frameworks lack a hierarchical structure or a systematic organization of issues and aspects related to sustainability. Indeed, although most of the above mentioned frameworks are multidimensional and cover the social, economic and environmental dimensions of the agro-ecosystem, the selection of appropriate indicators follows a more or less arbitrary choice due to a lack of a solid, holistic organizational basis. Thirdly, many frameworks have a sector or problem-based character concentrating on the lack of sustainability in a particular area rather than in the whole system. Consequently one acts to solve the specific problem rather than the general one (von Wirén-Lehr, 2001). Fourthly, few frameworks are universally applicable. While universal applicability is not a strict requirement for sustainability frameworks, the elaboration of one or a few generally applicable frameworks is definitely worthwhile. In this context it should be noted that, whereas the framework should have a general, comprehensive character, selected sustainability indicators could and/or should be site- and scale-, and problem/sector-specific. It should also be accepted that the frameworks themselves may change over time, as scientific knowledge, societal values and concerns evolve. Finally, amongst the numerous initiatives, only a few studies deal with sustainability assessment at the field or farm levels. Most studies work at larger scales, mainly the national or international levels (Smith & Dumanski, 1994; Piveteau, 1998; NRC, 2000; MAFF, 2000; Wascher, 2000; OECD, 2001; Delbaere, 2002; de Angelis, 2002). Important links between management by the farmer and impacts and effects on the agro-ecosystem and its sustainability levels are therefore not addressed.

III INDICATOR SELECTION

This chapter introduces ***SAFE's selection procedure of indicators*** (Figure 4), *a process that has lead to the determination of a* ***coherent list of relevant and performing sustainability indicators*** (table 4).

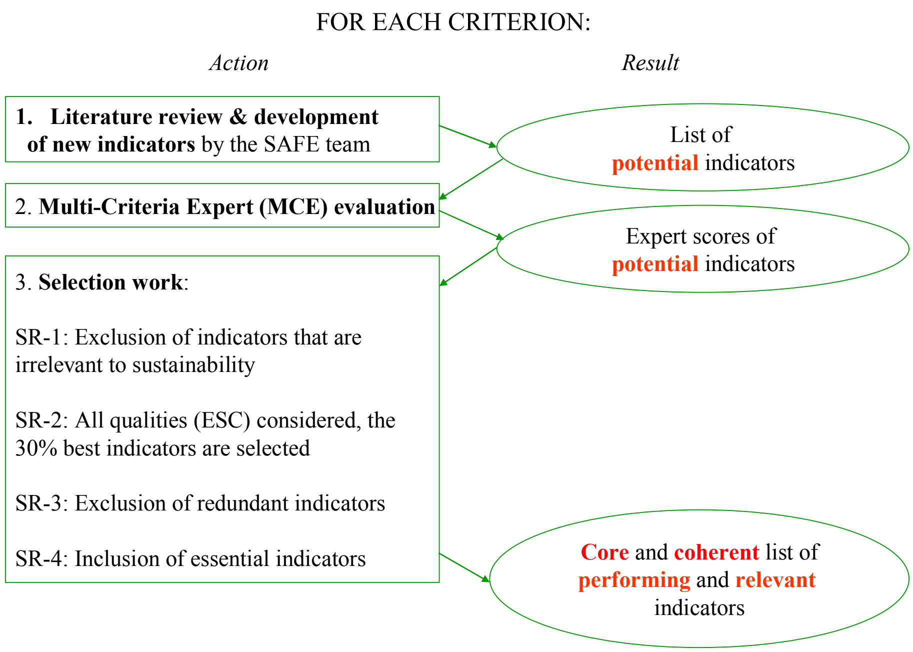


Figure 4. SAFE's selection procedure for agricultural sustainability indicators. ESC: Expert Selection Criterion; SR: Selection rule (see below).

III.1 Selection procedure

III.1.1 Step 1 - Literature review

An extensive **literature review** has been carried throughout the whole project (all covered references can be found in annex V). The result is a **list of 357 potential indicators** covering the three Pillars of sustainability (annex V). Among others, it included:

- Indicators used by *international and national institutions* (Piveteau, 1998; NRC, 2000; MAFF, 2000; Wascher, 2000; Delbaere, 2002; OECD, 2001; de Angelis, 2002; Mc Rae, 2000, Lewis & Bardon, 1998; Pointereau *et al.*, 1999; Girardin *et al.,* 2000; SITEREM, 2001; PAEXA, 2000; Ministère de l'Aménagement du Territoire, de l'Urbanisme et de l'Environnement, 2004 ; Gouvernement wallon, 2002)

- *specific references* (Kutsch *et al.,* 2001; Doran & Parkin, 1994; Tellarini & Caporali, 2000; Maraite *et al.*, 2005; Dalgaard *et al.*, 2001; Arshad & Martin, 2002; Hermy & Cornelis, 2000; Forman, 1995)

- indicators developed within the *SAFE team*

III.1.2 Step 2 - Multi-Criteria Expert (MCE) evaluation

III.1.2.1 Concept

Validation of potential indicators was performed by **experts**. Participants were chosen on the basis of their expertise and so as to represent a mix of Flemish and Walloon scientists, functionaires and farmers' representatives. Indicators and experts were thematically grouped in 4 panels: (a) Soil & Water, (b) Biodiversity, (c) Socio-economic and (d) Air, Energy & Ecosystem Integrity. For each panel, 10 experts were invited to perform a **multi-criteria evaluation** against eight Expert Selection Criteria (ESC).

III.1.2.2 Expertise Selection Criteria (ESC)

The evaluation of the potential indicators by experts was performed against **eight ESC** (table 3)[4]:

Table 3. Potential indicators are evaluated against eight 'Expertise Selection Criteria' (ESC).

ESC		Description
1 & 2	Discriminating power in (1) time / (2) space	Ability to discriminate (1) in time / (2) in space between changes due to external factors and changes due to management
3	Analytical soundness	An indicator should be scientifically valid, i.e. be measured and/or calculated in well-founded technical and scientific terms
4	Measurability	An indicator should be easily and technically measurable. Hence, its use should be justified in terms of cost and time consumption
5	Transparency	The meaning of an indicator should be easy to seize, clear, simple and unambiguous
6	Policy relevance	The indicator should help in monitoring effects of policy measures and in identifying areas where policy action is needed
7	Transferability	The indicator should make sense in major farm types implementing common and/or alternative practices
8	Relevance to sustainability issue	The indicator should be as relevant as possible to the sustainability aspect it is related to in the database

III.1.2.3 Scoring procedure

Upon agreement to participate, experts received **three documents**: (1) a concise *database* with the characteristics of the indicators (name, related sustainability aspect to consider when evaluating, description, source, calculation method, data needed, spatial and temporal scale of measurement and expression) (annex V); (2) an *evaluation procedure guideline* (annex VIII); (3) *complementary information* on indicators if necessary (calculation method) (annex IV).

On the basis of these documents, experts assigned **scores** to each individual indicator of his/her thematic list **individually** and for each of the **eigh**t **ESC** (Expertise Selection Criteria). The scoring system corresponded to a **1-to-5 scale**, where 5 is the best score possible.

[4] Detailed information for each ESC can be found in annex VIII.

III.1.3 Step 3 – Indicator selection

III.1.3.1 Preliminary step

The different scores of experts concerning a given indicator I_i were first synthesised in an ‘agreement’, i.e. the actual input of the selection work

Figure *5*):

Expert Agreed Score$_{ij}$ (EAS_{ij}) = equal weight arithmetic average[5] of the scores given by experts (for a specific indicator i and for Expertise Selection Criterion j).

$$EAS_{ij} = \frac{1}{n}\sum_{k=1}^{n} ESC_{ijk}$$

$$\overline{EAS_i} = \frac{1}{8}\sum_{j=1}^{8} EAS_{ij}$$

Figure 5. Agreement between experts is obtained by averaging their scores.
where ESC_{ijk} is the score for indicator i, expert selection criterion j (ESC) and expert k, n = number of experts evaluating a given indicator, EAS_{ij} is the score for indicator i, expert selection criterion j (ESC) over all experts, called Expert Agreed Score, and $\overline{EAS_i}$ is the average EAS over all eight expert selection criteria (ESC) for a given indicator i.

III.1.3.2 Selection rules

The selection work consists of **4 successive and logical selection rules (SR)** (Figure 6).

[5] Many possibilities exist for coming to an **agreement between the opinions of diffent persons** (social choice theory). Among others: (1) ‘*Leximin*’: maximum/minimum among expert scores is selected (2); ‘*Utilitarism*’: equal weights arithmetic average/sum of expert scores; (3) *other linear combinations* of experts scores (Principal Component Analysis, …). But (3) does not respect the two following properties: a) ‘anonymity’ which ensures that the opinions of experts are treated the same way b) ‘separability’ which ensures that if an extra-expert whose judgment is indifferent between all the indicators is added afterward, this extra-expert does not influence the selection outcome (Sen, 1986). Hence, (1) has the disadvantage of synthesizing various opinions by choosing one among the many. In the SAFE case, indicators related to many different aspects of agricultural sustainability were submitted to experts who sometimes weren’t competent enough simultaneously for all these themes. By using such a method, the EAS could end up being the opinion of an expert that wasn’t competent for the given theme. Thus, by using (2), SAFE compensates the scores of potentially ‘incompetent’ experts by the scores of other experts.

FOR EACH SUSTAINABILITY CRITERION:

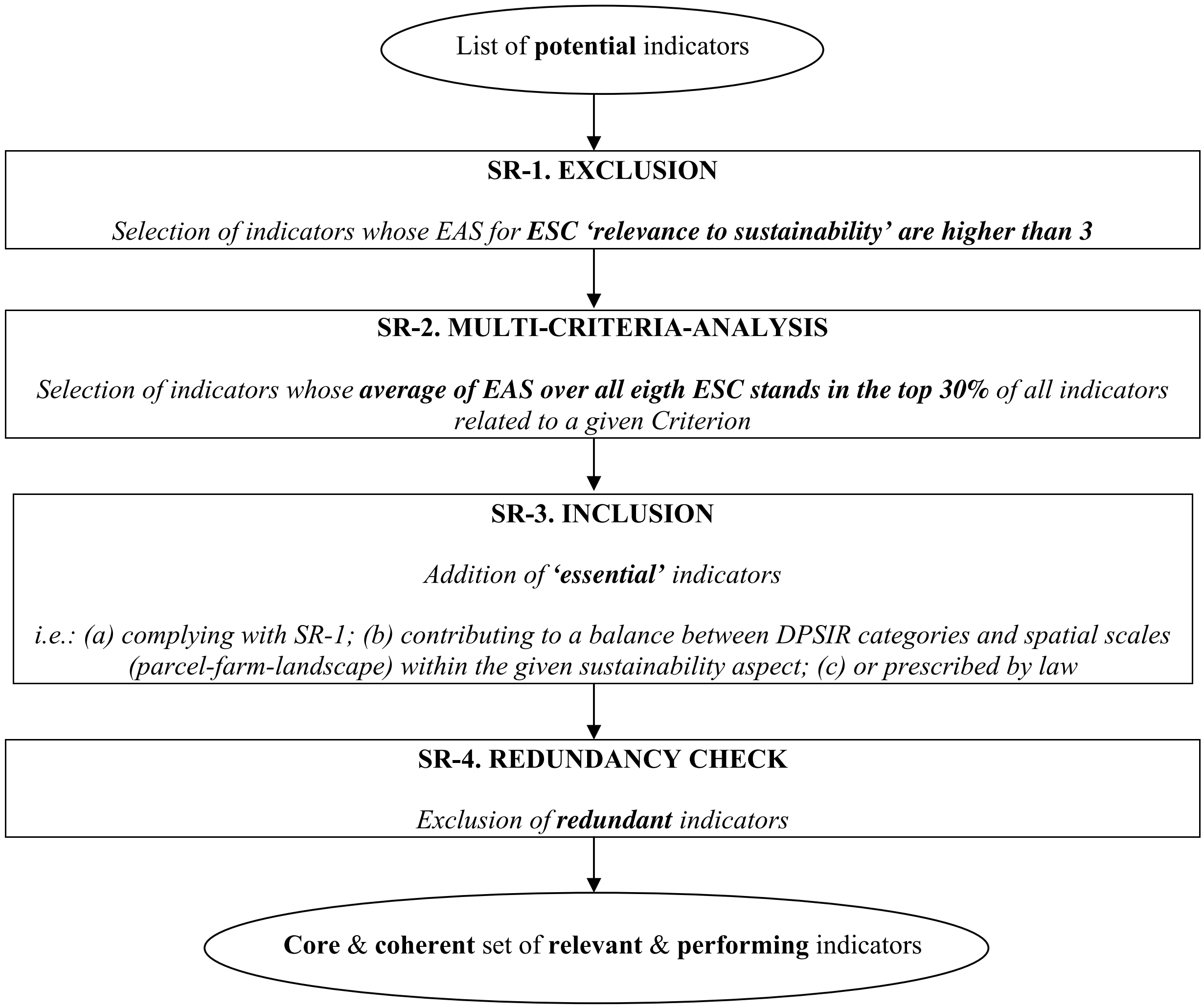


Figure 6. The indicator selection based on four selection rules is the third step of 'SAFE's selection procedure' for agricultural sustainability indicators.

The first two rules aim at narrowing the number of selected indicators to a **core** set of **relevant** and **performing** indicators (with respect to all eight ESC). The last two rules eliminate redundant indicators or can add essential indicators that were not preselected by the experts, providing the selection with some flexibility. An indicator is essential if it (a) complies with SR-1; (b) contributes to a balance between DPSIR categories (OECD's & EEA's Driving Force Pressure State Impact Response models) and spatial scales (parcel-farm-landscape) within the given sustainability aspect; (c) or is prescribed by law. Whereas SR-1 and SR-2 look at the individual qualities of indicators, SR-3 and SR-4 rather consider complementarities or redundancies between indicators and ensure the coherence of the list of selected sustainability indicators.

III.2 Selected indicators

Whereas principles & criteria are universally applicable, the **coherent list of 87 relevant and performing sustainability indicators** selected by SAFE (table 4) is specific to the Belgian agricultural context.

Table 4. Principles, Criteria of the SAFE hierarchical framework and selected sustainability indicators.

PRINCIPLES	CRITERIA	INDICATORS	Description	Unit	Measurement scale	Expression scale	Source
ENVIRONMENTAL PILLAR							
ECOSYSTEM INTEGRITY							
Ecosystem stability regulation function	Resistance and resilience of the ecosystem is maintained/increased	Ratio of net radiation flux and incoming net solar radiation (Rn/K)	Ratio of the net radiation transformed into nonradiative energy at the soil surface and the short wave radiation balance (the higher this ratio, the higher the system's ability to dissipate the radiative gradient, the more integer the ecosystem)	no unit	E	E	Kutsch *et al*., 2001
		Free net primary biomass productivity	The amount of biomass free for the spontaneous development of the ecosystem, to fulfil its life support functions and to support the food web	t ha^{-1}	E	E	Lindeyer, 1998; Blonk & Lindeyer, 1995
AIR							
Supply of quality air function	Air quality is maintained/enhanced	Methane emission (CH_4)	Estimation of methane emitted by the system	t $eqCO_2.ha^{-1}.yr^{-1}$	F	F	Siterem, 2001
		Ammonia emission (NH_3)	Estimation of ammonia emitted by the system	t $eqA.ha^{-1}.yr^{-1}$	F	F	Siterem, 2001
		Nitrous oxide emission (N_2O)	Estimation of nitrous oxide emitted by the system	t $eqCO_2.ha^{-1}.yr^{-1}$	F	F	Siterem, 2001
		Indirect carbon dioxide emissions (CO_2)	Estimation of carbon dioxide emitted during the synthesis of mineral nitrogen fertilizers spread on the farm	t $eqCO_2.ha^{-1}.yr^{-1}$	F	F	SAFE
		Pesticide Risk Score (RS) to air	Risk for presence of pesticide residues in the air compartment	no unit [-10→10]	P	P/F	POCER-2 (Maraite *et al.*, 2005)
Air buffering function	Wind speed is adequately buffered	Land use pattern	Organisation/orientation/proportion of different landuse types in the landscape, landuse being series of activities undertaken to produce one or more goods or services	no unit	Catch.	Catch.	FRAGSTATS (McGarigal and Marks, 1994)
SOIL							
Stock of soil function	Soil loss is minimised	Water erosion risk	Risk for soil loss caused by water as calculated by USLE equation Erosion = R K C LS P. Long term yearly average value.	$t.ha^{-1}.yr^{-1}$	P/C	P/F	OECD, after USLE, modeled by WATEM (Van Oost *et al*., 2000)
		Harvest erosion	Loss of soil occurring during harvest operations ~ Amount of non-agricultural product (leaves, dirt, soil) present at the factory.	t ha^{-1}	C	P-C-F	SAFE; Poesen *et al*., 2001
		Tillage erosion risk	Risk for transport of the soil caused by tillage activities	$t.ha^{-1}.yr^{-1}$	P	P/F	modeled by WATEM (Van Oost *et al*., 1999)
Stock of quality soil function	Soil chemical quality is maintained/increased	Soil organic carbon content	Organic carbon content	%	P	P/F	Doran & Parkin, 1994
		Soil acidiy - pH	pH	no unit	P	P/F	Doran & Parkin, 1994
		Phosphorus P	Phosphorus content	$mg.kg^{-1}$	P	P/F	

		Nitrogen N	Total nitrogen content	mg.kg^{-1}	P	P/F	
		Pesticide residues	Risk for presence of pesticide residues in the liquid phase of soil	no unit [-10→10]	P-F	P/F	POCER-2 (Maraite *et al.*2005)
		Nitrogen Annual Balance	Input of nitrogen from different sources minus output of nitrogen in vegetal and animal production (over one year)	kg N.ha^{-1}.yr^{-1}	P	P/F	OECD
		Phosphorus Annual Balance	Input of phosphorus from different sources minus output of phosphorus in vegetal and animal production (over one year)	kg P.ha^{-1}.yr^{-1}	P	P/F	OECD
		Potassium Annual Balance	Input of potassium from different sources minus output of potassium in vegetal and animal production (over one year)	kg K.ha^{-1}.yr^{-1}	P	P/F	OECD
		Addition of heavy metals	Total amount of heavy metals added to the soil, originating from amendments	mg.kg^{-1}	P	P/F	Arshad and Martin, 2002
	Soil physical quality is maintained/increased	Soil organic carbon input	Input of organic carbon in soil under form of amendments, harvest residues, etc.	kg.ha^{-1}.	P	P/F	SAFE
		Soil carbon balance	Input minus output of carbon in soil	kg.ha^{-1}.	P	P/F	OECD
		Tillage pressure	Cumulated depth of soil work on a parcel, all types of machines included	cm.yr^{-1}	P	P-F	SAFE
		Compaction risk	Risk for compaction of soil (= decreasing porosity or increasing dry bulk density (BD) as a result of firm-pack soil particles ([McKyes, 1985]) due to pressure provoked by tillage activities	no unit	C	P/F	SAFE
WATER							
Supply of water function	Adequate amount of surface water is supplied	Surface water balance	Input minus output of surface water under different forms in a specified area	m³.ha^{-1}.	Catch	Catch	after ECNC, modelled by SWAT (Arnold & Allen, 1993)
	Adequate amount of soil moisture is supplied	Irrigation practices	Practices of artificial application of water to lands for agricultural purposes (expressed as % of irrigated land of total arable land)	%	C	F	OECD
		Drought stress	Stress to plant growth related to the cumulative effects of either an absolute or an abnormal transpiration deficit caused by a prolonged absence or marked deficiency of precipitation	number.yr^{-1}	P	P-F	after ECNC; modelled by WAVE (Vereecken *et al.*, 1991)
	Adequate amount of ground water is supplied	Groundwater level	Elevation, at a certain location and time, of the water table or piezometric surface of an aquifer	m	P	P-F	ECNC (p77), (methods for soil analysis p547)
		Water consumption	Amount of water consumed during agricultural activities on farm	m³. yr^{-1}	F	F	OECD
Supply of quality water function	Surface water of adequate quality is supplied	Pesticide runoff risk	Risk for transport of pesticides to small ponds and rivers by the part of precipitation that appears as streamflow	kg.ha^{-1}.yr^{-1}	P	P-F-L	SAFE (recommended but not developed by OECD); modelled by SWAT (Arnold & Allen, 1993)
		Presence of grass strips/riparian areas	Presence of strips planted with grass adjacent to fields or of riparian areas whicare lands directly adjacent to rivers and streams. Both can potentially buffer streams from the impacts of agriculture	m². ha^{-1}	F-L	F-L	VLM, DGRNE

	Soil water of adequate quality is supplied	Pesticide residues	Risk for presence of pesticide residues in the liquid phase of soil	no unit [-10→10]	P-F	P-F	POCER-2 (Maraite *et al.*2005)
	Groundwater of adequate quality is supplied	Vegetation cover during nitrate leaching period	Percentage of days that soil is 'covered' by vegetation during the particular nitrate leaching period (15-09 → 15-01) (covered = between sowing and harvest)	% (of days)	P	P-F	SAFE
		Good agricultural practices	Percentage of positive answers in a questionnaire on good pest management and fertilization practices	% (of positive answers)	F	F	SAFE
		Soil link rate - 2 (SL-2)	Ratio between the nitrogen that is spread on the farm and the nitrogen that can be used by the plants, importations and exportations contracts included	no unit	F	F	Gouvernement wallon, 2002
		Potentially Leachable Nitrogen - PLN	Nitrate content in the soil profile in November	$kg\ N\text{-}NO^-_3.ha^{-1}$	P	P-F	Ministère de l'Aménagement du Territoire, de l'Urbanisme et de l'Environnement, 2004.
		Nitrogen Systemic Balance (cropping plan scale) - NSB_{cp}	$NSB_{cropping\ plan}$ = (N Input) – (N Output) = N losses (denitrifiction, volatilisation, leaching & runoff) + Δ Humus.	$kg\ N.ha^{-1}.yr^{-1}$	CP	CP	Ministère de l'Aménagement du Territoire, de l'Urbanisme et de l'Environnement, 2004.
Water buffering function	Flooding and run-off regulation function of the agro-ecosystem shall be maintained/enhanced	Runoff risk	Risk for transport of soil from agricultural fields to small ponds and rivers by the part of precipitation that appears as streamflow	$kg.ha^{-1}.yr^{-1}$	P-F-L	P-F-L	SWAT (Arnold & Allen, 1993)
		Soil cover index	Index indicating the extent of soil cover by vegetation	no unit	P	P-F-L	Revised Universal Soil Loss equation (RUSLE) (Renard *et al,* 2003).
		Vegetation cover	Percentage of soil cover by vegetation (in contrast to nude soil parts)	%	P	P-F-L	SAFE
		Presence of grass strips/riparian areas	Presence of strips planted with grass adjacent to fields or of riparian areas whicare lands directly adjacent to rivers and streams. Both can potentially buffer streams from the impacts of agriculture	$m^2.\ ha^{-1}$	F-L	F-L	VLM, DGRNE
ENERGY							
Supply of energy function	Adequate amount of energy is supplied	Direct energy output	Energy output produced by means of recycling (e.g. methanisation), windmills, capture of solar energy… or contained in energetic crops (under contract) and exported out of the farm, per ha of AA	$GJ.ha^{-1}$	F	F-R	SAFE
Energy flow buffering function	Energy flow is adequately buffered	Direct energy input	Energy input used for the production of agricultural products (until it is sold or leaves the farm or is used as fodder for livestock) that can be directly converted into energy units (diesel-fuel, electricity and lubricants), per ha	$GJ.ha^{-1}$	F	F	Dalgaard *et al*., 2001.
		Renewable direct energy input	Direct energy input of a farm that is renewable	$GJ.ha^{-1}$	F	F	SAFE and Dalgaard *et al*., 2001.
		Energy balance	((Direct & indirect energy output - (Direct & indirect energy input)	$GJ.ha^{-1}$	F	F	SAFE and Dalgaard *et al*., 2001.

