SAFE

Framework for Assessing Sustainability levels in Belgian agricultural systems

This project was funded by the Belgian Federal Science Policy office

'Framework for Assessing Sustainability levels in Belgian agricultural systems' (SAFE) was a three-year project (2003-2005) funded by the Belgian Federal Science Policy Office (ex-OSTC) within the scope of SPSD II (Scientific Support Plan for a Sustainable Development Policy / Part 1: sustainable production and consumption patterns). The project was executed by a multi-disciplinary team:

Unité d'Ecologie des Prairies (ECOP-UCL) Prof. A. Peeters Ir. X. Sauvenier *Coordination* *Air, energy, nitrates, agricultural biodiversity & farming system*	Unité de Génie Rural (GERU-UCL) Profs. C. Bielders & M. Vanclooster Ir. N. Van Cauwenbergh *Air, soil & water*	Laboratorium voor Bos, Natuur en Landschap (LBNL-KUL) Profs. M. Hermy and B. Muys Ir. J. Valckx *Biodiversity & landscape*	Centrum voor landbouw- en voedseleconomie (CAFE-KUL) Prof. E. Mathijs Ir. E. Wauters *Social & economic aspects*
ECOP	Génie Rural UCL	LABORATORIUM VOOR BOS, NATUUR EN LANDSCHAP	125 FLTBW

This booklet is a synthesis of the SAFE final report. All scientific references and further information can be found in:

Sauvenier X., Valckx J., Van Cauwenbergh N., Wauters E., Bachev H., Biala K., Bielders C., Brouckaert V., Franchois L., Garcia-Cidad V., Goyens, S., Hermy M., Mathijs E., Muys B., Reijnders, J., Vanclooster M., Van der Veken S. and Peeters A. (2005). 'Framework for assessing sustainability levels in Belgian agricultural systems – SAFE. Final scientific report'. Belgian Science Policy Office, Brussels: 116 pp. The SAFE final report, its annexes and the present booklet are downloadable from the SAFE website: http://www.geru.ucl.ac.be/

This booklet should be referred to as:

Sauvenier X., Valckx J., Van Cauwenbergh N., Wauters E., Bachev H., Biala K., Bielders C., Brouckaert V., Franchois L., Garcia-Cidad V., Goyens, S., Hermy M., Mathijs E., Muys B., Reijnders, J., Vanclooster M., Van der Veken S. and Peeters A. (2005) 'SAFE - Framework for assessing sustainability levels in Belgian agricultural systems'. Belgian Science Policy Office, Brussels: 23 pp.

Table of contents

Introduction

This booklet aims to introduce the results of the SAFE project to scientists, policy makers and administration officers working in the agricultural and environmental sectors. The **SAFE tool** offers a sound, flexible and practical tool for evaluating the sustainability of Belgian agricultural systems. The **SAFE methodology** offers a method for developing such tools in other geographical and sectorial contexts.

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 agreements 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 (Figure 1).

Figure 1
Sustainable farming deals with responsible use of natural resources such as: erosion control (upper left, *C. Bielders*); prevention from water, air and soil pollution with persistent and/or toxic agricultural chemicals such as pesticides (upper right, *J.-F. Ledent*) and conservation of biodiversity (lower left, © *J. Mentens*). Agricultural sustainability is also concerned about the economic profitability of farms or the welfare of the rural community, the whole society and the farm animals (lower right, *V. Cielen*).

Introduction

In the last decade, different sets of sustainability indicators for agriculture have been designed both at national and international levels. Meanwhile, more practical environmental impact (EIA) assessment systems have also been developed at the farm level. However, these indicator sets cannot usually be used at both levels. 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 an increasing 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.

For the first time, **SAFE** provides Belgium with **a sound and flexible tool for evaluating the sustainability of agricultural systems**. In comparison with similar frameworks abroad, SAFE's originality rests on 5 main points (Table 1):

Table 1. Main characteristics of SAFE

1	**Holistic assessment of sustainability**. All three pillars of sustainability are considered: environmental, economic & social.
2	The backbone of the SAFE framework is **(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 the knowledge and experience of more than 25 experts.
3	SAFE has been built with a **generic methodology**, though the set of selected sustainability indicators is specific to the Belgian agricultural context. The method developed for the construction of the SAFE tool can be transferred for assessing sustainability in other geographical (Europe, World) and sectorial contexts. In particular, principles and criteria defined in SAFE have a universal value.
4	A sustainability assessment that takes action at **three spatial scales: (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 social and economic issues.
5	The SAFE tool is **easy to interpret and to use**, thanks to the procedure for integration of indicators and the graphic expression of the results.

Apart from the theoretical construction of the tool, four farms with different production systems and agricultural practices were chosen for the testing of the SAFE tool and methodology. Data were collected on the farms for a period of two years to perform a first sustainability assessment with SAFE.

SAFE offers **a 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. For the development of the tool and the methodology the boundaries of the agricultural system were defined as explained in Box 1.

Box 1. Boundaries of the agricultural system in SAFE

In SAFE the agricultural system was restricted to **on-farm activities of the production cycle.** Down-stream activities (*i.e.* transport, food transformation and packaging) are not taken into account. Up-stream activities (*i.e.* fertilizer or biocide manufacturing and fossil fuel or phosphate extraction) are also excluded, except for the calculation of energy indicators and indirect CO_2 emissions. Including these input-related issues is important because it reflects the impact on sustainability of the farmer's choices of inputs (chemical nitrogen fertilizers namely).

The **horizontal scale** of the SAFE tool depends on the user-defined scale of application (Figure 2).

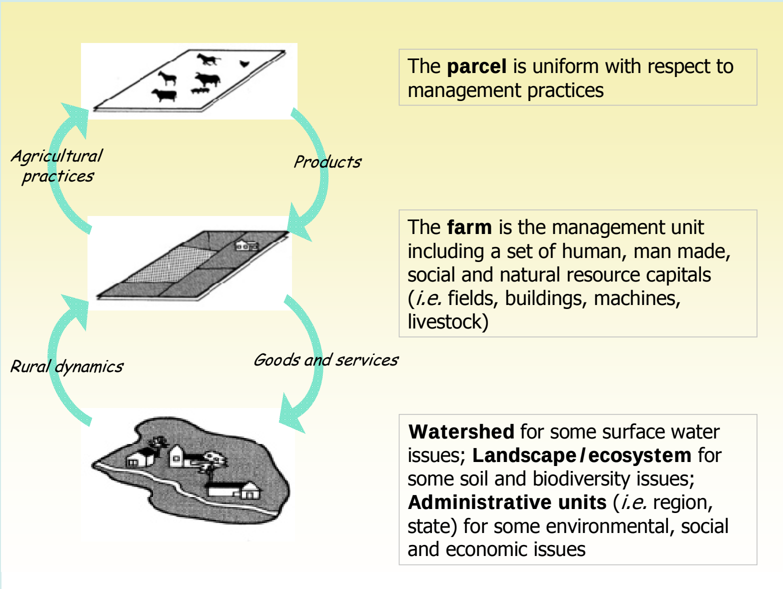


Figure 2. Scales of application of the SAFE tool

The **vertical scale** is limited to the biosphere. Effects on higher layers of the atmosphere (*e.g.* greenhouse gas emissions) or the geosphere (*e.g.* nitrate leaching to groundwater) are considered through the fluxes across the system boundaries.

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.

