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Sustainability assessment of crop protection strategies for orchard systems based on multicriteria methods

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RE Restricted to a group specified by the consortium (including the Commission Services)	
CO Confidential, only for members of the consortium (including the Commission Services)	

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Glossary

Active ingredients: The chemical in a pesticide formulation that kills or otherwise controls a pest or a weed. The remainder of a formulated pesticide is one or more inert ingredients. (Source: http://www.alanwood.net/pesticides/glossary.html#active)

Alternative crop protection methods/ measures: All plant protections measures without synthetic-chemical pesticides. Alternative methods replace synthetic-chemical pesticides or reduce their use. Examples for alternative methods are biological control (e.g. enhancement of predatory mites), plant resistance (e.g. apple scab resistant cultivars), mating disruption for codling moth and exclosure netting.

Attributes: These are criteria for assessing and rating the ecological as well as the economic sustainability. Altogether build the hierarchical attribute tree. We distinguish between Basic attributes and Aggregated attributes. Basic attributes are at the bottom of the branches of the attribute tree, referring to results of Life cycle assessment (LCA), Environmental risk assessment (SYNOPS) or Full cost calculation (Arbokost). Aggregated attributes are built on two or more basic attributes.

Crop protection strategy: A crop protection strategy is the sum of all crop protection measures within a defined production system. We defined production systems with their specific plant protection strategies by setting data for Context parameters, Target parameters and Corp protection parameters. Four systems are defined in our study: Baseline System (BS), Advanced System 1 (AS1), Advanced System 2 (AS2) and Innovative System (IS). The definitions of these systems are given in the section 3.2. “Production systems and their crop protection strategies”. Further details can be found in DR2.23.

SustainOS: It is the methodology and a tool developed in this study for defining and evaluating **Sustain**able **O**rchard **S**ystems. The tool SustainOS contains Excel sheets for the System description (context, target and crop protection parameters), the assessment results (LCA, SYNOPS, Arbokost) and the rating results of the overall sustainability evaluation. A SustainOS file is available for each country under study at the ENDURE’s collaborative workspace of RA3.1.

Exclosure netting: Nets around an orchard for keeping out codling moth adults; these nets are fixed in addition to hail nets, in order to close the orchard completely after blooming.

Full cost calculation (Arbokost): See section 3.4 “Quantitative assessment methods”

Integrated pest management (IPM): Concept of using different techniques in combination to control arthropod pests, diseases and weeds efficiently, with least adverse effects on the environment and high specificity to the particular pest. A set of decision rules is used to identify the need for and the selection of appropriate control measures that provide economic benefits to growers and society while keeping chemical control to a minimum.

Life Cycle Assessment (LCA): See section 3.4 “Quantitative assessment methods”

Orchard system case study (OS): Only apple orchards. Results of the OS are reported in this deliverable (DR3.12) and the deliverable DR2.23 (Report of description of BS, AS and IS for Orchards)

Pesticides: Chemical plant protection products containing fungicides, insecticides, bactericides or herbicides. We distinguish between <u>*synthetic chemicals*</u> (e.g. Captan) and <u>*natural chemicals*</u> (e.g. copper, sulphur, Neem) that are consistent with organic farming.

Risk assessment for pesticide use (SYNOPS): The indicator model SYNOPS assesses the risk potential for terrestrial (i.e. soil and field margin biotopes) and aquatic (i.e. surface water) organisms caused by the application of plant protection products (PPP). See section 3.4 "Quantitative assessment methods"

Sanitation: Preventive measures for disease control by reducing inoculums; e.g. mulching or collecting leaves on the ground.

Abbreviations

A.I.	Active Ingredient(s), see Glossary
Arbokost	Full cost calculation tool for fruit production, see Glossary
AS1	Advanced System 1, see Glossary "Crop protection strategy".
AS2	Advanced System 2, see Glossary "Crop protection strategy".
BS	Base line System, see Glossary "Crop protection strategy".
CH	Switzerland, Lake Constance Region
DE	Germany, Lake Constance Region
SustainOS	System Description and sustainability rating tool, see Glossary
ENDURE	European Network for Durable Exploitation of crop protection strategies
ES	Spain; Lleida
FR	France, Rôhne Valley
IFSA	International Farming Systems Association
IPM	Integrated Pest Management, see Glossary
IS	Innovative System, see Glossary "Crop protection strategy".
ISO	International Organization for Standardization
LCA	Life Cycle Assessment, see Glossary
NL	The Netherlands, whole country
OS	Orchard System Case Study, see Glossary
SYNOPS	Risk assessment tool for pesticide drift, see Glossary

Summary

The goal of this study is to define and evaluate crop protection strategies for commercial apple orchards in five European regions with reduced “Ecotoxicity” compared to a reference system in each region. At the same time, other attributes referring to the ecological and economic sustainability should not be disadvantaged. The crop protection strategies should be within the guidelines for integrated pest management (IPM) of the countries. Therefore we developed a methodology called “SustainOS”. This methodology consists of a system description tool created especially for data collection required by life cycle assessment, environmental risk assessment and full cost calculations. Using the various results from these assessments as qualitative attributes we designed a multicriteria rating tool that allows us to aggregate sustainability attributes to an overall sustainability rating. By applying the SustainOS methodology among a network of experts we detected for all five countries under study that the “Ecological sustainability” can be improved using alternative crop protection measures that are available on the present supply market. Economic disadvantages are the price for the ecological progress for such strategies in the case of three countries. In contrast, the two other countries show a win-win situation between ecology and economy. However, if promising innovations in crop protection systems are assumed to work in practice in all countries, an improved economic situation can be expected, based on higher or more stable yield and portions of 1st class fruits. We experienced that the SustainOS methodology highly supports defining and optimising region-specific crop protection strategies. The network established during the Orchard system case study was very effective to develop the SustainOS tool, to discuss results and to exchange ideas for regional crop protection strategies. Such a network is a secure way to cope with the complexity of crop protection optimisation in order to discover the relevant points for improving the sustainability of orchard systems.

Keywords: multicriteria assessment, apple orchard, crop protection strategy, sustainable development, life cycle assessment (LCA), SYNOPS, full cost calculation

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ENDURE partners involved:

Abbreviation	Institute	Country
AGROS	Research Station Agroscope ART	Switzerland
INRA	Institut national de la recherche agronomique	France
JKI	Julius Kühn-Institut	Germany
UdL	Universitat de Lleida	Spain
WUR/PPO	Wageningen University and Research Centre/ Praktijkonderzoek Plant & Omgeving (Applied Plant Research)	Netherlands

Geographical areas covered:
Five regions of five countries are included in this study:
France (FR): Rhône Valley
Germany (DE): Lake Constance Region
Netherlands (NL): Whole country
Spain (ES): Lleida
Switzerland (CH): Lake Constance Region

Degree of validation and operability of findings:
Multicriteria methods for sustainability rating: The scheme and procedure for the multicriteria assessment was developed in this study. This method was presented as a peer reviewed proceeding at the IFSA Symposium, 4-7 July 2010, in Vienna. The proceeding is published online as contribution to IFSA workshop 2.1 (WS2.1), available at http://ifsa.boku.ac.at/cms/index.php?id=109.
The individual assessment methods were conducted by experienced experts: Frank Hayer (AGROS) for the LCA, Jörn Strassemeyer (JKI) for the SYNOPS and José Hernandez/ Gabi Mack/ Patrik Mouron (AGROS) for the full cost calculation with "Arbokost". The results had been discussed at three workshops and two phone conferences.

Assessment results: The results of LCA, SYNOPS, Arbokost and Sustainability rating will be submitted to an international journal this year. For each of these three methods the assessments had been conducted by researchers with expertise in this field. The assessment results were discussed in workshops and phone conference.

Defined crop protection systems: The defined crop protection systems (BS, AS1, AS2 and IS) are based on expert estimations. The list of involved experts is given at the top of this report. The data defining the synthetic-chemical applications and the alternative measures had been optimised in an iterative process with three loops after discussing previous assessment results during three workshops.

Harmonization of material and methods among the Network

The tool for system description and sustainability rating called "SustainOS" has been developed during the Orchard system case study: This tool provides a practical structure for defining orchard systems with different crop protection strategies. It is based on Excel sheets. SustainOS could be very useful for advisors and researchers defining and optimising region-specific crop protection strategies for apple orchards. SustainOS can be easily adapted to all kind of fruit orchards.
SustainOS files for the five countries under study are available at ENDURE's collaborative workspace of RA3.1. At the moment the structure of SustainOS is for ENDURE internal use only. For public use further improvements concerning the layout are necessary and a handbook should be written.

1. Introduction

Apple crop protection mainly relies on pesticides although several alternative pest management strategies being available. This is largely caused by the problem that multiple environmental and economic aspects are to consider simultaneously, hiding if one strategy is more sustainable than another. In our study we investigated the elements that need to be considered in order to reach transparency upon the overall result of the sustainability assessment.
The main pests for apple orchards in Europe are codling moth and apple scab. But also many minor pests need to be regarded at the same time. Thus, the control of arthropod pests, diseases and weeds on commercial apple orchards require much more pesticide applications as for instance in wheat or maize production. Crop protection strategies are embedded into the whole growing system since the context, such as pest pressure or quality of the sites, as well as the targets, such as amount of yield and portion of 1st class fruit, have to be regarded over the whole live span of an orchard (10-20 years). Thus a proper system description is crucial to discus optimisation potentials among experts addressing crop protection measures for apple growing.

Justification of the content of this deliverable:

Originally the following wording was used for the planning of the 4th JPA:
"- Methodology of system description and multicriteria assessment with DEXiOS for plant protection strategies in orchard systems.
- Multicriteria assessment results of DEXiOS for the five regions under study
- Conclusions on strategies optimizing crop protection in apple orchards"

All three items are fully addressed in this deliverable. The only thing that has changed is the name of the methodology for the sustainability assessment: It is called now ' SustainOS' and not 'DEXiOS' as planned. The reason is that DEXi software is not suitable for handling multicriteria analysis with quantitative input data. DEXi is designed for qualitative input data. We were not aware of this fact while planning the 4th JPA. Since the orchard system case study has used quantitative input data, as planned, we developed an own methodology call 'SustainOS'.

The goals of the Orchard System Case Study are:

To define advanced and innovative crop protection strategies with reduced ECOTOXICITY compared to a reference system in five European regions with commercial apple orchards. At the same time, other criteria referring to the ecological and economic SUSTAINABILITY should not be disadvantaged. The crop protection strategies should be within the guidelines for integrated pest management (IPM) of the countries. For advanced systems: Alternative crop protection measures that are available on the market today should be integrated. For innovative systems: Alternative measures that will probably be on the market in future should be integrated.

To develop a method and tool for quantitatively defining and assessing advanced and innovative crop protection strategies (= System description and sustainability rating tool, called SustainOS). The SustainOS tool should refer to the following goals:

(a) Reach TRANSPARENCY in order to optimise crop protection strategies
i.e.:
- tracks cause-effect relation
- shows if a modification is relevant
- can be communicated clearly

(b) Cope with UNCERTAINTIES of assessments
(c) Be REGION-SPECIFIC

The SustainOS tool will be only for internal use of the Orchard system case study. Further improvements required for public use of SustainOS will be realised after 2010 if demanded.

Duration of the Orchard System Case Study:
February 2009 till October 2010

Organisation of the Orchard system case study:
RA3.1 has worked in close collaboration with RA2.5 organising the orchard system case study. For the assessments were conducted by RA3.2, RA3.3 and RA3.4.
Social aspects of the sustainability (RA3.5) are not included in this study, since there was no budget for such quantitative analysis.

Achievements:

- A system description and sustainability rating tool called SustainOS had been developed
- Quantitative assessments of the proposed systems had been conducted
- The quantitative assessment results were rated relatively to a reference system (BS) and aggregated to an overall sustainability concerning ecology and economics

SustainOS files are available at:
ENDURE Collaborative Workspace of RA3.1

Complementary deliverables of the Orchard system case study:
DR2.23: Provides further details about the system description for baseline, advanced and innovative crop protection strategies
DR3.14: Provides further information about the SYNOPS method
DR3.13: Provides further results of the economic assessment with "Arbokost"

2. State of the art

European agricultural policy requires the implementation of integrated pest management (IPM) by 2014. The goal is to promote crop protection strategies that are less relying on synthetic-chemical pesticides (ENDURE, 2009). All members of the EU will have to propose a national action plan in order to implement IPM strategies adapted to regional conditions. Therefore methods and tools to evaluate the overall sustainability of such region-based IPM strategies are needed, though rarely available. In contrast assessments of single aspects of sustainable development have often been published. For environmental aspects of the sustainability of agricultural systems Foster et al. (2006) provide a review for European countries, mainly based on life cycle assessment methodology. Methods that include socio-economic beside environmental aspects are provided by the approach of Response Induced Sustainability Evaluation RISE (Grenz et al., 2009) and the concept of sustainability solution spaces (Wiek and Binder, 2005; Castoldi et al., 2007). However, these tools do not aggregate the various aspects of sustainability to a rating of the overall sustainability of a system. Multi-attributive decision making offers a methodological framework suitable to define hierarchical trees of attributes that build up a rating for an overall sustainability (Bockstaller et al., 2008; Sadok et al., 2009). This is demonstrated by Bohanec et al. (2008) applying a multi-attribute model for economic and ecological assessment of genetically modified crops whereas Lô-Pelzer et al. (2009) evaluated innovative crop protection strategies for arable production systems. All these multi-attributive studies have in common that they allow for reflecting the complexity of agricultural system adequately. The number of attributes used in these models is very high, usually more than 80 attributes on more than seven hierarchical levels. Although such large attribute trees can easily be handled by computer programs (Bohanec, 2009), much effort is required to understand and communicate the cause-effect relations in such models. Transparency should be enhanced in order to contribute to region-specific optimisation of crop protection strategies.

3. Methodology of system description and multicriteria assessments

3.1. SustainOS scheme for sustainability evaluation

We propose a scheme for sustainability assessment of orchard systems that includes five elements (Fig. 1, a-e). Starting point is the description of the farming systems with parameters (Fig. 1, a). The settings of these parameters are then used to conduct quantitative assessments referring to the main dimensions of sustainability, which are in our

study ecology and economics (Fig. 1, b). Social assessments could be included in the same manner, but were not part of our study. The diverse output variables of the assessments, called basic attributes, are then entered at the bottom of a hierarchical attribute tree (Fig. 1, c). Here the quantitative results are transformed into qualitative ratings in order to aggregate them into attributes of higher levels (Fig. 1, d). The ecological-economic sustainability is the top attribute (Fig. 1, e) also called overall sustainability. However, for optimising crop protection systems we need to know which parameters of the system description influence a certain overall sustainability evaluation result. Such cause-effect relations can be easily obtained by investigating the results top-down in the proposed scheme in Fig. 1 (white arrows). This reflexion process helps to optimise the quantitative system description parameters. For example, hail nets cause higher energy consumption but lowers the number of applications at a more stable yield. In our study we did three circles of assessing and reflecting.

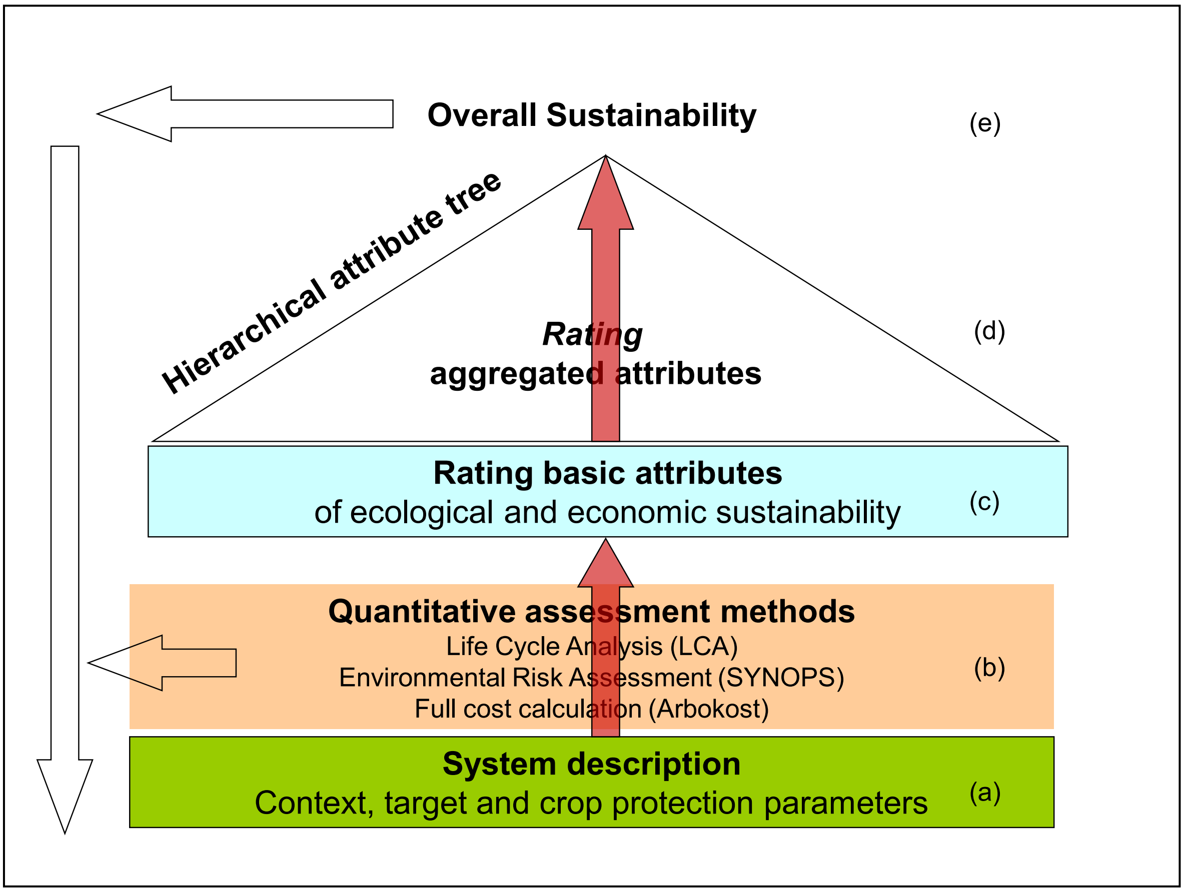

Figure 1. The SustainOS scheme for optimising the overall sustainability of orchard systems. Red arrows mark the direction of the assessment process. Wight arrows show the direction of the reflection process in order to optimise the system description.

3.2. Qualitative definition of crop protection strategies

In our study we defined four orchard systems as follows:

BS: The Baseline System strategy is used as the reference for comparison of the Advanced and Innovative System strategies. It is not representative of what is carried out in each region. It is defined as a crop protection strategy where only synthetic-chemical pesticides are used. The pesticides are selected and used within the legal framework referring to the year 2009. The criteria to select the pesticides are mainly efficacy and price, and, secondarily, selectivity to the main natural enemy. Pesticide resistance management and

decision support systems for the main pests are taken into account and used. These criteria are defined as context and target parameters in the system description file.

AS1 and AS2: Two Advanced System strategies are considered. Both of them are defined as crop protection strategies where non-conventional chemical control techniques are favoured over pesticides. AS2 is a more advanced system than AS1, in terms of ecotoxicity of crop protection techniques used. The techniques used in AS1 are available on the market, and might be adopted by the average grower in about five years. The techniques used in AS2 might also be in their final steps of implementation, and, consequently, they may be used by pioneer growers. Pesticide resistance management and decision support systems for most of (AS1) or all the pests (AS2) are taken into account and used. The criterion to select the pesticides is mainly ecotoxicity, paying special attention to selectivity to the main natural enemies.

IS: The Innovative System strategy is defined as a crop protection strategy where the ecotoxicity is further reduced to the minimum. The Crop Protection techniques used are not yet commercially available, but already under research, such as multi-gene resistance. Experts estimate a time horizon of 30 years for a genetic solution for apple scab, fire blight, powdery mildew and aphids integrated in the same cultivar. In addition, it takes at least 10 years till a new cultivar is established in the apple market to a relevant portion

The current situation in a region is a mixture of BS and AS1 and AS2 strategies. We estimate that the current situation is mainly represented by the BS strategy with some elements from AS1 (e.g. mating disruption) used in some cases. The pure AS1 strategy is probably only practiced in very few cases, since resistant cultivars are a niche on the current apple market. The AS2 strategy has been practiced only from few pioneers or for demonstration purposes on research stations.

3.3. System description parameters

Within the frame of the above defined qualitative definition of the four crop protection strategies (BS, AS1, AS2 and IS) we developed an Excel sheet in order to define numeric parameters. The quantitative system description needs to reflect in detail the level of direct crop protection telling which active ingredients were used, which dosage was applied and in which calendar week the application was conducted. Such definitions need to be related to expected yield levels. It turned out that for experts it is practicable to follow the target yield concept (Bera et al., 2006). The target approach takes in consideration the desired target parameters level (e.g. yield) for the setting of crop protection parameters within the frame of given context parameters for a particular orchard system. Figure 2 illustrates how the definitions of crop protection parameters are embedded into context and target parameters in our system description tool. By keeping context and target parameters for a region constant we were able to compare the contribution to sustainability of the proposed systems by assessing not only the crop protection but all activities for apple growing. We also refer to the system approach since we have taken into consideration a time horizon of 10 years for estimating the data for the system description parameters. For example, for the target yield not only a mean value but also the variability was defined. Furthermore, we addressed not only the main pests, but also the ones that occur irregularly, and considered consequences for the resistance management within this time horizon.

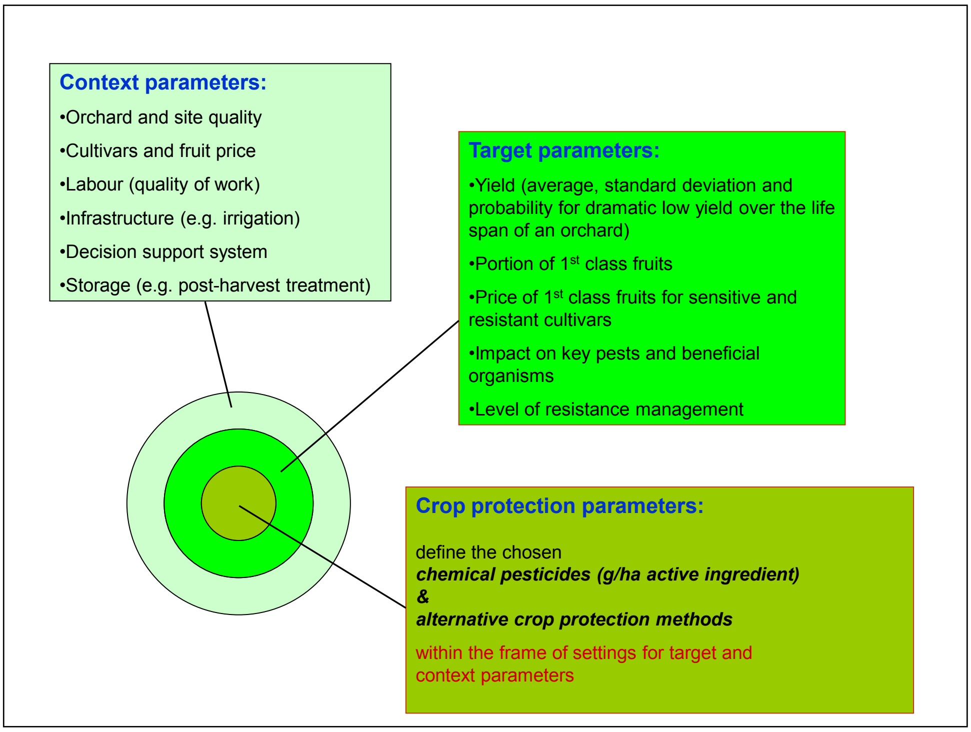

Figure 2. Three types of system description parameters for defining crop protection strategies for apple production.

A detailed description of the system description parameter for each country is given in the deliverable **DR2.23**. The complete data setting for each country is part of the SustainOS file available on the collaborative workspace of RA3.1.

3.4. Quantitative assessment methods

Values from system description parameters described above were taken as input data for the quantitative assessments using Life Cycle Assessment, SYNOPS and Arbokost (full cost calculation) as follows:

Life cycle assessment

The design of a LCA study is outlined by the International Organization for Standardization in the international management standard ISO 14044 (ISO, 2006). Values from system description parameters (Fig. 2) defining crop protection systems for apple orchards are transformed into the life cycle inventory which is used in the impact assessment to evaluate the environmental effects. The system includes the time span from the previous harvest to the next harvest. It does not include the creation and uprooting of the orchard, irrigation and post harvest processes like storage. These aspects couldn't be included because within the SCS there were no resources available to create new inventories. Unfortunately the same applies for many of the alternative control techniques like sanitary methods, mass trapping, resistant varieties, mating disruption, attract and kill, push and pull, predators or parasitoids. No life cycle inventories are available and mostly also data are missing to describe them properly. A main problem is the wide range of techniques and machinery which could be used and that a clear description of many of the alternative methods is very difficult. The

energy demand, as a screening indicator for the environmental impact, was roughly estimated for most of the alternative methods to get an idea which ones are most important. A result was, that the energy demand of the exclosure netting is by far the highest. The exclosure netting is estimated in the study with a hail net, meaning that the impacts of the AS and IS strategies are still underestimated, but the most important alternative method is included in the analysis. With the above mentioned exceptions the system includes all inputs like fertilisers, production of pesticides and machinery and the field operation processes. We use the life cycle inventories from the ECOINVENT database version 2.01 (Frischknecht et al., 2007; Nemecek and Kägi, 2007) to assess the infrastructure, inputs and processes used in the apple orchards. The models to estimate the various direct field emissions (i.e. NH_3, N_2O, Phosphorus, NO_3^-, heavy metals and pesticides) and are described in the SALCA method (Gaillard and Nemecek, 2009; Nemecek et al., 2005, 2008). The following mid-point impact categories were used to provide the basic attributes related to LCA used in SustainOS.

- Demand for non-renewable energy resources (oil, coal and lignite, natural gas and uranium), using the upper heating or gross calorific value for fossil fuels according to Hischier et al. (2009)
- Global warming potential over 100 years (IPCC, 2006)
- Terrestrial and aquatic ecotoxicity potential. The impact of toxic pollutants on terrestrial and aquatic ecosystems calculated according to the Guinée et al. (2001)
- Human toxicity potential. The impact of toxic pollutants on human health calculated according to Guinée et al (2001) The human toxicity in LCA is not related to the toxicity of workers but assesses the toxicity for the population via exposure through food, tab water and air.
- Eutrophication potential (impact of the losses of N and P to aquatic and terrestrial ecosystems, according to the EDIP97 method (Hauschild and Wenzel, 1998).

SYNOPS

The indicator model SYNOPS assesses the risk potential for terrestrial (i.e. soil and field margin biotopes) and aquatic (i.e. surface water) organisms caused by the application of plant protection products (PPP). It combines use data of PPM's with the environmental conditions linked to the application and the chemical, physical and eco-toxicological properties of the applied active ingredients (Gutsche and Strassemeyer, 2007).

In general the acute and chronic risk potentials are calculated as exposure toxicity ratios (ETR) for reference organisms in the three compartments soil, surface water and field margin biotopes. These organisms are earthworms for soil, bees for edge-biotopes and daphnia, algae and fish for surface water. SYNOPS estimates for each application the loads of an active ingredient into the soil, edge-biotopes and surface water considering the exposure pathways drift, run-off, and drainage. Based on the estimated loads of active ingredients a time dependent curve of the predicted environmental concentration (PEC) is derived assuming a temperature dependent degradation of the active ingredients. From the time dependent concentration curves the acute and chronic risk potentials are derived by relating the maximum PEC values to lethal concentration (LC50) and the no effect concentration (NOEC).

All necessary physico-chemical and eco-toxicological parameters of the applied active ingredients are summarised in a database (n > 400), which were derived mainly from the monographs produced as part of the review process on EU or national level.
For each orchard system, which was defined within RA 2.5 (BS, AS1, AS2 and IS) the indicator model SYNOPS was applied to assess the region specific environmental risk potentials. Depending on the orchard region a number of 72 to 288 input scenarios were assessed with SYNOPS. These region specific environmental input data and scenarios are described and summarised in Appendix 1. As input parameters for SustainOS, the results of the single scenarios were aggregated as also described in Appendix1.

Full cost calculation (Arbokost)

Orchard systems are capital (e.g. establishment costs) and labour intensive (e.g. harvest hours) production systems with a live span of 10 to 15 years. Income may vary considerably between the years mainly depending on variability of yield and portion of 1st class fruits (Mouron et al., 2007). Thus, the economic assessment highlights the average profitability, the financial autonomy as well as the income risk. Crop profitability evaluates the economic efficiency of the orchard systems by calculating the family income per labour hour, the total production cost per kilogramme 1st class apples as well as the net profit per hectare. Farm autonomy is represented by the amount of invested capital per hectare and the return on investment since they evaluate the grower's capacity to amortise or reinvest and therefore refer to the viability in the long run. Production risk is represented by calculation of the income variability due to the standard deviation of yield and fruit quality over the life span of the orchard. Furthermore, the income risk is considered by estimating the portion of years with a dramatic yield loss, i.e. years with less than half of the average harvest.
Full cost principles are applied. The calculations are conducted by utilising the managerial-economic software-tool Arbokost (Arbokost, 2009). This full cost calculation tool is designed especially for perennial crops. It had been created by the Swiss research station Agroscope Changins-Wädenswil.

> For more details see deliverable **DR3.13** "Final report on economic assessment of current, advanced and innovative crop protection systems for orchards".

3.5. Sustainability rating method

Building a hierarchical attribute tree

The attribute tree was built both from top-down as well as from bottom-up. The resulting tree is given in Fig. 3. From top-down the direct sub-attributes referring to "Ecological sustainability" were selected which are "Resource use", "Environmental quality" and "Human toxicity" according to *the areas of protection* described by Udo de Haes and Lindeijer (2002). With regard to apple production environmental attributes were chosen according to Mouron et al. (2006a, 2006b) and Mila i Canals et al. (2007).
The sub-attributes for "Economic sustainability" are "Profitability", "Production risk" and "Autonomy" according to Lô-Pelzer et al. (2009). From bottom-up the basic ecological attributes were given by the result parameters of the Life Cycle Assessment respectively the SYNOPS assessment. Since the rating of "Ecotoxicity" is the focus of our study, this attribute is decomposed further and represented with the most sub-attributes providing detailed information on how the "Ecotoxicity" is influenced.
The basic attributes referring to economic sustainability of orchard systems were selected with regard to previous studies (Mouron et al., 2001, 2007; Bravin et al., 2010).