BIODIVERSITY							
A. Biotic Resources							
Stock of biotic resources function	Planned biodiversity is maintained/increased	Number of crop species	Number of crop species cultivated on the AA (culture and interculture)	n°	F	F-R	SAFE
		Number of threatened and rare crop varieties	Number of threatened and rare crop varieties cultivated on the AA (culture and interculture)	n°	F	F-R	PAEXA, 2000. (based on Agri-Environmental Measures of the Walloon Region)
		Number of livestock species	Number of livestock species raised by the system	n°	F	F-R	SAFE
		Number of threatened and rare livestock breeds	Number of threatened and rare livestock breeds raised by the system	n°	F	F-R	SAFE (based on Agri-Environmental Measures of the Walloon Region)
	Functional part of natural/spontaneous biodiversity is maintained/increased	Total number of wild plant species in permanent grassland	Total number of wild plant species occurring in permanent grassland (inventory)	n°	P	P-F	SAFE
		Soil biological activity	Soil microbial community composition	n°	P	P	SAFE
		Earthworm species saturation	The proportion of earthworm species present in the farmer's parcels in relation with the potential earthworm species pool of agro-ecosystems	%	P	P-F	SAFE; Hermy & Cornelis, 2000
	Heritage part of natural/spontanous biodiversity is maintained/increased	Butterfly species saturation	The proportion of butterfly species present in relation with a regional butterfly species pool potentially occurring in the agro-ecosystem.	%	T	F/L	SAFE; Hermy & Cornelis, 2000
		Number of protected and Red List butterfly species	The number of present butterfly species protected by supranational, national or regional legislations or mentioned in the Red List.	n°	T	F/L	SAFE
		Breeding bird species saturation	The proportion of present breeding bird species in relation with a regional breeding bird species pool potentially occurring in the agro-ecosystem.	%	T	F/L	SAFE; Hermy & Cornelis, 2000
		Number of protected and Red List bird species	The number of the present bird species (winter visitors/residents and breeding birds) protected by supranational, national or regional legislations or mentioned in the Red List.	n°	T	F/L	SAFE
		Number of European Bird Directive species	The number of present bird species (winter visitors/residents and breeding birds) mentioned in the European Bird Directive.	n°	T	F/L	SAFE
		Wild flora species saturation	The proportion of present wild flora species in relation with a regional wild flora species pool potentially occurring in the agro-ecosystem.	%	P	P/F/L	SAFE; Hermy & Cornelis, 2000
		Number of protected and Red List wild flora species	The number of present wild flora species protected by supranational, national or regional legislation or mentioned in the Red List	n°	P	P/F/L	SAFE
		Total number of wild plant species in permanent grassland	Total number of wild plant species occurring in permanent grassland (inventory)	n°	P	P-F	SAFE
		Pesticide Risk Score to biodiversity (POCER-2 RS)	Equal weights average of pesticide Risk Scores (RS) to five biodiversity compartments: birds, bees, beneficials and water organisms.	no unit [-10→10]	P	P-F	POCER-2 (Maraite *et al.*, 2005)
		Fertilizer pressure on Natura 2000 grasslands	Amount of N and P (min/org) spread by ha, on Natura 2000 grasslands	U N, P.ha^{-1}	P	P-F	SAFE
		Proportion of high biological value meadows in permanent grassland	Surface proportion of high biological value meadows that are cut late after a specified date (Mesures agri-environnementales", RW).	%	F	F	SAFE

		Existence of special devices for wild fauna	Number of significant types of devices for wild fauna (e.g.: nesting boxes, nests, corn heads...) on the farm and on the farmland.	n°	F	F	SAFE
B. Habitats							
Stock of habitat function	Diversity of habitats is maintained/increased	Habitat saturation	The proportion of habitats that is present in a landscape surrounding the farm in relation with a list of habitats that can potentially be found in agro-ecosystems	%	F/L	F / L	SAFE; Hermy & Cornelis, 2000
		Agricultural area under management contract	The area of agricultural land for which the farmer has entered into a management contract (e.g meadow birds, parcel margins, small landscape elements, botanical management)	ha	P	F/L	SAFE; Hermy & Cornelis, 2000
		Agricultural area managed for wild biota without management contract	The area of agricultural land that is ecologically managed by the farmer but for which he has not entered into a management contract	ha	P	F/L	SAFE
		Agricultural area under organic farming contract	The area of agricultural land for which the farmer has entered into a contract of organic farming	ha	P	F/L	SAFE
Stock of qualitative habitat function	Functional quality of habitats is maintained/increased	Density of Linear Landscape Elements	The total length of linear landscape elements within a landscape surrounding the farm	$m.ha^{-1}$	F / L	F/L	SAFE
		Connectivity index (γ-index) of LLE network	The connectedness of the nodes and segments in percent of the linear landscape elements network.	no unit	F / L	F/L	SAFE
ECONOMIC PILLAR							
VIABILITY							
Economic function	Farm income is ensured	Family farm income/ family work units/year	This value is revenues minus costs (own labour costs excluded)	$€.VAK^{-1}.yr^{-1}$	F	F	EU
	Dependency on direct and indirect subsidies is minimised	% of real net farm income from all subsidies	This indicator gives the part of the real net farm income coming from all subsidies	%	F	F	EU
	Dependency on external finance is optimal	Solvency = own capital/total capital	This indicator gives the part of the total capital that is owned by the farmer	%	F	F	SAFE
	Agricultural activities are economically efficient	Total output from total input (total factor productivity)	This value is the euro obtained from the production process per euro, from any source, introduced into the system	% (€)	F	F	EU
		Value added/work units = labor productivity	/	$€.unit^{-1}$	F	F	T & C, MAFF
	Agricultural activities are technically efficient	Total output from total input	This indicator is the number of J obtained from the production process per J, from any source, introduced into the system.	% (J)	F	F	EC, MAFF
	Market activities are optimal	Diversity of agricultural income sources, production as well as non-production	Gives the number of agricultural income sources, production (e.g milk, sugar beet) as well as non-production (e.g. agritourism, contract work), NOT non-agricultural income sources	n°	F	F	T & C
	Farmer’s professional training is optimal	Years of professional experience	Gives the number the farmer has professional experience with the farming business. It does not hold into account the years the farmer was helping his parents on the farm.	years	F	F	SAFE
	Inter-generational continuation of farming activity is ensured	Existence of a new generation willing to take over the exploitation	Expresses if the farmer knows there is someone who is willing to take over the farm.	Scale (yes, ?, no)	F	F	SAFE

	Land tenure arrangements are optimal	/	/	/	/	/	/
	Adaptability of the farm is sufficient	Index of farm adaptability	State whether farm has unsolvable problems for: meeting institutional restrictions (Laws, regulations, standards…); and/or for effective land supply; and/or for effective labor/service supply; and/or for effective manager supply; and/or for effective funding of activities; and/or for effective input supply; and/or for effective know-how & innovation supply; and/or for effective output marketing	no unit (0 or 1)	F	F	SAFE
SOCIAL PILLAR							
FOOD SECURITY & SAFETY							
Production function of the agro-ecosystem	Production capacity is compatible with society’s demand for food	Consumption/production	Gives for the major agricultural products the ratio of amount of consumption over the amount of production, in one country.	%	L	Land	Land
	Diversity of food and raw materials is maintained/increased	diversity of main food types	Diversity of main food types exported of the farm (by 'main' are excluded all on-site transformed food products and all secondary production (straw, greens...) / by 'food' is meant food potentially eaten by humans	n°	F	F	Land
	Quality of food and raw materials is maintained/increased	/	/	/	/	/	/
	Adequate amount of agricultural land is maintained	/	/	/	/	/	/
QUALITY OF LIFE							
Physical well-being of the farming community function	Labour conditions are optimal	Hours per year for farm labour	Gives the hours per year for farm labour by the farmer and his family.	hours	F	F	SAFE
	Health of the farming community is acceptable	Days of working incapacity	Gives the number of days in year the farmer is incapable to work	days. yr^{-1}	F	F	SAFE
Psychological well-being of the farming community function	Education of farmers and farm workers is optimal	Extra courses	Expresses if the farmer does extra courses.	binary (yes, no)	F	F	SAFE
	Family situation, including equality in the man-woman relation is acceptable	Equality man-women status	On the basis of the respective role of the man and the woman in farming activities (type and amount of work) and extra-agricultural professional activities (type and amount of work), expresses the man/woman equality ratio	binary (yes, no)	F	F	SAFE
	Family access to and use of social infrastructures and services is acceptable	Distance to administration services	Trivial	km	F	F	SAFE
	Family integration in the local and agricultural society is acceptable	Membership to non-agricultural organisations	Trivial	binary (yes, no)	F	F	SAFE
	Farmer’s feeling of independence is satisfactory	Farmer' s feeling of independence of subsidies	Expresses how independent (on a scale from 1 to 5) the farmer feels towards subsidies	scale 1-5	F	F	SAFE
		Farmer' s feeling of independence of contracts	Expresses how independent (on a scale from 1 to 5) the farmer feels towards contracts	scale 1-5	F	F	SAFE
SOCIAL ACCEPTABILITY							

Well-being of the society function	Amenities are maintained/increased	Amenities	/	/	/	/	/
	Pollution levels are reduced	Noise effect	Shows if the farmer holds noise to the environment and neighbours into account, and acts upon this.	Binary (yes/no)	F	F	/
	Production methods are acceptable	Livestock welfare	Expresses the livestock welfare level by integrating 3 factors: 1) freedom to move: animals are not attached 2) access to an outside surface and are possibility to graze when the physiological state, climatic and ground conditions allow it 3) stables surface	scale [0, 1, 2 → 3]	F	F	SAFE
	Quality and taste of food is maintained or increased	/	/	/	/	/	SAFE
	Equity is maintained/increased	Ratio income received by the highest earning 20% and the lowest earning 20%	Trivial	%	R	R	/
	Stakeholder involvement is maintained/increased	Open houses	Expresses if the farmer does open houses	Binary (yes, no)	F	F	EC
CULTURAL ACCEPTABILITY							
Information function	Educational and scientific value features are maintained/increased	Open houses	Expresses if the farmer does open houses	Binary (yes, no)	F	F	SAFE
	Cultural and spiritual heritage value features are maintained/increased	/	/	/	/		

Legend. E = ecosystem / P = parcel / F = farm / L = landscapte / R = region / T = transect / W = watershed / C = crop / Catch = catchment / CP = cropping plan (all fields)

III.3 Discussion

A flexible scientific process

In many existing indicator sets for sustainable agriculture, indicators are often selected either arbitrarily or on the basis of 'expert judgements', in which case little is said about the method itself (Pacini *et al.*, 2002; Lòpez-Ridaura *et al.*, 2002; Peeters & Van Bol, 2000; Bockstaller *et al.*, 1997; Häni *et al*., 2002, …). In SAFE, the indicator selection procedure is considered as **a crucial step of the operative cycle**: it defines the backbone of the tool, i.e. the 'list of indicators for measuring sustainability'. Consequently, SAFE's selection procedure is built on a **stronger scientific basis** (Cf. section IV).

However, this does not mean that the process of selecting indicators must rely blindly on pure mathematical analysis of expert judgements. Selecting indicators also requires **flexibility** and this, for two main reasons:

- Redundancies between selected indicators and/or important issues that might not be covered by these cannot be identified by purely mathematical data processing.

- Experts are playing increasing roles in the practice of strategic environmental assessment (SEA) (Noble, 2004). Thus, the value of an SEA decision rests considerably on the quality of experts' judgments. However, there is little guidance to SEA practitioners on ensuring the quality of experts' panel judgments[6]. Furthermore, limitations of expert judgment in impact assessment are largely due to the way in which judgments are analysed and applied in SEA decision processes (Kontic, 2000). In SAFE, the possibility that, in some rare cases, expert's judgments might not be of sufficient quality was not ignored.

These two elements are taken into account in SAFE's selection procedure, mainly through 'SR 3 & 4'('Inclusion step' & 'Redundancy check'), but also in the choice of the manner for synthesizing experts opinions concerning a given indicator (equal weights arithmetic average). However, one must keep in mind that the score of an indicator reflects as much the indicator itself as the calculation procedure proposed by the SAFE team. In many cases, a given indicator can be estimated using widely different calculation procedures. For instance, soil loss could be estimated by field measurements or modeling. In addition, models with with various degrees of complexity are available for this. In SAFE, a single calculation procedure was proposed for each indicator based on the literature review and its own expertise. The identification of the best possible calculation procedure for a given indicator remains an object for future research.

SAFE: a generative tool

The selection procedure has retained a list of 97 indicators in total covering many different fields in environmental, social and economical sciences. However, depending on the goal pursued by the user, it should be highlighted that this list is not immutable:

- On the basis of the scores given by experts, it can be restricted in order to allow the routine application of the SAFE tool.

- The user can also focus on a specific aspect of sustainability and decide to use only part of the tool (a specific pillar, …). This can also be achieved by assigning unequal weights to different indicators in order to emphasise politically more sensitive indicators, for instance.

- New potential indicators - related to new issues or using new verifiers, … - may and should constantly be added in the framework, in order to progressively update the system.

[6] A consistency analysis of expert judgments for soil & water indicators can be found in annex XII.

- SAFE is also a generative tool for the assessment of agricultural sustainability in the sense that it can be applied at three different spatial scales: the parcel, the farm or even the administrative region.

Selection results

Comments

As a result of SR 1 ('exclusion step' – indicators with an EAS[7] 'relevance to sustainability issue equal or lower than three are excluded of the framework), **some Criteria of the economic and social pillar are currently not represented by any indicators**: 'Land tenure arrangements are optimal', 'Adequate amount of agricultural land is maintained', 'Quality of food and raw materials is increased', 'Cultural and spiritual heritage value features are maintained/increased', 'Quality taste and of food increases'. Two reasons explain this situation:

- The issue expressed by the Criterion itself was simply not considered as 'relevant to sustainability' by experts on average. However, this does not mean that, in the future or in another geographical context, the same Criterion might not become relevant. Since the 'P, C & I' analytical framework developed by SAFE has the ambition of being universally applicable, these Criteria are not ejected from the framework.

- Potential indicators were not found to be relevant enough by experts for representing these Criteria. In this case, new potential indicators added in the future could solve this problem (SAFE update).

- The proposed calculation procedure for the indicators was not judged adequate by the experts.

Air

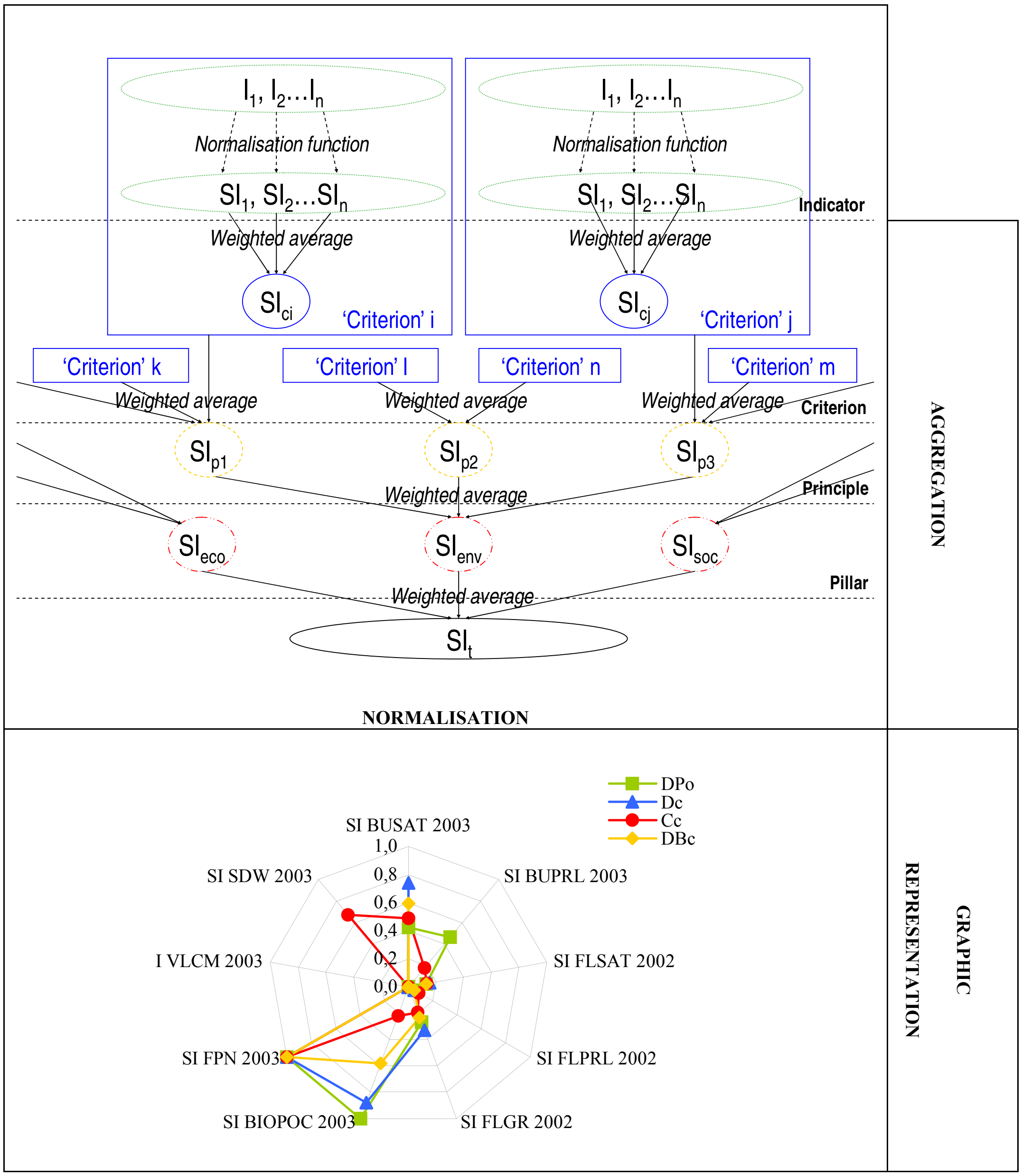
In Criterion 'Air quality is maintained/enhanced', the indicator 'Carbon dioxide emission' was not selected by SAFE. Indeed, it is commonly accepted that agriculture is not a main source of CO_2, in comparison with other sectors such as industry, transport, residencies and energy transformation (Cellule de l'Etat de l'Environnement Wallon, 2004). However, it is not the type of emissions that should matter but rather the total amount of $eqCO_2$ emitted by the farm. In this sense, an integrated indicator of CH_4, N_20 and CO_2 emissions expressed in $eqCO_2$ could replace the two indicators 'CH_4 and N_20 emissions'. Furthermore, the role of agriculture as a CO_2 sink has to be taken into consideration, in order to include the possibility of participating to the Kyoto protocol by reducing emissions *and* increasing the ability to capture CO_2. In conclusion, the ideal indicator for direct greenhouse gases emissions would most likely tend to be: **'GHG direct net emissions' [$eqCO_2$/ha]**.

Only indirect emissions of CO_2 caused by the manufacturing of synthetic N fertilizers are taken into account in SAFE. Nitrogen production is known to be a very energy consuming process (McLaughlin *et al.*, 2000). However, an indicator that would consider more indirect sources of carbon dioxide emissions could also be considered (fertilizers, biocides, lime, concentrated food, …). The inclusion of such input-related issues is important because it reflects the impact that the farmer's choices of external inputs may have on sustainability.

[7] EAS = expert agreed score (Cf. IV.1.3.1).

IV INTEGRATION OF SELECTED INDICATORS

In this section, a method for progressively aggregating the selected indicators is proposed. Based on fuzzy models, ***SAFE's integration procedure*** (Figure 7) *formulates a sustainability index at each level of the P, C & I table: Criterion (SI_c), Principle (Si_p), Pillar (SI_P) or overall level (SI_t).*



Legend. I=indicator / SI=sustainability index / Eco=economic / Env=environmental / Soc=social / t=overall / DPo, Dc, Cc and DBc are the abbreviations used for four different farms / The axes of the amoeba represent indicator values relating to a given sustainability aspect ('Criterion').

Figure 7. SAFE's integration procedure: normalisation, aggregation & graphic representation.

IV.1 Why integrate?

The need to integrate agricultural sustainability indicators is directly related to the **need of interpretation**. Indeed, because sets of sustainability indicators are often long (López-Ridaura *et al.*, 2002), including both qualitative and quantitative factors expressed in various units and sometimes dealing with conflicting issues (or ‘trade-offs’ (Cornelissen *et al.*, 2001), such lists can be highly impractical. In the last couple of years, a growing consensus on the necessity to integrate indicators when assessing the sustainability of a system has been reached.

IV.2 SAFE’s integration procedure

Fuzzy set theory (Zadeh, 1965) assumes that the membership of an object (in SAFE, the value taken by an indicator) is not dichotomous: sustainable or not. Rather, it states that the membership of an element evolves gradually: a degree of membership ranging from 0 to 1. Fuzzy models are derived from this theory and have become widely used when dealing with the integration challenge linked to sustainability assessment (Cornelissen *et al*., 2001; Mendoza & Prabhu, 2003; Marks *et al.* 1995; Peterseil *et al.*, 2004). Indeed, Fuzzy methods are **designed for complex** (broad scope, trade-offs, qualitative and quantitative factors expressed in various units) **and ill-defined issues** such as sustainability assessments (Mendoza & Prabhu, 2003).

SAFE’s integration procedure is based more specifically on fuzzy models applying fuzzy set aggregation operations (Cornelissen *et al.*, 2001) and consists in **three main steps** (Figure 7).

IV.2.1 Step 1 - Normalisation: $I_k \rightarrow SI_k$ [0…1]

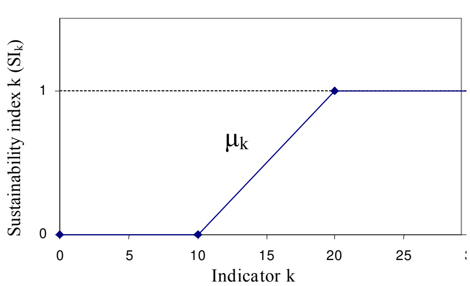
IV.2.1.1 Purpose

Before being aggregated, indicators should ideally be expressed in **commensurate units**: fuzzy logic offers a flexible mean for normalizing all types of information.

IV.2.1.2 Mechanism

Normalisation functions

With respect to a specific sustainability aspect (i.e. ‘Criterion’), a **normalisation function** μ_k is built for each indicator I_k. This function assigns to each possible value taken by I_k a corresponding value of sustainability index ‘SI_k’ ranging from 0 (“unacceptable level of sustainability”) to 1 (“desired level of sustainability”). Figure 8 provides an example of a simple linear normalisation function. Other **more or less complex shapes** can be used in practice.



$$\mu_k \begin{cases} SI_k = 0 & \text{if } I_k \leq a \\ SI_k = 1 - \dfrac{b - I_k}{b - a} & \text{if } b < I_k < a \\ SI_k = 1 & \text{if } I_k \geq b \end{cases}$$

Where a and b (10 and 20 respectively in the graph) are the support points of the normalisation function

Figure 8. Normalisation function μ_k of indicator k.

In SAFE

The construction of a normalisation function requires the definition of a **shape** and of **support points or parameters** ('a' and 'b' in Figure 8). In SAFE, these definitions were decided on the basis of expert judgement. More specifically:

1. A **shape** is defined: a typology of 12 different shapes has beens used in SAFE (table 5).

2. A **reference value** is chosen. To address this issue, SAFE's typology of reference values is used (section III.4.). By decreasing order of preference, reference values can either be:

   Decreasing order of preference

   1. Legislative norm
   2. Scientific norm
   3. Based on observations in the studied farms: median, average…

   For some (environmental) issues, farms can stand well beyond or below a defined reference. As a consequence, if the reference value is adjusted at SI=0 or 1, significant differences between farms would not always be shown by their Sustainability index. For this reason, in SAFE, **reference values are usually set at SI=0.5**.

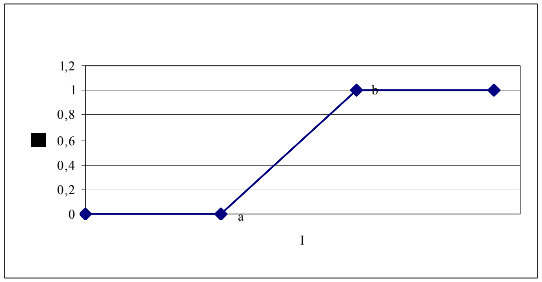
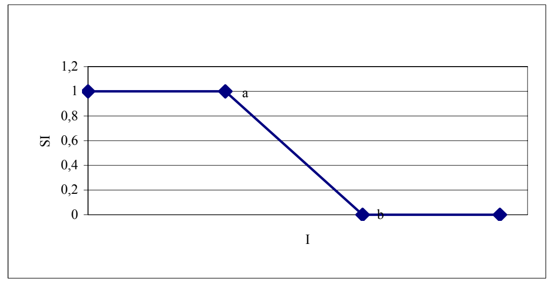
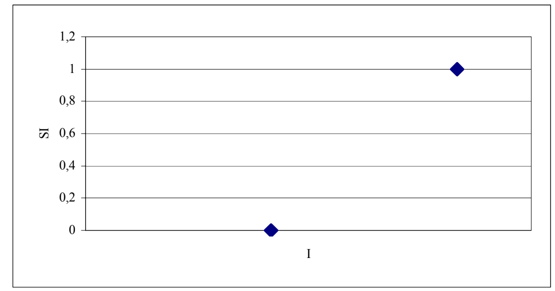
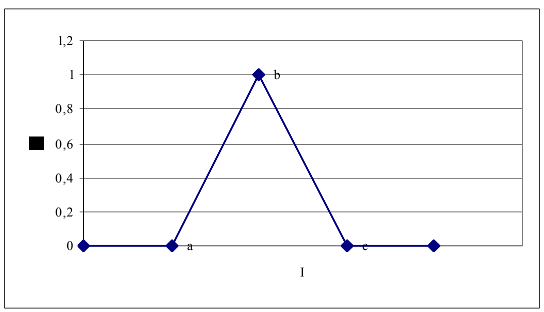
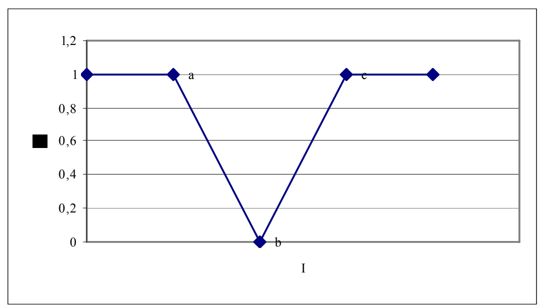
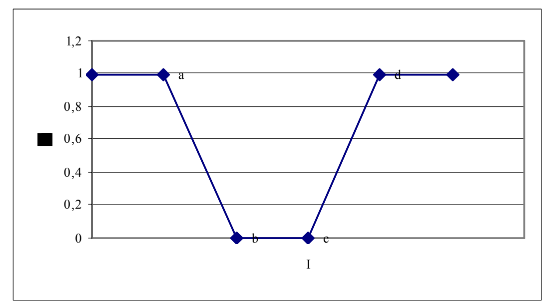
3. **Support points** are derived from the reference value in a specific way for each indicator. For linear functions for instance, the reference value is used as the first support point (SI = 0.5) while the second support point depends on the basis of the variation domain of the given indicator (SI = 0 or 1).

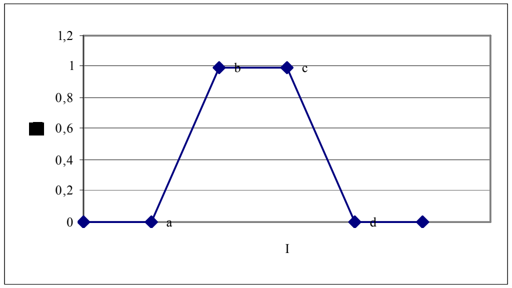
The **normalisation function of each indicator** can be found in annex XIII**.**

Perspectives

Generating normalisation functions is at the core of Fuzzy models. Consequently, in the future, their construction should deserve special attention and rely on **existing techniques** often based on experts' knowledge (Cornelissen *et al.*, 2003; Mendoza & Prabhu*,* 2003).

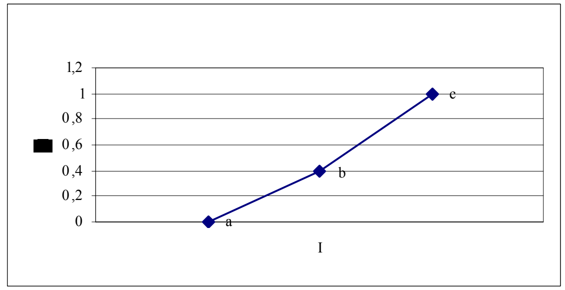
Table 5. Normalisation functions typology.