1. Hierarchical framework

Structure

The **hierarchical structure of Pillars, Principles, Criteria, Indicators and Reference Values** was used in SAFE to allow an easy, sound and coherent formulation of sustainability indicators (Figure 3):

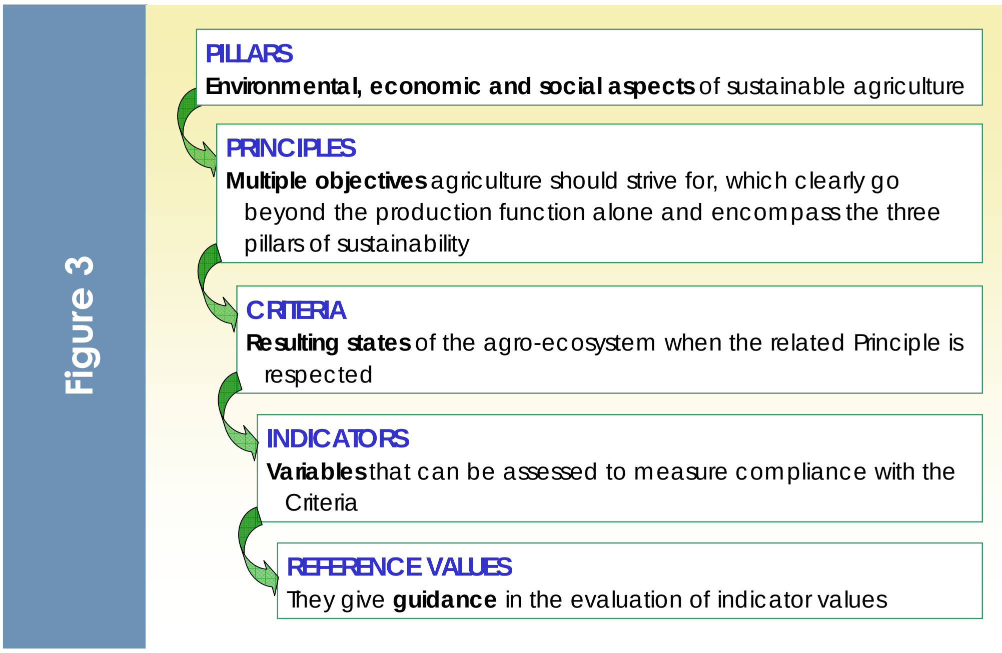


Figure 3. The hierarchical structure of the SAFE framework.

Content

Based on thorough investigation of the agricultural system by all SAFE partners, a list of Principles & Criteria for Sustainable Agriculture was defined: **the SAFE hierarchical framework** (Table 2).

For the environmental pillar, principles and criteria have been defined at the level of each natural resource (air, water, soil, energy, biodiversity) as well as at the level of the ecosystem itself (ecosystem integrity). For the different resources, a consistent set of principles and criteria was then derived by considering two main ecosystem functions: a buffer function against damaging effects and a stock or supply regulation function which describes the 'availability' of a resource both in terms of its quantity and quality.

For the economic pillar, only a single function was needed to evaluate the economic viability.

Four aspects have been taken into account in the social pillar: food security and safety, quality of life, social acceptability and cultural acceptability.

Table 2 The SAFE framework

Principles	Criteria
Environmental pillar	
Air	
Supply of quality air function	Air quality is maintained or increased
Air flow buffering function	Wind speed is adequately buffered
Soil	
Stock of soil function	Soil loss is minimised
Stock of quality soil function	Soil chemical quality is maintained or increased
	Soil physical quality is maintained or increased
Water	
Supply of water function	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	Surface water of adequate quality is supplied
	Soil water of adequate quality is supplied
	Ground water of adequate quality is supplied
Water flow buffering function	Flooding and run-off regulation function is maintained or increased
Energy	
Supply of energy function	Adequate amount of energy is supplied
Energy flow buffering function	Energy flow is adequately buffered
Biodiversity	
	A. Biotic resources
Stock of biotic resources function	Planned biodiversity is maintained or increased
	Functional part of natural/spontaneous biodiversity is maintained or increased
	Heritage part of natural/spontaneous biodiversity is maintained or increased
	B. Habitat resources
Stock of habitat function	Diversity of habitats is maintained or increased
Stock of qualitative habitat function	Functional quality of habitats is maintained or increased
Ecosystem integrity	
Ecosystem stability regulation function	Resistance and resilience of the ecosystem is maintained or increased
Economic pillar	
Viability	
Economic function	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	Production capacity is compatible with society's demand for food
	Quality of food and raw materials is maintained or increased
	Diversity of food and raw materials is maintained or increased
	Adequate amount of agricultural land is maintained
Quality of life	
Physical well-being of the farming community function	Labour conditions are optimal
	Health of the farming community is acceptable
Psychological well-being of the farming community function	Education of farmers and farm workers is optimal
	Family situation, including the man-woman equality, is acceptable
	Family access to and use of social infrastructures/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 society function	Amenities are maintained or increased
	Pollution levels are reduced
	Production methods are acceptable
	Quality and taste of food is maintained or increased
	Equity is maintained or increased
	Stakeholder involvement is maintained or increased
Cultural acceptability	
Information function	Educational and scientific value features are maintained or increased
	Cultural & spiritual heritage value features are maintained or increased

2. Selection procedure of sustainability indicators

Together with the hierarchical framework, SAFE's selection procedure of indicators ensures the identification of a **coherent list of indicators** for assessing sustainability levels in the studied system. This process involved contributions from more than 25 experts (see Acknowledgements). It consists in three main steps (Figure 4):

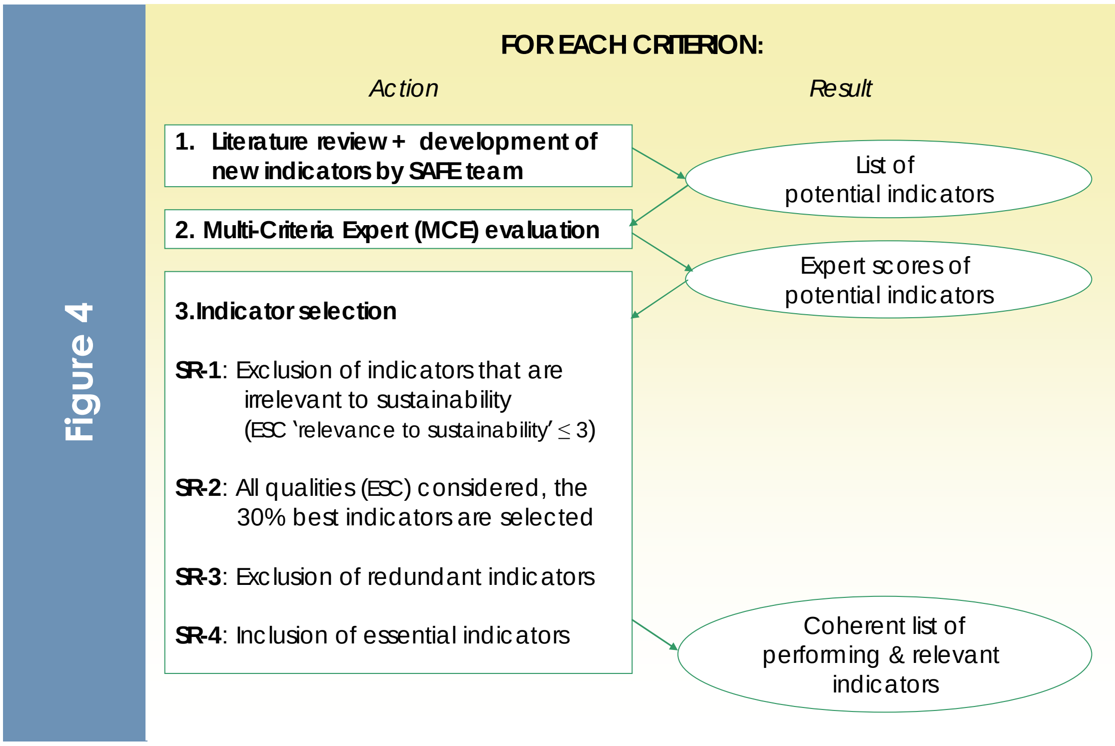


Figure 4. The 3 main steps in the SAFE indicator selection procedure. ESC: Expert Selection Criterion; SR: Selection rule (see below)

Step 1 - Literature review

Indicators used by international and national institutions, scientific teams and environmental NGOs were compiled on the basis of an extensive literature review and combined with indicators developed by the SAFE team into a list of 357 **potential indicators** covering the different aspects of the three sustainability pillars.