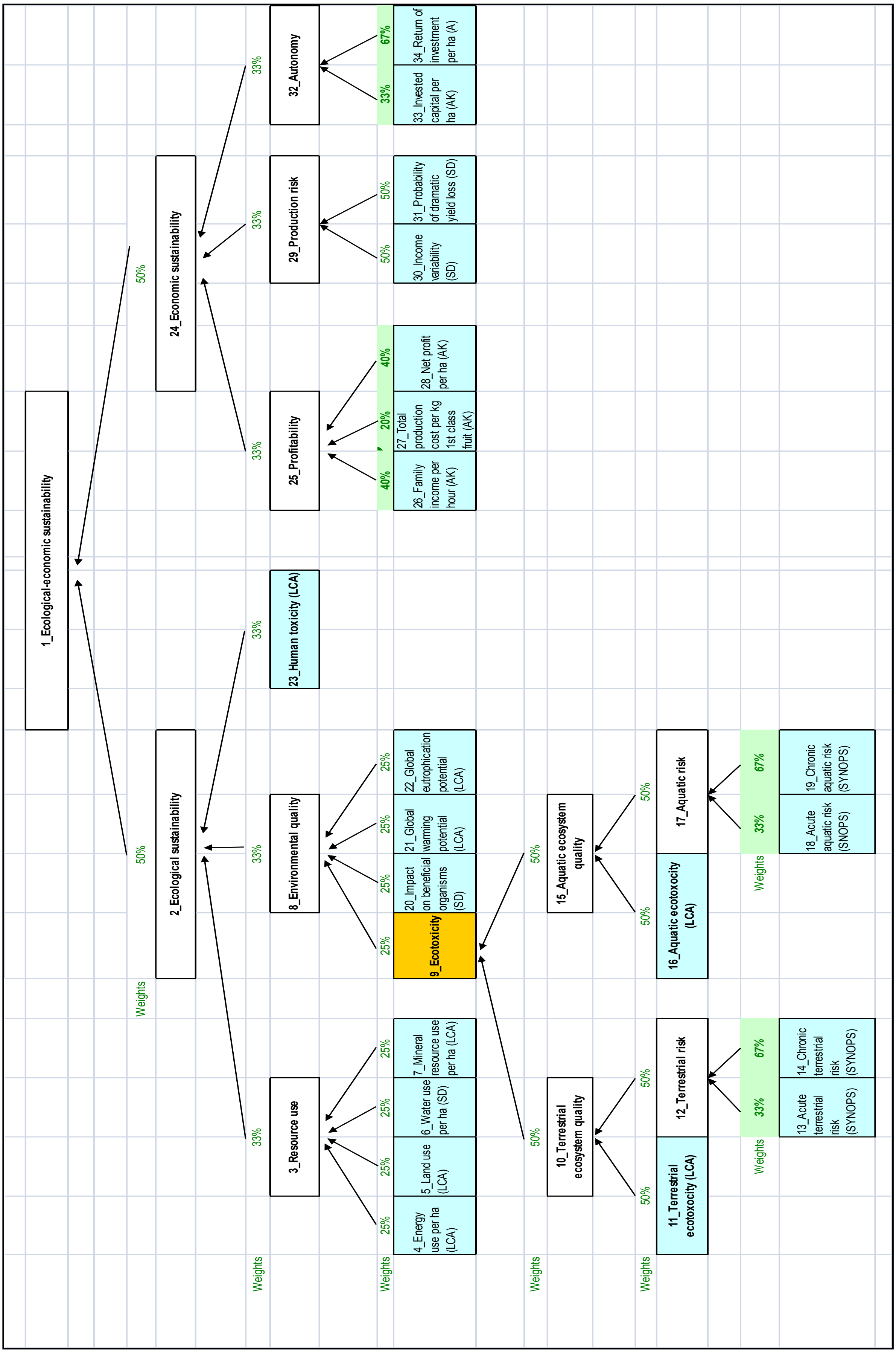

Figure 3. Hierarchical attribute tree for assessing the ecological and economic sustainability of orchard systems; basic attributes are in blue print; the attribute being optimised primarily is in yellow print.

Rating basic attributes

Basic attributes are all attributes at the bottom of the attribute tree, marked in blue in Fig. 3. Basic attributes are directly related to a numeric assessment result. Such numeric results need to be assessed relatively in comparison with the BS strategy. Table 1 shows the five relative ratings classes that were used.

Table 1. Rating classes for sustainability rating.

Rating class	
1	much worse than BS
2	worse than BS
3	similar to BS
4	better than BS
5	much better than BS

BS is the Baseline System strategy of a specific region

Assessment results with strictly positive numeric values need a ***rating scale*** which is applicable to the region-specific reference systems (i.e. BS) which might differ in their numeric values. Therefore the boundary between similar and better is the reciprocal of the ones between similar and worse as well as the one between better and much better is the reciprocal of the boundary between worse and much worse. Figure 4 shows the asymmetric rating scales we used for LCA results according to Nemecek et al. (2005). As an example for an asymmetric rating here the boundaries for rating ecotoxicity results from LCA: similar to BS = 67%-150% (6/9-9/6); better than BS = 40%-67% (6/15-6/9); worse than BS = 150%-250% (9/6-15/6)
As can be taken from Fig. 4 the range for the classes related to ecotoxicity are wider than for nutrient and resource management reflecting that methodologies for assessing ecotoxicity are less reliable than those for nutrition and resource assessments. Applying this kind of rating scales we consider the uncertainty of the assessment methods, preventing an over or under estimation if a result of an advanced or innovative system differs from the BS strategy.

For basic attributes with possibly negative or positive numeric values which are “Family income”, “Net profit” and “Return on investment” we used symmetric rating scales, assuming that a deviation from the reference system (i.e. BS = 100%) to the desired side is of the same relative effect as it is to the undesired side. Example for a symmetric rating scale: similar to BS = 90% -110%; better than BS = 110% - 140%; worse than BS = 60% - 90%

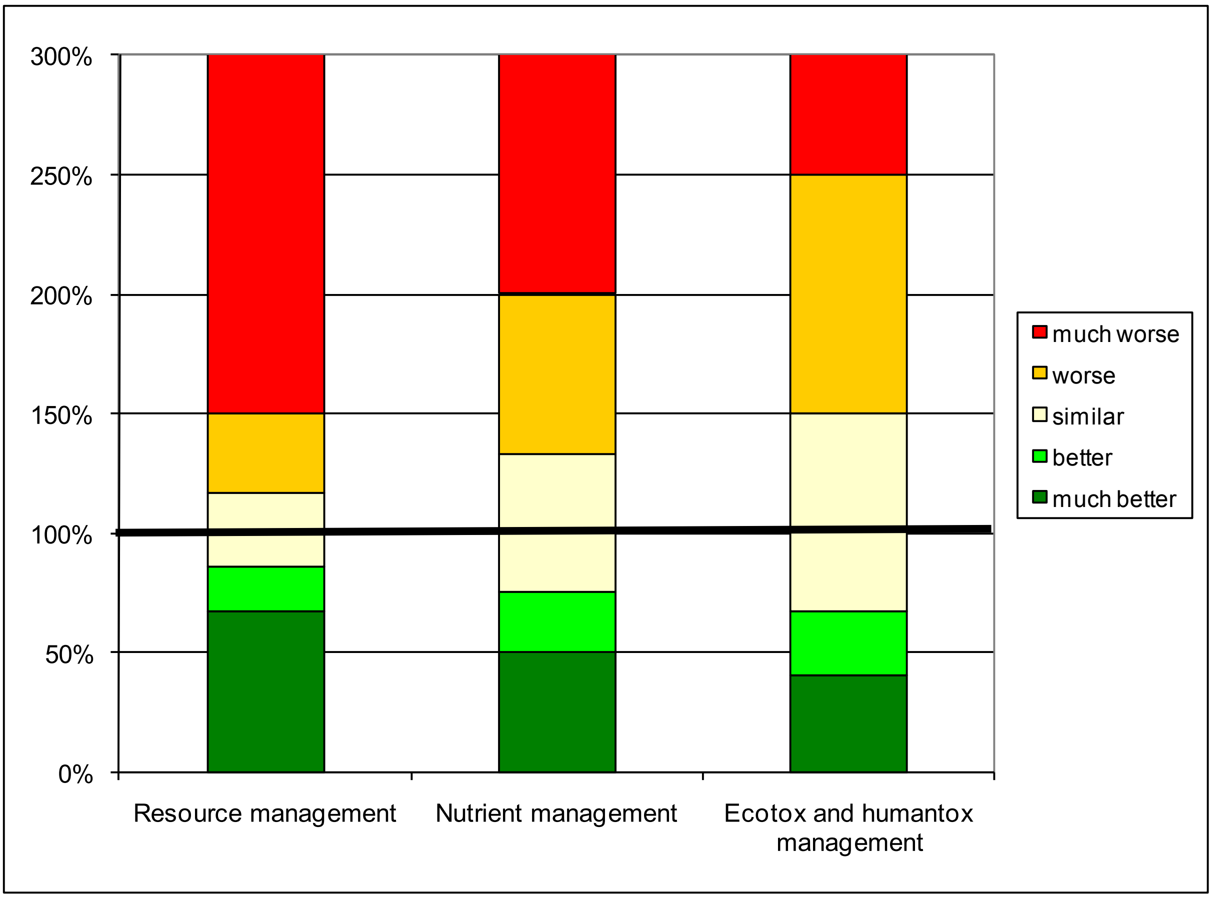

Figure 4. Asymmetric scales for rating Life Cycle Assessment results in relation to a Baseline System (= 100%). Resource management is represented by the following attributes: "Energy use", "Land use", "Water use" and "Mineral resource use"; Nutrient management is represented by the attribute "Global Eutrophication"; Ecotoxicity and humantox management are represented by the attributes: "Terrestrial Ecotoxicity", "Aquatic Ecotoxicity" and "Human toxicity".

Rating aggregated attributes

An aggregated attribute refers to at least two basic attributes. We calculated the weighted mean from the rating class of the related basic attributes. The weight for each attribute was fixed by the expert group and is given in Fig. 3. In general the weights of all sub-attributes of an aggregate attribute sum to 100% and are equally distributed between the sub-attributes. However there are three exceptions:

A) Acute Risk/ Chronic risk → 33%/ 66% since the chronic risk is considered to be of higher importance for the ecosystem in the case of apple orchards.
B) "Invested capital per ha"/ "Return on investment" → 33%/ 66% since a bad "Return on investment" can cause existential problems since an increased "Invested capital" is not a severe problem as long as the profitability is fine.
C) "Family income per hour"/ "Total production cost per kg"/ "Net profit per ha" → 40%/ 20%/ 40% since a change of the "Total production cost per kg" is only of interest if the revenue is not compensating this change.

The weighted mean is called "score" of an aggregated attribute. The score of an attribute of a higher level in the tree was calculated by the weighted mean of the scores of the related sub-attributes. Scores were translated into ratings by applying the mathematical rounding rule, where for instance the score of 3.50 is up rounded to the rating class 4. Scores help to interpret a rating class of an aggregated attribute. For instance the rating class 4 with a score between 3.50 and 3.99 indicates that at least one sub-attribute belongs to a rating class

lower than 4. If the score is between 4.00 and 4.49 it means that at least one sub-attribute belongs to the rating class 5.

4. Results for Switzerland

4.1. Overall sustainability rating

The AS1 strategy is not rated “better than BS” either for the “Ecological sustainability” nor for the “Economic sustainability”, as can be taken from Fig.5. In fact the AS1 strategy reaches the rating class “similar to BS” for the top attribute of the ecological branch of the attribute tree. Still, the score of 3.47 indicates that at least for some ecological sub-attributes the AS1 strategy achieves an improvement compared to the BS strategy. In contrast, the top attribute of the economic branch reaches only the rating class “worse than BS” (Fig. 5). With a score of 2.40 it is clear that AS1 pays the ecological improvements with some disadvantages among some economic sub-attributes. Thus, AS1 is characterised by a negative trade-off between ecology and economy.

The AS2 strategy reaches the same rating classes as the AS1 strategy for the three top attributes of the tree (Fig. 5). Still, AS2 differs from AS1 to some extent since the score for the “Economic sustainability” is lower than for AS1. Although the score for the “Ecological sustainability” is exactly the same (3.47) for both advanced strategies, the profile among the ecological sub-attributes might be different between these strategies, as the next result section is demonstrating.

The IS strategy is characterised by being rated “better than BS” for the Ecological as well as for the Economic sustainability (Fig. 5). Thus, the IS strategy overcomes the negative trade-off between ecology and economy while promising clear improvements not only compared to BS but also compared to AS1 and AS2.

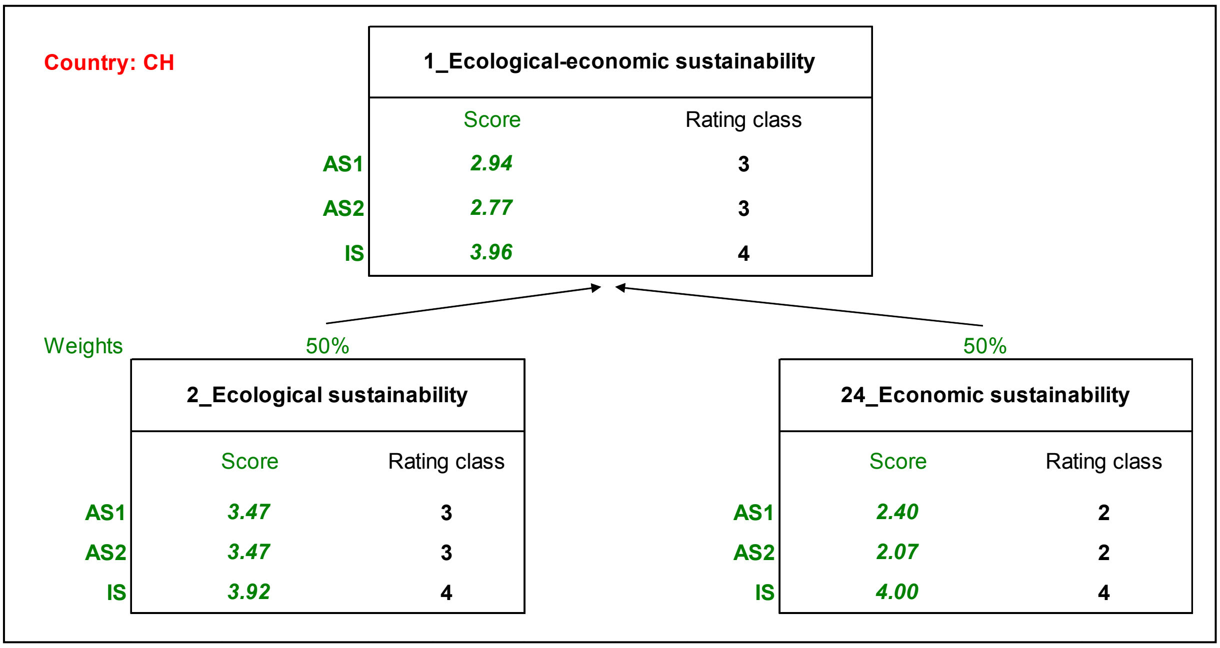

Figure 5. Ecological-economic sustainability rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, **3 = similar to BS**, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System. Scores: Weighted mean value of ratings of direct sub-attributes.

4.2. Ecological sustainability rating

The AS1 strategy is rated "similar to BS" for each sub-attribute of "Resource use" as shown in Fig. 6. The same holds true for the sub-attributes of "Environmental quality" with one remarkable exception: "Ecotoxicity" is rated with "much better than BS" (5), the highest rating class of our evaluation. "Human toxicity" is also improved, reaching the rating class 4 (better than BS).

The AS2 strategy differs from the AS1 only among the rating class of two sub-attributes: AS2 is rated one class lower than AS1 regarding "Mineral resource use" through input of Potassium Bicarbonate disease control. On the other hand AS2 is rated one class higher than AS1 for positive "Impact on beneficial organisms" (Fig. 6).

The IS strategy is rated with the same classes as AS2 for all sub-attributes of "Resource use" and "Environmental quality". The progress of IS strategy compared to AS2 refers on one sub-attribute only, being "Human toxicity" which is rated with 5 instead of 4 (Fig. 6).

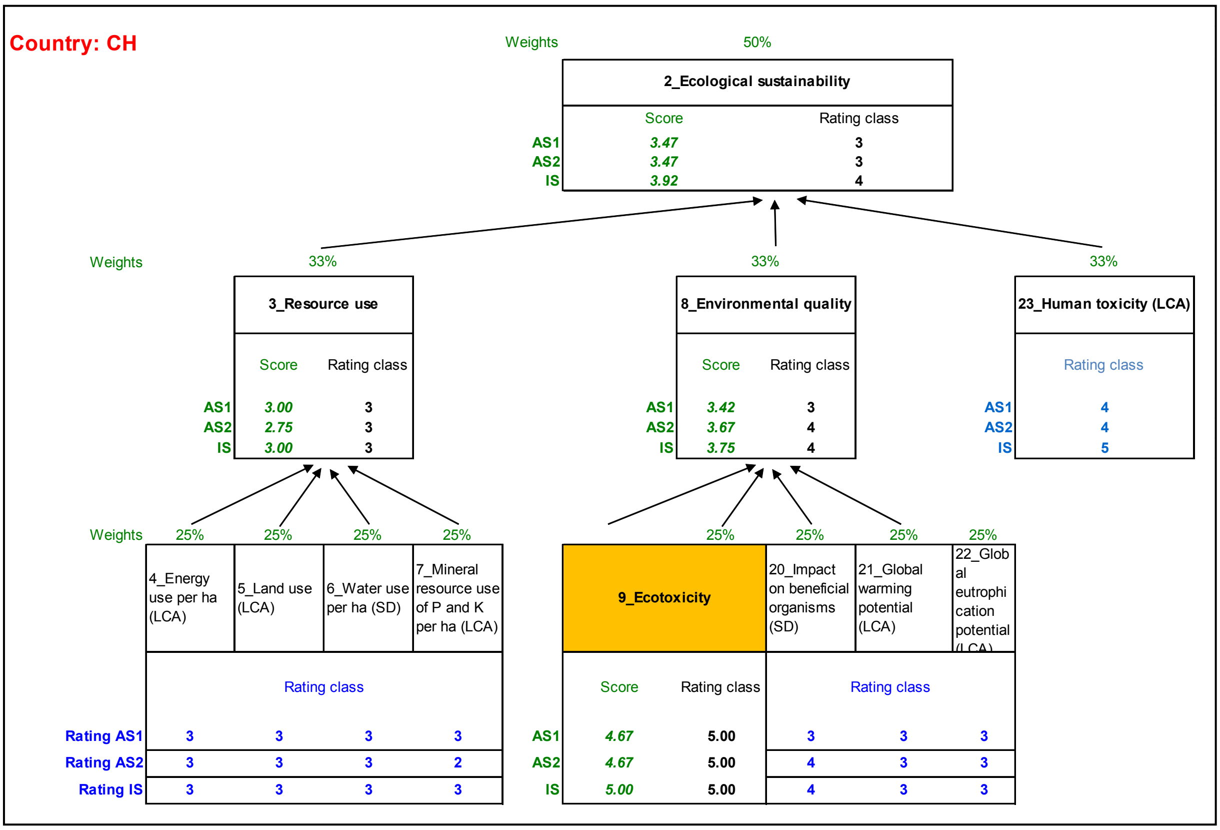

Figure 6. Ecological sustainability rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, 3 = similar to BS, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System; Scores: Weighted mean value of ratings of direct sub-attributes.

4.3. Ecotoxicity rating

The AS1 strategy shows improvements across all sub-attributes of "Ecotoxicity" compared to the BS strategy (Fig. 7). The strongest advantages are reached for the sub-attributes

"Terrestrial ecotoxicity", "Aquatic ecotoxicity" and "Aquatic risk" by strongly lowering the "Chronic aquatic risk".

The AS2 strategy shows the same rating classes and scores as AS1 for all ecotoxicity attributes (Fig. 7). It has to be admitted that AS2 shows better results than AS1 for some ecotoxicity attributes but this improvement cannot be reflected by a higher rating class if an attribute has reached already the highest rating class for the AS1 strategy. Therefore, more detailed results of LCA and SYNOPS assessments referring to ecotoxicity attributes are presented in the next section.

The IS strategy shows further progress compared to AS2 for the three attributes "Acute terrestrial risk", "Chronic terrestrial risk" and "Acute aquatic risk" (Fig.7).

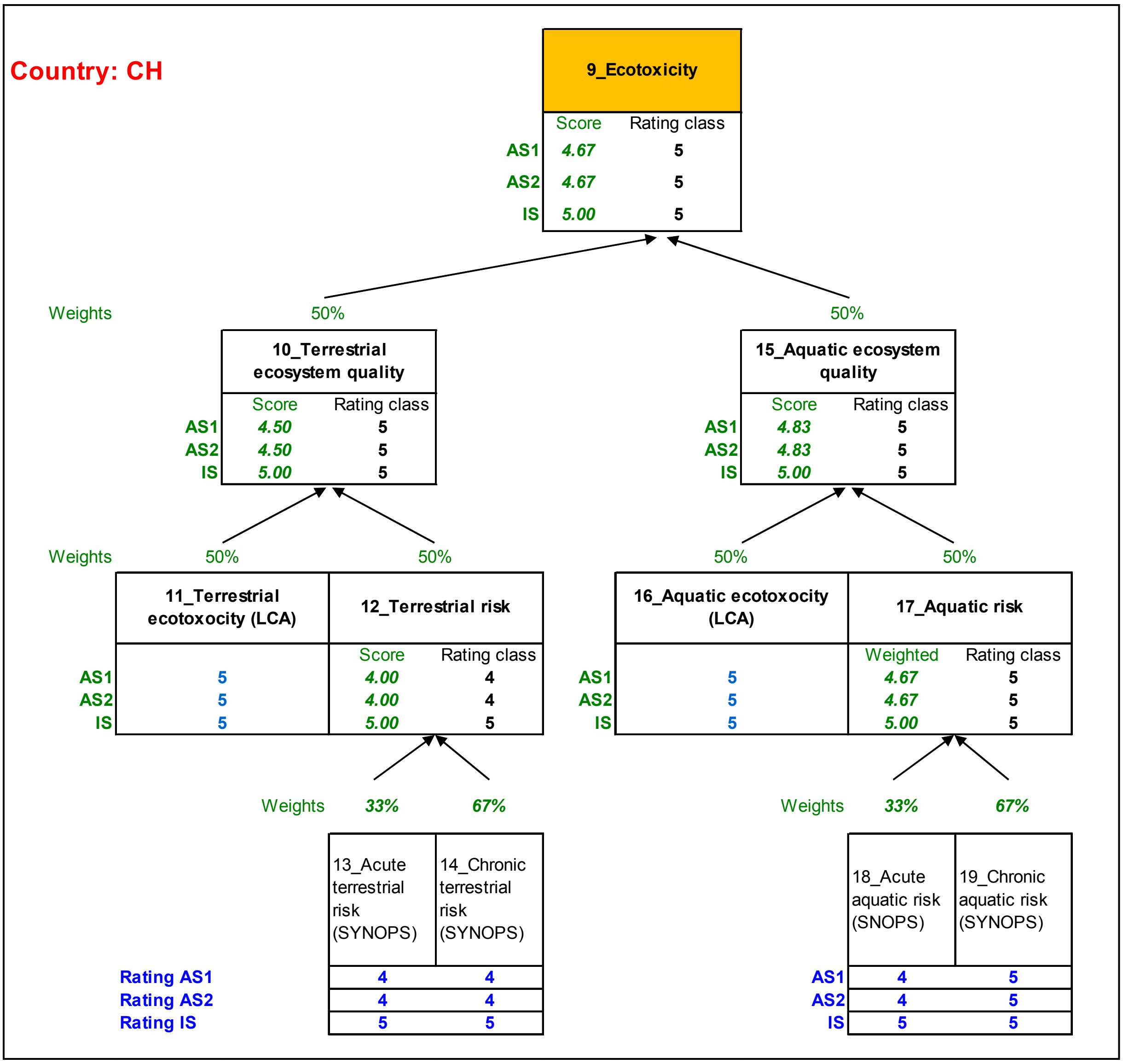

Figure 7. Ecotoxicity rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, 3 = similar to BS, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System; Scores: Weighted mean value of ratings of direct sub-attributes.

4.4. Optimising ecotoxicity and human toxicity attributes

Ecotoxicity and human toxicity is mainly related to pesticide use. There are three approaches to optimise the toxicity of apple orchard systems:

- Replace active ingredients (A.I.) which have a high impact with A.I. with a lower impact.
- Replace A.I. by alternative crop protection measures (e.g. exclosure netting, resistant cultivar)
- Enhance drift reduction measure (e.g. special sprayers, hedges).

LCA results

The “Aquatic ecotoxicity” of the BS strategy is dominated by the input of three applications per season of herbicides, causing more than 80% of the total impact (Fig. 8). In fact this impact on the aquatic ecotoxicity is due to one application per season of the herbicide Diuron. AS1 strategy avoids this impact by replacing Diuron since a cover crop with mowing is established from mid June to harvest. For the remaining two applications for weed control Organophosphorus and Phenoxypropionic herbicides are used, causing no relevant aquatic ecotoxicity. In AS2 and IS strategies herbicides are totally replaced by mechanical weeding.

The “Terrestrial ecotoxicity” for the BS strategy is mainly caused by fungicide applications, but also relevant impacts are due to herbicide applications (Fig. 9). A more than 95% reduction of the terrestrial ecotoxicity is observed for the AS1 strategy. This effect is achieved by optimisation of weed control as described above and by optimisation of disease control (Fig. 10). Fungicides could be replaced in AS1 by introducing cultivars with scab resistance, sanitation measures. Especially the replacement of copper-hydroxide that is applied twice per season in the BS strategy reduces the “Terrestrial Ecotoxicity” of AS1. The use of an antibiotic against fire blight could be omitted by the application of antagonistic microorganisms. In AS2, the application of fungicides corresponds with AS1 until end of bloom but afterwards diseases are controlled with natural fungicides with lower terrestrial ecotoxicity than those used in BS.

The “Human toxicity” for the BS strategy is mainly caused by herbicide use and non pesticide impacts (e.g. machinery use) and to a smaller extent by fungicide and insecticide use (Fig. 10). The improvements of AS1 are mainly based on reduced herbicide and fungicide use due to measures described above. Human toxicity of AS2 could not be further improved as compared to AS1, because the improvement by the omission of fungicides is compensated by shorter application intervals of the natural fungicides used after bloom resulting in an extended use of sulphur. The improvement of the IS strategy is given through a disease control that is based on cultivars with genetic resistance against major diseases, assuming that only a few fungicide applications are necessary.

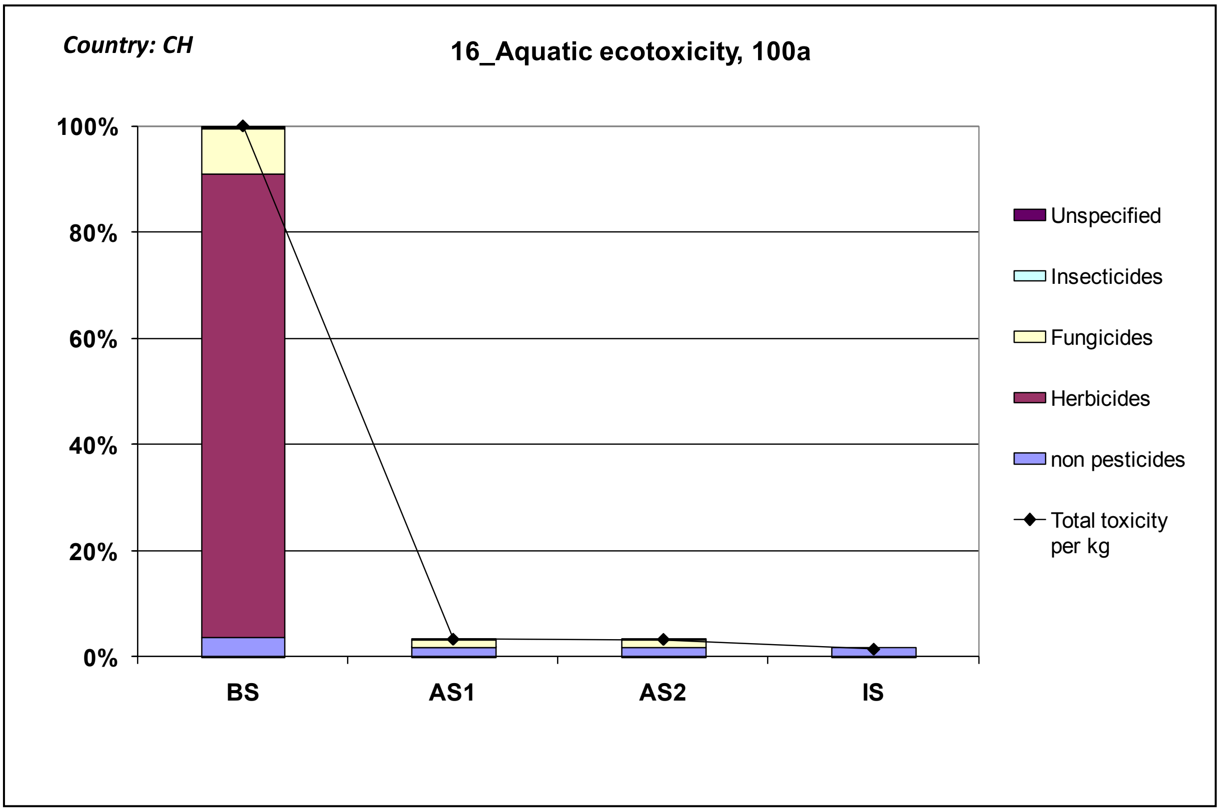

Figure 8. LCA results for aquatic ecotoxicity according to CML2001. Impacts are presented relatively to the BS strategy. Bars represent the impact per ha and the impact per kg fruit produced is indicated by the line.