		
Shape "Linear ascending"	**Shape** "Linear descending"	**Shape** "binary"
Support a b / /	**Support** a b / /	**Support** a b / /
		
Shape "Peak"	**Shape** "Pit"	**Shape** "Valley"
Support a b c /	**Support** a b c /	**Support** a b c d



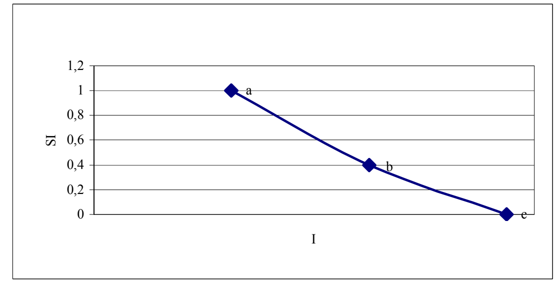
Shape "Plateau"

Support a b c d



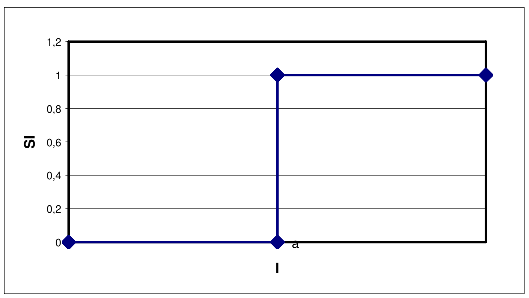
Shape "Broken line ascending"

Support a b c /



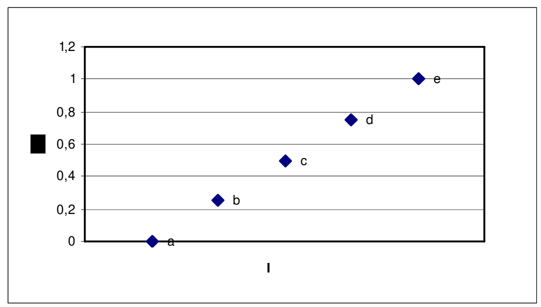
Shape "Broken line descending"

Support a b c /



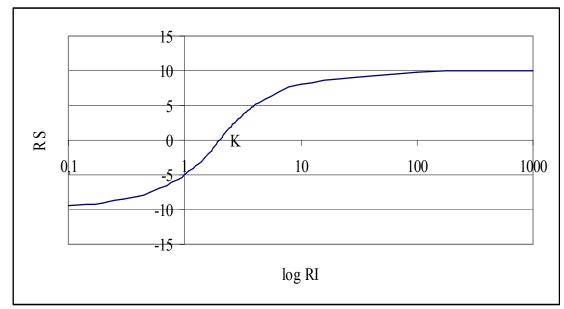
Shape "Stepwise"

Support a / / /



Shape "Discrete"

Support a b c /



Shape "POCER-2" (Maraite *et al.*, 2005)

Support K Max / /

+ Normalisation of RS [-10;10] in SI [0;1]

IV.2.2 Step 2 - Aggregation

In step 1, with the help of normalisation functions, indicator values have been translated in SI values [0→1], that now have to be combined together with the help of an **aggregation operation**.

The choice of this operation is crucial because it expresses an attitude toward sustainable development: conservative (minimum operators), liberal (maximum operators) or a compromise between the two (averaging) (Cornelissen, 2001). In contrast with other aggregation operations (such as minimum or maximum operators), averaging normalisation functions allows to compensate between various economic, social and environmental issues (Silvert, 1997). Moreover, the use of weighting is an opportunity that should be taken into consideration because environmental impacts are most likely of different significance (Silvert, 1997).

⇨ SAFE **progressively** aggregates indicators in an 'overall sustainability index' (SI_t) using **weighted averages**.

- Aggregation of indicators within a given Criterion c

$$SI_c = \sum_{k=1}^{n} w_k SI_k$$

Where w_k is the relative importance of indicator k within Criterion c; SI_k is the SI value taken by indicator k [0→1] and SI_c is the sustainability index value of Criterion c [0 → 1]

Criterion

- Aggregation of Criteria under a given Principle p

$$SI_p = \sum_{c=1}^{m} w_c SI_c$$

Where w_c is the relative importance of Criterion c within Principle p; SI_c is the SI value taken by Criterion c [0→1] and SI_p is the SI value for Principle p [0 → 1]

Principle

- Aggregation of Principles under a given pillar

$$SI_{env,soc,eco} = \sum_{p=1}^{q} w_p SI_p$$

Where w_p is the relative importance of Principle p within a given pillar; SI_p is the SI value taken by Principle p [0→1] and $SI_{env,\ soc,\ eco}$ is the SI value for the environmental, economic or social pillar [0 → 1]

Pillar

- Overall aggregation

$$SI_t = \sum_{P=1}^{3} w_P SI_P$$

Where w_P is the relative importance of Pillar P within the 3 Pillars of sustainability; SI_P is the SI value taken by Pillar P [0→1] and SI_t is the 'overall sustainability index' [0 → 1]

Overall

Who should weight and how?

The **relative importance** of indicators within a given Criterion (W_k) was not assessed in the framework of this project. However, this point should receive special attention in future research. In the case-study presented later in this report, equal weights are used, but only to provide an example of the SAFE technique.

The **relative importance** of Criteria within a Principle (w_c), of Principles within a Pillar (w_p) and of Pillars within overall sustainability (w_P) is an issue that is **not of the scientific domain**. It is the responsibility of the end user (*e.g.* policy makers) to determine these weights, preferably after stakeholder consult.

Missing data

Wherever an indicator value is missing in a farm, the integration shall proceed as if this indicator had been calculated. This means that if, for instance, a farm has only three indicator values instead of four as in the other farms, the aggregation within the Criterion will simply be performed through an ‘equal weights arithmetic average’ based on three data in the first farm and four in the others[8].

IV.2.3 Graphic representation

AMOEBAs (Brink Ten *et al.*, 1991) are extensions of radar plots that allow to show results of multi-objective indicator scoring simultaneously. In SAFE, such graphs are used to aid in the visualization of results at each level of the hierarchical framework: from the most detailed level (the indicators within a given Criterion)(Figure 7) until the most overall level (the three sustainability Pillars).

IV.3 Discussion

Integration does not mean loss of information

The need to integrate agricultural sustainability indicators is directly related to the **need of interpretation**. One common critic is that ‘integration’ goes together with ‘condensation of the information’ whereas, for many, sustainability is a multifaceted concept that cannot be synthesised in a single definition (Panell & Glenn, 2000).

However, condensing the information does not mean losing information. It should be clearly understood that the integration of indicators is **a net advantage:** since indicators are a prerequisite to integration, the most detailed level of information stays always available. In other words, it is always possible to start analysing the top of the pyramid (condensed information) and then go progressively to the bottom of it where needed (more detailed information) (Figure 9).

Depending on the end user, the choice of the aggregation level can change. Policy makers and the general public will most likely prefer to look at fully aggregated data (e.g. the ‘ESI framework’ that provides a sustainability index for a country) (Collective, 2005) while scientists will probably focus on the original disaggregated information. In between, farm managers will ask for detailed data in relation with reference values set by policy, thus intermediary-condensed data (Pacini *et al.*, 2002). In this sense, the aggregation process also provides SAFE with **polyvalency.**

[8] This is discussed farther in the report (section VIII: ‘Discussion’) .

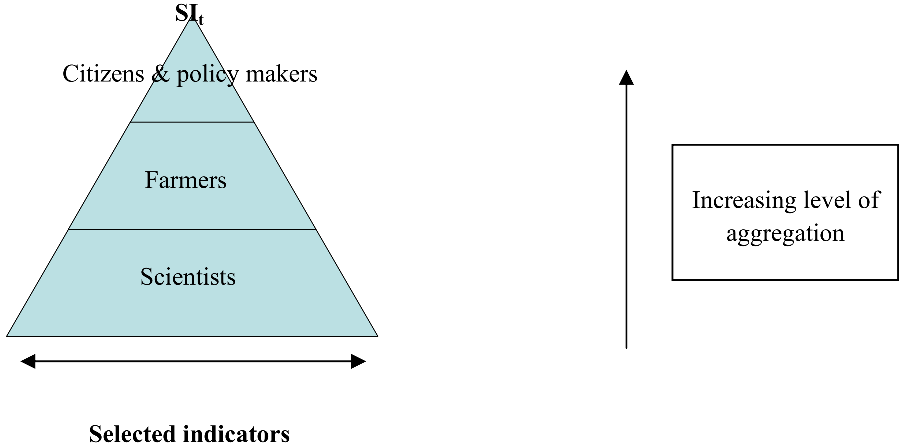


Figure 9. The desired level of aggregation may depend on the end user type (inspired from Braat, 1991).

Advantages and disadvantages of fuzzy modelling

Fuzzy methods are purposely designed for **complex** (broad scope, trade-offs, involving both qualitative and quantitative factors moreover expressed in incommensurate units) and **ill-defined** problems such as sustainability assessments (Mendoza & Prabhu, 2003). Indeed, sustainable development is a concept that has no well-defined meaning, no precise boundaries (Sun *et al.*, 1994). This type of uncertainty is being referred as fuzzy uncertainty in mathematical terms (Cornelissen *et al.*, 2001) and Fuzzy models enables to cope with this type of uncertainty. Indeed, they allow intermediate assessment between strictly sustainable and strictly unsustainable by describing the *degree* to which an event occurs rather that whether it occurs or not[9]. The advantages and disadvantages of using Fuzzy modelling in this specific field are listed in table 6.

Table 6. Advantages (+) and disadvantages (-) of using fuzzy modelling for assessing sustainability levels.

+	*Assessment in terms of degrees of sustainability [0 → 1] rather than in dichotomous terms (sustainable / not sustainable)* - This is a great advantage considering the fact that: (1) precise estimates of sustainability are unlikely to happen (Mendoza & Prabhu, 2003) (2) sustainability does not have sharp boundaries (Cornelissen *et al.*, 2001; Mendoza & Prabhu, 2003)
+	*Fuzzy logic offers a solution to the scaling problem* - It deals with the obstacle of quantitative variables expressed in different types of units (Marks *et al.*, 1995)
+	The choice of a specific aggregation operator (min, max or linear combination) and the weighting of indicators has some policy implications (Silvert, 1997; Cornelissen *et al.*, 2001)
+	Fuzzy modelling translates expert judgements about sustainability through the elicitation of normalisation functions (Mendoza & Prabhu, 2003)

-	*The construction of normalisation functions deserves special care* - it should rely on existing techniques often based on experts' knowledge and consultation between scientists, policy makers and stakeholders (Cornelissen *et al.*, 2002; Mendoza & Prabhu, 2003).

Remark: SAFE's integration procedure uses fuzzy models to overcome scaling problems due to quantitative variables expressed in various units. To cope with qualitative data (often described in linguistic terms), SAFE simply converts these to a numerical interval scale ranging from 0 to 1 (e.g. Indicator 'farm adaptability': adaptable/not adaptable → 1/0).

[9] In contrast to probabilistic uncertainty that relates to events that have a well-defined, unambiguous meaning and that assess whether an event will occur or not (Kosko, 1992)

Missing data

There are two reasons why an indicator could be missing in one or several test sites:

1. An indicator might not always be relevant for all farms (e.g. animal welfare on a farm with no animals)

   In this case, the indicator should simply be left out of the integration process for all farms where it is not relevant and included wherever relevant.

2. Data needed for the calculation of an indicator was not collected in some farms

   ⇨ In this case, a clear bias is introduced in the integration process. Thus, the most rigorous approach would be not to include missing indicators in the integration process and this, for all farms. However, these kinds of 'event' are not rare and some Criteria of the P C & I framework are only represented by a single indicator (especially for socio-economic Criteria). As a consequence, the problem of missing indicators within a given Criterion, if treated with the above and most rigorous manner, would further generate problems of missing Criteria within a given Principle or even missing Principles within a given Criteria (in the case a Principle is only represented by a single Criterion).

⇨ For this reason, it was decided in SAFE to treat the problem of missing data the same way in case 1 and 2: **missing indicators are left out of the integration process**. When an indicator is missing in a farm because of reason 2, it shall be mentioned next to the $SI_{\text{Criterion, Principle, Pillar, global}}$ of the farm the ratio of indicators that were used to produce the index (e.g. $SI_{\text{Principle a}}$, farm x: 9/10).

V CASE-STUDIES

*In order to facilitate the development of SAFE and allow its testing, **four farms** were selected and monitored during two years: 2002 & 2003. Collected data are used as input for the calculation of selected indicators. In this chapter, the four test sites are first briefly described. An introduction follows on how data monitoring was performed on the test sites (details in annex VII). Finally, results of the sustainability assessment in the four farms are presented and commented.*

Important

This sample of farms is certainly not representative of Belgian agriculture (both in terms of number and characteristics). Therefore, results in these farms cannot be used for comparing different management types.

V.1 Description of test sites

Four farms were selected on the basis of the following criteria:

- *Geographic position* - farms had to be located in different regions of Belgium
- *Alternative factor(s)* - use of alternative or innovative agricultural practices
- *Willingness to cooperate and enthusiasm* of the farmer for the project
- *Representativeness* of the farms with respect to their respective agricultural regions

The characteristics of the four farms selected for the SAFE project are summarised in table 7. Aerial views of the farms are available in annex I.

Legend (table 7)

1. DP_O = Dairy-poultry-organic; D_C = Dairy conventional; DB_C = Dairy beef conventional; C_C = Crop conventional.
2. A.E.M. = agri-environmental measure
3. F.C.M. = Fat Corrected Milk (36.58 g/l)
4. B.B.B. = Belgian Blue Breed
5. P = potato; W = wheat; T = triticale; Wt = witloof; Ps = *Poa pratensis* L. seeds (Meadow/Kentucky bluegrass); S = spelt; FB = fodder beet; SB = sugar beet; G = grassland; F = flax
6. LU = Livestock Unit / ch. = chicken
7. TF = Type of farming (Official classification of the F.A.D.N. (Farm Accountancy Data Network) of the European commission
8. AA = agricultural area

Table 7. Test sites description.

Symbol	***TF***	***Location***	***AA (ha)***	***Land use (ha)***			***Main activities***			***Stocking rate on grassland (LU/ha)***		***Alternative factor***
					2002	***2003***		***2002***	***2003***	***2002***	***2003***	
DP_O	*Mixed livestock: granivores & dairying (721)*	*Fauvillers (Ardenne)*	*64*	***Crop***	*P & S: 5.5 Partly marketed*	*P & S: 8.5 Partly marketed*	***Milk***	*Holstein 84 LU 252336 L FCM*	*Holstein 69 LU 289261 L FCM*	*1,4*	*1,2*	*Organic farming & A.E.M. – (1) management of 800 m of hays (2) management of 2 pools (3) low stocking rate on grassland (0.4-1.6 LU/ha)*
				Grassland	*58.6*	*55.6*	***Chicken***	*19933 ch./yr*	*19065 ch./yr*			
					2002	***2003***		***2002***	***2003***	***2002***	***2003***	
D_c	*Specialist dairying: milk (411)*	*Wijchmaal (Limburgse kempen, Zandstreek)*	*51*	***Crop***	*FB & T: 3.8 No export*	*T: 8.5 No export*	***Milk***	*Holstein 106.1 LU 565805 L FCM*	*Holstein 100.9 LU 576251 L FCM*	*4,2*	*4*	*‘Management agreement’ (1) grassland with fertilizer limited input, late mowing date, pool management… - 2,37 ha*
				Maize	*22*	*22*						
				Grassland	*25*	*26*						
DB_c	*Specialist*	*Ternat*	*82.11*		***2002***	***2003***		***2002***	***2003***	***2002***	***2003***	

	dairying: milk and cattle rearing (412)	(Leemstreek)		**Crop**	SB & W: 6.8 No export	SB & W: 6.8 Partly marketed	**Milk**	Holstein 106 LU 398385 L FCM	Holstein 106 LU 410000 L FCM	4.3	4.3	A.E.M. (1) 'Soil cover during interculture' - 27.13 ha (2) 'Mechanical weeding' - 24.52 ha
				Grassland	44	44						
				Maize	28.5	24.7	**Beef**	B.B.B. 40 LU	B.B.B. 40 LU			
C_C	General field cropping: various field crops combined (1443)	Sart Messire Guillaume (Région limoneuse)	109	**Crop**	***2002*** SB: 34.2 W: 33.7 G: 3 Ps: 9.2 Wt: 16 Fx: 8 Export only	***2003*** SB: 32.2 W: 34.6 G: 3 Ps: 9.2 Wt: 14.6 Fx: 10 Export only		***Cash crops***		/		No tillage & A.E.M. (1) 'Soil cover during interculture' - 39 ha

Legend. Cf page 38.

V.2 Data collection

V.2.1 Parcel selection

For reasons of time, energy and money costs, **some data were only monitored on selected parcels** of the test sites (e.g. nitrate residues or floristic surveys): 32 fields distributed between the four sites (cf. annex II). Their selection was based both on soil and crop types:

- *Maize and grassland* were chosen as the most important crop types in all farms. For the crop farm, the latter were not cultivated and the selection was based on land use history.

- Fields with an acceptable *homogeneity of soil types* were selected because they made fieldwork easier.

For indicators requiring data that was only collected on selected parcels, the calculation of the **indicator at farm scale** is almost always based on a weighted average of indicators at parcel scale (the weights being based on area proportions). Averaging of data is a common way to proceed for up scaling problems with environmental indicators (Stein *et al.*, 2001).

V.2.2 Data monitoring in test sites

V.2.2.1 Farm management

A **logbook** was kept by all four farmers during the year 2002 and 2003. Yearly information on livestock and crop management for each parcel of the farm was reported in it (cf. annex III):

Crop

- Land use history
- Sowing data (dates, species, kg/ha, …)
- Pesticide and fertiliser use (N-P-K$_{org/min}$: type, composition, U/ha, …)
- Soil operations (machine type, number of passages and depth of work)
- Irrigation practices (date, type, amount of water applied)
- Harvesting data (dates, machine type, yield and destination, …)

Livestock

- Livestock inventory
- Livestock production means (Gross fodder, concentrated food, other)
- Livestock production (Milk, butter, meat, …)
- Pasture calendar

A **questionnaire on 'good agricultural practices'** (GAP) (fertilisation & pest management) was given to each farmer when visiting the farms and was filled with a team member (cf. annex IVa).

V.2.2.2 Environmental Pillar

Air & energy

No monitoring of air and energy was planned in this project. Indicators related to these aspects were calculated on the basis of data collected in the logbook.

Ecosystem integrity

No monitoring for ecosystem integrity was initially planned in this project.

Soil & water

In general, monitoring of soil and water was performed through both **field work** and **analysis of geographical and meteorological information**. Since monitoring of all fields would be practically impossible, experimental plots were selected on which detailed monitoring by field work was performed (cf. section VI.2.1). A complete description of the monitored data (description, frequency, relation to indicators, ...) at the experimental plots is given in annex VII.

Soil moisture was monitored on a 3-4 weeks basis at different depths. Soil moisture data allow validating leaching and hydrological models later. Together with soil moisture monitoring, data on vegetation cover were collected by digital photography. A detailed soil physico-chemical analysis on soil samples was done during spring 2003. In November 2003, analysis of nitrate residues in soil profiles for selected parcels was performed (NPL - cf. annex IV). Complete soil analysis results can be found in annex XII. Furthermore, infiltration measurements were done during the summer 2003 to evaluate crusting and water holding capacity of the soil.

Extra monitoring data on soil and water are meteorological and geographical information such as topographical, soil and hydrographical network maps. A digital terrain model was derived from 1:10.000 height lines to use as an input in erosion models.

Biodiversity

For practical reasons, field data were only collected for a subset of the initially proposed indicator taxa**: earthworms** (functional biodiversity)**, butterflies** (heritage biodiversity) **and vascular flora** (functional & heritage biodiversity) (no data collected for birds, carabid beetles, and spiders).

Earthworm sampling was carried out in October-November 2002 in the selected parcels of each site using an ethophysical sampling method (annex VII). Species were determined and weighted in laboratory.

Butterflies were surveyed by the census transect method (annex VII). From May-June until August 2003, all transects were walked 3 times when meteorological conditions were appropriate (sunny, warm and little windy weather).

Vascular flora data were collected by vegetation surveys (method described in annex VII) during which both occurrence and coverage of plant species were recorded in parcels and in parcel margins. Most of the fields were surveyed during the period June-July 2002. In August 2002, additional parcels were investigated while other parcels were surveyed a second time. A total of 91 parcels and 570 margins were analysed over the four sites.

Apart from the indicator taxa, **landscape characteristics were also assessed partly by field monitoring and partly in a GIS environment**. Digital 'landscape structure maps' were developed on the basis of all available digital maps containing useful information (e.g. topographic, orthophoto & land use maps, …). For an area within a defined GIS perimeter, ground thruthing was carried out in the four monitored sites in spring 2003. Based on these observations, landscape maps were updated. In the growing season of 2003, structural (e.g. length, width, height) and biotic (presence of woody species) parameters were collected in all woody point and linear landscape elements.

V.2.2.3 Economic Pillar

For the monitoring of the economic data, two approaches have been taken. First, financial data were collected from the accountancy data. The reports of all farms were obtained during three subsequent years (2001, 2002 and 2003). Second, a questionnaire was designed containing all economic and social indicators that could not be deduced from the accountancy report. The questionnaire was filled out following face-to-face interviews with the farm managers, first in 2002 and for a second time in 2003. The questionnaire can be found in annex IV.

V.2.2.4 Social Pillar

See economic pillar.

V.2.3 Data management

The project-website is linked to an **FTP-server.** This makes it possible for the project partners to transfer and store collected data. All general data, as maps, information about the farms, and field information is stored on the FTP-server and can be accessed by all project partners.

An **ACCESS database** in which all data of the different project partners are stored in a structured way was developed and continually updated. Except for farm and field management data which are treated in excel, general data on e.g. soil characteristics, fertilisers, pesticides and machines are stored in this database. Data management for indicator calculation is also possible in Access. The database is linked to a GIS (ArcView 3.2) for visualisation of the fields and indicator results.

V.3 Calculation methods of selected indicators

*In this section, **calculation methods for selected indicators are only mentioned**. A complete description of these can be found in annex IV. Similar information on potential indicators is listed in annex V.*

V.3.1 Environmental pillar

Air

Gaseous emissions (Greenhouse gases & ammonia) at the farm and region scale can be estimated with the SITEREM method (2001). Estimations are mainly based on livestock size and composition, days spent at grazing by animals, land use and fertilization practices (type and amount). On the basis of this method, an Excel template file has been developed that allows easy and fast estimation of gaseous emissions.

The computer software POCER-2 enables the assessment of pesticide Risk Scores (RS) in 14 different compartments, 'air' included (Maraite *et al.*, 2005). POCER-2's databank has been drastically updated with physico-chemical, toxicological and ecotoxicological characteristics of pesticides. However, data needed for the calculation of a **pesticide Risk Score to air** are still hardly available, making the calculation of this indicator currently impossible.

Energy

The ‘model for fossil energy[10] use’ of Dalgaard (2001) was selected by SAFE to classify **energy inputs** in a farm into two types:

- **Direct energy input** is energy used in production when such an input can be directly converted into energy units (e.g. diesel-fuel, lubricants and electricity, …)

- **Indirect energy input** is energy used for the production of inputs that cannot be converted directly into energy units (e.g. machinery, fertilisers, pesticides, …)

A process analysis (Life Cycle Assessment – LCA) permits to compile all net energy inputs for agricultural production of a system until products are sold, leave the farm or are used as fodder for livestock. This method is mainly based on Dalgaard’s model for fossil energy[11] use itself (2001) and the data it provides (except that the consumption of diesel used on the farm, compiled with data provided by Meiers (1996)). However, it has been completed by: indirect energy input for (1) imported organic effluents (2) seed production (3) concentrated food.

SAFE extrapolates the above direct/indirect classification to **energy outputs**. Similarly, energy output can thus be of two types:

- **Direct energy output** is the energy exported from the farm by the cultivation of energy crops (area-based subsidies), biomethanisation, wind mills or capture of solar energy

- **Indirect energy output** is energy exported from the farm under the form of biomass (energy crops excluded)

The calculation of these indicators is straightforward.

The **energy balance** is the difference between total energy input (direct & indirect) and total energy output (direct & indirect). A **template Excel file** has been developed within the SAFE project that allows an easy and fast calculation of all energy indicators.

Ecosystem integrity

No data for calculating ecosystem integrity indicators were collected. For completeness we give a short description of how indicators should have been calculated if data were at hand in annex IV.

Soil & water

Indicator calculation methods, further referred to as verifiers, are either based on (1) direct terrain observations, interviews or field measurements, or on (2) results of simulation models integrating field observations and more general geographical and meteorological information. The different types of verifiers will be shortly described below. For reasons of comprehension, a short description of the calculation method for each indicator is included in the results section. A complete description of used calculation methods or verifiers can be found in annex IV.

1. As mentioned above, in some cases, **indicators will be calculated from direct terrain observations or interviews**. An example of such an indicator is the “presence of grass strips or

[10] The term ‘energy’ is used here only for reasons of comprehension. In correct scientific terms, it should be replaced by the term ‘exergy’, not commonly used by decision makers and farmers. Exergy is energy that is available to do work.

riparian areas" which indicates risk for erosion or flooding. The "good agricultural practices" (GAP) indicator is derived from interviews with the farmer. Other indicators, such as the ones informing us on soil chemical and physical quality or the nitrogen potentially leachable (NPL - nitrate residue in the soil profile in November-October), will be derived from analysis of soil samples.

2. In the second case, **indicators will be calculated using prediction/simulation models as verifiers**. The selection of these verifiers or prediction/simulation models is strongly *dependent on the scale* at which indicators are defined. At the field scale, models that represent the detail of field management are selected. Model input are field specific parameters and output of the model can be aggregated over the different fields to obtain a farm scale indicator.

   At the landscape scale, it may be not desirable to derive indicators from aggregating field or farm level indicators since at this level relations may exist between different processes that aren't explicit at the field scale. In such cases, different models are needed.

   Evaluation of off-farm impacts requires indicators at the landscape level. Although it could be said that the link with a specific farm management is not clear anymore, indicators at this level are very important since they represent the impact of the land use as a whole and indicate vulnerable zones where policy actions should be taken.

   Since it is our objective to use *integrated evaluation tools* as much of possible, some models were selected to quantify a range of indicators. For the landscape scale the SWAT (Soil and Water Assessment Tool) model is selected to describe and simulate the water flow, erosion and sediment production and fate of N, P and pesticides throughout the landscape or catchment. At field scale WaTEM (Water and Tillage Erosion Model) is used to represent major soil loss processes and for the risk related to use of nutrients and pesticides both the Wave model and POCER are explored.

Biodiversity

Most biodiversity indicators are calculated straightforwardly without modelling or other complex calculations. Some indicators at landscape scale are calculated by analysis in GIS. Full details can be found in annex IV.

V.3.2 Economic pillar

Most of the economic indicators were calculated using the FADN definitions of economic variables. For the indicators for which the data was obtained by means of a questionnaire, no particular calculations methods were needed. The calculation methods of all selected economic indicators can be found in annex IV.