Step 2 - Multi-Criteria Expert (MCE) evaluation

Validation of potential indicators was carried out by experts (scientists, civil servants and farmers' representatives). Indicators and experts were thematically grouped in 4 panels: (a) Soil & water, (b) Biodiversity, (c) Socio-economics and (d) Air, energy & ecosystem integrity. For each panel, 10 experts from Flanders and Wallonia were invited to perform a multi-criteria evaluation against eight **Expert Selection Criteria (ESC)** (Table 3). Experts received detailed information on potential indicators and then assigned **expert scores** to each ESC for each indicator.

Table 3. Potential indicators are evaluated by experts against eight 'Expert Selection Criteria' (ESC)

	ESC	Description
1	Discriminating power in time	Ability to discriminate in time between changes due to external factors and changes due to management
2	Discriminating power in space	Ability to discriminate 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 understand, 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 for the sustainability aspect it is related to in the framework

Step 3 – Indicator selection

The selection work consists in four successive Selection Rules (SR) that are applied to potential indicators on the basis of the expert evaluation (see step 2). **SR-1 & 2** aim at narrowing the number of selected indicators to a **core set of relevant and performing indicators** with respect to each 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: (a) it 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 within the given sustainability aspect; (c) or it 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 thus ensure the **coherence of the list** of selected sustainability indicators.

Selected sustainability indicators

Table 4 presents the **coherent list of 87 relevant and performing sustainability indicators** selected by SAFE. Whereas Principles & Criteria are universally applicable, this set of indicators is specific to the Belgian agricultural context.

Table 4 Core list of sustainability indicators

Principles	Criteria	Indicators	Unit	Application scale
Environmental pillar				
Ecosystem integrity				
Ecosystem stability regulation function	Resistance and resilience of the ecosystem is maintained or increased	Ratio of net radiation flux and incoming net solar radiation	no unit	E
		Free net primary biomass productivity	$t.ha^{-1}$	E
Air				
Supply of quality air function	Air quality is maintained or enhanced	Greenhouse gases emissions (CH_4 & N_20)	$t\ eqCO_2.ha^{-1}.yr^{-1}$	F
		Indirect CO_2 emisions due to the use of synthetic N fertilizers	$t\ eqCO_2.ha^{-1}.yr^{-1}$	F
		Ammonia emission (NH_3)	$t\ eqA.ha^{-1}.yr^{-1}$	F
		Pesticide Risk Score (RS) to air	no unit [-10→10]	P/F
Air flow buffering function	Wind speed is adequately buffered	Land use pattern	no unit	W
Soil				
Stock of soil function	Soil loss is minimised	Water erosion risk	$t.ha^{-1}.yr^{-1}$	P/F
		Harvest erosion	$t.ha^{-1}$	P/C/F
		Tillage erosion risk	$t.ha^{-1}.yr^{-1}$	P/F
Stock of quality soil function	Soil chemical quality is maintained or increased	Soil analysis (organic C, N and P soil content, soil pH)	various	P/F
		Pesticide residues	no unit [-10→10]	P/F
		Nitrogen, Phosphorus and Potassium Annual Balance	$kg.ha^{-1}.yr^{-1}$	P/F
		Addition of heavy metals	$mg.kg^{-1}$	P/F
	Soil physical quality is maintained or increased	Soil organic carbon input	$kg.ha^{-1}$	P/F
		Soil carbon balance	$kg.ha^{-1}$	P/F
		Tillage pressure	$cm.yr^{-1}$	P/F
		Compaction risk	no unit	P/F
Water				
Supply of water function	Adequate amount of surface water is supplied	Surface water balance	$m^3.ha^{-1}$	W
	Adequate amount of soil moisture is supplied	Irrigation practices	%	F
		Drought stress	$number.yr^{-1}$	P/F
	Adequate amount of ground water is supplied	Groundwater level	m	P/F
		Water consumption	$m^3.yr^{-1}$	F
Supply of quality water function	Surface water of adequate quality is supplied	Pesticide runoff risk	$kg.ha^{-1}.yr^{-1}$	P/F/L
		Presence of grass strips/riparian areas	$m^2.ha^{-1}$	F/L
	Soil water of adequate quality is supplied	Pesticide residues	no unit [-10→10]	P/F
	Groundwater of adequate quality is supplied	Vegetation cover during nitrate leaching period	%	P/F
		Good agricultural practices	%	F
		Soil link rate - 2 (SL-2)	no unit	F
		Potentially Leachable Nitrogen - PLN	$kg\ N\text{-}NO_3.ha^{-1}$	P/F
		Nitrogen Systemic Balance (cropping plan scale) - NSB_{cp}	$kg\ N.ha^{-1}.yr^{-1}$	CP
Water flow buffering function	Flooding and run-off regulation function of the agro-ecosystem shall be maintained or enhanced	Runoff risk	$kg.ha^{-1}.yr^{-1}$	P/F/L
		Soil cover index	no unit	P/F/L
		Vegetation cover	%	P/F/L
		Presence of grass strips/riparian areas	$m^2.ha^{-1}$	F/L

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

Table 4 Core list of sustainability indicators - continued

PRINCIPLES	CRITERIA	INDICATORS	UNIT	APPLICATION SCALE
		ENERGY		
Supply of energy function	Adequate amount of energy is supplied	Direct energy output	$GJ.ha^{-1}$	F/R
Energy flow buffering function	Energy flow is adequately buffered	Direct energy input	$GJ.ha^{-1}$	F
		Renewable direct energy input	$GJ.ha^{-1}$	F
		Energy balance	$GJ.ha^{-1}$	F
		BIODIVERSITY		
		A. Biotic Resources		
Stock of biotic resources function	Planned biodiversity is maintained or increased	Number of crop species	n^r	F/R
		Number of threatened and rare crop varieties	n^r	F/R
		Number of livestock species	n^r	F/R
		Number of threatened and rare livestock breeds	n^r	F/R
	Functional part of natural/spontaneous biodiversity is maintained or increased	Total number of wild plant species in permanent grassland	n^r	P/F
		Soil biological activity	n^r	P
		Earthworm species saturation	%	P/F
	Heritage part of natural/spontanous biodiversity is maintained or increased	Butterfly species saturation	%	F/L
		Number of protected and Red List butterfly species	n^r	F/L
		Breeding bird species saturation	%	F/L
		Number of protected and Red List bird species	n^r	F/L
		Number of European Bird Directive species	n^r	F/L
		Wild flora species saturation	%	P/F/L
		Number of protected and Red List wild flora species	n^r	P/F/L
		Total number of wild plant species in permanent grassland	n^r	P/F
		Pesticide Risk Score to biodiversity (POCER-2 RS)	no unit [-10→10]	P/F
		Fertilizer pressure on Natura 2000 grasslands	U N, P $.ha^{-1}$	P/F
		Proportion of high biological value meadows in permanent grassland	%	F
		Existence of special devices for wild fauna	n^r	F
		B. Habitat Resources		
Stock of habitat function	Diversity of habitats is maintained or increased	Habitat saturation	%	F/L
		Agricultural area (AA) under management contract	ha	F/L
		AA managed for wild biota without management contract	ha	F/L
		AA under organic farming contract	ha	F/L
Stock of qualitative habitat function	Functional quality of habitats is maintained or increased	Density of linear landscape elements (LLE)	$m.ha^{-1}$	F/L
		Connectivity index (γ-index) of LLE network	no unit	F/L