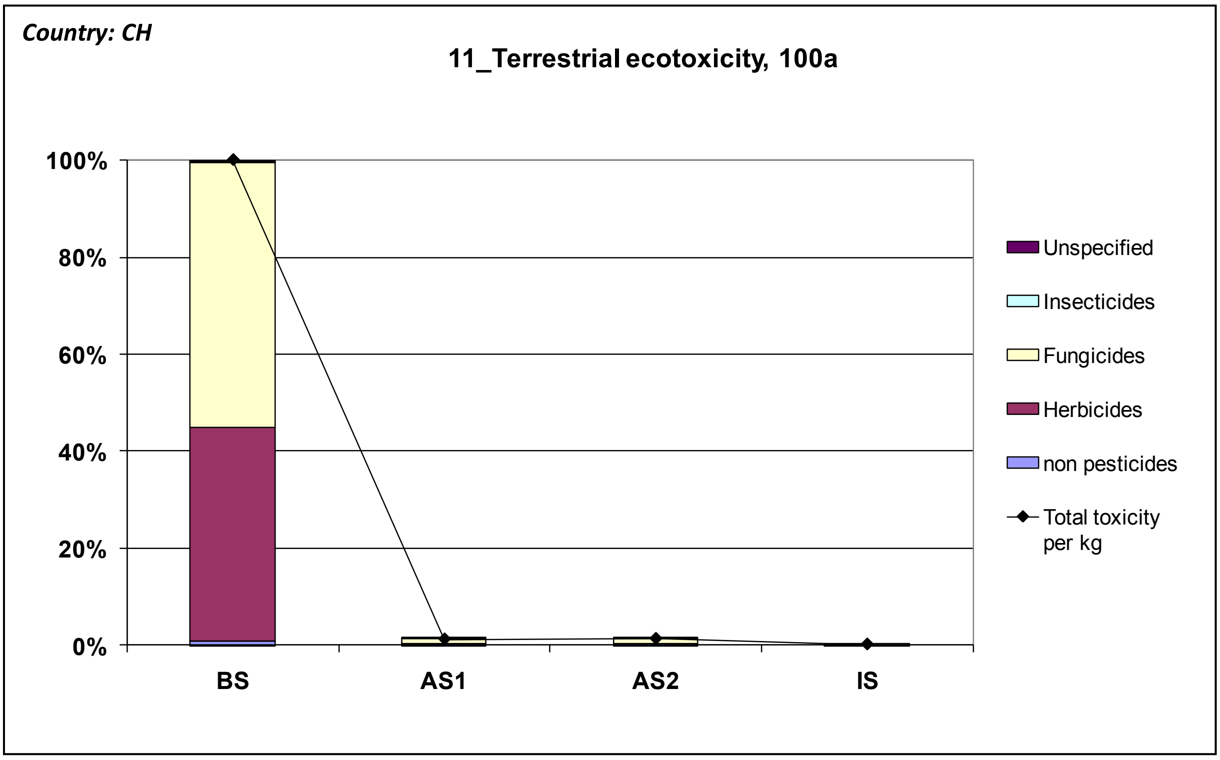

Figure 9. LCA results for terrestrial ecotoxicity according to CML2001. Impacts are presented relatively to the BS strategy. Bars represent the impact per ha and the impact per kg fruit produced is indicated by the line.

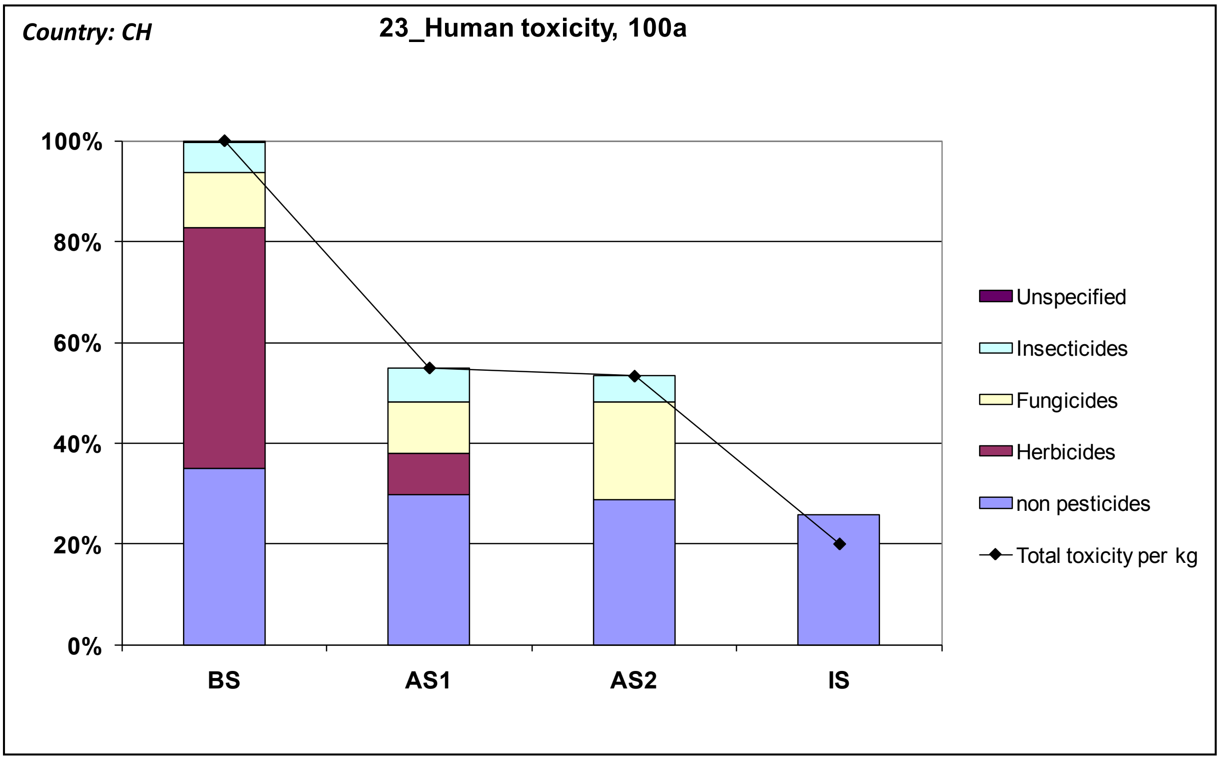

Figure 10. LCA results for human toxicity according to CML2001. Impacts are presented relatively to the BS strategy. Bars represent the impact per ha and the impact per kg fruit produced is indicated by the line.

SYNOPS results

The acute aquatic risk of pesticide use in the BS strategy is high, indicated by the red colour (Fig. 11a). About 80% of this risk is reduced in the AS1 strategy and belongs to the medium risk class. AS2 strategy further reduces the acute aquatic risk but remains in the medium risk class. The acute aquatic risk of IS strategy is less than 1% compared to the BS strategy and belongs to the low risk class. The risk reduction of the two advanced and innovative strategy is based on the replacement of pesticides through alternative measures and on a higher portion of drift reduction. Table 2 shows that in the BS strategy measures that provide 75% drift reduction are used on 4% of the orchard area with only and 90% drift reduction is not used. AS1 strategy is assumed to have either 75% or 90% drift reduction each on half of the orchard area. AS2 and IS strategies have 82% and 91% of the area with 90% drift reduction, the remaining portion having 75% drift reduction. For Switzerland the main drift reduction is due to the use of drift reducing sprayers and an increased portion of orchards under hail net. Hedges are not assumed to be relevant for Switzerland since they are estimated to be present on 10% of the area only for all four strategies.

The chronic aquatic risk of the BS strategy is rated as high risk (Fig. 11b). The improvement of the AS1 strategy is very strong, being less than 1% of the BS strategy and belonging to the low risk class. The same holds true for the AS2 and IS strategies.

The acute terrestrial risk of the BS strategy is rated as medium risk (Fig. 11a). AS1, AS2 and IS strategies reduce the risk down to 40%, 20% and 1%, respectively, compared to BS. These three strategies belong to the low risk class.

The chronic terrestrial risk (Fig. 11b) of the BS strategy belongs already to the low risk class. However, the risk of the AS1, AS2 and IS strategies is lowered strongly compared to BS.

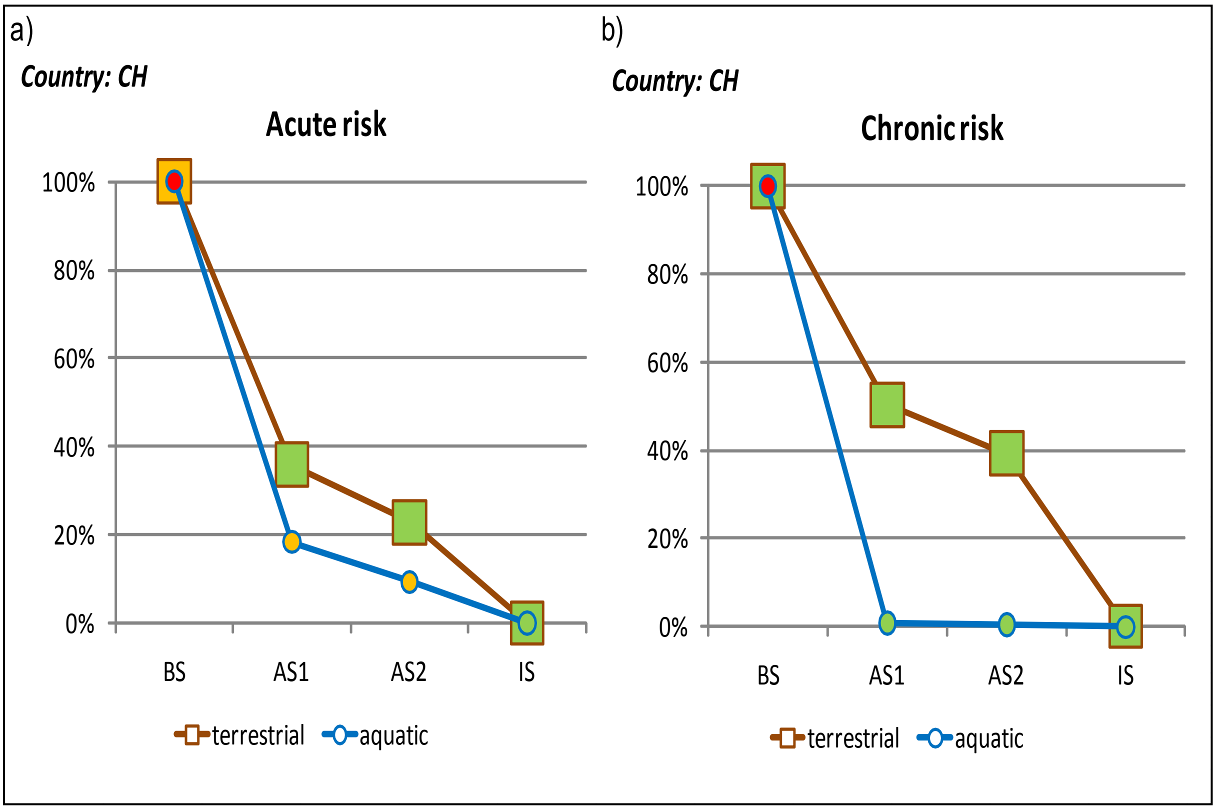

Figure 11. Terrestrial and aquatic SYNOPS results per hectare for (a) Acute risk and (b) Chronic risk for four crop protection strategies in apple orchard systems. Impacts are presented relatively to the BS strategy. Risk classes are given by different colours; Red: High risk, Yellow: Medium risk, Green: Low risk.

Table 2. Percentage of area in the region with measures for 0%, 50%, 75% and 90% drift reduction for four crop protection strategies in apple orchard systems.

Country: CH

	Portion of drift reduction				
	0%	50%	75%	90%	sum
BS	54%	42%	4%	0%	100%
AS1	0%	9%	46%	45%	100%
AS2	0%	0%	18%	82%	100%
IS	0%	0%	9%	91%	100%

4.5. Economic sustainability rating

The AS1 strategy is not rated better than BS for any economic sub-attribute (Fig. 12). “Similar to BS” is the rating result for the AS1 strategy regarding “Total production cost”, and the two sub-attributes referring to “Production risk”, i.e. “Income variability” and “Probability of dramatic yield loss”. AS1 strategy is rated “worse than BS” for “Family income”, “Net profit”, “Invested capital” and “Return on investment” (Fig.12).

The AS2 strategy gets the same economic ratings as the AS1 strategy, with one exception: the “Production risk” is increased compared to AS2.

The economic profile of the IS strategy shows relevant economic advantages compared to the other strategies (Fig.12), since "Profitability" and the economic "Autonomy" are rated "better than BS".

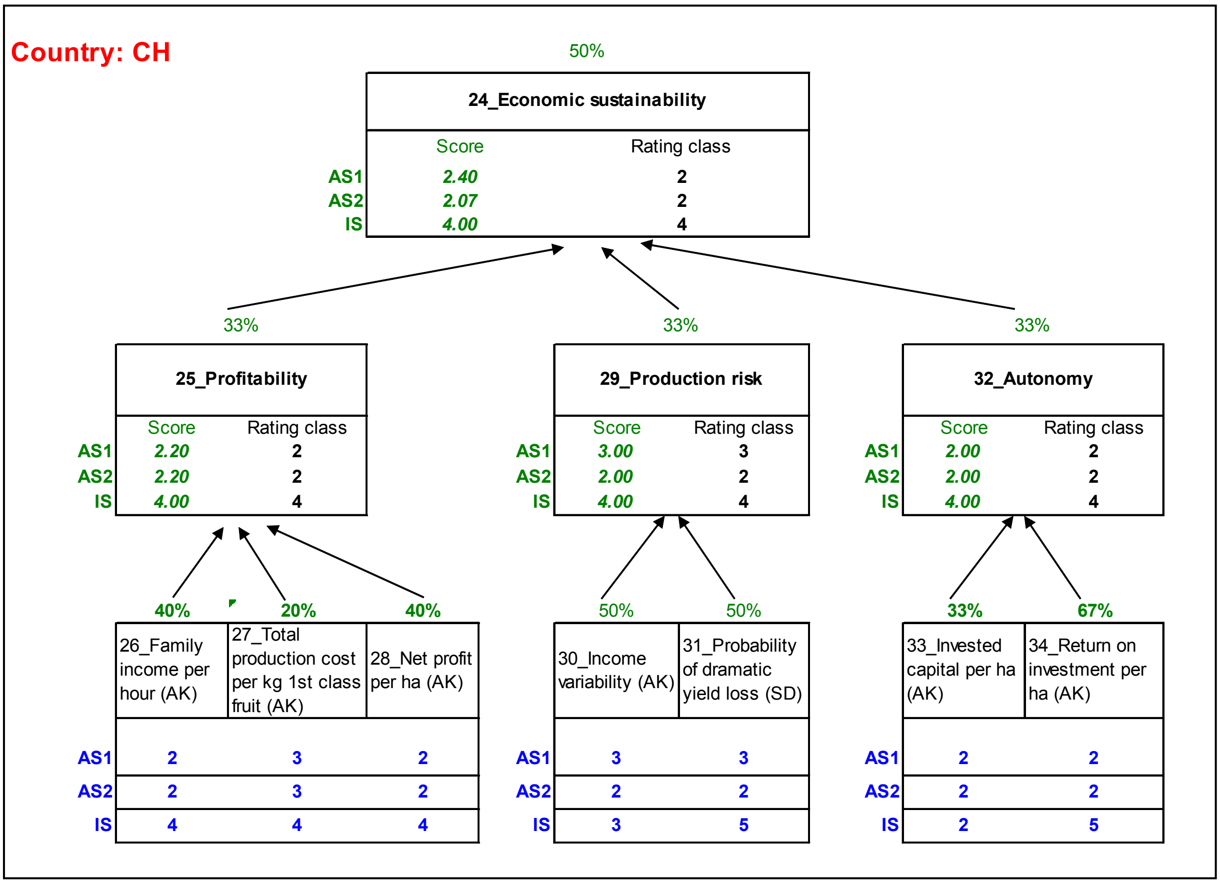

Figure 12. Economic sustainability rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, 3 = similar to BS, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System. Scores: Weighted mean value of ratings of direct sub-attributes.

4.6. Optimising economic attributes

The economic advantages or disadvantages can be located on the revenue as well as on the cost side of the production process. For the AS1 strategy the revenue side is the same as for the BS strategy due to the same amount and variability of yield (Fig. 13) and portion of 1st class fruit (Fig. 14), since for all strategies the same fruit prices are assumed. The production cost side of the AS1 strategy requires about 20% more "Invested capital" than for the BS strategy (Fig. 15), mainly caused through a higher portion of hail nets and exclosure netting. Furthermore, replacing synthetic chemicals by alternative measures cause higher total costs mainly through increased labour hours linked to requirements for monitoring and training. Since the yield is the same as for BS, the AS1 strategy shows 10% higher "Total production costs per kg" and 20% lower "Family income per hour" (Fig. 15).

The AS2 strategy follows the same economic profile as the AS1 strategy but with an disadvantage concerning the "Family income variability" and "Probability of dramatic yield loss" that are increased both for about 50% compared to BS (Fig. 15).

The IS strategy overcompensates the disadvantages of the cost side by higher yields turning it into a 40% higher "Family income per hour" compared to BS (Fig. 15).

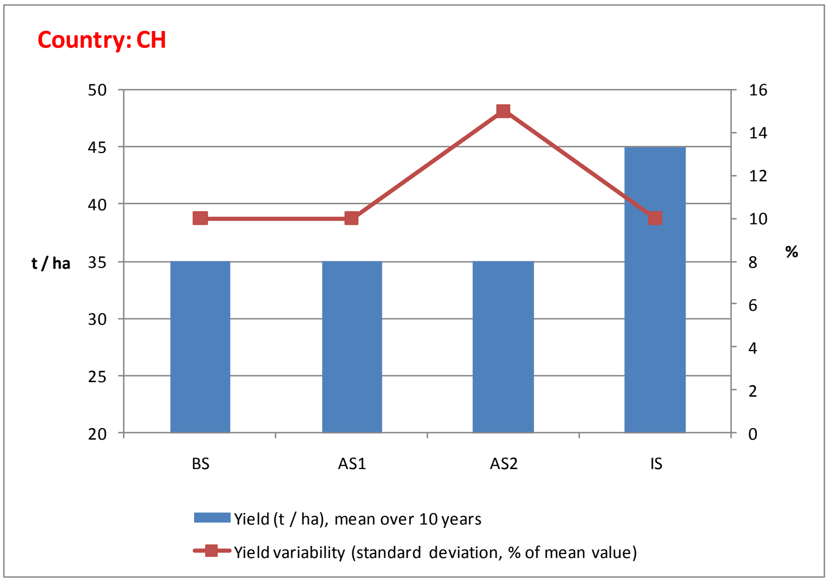

Figure 13. Target values for mean (left scale) and standard deviation (right scale) of yield for four crop protection strategies in apple orchard systems.

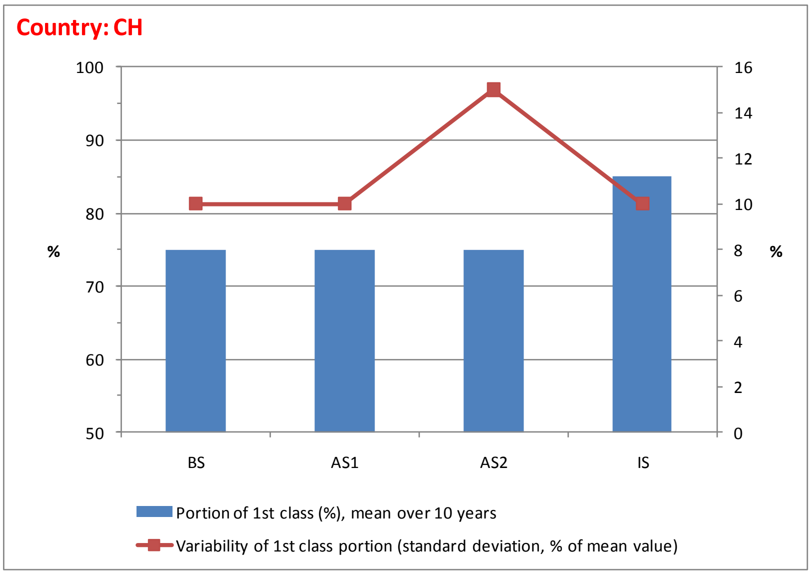

Figure 14. Target values for mean (left scale) and standard deviation (right scale) of the portion of 1st class fruits for four crop protection strategies in apple orchard systems.

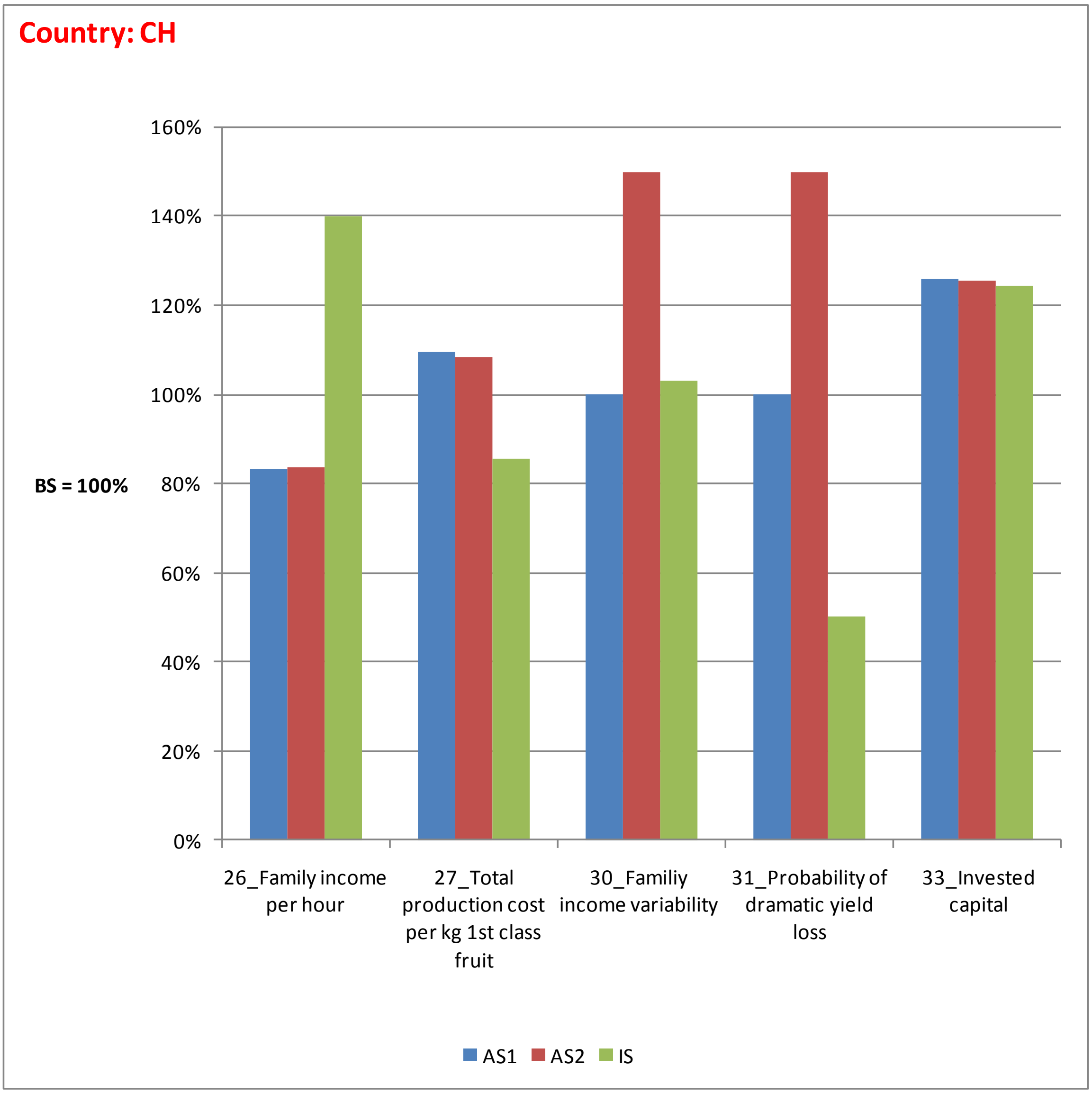

Figure 15. Income, production cost and economic risk for four crop protection strategies in apple orchard systems in relation to the BS.

4.7. Conclusion on optimising crop protection strategies

The AS1 strategy is characterized by a reduction of plant protection sprays through integration of alternative plant protection measures like using scab resistant cultivars, mating disruption for codling moth, enhancement of predatory mites, biocontrol of fire blight and cover crop from mid June to harvest. In addition, the remaining plant protection sprays are done with chemicals with relatively low ecotoxicity using drift reducing techniques. As intended, the ecotoxicity attribute of AS1 is rated much better than BS. Furthermore, human toxicity is significantly reduced. These improvements for ecotoxicity and human toxicity of AS1 compared to BS are partially masked in the aggregated ecological sustainability (rated similar to BS) because the selected innovations in AS1 do not improve other ecological attributes such as resource use or global warming potential. On the same time, AS1 is rated worse than BS for the economic side of the multi attribute assessment resulting from lower profitability and autonomy. This result indicates that a reduction of direct plant protection measures by alternative strategies can reduce the environmental impact but may cause a decreased economic efficiency of the apple production at the same time.

Such an interpretation is supported by the results for the AS2 strategy in which more alternative plant protection strategies are used than in AS1 (e.g. mechanical weeding and exclosure netting) and natural fungicides are used after bloom in order to reduce detectable residues of plant protection products. These changes in the plant protection strategy do not result in higher scores for ecotoxicity and other ecological attributes compared to AS1 but cause a lower economic sustainability. The missing improvement in ecology can be explained by the environmental impact of intensively used natural fungicides such as sulphur. The economic deterioration is caused by an increased production risk (i.e. increased variability for yield and lower portion of 1st class fruit) because damages due to minor pest are more likely to reach economic threshold than in AS1 or BS.

The IS strategy performs significantly better for the "Ecological sustainability" as well as for the "Economic sustainability". These advantages are based on the assumption that promising alternative plant protection strategies currently at the stage of basic research will be available on the market in future. One example is the breading of new cultivars with multigene resistance against several major pests. Experts estimate a time horizon of 30 years for a genetic solution for apple scab, fire blight, powdery mildew and aphids integrated in the same cultivar. In addition, it takes at least 10 years till a new cultivar is established in the apple market to a relevant portion. The assumed higher yield per hectare and the higher portion of 1st class fruit for the IS strategy are the prerequisites for the economic success.

Over all, AS1 and AS2 demonstrate that with alternative measures available on the market today ecotoxicity can be lowered to a relevant extent while other ecological attributes will not be disadvantaged. But both advanced strategies still cause higher production costs per kg compared to the BS strategy, while the yield and portion of 1st class fruit is still the same as for the BS. Thus, disadvantages concerning the "Family income" occur compared to the BS strategy. Further improvements of the "Ecological-economic sustainability" can be expected if the innovations presumed for the IS strategy become commercially available.

5. Results for Germany

5.1. Overall sustainability rating

The AS1 strategy is rated "better than BS" for the "Ecological sustainability" whereas for the "Economic sustainability" the rating is "similar to BS" (Fig. 5). The score of 3.79 for the "Ecological sustainability" indicates that at least one ecological sub-attribute has not reached the rating class 4. Also for the "Economic sustainability" the rating class 3 results from an up rounded score (2.67) telling that at least one economic sub-attribute is rated with worse "than BS".

The AS2 strategy reaches the same rating classes for the three top attributes of the attribute tree as the AS1 strategy (Fig. 5). Still, AS2 differs from AS1 to some extent since the score of the "Ecological sustainability" is slightly higher for AS1. In contrast, for AS2 the score for the "Economic sustainability" is slightly lower than for AS1.

The IS strategy shows an improvement compared to AS2 for the "Economic sustainability" reaching the rating class 4 with a score of 4.30. This score indicates that at least one sub-attribute of the "Economic sustainability" has reached the highest rating class.

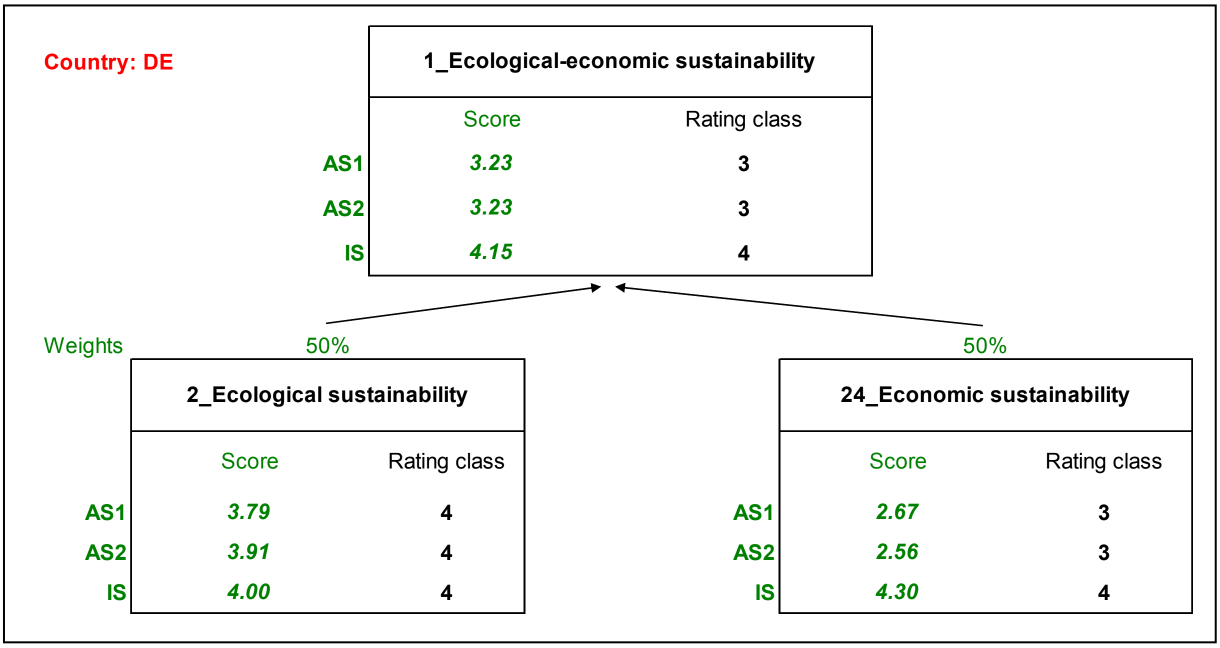

Figure 5. Ecological-economic sustainability rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, **3 = similar to BS**, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System. Scores: Weighted mean value of ratings of direct sub-attributes.

5.2. Ecological sustainability rating

The AS1 strategy strongly improves the “Human toxicity” as well as the “Ecotoxicity” compared to the BS strategy (Fig. 6). For both of these attributes AS1 reaches already the highest rating class. For all other sub-attributes referring to “Resource use” and “Environmental quality” the AS1 strategy stays similar to BS.

The AS2 strategy slightly improves the “Ecotoxicity” compared to AS1 by raising the score from 4.50 to 4.92 (Fig. 6). Furthermore AS2 has a one class higher rating for “Impact on beneficial organisms”. The ratings for the rest of the attributes do not differ between AS2 and AS1.

The IS strategy shows an advantage compared to the AS2 strategy for the “Energy use” and raises the score for Ecotoxicity from 4.92 to 5.00 which is the maximum score (Fig. 6).