V.3.3 Social pillar

For the social indicators, no particular calculation methods were developed. The results for the selected indicators were obtained were straightforward using the questionnaire. For the indicators *consumption/production* and *ratio of income received by highest earning 20% and lowest earning 20%*, national statistics were used, so calculation was also very straightforward.

A summary of the calculation methods for the selected social indicators can be found in annex IV.

V.4 Results

Indicator results are shown and commented ***for selected indicators, at the farm level and mostly for the year 2003****. In case no data were available for 2003, data from 2002 were used. However, in the case of particularly interesting results at other spatial scales or time trends between 2002 and 2003, they will be mentioned. Full results at parcel and farm levels for both 2002 and 2003 can be found in annex X.*

Important

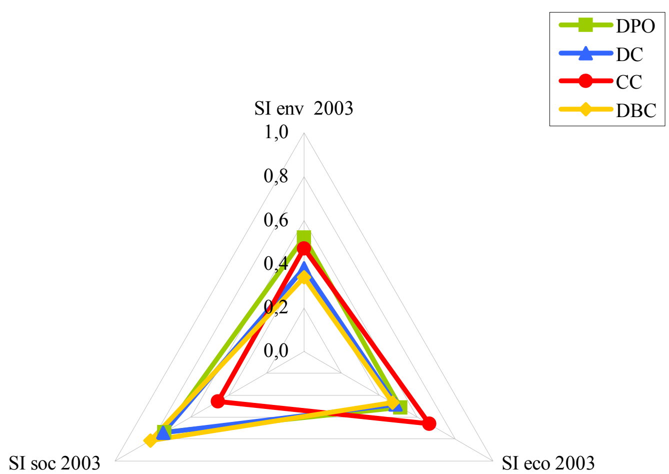
Consulting results of the sustainability assessment should be done just like opening a piece of furniture that would be made of three main drawers (= Pillars), each containing series of intermediate drawers (= related Principles) that would themselves be made of smaller drawers (= related Criteria & Indicators). In that way, the lecture does not have to be linear: at each level of the P, C & I, links to each possible related under-levels are available so that the reader can 'jump' from the global level to a specific Criterion of his interest.

V.4.1 Overall Sustainability Index (SI_t)

Table 8. Overall Sustainability Index (SI_t) (2003).

Farm	Overall Sustainability Index SI_t 2003
DP_O	0.59
D_C	0.54
C_C	0.53
DB_C	0.54

Figure 10. AMOEBA picturing Sustainability Indexes (SI) of the environmental, social and economic pillars (2003).



At the overall level, DP_0 reaches the highest sustainability index among the four test sites - The three other farms – D_c, DB_c & C_c – have similar and slightly less performing overall results.

In each case, the respective contribution of each sustainability Pillar to SI_t varies - Indeed, DP_o mainly owes its high SI_t result to the environmental and social pillars. In C_c, the economic and environmental components play a more significant role in the overall score. Finally, the social pillar seems to contribute the most to DB_c and D_c's final SI_t results. These differences in Sustainability Profiles show that for a farming system, there could be different manners for progressively reaching higher sustainability levels: some could relate to the social, others to environmental aspects, and so on.

Environmental, social and economic sustainability do not seem to be conflicting - DB_c and D_c both integrate high sustainability scores for economic and social issue. C_c and DP_o manage to reach high sustainability scores in the economic and environmental pillars.

If the intrinsic meaning of **SI_t and sustainability indexes in general** is questionable, it must be highlighted that (1) **their analysis should stay comparative**; (2) not be considered as a purpose itself but rather as **a way to identify easily the stronger and weaker points in farms** so as to know how to reach the most efficiently a more sustainable agriculture in the future.

for Environmental Pillar results → see p. 50
for Economic Pillar results → see p. 51
for Social Pillar results → see p. 52

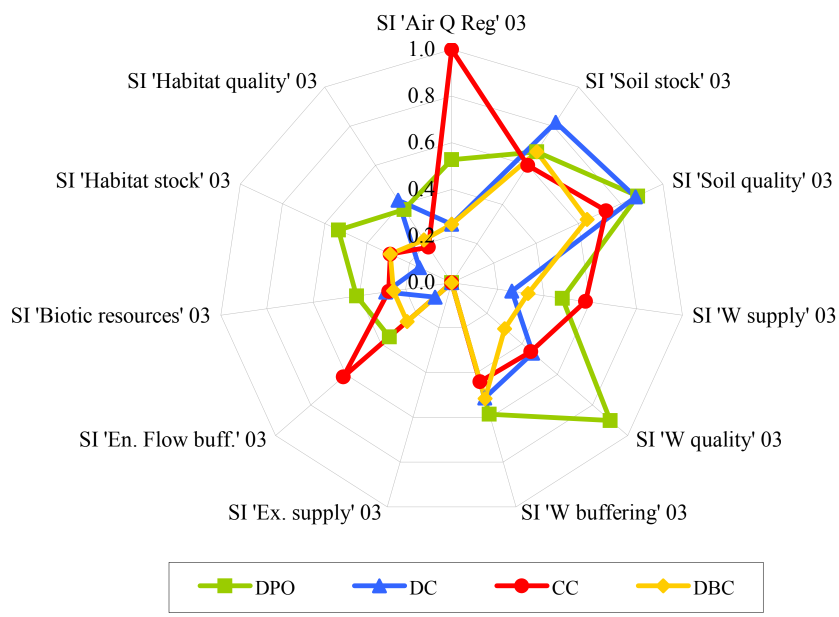
V.4.2 Pillar level

V.4.2.1 Environmental Pillar

Table 9. Sustainability Index for the Environmental Pillar (SI_{env}) (2003).

Farm	SI Environmental Pillar SI_{env} 2003
DP_O	0.52
D_C	0.38
C_C	0.47
DB_C	0.34

Figure 11. AMOEBA for the Environmental Pillar (2003) showing Sustainability Indexes of related Principles.



Environmentally speaking, DP_o performs the best among all four farms. Its environmental performance is not only globally good but also characterised with homogeneity in all the aspects approached (cf. AMOEBA) - The strongest points of DP_o concern 'Biotic resources', 'Habitat stock' & 'Water quality' functions. At first sight, 'Energy Flow buffering' and 'Air quality regulation' functions appear as two aspects where improvement would be possible in the future.

If the global environmental score of C_c is decent, environmental scores fluctuate from one ecological aspect to the other. Indeed, high scores are observed in 'Air quality regulation', 'Energy flow buffering' and 'Water supply' functions; intermediary results are noticed in 'Water quality' and 'Soil regulation' functions whereas lower scores can be identified in 'Habitat quality', 'Habitat stock', and 'Biotic resources' functions.

DB_c and D_c have similar and lower environmental scores than DP_o and C_c - Because the set of test sites used in SAFE is quite unrepresentative of Belgian farms, it cannot be affirmed that these two farms are not environmentally sustainable enough. Possible weaknesses relate to ‘Air quality regulation’, ‘Energy flow buffering’, ‘Biotic resources’ and ‘Water quality’ functions.

In a general manner, ‘Water buffering’ function does not seem to cause much differences between farms.

for details on related environmental Principles → see p. 53

V.4.2.2 Economic Pillar

Table 10. Sustainability Index for the Economic Pillar (SI_{eco}) (2003).

Farm	Economic pillar 2003
	SI 'Economic' 2003
DP_O	0.51
D_C	0.48
C_C	0.66
DB_c	0.47

Figure 12. AMOEBA for the Economic Pillar showing Sustainability Indexes of related Principles (2003).

A single Principle represents the Economic Pillar (‘Economic function’) → No AMOEBA

C_c reaches a significantly higher SI_{eco} than the three other farms - In other terms, it means that the crop farm C_c has a higher economic viability than the three cattle farms DB_c, D_c and DP_o.

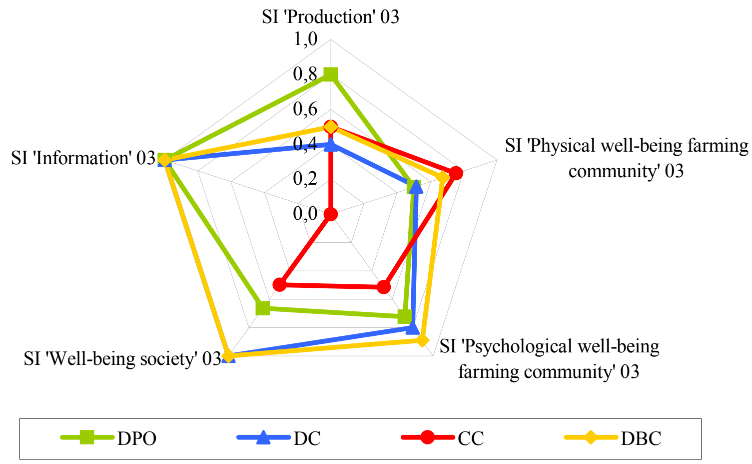
for details on related economic Principle → see p. 57

V.4.2.3 Social Pillar

Table 11. Sustainability Index for the social Pillar (SI_{soc}) (2003).

Farm	Social pillar SI_{soc} 2003
DP_O	0.74
D_C	0.74
C_C	0.45
DB_c	0.81

Figure 13. AMOEBA for the Social Pillar (2003) showing Sustainability Indexes of related Principles.



On a social level, two groups of farms can roughly be identified - On one hand, farms DB_c, D_c and DP_o achieve high social performances; on the other hand, farm C_c reaches a relatively lower social score. This is notably due to a difference of behaviour in C_c with respect to the 'Information' function of the farm.

It must be highlighted here that the social component of agricultural sustainability seems to be the most difficult to evaluate. Because of its inherent subjectivity, of the difficulty to collect useful data (many social data are collected through interviews with the farmer who is free to answer honestly or not to questions) and of the qualitative or even binary character of many social indicators, results in the social pillar must be interpreted with caution. Much improvement of the social pillar is needed for the future.

for details on related social Principles → see p. 61

V.4.3 Principles

Table 12. Sustainability Indexes of Principles (SI_p) and corresponding AMOEBAs picturing Sustainability Indexes of related Criteria (SI_c) (2003).

PRINCIPLES	CRITERIA

ENVIRONMENTAL PILLAR

AIR

Farm	Air quality regulation function SI 'Air Q Reg' 2003
DP_O	0.53
D_C	0.25
C_C	1.00
DB_c	0.25

A single Criterion represents this Principle ('Air quality') → No AMOEBA

→ see related Criteria & Indicators p. 62

Farm	Air buffering function SI 'Air Buff.' 2003
	/

/

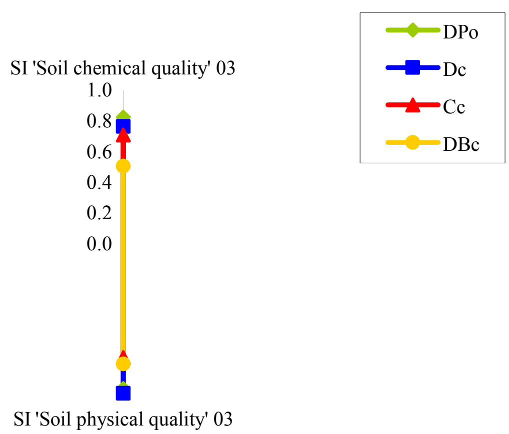
SOIL

Farm	Stock of soil function SI 'S. Stock' 2003
DP_O	0.67
D_C	0.82
C_C	0.60
DB_c	0.67

A single Criterion represents this Principle ('Soil loss is minimized') → No AMOEBA

→ see related Criteria & Indicators p. 68

Farm	Stock of quality soil function SI 'S. Qual.' 2003
DP_O	0.88
D_C	0.87
C_C	0.73
DB_c	0.64

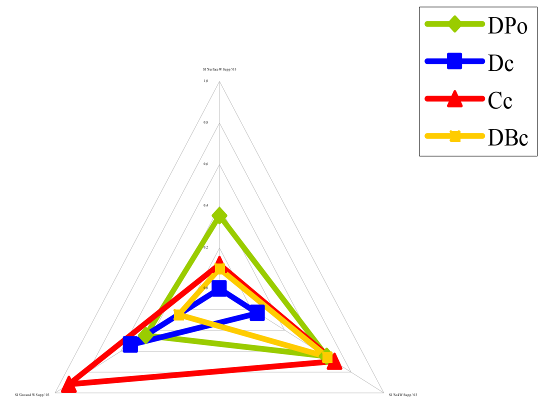


Comment: In the four studied test sites, performances for 'Stock of quality soil' function are globally satisfying. Farm DP_o *and* D_c *perform very well for both Criteria contributing to the Principle, which is reflected in their Sis at Principle level. The lowest score for* DB_c*,is related with its lower score for the Criterion 'Soil chemical quality'.*

→ see related Criteria & Indicators p. 70

WATER

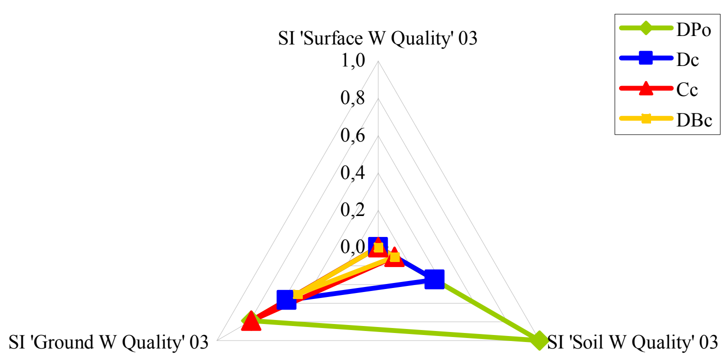
Farm	Water supply function SI 'W. Supp.' 2003
DP_O	0.48
D_C	0.26
C_C	0.58
DB_c	0.33



Comment: Performances for 'Water supply function are quite variable among the four studied farms. The AMOEBA tells that each related Criterion plays an important role in this variability.

→ see related Criteria & Indicators p. 73

Farm	Water quality supply function SI 'W quality supply' 2003
DP_O	0.90
D_C	0.46
C_C	0.45
DB_c	0.30



Comment: Performances for 'Water quality supply' function vary among the four studied farms. The AMOEBA shows that 'Ground water quality' and - in a more significant manner - 'Soil Water quality' play a role in this variability.

→ see related Criteria & Indicators p. 76

Farm	Water buffering function SI 'W bufferinng' 2003
DP_O	0.59
D_C	0.51
C_C	0.44
DB_c	0.52

A single Criterion represents this Principle ('Flooding and runoff regulation is maintained/enhanced') → no AMOEBA

Comment:

→ see related Criteria & Indicators p. 78

ENERGY

Farm	Energy supply function SI 'En. supply' 2003
DB_C	0.00
D_C	0.00
DP_O	0.00
C_C	0.00

A single Criterion represents this Principle ('Adequate amount of energy is supplied') → no AMOEBA

Comment:

→ see related Criteria & Indicators p. 64

Farm	Energy flow buffering function SI 'En. Flow buff.' 2003
DP_O	0.35
D_C	0.09
C_C	0.62
DB_C	0.25

A single Criterion represents this Principle ('Energy flow is adequately buffered') → No AMOEBA

Comment:

→ see related Criteria & Indicators p. 65

ECOSYSTEM INTEGRITY

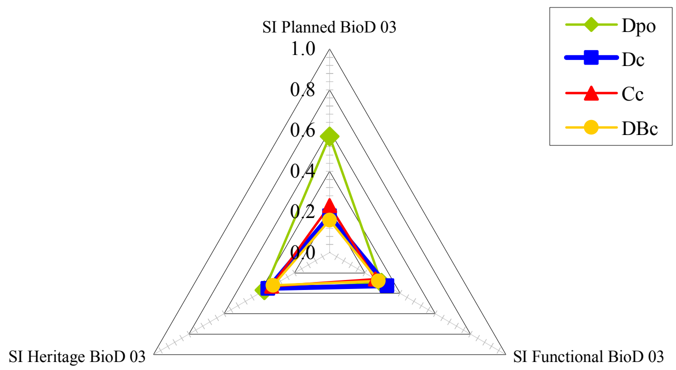
Farm	SI Ecosystem integrity regulation function SI 'Eco. Int. Reg.' 2003
/	

/

BIODIVERSITY

A. Biotic resources

Farm	Stock of biotic resources function SI 'Biotic resources' 2003
DPo	0.41
Dc	0.28
Cc	0.27
DBc	0.25



Comment: It is striking to notice that very few differences exist between farms on the 'Heritage biodiversity' and 'Functional biodiversity' level. Only 'Planned biodiversity' generates variability between test sites.

→ see related Criteria & Indicators p. 80

B. Habitats

Farm	Stock of habitat function SI 'Habitat stock' 2003
DPo	0.54
Dc	0.15
Cc	0.29
DBc	0.29

A single Criterion represents this Principle ('Diversity of habitats is maintained/increased') → No AMOEBA

Comment:

→ see related Criteria & Indicators p. 85

Farm	Stock of qualitative habitat function SI 'Habitat quality' 2003
DPo	0.37
Dc	0.42
Cc	0.18
DBc	0.22

A single Criterion represents this Principle ('Functional quality of habitats is maintained/increased') → No AMOEBA

Comment:

→ see related Criteria & Indicators p. 86

SOCIAL PILLAR

FOOD SECURITY AND SAFETY

Farm	Production function SI 'Prod.' 03
DP_O	0.80
D_C	0.40
C_C	0.50
DB_c	0.50

This Principle declines in 4 Criteria. Two out of these criteria have no selected indicators. The third one, 'Production capacity is compatible with society's demand for food', is represented by a single indicator, expressed at the regional level only.

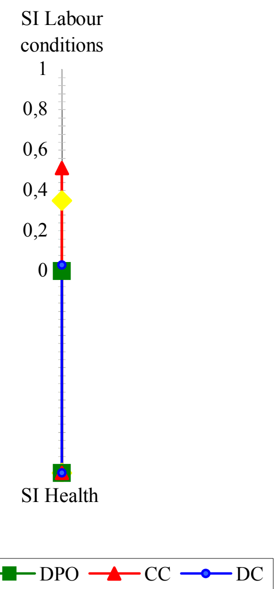
Therefore, this Principle at the farm level is currently being represented by a single Criterion ('Diversity of food and raw materials is increased') → no AMOEBA

Comment: A significant difference is observed between the DP_o farm and the other farms. It is, however, noteworthy to stress that, at the farm level, this principle is represented by only one indicator, 'diversity of main food types', for which the DP_o scores better than the other farms.

→ see related Criteria & Indicators p. 93

QUALITY OF LIFE

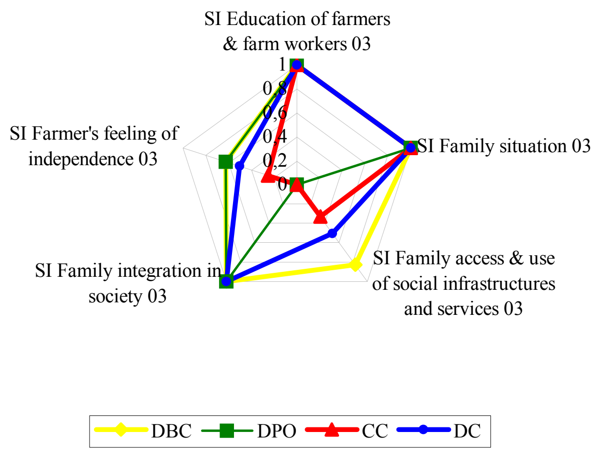
Farm	Physical well-being function of the farming community SI 'Physical W. F.' 03
DP_O	0.50
D_C	0.52
C_C	0.76
DB_c	0.68



Comment: Two groups of farms can be identified here: C_c and DB_c have higher scores for 'Physical well-being of the farming community' function than DP_o and D_c. Looking at the AMOEBA, this difference is only linked to Criterion 'Labor conditions'. Indeed, all four farms have the highest possible results for Criterion 'Health of the farming community'.

→ see related Criteria & Indicators p. 94

Farm	Psychological well-being function 2003
	SI 'PsWFME' 2003
DP_O	0.73
D_C	0.80
C_C	0.52
DB_c	0.89

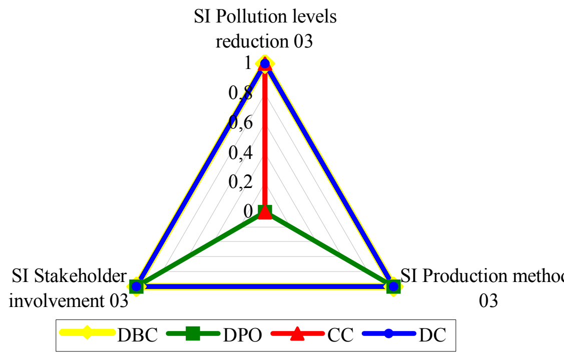


Comment: *A high variability is observed concerning Sustainability Indexes of 'Psychological well-being of the farming community' function:* DB_c *and* D_c *rank first while* DP_o *and more particularly* C_c *show lower performances. Two Criteria do not contribute to this variability: all four farms have maximum scores for 'Education of farmers & farm workers' and 'Family situation, including the equity woman/man statuses. Criterion 'Family integration in farming and local society' accounts for a great part of the low* C_c *score.*

→ see related Criteria & Indicators p. 96

SOCIAL ACCEPTABILITY

Farm	Well-being of the society function 2003 SI 'WSFME' 2003
DP_O	0.67
D_C	1.00
C_C	0.50
DB_c	1.00



Comment: *No data concerning acceptability of production methods were available for the C_c farm, since this was only measured by the indicator livestock welfare, while the C_c farm has only crops ($SI_{production\ methods}$: 2(3) for C_c). Again, farms D_c and DB_c perform the best for this social principle.*

→ see related Criteria & Indicators p. 99

CULTURAL ACCEPTABILITY

Farm	Information function 2003 SI 'IFME' 2003
DP_O	1.0
D_C	1.0
C_C	0.0
DB_c	1.0

This principle has two criteria, of which there is one with no selected indicators. The remaining criterion is 'Educational and scientific value features are maintained/increased'. → no AMOEBA

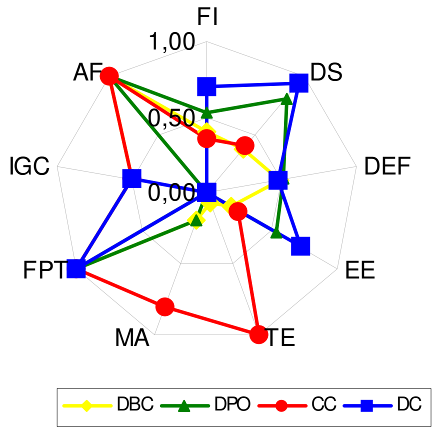
Comment: *This Principle is represented by one selected indicator, open houses. Therefore, the variability in Sustainability Indexes for this Principle is totally explained by the performance for this indicator. The C_c farm does not do open houses, therefore it has value 0; the other farms do open houses, which gives them value 1.*

→ see related Criteria & Indicators p. 101

ECONOMIC PILLAR

VIABILITY

Farm	Economic function
	SI 'EFME' 2003
DP_O	0.51
D_C	0.48
C_C	0.66
DB_c	0.47



<u>Comment</u>: Crop farm C_c is characterised by a global economic performance that is significantly higher than for the three cattle farms. Observing the AMOEBA, it seems that most related Criterion play a role in this result. It is however remarkable to notice that the Cc farm has a better score than the other farms for only two criteria namely 'Agricultural activities are technically efficient' and 'Market activities are optimal', whereas for every other criterion it has a lower or equal score than the other farms. The fact that the difference between the Cc farm and the other farms is, for those two criteria mentioned, very high, results in the best overall score for the viability principle..

→ see related Criteria & Indicators p. 87

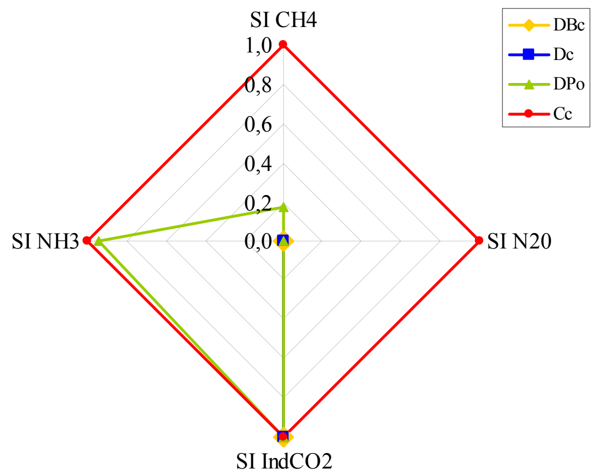
V.4.4 Criteria level

V.4.4.1 Criterion 'Air quality is maintained/enhanced'

Table 13. Sustainability Index (SI) for Criterion 'Air quality is maintained / enhanced' (2003)[12].

Farm	SI AIR QUALITY
	SI Air Q 2003
DP_O	0.53
D_C	0.25
C_C	1.00
DB_C	0.25

Figure 14. AMOEBA for Criterion 'Air quality is maintained / enhanced' (2003) picturing Sustainability Indexes of related indicators.



<u>Comment</u>: The crop farm C_c performs the best ($SI_{air\ quality}$ = 1) among all test sites. DP_O, the organic cattle-poultry farm, comes second with a $SI_{air\ quality}$ = 0.53 in 2003. The $SI_{air\ quality}$ of the other two cattle farms reach 0.25. Such results are mainly explained by very low direct emissions of greenhouse gases and acidifying substances in C_c in comparison with the other cattle farms.

⇨ For greenhouse gases and acidifying substances emissions, the performances of the cattle farms are improvable.

Table 14. Results for selected indicators of Criterion 'Air quality is maintained/enhanced' (2003).

Farm	Methane emissions [t éq CO_2/(ha.yr)]	Nitrogen protoxyde emissions [t éq CO_2/(ha.yr)]	Ammonia emissions [k Aeq/(ha.yr)]	Indirect CO_2 emissions due to synthetic N fertilizer input [t éq CO_2/ha.yr]	Pesticide Risk Score to Air [nb]
	CH_4 2003	N_20 2003	NH_3 2003	Ind CO_2 2003	PRS Air 2003
DP_O	2,98	5,36	1,121	0,00	/
D_C	5,65	8,88	5,096	0,21	/
C_C	0,00	3,92	0,220	0,22	/
DC_C	4,83	6,32	6,177	0,09	/

Legend. *1 t CH_4 = 21 t eqCO_2 / 1 t N_20 = 310 t eqCO_2 / 1 t CO_2 = t eqCO_2 / 1 kg NH_3 = 0,0588 kg Aeq*

[12] The integration procedure does not take into account 'Pesticide Risk Score to air' (Cf. V.I.I) for none of the four farms → "$SI_{air\ quality}$ 4(5)" for DBC, D_C, DP_O and C_C.