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

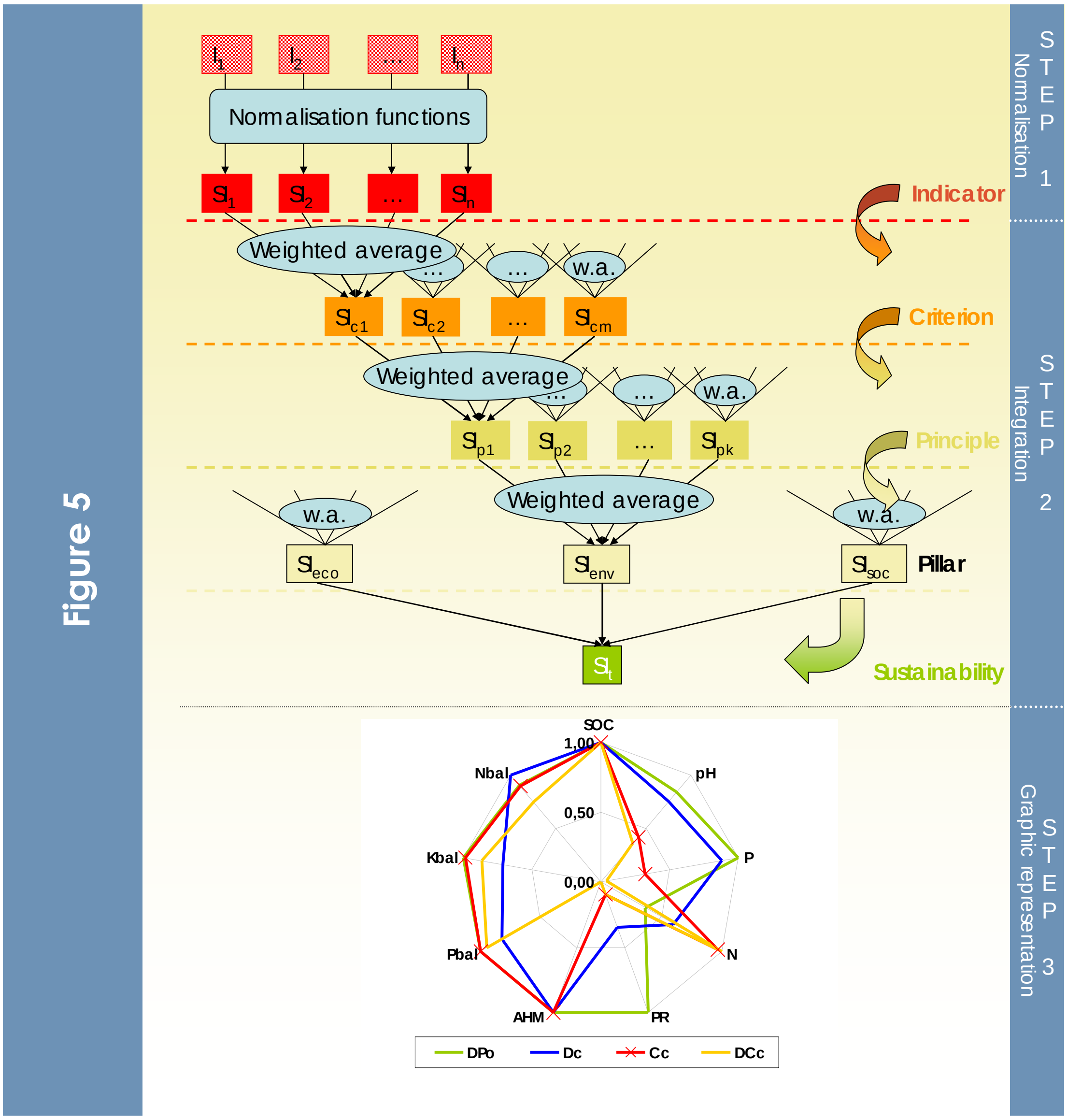
Table 4 Core list of sustainability indicators - continued

PRINCIPLES	CRITERIA	INDICATORS	UNIT	APPLICATION SCALE
ECONOMIC PILLAR				
VIABILITY				
Economic function	Farm income is ensured	Family farm income/ family work units/year	€.VAK^{-1}.yr^{-1}	F
	Dependency on direct and indirect subsidies is minimised	% of real net farm income from all subsidies	%	F
	Dependency on external finance is optimal	Solvency = own capital/total capital	%	F
	Agricultural activities are economically efficient	Total output from total input (total factor productivity)	%	F
		Value added/work units = labor productivity	€.unit^{-1}	F
	Agricultural activities are technically efficient	Total output from total input	%	F
	Market activities are optimal	Diversity of agricultural income sources from (non)-production	n^{r}	F
	Farmer's professional training is optimal	Years of professional experience	years	F
	Inter-generational continuation of farming activity is ensured	Existence of a new generation willing to take over the exploitation	scale (yes, ?, no)	F
	Land tenure arrangements are optimal	/	/	/
	Adaptability of the farm is sufficient	Index of farm adaptability	no unit (0 or 1)	F
PRINCIPLES	**CRITERIA**	**INDICATORS**	**UNIT**	**APPLICATION SCALE**
SOCIAL PILLAR				
FOOD SECURITY AND SAFETY				
Production function	Production capacity is compatible with society's demand for food	Consumption/production	%	Country
	Quality of food and raw materials is maintained or increased	Diversity of main food types	n^{r}	F
	Diversity of food and raw materials is maintained or 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	hours	F
	Health of the farming community is acceptable	Days of working incapacity	days.yr^{-1}	F
Psychological well-being of the farming community function	Education of farmers and farm workers is optimal	Extra courses	binary (yes, no)	F
	Family situation, including man-woman equality is acceptable	Equality man-women status	binary (yes, no)	F
	Family access to and use of social infrastructures/services is acceptable	Distance to administration services	km	F
	Family integration in the local and agricultural society is acceptable	Membership to non-agricultural organisations	binary (yes, no)	F
	Farmer's feeling of independence is satisfactory	Farmer' s feeling of subsidies' independence	scale (1-5)	F
		Farmer' s feeling of contracts' independence	scale (1-5)	F
SOCIAL ACCEPTABILITY				
Well-being of the society function	Amenities are maintained or increased	Amenities	/	/
	Pollution levels are reduced	Noise effect	binary(yes,no)	F
	Production methods are acceptable	Livestock welfare	scale [0, 1, 2 , 3]	F
	Quality and taste of food is maintained or increased	/	/	/
	Equity is maintained or increased	Ratio of 20 % highest and 20 % lowest incomes	%	R
	Stakeholder involvement is maintained or increased	Open houses	binary (yes, no)	F
CULTURAL ACCEPTABILITY				
Information function	Educational and scientific value features are maintained or increased	Open houses	binary (yes, no)	F
	Cultural & spiritual heritage value features are maintained or increased	/	/	/

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

3. Integration procedure

The SAFE integration procedure is derived from fuzzy models[1] and consists in three main steps (Figure 5):



Legend: I=indicator / SI=sustainability index / Eco=economic / Env=environmental / Soc=social

Figure 5. The 3 main steps of the SAFE integration procedure.