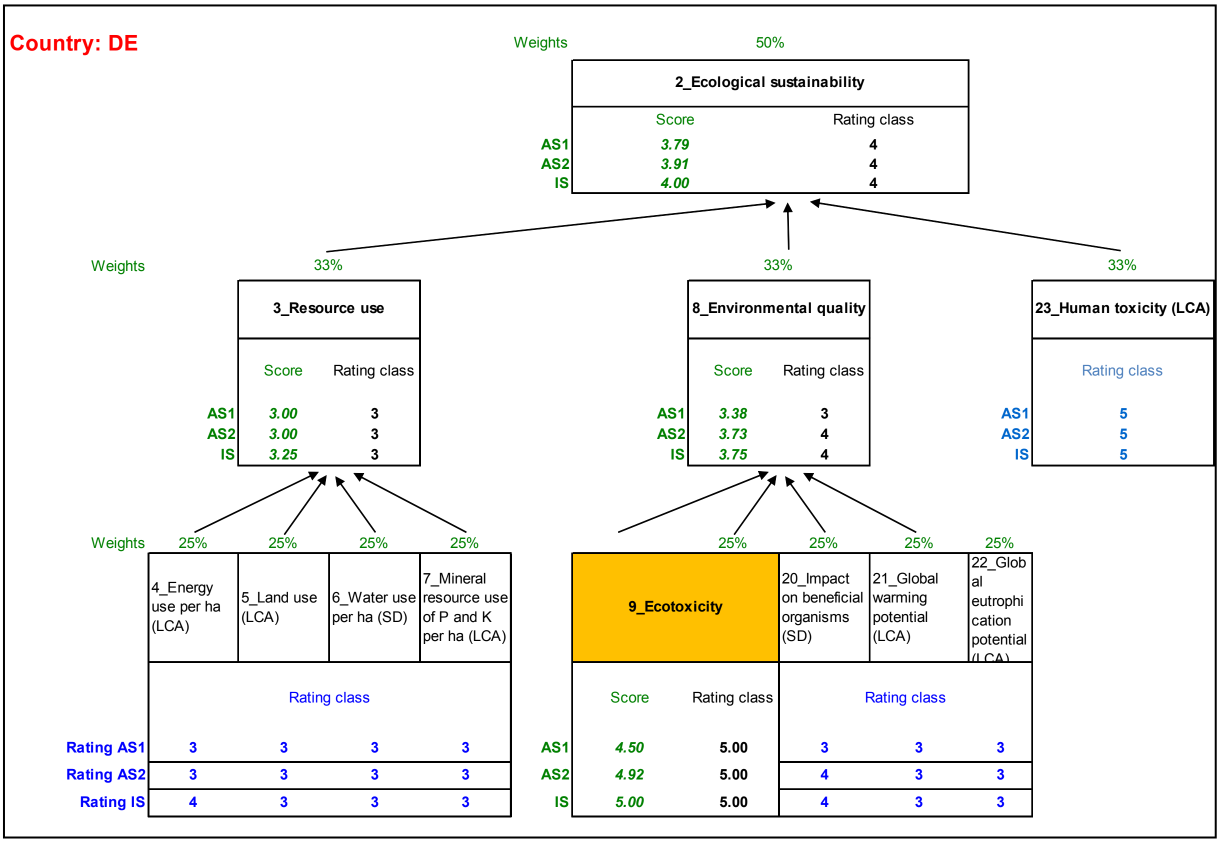

Figure 6. Ecological sustainability rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, **3 = similar to BS**, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System; Scores: Weighted mean value of ratings of direct sub-attributes.

5.3. Ecotoxicity rating

The AS1 strategy strongly improves the “Terrestrial ecotoxicity” and the “Aquatic Ecotoxicity” reaching already the highest rating class (Fig. 7). Also the “Terrestrial risk” and the “Aquatic risk” have a higher rating for AS1 than for BS reaching the rating class 4.

The AS2 strategy improves the “Acute terrestrial risk”, the “chronic aquatic risk” and the “Chronic terrestrial risk” each for one rating class compared to the AS1 strategy (Fig. 6). The improvements in the AS1 and AS2 strategy are based on a bundle of measures that are: A selective use of pesticides, a lower application frequency, an increased use of drift reducing techniques and expansion of hail nets and buffer strips. This counts for all sub-attributes except for the “Aquatic risk” and the “Terrestrial risk” for AS1. In these cases the selective use of pesticides is not sufficient if not combined with lower application frequencies and more drift reducing measures.

The IS strategy improves also the “Acute aquatic risk” compared to AS2 for one rating class. Thus, the IS strategy reaches for all Ecotoxicity related sub-attributes the highest possible rating. For the arthropod control in the IS strategy no chemical pesticides are used any more.

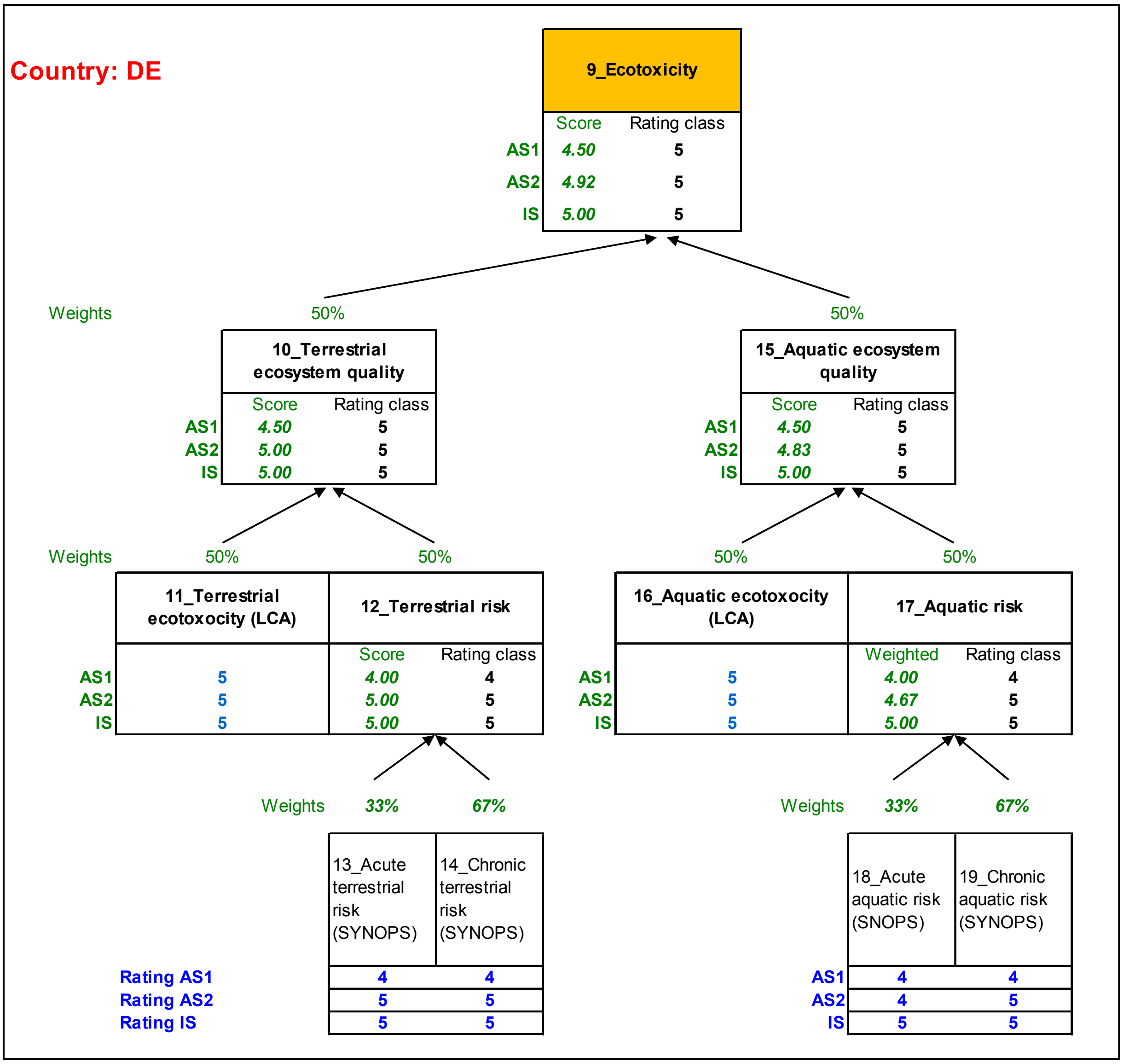

Figure 7. Ecotoxicity rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, **3 = similar to BS**, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System; Scores: Weighted mean value of ratings of direct sub-attributes.

5.4. Optimising ecotoxicity and human toxicity attributes

LCA results

The "Aquatic ecotoxicity" in the BS strategy is dominated by the input of herbicides. They cause about 50% of the total impact (Fig. 8). A proportion of 30% is caused by fungicides, 10% by insecticides. In the AS1, AS2 and IS strategy the impact of herbicides is avoided due to replacing the herbicides Diuro and Amitrol by mechanical weeding. The impact of fungicides is avoided by replacing Copperoxichloride und Pyrimethanil by introducing resistant cultivars, sanitation and antagonistic microorganisms. The "Aquatic Ecotoxicity" of insecticides could be reduced in the IS strategy since Pirimicarb is replaced.

The "Terrestrial ecotoxicity" in the BS strategy is cause for almost 90% by the use of fungicides (Fig. 9). The highest reduction compared to BS is achieved for the "Terrestrial Ecotoxicity" in the AS1, AS2 and the IS strategy. Also for "Terrestrial Ecotoxicity" the impact of insecticides could not be reduced probably for the same reason given above.

For "Human toxicity" the impact profile (Fig. 10) looks similar to the profile of "Aquatic Ecotoxicity", but insecticides and non pesticide inputs cause a higher portion of the total impact. The AS1 strategy reduces the impact for about 70% compared to BS, mainly through lower impact due to herbicides and insecticides. The AS2 strategy lowers the impact not much compared to AS1. The IS strategy shows no impact related to pesticides any more, only non pesticide impacts remain.

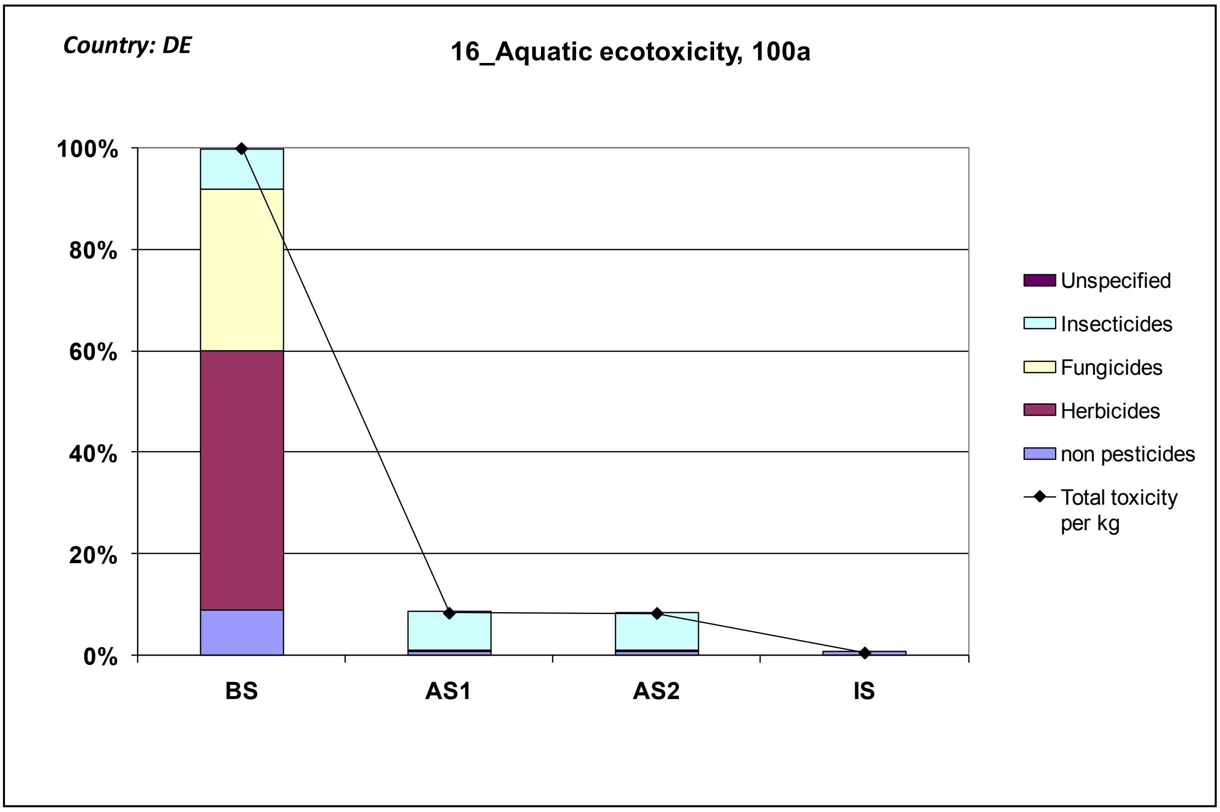

Figure 8. LCA results for aquatic ecotoxicity according to CML2001. Impacts are presented relatively to the BS strategy. Bars represent the impact per ha and the impact per kg fruit produced is indicated by the line.

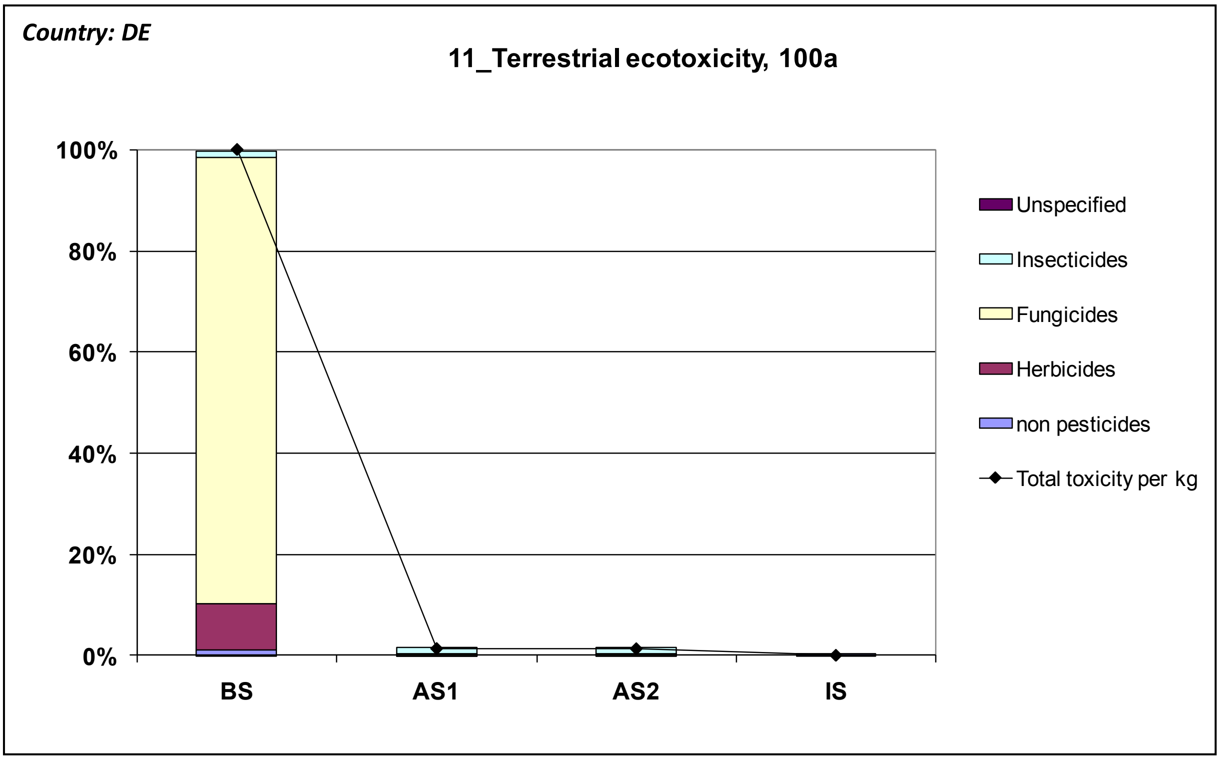

Figure 9. LCA results for terrestrial ecotoxicity according to CML2001. Impacts are presented relatively to the BS strategy. Bars represent the impact per ha and the impact per kg fruit produced is indicated by the line.

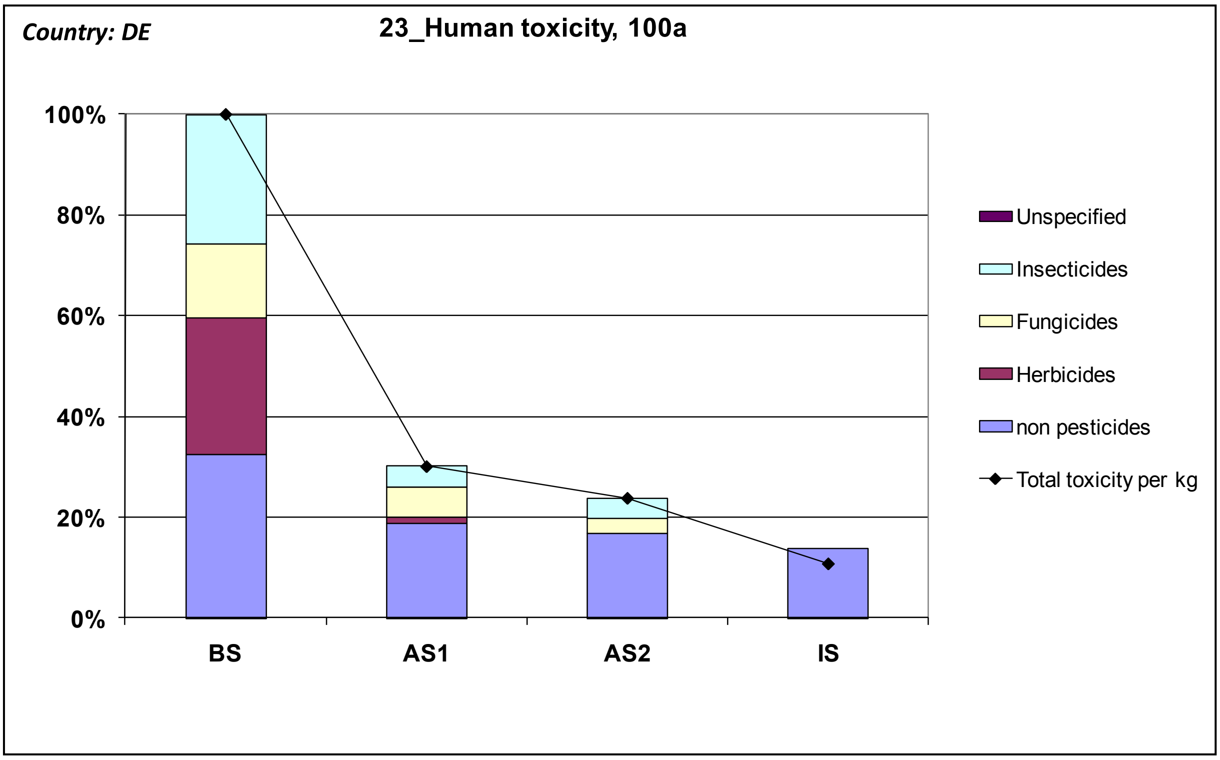

Figure 10. LCA results for human toxicity according to CML2001. Impacts are presented relatively to the BS strategy. Bars represent the impact per ha and the impact per kg fruit produced is indicated by the line.

SYNOPS results

The acute aquatic risk of pesticide use in the BS strategy is belongs to the medium risk class, indicated by the yellow colour (Fig. 11a). About 80% of this risk is reduced in the AS1 strategy that still belongs to the medium risk class. AS2 strategy reduces the acute aquatic risk further and reaches the low risk class. The acute aquatic risk of IS strategy is less than 1% compared to the BS strategy and belongs to the low risk class. The risk reduction of the two advanced and innovative strategy is based on one hand on the replacement of pesticides through alternative measures and on the other through a higher portion of drift reduction. Table 2 shows that in the BS strategy measures that provide 90% drift reduction are used on 15% of the area with orchards, whereas for the AS1, AS2 and IS strategy the area with 90% drift reduction is much increased up to 59%, 89% and 98%, respectively. For Germany the drift reduction is due to several measures namely the use of drift reducing sprayers, an increased portion of orchards under hail net (75% for IS) and an increased portion of orchards with hedges (70% for IS).

The chronic aquatic risk of the BS strategy is rated as high risk (Fig. 11b). The AS1 strategy reduces the risk for 80%, belonging to the medium risk class. The AS2 strategy shows less than half of the risk compared to AS1 but still belongs to the medium risk class. The risk for the IS strategy is less than 1% of the BS strategy and belongs to the low risk class.

The acute terrestrial risk of the BS strategy is rated as high risk (Fig. 11a). Even AS1 strategy belongs still to the high risk class even the risk is only 20% of the BS strategy. The AS2 strategy shows about 1% of the risk compared to BS and belongs to the medium risk class, whereas the risk of the IS strategy is close to zero belonging to the low risk class.

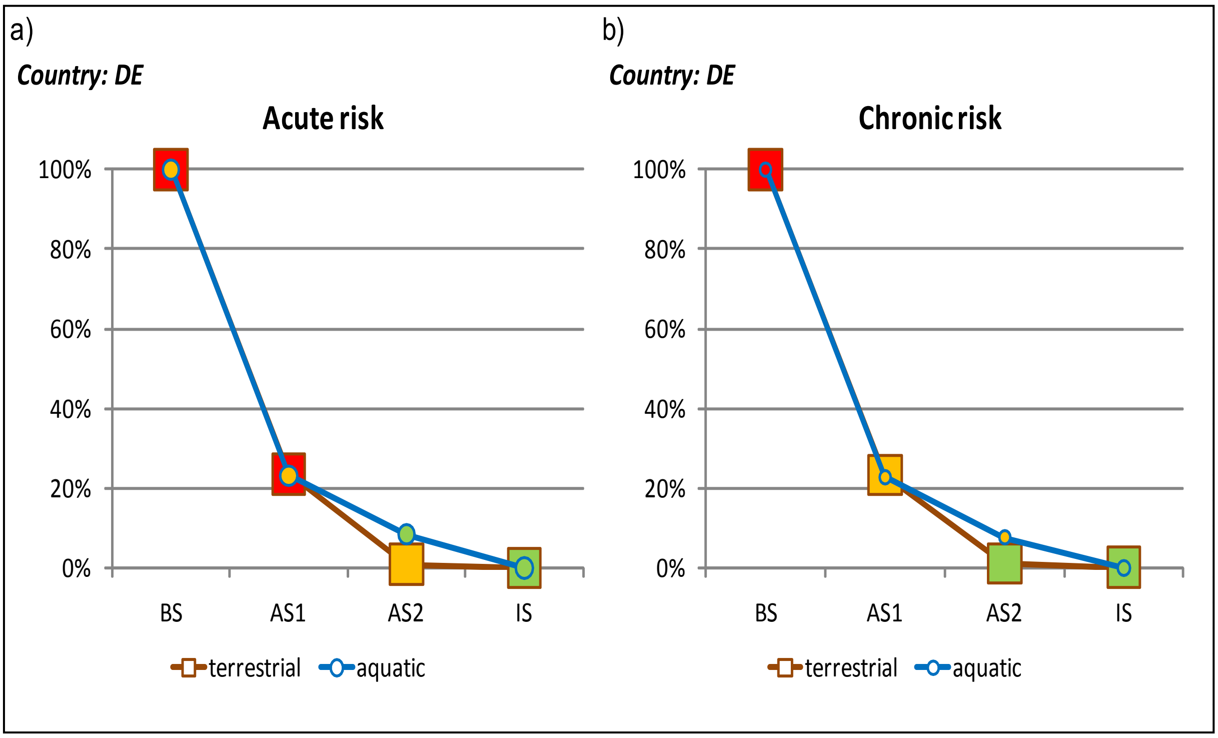

Figure 11. Terrestrial and aquatic SYNOPS results per hectare for (a) Acute risk and (b) Chronic risk for four crop protection strategies in apple orchard systems. Impacts are presented relatively to the BS strategy. Risk classes are given by different colours; Red: High risk, Yellow: Medium risk, Green: Low risk.

Table 2. Percentage of area in the region with measures for 0%, 50%, 75% and 90% drift reduction for four crop protection strategies in apple orchard systems.

Country: DE

	Portion of drift reduction				
	0%	50%	75%	90%	sum
BS	18%	25%	43%	15%	1
AS1	0%	9%	32%	59%	1
AS2	0%	0%	11%	89%	1
IS	0%	0%	2%	98%	1

5.5. Economic sustainability rating

The AS1 strategy is rated "similar to BS" or the sub-attributes of "Profitability" and "Autonomy" (Fig. 13). For the two attributes "Income variability" and "Probability of dramatic yield loss", both referring to the aggregated attribute "Production risk", the AS1 strategy is "worse than BS".

The AS2 strategy improved the "Production risk" compared to AS1 and reaches again the same risk as the BS strategy. But all sub-attributes of referring to "Profitability" and the "Invested capital" are rated one class lower than the AS1 strategy.

The IS strategy improves all economic sub-attributes compared to AS2 and reaches the rating class 4 or 5. Only for the "Invested capital" the IS strategy is rated "worse than BS" since IS due to the use of a higher portion of orchards under hail net.

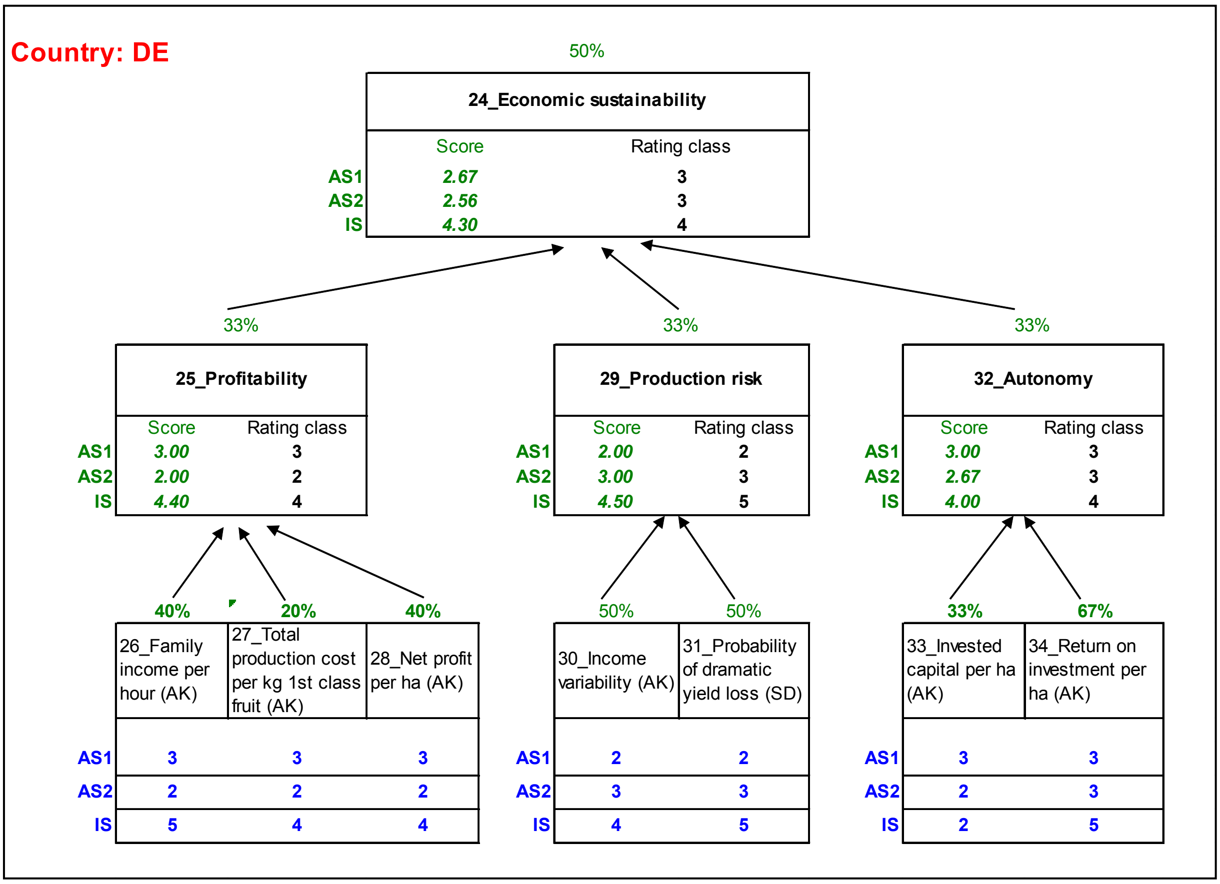

Figure 12. Economic sustainability rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, 3 = similar to BS, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System. Scores: Weighted mean value of ratings of direct sub-attributes.

5.6. Optimising economic attributes

The economic advantages or disadvantages can be located on the revenue as well as on the cost side of the production process. For the AS1 strategy the revenue side is slightly lower as for the BS strategy due to the same amount of yield (Fig. 13) and a lower portion of 1st class fruit (Fig. 14), since for all strategies the same fruit prices are assumed. The production cost side of the AS1 strategy requires a little lower "Invested capital" than for the BS strategy (Fig. 15). For AS1 the costs of pesticide products plus their application are equivalent to the costs of non-chemical tools but are slightly increased by higher labour hours. As a result, the "Total production costs per kg" and "Family income per hour" (Fig. 15) of AS1 is about the same as for the BS strategy.

The AS2 strategy requires about 20% more "Invested capital" as AS1, mainly caused through a higher portion of hail nets and exclosure netting. Furthermore, replacing synthetic chemicals by alternative measures cause higher total costs mainly through increased labour hours linked to requirements for monitoring and training. Since the AS2 strategy has the same yield and portion of 1st class fruit as the AS1 the "Total production costs per kg" are about 25% higher than for AS1 and the "Family income per hour" is about 30% lower than for AS1 (Fig. 15).

The IS strategy overcompensates the disadvantages of the cost side by higher yields turning it into a 40% higher "Family income per hour" compared to BS (Fig. 15).