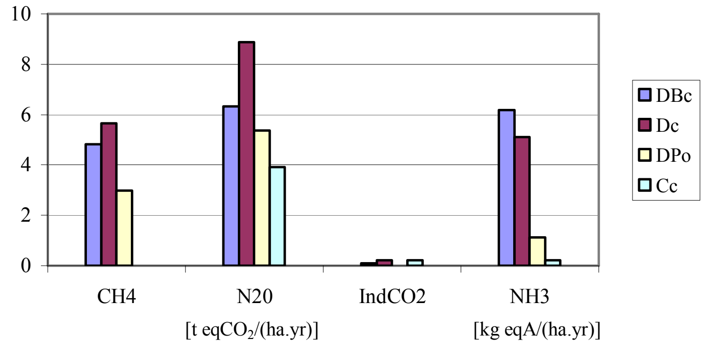


Figure 15. Greenhouse gases & acidifying substances emissions (2003).

Pesticide residues

No Pesticide Risk Score to air was calculated because for most active substances the required air-related toxicological and ecotoxicological characteristics are not yet listed in POCER-2's database.

Greenhouse gases

Emissions of CH_4 are very low in C_C – This farm does not rear cattle whereas the agricultural release of methane in the atmosphere comes mostly from enteric fermentations and animal effluents stocking and spreading.

DP_O is responsible for significantly less CH_4 emissions than the other two dairy farms - This is mainly due to the fact that both D_c and DB_c farms stock animal effluents under the form of slurry. Indeed, slurry has drastically higher CH_4 emission coefficients than manure (SITEREM, 2001).

DP_O does not contribute to indirect CO_2 emission – Indeed, such emissions can directly be related to the use of synthetic nitrogen fertilizers, a type of fertilizer that is not allowed in organic farming.

N_2O emission, mainly due to denitrification and nitrification in the soil, concerns all four farms

Between the three cattle farms (DP_O, D_C, DB_c), the organic farm emits the least N_20 - This is because, even if animal effluents are stocked there under the form of manure (that has higher N_20 emission coefficients at stocking than slurry – the exact opposite than CH_4), emissions from fields due to the application of organic and mineral fertilizers are respectively much lower and inexistent.

Acidifying substances

Emission of NH_3 is very low in C_C – This farm does not raise cattle whereas ammonia emissions are closely linked to the presence of animals (stocking and application conditions mainly (Cellule état de l'environnement wallon, 2004).

DP_O emits the least ammonia among the three cattle farms – This is mainly because DP_O does not stock or spread animal effluents under the form of slurry and because it does not use mineral fertilizers.

V.4.4.2 Criterion 'Wind speed is adequately buffered'

The indicator 'Land use pattern' was selected to represent this Criterion but was not calculated.

V.4.4.3 Criterion 'Adequate amount of energy is produced'

Table 15. Sustainability Index (SI) for Criterion 'Adequate amount of energy is produced'.

Farm	SI ENERGY PRODUCTION
	SI 'EN P' 2003
DP_O	0.00
D_C	0.00
C_C	0.00
DB_C	0.00

Figure 16. AMOEBA for Criterion 'Adequate amount of energy is produced'.

Only one indicator represents this Criterion ('Direct energy output')

→ no AMOEBA

Comment:

⇨ ***In all four studied farms, performances are at the lowest for this aspect of agricultural sustainability***

Table 16. Results for selected indicators of Criterion 'Adequate amount of energy is produced'.

Farm	Direct energy output [GJ/ha]
	D NRJ O 2003
DP_O	0.0
D_C	0.0
C_C	0.0
DB_C	0.0

Direct energy output

None of the farms studied exported energy directly - i.e. through recycling (biomethanisation), capture of solar energy, windmills or energetic crops[13]. Such diversification of agricultural production activities will most likely play an increasing role in the future.

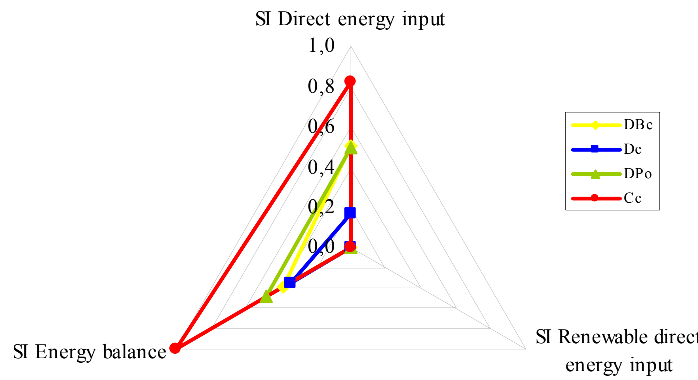
[13] Crops that are declared as 'energetic crops' in the area registration of the corresponding year.

V.4.4.4 Criterion 'Energy flow is adequately buffered'

Table 17. Sustainability Index (SI) for Criterion 'Energy flow is adequately buffered' (2002)[14].

Farm	SI ENERGY FLOW BUFFERING
	SI 'NRJ F B' 2002
DP_O	0.35
D_C	0.09
C_C	0.62
DB_C	0.25

Figure 17. AMOEBA of Criterion 'Energy flow is adequately buffered (2002) picturing Sustainability Indexes of related indicators.



<u>Comment</u>: C_c, the crop farm, performs the best ($SI_{energy\ flow\ buffering}$ = 0.62 in 2002). DP_O comes second with a $SI_{energy\ flow\ buffering}$ = 0.38 in 2003. DB_C and D_C stand respectively third and fourth. These results are almost equally explained by the respective performances of the farms concerning direct energy inputs and energy balances.

Table 18. Results for selected indicators of Criterion 'Energy flow is adequately buffered' (2002 & 2003).

Farm	2002		
	Direct energy input [GJ/ha]	Renewable direct energy input [GJ/ha]	Energy balance [GJ/ha]
	D NRJ I 2002	RD NRJ I 2002	NRJ B 2002
DP_O	10,15	0,00	7,77
D_C	16,83	0,00	-7,25
C_C	3,49	0,00	135,41
DB_C	9,99	0,00	-2,28

Farm	2003		
	Direct energy input [GJ/ha]	Renewable direct energy input [GJ/ha]	Energy balance [GJ/ha]
	D NRJ I 2003	RD NRJ I 2003	NRJ B 2003
DP_O	10,20	0,00	23,35
D_C	/	/	/
C_C	3,74	0,00	160,51
DB_C	9,51	0,00	16,29

Direct energy input

None of the studied farms used renewable direct energy inputs – If farmers here undeniably depend on the energy policy implemented in their respective administrative regions, they can also cover part of the energy needed for their production activities through voluntary installation of windmills, biomethanisation units or solar energy captors. The energy produced can then be either used on the farm site (direct energy input) or

[14] Integration was exceptionally performed with data of 2002 (data for D_C not available in 2003).

exported (direct energy production). Again, this indicator will most likely become more and more important in the future because of growing concerns on sustainable energy management.

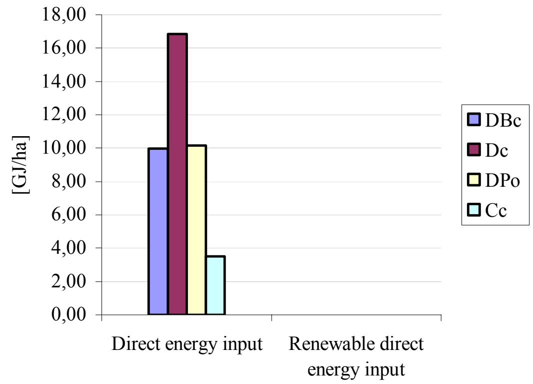


Figure 18. Direct energy input & renewable direct energy input (2002)**.**

Direct energy inputs reach their lowest level in the C_C farm - Indeed, even if operations in fields generate particularly high energy costs in this farm (crops only and high level of mechanization), these are by far exceeded by energy costs due to operations in livestock houses of dairy farms.

Among the three cattle farms, DBC and DP_O have similar direct energy inputs - Two main elements at least must be taken into account here. First, both farms have a close number of dairy LU/ha. That is, energy indicators are expressed by ha and milking cows are responsible for a large part of direct energy costs in stables (light, ventilation, milking, milk cooling, and fodder milling and pumping). Second, whereas DP_O does require extra-energy inputs for poultry, these are moreover covered by direct energy inputs for other cattle than dairy cows in DBC (light, ventilation, fodder milling and pumping). Indeed, DBc raises dairy and meat-type breeds (between 25 and 30% of this cattle is meat cows that are not milked).

D_C is by far the cattle farm that reaches the highest direct energy input levels - Again, this can be explained by two main elements. First, D_c has the highest number of dairy LU/ha: around 1.4 against 0.85 and 0.89 for DBc and DPo respectively in 2002). Second, D_c uses more diesel and lubricants than the two other cattle farms:

- In comparison with DP_O whose AA is mainly composed of grassland (about 59 ha out of 64 ha in 2002), D_c grows maize on a significant part of its AA (about 22 ha out of 51 ha, the rest being mainly grassland in 2002). And maize is a crop with a higher diesel cost per ha than grassland in the two farms considered here. Moreover, the cultural operations scheme on grasslands for D_c is more complex and thus costs more energy.

- Like D_c, DB_c also cultivates maize on a significant area. However, on average, D_c uses more diesel per ha than DB_c for grassland and maize. In both cases, this is due to more complex and energy-costly schemes of cultural operations.

Energy balance

C_c has by far the most positive energy balance[15] - This is because C_c is a pure crop farm that thus export a great amount of vegetal productions (148624 MJ/ha) that largely cover direct and indirect energy inputs of the farm.

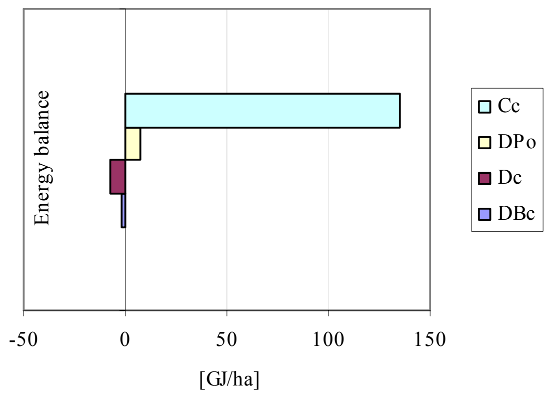


Figure 19. Energy balances (2002).

In 2002, DP_O's energy balance is the only cattle farm whose energy balance is positive – This farm cultivates around 0.5 ha of potatoes and 5 ha of spelt in 2002) that are devoted to cattle and exportation, the latter contributing in a significant manner to indirect energy production (10125 MJ/ha, a third of the total indirect energy production). Moreover, its direct energy input is kept low (cf. direct energy input) while the non-use of pesticides and synthetic fertilizers reduces the indirect energy costs usually generated by their manufacturing.

DB_c only reaches a positive balance in 2003 - This is partly because the farm did not export any of its vegetal production in 2002. In 2003, the farm exported wheat (sugar beets were destroyed because too dirty) and thus reaches a positive balance.

DB_c owns the lowest energy balance of all farms – D_C does not export crop at all (cattle farm only) and has by far the highest direct energy input among all the farms (Cf. energy inputs). Further more, its indirect energy costs are also higher than (1) DB_c that causes less indirect energy costs through the manufacturing of pesticides and synthetic fertilizers, simply because it uses less herbicides thanks to mechanical weeding on its maize (about 15 g a.s./ha of total pesticides against 919 g a.s./ha; respectively 17 UN/ha, 141 UP/ha and 253 UK against 108,07 UN/ha, 218 UP/ha and 223,15 UK/ha, nitrogen synthetic fertilizers being the most energivorous); (2) DP_O that does not use pesticides or synthetic fertilizers at all.

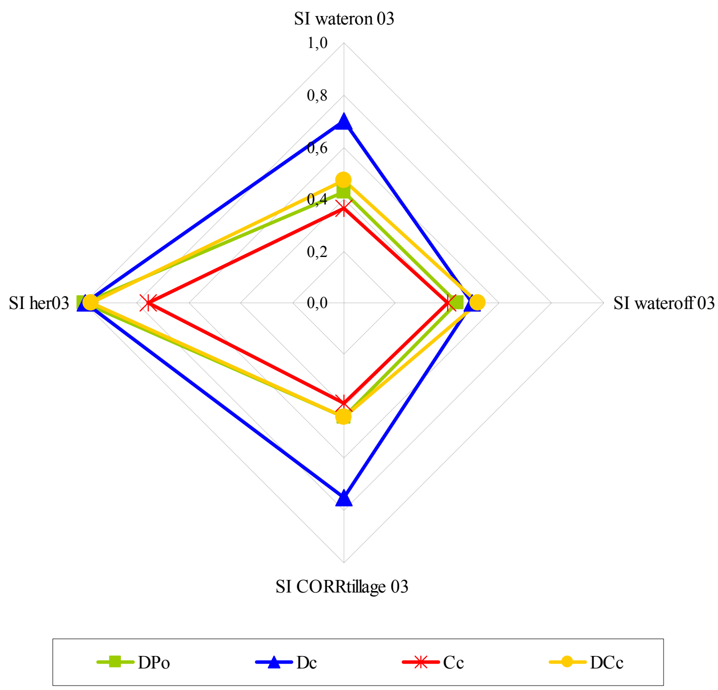
[15] Energy balance = (Indirect + direct energy output) – (Indirect + direct energy input)

V.4.4.5 Criterion 'Soil loss is minimised'

Table 19. Sustainability Indexes (SI) of Criterion 'Soil loss is minimised'.

Farm	SI Soil loss is minimised
	SI SLM 2003
DP_o	0.67
D_c	0.82
C_c	0.60
DB_c	0.67

Figure 20. AMOEBA for Criterion 'Soil loss is minimised' picturing SI of related indicators.



Comment: The AMOEBA shows that D_c, the organic cattle-poultry farm, performs the best among all four farms in 2003 ($SI_{soiloss03}$ = 0.82). DB_c and DP_o come second. The $SI_{soil\ loss}$ of the arable farm C_c (0.6) is the lowest due to strong relief and elevated harvest erosion.

Table 20. Results for selected indicators of Criterion 'Soil loss is minimised'[16].

Farm	Water erosion on site [t/(ha.yr)]	Water erosion off site [t/(ha.yr)]	Tillage erosion on site [t/(ha.yr)]	Corrected tillage erosion on site [t/(ha.yr)]	Harvest erosion 2003 [t/(harv.ha)]
	Wateron	Wateroff	Tillage	CORRtillage	Her 2003
DP_o	4,35	3,62	10,38	3,67	0,000
D_c	0,46	0,41	0,29	0,12	0,538
C_c	8,02	5,63	7,82	6,74	4,725
DB_c	1,68	0,34	10,53	3,62	0,065

[16] Water erosion and tillage erosion indicators are calculated on the basis of a three years rotation (2000 until 2003).

Water erosion

When interpreting the erosion risk indicator, one has to take the following points into account:

- Erosion values for on-site erosion do not consider the global soil translocations that occur on a parcel. Only pixels where erosion occurs are accounted for, deposition is not considered[17]. As a consequence, the heterogeneity of the parcel's geomorphology - which leads to erosion on convexities and deposition in concave areas - is not taken into account.

- In off-site erosion both erosion and deposition are evaluated as being soil translocation processes. When the geomorphology of a parcel is highly variable (combination of convexities and concave areas), large differences may exist between on-site and off-site erosion. Off-site erosion will be less extreme than on-site erosion through neutralization of erosion on convexities by deposition in concave areas. This difference in off- and on-site erosion is higher where geomorphology of the parcels is more extreme. Indeed, farm D_c in the Flemish "Zandstreek" (a flat area) doesn't show a difference between on- and off-site erosions, whereas this difference does exist in the Loambelt (farm C_c - undulating area).

Water erosion is most elevated in farm C_c – This is due to its location (undulating area) and to the fact that it is an arable farm, where almost all parcels are tilled (cf. 'tillage pressure indicator') and have a period of low crop covering, which makes the land more susceptible to erosion.

Water erosion is least present in farm D_c - primarily due to the flat geomorphology of its region.

Tillage erosion

Tillage erosion is calculated with a standard Ks factor which is related to the intensity of soil operations. For grasslands, this standard Ks value leads to an overestimation of the amount of soil which is translocated. Hence, the indicator (tillage) is corrected for those parcels in the farm where lower soil operations intensities exist (CORRtillage). Farm DP_o, where almost all parcels are grasslands, obtains a significantly lower tillage erosion value. This difference is far less important in farm C_c, due to the fact that almost all parcels in the farm are arable - and thus tilled - land.

Harvest erosion

Harvest erosion, or the amount of soil transported during harvesting activities, is most elevated in the arable farm C_c. Differences between 2002 and 2003 are due to higher production of root crops (susceptible to harvest erosion) in 2003 (see annex X for detailed results). The organic grassland farm DP_o has a zero harvest erosion value since the parcels susceptible to harvest erosion are harvested by hand (potatoes).

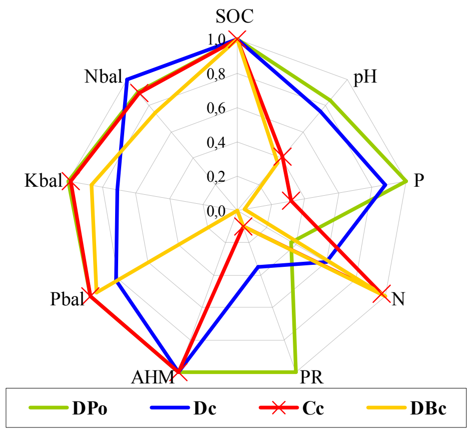
[17] See annex IV for calculation methods.

V.4.4.6 Criterion ‘Soil chemical quality is maintained/enhanced’

Table 21. Sustainability Index (SI) of Criterion ‘Soil chemical quality is maintained/enhanced’

Farm	SOIL CHEMICAL QUALITY
	SCQ 2003
DP_O	0.82
D_C	0.77
C_C	0.71
DB_C	0.51

Figure 21. AMOEBA of Criterion ‘Soil chemical quality is maintained/enhanced’ picturing SI of related indicators.



<u>Comment</u>: The AMOEBA graph clearly shows that DP_c, the organic cattle-poultry farm, performs the best among all four farms in 2003 ($SI_{soil\ chemical\ quality}$ = 0.82). D_c, the milking cows farm, comes second with a $SI_{soil\ chemical\ quality}$ = 0.77. The arable farm C_c has similar results with a $SI_{soil\ chemical\ quality}$ = 0.71. The dairy farm DBc comes last with a $SI_{soil\ chemical\ quality}$ of 0.51.

⇨ In general all farms perform rather satisfactory for this criterion

Table 22. Results for selected indicators of Criterion ‘Soil chemical quality is maintained or enhanced’[18].

Farm	Soil organic carbon content [%]	pH	Phosphorus [mg/kg]	Pesticide residues [index]	Nitrogen [mg/kg]	Addition of heavy metals [mg/kg]	P balance [kg P_2O_5/ha]	K balance [kg K_20/ha]	N balance [kg N/ha]
	2002								
	SOC 2002	pH 2002	P 2002	PR 2002	N 2002	AHM 2002	Pbal 2002	Kbal 2002	Nbal 2002
Score	<u>avg</u>	<u>avg</u>	<u>avg</u>	<u>max</u>	<u>avg</u>	<u>avg</u>	<u>avg</u>	<u>avg</u>	<u>avg</u>
DP_o	6,80	5,01	143,44	-10,00	337,78	0,00	17,17	-4,34	46,66
D_c	5,60	4,91	102,28	3,00	260,44	0,00	143,38	44,78	132,00
C_c	3,73	4,50	65,67	10,00	138,33	0,00	-7,36	-9,68	44,87
DB_c	3,37	4,43	47,17	-6,00	102,67	3,95	-10,49	-41,53	-21,77

[18] Values of soil organic carbon content, pH, phosphorous and nitrogen are the same for 2002 and 2003 since they are both derived from one physico-chemical soil analysis performed early 2003

Farm	2003								
	Soil organic carbon content [%]	pH	Phosphorus [mg/kg]	Pesticide residues [index]	Nitrogen [mg/kg]	Addition of heavy metals [mg/kg]	P balance [kg P_2O_5/ha]	K balance [kg K_20/ha]	N balance [kg N/ha]
Score	avg	avg	avg	max	avg	avg	avg	avg	avg
DP_o	6,80	5,01	143,44	-10,00	337,78	0,00	12,45	-0,04	44,18
D_c	5,60	4,91	102,28	3,00	260,44	0,00	148,63	193,12	0,00
C_c	3,73	4,50	65,67	8,00	138,33	0,00	8,24	15,19	46,91
DB_c	3,37	4,43	47,17	8,00	102,67	1,98	46,57	92,78	105,22

Legend. Up scaling of indicator values from the parcel to the farm level can either be performed with: max = the maximum of all parcel values (Pesticide residues index only) / Avg = weighted average of all parcel values (on basis of area proportions).

Soil organic carbon content, pH, P and N content

It is clearly seen that strong relations exist between SOC content, pH and nutrients for all farms. DP_o has the highest values for soil organic carbon content, pH and most nutrients.

Pesticide residues

The pesticide residue risk indicator is calculated with POCER-2 which translates pesticide risk into a -10 (no risk) to +10 (highest risk) index. The indicator value attributed to the farm is the one of the pesticide application with the highest risk executed on one of its parcels. The organic farm DP_o has no risk at all (~value -10), since no pesticides are used.

Although farm DB_c practices mechanical weeding on most of its fields, high pesticide residues indexes are observed in 2003 - because of the use of Azoxytrobine, a highly persistent pesticide.

Addition of heavy metals

DB_c is the only farm with heavy metals added to the soil – this relates to the use of food industry residues as fertilizer for some of the fields.

P, K, N balances

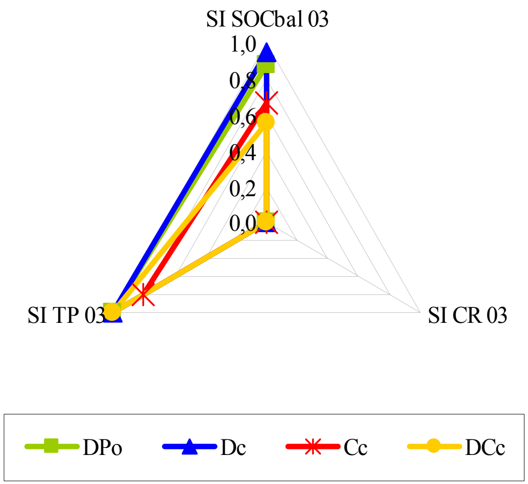
As for the nutrient balances it can be observed that both the organic dairy farm and the arable farm present rather equilibrated results. Large differences exist between 2002 (deficits) and 2003 (high surpluses) for farm DB_c. This argues for an evaluation of these balances on a larger time frame.

V.4.4.7 Criterion 'Soil physical quality is maintained/enhanced'

Table 23. Sustainability index of Criterion 'Soil physical quality is maintained / enhanced'[19].

Farm	SI SOIL PHYSICAL QUALITY
	SPQ 2003
DPo	0.94
Dc	0.97
Cc	0.74
DBc	0.78

Figure 22. AMOEBA of 'Soil physical quality is maintained / enhanced' picturing the Sustainability Indexes (SI) of related indicators.



Comment: The AMOEBA graph clearly shows that D_c and DP_o perform the best among all four farms. DB_c and C_c come second with an averaged $SI_{soil\ physical\ quality}$ of approximately 0.75.

⇨ In general all farms perform very satisfactory for this criterion.

Table 24. Results for selected indicators of Criterion 'Soil physical quality is maintained/enhanced'.

Farm	Organic carbon balance [t/ha]	Compaction risk [Pa/ha]	Tillage pressure [cm]
	SOCbal 2003	CR 2003	TP 2003
DPo	-2,27	/	0,95
Dc	0,94	/	9,82
Cc	-5,43	/	61,83
DBc	-7,15	/	5,51

Legend. / = data not available.

Organic carbon balance

See annex IV on calculation methods for more details on this indicator.

[19] The integration procedure does not take into account 'Compaction risk' for none of the four farms → "$SI_{soil\ physical\ quality}$ 2(3)" for DB_C, D_C, DP_O and C_C.

Compaction risk

Due to a lack of detailed data on soil operations (exact dates, soil moisture content at time of soil operation), the compaction risk indicator was not calculated.

Tillage pressure

The arable farm C_c presents the largest tillage pressure **-** since all of its fields are cropped and hence soil operations are performed.

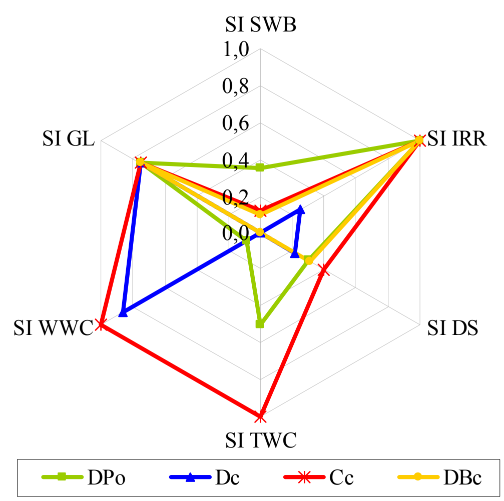
D_c and DB_c presents higher tillage pressure than DP_o – Indeed, the agricultural area of DP_O is almost entirely made of grassland whereas D_c and DB_c grow maize on respectively 50% and 35% of their AA.

V.4.4.8 Water quantity Criteria: 'Adequate amount of (1) surface water (2) soil water and (3) ground water is supplied'

Table 25. Sustainability index (SI) of Criteria 'Adequate amount of (1) surface (2) soil (3) ground water is supplied' (2003)[20].

Farm	Surface water supply	Soil water supply	Ground water supply
	SI 'Surf. W Supp' 2003	SI 'Soil W Supp' 2003	SI 'Ground W Supp' 2003
DPo	0,35	0,65	0,45
Dc	0,00	0,23	0,54
Cc	0,12	0.70	0,92
DBc	0,10	0,66	0,25

Figure 23. AMOEBA of Criteria 'Adequate amount of (1) surface water (2) soil water (3) ground water is supplied' (2003) picturing Sustainability Indexes of related indicators.



Comment: C_c, the crop farm, performs the best ($SI_{air\ quality}$ = 0.71). DP_O, the organic comes second with a $SI_{air\ quality}$= 0.50 in 2003. The $SI_{air\ quality}$ of the other two cattle farms reach 0.35.

⇨ For water quantity, the performances of dairy farms are lower then for arable farms. Moreover, the performances of the farms decrease when farming activities become more intensive.

[20] For Criterion 'Adequate amount of groundwater is supplied', the integration procedure was performed with a standard value of groundwater level indicator SI of 0.75 for DB_C, D_C, DP_O and C_C.