[1] Fuzzy set theory assumes that the membership of an object (in SAFE, the value taken by an indicator) is not dichotomous: sustainable or not. Rather, it evolves gradually: a degree of membership ranging from 0 (unsustainable) to 1 (sustainable). Fuzzy models are derived from this theory and have become widely used when dealing with the integration challenge linked to sustainability assessment. Indeed, fuzzy methods were purposely **designed for complex** (broad scope, trade-offs, qualitative and quantitative factors expressed in various units) **and ill-defined issues** such as sustainability assessments.

Step 1 – Normalisation: Indicator → Sustainability Index

During this step, all indicators are expressed in **comparable units**. With respect to a given sustainability issue (a 'Criterion' in SAFE), a **normalisation function** is built for each indicator. This function translates each possible value taken by an indicator in a corresponding value of sustainability index (SI) ranging from 0 (unacceptable) to 1 (desired level of sustainability). Figure 6 gives an example of a normalisation function. Other more or less complex shapes can be used in practice.

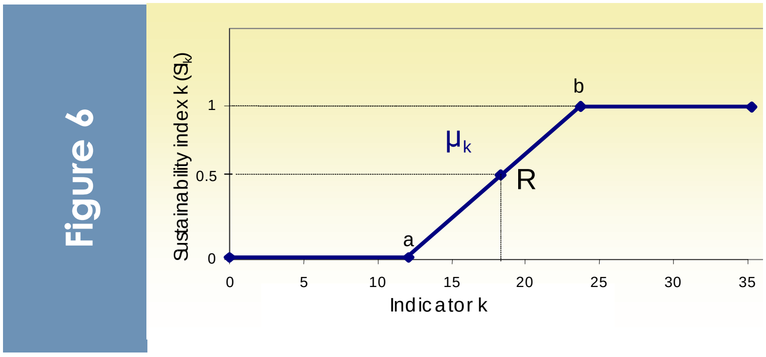


Figure 6. Linear ascending normalisation function μ_k of a sustainability indicator k with support points a and b and reference value R.

The construction of a normalisation function requires the definition of a **shape** and of **support points** ('a' and 'b' in Figure 6). In SAFE, these definitions were decided on the basis of expert judgement.

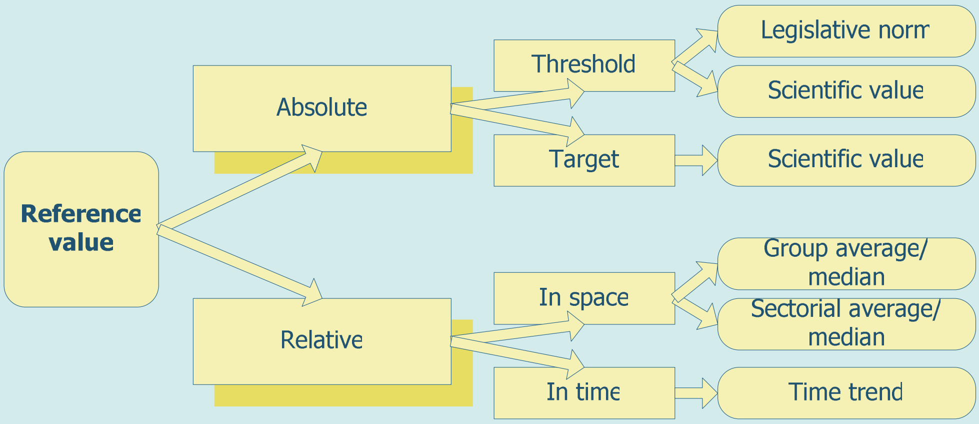
1. A **shape** is first defined: a typology of 12 different shapes has been used in SAFE.

2. A **reference value** is chosen (Box 2).

   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 2nd support point depends on the domain of variation of the indicator.

Box 2. How does SAFE define reference values?



Absolute references include **legislative** and **scientific** norms.

- Legal values are typically the result of negotiations (e.g. between policy makers, scientists, farmer representatives and advisory organisms). Because their compliance is compulsory, these are considered in priority.
- Scientific values are brought forward by scientists as the result of state-of-the-art knowledge in combination with the precautionary principle.

Absolute reference values can also be divided into target (desirable conditions) and threshold values (minimum or maximum levels or ranges of acceptable values, which should not be passed).

For some indicators, absolute reference values cannot always be defined. In such case, a possible approach consists of using relative assessment: references take then the value of **regional averages/medians** or, if these are not available, **sectorial averages or median**.

For specific issues, the definition of instantaneous indicators and reference values makes little sense. In such cases reference values should be defined to evaluate a desirable **trend**. Assessing changes in time may be achieved by presenting the trend in time of the system state variable from which trend indicators and reference values can be inferred. Trends may be useful for instance to describe insect or plant diversity.

Step 2 - Aggregation

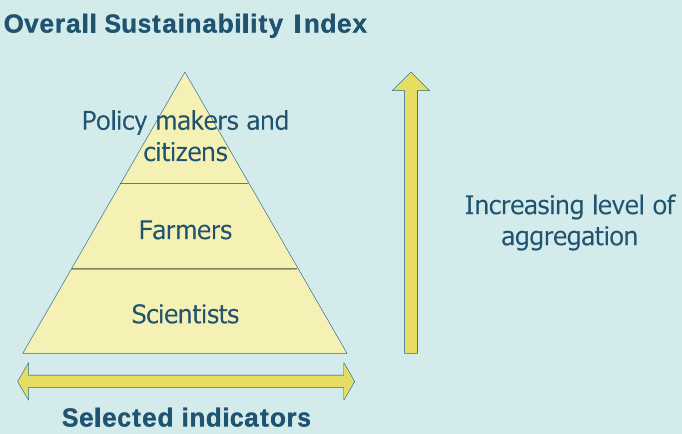
In step 1, indicators have been translated in Sustainability Indexes ('SI' [0 → 1]). These have now to be combined using an **aggregation operation** (Box 3). The choices made during this operation are crucial because they express an attitude towards sustainable development: conservative (minimum operators: the minimum SI in a group of elements - indicators, criteria, principles or pillars – is chosen as the aggregated SI value of the group), liberal (maximum operators: the maximum SI value in a group of elements - indicators, criteria, principles or pillars - is chosen as the aggregated SI value of the goup) or a compromise between the two (averaging the SI values in a group of elements - indicators, criteria, principles or pillars - determine the aggregated SI value of the group). In contrast with other aggregation operations, averaging allows to compensate between various economic, social and environmental issues. Moreover, the use of weights (Box 4) is an

allows to consider the possibility that environmental impacts might be of different significance.

Box 3. Why do we need to aggregate indicators?