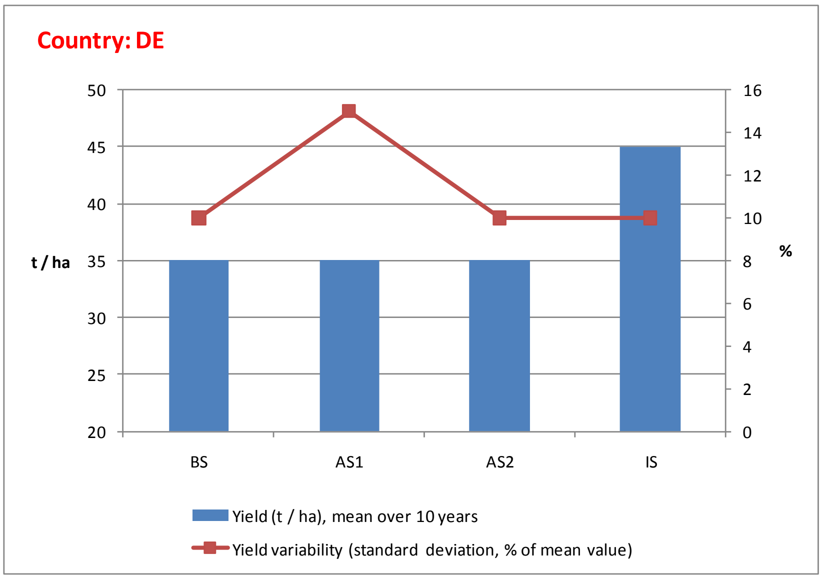

Figure 13. Target values for mean (left scale) and standard deviation (right scale) of yield for four crop protection strategies in apple orchard systems.

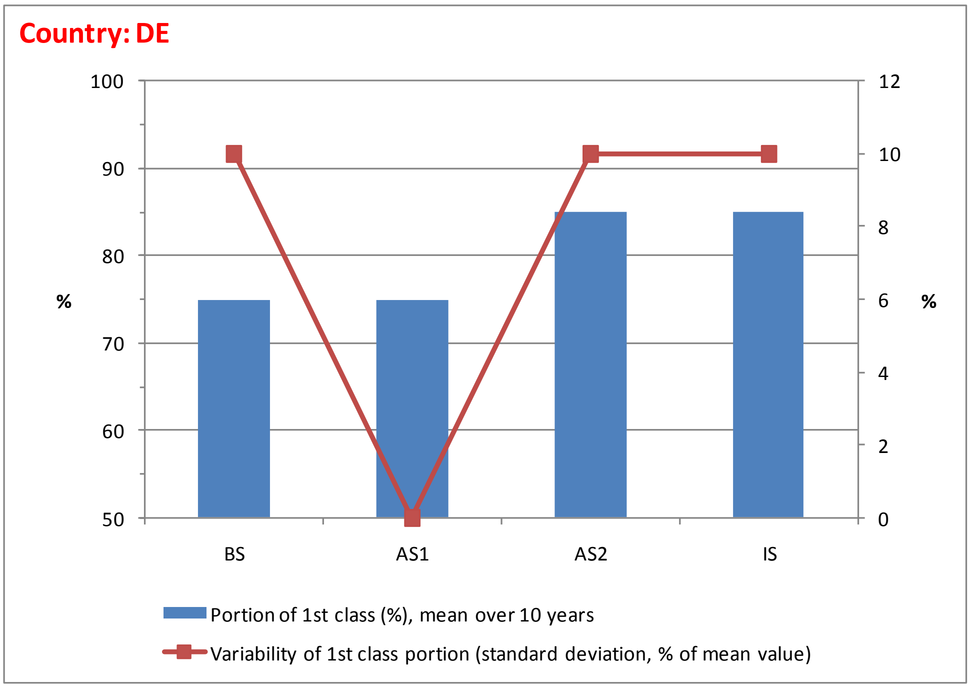

Figure 14. Target values for mean (left scale) and standard deviation (right scale) of the portion of 1st class fruits for four crop protection strategies in apple orchard systems.

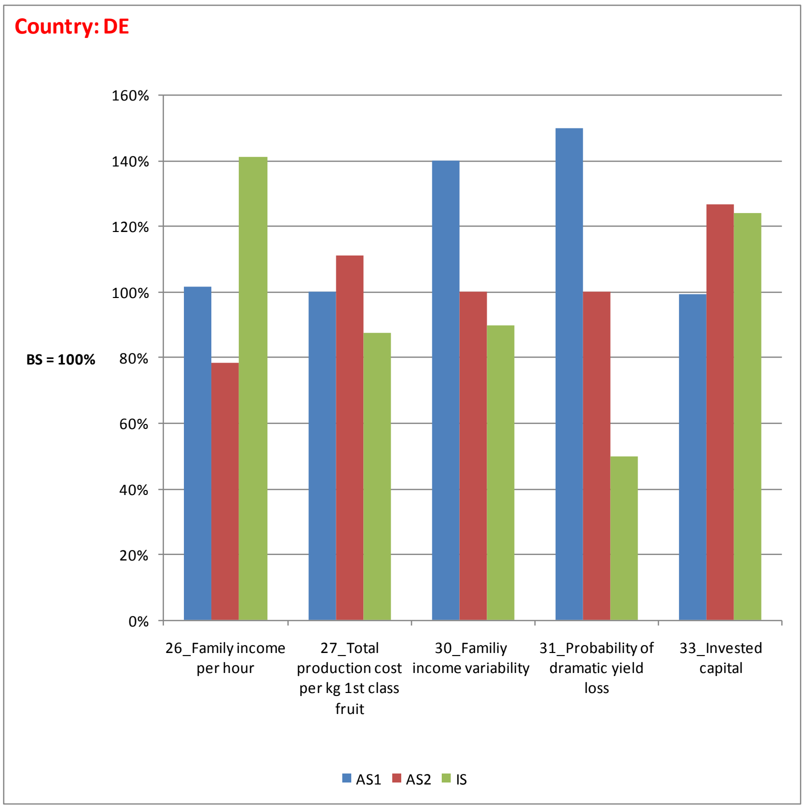

Figure 15. Income, production cost and economic risk for four crop protection strategies in apple orchard systems in relation to the BS.

5.7. Conclusion on optimising crop protection strategies

The goal of the AS strategy is to improve the ecological and environmental sustainability of the production system as compared to the BS strategy. Both of them are defined as crop protection systems where non-conventional chemical control techniques are preferred to pesticides. The IS strategy is designed to be the production system with the lowest negative impact on the ecological and environmental sustainability.

The results show, that for AS2 and IS this goal was achieved. This is due to a reduction of chemical plant protection product application to an absolute minimum. This is achieved by applying alternatives measures which are currently tested in the field and pursuing of alternative strategies to a maximum. This means for IS that arthropod control is realised without chemical pesticides but mainly with the use of resistant varieties, pheromones and bio pesticides. For disease control also technical measures as rain shelters are installed. Decision support systems are used to the full available extent and are supplemented with automated scouting technologies. The cultivars have resistance/tolerance genes against multiple diseases. No chemical weed control is conducted. 45% to 65% of the production sites are under hail net. The use of 75% (AS2) to 90% (IS) drift reducing equipment in the first five rows from the edge of the field is standard. Different products of 99% drift reducing equipment are available which fulfil the practical requirements of outdoor use. 90% of the orchards have a minimum distance of 20 meters to surface waters. The buffer zones and their drift filtering vegetations are optimised to protect surface waters from pesticide exposure.

6. Results for The Netherlands

6.1. Overall sustainability rating

The AS1 strategy is rated “similar to BS” for the “Ecological sustainability” and “better than BS” for the “Economic sustainability” (Fig. 5). The sore of the “Ecological sustainability” of 3.06 indicates that at least one ecological sub-attribute must be rated with “better than BS”. The score of 3.54 for the “Economic sustainability” indicates that at least one economic sub-attribute is rated with “similar to BS” or even “worse than BS”. The resulting score for the “Ecological-economic sustainability” is 3.30 (equally weighted sub-attributes assumed) which is equivalent with the rating class 4 (“better than BS”).

The AS2 strategy remains in the same rating class than AS1 for the “Ecological sustainability” (Fig. 5). But AS2 shows a moderate improvement compared to AS1 since the score for AS2 is slightly higher (3.41) than the one for AS1 (3.06). Regarding the “Economic sustainability the rating and score for AS2 is exactly the same than for AS1.

The IS strategy improves the score for the “Ecological sustainability” compared to AS2 not much but enough to reach the next higher rating class. The IS strategy also improves the score for the “Economic sustainability” compared to AS2 but remains in rating class 4.

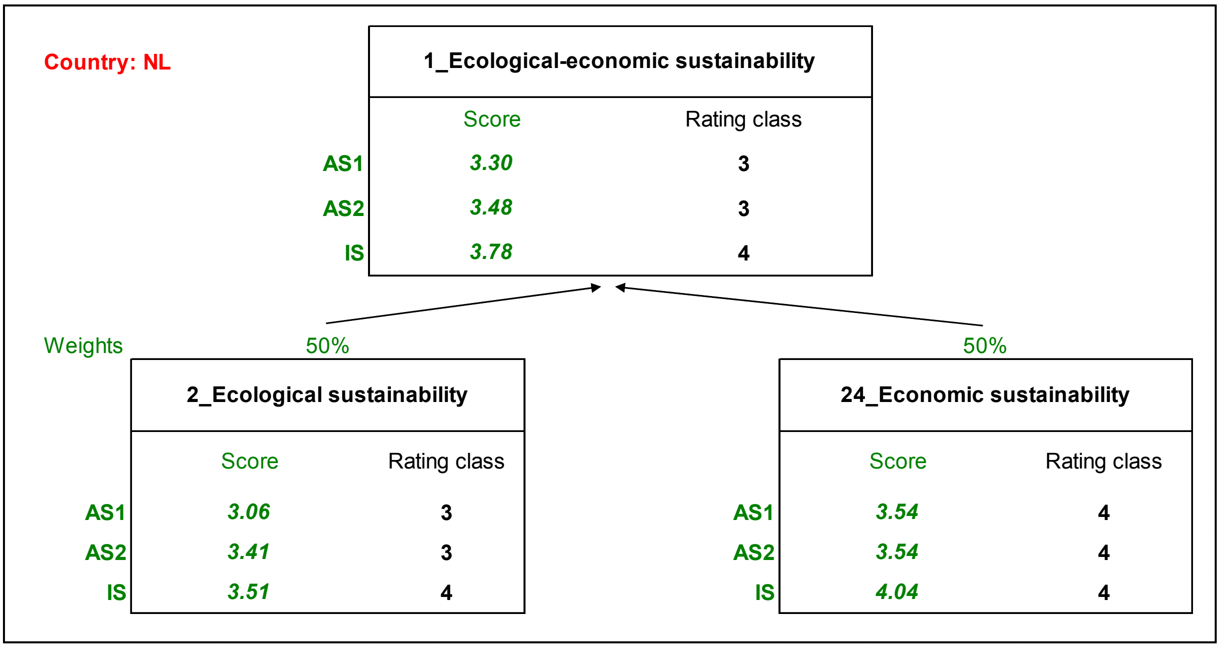

Figure 5. Ecological-economic sustainability rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, **3 = similar to BS**, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System. Scores: Weighted mean value of ratings of direct sub-attributes.

6.2. Ecological sustainability rating

The AS1 strategy has improved the “Ecotoxicity” compared to BS reaching the rating class 4 with a score of 3.67 (Fig. 6). All other ecological sub-attributes are rated with “similar to BS” and therefore not affected by the improvement of the “Ecotoxicity”.

The AS2 strategy improves the “Ecotoxicity” further compared to AS1, indicated by a slightly higher score but remains in the rating class 4 as AS2. In addition AS2 improves the “Human toxicity” being rated on class higher than AS1 (Fig. 6).

The IS strategy improves the “Ecotoxicity” slightly compared to AS2 raising the score from 3.92 to 4.17 remaining in the same rating class as AS2 (Fig. 6). Furthermore, the IS strategy improves “Energy use” and “Impact on beneficial organisms” for one rating class compared to AS2. In contrast, the IS strategy gets a lower rating class for “Mineral resource use” than AS2. The reason is the doubled input compared to AS2 of calcium hydroxide and potassium bicarbonate used as alternative measures for disease control.

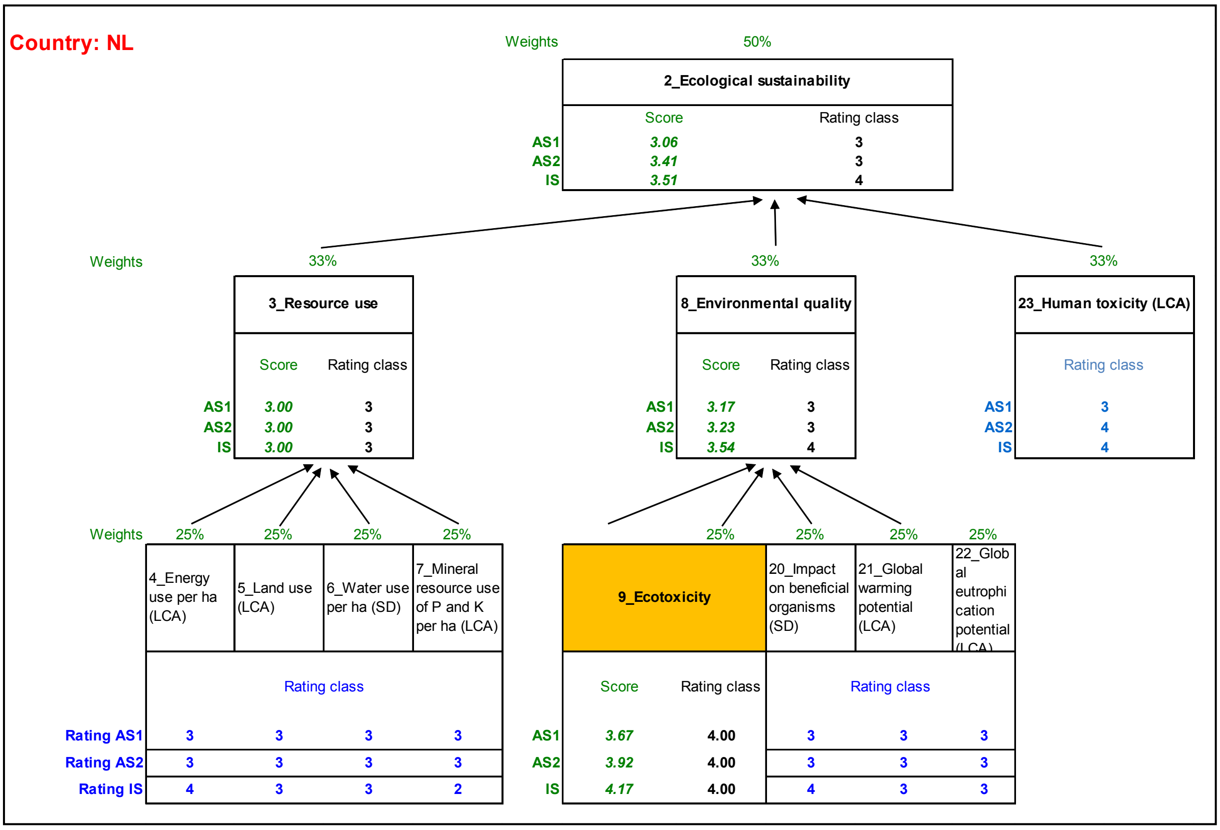

Figure 6. Ecological sustainability rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, **3 = similar to BS**, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System; Scores: Weighted mean value of ratings of direct sub-attributes.

6.3. Ecotoxicity rating

The AS1 strategy lowered the “Terrestrial risk” strongly compared to the BS strategy, since the “Acute terrestrial risk” as well as the “Chronic terrestrial risk” reached the highest rating class (Fig. 7). The AS1 strategy also improved the “Chronic aquatic risk” being rated with “better than BS”, whereas for the “Acute aquatic risk” is not improved compared to the BS strategy. Also the “Terrestrial ecotoxicity” and the “Terrestrial ecotoxicity” of the AS1 strategy remain similar to the BS strategy.

The AS2 strategy achieves an advantage compared to the AS1 strategy concerning the “Acute aquatic risk” and the “Chronic aquatic risk” (Fig. 7). The rest of the ecotoxicity attributes show the same rating class for AS2 as for AS1.

The IS strategy improves the “Aquatic Ecotoxicity” for one rating class compared to AS2. Among the other attributes no advantage occurs for the IS strategy compared to the AS2 strategy.

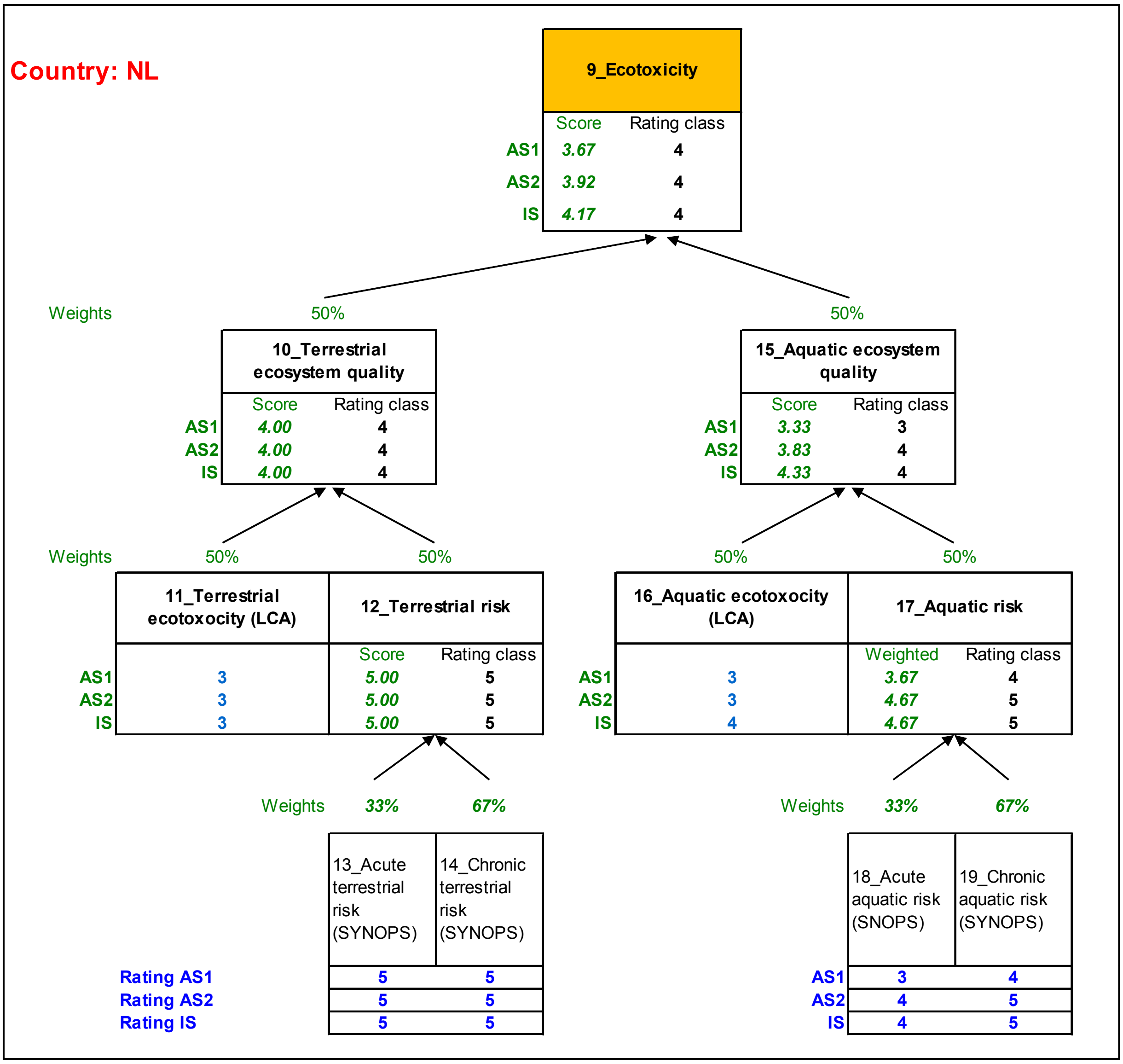

Figure 7. Ecotoxicity rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, **3 = similar to BS**, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System; Scores: Weighted mean value of ratings of direct sub-attributes.

6.4. Optimising ecotoxicity and human toxicity attributes

LCA results

The "Aquatic ecotoxicity" of the BS strategy is dominated by fungicide use, causing close to 60% of the total impact (Fig. 8). This impact on the aquatic ecotoxicity is mainly due to the use of Pyrimethanil and also Difenoconazole. The rest of the impact is due to the use of insecticides and herbicides with a similar portion each. The AS1 strategy shows still the same impact as the BS strategy regarding the impact due to the use of fungicides. But the "Aquatic Ecotoxicity" due to insecticides is practically down to zero, mainly by replacing Abamectin even four insecticide applications remain in the AS1 strategy. Furthermore, AS1 strategy shows only about half of the impact compared to BS due to herbicides. This is achieved by replacing Metazachlor. Two herbicide applications still remain. The AS2 strategy has slightly reduced the "Aquatic ecotoxicity" (- 7%) due to fungicide optimisation compared to the AS1 strategy. The IS strategy avoids "Aquatic Ecotoxicity" through herbicide use by only using Glyphosate (one applications) and natural herbicides (two applications). The IS

strategy replaced the herbicides Fluazifop-p, MCPA, Linuron, and Mecoprop (mcpp) by cover crop from mid June to harvest with mowing and mechanical weeding. In contrast, the impact due to fungicide use is also for the IS strategy still the same than for AS2 and AS1 (Fig. 8).

The "Terrestrial ecotoxicity" of the BS strategy (Fig. 9) shows a similar situation as described above for the "Aquatic Ecotoxicity". The AS1 strategy reduces the impact by 25% compared to the BS strategy. AS2 and IS do not achieve relevant progress compared to AS1, since lower impacts due to optimised fungicide and herbicide use raises of the impact of non pesticide inputs such as mechanical weeding.

The "Human toxicity" of the BS strategy is mainly caused by herbicide use and non pesticide impact (e.g. machinery use) and to a smaller extent by fungicide and insecticide use (Fig. 10). The improvements of AS1 mainly are due to optimised herbicide use as described above. In contrast, the changes of AS1 strategy for fungicide use turned into higher "Human toxicity". Thus, the total impact of AS1 is still 80% of the BS strategy. The improvements of AS2 and IS strategy are due to optimised herbicide use but the effect is not very strong.

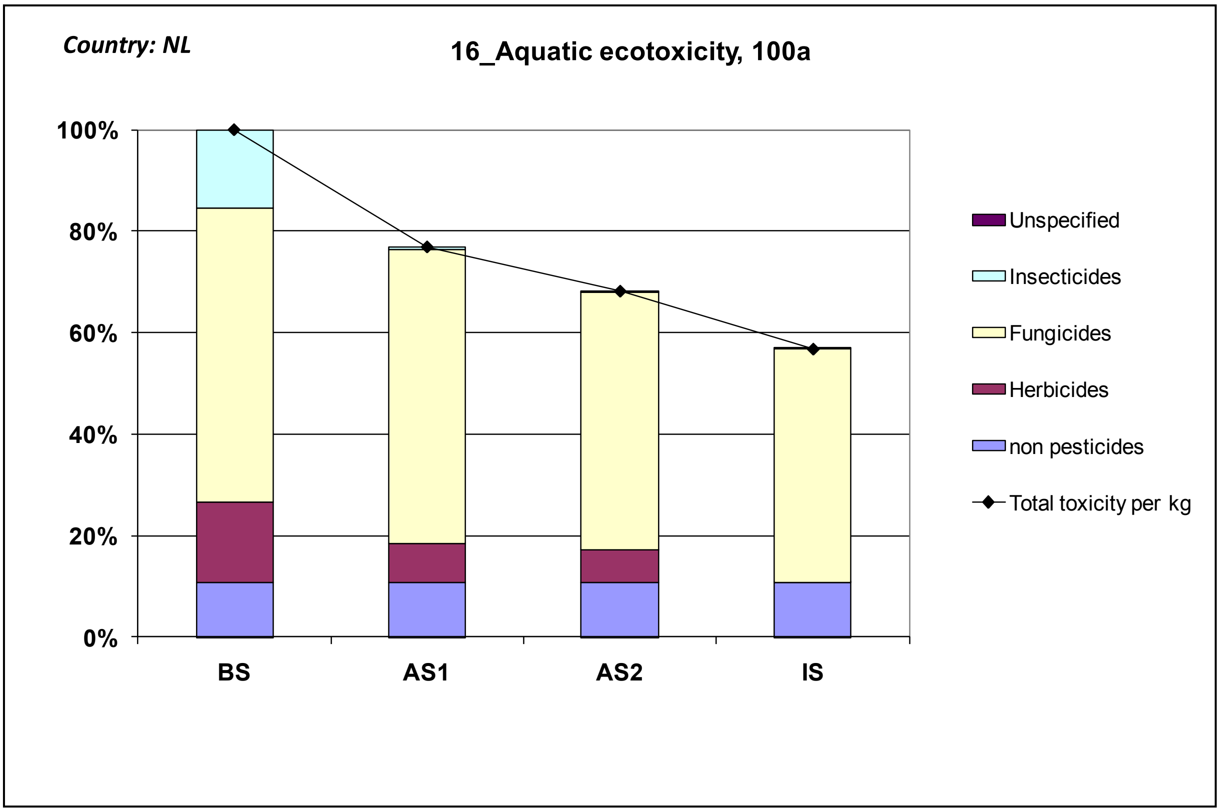

Figure 8. LCA results for aquatic ecotoxicity according to CML2001. Impacts are presented relatively to the BS strategy. Bars represent the impact per ha and the impact per kg fruit produced is indicated by the line.

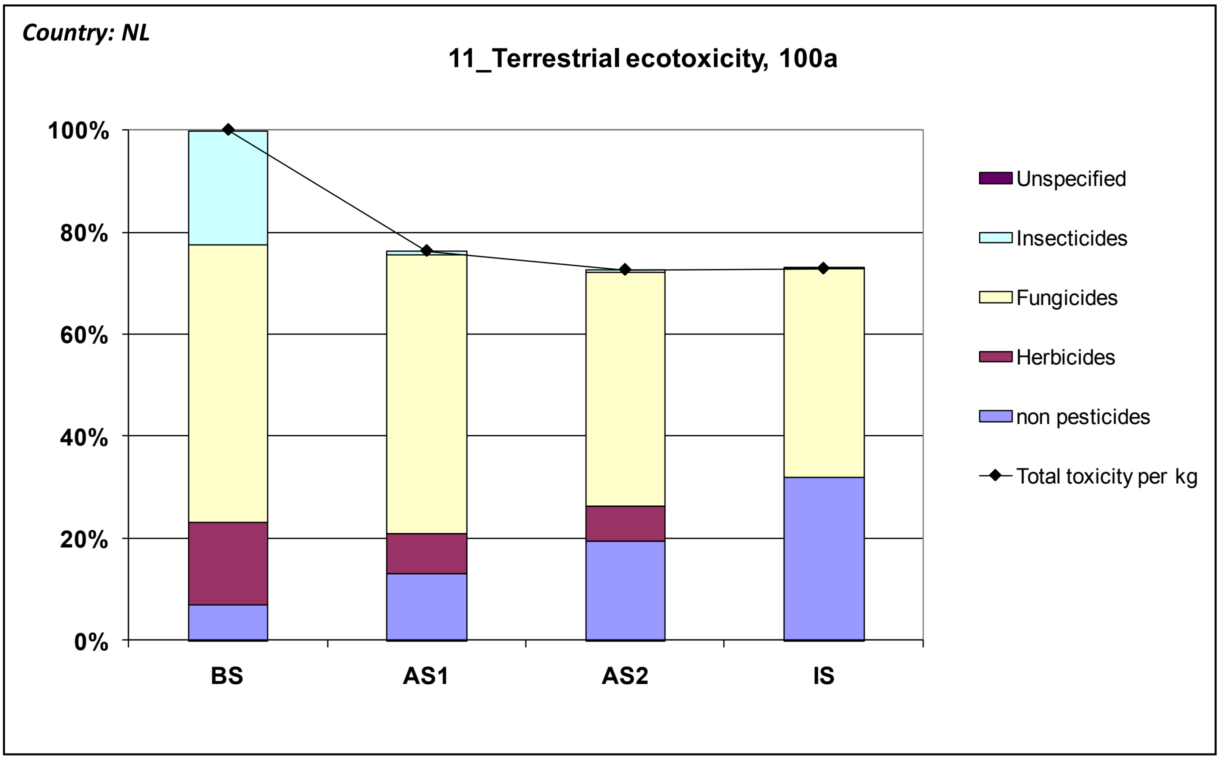

Figure 9. LCA results for terrestrial ecotoxicity according to CML2001. Impacts are presented relatively to the BS strategy. Bars represent the impact per ha and the impact per kg fruit produced is indicated by the line.

Figure 10. LCA results for human toxicity according to CML2001. Impacts are presented relatively to the BS strategy. Bars represent the impact per ha and the impact per kg fruit produced is indicated by the line.

SYNOPS results

The acute aquatic risk of pesticide use in the BS and AS1 strategy is high, indicated by the red colour (Fig. 11a). AS2 and IS strategy reduce the acute aquatic risk for about 90% belonging to the medium risk class. The risk reduction of the AS2 and IS strategy is based on one hand on the replacement of pesticides through alternative measures and on the other through a higher portion of drift reduction. Table 2 shows that in the BS strategy measures that provide 90% drift reduction are used on 21% of the area with orchards only whereas the AS1 strategy has already doubled this area and in the AS2 and IS strategy nearly in all orchards 90% drift reduction measures are implemented. For The Netherlands the main drift reduction is due to the use of drift reducing sprayers and hedges on 60% of the area for BS and AS1 strategy, 70% and 80% for the AS2 and IS strategy.

The chronic aquatic risk of the BS strategy is rated as high risk (Fig. 11b). The AS1 strategy lowers the risk for 40% but still remains to the high risk class. AS2 strategy shows relevant improvement with less than 5% risk compared to BS but belonging to the medium risk class. The IS strategy lowers the risk again reaching the low risk class.

The acute terrestrial risk of the BS strategy is rated as high risk (Fig. 11a). AS1, AS2 and IS strategies reduce the risk down to less than 1% compared to BS. These three strategies belong to the low risk class.

The chronic terrestrial risk (Fig. 11b) of the BS strategy belongs already to the medium risk class. However, the risk of the AS1, AS2 and IS strategies is lowered strongly compared to BS, while these strategies belong to the low risk class.