Table 26. Results for indicators of Criteria 'Adequate amount of (1) surface (2) soil (3) ground water is supplied' (2002 & 2003).

Farm	1		2				3		
	Surface water balance [avg mm/day]		Irrigation practices [%]		Drought stress [#days/yr]		Tap Water consumption [m³/yr]	Well Water consumption [m³/yr]	Groundwater level [m]
	SWB 2002	SWB 2003	IRR 2002	IRR 2003	DS 2002	DS 2003	TWC 2002/03	WWC 2002/03	GL 2002/03
DPo	-0,04	-2,27	0	0	253,3	256,0	180	1801	/
Dc	-1,68	-3,51	31,4	24,8	279,5	286,5	274	1048	/
Cc	2,87	-3,10	0	0	181,0	221,0	150	0	/
DCc	-17,10	-3,17	0	0	319,3	251,7	/	3624	/

Criterion 'Adequate amount of surface water is supplied' (1)

Surface water balance

Due to a lack of data, this indicator could not be calculated with the proposed SWAT model. However, an estimation based on the averaged daily difference between measured evapotranspiration (ET_o) and precipitations (P) in the catchment is shown in the figure 24.

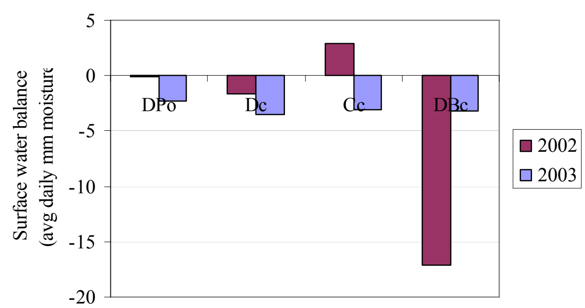


Figure 24. Surface water balance (2002 and 2003).

Criterion 'Adequate amount of soil water is supplied' (2)

Irrigation practices

This is a crop and farm scale indicator representing the relative amount of parcels irrigated in a farm. It is expressed as a percentage of total surfaces (irrigated surface/total surface). Only farm D_c is irrigated, other farms obtain a 0 value for this indicator.

Drought stress

Drought stress was originally defined as the difference between precipitations and evaporation at the parcel level. Since this is a rather approximate calculation method - it doesn't consider specific soil hydraulic kinetics - this indicator was instead calculated with the WAVE model. WAVE simulates potential and actual evapotranspiration based on soil hydraulic characteristics, plant growth parameters and meteorological information (precipitation, temperature, potential evapotranspiration ET_0 and radiation)[21].

[21] For a detailed explanation on calculation methods, please refer to annex IV.

In table 25, drought stress is shown at farm level. The indicator is expressed as the amount of days where modeled actual evapotranspiration is lower than the potential evapotranspiration. Results for the different farms are similar and rather elevated, with exception of farm C_c where lower values for drought stress are observed. This difference could be explained by meteorological conditions that are more favorable (less dry) in site C_c (as shown in the figure of estimated surface water balance above).

Criterion 'Adequate amount of ground water is supplied'

Water consumption

Water consumption was evaluated through farmers interviews and data derived from official water bills. Dutch norms for water use on dairy farms were used to complete data with standard values (source KWIN, 2000). These norms state water consumption on a yearly basis amounts 23.15m³ for milking cows and 16.0 m³ for young cattle. For horses was assumed that they need 7.93 m³ of water yearly[22].

In the table and the figure below, farm results are presented. Tap water only contributes to approximately 10-20% of total water consumption. The arable farm C_c has the lowest water consumption. The dairy farm DBc has the highest water consumption, related to the greater number of animals on the farm.

Farm	Tap water [m³]		Well water [m³]	
DPo	180	Poultry	*1801*	Cattle (77.8 LU bovine animal* 23.15m³)
Dc	274	Household + young cattle	1048	Rest of farm (cattle, milking machine, cooling tank)
Cc	150	Household + crops	0	
DBc	no data	Household + milking installation	*3624*	154 LU cattle 7 LU horses

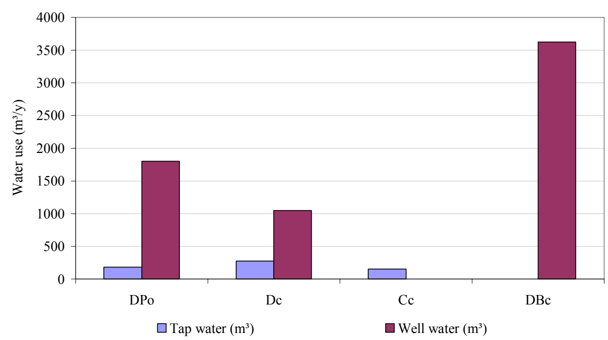


Table 27 & Figure 25. Tap and well consumption (2002/2003).

Groundwater level

No farm specific data on groundwater was available (see annex IV for details).

[22] Source: http://www.sfr.cas.psu.edu/water/water%20use.pdf)

V.4.4.9 Water quality Criteria: '(1) Surface water (2) soil water and (3) ground water of adequate quality is supplied '

Criterion 'Surface water of adequate quality is supplied' (1)

Presence of grass strips/riparian areas

Since none of the test sites has grass strips on field sides as a measure to reduce erosion risk, indicator scores for all farms is equal to zero (see criteria on flooding).

Pesticide runoff risk

Due to a lack of precise data on pesticide applications, this indicator could not be calculated. In the integration procedure, the indicator will be estimated by the SI values of off site water erosion risk.

Criterion 'Soil water of adequate quality is supplied' (3)

Pesticide residues

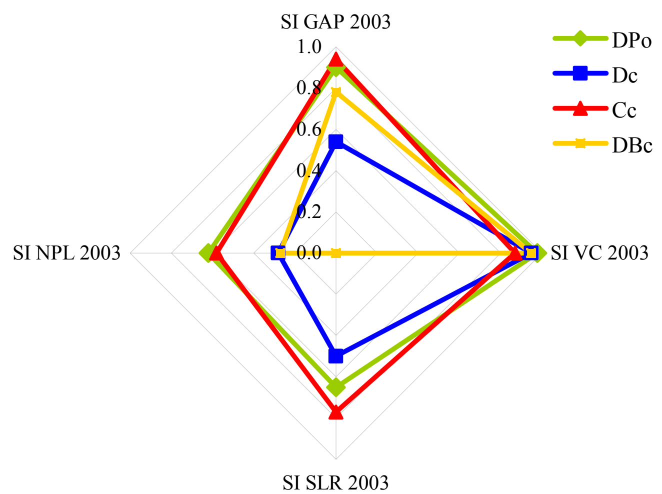
Results for this indicator are the same as for pesticide residues under the Criterion "soil chemical quality", the reader shall refer to this section.

Criterion 'Groundwater of adequate quality is supplied'

Table 28. Sustainability Index of Criteria 'groundwater of adequate quality is supplied' (3) (2003).

Farm	SI GROUND WATER QUALITY GWQ 2003
DPo	0.79
Dc	0.57
Cc	0.79
DBc	0.50

Figure 26. AMOEBA of Criteria 'groundwater of adequate quality is supplied'.



Comment: With respect to 'Ground water quality', C_c and DP_O perform in a satisfying manner. The performances of farms DB_c and D_c are more mixed, this mainly because of higher nitrogen residues in the soil profiles (NPL).

Table 29. Results for selected indicators of Criteria '(3) groundwater of adequate quality is supplied'.

	3						
Farm	GAP [%]	Vegetation cover during the nitrate leaching period		Soil link rate-2 [nd]		NPL - Nitrogen potentially leachable [kg N-NO3/ha]	NSB_{cp} - N Systemic Balance at cropping plan scale [kg N/(ha.yr)]
	GAP 2002/03	VC 2002	VC 2003	SLR 2002	SLR 2003	NPL 2003	NSB_{cp} 2003
DPo	90,10	98,54	97,74	0,70	0,70	27,06	33,00
Dc	54,00	94,91	94,91	1,00	1,00	46,62	/
Cc	94,00	84,78	86,95	0,68	0,46	29,22	144,00
DBc	78,50	96,15	94,77	1,98	2,00	47,31	51,00

Legend. / = indicator could not be calculated because of a lack of data

GAP

D_c and DB_c have moderate GAP scores. D_c's score is equally due to its fertilization practices and its pest management practices whereas for DB_c, the contribution of fertilization practices is more important than the one related to pest management.

Both C_c and DP_o performs really well for this indicator. For the latter, the good pest management practices are simply reached because the farm is almost entirely organic. Conversely, C_c has a better score because the farmer uses phytosanitary products with more appropriate techniques than D_c or DB_c.

However, one could easily argue that such an indicator is inappropriate for assessing sustainability levels since it is based only on what the farmer says he does and not what he actually does.

Vegetation cover in the nitrate leaching period

Results for this indicator are similar and rather elevated for farms DP_o, D_c and DB_c - This relates to the great number of grasslands with permanent vegetation cover in these farms and the soil cover in the interculture with green manure in D_c and DB_c. Only the arable farm C_c presents some lower values for this indicator, due to the periods where crops are harvested and the fields are left bare.

Soil link rate - 2

The soil link rate-2 is the ratio between organic nitrogen spread on the farm and organic nitrogen used by the plants (importations and exportations contracts included). In Wallonia, the PGDA (Programme de Gestion Durable de l'Azote en Agriculture) prompts all exploitations to have sufficient areas to spread organic fertilizers without causing nitric pollution: LS (1 or 2 if contracts exist) lower or equal to 1 is compulsory (if exceeded, the farmer can commit himself to taking part in a fertilizer management program).

DBc is the only farm with a significantly high LS-2. However, this is not translated by important NPL values (cf. above), possibly because this farm grows green manure in the interculture on all his maize parcels (cf. high percentage of 'vegetation cover in the nitrate leaching period'). This shows the limitations of the LS indicator that only accounts for the absolute amount of organic fertilizers spread on a farm and does not consider the importance of the interculture management, the moment of application, the type of fertilizers, …

NPL

C_c and DP_o have low nitrate residues whereas DB_c & D_c have higher nitrate residues. *However, none of these four farms have averaged soil profiles that present a serious danger of nitric pollution* - C_c and DP_o had low nitrate residues in the soil before winter ('Potentially leachable nitrogen (PLN)') whereas, in DB_c and D_c, these were higher (about 47 kg $N\text{-}NO_3^-.ha^{-1}$) (table 7). Lambert *et al*. (2002) and Peeters *et al*. (2000)

refer to a PLN value of 34 kg $N^{-}NO_3^{-}.ha^{-1}$ before winter as the PLN value[23] leading to the critical nitric concentration (50 ppm) in the water feeding the groundwater during winter. On average thus, soil profiles in these two farms only slightly exceeded this value.

NSB **$_{cropping\ plan}$**

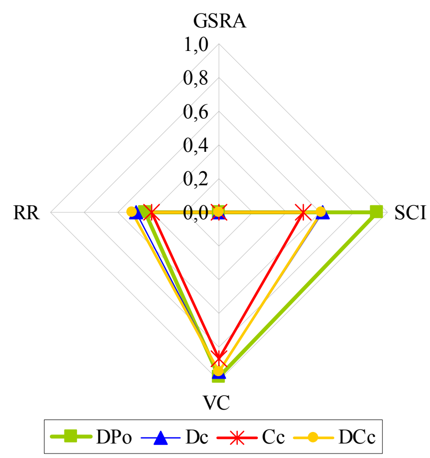
The result of a Nitrogen Systemic Balance at cropping plan includes: nitrogen losses in fields towards air and water and gains of humus in the soil. In farm C_c, it is striking to see that, unlike the other farms, NSB_{cp} exceeds by far the NPL value at farm scale. Considering that C_c fields have always been poor in organic matter, the farmer might have been trying to increase the amount of humus in the soil by diverse means such as no tillage and massive organic fertilization. If it apparently does not result in nitric pollution so far, it could evolve differently in the long term as the soil organic content will not continue to increase indefinitely.

V.4.4.10 Criterion 'Flooding and runoff regulation is maintained/enhanced'

Table 30. Sustainability index (SI) for Criterion 'Flooding and runoff regulation is maintained/enhanced'[24] (2003).

Farm	FLOODING AND RUNOFF SI FLRO 2003
DPo	0.59
Dc	0.51
Cc	0.44
DBc	0.52

Figure 27. AMOEBA for Criterion 'Flooding and runoff regulation is maintained / enhanced' picturing Sustainability Indexes of related indicators (2003).



Comment: DP_o, the organic cattle-poultry farm, performs the best among all four farms ($SI_{flooding\ and\ runoff}$ = 0.59). D_c and DBc, the two other dairy farms, have similar results with $SI_{flooding\ and\ runoff}$ of approximately 0.51. The $SI_{flooding\ and\ runoff}$ of the crop farm C_c is the lowest with a value of 0.44.

⇨ In general, for flooding and runoff regulation, the results of the farms are acceptable

[23] This value is based on the following hypothesis: 300 mm of water percolation through soil during winter and 100% of pre-winter nitrogen residue leached (considering a clay content superior to 15%).

[24] The integration procedure was performed with an estimation of runoff SI based on the SI of off site water erosion (cf .soil loss is minimized criterion) for DBC, D_C, DP_O and C_C.

Table 31. Results for selected indicators of Criterion 'Flooding and runoff regulation is maintained/enhanced'.

Farm	Presence of grass strips [m^2/ha]	Soil cover index [ndim]	Vegetation Cover [%]		Runoff risk [avg mm/day]	
	GSRA 2002/03	SCI 2002/03	VC 2002	VC 2003	RR 2002	RR 2003
DPo	0,00	0,068	98,54	97,74	/	/
Dc	0,00	0,230	94,91	94,91	/	/
Cc	0,00	0,319	84,78	86,95	/	/
DBc	0,00	0,246	96,15	94,77	/	/

Legend. / = data not available

Presence of grass strips

No grass strips were present. All farms have zero values for this indicator.

Soil cover index

This index presents the soil cover during a 3-year cropping period. High SCI values mean lower crop covering and higher susceptibility of the fields to erosion. Results of SCI confirm that the arable farm Cc has less elevated vegetation cover.

Vegetation cover

Results for this indicator are similar and rather elevated for farms DP_o, D_c and DBc. This is related to the great number of grasslands with permanent vegetation cover on these farms. Only the arable farm C_c presents some lower values for this indicator, due to the periods where crops are harvested and the fields are left bare.

Runoff risk

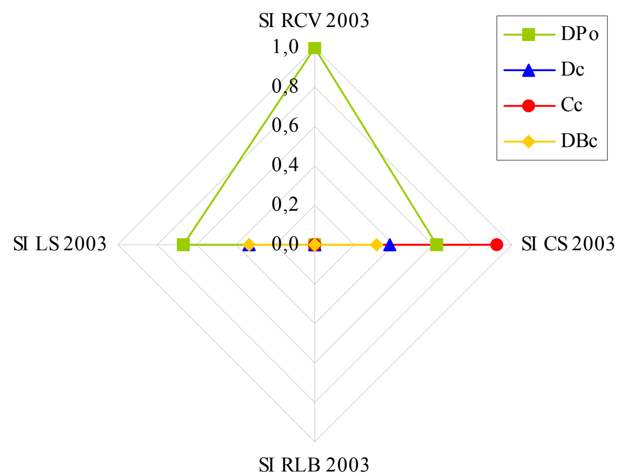
This indicator could not be calculated with the SWAT model due to lack of data. In the integration part, an estimation of this risk will be based on the indicator values of off site water erosion.

V.4.4.11 Criterion 'Planned biodiversity is maintained/increased'

Table 32. Sustainability Index (SI for Criterion 'Planned biodiversity is maintained / enhanced'.

Farm	SI Planned Biodiversity
	SI PLANBIODIV 2003
DPo	0.57
Dc	0.18
Cc	0.23
DBc	0.16

Figure 28. AMOEBA for Criterion 'Planned biodiversity is maintained/enhanced' picturing Sustainability Indexes of related indicators.



Comment: DP_o, the organic cattle-poultry farm, performs the best among all four farms ($SI_{planned\ biodiversity}$ = 0.49). D_c, DB_c and C_c have similar results with $SI_{planned\ biodiversity}$ of approximately 0.2.

⇨ Except for farm DP_o, all three other farms perform rather dissatisfactory for 'Planned biodiversity is maintained / enhanced'.

Table 33. Results for selected indicators of Criterion 'Planned biodiversity is maintained/increased'.

Farm	Number of threatened and rare crop varieties	Number of crop species	Number of threatened and rare livestock breeds	Number of livestock species
	RCV 2003	CS 2003	RLB 2003	LS 2003
DPo	1	8	0	2
Dc	0	5	0	1
Cc	0	12	0	0
DBc	0	4	0	1

Number of crop species, threatened & rare crop varieties, livestock species, threatened & rare livestock breeds.

Whereas these issues are undeniably important in strict biodiversity terms, they also have significance for future genetic progress. In the last decades, research for greater stability and productivity in animal and plant production partially relied on animal and plant breeding. On the basis of performing but sometimes too genetically-narrowed based populations, breeders selected races and varieties. Moreover, because these where synonymous with high performance, farmers began to rear and cultivate these almost exclusively. Though economically speaking this strategy turned out to be very satisfying, it also presented risks of leading to irreversible genetic erosion which in the long term could in turn cause serious problems of adaptability among the cultivated and reared populations (Piveteau, 1998). In practice, these issues found responses with conservation programs among breeders and agri-environmental measures encouraging farmers to rear and cultivate traditional breeds and crop varieties. Today, these efforts should be maintained.

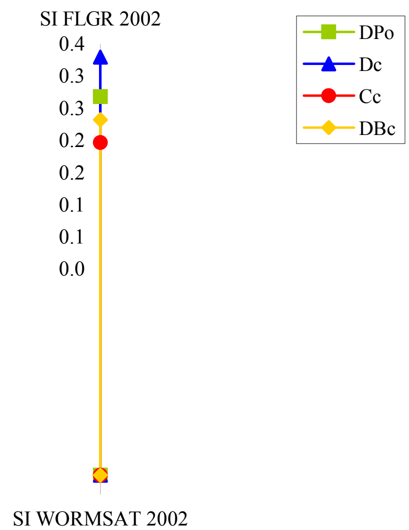
DP_o has both the greatest number of livestock species and threatened & rare crop varieties – Indeed this farm cultivates a rare variety of potatoes ('Corne de Gatte') and rears both dairy cows and chickens.

V.4.4.12 Criterion 'Functional part of natural/spontaneous biodiversity is maintained/increased'

Table 34. Sustainability Index (SI for Criterion 'Functional part of natural/spontaneous biodiversity is maintained / enhanced'.

Farm	SI Functional Biodiversity
	SI FUNCBIODIV 2003
DPo	0.29
Dc	0.33
Cc	0.26
DBc	0.28

Figure 29. AMOEBA for Criterion 'Functional part of natural/spontaneous biodiversity is maintained/enhanced' picturing Sustainability Indexes of related indicators.



<u>Comment</u>: For Criterion 'Functional part of natural/spontaneous biodiversity is maintained / increased' SI scores are similar and they range between 0.26 and 0.33. D_c ranks best with a $SI_{FunctionalBiodiversity}$ = 0.33. Closely behind follows DP_o and DB_c ($SI_{FunctionalBiodiversity}$ = 0.29 and 0.28 respectively). C_c scores 0.26.

Table 35. Results for selected indicators of Criterion 'Functional part of natural/spontaneous biodiversity is maintained/increased'.

Farm	Total nr of wild plant species in permanent grassland	Soil biological activity	Earthworm species saturation
	FLGR 2002	SOBIO 2002	WORMSAT 2002
DPo	135	/	32
Dc	166	/	32
Cc	99	/	32
DBc	117	/	32

Total number of wild plant species in permanent grassland

This indicator is commented under the Criterion 'Heritage part of natural/spontaneous biodiversity is maintained/increased'.

Soil biological activity

For this indicator no data were collected. Hence, it is not calculated.

Earthworm species saturation

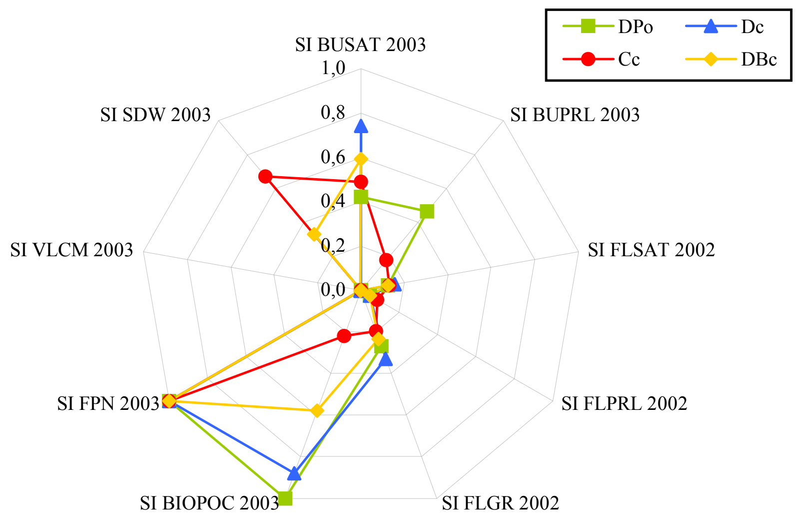
Earthworm species saturation is equal for all farms: 32%. In each farm 7 out of 22 potential earthworm species were recorded. While at the farm level no differences between the farms, parcels were characterized by variability both in species numbers and in species composition. Species numbers vary between 1 and 7 at the parcel level with many parcels counting around 5 earthworm species.

V.4.4.13 Criterion 'Heritage part of natural/spontaneous biodiversity is maintained/increased'

Table 36. Sustainability index (SI) for Criterion 'Heritage part of natural / spontaneous biodiversity is maintained / enhanced'.

Farm	SI Heritage biodiversity
	SI HERBIODIV 2003
DPo	0.37
Dc	0.35
Cc	0.33
DBc	0.32

Figure 30. AMOEBA for Criterion 'Heritage part of natural/spontaneous biodiversity is maintained / enhanced' picturing Sustainability Indexes of related indicators.



<u>Comment</u>: For Criterion 'Heritage part of natural/spontaneous biodiversity is maintained / increased' all farms have similar SI scores. DP_o ranks best with a $SI_{NaturalBiodiversity}$ = 0.37. Closely behind follows D_c ($SI_{NaturalBiodiversity}$ = 0.35). C_c and DB_c have SI scores of respectively 0.33 and 0.32.

Table 37. Results for selected indicators of Criterion 'Heritage part of natural/spontaneous biodiversity is maintained/increased'.

Farm	Butterfly species saturation	Number of protected and Red List butterfly species	Breeding bird species saturation	Number of protected and Red List bird species	Number of European Bird Directive species	Wild flora species saturation	Number of protected and Red List wild flora species	Total number of wild plant species in permanent grassland
	BUSAT 2003	BUPRL 2003	BISAT 2003	BIPRL 2003	BIEUR 2003	FLSAT 2002	FLPRL 2002	FLGR 2002
DPo	42.22	6	/	/	/	12.50	1	135
Dc	74.07	0	/	/	/	15.52	1	166
Cc	48.89	1	/	/	/	13.00	2	99
DBc	59.26	0	/	/	/	12.50	1	117

Farm	Pesticide Risk Score (POCER-2)	Fertilizer pressure on Natura 2000 grassland (kg N, Pmin/org /ha)	Proportion of high biological values meadows (%)	Existence of special devices for wild fauna (nb)
	BIOPOCER 2003	FPN 2003	VLCM 2003	SDW 2003
DPo	-10,00	0,00	0,00	0,00
Dc	-8,80	0,00	0,00	0,00
Cc	-2,20	0,00	0,00	2,00
DBc	-5,80	0,00	0,00	1,00

Butterfly species saturation

Butterfly saturation decreases from D_c over DB_c and C_c.to DP_o and ranges between +- 75% and 42%. While similar numbers of butterfly species occurred in the four sites (23, 20, 23 and 16 for DP_o, D_c, C_c and DB_c respectively), saturation is clearly lower in the Walloon sites (DP_o and C_c). The potential species pool (PSP) against which observed species were checked consisted of the safe species of the regional Red Lists. The Flemish PSP contains 27 species while the Walloon PSP counts 33 species. This explains why the Walloon sites, while being the most species rich, have lower saturation. Nevertheless, there is no doubt that working with more local reference values, reflecting local circumstances and potentials, results in more accurate indicator values.

Number of protected and Red List butterfly species

On farm DP_o 6 protected and Red List butterfly species were observed. This was a lot more than the respectively 1, 0 and 0 of protected and Red List species that were recorded in C_c, D_c and DB_c.

It is striking that farms with high butterfly saturation (D_c and DB_c) have low numbers of protected and Red List butterfly species and vice versa. The reference list that was used for the 'Number of protected and Red List butterfly species' consisted of the non-safe species of the regional Red Lists. This list is thus complementary with the PSP used in the calculation of 'Butterfly species saturation' (see above). Therefore, species that appear in the PSP for 'Butterfly species saturation' can not appear on the 'Number of protected and Red List butterfly species' list and vice versa. DP_o and to a lesser degree C_c 'suffer' from this artefact when looking at their 'Butterfly species saturation' value, while also the use of regional PSP's plays a role (as explained above).

Breeding bird species saturation

No bird data were collected in the course of the project. Hence, the indicator is not calculated.

Number of protected and Red List bird species

No bird data were collected in the course of the project. Hence, the indicator is not calculated.

Number of European Bird Directive species

No bird data were collected in the course of the project. Hence, the indicator is not calculated.

Wild flora species saturation

Wild flora species saturation on the four farms lies in a small range from 12.5% to 15%. D_c was the most species rich farm in terms of wild flora: 216 of vascular plant species were recorded. The species richness can be linked with the location of the D_c farm in the species rich valley of the Dommel River. The cropland farm (C_c) ranks second with 193 observed species. DP_o and DB_c have similar and the lowest number of wild flora species on their parcels: 180 and 174 respectively.

Number of protected and Red List wild flora species

With only between 1 and 2 observed species, protected and Red List wild flora species are very rare in the studied farms. *Epipactis helleborine L.* occurs in all sites and *Centaurium erythraea Rafn*. occurs additionally in the cropland farm (C_c).

Total number of wild plant species in permanent grassland

The ‘Total number of wild plant species in permanent grassland’ follows the same trend as the ‘Wild flora species saturation’. This means farm D_c ranks first with 166 species, with DP_o and D_c behind it (135 and 117 species respectively). The cropland farm (C_c), which is taking second place for ‘Wild flora species saturation’ is an exception to the similar trend: only 99 species were observed in grassland in this site. This is not surprising since amongst the farmland, only two grassland parcels existed.