Because sets of sustainability indicators are often long, including both qualitative and quantitative factors expressed in various units and sometimes dealing with conflicting issues ('trade-offs'), lists of indicator scores are highly impractical. A major interest of aggregating indicators therefore is the **ease of interpretation.**

Aggregating indicators does not mean losing information. 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 looking at the top of the pyramid (condensed information) and then go progressively to the bottom of it where needed (more detailed information):



Depending on the 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 while scientists will probably focus on the original disaggregated information. In this sense, the aggregation process also confers **polyvalence**.

In SAFE, indicators are progressively aggregated in an overall sustainability index (SI_t) by **weighted averaging** (Figure 7).

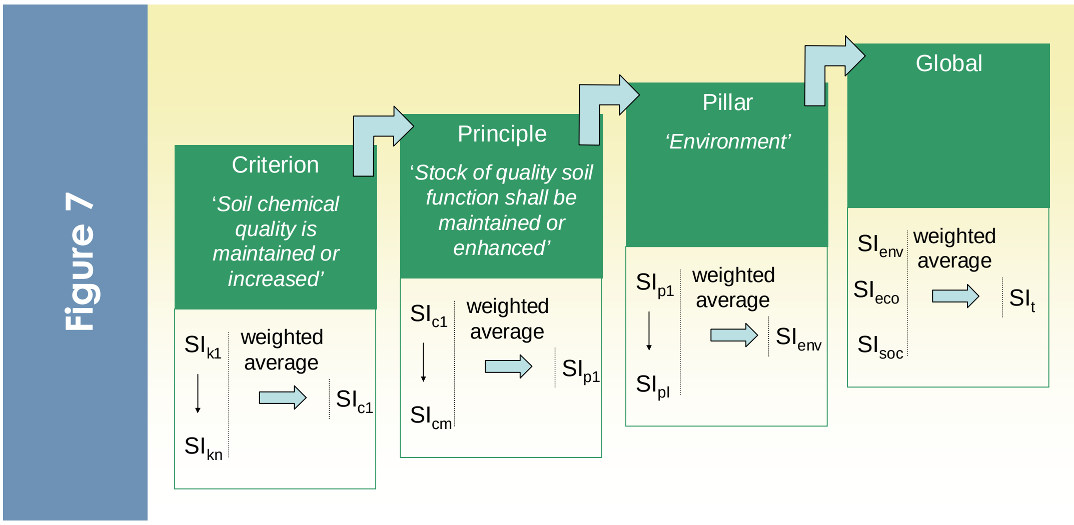


Figure 7. Integration of Sustainability Indices in an overall Sustainability Index.

Step 3 – Graphic representation

AMOEBAs are extensions of radar plots that allow showing results of multi-objective indicator scoring simultaneously (see step 3 in Figure 5). In SAFE, such graphs are used to aid in the visualisation of results at each level of the hierarchical framework, such as indicators within a criterion for instance.

Box 4. Who should weight the indicators and how?

The relative importance of **indicators within a criterion** was not assessed in the framework of this project. This point should receive special attention in future development. So far, SAFE has been using equal weights.

The relative importance of **criteria within a principle, principles within a pillar or pillars within overall sustainability** is an issue that is not within the scientific domain. It is the responsibility of the end user (*e.g.* policy makers) to determine these weights, preferably after stakeholder consultation.

Section 2: The SAFE tool

1. Data monitoring

Data collection on farms is performed on the basis of specific protocols (*i.e.* flora surveys, soil physico-chemical analysis) and with the help of several collection devices (such as a logbook, questionnaires or accountancy records)[2]. Background information is derived from existing databases (*i.e.* climate data, soil type).

2. Indicator calculation

Collected data are used as input for the calculation of selected indicators. Various calculation methods ('verifiers') are used in SAFE such as modelling, direct measurement or life cycle assessment procedures. Template Excel® files have been developed to allow easy and fast calculation of selected indicators.

3. Indicator integration

Once calculated, sustainability indicators can be aggregated with the 'SAFE integration procedure' (cf. section 1).

4. Case study

In 2002 and 2003, SAFE was tested for its ability to perform a sustainability assessment (SA) in four Belgian farms with various agricultural practices (the main characteristics of these farms are listed in table 5). In the next pages, some aspects of this evaluation are commented for the purpose of illustration.

Table 5. General characteristics of the four monitored farms

Symbol	Farm type	Municipality	Region	Area of holding [ha]
DP_O	Organic dairy and poultry	Fauvillers	Ardennes	64
D_C	Conventional dairy	Peer	Campine	51
DB_C	Conventional dairy and beef	Ternat	Loam belt	82
C_C	Conventional crops	Court-Saint-Etienne	Loam belt	109

[2] Details on data monitoring, indicator calculation and case-studies can be found in the final report and its appendices.

Overall Sustainability Index (SI_t)

The overall Sustainability Index of a farm (SI_t) corresponds to the average sustainability score of the three sustainability pillars (SI_{env}, SI_{soc} and SI_{eco}; figure 8).

Figure 8

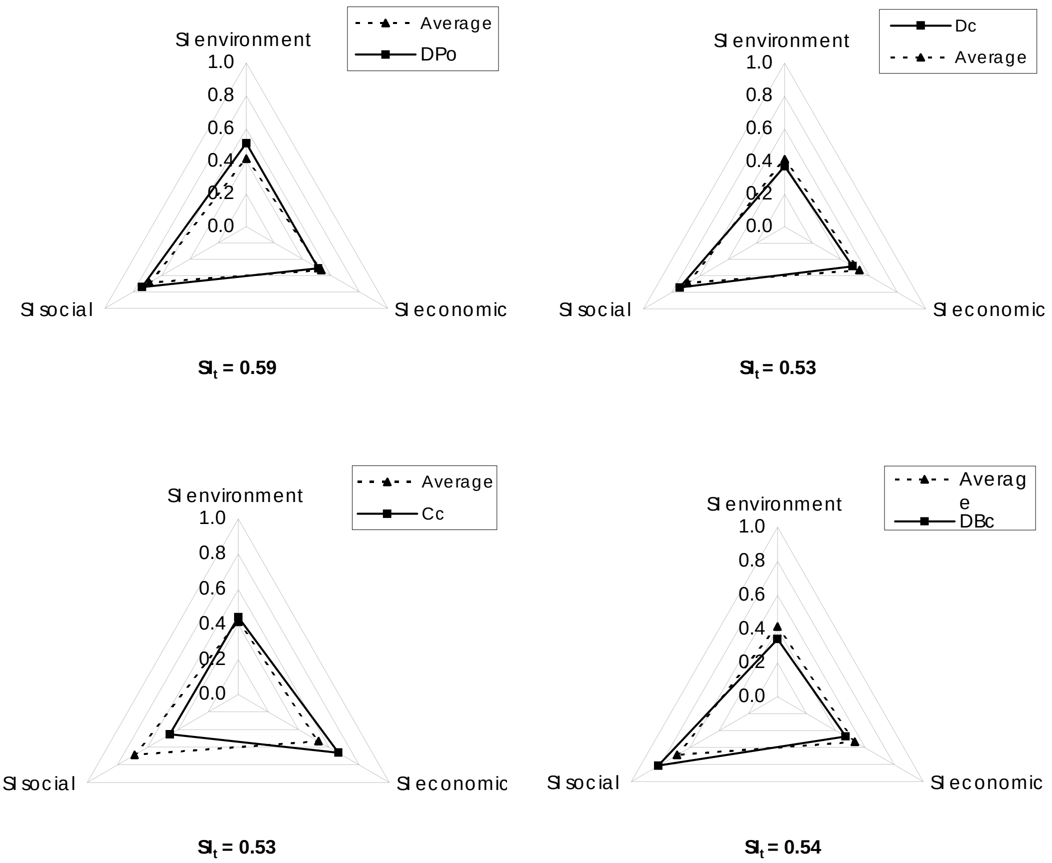


Figure 8. Overall Sustainability Index (SI_t) and corresponding amoebas, picturing Sustainability Indices of the environmental (SI_{env}), social (SI_{soc}) and economic pillar (SI_{eco}) for the four selected farms. Dashed line represents the average value over the four farms.