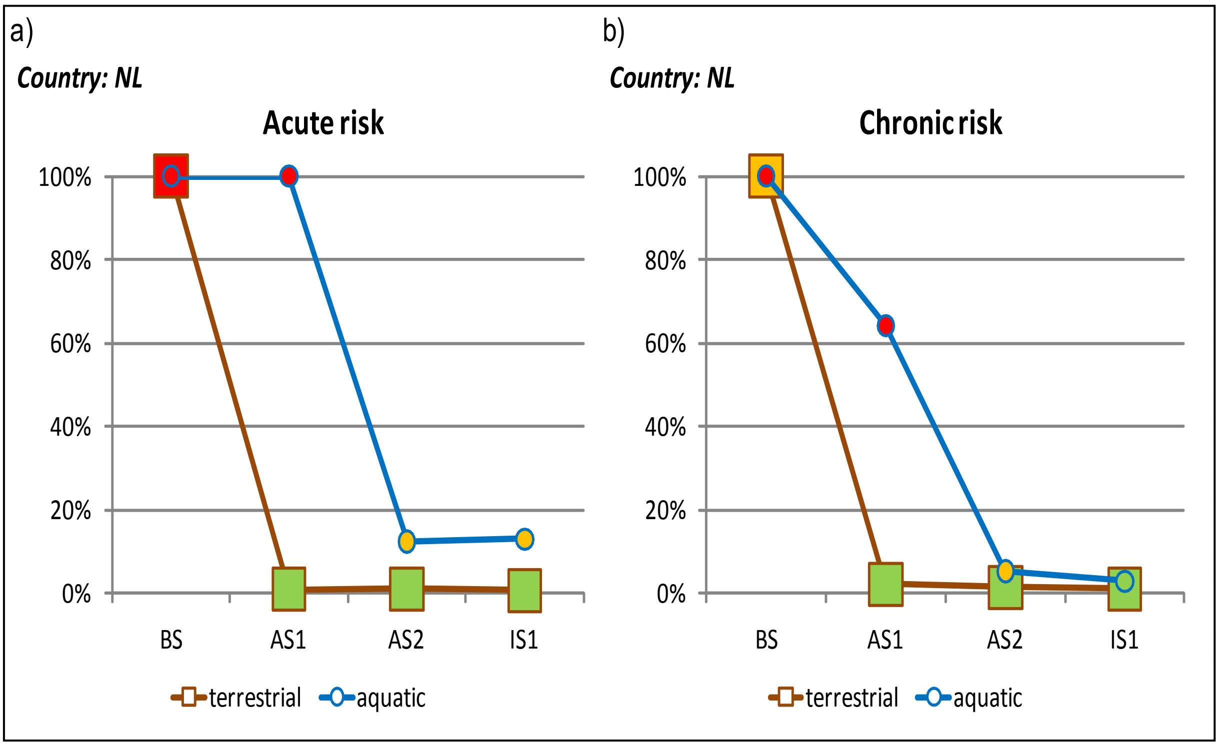

Figure 11. Terrestrial and aquatic SYNOPS results per hectare for (a) Acute risk and (b) Chronic risk for four crop protection strategies in apple orchard systems. Impacts are presented relatively to the BS strategy. Risk classes are given by different colours; Red: High risk, Yellow: Medium risk, Green: Low risk.

Table 2. Percentage of area in the region with measures for 0%, 50%, 75% and 90% drift reduction for four crop protection strategies in apple orchard systems.

Country: NL

	Portion of drift reduction				
	0%	50%	75%	90%	sum
BS	26%	39%	14%	21%	1
AS1	11%	18%	28%	43%	1
AS2	0%	0%	6%	94%	1
IS	0%	0%	3%	97%	1

6.5. Economic sustainability rating

The AS1 strategy improves “Family income”, “Net profit”, “Return on investment” and “Production cost” compared to the BS strategy while the “Invested capital” stays similar to BS (Fig. 12). But these strong advantages go along with strongly increased “Production risk” since “Income variability” and “Probability of dramatic yield loss” have the rating “worse than BS” and “much worse than BS”.

The AS2 strategy shows exactly the same ratings for all economic sub-attributes (Fig. 12).

The IS strategy keeps the advantages of AS1 and AS2 strategy for the attributes referring to the “Profitability” and the economic “Autonomy” but reduces the “Production risk” compared to AS1 and AS2 strategy (Fig. 12). Still, the IS strategy is not improving the “Production risk” compared to the BS strategy.

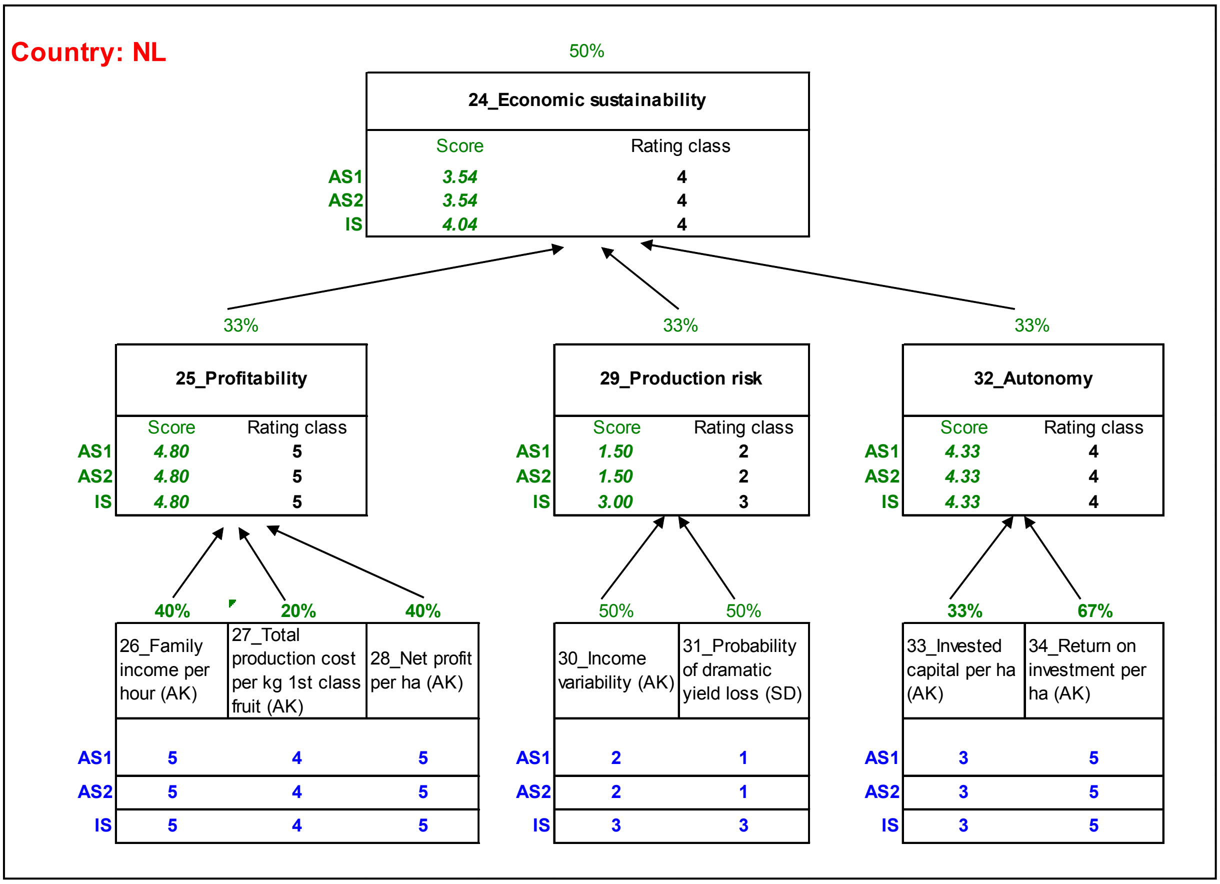

Figure 12. Economic sustainability rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, 3 = similar to BS, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System. Scores: Weighted mean value of ratings of direct sub-attributes.

6.6. Optimising economic attributes

The economic advantages or disadvantages can be located on the revenue as well as on the cost side of the production process. For the AS1 strategy the revenue side is improved compared to the BS strategy due to higher amount of yield (Fig. 13) and same portion of 1st class fruit (Fig. 14), since for all strategies the same fruit prices are assumed. The production cost side of the AS1 strategy requires about the same "Invested capital" than for the BS strategy (Fig. 15). For AS1 the costs of pesticide products plus their application are equivalent to the costs of non-chemical tools but are increased by higher labour hours. As a result, the "Total production costs per kg" is 20% lower and the "Family income per hour" is improved for about 40% compared to BS (Fig. 15).

The AS2 strategy compared to AS1 requires higher labour hours linked to requirements for monitoring and training but compensates this with a higher portion of 1st class fruits. Thus, the AS2 strategy shows a little higher "Total production cost per kg" and a little lower "Family income per hour" than AS1 but still 40% higher than for BS. But this advantage of AS1 and the AS2 has to take into account that the income variability is increased compared to BS.

The IS strategy overcompensates the disadvantages of the cost side by higher yields and portion of 1st class fruit turning it into a slightly higher "Family income per hour" compared to AS2 (Fig. 15). But the strongest advantage of the IS strategy compared to AS1 and AS2 strategy given through yield and portion of 1st class fruit that are more stable.

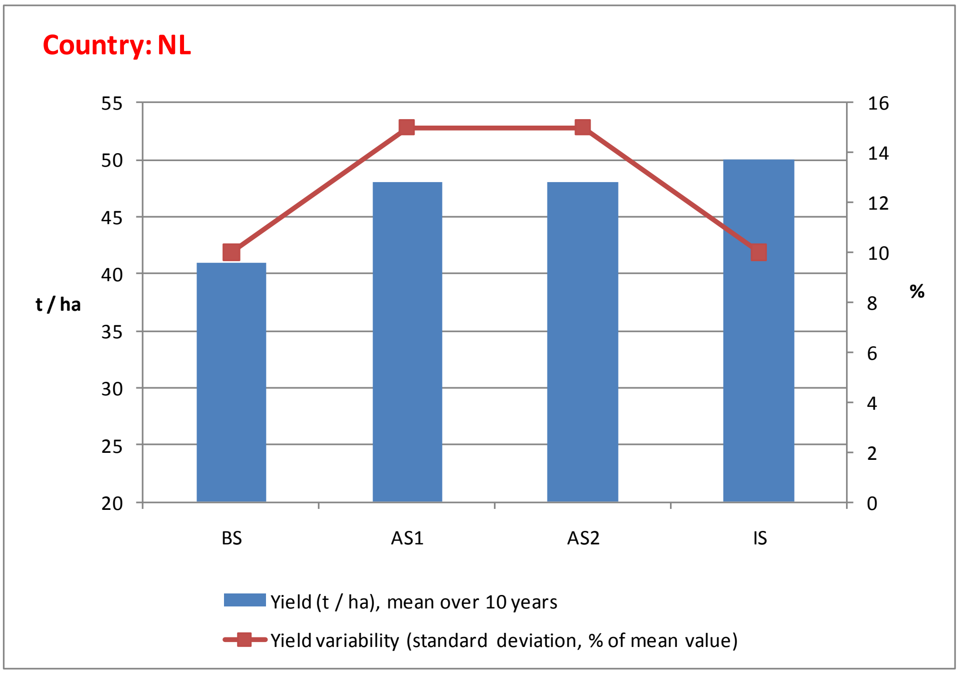

Figure 13. Target values for mean (left scale) and standard deviation (right scale) of yield for four crop protection strategies in apple orchard systems.

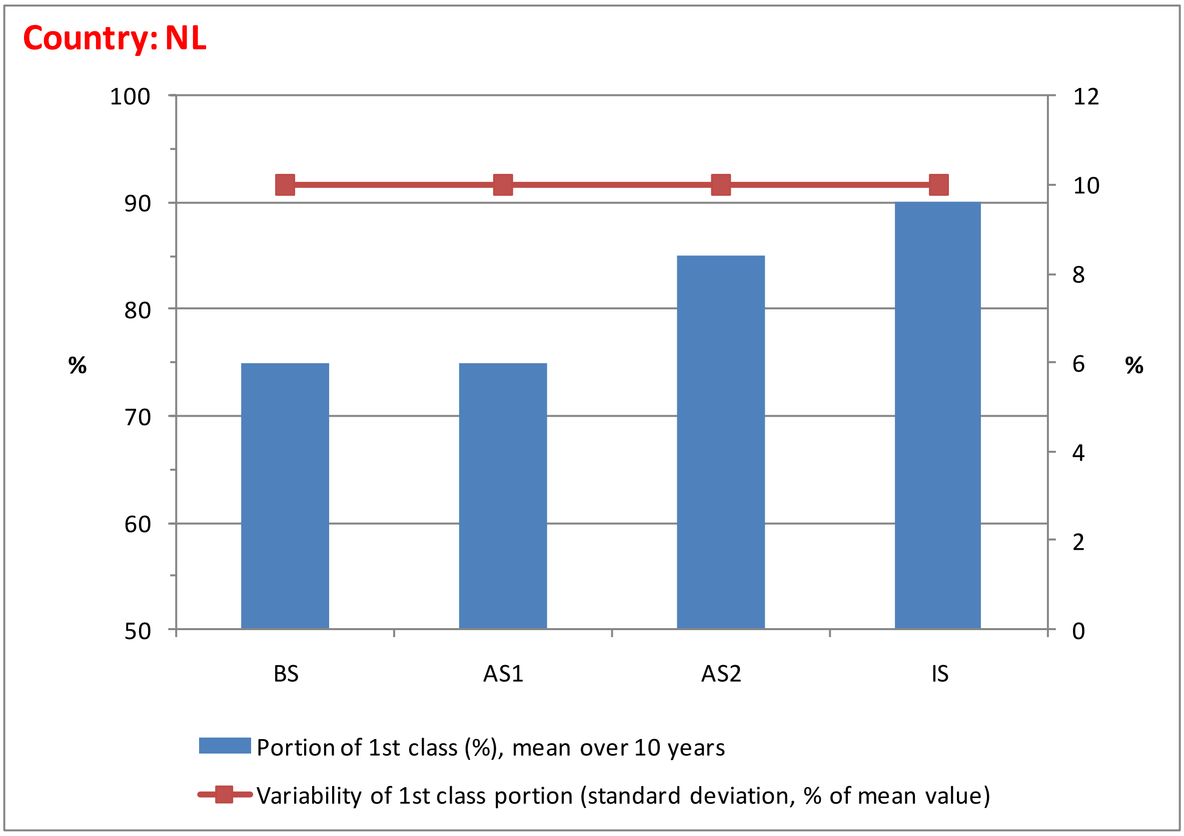

Figure 14. Target values for mean (left scale) and standard deviation (right scale) of the portion of 1st class fruits for four crop protection strategies in apple orchard systems.

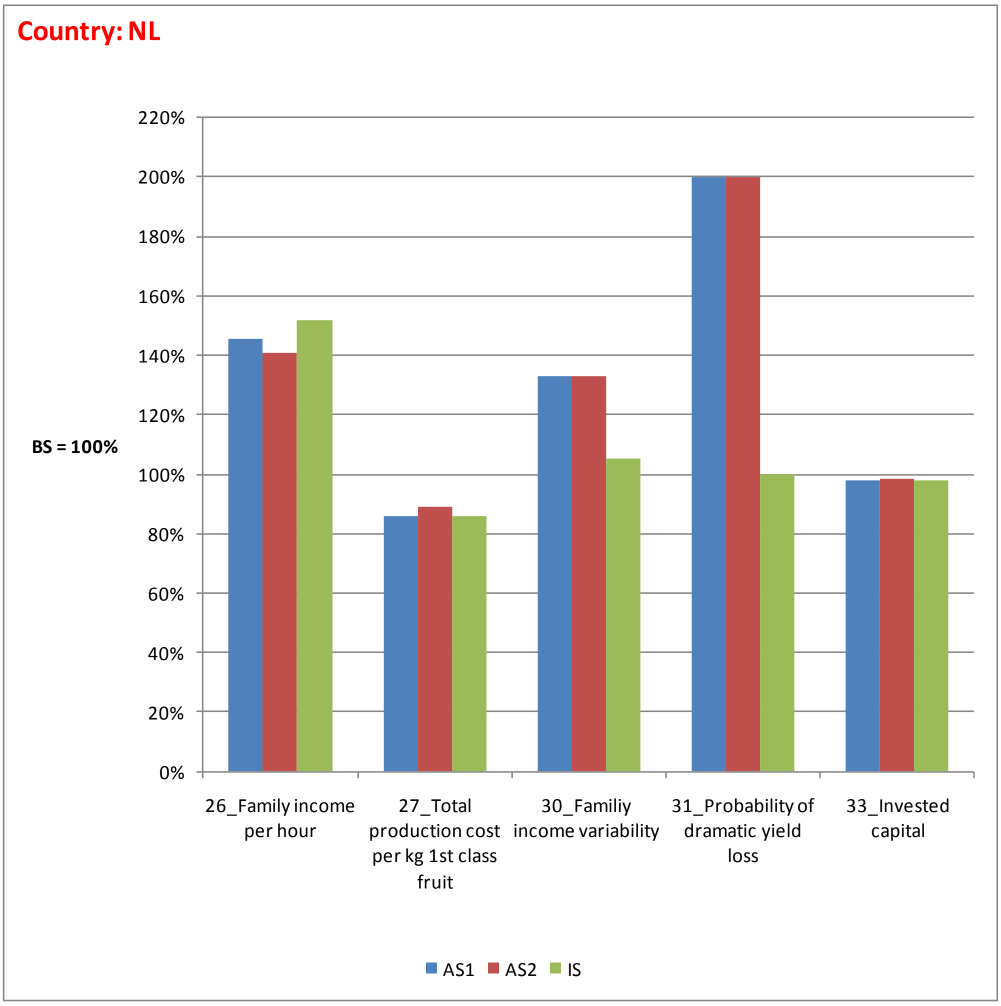

Figure 15. Income, production cost and economic risk for four crop protection strategies in apple orchard systems in relation to the BS.

6.7. Conclusion on optimising crop protection strategies

In the Netherlands, the presence of surface water in the neighbourhood of orchards and the north-western climate conditions strongly determine the AS1 strategy. Drift reduction is important in AS1. Furthermore, the AS1 is described as replacing pesticides with high impact on the environment by pesticides with better ecotoxicity profile, reducing the number of applications and by use of non-chemical control methods. The ecotoxicity attribute of AS1 is rated better than BS. This is for a large part due to replacing insecticides by alternative methods, which is realistic because the northern cooler climatic conditions do not promote insect development strongly. Similarly, the underlying attributes aquatic ecotoxicity and terrestrial ecotoxicity were better in AS1 than BS mainly because changes in insect control. Also human toxicity is reduced. However, apart from a changed insect control, this is for a large part the result of replacing herbicides. The AS1 had no effect on resource use, global warming or global eutrophication potential. And therefore, the improvements for ecotoxicity of AS1 compared to BS are partially masked in the aggregated ecological sustainability. On top of a better ecotoxicity effect, AS1 is better than BS for the economic side of the multi attribute assessment. This is mainly the result of higher family income, better net profit per ha and higher portion fist class fruit. However, the better economic result of AS1 is associated with strongly increased production risk with both underlying attributes, income variability and probability of dramatic yield loss, being increased.

A very similar tendency can be seen by the results for the AS2 strategy in which more drift reduction and alternative plant protection strategies are used than in AS1. The overall ecotoxicity of AS2 is improved only slightly compared to AS1. Further drift reduction and mechanical weeding are major factors for this improvement. A lower acute and chronic risk for both terrestrial and aquatic environmental compartments is achieved by AS2 through drift reduction. Although more sanitation practices are used for fungal diseases, there is hardly any effect of fungicide use on the overall ecotoxicity of AS2 compared to AS1. Similar to AS1, the AS2 is associated with strongly increased production risk with both underlying attributes, income variability and probability of dramatic yield loss, being increased compared to BS. Especially the risks of minor pests becoming economic important is improved.

A significant improvement of the IS strategy is the use of multigene resistance against several major pests. The IS performs better for the “Ecological sustainability” due to this resistances, together with strong drift reduction, minimal herbicide use and using salts, such as potassium bicarbonate and calcium hydroxide, to control fungal diseases. As a consequence the attribute “mineral resource use” was increased. The IS contains aspects of ecological farming combined with high technology solutions. Therefore, the pest dynamics are more buffered and less vulnerable for extreme outbreaks. Thereby the production risks of IS, which was affected in AS1 and AS2, is similar to BS.

Optimisation strategies of pest control in orchards clearly demonstrated possibilities for durable orchard systems in the Netherlands. It showed that ecological optimised orchard systems can be economically sound. Resulting in orchard systems which have both economic and ecological prospects for future.

7. Results for France

7.1. Overall sustainability rating

The AS1 strategy is rated “better than BS” for the “Ecological sustainability” whereas for the “Economic sustainability” the rating is “similar to BS” (Fig. 5). The score of 3.62 for the “Ecological sustainability” indicates that at least one ecological sub-attribute has not reached the rating class 4. Also for the “Economic sustainability” the rating class 3 results from an up rounded score (2.83) telling that at least one economic sub-attribute is rated with worse “than BS”.

AS2 reached the same rating classes for the Ecological and the Economic sustainability as AS1. But the score for the “Economic sustainability” is slightly higher than the score for AS1. Thus, the top attribute “Ecological-economic sustainability” reaches a score above 3.5, being up rounded to the rating class 4.

The IS strategy reaches the same rating class than AS2 for the ecological and for the economic sustainability. A slight improvement compared to AS2 for the “Economic sustainability” of the IS strategy is indicated by the score of 3.44 for IS compared to 3.11 for AS2.

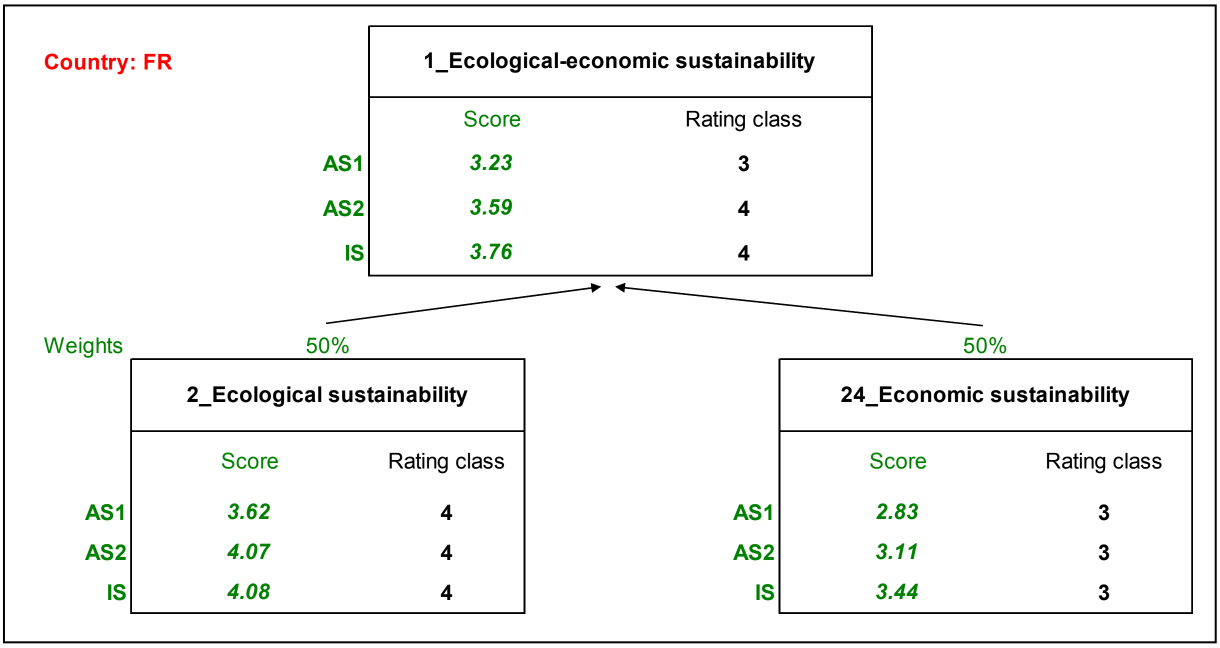

Figure 5. Ecological-economic sustainability rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, **3 = similar to BS**, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System. Scores: Weighted mean value of ratings of direct sub-attributes.

7.2. Ecological sustainability rating

The AS1 strategy has improved for one rating class the economic sub-attributes “Energy use”, “Ecotoxicity”, “Impact on beneficial organisms” and “Human toxicity” compared to the BS strategy (Fig. 6). “Similar to BS” is the rating for AS1 strategy concerning “Land use”, “Water use”, “Mineral resource use”, “Global warming potential” and “Global eutrophication potential”.

The AS2 strategy has achieve improvements compared to AS1 addressing “Ecotoxicity”, “Impact on beneficial organisms” and “Human toxicity” with reaching the rating class 5 for these ecological sub-attributes (Fig. 6).

The IS strategy reaches further improvements compared to AS2 addressing “Ecotoxicity” by reaching the best possible score of 5.00 compared to AS2 with a score of 4.83. For all other ecological sub-attributes the ratings for IS are the same than for AS2 (Fig. 6).

In general, the optimisation of crop protection, reflected by higher scores for “Environmental quality” and “Human toxicity”, has not affected the sub-attributes of “Resource use”.

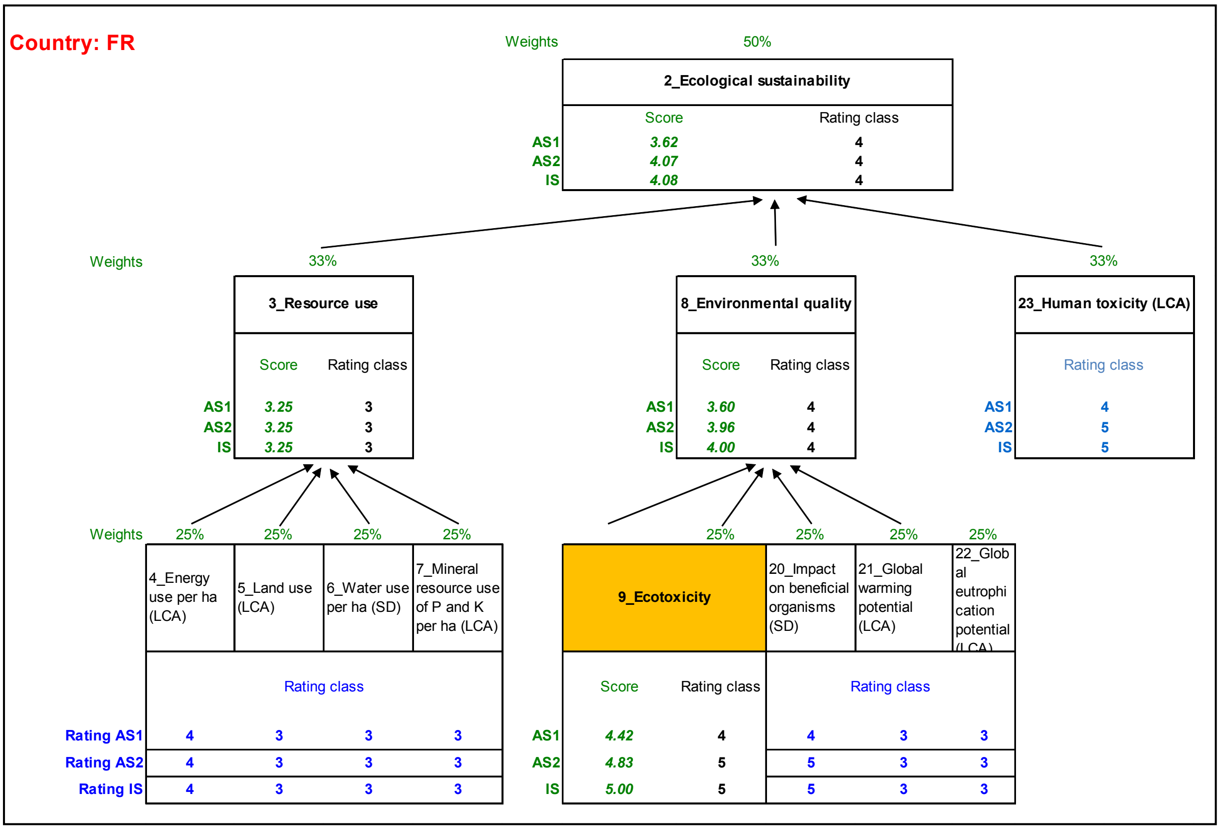

Figure 6. Ecological sustainability rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, 3 = similar to BS, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System; Scores: Weighted mean value of ratings of direct sub-attributes.

7.3. Ecotoxicity rating

The AS1 strategy has lowered risks compared to BS strategy due to better ratings for "Chronic terrestrial risk", "Chronic aquatic risk" and "Acute aquatic risk" (Fig. 7). Furthermore, the "Terrestrial Ecotoxicity" and "Aquatic Ecotoxicity" of AS1 strategy is much improved compared to BS reaching the highest possible rating class (Fig. 7).

The AS2 strategy has improved the "Acute terrestrial risk" for two rating classes compared to AS2 (Fig. 7). Also higher ratings for AS2 compared to AS1 result for "Acute aquatic risk" and "Chronic aquatic risk".

The IS strategy shows a one class higher rating than AS2 for "Chronic aquatic risk" reaching the highest rating class. Thus, the IS strategy reaches the highest possible rating for all ecotoxicity related attributes.