Pesticide risk

The POCER-2 index based on the compartments relevant to biodiversity (beneficial arthropods, bees, birds, earthworms, and water organisms) ranges from -10 (best score) to + 10 (worst score). It is evident that the organic farm (DP_o) scores best (-10) since no pesticides are allowed nor used in this type of farming. The dairy-specialized farm (D_c) comes second (-8.8) and the dairy-beef farm DB_c follows close behind with a score of -5.8. The worst score (-2.2) is for the cropland farm (C_c). Here the greater use of pesticides might be necessary to cope with the believed more abundant weed populations in minimum tilled fields. It is striking none of the farms reaches positive scores however.

N & K fertilizer pressure in Natura 2000 grasslands

None of the four farms had ‘Natura 2000’ labelled areas.

Proportion of high biological value meadows

None of the four farms had agri-environmental measures contracts for late or very late cut meadows during the sampling period.

Existence of special devices for wild fauna

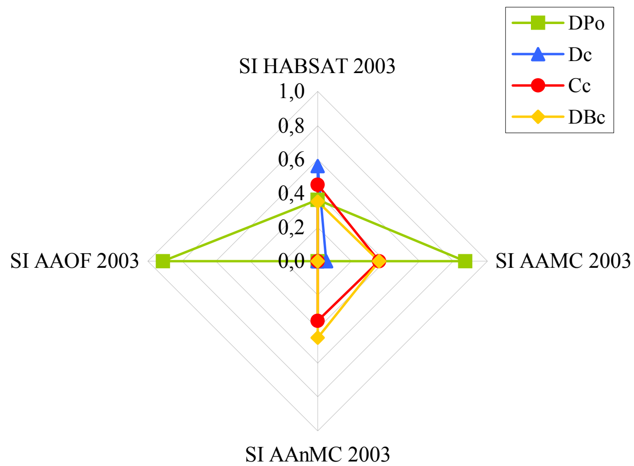
The farmer of C_c lays troughs for pheasants in specific areas and cereals heads in the fields and in the farmyard for birds. In $DB_{c,}$ a nesting box for owls can be found

V.4.4.14 Criterion 'Diversity of habitats is maintained/increased'

Table 38. Sustainability index (SI) for Criterion 'Habitat diversity is maintained / enhanced'.

Farm	SI Habitat diversity
	SI HABDIV 2003
DPo	0.54
Dc	0.15
Cc	0.29
DBc	0.29

Figure 31. AMOEBA for Criterion 'Habitat diversity is maintained / enhanced' picturing Sustainability Indexes of related indicators.



<u>Comment:</u> The organic farm (DP_o) clearly scores best ($SI_{HabitatDiversity}$ = 0.54). It thanks this first position especially to its area under management contract and its area under organic farming contract. The diary-beef farm (DB_c) and the cropland farm (C_c) share the second place with $SI_{HabitatDiversity}$'s = 0.29. Both farms have similar scores over all indicators within the Criterion. The diary-specialised farm (D_c), only has a $SI_{HabitatDiversity}$ = 0.15. Small area under management contract, no area managed ecologically without management contract and no organic farming take down its good score for SI 'Habitat saturation'.

Table 39. Results for selected indicators of Criterion 'Diversity of habitats is maintained / increased'.

Farm	Habitat saturation (%)	AA under management contract (%)	AA managed for wild biota without management contract (%)	AA under organic farming contract (%)
	HABSAT 2003	AAMC 2003	AAnMC 2003	AAOF 2003
DPo	36	87	0	91
Dc	56	5	0	0
Cc	45	36	5	0
DBc	35	36	8	0

Habitat saturation

Habitat saturation is highest for D_c. DP_o and DB_c have similar and low habitat saturation while C_c has an intermediary value. A total of 55 different habitat types were used in calculation of habitat saturation.

Agricultural area under management contract

DP_o has 87% of its farm area under management contract. This is remarkably more than C_c and DB_c (both 36%) and a lot more than D_c (5%). DP_o, although being under organic farming contract, receives subsidies for low stocking rate on 55.6 ha of grassland (<1.4 LU/ha of grassland; 100 €/ha of grassland), 800 m of hays (200 €) and the management of 2 pools (the equivalent of 400 m of hays; 100 €). C_c receives subsidies for the use of green manure on 39 ha of its farmland. DB_c gets subsidized for mechanical weeding and the use of green manure on 29.5 ha of its farmland. D_c has a management contract for a parcel of 2.5 ha on which the farmer maintains a pool, uses low stocking and fertilizer rates and applies late mowing dates.

Agricultural area managed for wild biota without management contract

In general farmers barely manage their farmland following the conditions and guidelines of management contracts when they do not have management contracts for the parcels in question. Farm C_c grows 5.6 ha (or 5%) of its farmland with green manure without receiving any subsidies for it. The farmer of farm DB_c takes care of breeding meadow birds in some of his parcels with a total area of 6.45 ha in consultation with the local nature conservation organization. He receives no subsidies for this, but he could if he wanted. The other farmers do not take any agri-environmental measures without actually having management contracts.

Agricultural area under organic farming contract

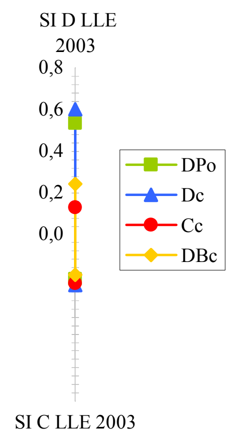
DP_o is the only farm with an organic farming contract; 58.22 ha or 91% of its farming area is covered by such a contract.

V.4.4.15 Criterion 'Functional quality of habitats is maintained/increased'

Table 40. Sustainability index (SI) for Criterion 'Functional quality of habitats is maintained / enhanced'.

Farm	SI Habitat quality SI HABQUA 2003
DPo	0.37
Dc	0.42
Cc	0.18
DBc	0.22

Figure 32. AMOEBA for Criterion 'Functional quality of habitats is maintained / enhanced' picturing Sustainability Indexes of related indicators.



Comment: *D_c and DP_o score best ($SI_{HabitatQuality}$ = 0.42) and second best ($SI_{HabitatQuality}$ = 0.37) with SI's more or less twice as high as DB_c and C_c ($SI_{HabitatQuality}$ = 0.22 and $SI_{HabitatQuality}$ = 0.18 respectively). In these results the influence of the SI 'Density of linear landscape elements' can be clearly seen. Indeed, equal indicator weighting and similar results for farms for the SI 'Connectivity of linear landscape elements' have as result that SI score at the Criterion level is a reflection of SI 'Density of linear landscape elements'.*

Table 41. Results for selected indicators of Criterion 'Functional quality of habitats is maintained/increased'.

Farm	Density of linear landscape elements (m/ha)	Connectivity of linear landscape elements (-)
	DENLLE 2003	CONLLE 2003
DPo	46.79	0.21
Dc	63.94	0.24
Cc	7.29	0.23
DBc	12.24	0.19

Density of linear landscape elements

D_c has the highest density of linear landscape elements, followed by DP_o. Linear landscape elements occur in low and very low densities in DB_c and C_c respectively. These results are not surprising since they reflect regional landscape characteristics. D_c is situated in the Campine region with traditionally small parcels surrounded by hedges. C_c is on the other extreme with its location in the loam belt characterised by large-scale parcels.

Connectivity of linear landscape elements

Whereas the 'Density of linear landscape elements' reflects regional differences, the 'Connectivity of linear landscape elements' is less differentiating between farms from different regions. It suggests that networks of linear landscape elements are more or less in the same way connected, independent of their density. Of course, care has to be taken not to generalize since these findings are based on only 4 case studies.

V.4.4.16 Criterion 'Resistance & resilience of the ecosystem is maintained / enhanced'

None of the two indicators selected could be calculated in the framework of this project.

V.4.4.17 Criterion 'Farm income is ensured'

Table 42. Sustainability Index (SI) for Criterion 'Farm income is ensured'.

Farm	SI 'Farm income is ensured'
	SI 'FI' 2003
DP_O	0.53
D_C	0.70
C_C	0.36
DB_C	0.40

Figure 33. AMOEBA for Criterion 'Farm income is ensured'.

For the Criterion 'Farm income is ensured', a single indicator was selected

→ no AMOEBA graph

Table 43. Results for selected indicators of Criterion 'Farm income is ensured' (2003).

Farm	Family farm income/family work (unit/year)
	FFI 2003
DP_O	36 096
D_C	47 456
C_C	24 569
DB_C	27 511

A difference is observed between the DP_o and the D_c farms on the one hand and the C_c and the DB_c farms on the other hand. The same difference can be found in terms of economic efficiency (total factor productivity and labour productivity). However, there is no straightforward explanation for this difference in economic performance.

V.4.4.18 Criterion 'Dependency on direct and indirect subsidies is minimised'

Table 44. Sustainability Index for Criterion 'Dependency on direct & indirect subsidies is minimised'.

Farm	SI 'Dependency on direct and indirect subsidies is minimised'
	SI 'DS' 2003
DP_O	0,82
D_C	0,95
C_C	0,70
DB_C	0,37

Figure 34. AMOEBA for Criterion 'Dependency on direct & indirect subsidies is minimised'.

For the Criterion 'Dependency on direct and indirect subsidies is minimised', a single indicator was selected

→ no AMOEBA graph

Table 45. Results for indicators of Criterion 'Dependency on direct & indirect subsidies is minimised' (2003).

Farm	% of real net farm income from all subsidies (%)
	FIS 2003
DP_O	18
D_C	5.3
C_C	59.8
DB_C	63.3

As in the previous criterion, there is a clear distinction between the Dpo and the Dc farm, having high Sustanaibilty Indexes for this criterion, and the Cc and the DBc farm, having lower values for the SI's.

V.4.4.19 Criterion 'Dependency on external finance is optimal'

Table 46. Sustainability Index (SI) for Criterion 'Dependency on external finance is optimal'.

Farm	SI Dependency on external finance is optimal
	SI 'DEF' 2003
DP_O	0.52
D_C	0.49
C_C	/
DB_C	0.49

Figure 35. AMOEBA for Criterion 'Dependency on external finance is optimal'.

For the Criterion 'Dependency on external finance is optimal', a single indicator was selected

→ no AMOEBA graph

Table 47. Results for selected indicators of Criterion 'Dependency on external finance is optimal' (2003).

Farm	Solvency (%)
	S 2003
DP_O	52
D_C	48.5
C_C	/
DB_C	49.2

No data were available concerning external finance for the Cc farm. There is apparently little variation between the other farms concerning this criterion. They all have a solvency of about 50%.

V.4.4.20 Criterion 'Agricultural activities are economically efficient'

Table 48. Sustainability Index (SI) for Criterion 'Agricultural activities are economically efficient'.

Farm	SI 'Agricultural activities are economically efficient'
	SI 'AAEF' 2003
DP_O	0.53
D_C	0.72
C_C	0.24
DB_C	0.18

Figure 36. AMOEBA for Criterion 'Agricultural activities are economically efficient'.

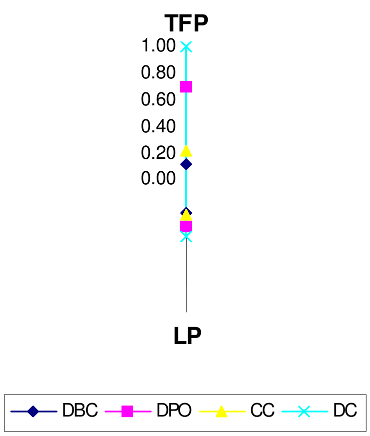


Table 49. Results for indicators of Criterion 'Agricultural activities are economically efficient'.

Farm	Total factor productivity [%]	Labour productivity [€/VAK]
	TFP 2003	LP 2003
DP_O	170	41 522.00
D_C	200	49 653.00
C_C	121	30 785.00
DB_C	111	29 156.00

As in the first two criteria of the economic pillar, there is also for this criterion a clear difference between the DPo and the Dc farm, and the Cc and the DBc farm on the other hand. The first two score better on economic efficiency. As the amoeba and table 45 show, both indicators account for this difference.

V.4.4.21 Criterion 'Agricultural activities are technically efficient'

Table 50. Sustainability Index (SI) for Criterion 'Agricultural activities are technically efficient'.

Farm	SI Agricultural activities are technically efficient
	SI 'AATE' 2003
DP_O	0.00
D_C	0.00
C_C	1.00
DB_C	0.07

Figure 37. AMOEBA for Criterion 'Agricultural activities are technically efficient'

For the Criterion 'Agricultural activities are technically efficient', a single indicator was selected

→ no AMOEBA graph

Table 51. Results for selected indicators of Criterion 'Agricultural activities are technically efficient' (2003).

Farm	Total output from total input (energy terms [%]
	TOTI 2003
DP_O	78
D_C	72
C_C	1258
DB_C	179

Here there is a striking difference between the crop farm and the cattle farms. The crop farm has a much higher SI for this criterion than the other farms. The reader shall refer to V.4.4.4 for a discussion of the difference in energy efficiency between the farms.

V.4.4.22 Criterion 'Market activities are optimal'

Table 52. Sustainability Index (SI) for Criterion 'Market activities are optimal'.

Farm	SI Market activities are optimal SI 'MA' 2003
DP_O	0.20
D_C	0.00
C_C	0.80
DB_C	0.20

Figure 38. AMOEBA for Criterion 'Market activities are optimal.'

For the Criterion 'Market activities are optimal', a single indicator was selected

→ no AMOEBA graph

Table 53. Results for selected indicators of Criterion 'Market activities are optimal' (2003).

Farm	Diversity of agricultural income sources, production as well as non production (number) DAI 2003
DP_O	5
D_C	4
C_C	9
DB_C	5

The C_c farm has a higher SI for this criterion. The number of income sources on this farm is higher than on the cattle farms.

V.4.4.23 Criterion 'Farmer's professional training is optimal'

Table 54. Sustainability Index (SI) for Criterion 'Farmer's professional training is optimal'.

Farm	SI 'Farmer's professional training is optimal' SI 'FPT' 2003
DP_O	1.00
D_C	1.00
C_C	1.00
DB_C	1.00

Figure 39. AMOEBA for Criterion 'Farmer's professional training is optimal.'

For the Criterion 'Farmer's professional training is optimal', a single indicator was selected

→ no AMOEBA graph

Table 55. Results for selected indicators of Criterion 'Farmer's professional training is optimal' (2003).

Farm	Years of professional experience (years) YPE 2003
DP_O	14
D_C	15
C_C	28
DB_C	16

While the manager of C_c has the most professional experience, there is no difference in SI due to the design of the normalisation function. It is set that from 10 years of experience on, the SI equals 1, because we assume that from then on, one year of extra experience does not have any significant extra return in sustainability. Since they all have more than 10 years of experience, their SI is the same and equal to 1.

V.4.4.24 Criterion 'Inter-generational continuation of farming activity is optimal'

Table 56. Sustainability Index (SI) for Criterion 'Inter-generational continuation of the farming activity is ensured'.

Farm	SI 'Inter-generational continuation of the farming activity is ensured' SI 'IGC' 2003
DP_O	0.00
D_C	0.50
C_C	0.50
DB_C	0.50

Figure 40. AMOEBA for Criterion 'Inter-generational continuation of the farming activity is ensured'.

For the Criterion 'Inter-generational continuation of the farming activity is ensured', a single indicator was selected

→ no AMOEBA graph

Table 57. Results for indicators of Criterion 'Inter-generational continuation of farming activity is optimal' (2003).

Farm	There exists a new generation willing to take over the farm NG 2003
DP_O	0
D_C	0.5
C_C	0.5
DB_C	0.5

The DP_o farm has score 0 on this criterion, while there is no difference between the other farms. This variability is explained by the single indicator for this criterion. DP_o does not have a successor, the other farmers don't know yet.

V.4.4.25 Criterion 'Land tenure arrangements are optimal'

There were no indicators selected to represent this Criterion, therefore they were not calculated.

V.4.4.26 Criterion 'Adaptability of the farm is sufficient'

Table 58. Sustainability Index (SI) for Criterion 'Adaptability of farm is sufficient'.

Farm	SI Adaptability of farm is sufficient
	SI 'AF' 2003
DP_O	1.00
D_C	0.00
C_C	1.00
DB_C	1.00

Figure 41. AMOEBA for Criterion 'Adaptability of farm is sufficient'.

For the Criterion 'Adaptability of farm is sufficient' a single indicator was selected

→ no AMOEBA graph

Table 59. Results for selected indicators of Criterion 'Adaptability of the farm is sufficient' (2003).

Farm	Index of farm adaptability
	IFA 2003
DP_O	1
D_C	0
C_C	1
DB_C	1

Adaptability for all farms is sufficient, except for D_c. This is due to the fact that farmer in D_c estimates having serious problem in meeting various institutional restrictions (Laws, regulations, standards, etc.).

V.4.4.27 Criterion 'Production capacity is compatible with society's demand of food'

For this criterion, the indicators 'Consumption/production' was selected and calculated. This indicator however is only measured and expressed at the regional level and is therefore not presented here. Results for this indicator can be found in annex X.

V.4.4.28 Criterion 'Quality of food and raw materials is maintained/increased'

There were no indicators selected to represent this criterion.

V.4.4.29 Criterion ‘Diversity of food and raw materials is maintained/ or increased’

Table 60. Sustainability Index (SI) for Criterion ‘Diversity of food and raw materials is increased’.

Farm	SI ‘Diversity of food and raw materials is increased’
	SI 'DFMI' 2003
DP_O	0.80
D_C	0.40
C_C	0.50
DB_C	0.50

Figure 42. AMOEBA for Criterion ‘Diversity of food and raw materials is increased’.

For the Criterion ‘Diversity of food and raw materials is increased’ a single indicator was selected

→ no AMOEBA graph

Table 61. Results for selected indicator of Criterion ‘Diversity of food and raw materials is increased’ (2003).

	Diversity of main food types [number]
Farm	DoFS 2003
DP_O	4
D_C	2
C_C	3
DB_C	3

DPo scores better for this criterion, whereas the difference between the other farms is rather low. The variability is explained by the single indicator for this criterion. The Dpo farm has a higher diversity of main food types.

V.4.4.30 Criterion ‘Adequate amount of agricultural land is maintained’

There were no indicators selected to represent this criterion.

V.4.4.31 Criterion ‘Labour conditions are optimal’

Table 62. Sustainability Index (SI) for Criterion ‘Labour conditions are optimal’.

Farm	SI ‘Labour conditions are optimal’
	SI 'LCO' 2003
DP_O	0.00
D_C	0.03
C_C	0.51
DB_C	0.35

Figure 43. AMOEBA for Criterion ‘Labour conditions are optimal’.

For the Criterion ‘Labour conditions are optimal’ a single indicator was selected

→ no AMOEBA graph

Table 63. Results for selected indicator of Criterion ‘Labour conditions are optimal’ (2003).

Farm	Hours per year for farm labour [hours/VAK/year]
	HYFL 2003
DP_O	3588
D_C	3540
C_C	2668
DB_C	2963

Hours per year for farm labour is the lowest in C_C – The farms with animals have more hours per labour unit per year, than the farm with only crops.

V.4.4.32 Criterion 'Health of the farming community is acceptable'

Table 64. Sustainability Index (SI) for Criterion 'Health of the farming community is acceptable'.

Farm	SI 'Health of the farming community is acceptable'
	SI 'HFA' 2003
DP_O	1.00
D_C	1.00
C_C	1.00
DB_C	1.00

Figure 44. AMOEBA for Criterion 'Health of the farming community is acceptable'.

For the Criterion 'Health of the farming community is a single indicator was selected

→ no AMOEBA graph

Table 65. Results for selected indicator of Criterion 'Health of the farming community is acceptable' (2003).

Farm	Days of working incapacity [number]
	DWI 2003
DP_O	0
D_C	0
C_C	0
DB_C	0

None of the farmers has been incapable to work because of illness or injury.

V.4.4.33 Criterion 'Education of farmers and farm workers is optimal'

Table 66. Sustainability Index (SI) for Criterion 'Education of farmers and farm workers is optimal'.

Farm	SI 'Education of farmers and farm workers is optimal'
	SI 'EFO' 2003
DP_O	1.0
D_C	1.0
C_C	1.0
DB_C	1.0

Figure 45. AMOEBA for Criterion 'Education of farmers and farm workers is optimal'.

For the Criterion 'Education of farmers and farm workers is optimal' is a single indicator was selected

→ no AMOEBA graph

Table 67. Results for indicators of Criterion 'Education of farmers and farm workers is optimal' (2003).

Farm	Extra courses [binary]
	EC 2003
DP_O	1
D_C	1
C_C	1
DB_C	1

All farmers follow extra courses.

V.4.4.34 Criterion 'Family situation, including equality in the man-woman relation is acceptable'

Table 68. Sustainability Index for Criterion 'Family situation, including equality in the man-woman relation is acceptable'.

Farm	SI 'Family situation, including equality in the man-woman relation is acceptable'
	SI 'FSA' 2003
DP_O	1.0
D_C	1.0
C_C	1.0
DB_C	1.0

Figure 46. AMOEBA for Criterion 'Family situation, including equality in the man-woman relation is acceptable'.

For the Criterion 'Family situation, including equality in the man-woman relation is acceptable', a single indicator was selected

→ no AMOEBA graph

Table 69. Results for indicators of Criterion 'Family situation, including equality in the man-woman relation is acceptable' (2003).

Farm	Equality man-woman status [binay]
	EMW 2003
DP_O	1
D_C	1
C_C	1
DB_C	1

There is no observed difference between the farms concerning this criterion. All farms have perfect equality man and woman with respect to status.

V.4.4.35 Criterion 'Family access to and use of social infrastructures and services is acceptable'

Table 70. Sustainability Index (SI) for Criterion 'Family access to and use of social infrastructures and services is acceptable'.

Farm	SI 'Family access to and use of social infrastructures and services is acceptable'
	SI 'FAUSI' 2003
DP_O	0.00
D_C	0.50
C_C	0.33
DB_C	0.83

Figure 47. AMOEBA for Criterion 'Family access to and use of social infrastructures and services is acceptable'.

For the Criterion 'Family access to and use of social infrastructures and services is acceptable' is a single indicator was selected

→ no AMOEBA graph

Table 71. Results for indicators of Criterion 'Family access to and use of social infrastructures and services is acceptable' (2003).

Farm	Distance to administration services [km]
	DAS 2003
DP_O	6
D_C	3
C_C	4
DB_C	1

The observed difference for this criterion is explained by only one indicator. Table 67 shows that the DPo farmer has to travel 6 km for the nearest administration services, whereas the DBc only 1 km.

V.4.4.36 Criterion ‘Family integration in the local and agricultural society is acceptable’

Table 72. Sustainability Index for Criterion ‘Family integration in the local & agricultural society is acceptable’.

Farm	SI ‘Family integration in the local and agricultural society is acceptable’
	SI 'FILAS' 2003
DP_O	1,0
D_C	1,0
C_C	0,0
DB_C	1,0

Figure 48. AMOEBA for Criterion ‘Family integration in the local and agricultural society is acceptable’.

For the Criterion ‘Family integration in the local and agricultural society is acceptable’ is a single indicator was selected

→ no AMOEBA graph

Table 73. Results for indicators of Criterion ‘Family integration in local & agricultural society is acceptable’ (2003).

Farm	Membership non-agricultural organisations[binary]
	MNAO 2003
DP_O	1
D_C	1
C_C	0
DB_C	1

Family integration is perfectly acceptable for all farms except for the Cc farm. As table 69 shows, this is totally explained by the fact that the C_c farmer is not a member of a non-agricultural organisation.

V.4.4.37 Criterion ‘Farmer’s feeling of independency is satisfactory’

Table 74. Sustainability Index (SI) for Criterion ‘Farmer’s feeling of independency is satisfactory’.

Farm	Farmer's feeling of indepedency is satisfactory
	SI 'FFIiS' 2003
DP_O	0.63
D_C	0.50
C_C	0.25
DB_C	0.63

Figure 49. AMOEBA for Criterion ‘Farmer’s feeling of independency is satisfactory’ picturing Sustainability Indexes of related indicators.

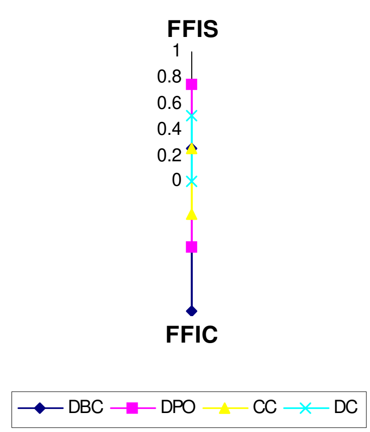


Table 75. Results for indicators of Criterion ‘Farmer’s feeling of independency is satisfactory’.

Farm	Farmer's feeling of independency of subsidies [scale 1 to 5]	Farmer's feeling of independency of contracts [scale 1 to 5]
	FFIS 2003	FFIC 2003
DP_O	2	3
D_C	3	/
C_C	4	4
DB_C	4	1

The feeling of independency is the least satisfactory for the Cc farm, with no big differences between the other farms. As table 71 shows, this is mostly explained by his lower feeling of independency of contracts. This is possibly because this farm has more return under contract than the other farms.

V.4.4.38 Criterion ‘Amenities are maintained / increased’

For this criterion, the indicator ‘Amenities’ was selected, but not calculated.

V.4.4.39 Criterion ‘Pollution levels are reduced’

Table 76. Sustainability Index (SI) for Criterion ‘Pollution levels are reduced’.

Farm	SI ‘Pollution levels are reduced’
	SI 'PLR' 2003
DP_O	0.00
D_C	1.0
C_C	1.0
DB_C	1.0

Figure 50. AMOEBA for Criterion ‘Pollution levels are reduced’.

For the Criterion ‘Pollution levels are reduced’ is a single indicator was selected

→ no AMOEBA graph

Table 77. Results for selected indicators of Criterion ‘Pollution levels are reduced’ (2003).

Farm	Noise effect [binary]
	NE 2003
DP_O	0
D_C	1
C_C	1
DB_C	1

Only the DP_O farm does not hold into account possible nuisance for his neighbours because of noise when farming – As the ‘Distance to administration services’ indicator shows, this farm is 6 km away from administration services. So possibly there are fewer neighbours who could be bothered by the noise coming from his farming activity.

V.4.4.40 Criterion 'Production methods are acceptable'

Table 78. Sustainability Index (SI) for Criterion 'Production methods are acceptable'.

Farm	SI 'Production methods are acceptable'
	SI 'PMA' 2003
DP_O	1.0
D_C	1.0
C_C	/
DB_C	1.0

Figure 51. AMOEBA for Criterion 'Production methods are acceptable'.