Although the four farms studied reached very close overall scores, they showed very different profiles for results at the pillar level. Indeed, the environmental, social and economic components had various contributions to the SI_t in each of the four farms. These results indicate that equivalent sustainability levels could be achieved through different paths. Furthermore, figure 8 also shows that farms with good environmental ratings also performed satisfactorily from an economic point fo view (e.g. DP_o). Hence, from an overall perspective at least, environmental and economic issues did not appear systematically as conflicting.

Environmental Pillar (SI_{env})

From an environmental point of view, the DP_o farm reached a higher score (SI_{env} = 0.51; figure 9) than the three other farms C_c (SI_{env} = 0.44), D_c (SI_{env} = 0.37) and DB_c (SI_{env} = 0.34).

Figure 9

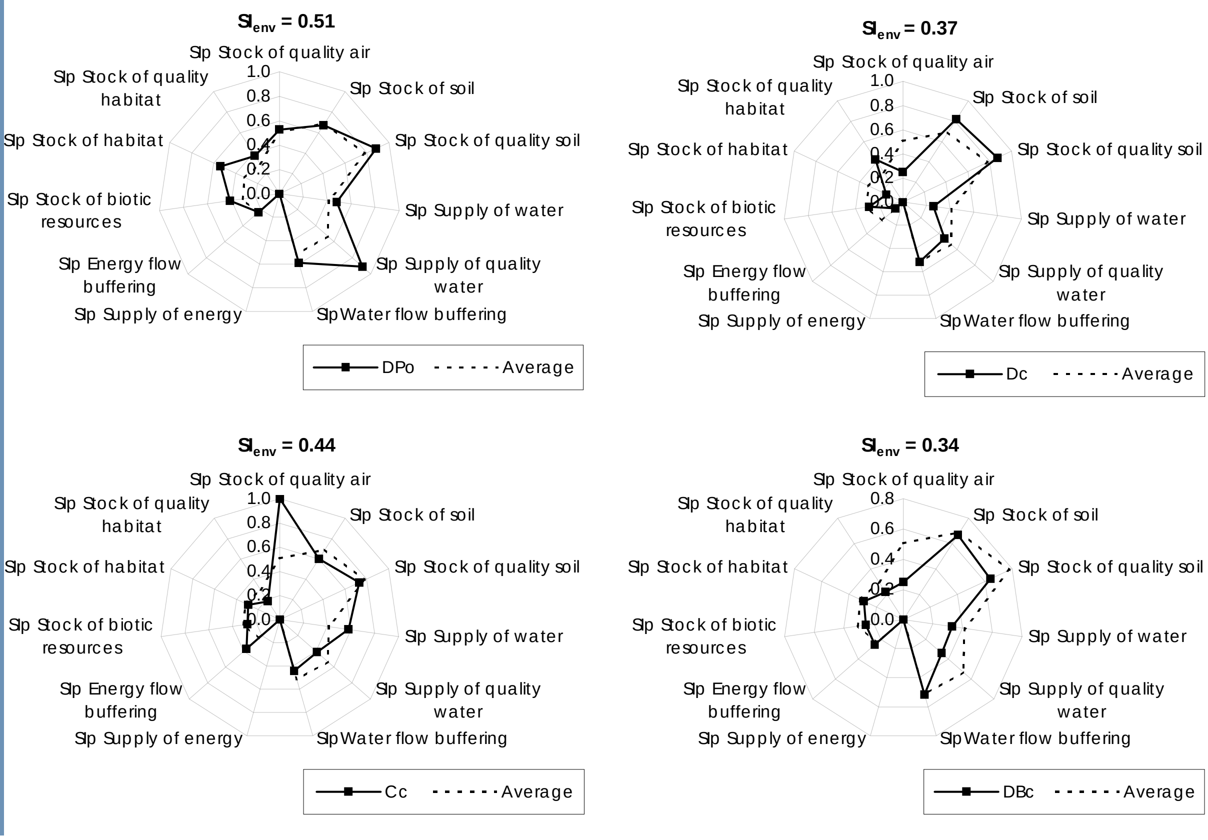


Figure 9. Sustainability Index for the 'environmental Pillar' (SI_{env}) and corresponding amoebas, picturing Sustainability Indices of related principles (SI_p) for the four selected farms. Dashed line represents the average value over the four farms.

All farms considered, the amoebas in figure 9 indicate that biodiversity and energy related functions (left part of the graphs) rated generally lower than soil and water related functions (right part of the graphs).

The comparison between farms of the overall shape of amoebas shows the environmental strengths and weaknesses of each studied farm (figure 9). In farm DP_o, 'Supply of quality water function' rated much higher than in the other farms, whereas other factors were generally close to or above the average. Farm C_c deviates from the average pattern by its low negative impact on air quality but also by its low stock of quality habitat. Patterns of farms D_c and DB_c were fairly similar.

Results for 'Supply of energy function' are very low in all farms (figure 9). Indeed, none of the farms exported energy through recycling (e.g. biomethanisation), capture of solar energy, windmills or biomass energy crops.

Principle 'Supply of quality water function'

This Principle is represented by three criteria: (1) 'Ground water of adequate quality is maintained or enhanced', (2) 'Soil water of adequate quality is maintained or enhanced' and (3) 'Surface water of adequate quality is maintained or enhanced (figure 10).