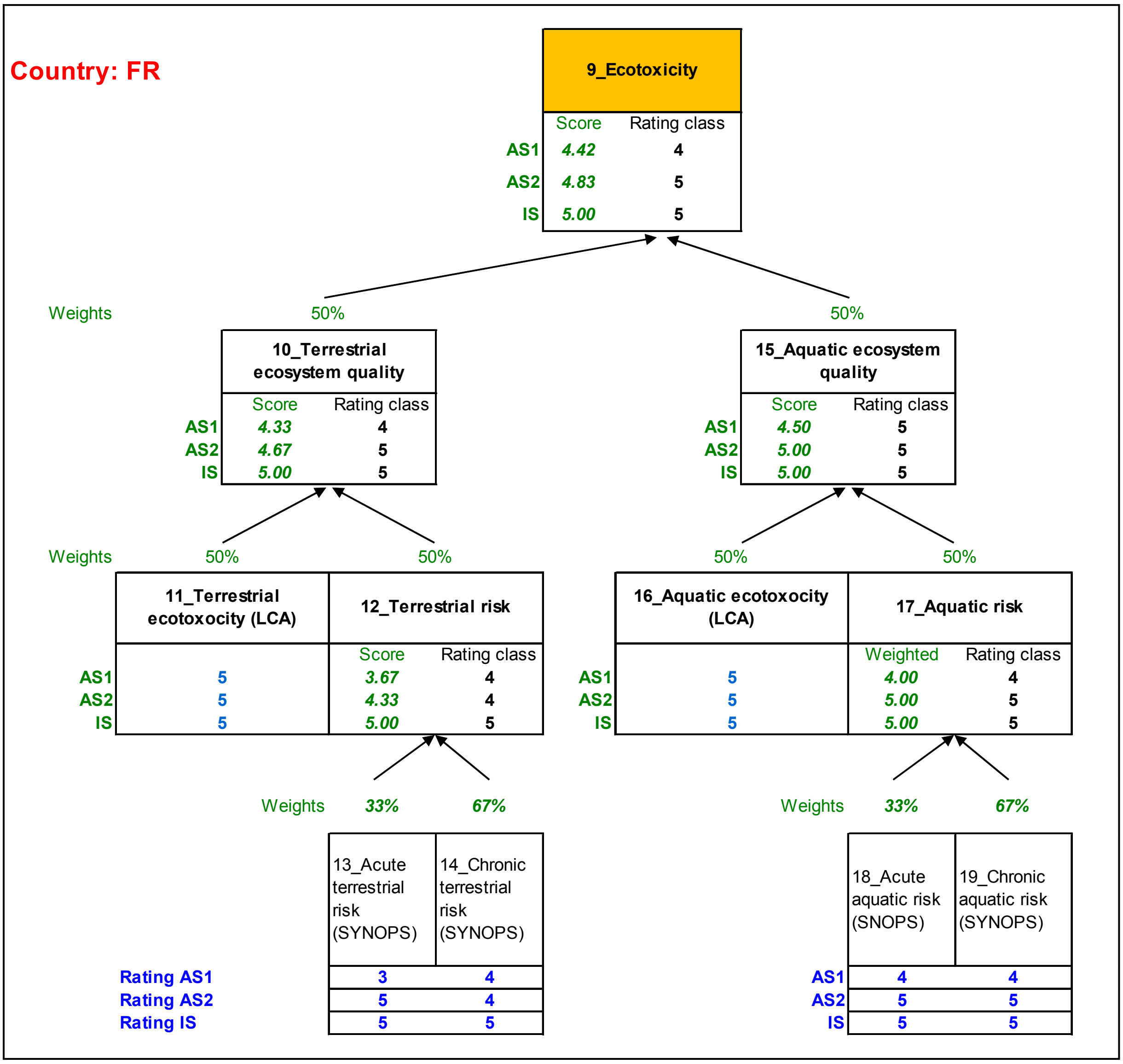

Figure 7. Ecotoxicity rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, 3 = similar to BS, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System; Scores: Weighted mean value of ratings of direct sub-attributes.

7.4. Optimising ecotoxicity and human toxicity attributes

LCA results

The "Aquatic ecotoxicity" of the BS strategy is dominated by the input of three applications per season, causing more than 80% of the total impact (Fig. 8). In fact this impact on the aquatic ecotoxicity is due to one application per season of the herbicide Diuron. AS1 strategy avoids this impact by replacing Diuron by mechanical weeding. For the remaining two applications for weed control Organophosphorus and Phenoxypropionic herbicides are used, causing no relevant aquatic ecotoxicity. In AS2 and IS strategies herbicides are totally replaced by mechanical weeding in AS2 strategy and full grass cover in the IS strategy.

The "Terrestrial ecotoxicity" for the BS strategy is for more than 95% caused by herbicide and fungicide to about the same extent (Fig. 9). AS1 strategy has no impact due to herbicides any more due to measures described above. In contrast, AS1 strategy still cause the same impact through fungicide application as the BS strategy even the number of

applications is reduced from 12 to 8 applications. The problem is that still copper is used in the AS1 strategy being responsible for the main impact. The AS2 strategy shows the same impact profile than AS1 even only five fungicide applications are used. Since copper is still used in the same amount as in AS1, no progress for the "Terrestrial ecotoxicity is achieved with the AS2 strategy compared to AS1. The IS strategy replaced the copper application by new fungicides available in future and thus reducing the "Terrestrial ecotoxicity" to nearly zero compared to BS.

The "Human toxicity" for the BS strategy is mainly caused by herbicide use and non pesticide impacts (e.g. machinery use) and to a smaller extent by fungicide and insecticide use (Fig. 10). The improvements of AS1 mainly relay on reduced herbicide use due to measures described above. Human toxicity of AS2 could be further reduced by replacing the herbicides. The improvement of the IS strategy compared to AS2 is given by replacing pesticides by the use of exclosure netting and resistant cultivars. The remaining impact of the IS strategy is due to non pesticide inputs such as machinery and fertiliser use (Fig. 10).

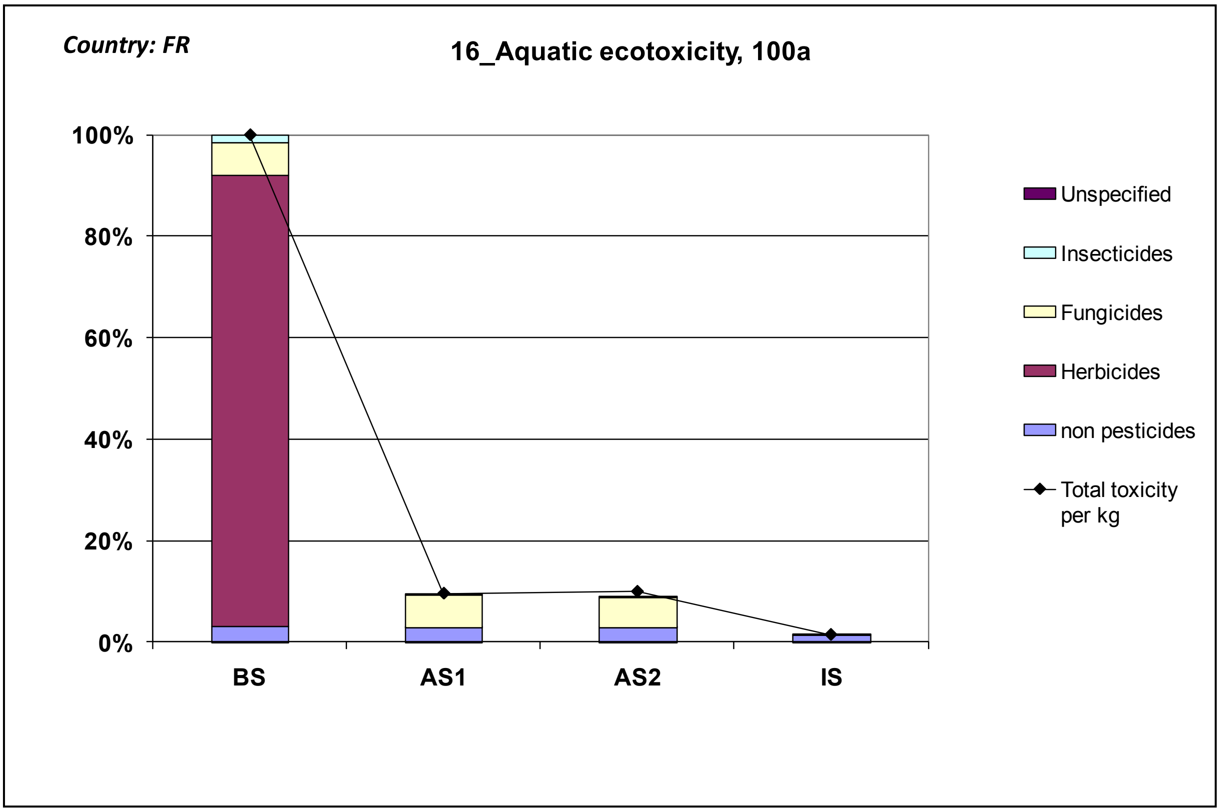

Figure 8. LCA results for aquatic ecotoxicity according to CML2001. Impacts are presented relatively to the BS strategy. Bars represent the impact per ha and the impact per kg fruit produced is indicated by the line.

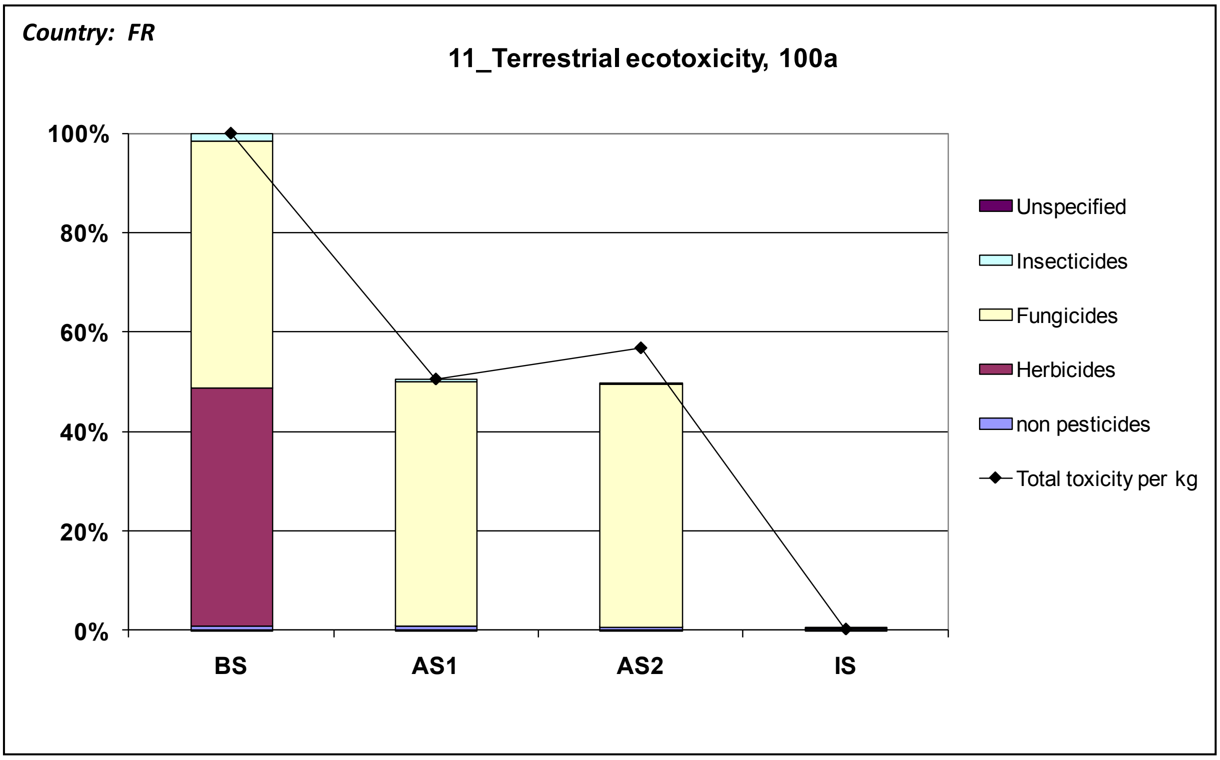

Figure 9. LCA results for terrestrial ecotoxicity according to CML2001. Impacts are presented relatively to the BS strategy. Bars represent the impact per ha and the impact per kg fruit produced is indicated by the line.

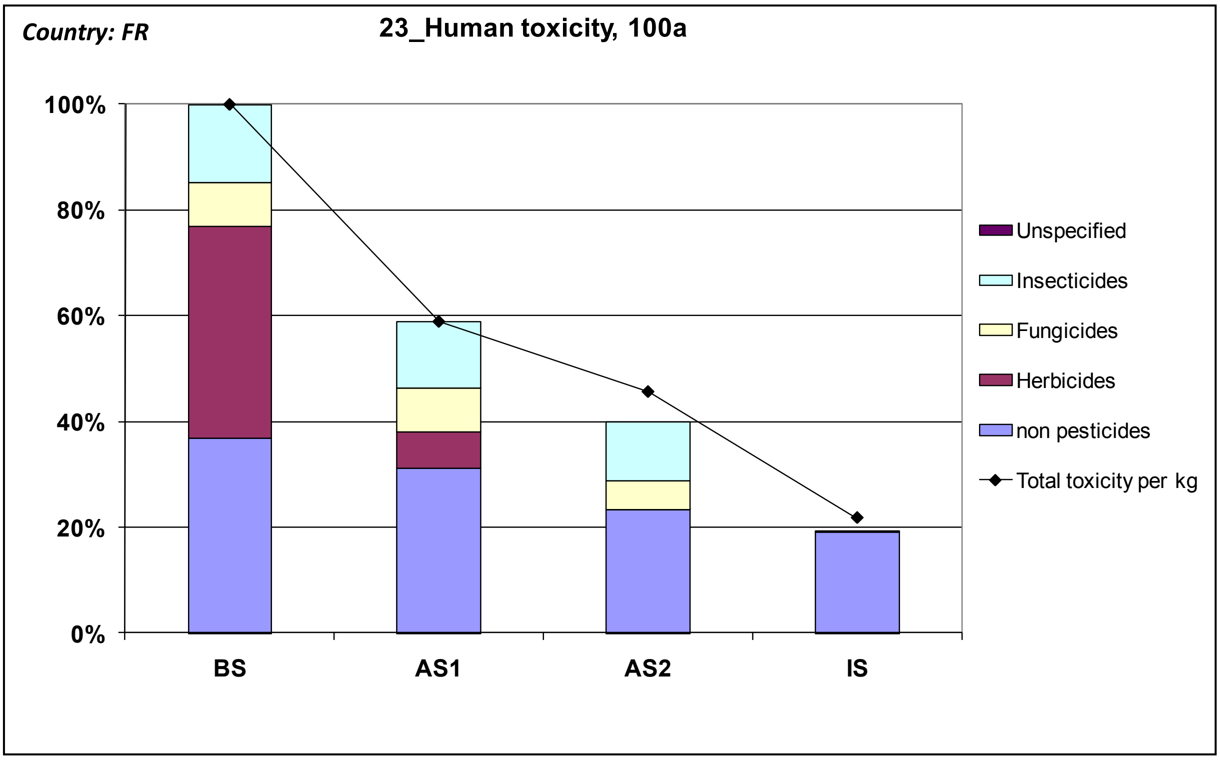

Figure 10. LCA results for human toxicity according to CML2001. Impacts are presented relatively to the BS strategy. Bars represent the impact per ha and the impact per kg fruit produced is indicated by the line.

SYNOPS results

The acute aquatic risk of pesticide use in the BS strategy is high, indicated by the red colour (Fig. 11a). About 60% of this risk is reduced in the AS1 strategy but it still belongs to the high risk class. AS2 strategy reduces the acute aquatic risk further and belongs to the medium risk class. The acute aquatic risk of IS strategy is less than 1% compared to the BS strategy and belongs to the low risk class. The risk reduction of the two advanced and innovative strategy is based on one hand on the replacement of pesticides through alternative measures and on the other through a higher portion of drift reduction. Table 2 shows that in the BS strategy on half of the area no drift reduction measures are used and on the other half of the area 50% drift reduction is practiced. AS1 strategy practices a higher drift reduction than BS. The AS2 and IS strategy apply in 75% of the orchards in the region 90% drift reduction measures and reach in the rest of the area 75% drift reduction. For France important measures for drift reduction are hedges, since hedges are planted on half of the orchard area in all four strategies. For AS1, AS2 and IS strategy most important are drift reducing sprayers and for AS2 and IS strategy also the use of hail net and exclosure netting.

The chronic aquatic risk of the BS strategy is rated as high risk (Fig. 11b). The AS1 strategy lowers the risk for 50% but still remains to the high risk class. AS2 and IS strategies show relevant improvements since both strategies belong to the low risk class with less than 1% risk compared to BS.

The acute terrestrial risk of the BS strategy is rated as high risk (Fig. 11a). AS1 strategy keeps the same risk than BS. AS2 and IS strategies reduce the risk down to less than 5% compared to BS and belong to the low risk class.

The chronic terrestrial risk (Fig. 11b) of the BS strategy belongs to the medium risk class. The AS1 strategy reduces the risk for 20%, but remains in the same risk class as BS. In contrast, AS2 and IS show a strong risk reduction belong to the low risk class.

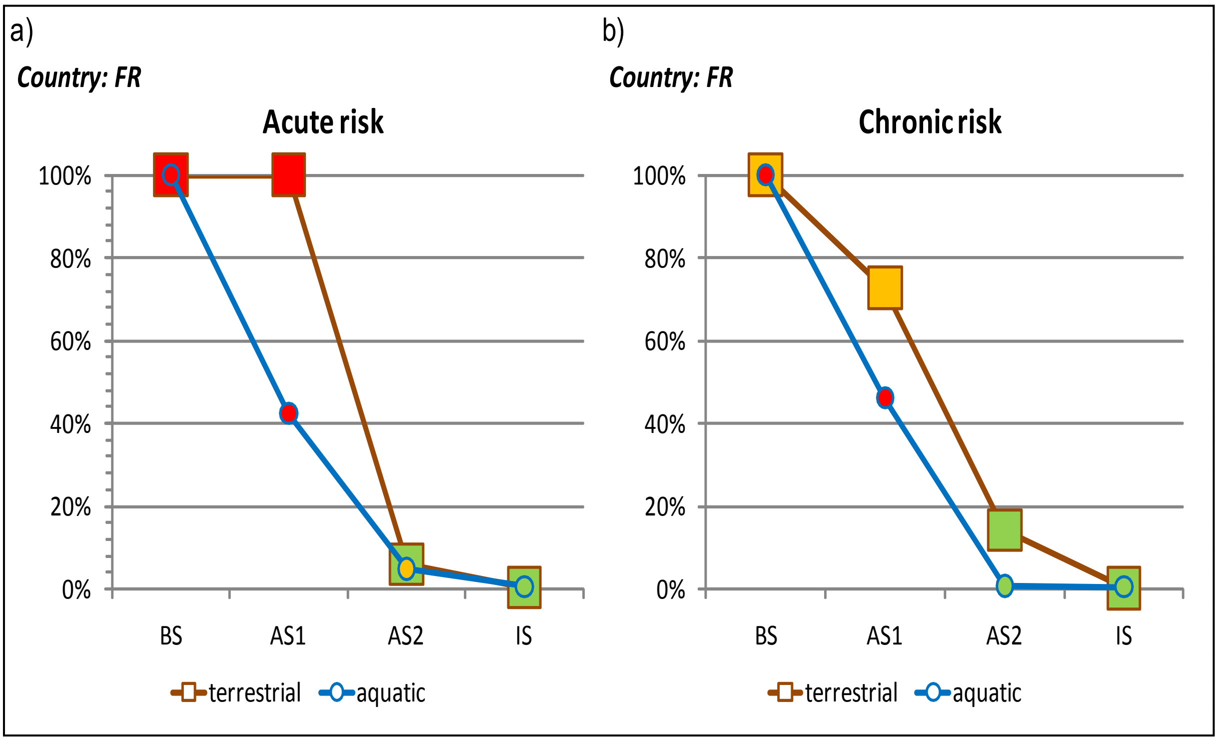

Figure 11. Terrestrial and aquatic SYNOPS results per hectare for (a) Acute risk and (b) Chronic risk for four crop protection strategies in apple orchard systems. Impacts are presented relatively to the BS strategy. Risk classes are given by different colours; Red: High risk, Yellow: Medium risk, Green: Low risk.

Table 2. Percentage of area in the region with measures for 0%, 50%, 75% and 90% drift reduction for four crop protection strategies in apple orchard systems.

Country: FR

	Portion of drift reduction				
	0%	50%	75%	90%	sum
BS	50%	50%	0%	0%	1
AS1	0%	25%	50%	25%	1
AS2	0%	0%	25%	75%	1
IS	0%	0%	25%	75%	1

7.5. Economic sustainability rating

Figure 12 indicates that none of the strategies reached higher ratings for the "Economic sustainability" compared to BS. Looking into details, none of the sub-attribute has changed except for the IS strategy where a lower "Production risk" and lower "Probability of dramatic yield loss" is expected compared to the BS strategy. For "Net profit" and "Family income" no change is expected between the different strategies, explained by the fact that the price of the kg fruit is considered to be stable and the "Production costs" are similar to BS. Since AS2 and IS strategy use hail net and exclosure netting on half of the area their "Invested capital" is higher than for BS and AS1. The AS1 strategy shows a higher variability for the "Family income", as the adoption of alternative methods increase the yield loss risk. However, we expect that once these new methods are adopted, the risk of AS1 for yield loss will not be different than the one of the baseline system.

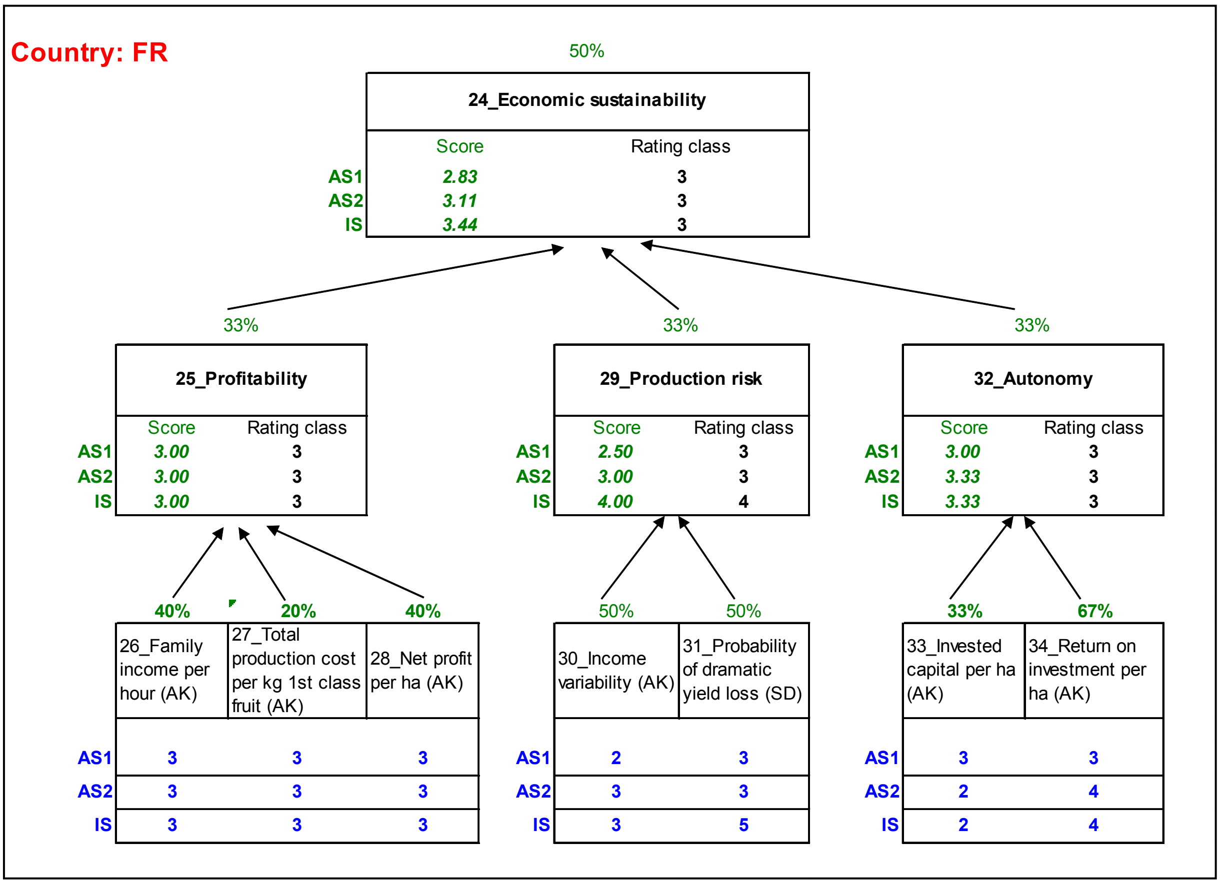

Figure 12. Economic sustainability rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, 3 = similar to BS, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System. Scores: Weighted mean value of ratings of direct sub-attributes.

7.6. Optimising economic attributes

Concerning the yield (Fig. 13), AS2 and IS strategies are expected to produce less compared to the BS and AS1 strategies. The yield variability is expected to be lower for AS2 and IS strategies compared to BS. For AS1, the yield variability is expected to be higher than for BS, due to the adoption of new techniques and active ingredients by the farmers. In the same reason, the portion for 1st class fruits is expected to decrease for AS1 and is comparable to BS for AS2 and IS (Fig.14).

Since AS2 and IS strategy use hail net and exclosure netting on half of the area their “Invested capital” is 20 % higher than for BS and AS1 (Fig. 15). This raises the “Production cost per kg” for about 10%. The “Income per hour” stays about at the same level as for BS. A strong advantage of IS compared the other strategies is a 50% lower “Probability of dramatic yield loss”(Fig. 15)

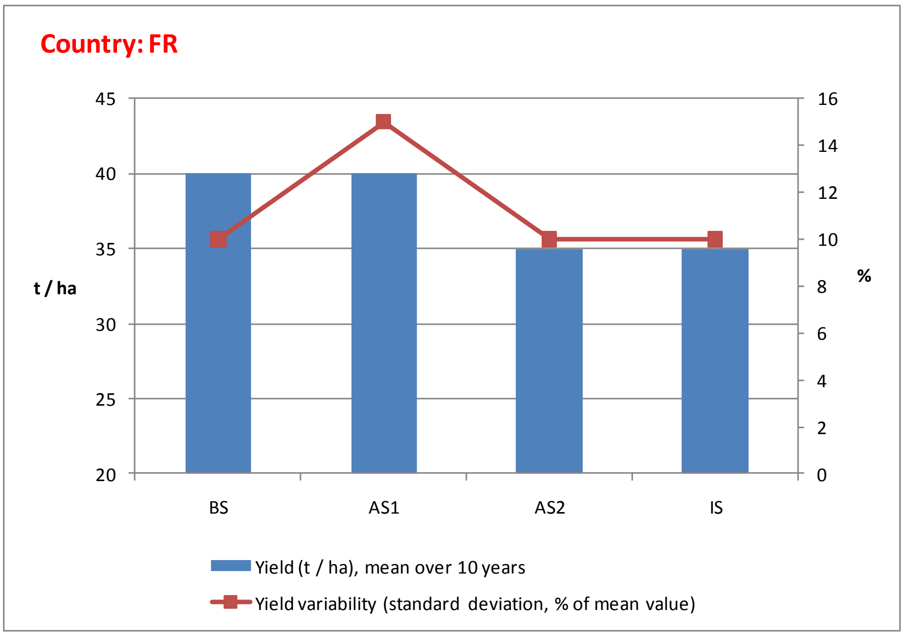

Figure 13. Target values for mean (left scale) and standard deviation (right scale) of yield for four crop protection strategies in apple orchard systems.

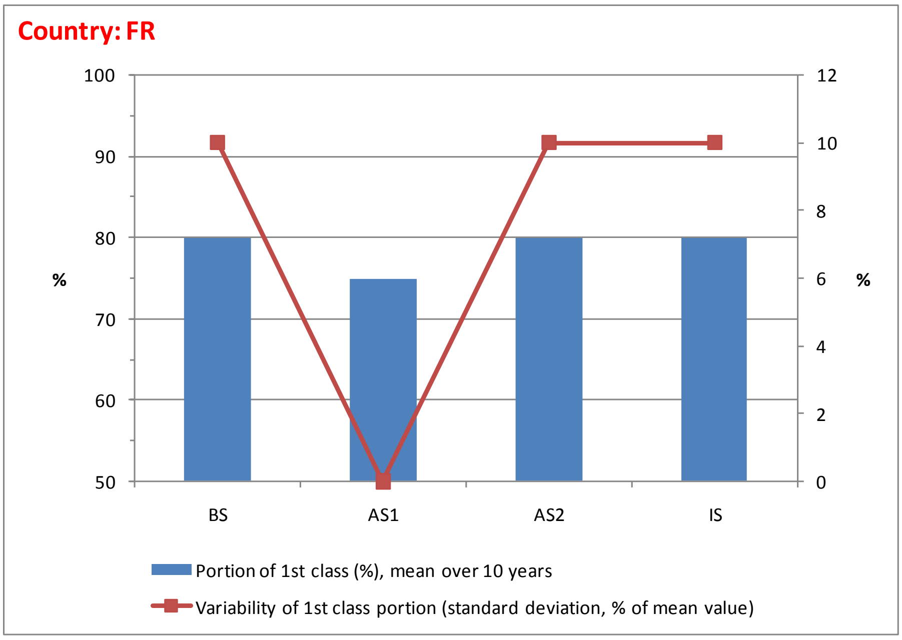

Figure 14. Target values for mean (left scale) and standard deviation (right scale) of the portion of 1st class fruits for four crop protection strategies in apple orchard systems.

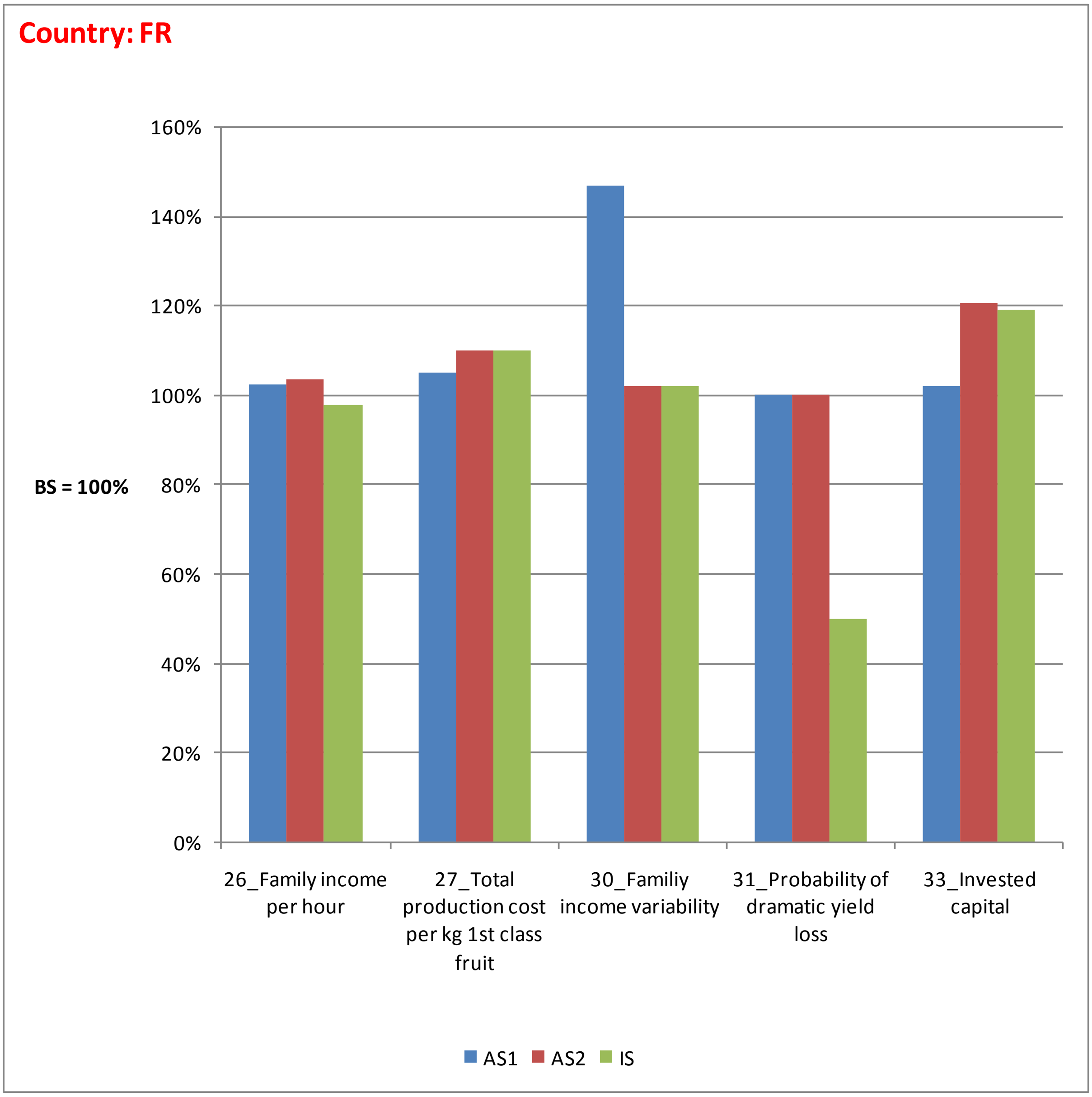

Figure 15. Income, production cost and economic risk for four crop protection strategies in apple orchard systems in relation to the BS.