For the Criterion 'Production methods are acceptable' is a single indicator was selected

→ no AMOEBA graph

Table 79. Results for selected indicators of Criterion 'Production methods are acceptable' (2003).

	Livestock welfare [scale: 0, 1, 2 →3]
Farm	LW 2003
DP_O	3
D_C	3
C_C	/
DB_C	3

V.4.4.41 Criterion 'Quality and taste of food is maintained/increased'

There were no indicators selected to represent this criterion.

V.4.4.42 Criterion 'Equity is maintained/increased'

The indicator 'Ratio income received by the highest earning 20% and the lowest earning 20%' was selected for this criterion. As this indicator is only measured and expressed at the regional level, it is not presented here. Full results can be found in annex X.

V.4.4.43 Criterion 'Stakeholder involvement is maintained/increased'

Table 80. Sustainability Index (SI) for Criterion 'Stakeholder involvement is maintained/increased'.

Farm	SI 'Stakeholder involvement is maintained or increased'
	SI 'SIMI' 2003
DP_O	1.0
D_C	1.0
C_C	0.0
DB_C	1.0

Figure 52. AMOEBA for Criterion 'Stakeholder involvement is maintained/increased'.

For the Criterion 'Stakeholder involvement is maintained or is a single indicator was selected

→ no AMOEBA graph

Table 81. Results for selected indicators of Criterion 'Stakeholder involvement is maintained / increased' (2003).

	Open houses [binary]
Farm	OH 2003
DP_O	1
D_C	1
C_C	0
DB_C	1

There is one farm which doesn't do open houses, namely the C_C – Farms with no animals are less attractive to the public than farms with animals. The C_C farm has only crops, so most of the farming activity is actually performed not on the farm but on the fields, which makes it less suitable to do open houses.

V.4.4.44 Criterion 'Educational and scientific value features are maintained / increased'

Table 82. Sustainability Index (SI) for Criterion 'Educational and scientific value features are maintained /increased'.

Farm	SI 'Educational and scientific value features are maintained or increased'
	SI 'ESVMI' 2003
DP_O	1.0
D_C	1.0
C_C	0.0
DB_C	1.0

Figure 53. AMOEBA for Criterion 'Educational and scientific value features are maintained /increased'.

For the Criterion 'Educational and scientific value features are maintained/increased is a single indicator was selected

→ no AMOEBA graph

Table 83. Results for indicators of Criterion 'Educational and scientific value features are maintained /increased'.

	Open houses (binary)
Farm	SI 'OH' 2003
DP_O	1.00
D_C	1.00
C_C	0.00
DB_C	1.00

V.4.4.45 Criterion 'Cultural and spiritual heritage value features are maintained/increased'

There were no indicators selected to represent this criterion.

VI CONCLUSIONS

VI.1 SAFE

In the last couple of years, the sustainability of agricultural systems has become a major concern for scientists, policy makers, environmental NGOs and farmers. Indeed, it is today widely accepted that successive political reforms and the intensification of agricultural practices might have long term consequences both on the productivity of the sector as well as the availability and quality of natural resources. Therefore, sustainability is now regarded as a crucial property of agricultural systems and its evaluation has become a main challenge for scientists, policy makers and farmers.

SAFE (**'Framework for Assessing Sustainability levels in Belgian agricultural systems')** proposes a means for answering the question 'how sustainable are agricultural systems in Belgium?'

The **SAFE methodology** (hierarchical framework, indicator selection procedure & integration procedure) was developed and used to create the **SAFE tool**. The quality of this method ensures the consistency, soundness and practicability of the tool.

1. **The SAFE methodology**. It is universal - in the sense that it can be used to assess sustainability levels in other geographical and/or sectorial contexts - and it consists in 3 steps corresponding to chapters 2,3 and 4 of this report:

Step 1 The *'SAFE hierarchical framework' (P, C & I)* defines the multi-functions that a farm should maintain or enhance in order to be sustainable. It participates to a coherent and consistent formulation of sustainability indicators.

Step 2 The *'SAFE selection procedure'* allows the determination of a core and coherent list of performing and relevant sustainability indicators (this list being, conversely to the selection procedure, specific to the geographical and sectorial context).

Step 3 *The 'SAFE integration procedure'* aggregates the indicators level by level, all along the P, C & I table and until the final formulation of a global sustainability index 'SI_g'. Moreover, the construction of AMOEBA graphs at each step of the process helps in understanding the results of the sustainability assessment in one or several farms at the same time.

2. **The SAFE tool**. This instrument allows the assessment of sustainability levels in agricultural systems. It consists in 3 successive steps and is specific to the Belgian agricultural context (Figure 54).

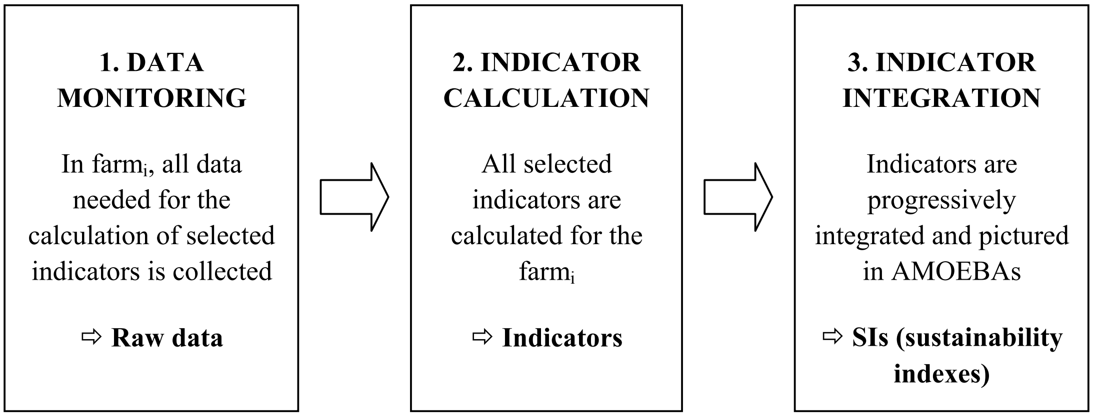


Figure 54. The SAFE tool assesses the sustainability level (SI_t) of a farm in three steps.

Significant achievements

SAFE provides Belgium for the first time with a tool for measuring sustainability levels in agricultural systems with a holistic approach. The most significant achievements are:

1. An agricultural sustainability assessment that considers **the environmental, economic & social pillar**
2. A **coherent list of performing and relevant sustainability indicators** that is the output of a selection based on the knowledge and experience of numerous **experts**
3. **Sustainability indicators are progressively integrated into an overall Sustainability Index**. This confers to the results of the sustainability assessment a certain ease of interpretation and use. It also provides SAFE with polyvalence: while scientists are expected to pay more attention to indicators, other stakeholders and policy makers will find in Sustainability Indices a decent means for communication and decision making
4. An agricultural sustainability assessment at **three spatial levels: (1) parcel (2) farm** and **(3) landscape**. Only a few studies deal with sustainability at field or farm level. Rather, they focus on national or international levels. Our approach makes the important link between farm management and its impacts on sustainability possible.

Future improvements

Despite the progress accomplished in the definition of sustainability indicators by SAFE, it would be naïve to believe it is an accomplished tool. It can certainly be improved:

1. The list of indicators selected is quite exhaustive, mainly because of the will to cover 'all' aspects lying behind the concept of agricultural sustainability. This has two consequences: (a) the application in practice of SAFE is time-consuming; (b) the calculation and the interpretation of all selected indicators require much competency in many different domains. Therefore, applying SAFE at a large scale (in terms of number of agricultural systems) will imply a shorter list of selected indicators, a standardization of both data collection and indicator calculation and collaboration between scientists.

2. Two crucial points will require further exploration in future research: the definition of normalisation functions and the determination of the respective weights of the indicators within each Criterion. These two elements are at the core of SAFE and therefore deserve to be defined with 'state of the art' techniques.

3. 'It is logically impossible to evaluate the contribution of a strategy (i.e. a given agricultural practice) to agricultural sustainability when adherence to that approach has already been used as a criterion for evaluating sustainability' (Hansen, 1996). In the SAFE framework, many means-based indicators[25] are included and used to assess agricultural sustainability (e.g. proportion of the AA under organic farming contract, proportion of the AA under M.A.E. contract, tillage pressure…). If one plans to use SAFE to identify locally more appropriate strategies (e.g. compare organic to conventional farming), these indicators should be carefully ejected of the SAFE framework in order to avoid circular logic.

4. So far, SAFE has implemented for each criterion a series of indicators and for some indicators a series of verifiers has been proposed. In some cases, alternative verifiers can be proposed for an indicator or alternative indicators for a criterion. Differences in assessment may be expected if different verifiers and indicators are used. Therefore, a need exist to validate the indicator selection and calculation procedure (i.e. the verifier definition). This could be done by indicator inter-comparison programs, intensive sensitivity analysis, robustness analysis of indicator calculation procedure, etc.

5. Facilitating indicator calculations by developing an appropriate DSS tools (Decision Support System). Within SAFE, a prototype of an integrated assessment tool was designed and tested on 4 Belgian farms. Yet, the final assessment needed an intensive and labor intensive phase of data collection, data structuring, modeling, interpretation and aggregation. The actual proto-type does not allow to asses sustainability level at larger spatial scales and smaller time spans. Therefore, a need exist to integrate the data collection and indicator calculation procedures into operational decision support systems. Such systems should be based on a critical analysis of data quality and data processing procedures, with a particular attention to the propagation of the uncertainty into the final assessment. These systems should be based on efficient state of the art data handling and information processing technology.

VI.2 Stakeholders opinion on the SAFE tool

On the basis of personal meetings, the SAFE partners have transmitted and explained results of sustainability assessment (SA) to **farm managers**. Two main comments emerged from these discussions:

1. SAFE is a *tool that is still a bit too abstractive for the farmers*. Good care should be taken to explain them how SA results should be interpreted (examples: SA results do not aim at stating whether a farm is sustainable or not; the intrinsic meaning of SIs is limited and SIs should rather be interpreted in comparison with other farms; the hierarchical structure of the framework and thus of SIs should be born in mind…)

2. Farmers showed much enthusiasm for the SAFE tool and, more particularly, for results of the SA in their own farm. As it was said before, discussions between scientists and farmers about their SA results did not lead to advices about specific changes for on-farm management that would allow reaching higher sustainability levels (even if suggestions were made). It was obviously not the objective of this project. However, the SAFE framework really appeared as a very *sound and effective communication tool between the farmer and the scientist to explain all the issues that are encompassed in the concept of farm sustainability.* It also gives an opportunity to discuss some of them in more details (e.g. greenhouse gases and ammonia emissions, an environmental aspect that farmer are not yet fully aware of).

[25] Means-based indicators are indicators that are based on strategies adopted and implemented in an agricultural system (e.g. tillage pressure, percentage of the agricultural area that is under 'environmentally friendly' management, …).

VI.3 Policy implications

PRELIMINARY NOTE: SAFE has not yet been applied to a representative sample of Belgian farms (it was, so far, only tested on four farms). It is thus not possible for the team to make recommendations on the relative sustainability of agricultural practices, labels, etc. or any kind of conclusions based on these results.

Recommendation 1

Agricultural sustainability is an ill-defined concept that covers many different issues (environmental, economic and social). Furthermore, research projects in this field are often based on multi-disciplinary teams, which sometimes define identical concepts differently. Within this project, we first defined the concept of agricultural sustainability using common and transversal definitions for its components: the PC&I framework. This framework also offered operationality by providing a sound basis for the coherent and easy formulation of sustainability indicators and their reference values.

For future research

We recommend the use of the **PC&I hierarchical framework as a common framework for the definition of agricultural sustainability at the farm level**. This framework is a solid basis for further research in the field of agricultural sustainability and has already been used for this purpose. For example, the SAFE framework as a guide to screen the literature for the impact of various erosion control measures in Belgium. This approach has ensured that all relevant principles and criteria have received attention. Moreover, the approach made it easier to identity gaps in the existing research.

For policy makers

We suggest using the 'PC&I' framework as a common frame for appropriate communication between scientists, decision makers, farmers and citizens/consumers. However, further simplification, refinement and improvement of the framework by communication specialists would be necessary. Only then a extension/sensibilisation operation by farmers and/or citizens is conceivable and this is a preliminary and essential step in the process of moving towards more sustainable farming systems/agriculture.

Recommendation 2

Time, knowledge and human resources were too scarce – and this despite the multi-disciplinary character of the team – to cover all tackled challenges (e.g. social issues, integration of indicators, standardisation ensuring the operationality of the tool, data collection protocols for a high number of farms…). Indeed, both a development and routine application of an sustainability assessment tool require many different competences and a tremendous amount of work. This should not be considered as an easy obstacle to overcome and certainly requires further and continuous investment.

For policy makers

Depending on government priorities, we recommend the **creation of a Sustainability Assessment (SA) platform for farms.** It would consist of a multi-disciplinary team with general (leadership, coordination and communication) and specific knowledge (strong environmental, social, economic, technical and informatics background), in collaboration with external experts for the validation of practical tools[26]. This is in order to:

1. **Start monitoring the sustainability of Belgian/regional farms.** This would allow: (1) the identification of areas were policy measures are the most-needed; (2) pollution control of our farms; (3) the comparison of the sustainability of production labels (conventional, organic…) and agricultural practices; (4) to highlight interrelations – synergies, trade-offs,… - between different sustainability components (there is an increasing need to deal with different sustainability issues in a

[26] For the selection of sustainability indicators (continuous process), it would be very efficient to organize discussions between experts to come to an agreement on which indicators to select (Delphi method).

more integrated manner, to ensure that when taking policy/management measures we do not replace one type of unsustainability by another. This important issue has so far not received sufficient attention by policy makers).

NOTE: Two types of trade-offs exist: *between issues* (e.g. solving one type of environmental pollution in the farm by creating another[27]; or trying to reach environmental sustainability by creating economic unsustainability) and *between systems* (not only the farm should be considered but also the whole food production chain and the whole local system). This need for completeness (the largest system and as many issues as possible being considered) seems however like utopia. Therefore, a balance (completeness Vs incompleteness) has to be found when choosing for the system and issues to cover and ways to reach it also (e.g. tight collaborations between research projects through the sustainability platform).

2. **Ensure a continuous improvement of the tool:** (1) Further elaboration of the integration process is required - especially concerning the identification of reference values and the definition of weights between sustainability issues; (2) Optimal set of core indicators should evolve as monitoring strategies, technologies and performances evolve. For instance, a continuous selection process for indicators and their corresponding verifiers would be necessary; (3) Simplification and standardization of the tool to increase its practicability.

NOTE**:** *How to increase the operationality of the SA tool?* Within SAFE so far, a prototype of an integrated assessment tool was designed and tested on 4 Belgian farms. The actual prototype does not allow to asses sustainability on a larger spatial scale (i.e. an important number of farms) and at smaller time scales (i.e. one year). Therefore, a need exist to integrate and standardize the data collection procedures, indicator calculation and indicator integration procedures into operational Decision Support Systems. In addition, it will also possibly require a shorter list of selected indicators (by selecting part the most important of the PC&I framework in function of the objective and the geographical and sectorial context).

Recommendation 3

For farmers

There is a need to both facilitate the collection of data related to farm management and increase its reliability (e.g. calculation of indicators related to the European Nitrate Directive). Therefore, in terms of data delivery, we advise the **use in farms of standardized logbooks for detailed recording of fields/stables operations -** such as the one developed and used in SAFE. This would enable efficient and reliable monitoring of farms by scientists/administration (SA tools or pollution control in farms). Such logbooks would also undoubtly be very useful for farmers themselves as they would help them to improve the management of their farms (today, many farmers have already adopted such systems on a voluntary basis). These logbooks could be slightly adapted and completed fort collecting a wider range of data that could be used for calculating not only economic but also environmental and social indicators.

NOTE: This statement could also be extended to accountancy reports. Their use could be generalized and their structure and content standardized.

[27] Example: what is the global environmental impact of composting? We can even go further by debating whether organic farming is more sustainable and thus whether it does 'deserve' financial support?

VI.4 Usefulness of the research

Is it useful to measure sustainability?

The intrinsic meaning of SI_t and sustainability indices in general (i.e. the results of a SA in a farm) is highly questionable. Such SA tools (e.g. SAFE) are therefore not appropriate to state whether a farm is sustainable (SI_t = 1) or not (SI_t=0), especially when considering the fact that its sustainability also depends on the sustainability of up-stream and down-stream related activities and/or on completely unpredictable events (environmental, social…). Besides, would such a statement be of any help? How will a farmer react when a scientist will tell him that his farm is not sustainable? Isn't more important to know how to reach higher sustainability levels?

Rather, the analysis of SI_t and sustainability indices in general can be confined to a **relative assessment between farms**: a higher sustainability level in farm a than in farm b simply means that a is likely to be more sustainable than b. So, the obtained SI_t should be considered as **a guide to identify in an objective way environmental, social or economic strengths and weaknesses of farm(s)**, or could be used to **quantify future management goals**.

Who are the targeted end-users and what are the potential applications of the tool?

SAFE is a Decision Support System for moving towards more sustainable agricultural systems. It is meant to be used by **scientists as an intermediary for (1) policy makers and (2) farmers**. Provided that the tool is adapted according to the application type, potential applications could include:

1. Communication tool between scientists, decision makers and citizens. Sustainability indices (SI_t, SI_{env}…) could be used as an efficient and easily understandable message for public

2. Monitoring standards for certification schemes and market labels interested in displaying a sustainable character

3. Contributing to policy supervision such as cross compliance in the CAP framework, international obligations (e.g. Kyoto Protocol) or management agreements (e.g. agri-environmental measures)

4. Environmental monitoring of administrative regions (pollution control, biodiversity monitoring). This would help to locate regions where policy measures supportive of a more sustainable agriculture are the most needed

5. Development and improvement of farms through partnerships between agronomists and farmers: scientists perform and interpret results of SA, define yearly objectives and provide farmers with guidance to reach these

6. Comparison of farming systems (e.g. integrated, conventional and organic) agricultural practices so as to identify those that are the most sustainable. In practice:

   - Ejection of all 'strategy-based[28]' indicators out of the SAFE framework. These agricultural features are not part of the SA tool anymore but are calculated to characterize the farms in terms of which agricultural practices, labels or measures are implemented in it.

[28] Indicators expressing the degree to which a given farm management strategy, supposedly 'sustainability-supportive', is implemented in an agricultural system (e.g. agri-environmental measure, organic farming, zero-tillage…).

- For a specific strategy (e.g. organic farming), identify all sustainability components in the PC&I susceptible of being influenced by the given strategy and exclude the others - and their related indicators - of the framework

- Perform a SA with the modified SAFE framework in a representative number of farms implementing to various degree the targeted strategy

- Study correlations between SA results and the value taken by the 'strategy-based' indicators

- Conclusions on the contribution of the strategy to the sustainability of the farm

NOTE: While this methodology presents the risk of not being able to show correlations (because of the high number of indicators included in the SA tool), it presents the advantage to consider trade-offs. Furthermore, the reduction in the number of indicators done in step a and b should help in showing correlations if any between 'strategy-based' indicators and sustainability.

VII DISSEMINATION

VII.1 SAFE Website

The **project-website**, which was created in the first project year, has been updated in 2003. It now contains a full description of the different project partners and their tasks next to general information about the project concept, members of the users committee, participation in conferences and a list of the first publications:

http://www.geru.ucl.ac.be/recherche/projets/Safe/publications/index.htm

VII.2 Publications

VII.2.1 Posters

Sauvenier X., Bielders C., Brouckaert V., Garcia V., Hermy M., Mathijs E., Muys B., Valckx J., Van Cauwenbergh N., Vanclooster M., Wauters E. and Peeters A., 2004. SAFE – a framework for assessing sustainability levels in agricultural systems. XX International Grassland Congress, Dublin, Ireland, June-July 2005.

Sauvenier X., Bielders C., Hermy M., Mathijs E., Muys B., Valckx J., Van Cauwenbergh N., Vanclooster M., Wauters E. and Peeters A., 2004. SAFE – a tool for assessing sustainability levels in agricultural systems. XX International Grassland Congress, Dublin, Ireland. Oxford Satellite Workshop 3rd, UK, July 2005.

Sauvenier X., Bielders C., Hermy M., Mathijs E., Muys B., Valckx J., Van Cauwenbergh N., Vanclooster M., Wauters E. and Peeters A., 2004. SAFE – a tool for assessing sustainability levels in agricultural systems: illustration. XX International Grassland Congress, Dublin, Ireland. Oxford Satellite Workshop 3rd, UK, July 2005.

Van Cauwenbergh N., Brouckaert V., Valckx J., Bielders C., Hermy M., Mathijs E., Muys B., Vanclooster M. and Peeters A., 2004. Framework for assessing the Sustainability of Agricultural Systems: the SAFE concept. Sixth International Farming Association Symposium, Vila Réal, Portugal, April 2004.

Van Cauwenbergh N., Brouckaert V., Valckx J., Bielders C., Hermy M., Mathijs E., Muys B., Vanclooster M. and Peeters A., 2004. Framework for assessing the Sustainability of Agricultural Systems: the SAFE concept – preliminary results. Sixth International Farming Association Symposium, Vila Réal, Portugal, April 2004.

VII.2.2 Proceedings

Brouckaert V., Peeters A., Biala K., Garcia V., Hermy M., Muys B., Van der Veken B., Mathijs E., Franchois L., Vanclooster M., Bielders C. and Van Cauwenbergh N., 2004. A method for assessing sustainability levels in agricultural systems (SAFE). In "Land Use Systems in Grassland Dominated Region". Lüscher A., Jeangros B., Kessler W., Huguenin O., Lobsiger M., Millar N. and Suter D. (eds.). AGFF 9: 94-96.

Brouckaert V., Peeters A., Biala K., Garcia V., Hermy M., Muys B., Van der Veken B., Mathijs E., Franchois L., Vanclooster M., Bielders C. and Van Cauwenbergh N., 2004. A method for assessing sustainability levels in agricultural systems (SAFE). In "Land Use Systems in Grassland Dominated

Region. Book of abstracts". Lüscher A., Jeangros B., Kessler W., Huguenin O., Lobsiger M., Millar N. and Suter D. (eds.). AGFF 9: 16.

VII.2.3 Articles

Biala K., Peeters A., Muys B., Hermy M., Brouckaert V., Garcia V., Van der Veken B. and Valckx J., 2003. Biodiversity indicators as a tool to assess sustainability levels of agro-ecosystems with a special consideration of grassland areas. In "Sustainable grazing, nutritional utiliszation and quality of sheep and goat produc. Abstracts". First joint seminar of the FAO-CIHEAM sheep and goat nutrition and mountain and Mediterranean pastures sub-networks, Granada, Spain. CSIC: 113.

Maljean J.F., Brouckaert V., Van Cauwenbergh N. and Peeters A., 2004. Assessment, monitoring, implementation and improvement of farm management for environmental and sustainable agriculture purposes: A Belgian Perspective (Walloon Region). Laboratoire d'Ecologie des Prairies, UCL, Agricultural Engineering Unit, KUL: 31 pp.

Peeters A., Biala K., Brouckaert V., Garcia V., Hermy M., Muys B., Van der Veken B., Valckx J., Mathijs E., Franchois L., Vanclooster M., Bielders C., Reijnders J. and Van Cauwenbergh N., 2003. Preliminary ideas on the development of a framework for assessing sustainability levels in agricultural systems (SAFE). In "Sustainable grazing, nutritional utiliszation and quality of sheep and goat produc. Abstracts". First joint seminar of the FAO-CIHEAM sheep and goat nutrition and mountain and Mediterranean pastures sub-networks, Granada, Spain. CSIC: 114.

Peeters A., Maljean J.F., Biala K. and Brouckaert V., 2004. Les indicateurs de biodiversité pour les prairies: un outil d'évaluation de la durabilité des systèmes d'élevage. Fourrages 178: 217-232.

Van Cauwenbergh N., Bielders C., Vanclooster M. and Peeters A., 2004. Agri-environmental indicators for soil and water as a tool for integrated sustainable assessment. In "Integrated methods for assessing water quality". COST629. Unité de Génie rural, UCL: 118-126.

A trilogy of articles has been submitted to the journal *Agriculture, Ecosystems and Environment:*

1. Van Cauwenbergh N., Biala K., Bielders C., Brouckaert V., Franchois L., Garcia V., Hermy M., Mathijs E., Muys B., Reijnders, Valckx J., Vanclooster M., Van der Veken B. and Peeters A. (in press). "Towards a Framework for assessing sustainability levels of agricultural systems – SAFE".
2. SAFE's selection and integration procedure.
3. SAFE's case study.

VII.2.4 Intermediary & final reports

Brouckaert V., Peeters A., Hermy M., Muys B., Mathijs E., Vanclooster M., Bielders C., Franchois L., Reijnders J., Van der Veken B. and Garcia V., 2002. Framework for assessing sustainability levels in Belgian agricultural systems – SAFE. Annual report 2002. Laboratoire d'Ecologie des Prairies, UCL, Laboratorium voor Bos, Natuur en Landschap, KUL: 41 pp + annex.

Brouckaert V., Van Cauwenbergh N., Biala K., Bielders C., Franchois L., Garcia V., Hermy M., Mathijs E., Muys B., Reijnders J., Valckx J., Vanclooster M., Van der Veken B. and Peeters A , 2003. Framework for assessing sustainability levels in Belgian agricultural systems – SAFE. Framework for assessing sustainability levels in Belgian agricultural systems – SAFE. Part 1: Sustainable production and consumption patterns (SPSD II). Annual intermediary report 2003. Belgian Science Policy: 37 pp + annex.

Sauvenier X., Brouckaert V., Van Cauwenbergh N., Garcia V., Goyens S., Valckx J., Wauters E., Bielders C., Hermy M., Mathijs E., Muys B., Vanclooster M. and Peeters A (2003). Framework for assessing sustainability levels in Belgian agricultural systems – SAFE. Part 1: Sustainable production and consumption patterns (SPSD II). Final report. Belgian Science Policy (BSP). Brussels.

VII.3 Participation at workshops, conferences, congress

2004

Sixth International Farming Association Symposium, Vila Réal, Portugal, April 2004.

20th General Meeting EGF 2004, Luzern, Switzerland 21-24 June 2004.

Eurosoil conference, Freiburg, Germany, September 2004.

COST action 629: Integrated methods for assessing water quality. Louvain-la-Neuve, Belgium, October 2004.

2005

1st Cluster Project Sustainable Agriculture Workshop, Brussels, Belgium, January 2005.

XX International Grassland Congress, Dublin, Ireland, June-July 2005

XX International Grassland Congress, Dublin, Ireland – Oxford Satellite Workshop, July 2005

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