Figure 10

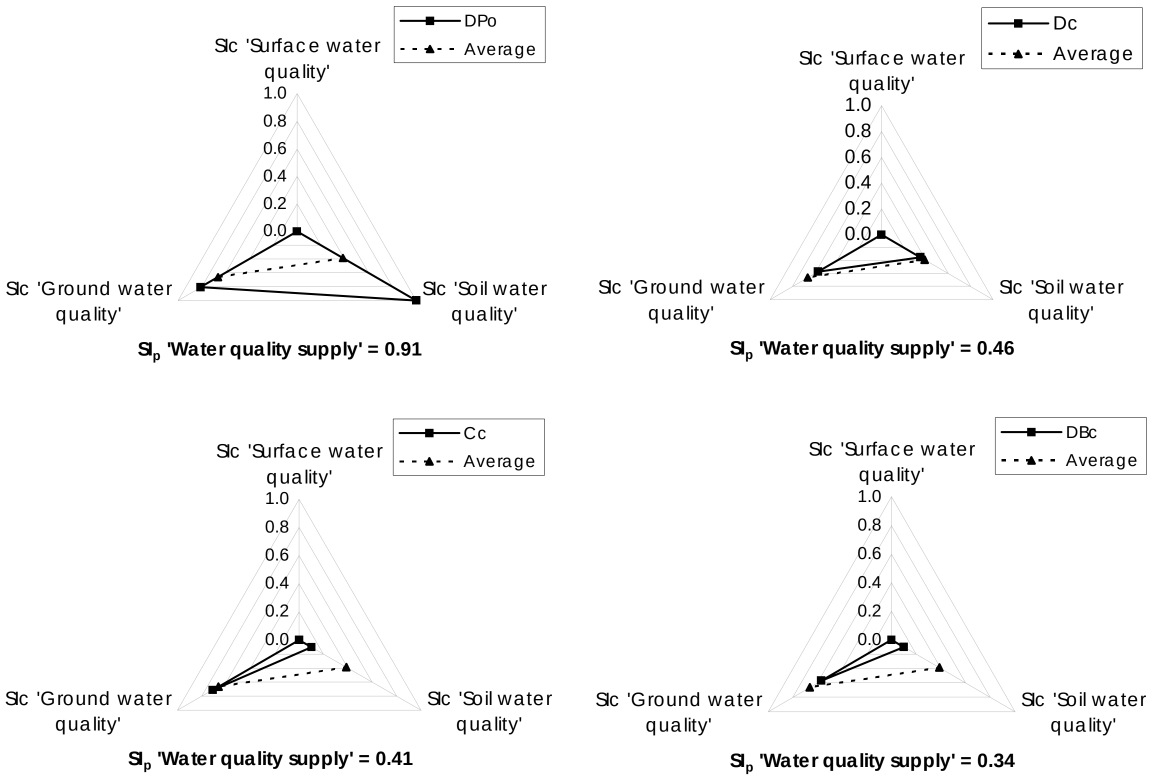


Figure 10. Sustainability Indices (SI_p) for Principle 'Supply of quality water function' and amoebas, picturing Sustainability Indices of related criteria (SI_c). Dashed line is the average over farms.

The main differences among farms related to Criterion 'Soil water quality is maintained or enhanced' (figure 10): soil water quality rated very high for DP_o, and low for C_c and DB_c, with intermediate results for D_c.

Criterion 'Soil water quality is maintained or enhanced'

This criterion is represented by a single indicator, the 'pesticide Risk Score to soil water ($RS_{soil\ water}$)', which is calculated with POCER-2 and is expressed on a scale ranging from -10 (no risk) to +10 (highest risk). The organic farm DP_o presented no possible risk to soil water ($RS_{soil\ water}$ = -10) since no pesticide was used on this site. Although farm DB_c weeded mechanically most of its fields, it achieved a high 'Pesticide Risk score to soil water' ($RS_{soil\ water}$ = 8) partly because of the use of azoxystrobine, a highly persistent active substance. In farm C_c, the greater use of pesticides (frequency, amount and diversity) associated with the cultivation of crops was partially responsible for the Pesticide Risk score of the farm

($RS_{soil\ water}$ = 8). Limited use of pesticides in farm D_c led to a medium Pesticide Risk score to soil water ($RS_{soil\ water}$ = 3).

Conclusions and perspectives

In the last couple of years, the sustainability of agricultural systems has become a major concern for scientists, policy makers, environmental NGOs 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.

In practice, SAFE consists in 3 successive steps (Figure 11):

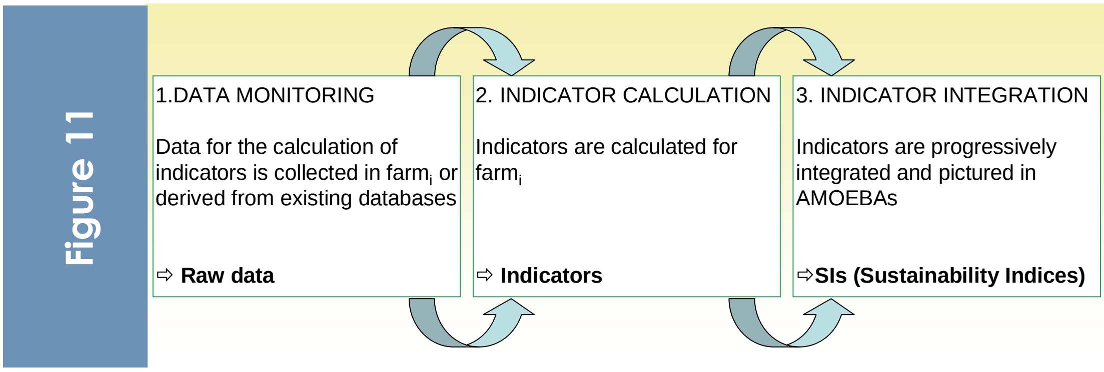


Figure 11. The 3 successive steps when applying the SAFE tool.

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** of the SAFE tool are (Table 6):

Table 6. The most significant achievements of the SAFE tool

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.

Conclusions and perspectives

The polyvalence of SAFE and its generic character ensures its ability to provide **many potential applications**:

1. *A powerful tool for decision making in agriculture, including sustainability concerns.*

   Applying SAFE on a representative set of farms/parcels of a region (in terms of number and characteristics: farm types and agricultural practices) and data analysis could help to identify, develop and promote locally more appropriate agricultural techniques and systems.

2. *A means to assess the sustainability of agricultural systems at large spatial scales (e.g. administrative units).*

   The sustainability assessment of an agricultural area (i.e. a group of farms) would help in locating regions where policy measures are the most needed. Furthermore, SAFE's sustainability indices (SI_t, SI_{env}...) could contribute to a decent communication between the agricultural and the consumer world for regilding the tarnished image that agriculture has among the public.

3. *An instrument for the monitoring of label and trademark standards.*

   The SAFE tool can be used in certification schemes of labels and trademarks which are interested in displaying and communicating the 'sustainable' character of their products.

4. *A means for monitoring policies' compliance.*

   SAFE could be the basis for supervising compliance with agricultural policies such as cross compliance of the Common Agricultural Policy of the European Union, compliance with international obligations (e.g. Kyoto protocol) or with specific management agreements (Agri-environmental Measurement programme).

5. *An instrument for improving farm management and sustainability.*

   SAFE's sustainability assessments can be used to define objectives for each farm and provide farmers with practical advices. Though in the short term such a routine use of SAFE is not realistic yet, a standardisation of the tool should help to reach this objective in the near future.

Acknowledgements

The SAFE team would like to thank:

The experts

Prof. C. Debouche (FUSAGx), Dr. P. Delmelle (ISSeP), Mrs. P. Deproost (AMINAL – Afdeling Land), Dr. M. Dumortier (IN), Prof. F. Gaspard (ECRU-UCL), Dr. F. Goor (IGEAT-ULB), Mrs. O. Jongeneelen (VLM), Mr. B. Kestemont (INS), Ir. Lambin (FUSAGx), Prof G. Mahy (FUSAGx), Prof. J-M. Marcoen (CWEDD-FUSAGx), Mrs. M. Meul (Stedula), Mrs. M. Swerts (AMINAL – Afdeling Land), Ir. M. Thirion (DGA), Mrs. L. Vandekerckhove (OECD), Ir. C. Vandenberghe (FUSAGx), Dr. L. Vanhecke (Nationale Plantentuin Meise), Mr. D. Van Lierde (Ministerie van de Vlaamse Gemeenschap – EBWL), Ir. S. Van Passel (Stedula), Ir. A. Warin (FUSAGx), Mr. K. Wellemans (ALT), Ir. H. Wustenberghs (CLE).

Others

Mr. T. Amerlinck (front cover), Mrs. M. Bourguignon (ECOP), Mrs. V. Cielen (RLD), Mr. O. Imbrecht (ECOP), Mr. B. Simon (GERU).

Last but not least the SAFE team would like to thank the farmers that participated in the project for their available time, their cooperation and their interesting comments.

KATHOLIEKE UNIVERSITEIT LEUVEN

UCL