7.7. Conclusion on optimising crop protection strategies

The AS1 strategy is not representing an improvement of the sustainability of the production system compared to the BS strategy. But the AS2 and IS are both improving the overall sustainability of these production systems relatively to the BS, due to an improvement of the ecological sustainability of the production system.

Lowering the “Human toxicity” and improving the “Environmental quality”, mainly based on the use of pesticides, was a major goal of this study. This goal can be reached with all three strategies proposed. Other attributes (e.g. water use, mineral resource use) could be improved by modifying other aspects of the crop production strategy such as fertilisation or irrigation for example, but this was not the focus of our study.

In general, the optimisation of crop protection, reflected by higher scores for “Environmental quality” and “Human toxicity”, has neither affected “Resource use” nor the “Economic sustainability”.

8. Results for Spain

8.1. Overall sustainability rating

All three strategies reached an “Ecological-economic sustainability” that is rated “better than BS” with increasing scores from AS1 to AS2 and to IS strategy (Fig. 5).

The AS1 strategy is rated “similar to BS” for the “Ecological sustainability” and “better than BS” for the “Economic sustainability” (Fig. 5). The sore of the “Ecological sustainability” of 3.19 indicates that at least one ecological sub-attribute must be rated with “better than BS”. The score of 4.02 for the “Economic sustainability” indicates that at least one economic sub-attribute is rated with “much better than BS”. Thus, the resulting score for the “Ecological-economic sustainability” is 3.60 (equally weighted sub-attributes assumed) which is equivalent with the rating class 4 (“better than BS”).

The AS2 strategy shows a clear improvement for the ecological branch of the attribute tree, being rated one class higher than the AS1 strategy. Regarding the “Economic sustainability the rating and score for AS2 is exactly the same than for AS1.

The IS strategy reaches the same rating class (4) than AS2, but with slightly better scores for both the “Ecological sustainability” and the “Economic sustainability”.

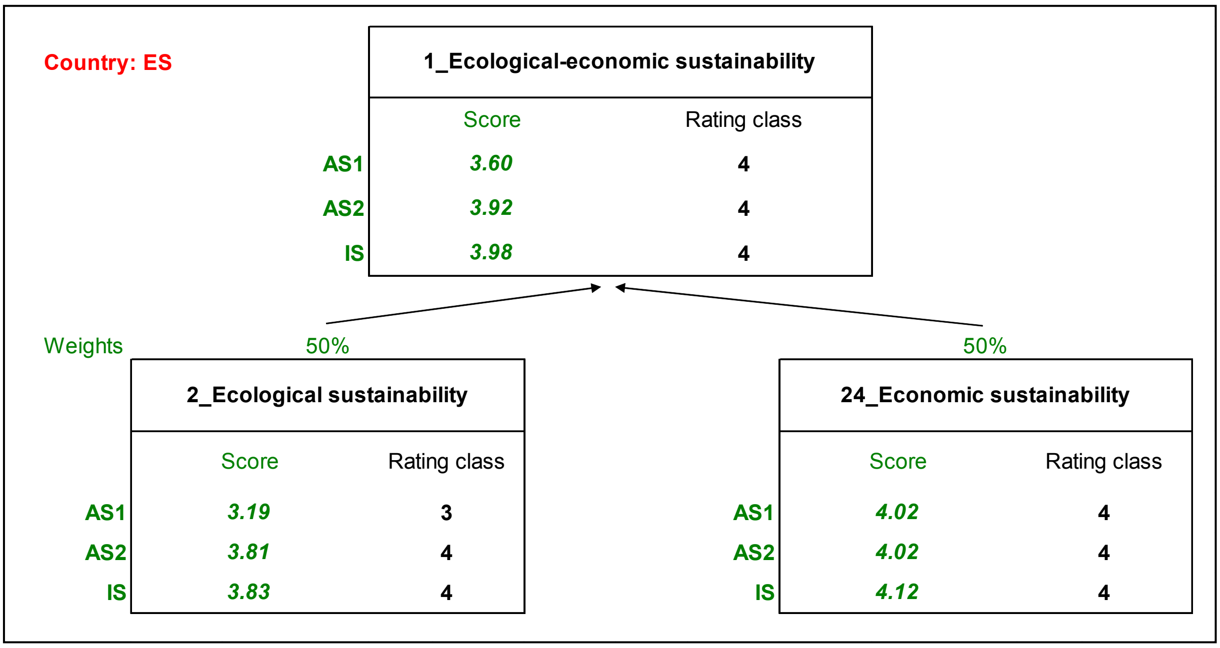

Figure 5. Ecological-economic sustainability rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, **3 = similar to BS**, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System. Scores: Weighted mean value of ratings of direct sub-attributes.

8.2. Ecological sustainability rating

The AS1 strategy is rated “better than BS” for the two ecological attributes “Water use” and “Ecotoxicity”. These progresses are due to replacing flooding irrigation with drip irrigation and introducing some alternative crop protection measures reducing the use of chemical pesticides.

The AS2 strategy has achieved a one class higher rating than AS1 for five ecological sub-attributes, namely “Energy use”, “Water use”, “Impact on beneficial organisms”, “Ecotoxicity” and “Human toxicity”. The remaining four sub-attributes of AS2 have the same rating class than AS1. Thus, the improvement of the ecological sustainability has broad base.

The IS strategy has reached the same rating classes as the AS2 strategy for all ecological sub-attributes. Despite of the already high score for “Ecotoxicity” of the AS2 strategy (4.75) the IS strategy lowered the ecotoxicity further, reaching the highest possible score (5.00).

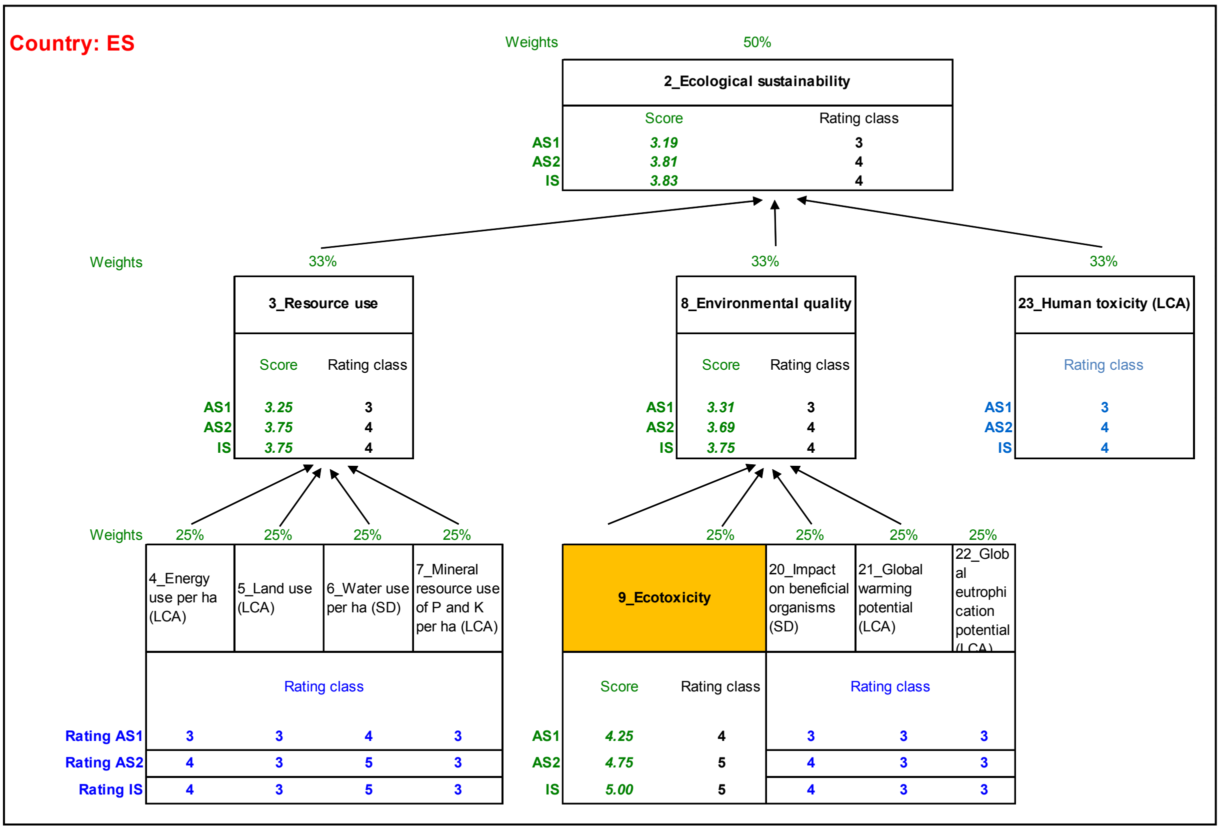

Figure 6. Ecological sustainability rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, **3 = similar to BS**, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System; Scores: Weighted mean value of ratings of direct sub-attributes.

8.3. Ecotoxicity rating

The AS1 strategy has lowered the “Acute aquatic risk” and the “Chronic aquatic risk” being rated one class higher than the BS strategy (Fig. 7). The “Terrestrial risk” of AS1 has not changed compared to BS. The strongest improvements of AS1 compared to BS occur for the “Terrestrial ecotoxicity” and the “Aquatic ecotoxicity” that reached the highest possible rating class.

The AS2 strategy reaches further progress compared to AS1 being rated one class higher than AS2 for all four risk attributes (Fig. 7).
The IS strategy improves the “Acute terrestrial risk” and the “Chronic terrestrial risk” further compared to AS2, reaching also for these two attributes the highest rating class (Fig. 7). Thus, the IS strategy is rated with “much better than BS” for all sub-attributes related to ecotoxicity.

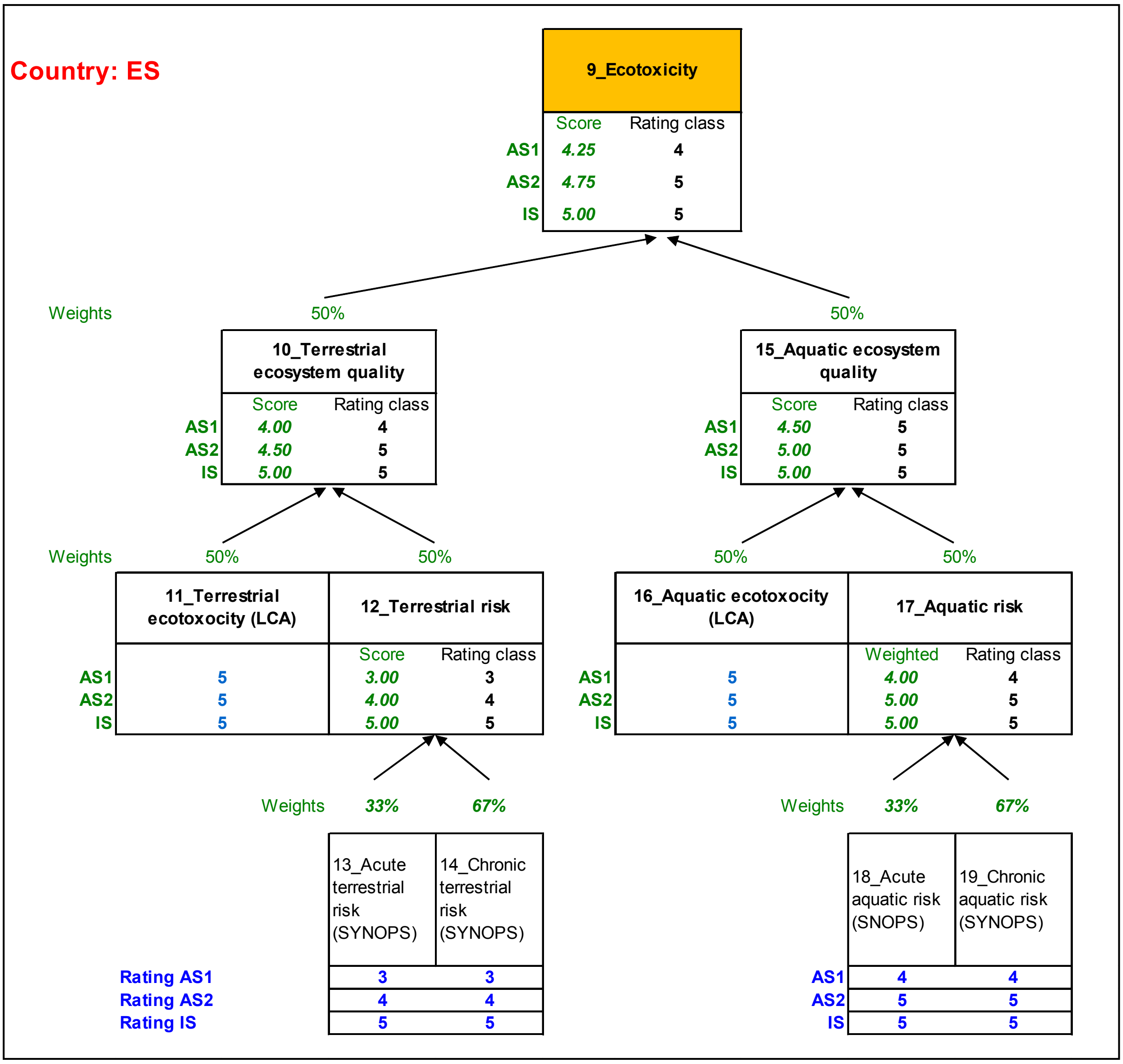

Figure 7. Ecotoxicity rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, **3 = similar to BS**, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System; Scores: Weighted mean value of ratings of direct sub-attributes.

8.4. Optimising ecotoxicity and human toxicity attributes

LCA results

The "Aquatic ecotoxicity" of the BS strategy is dominated by the input of insecticides, causing about 85% of the total impact (Fig. 8). About 10% of the total impact is related to the use of fungicides. No relevant impact is due to the use of herbicides. The impact of non pesticides, such as machinery and fertiliser input, is of minor importance causing less than 5% of the aquatic ecotoxicity. The AS2 strategy shows a "Aquatic ecotoxicity" that is about 75% lower than for the BS strategy, by replacing the use of the organophosphates Trichorfon and reducing (AS1) or replacing (AS2) Chlorpyrifos-methyl. The "Aquatic Ecotoxicity" for the AS2 and IS strategies is less than 5% of the Ecotoxicity of the BS replacing also copper that is used in BS and AS1 strategies.

The "Terrestrial Ecotoxicity" presented in Fig. 9 shows a very similar profile than the "Aquatic Ecotoxicity" where for the BS strategy the main impact is linked to arthropod control and a minor impact is caused by disease control. The improvements of AS1, AS2 and IS are strong

compared and are based on the same reasons as described above for the "Aquatic Ecotoxicity".

The "Human toxicity" for the BS strategy is dominated by impacts of non pesticides, mainly machinery use ,including emissions for construction, and the production of fertilisers. Of minor importance are the impacts due to the use of insecticides, fungicides and herbicides (Fig. 10). The AS1 and AS2 strategies show a relatively small improvement compared to the progress achieved for aquatic and terrestrial ecotoxicity since improvements among non pesticide inputs were not the focus of our study. The IS strategy causes no relevant "Human toxicity" since cover crop with mowing and mechanical weeding are replacing the input of Glyphosate, MCPA, Fluroxypyr and Fluozifop.

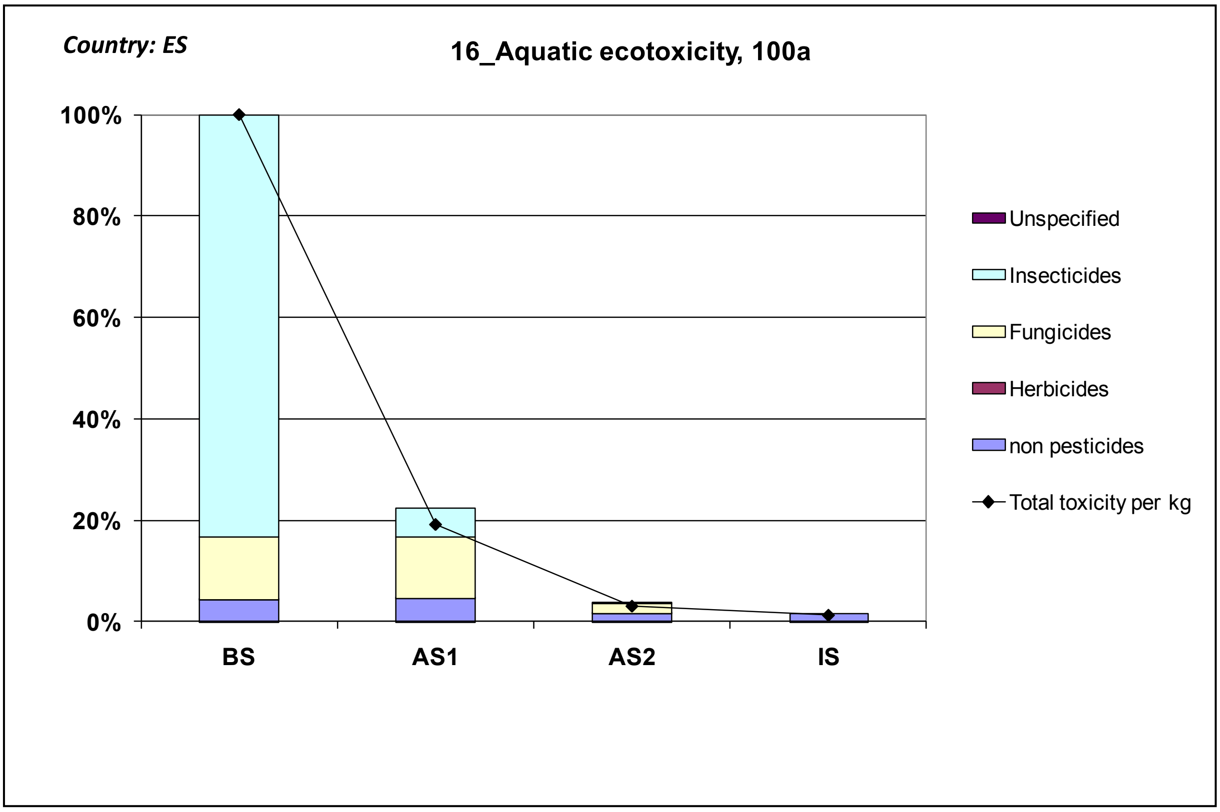

Figure 8. LCA results for aquatic ecotoxicity according to CML2001. Impacts are presented relatively to the BS strategy. Bars represent the impact per ha and the impact per kg fruit produced is indicated by the line.

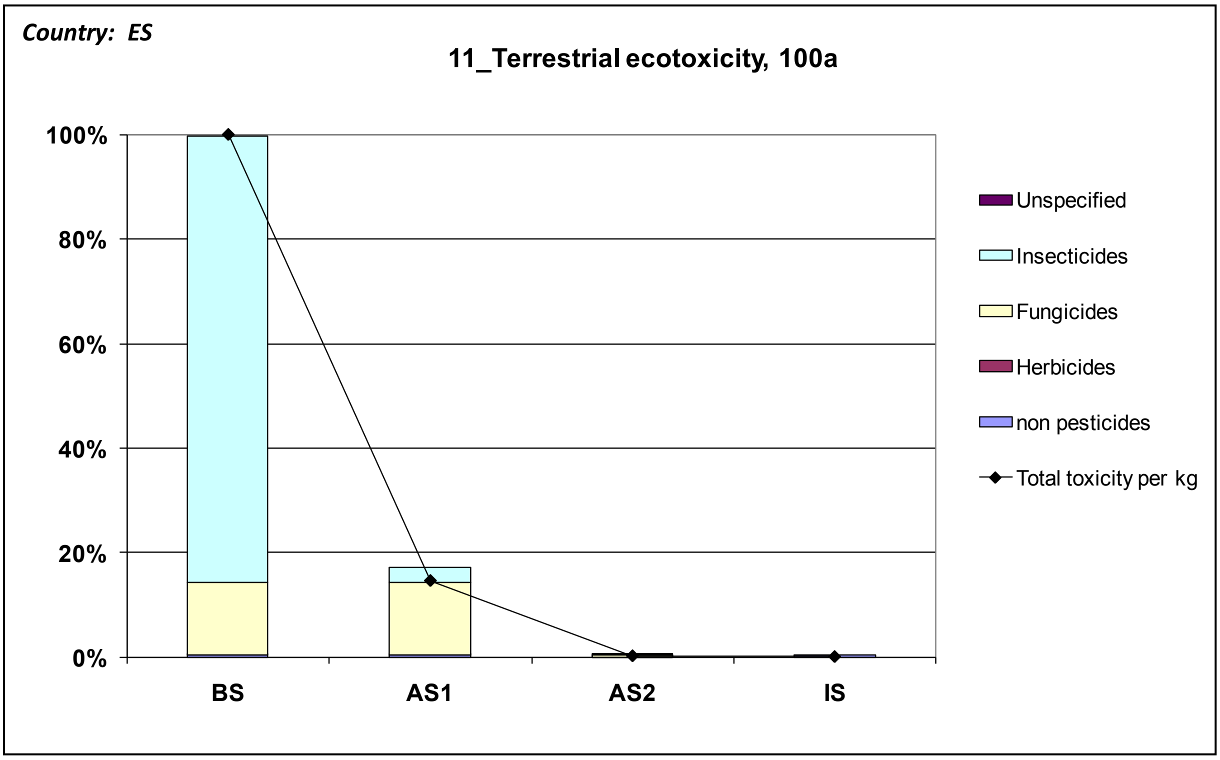

Figure 9. LCA results for terrestrial ecotoxicity according to CML2001. Impacts are presented relatively to the BS strategy. Bars represent the impact per ha and the impact per kg fruit produced is indicated by the line.

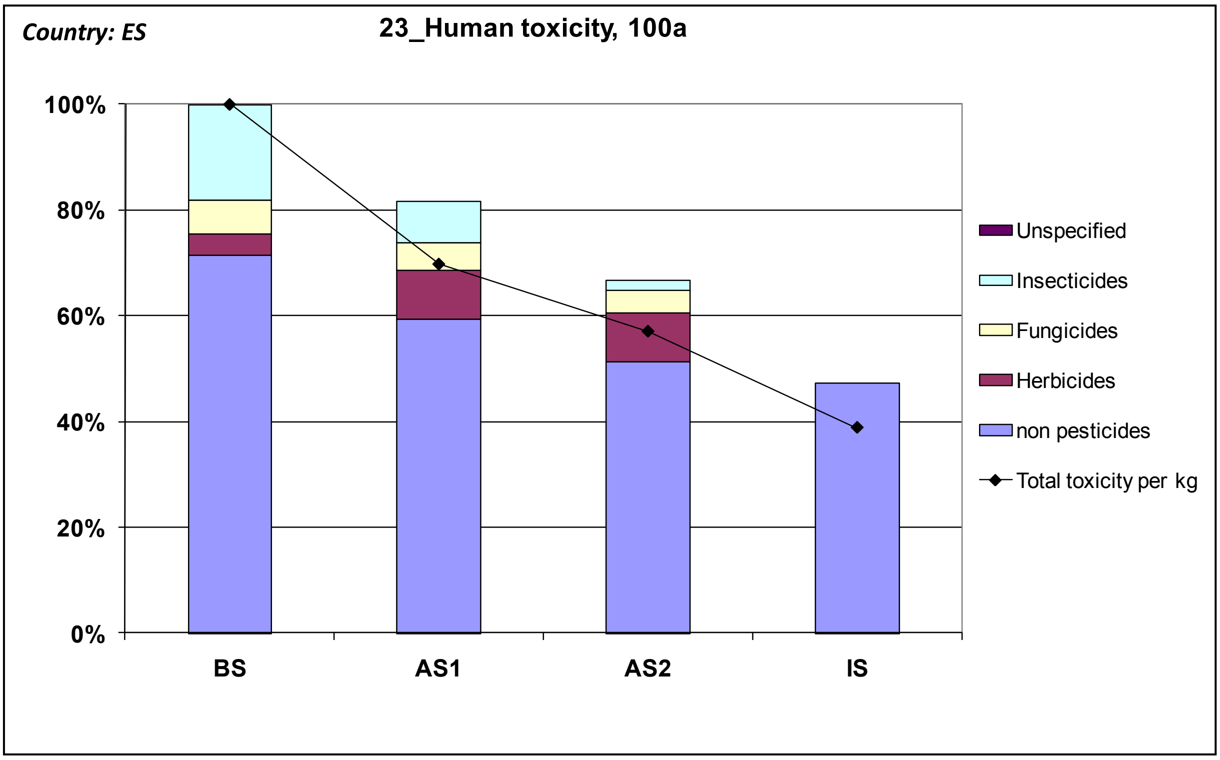

Figure 10. LCA results for human toxicity according to CML2001. Impacts are presented relatively to the BS strategy. Bars represent the impact per ha and the impact per kg fruit produced is indicated by the line.

SYNOPS results

The "Acute aquatic risk" of pesticide use in the BS strategy is high, indicated by the red colour (Fig. 11a). About 90% of this risk is reduced in the AS1 strategy but it still belongs to the high risk class. AS2 strategy reduces the acute aquatic risk further and belongs to the medium risk class. The acute aquatic risk of IS strategy is less than 1% compared to the BS strategy and belongs to the low risk class. The risk reduction of the two advanced and innovative strategy is based on one hand on the replacement of pesticides through alternative measures and on the other through a higher portion of drift reduction. Table 2 shows that in the BS and AS1 strategy no drift reduction measures are used on 98% of the area. The AS2 strategy has 35% and 15% of the area with 75% and 90% drift reduction respectively, due to the use of hail net and drift reducing sprayers. The IS strategies has 75% of the area with 90% drift reduction by more widely use of drift reducing sprayers. For Spain important hedges for drift reduction are not use in any strategy.

The "Chronic aquatic disk" for BS, AS1, AS2 and IS strategies (Fig. 11b) shows strong improvements practically in the same manner as for the "Acute aquatic risk" described above.

The "Acute terrestrial risk" of the BS strategy is rated as high risk (Fig. 11a). AS1 strategy keeps the same risk than BS. The AS2 strategy shows a 70% risk reduction but remains in the high risk class. The IS strategy reduce the risk down to less than 1% compared to BS and belongs to the low risk class.

The "Chronic terrestrial risk" (Fig. 11b) of the BS strategy belongs to the high risk class as do the AS1 and AS2 strategies as well. A real improvement is achieved only by the IS strategy where the risk is less than 1% of the BS strategy and belongs to the low risk class.

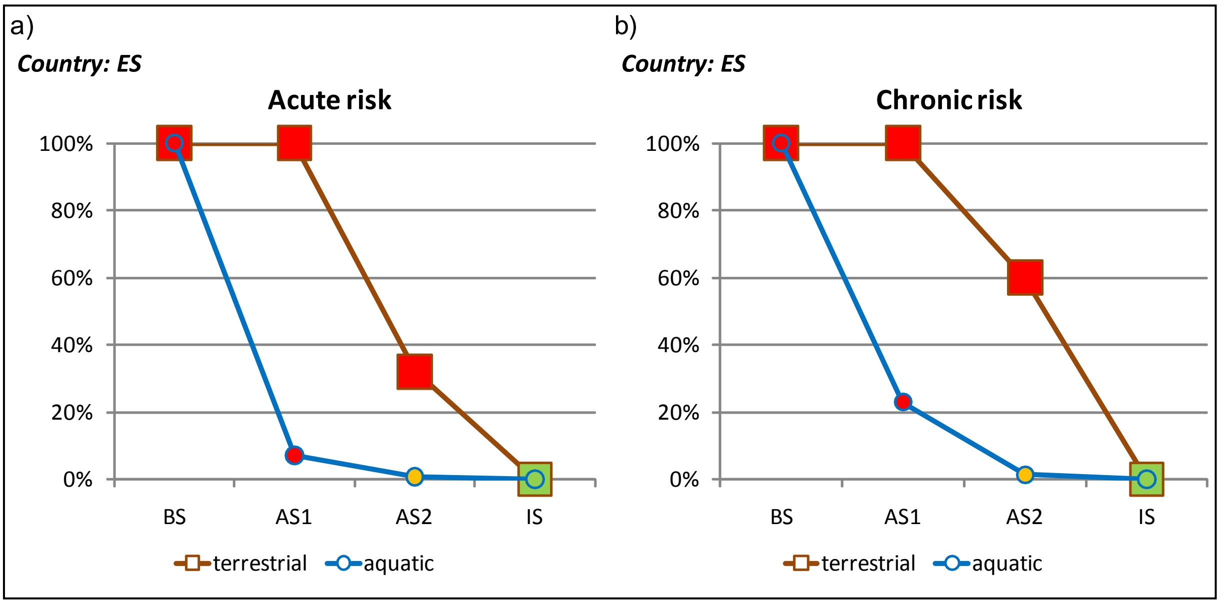

Figure 11. Terrestrial and aquatic SYNOPS results per hectare for (a) Acute risk and (b) Chronic risk for four crop protection strategies in apple orchard systems. Impacts are presented relatively to the BS strategy. Risk classes are given by different colours; Red: High risk, Yellow: Medium risk, Green: Low risk.

Table 2. Percentage of area in the region with measures for 0%, 50%, 75% and 90% drift reduction for four crop protection strategies in apple orchard systems.

Country: ES

	Portion of drift reduction				
	0%	50%	75%	90%	sum
BS	98%	2%	0%	0%	1
AS1	98%	2%	0%	0%	1
AS2	35%	15%	35%	15%	1
IS	0%	0%	25%	75%	1

8.5. Economic sustainability rating

The AS1 strategy improves the following economic sub-attributes compared to BS: “Total production cost”, “Net profit”, “Return on investment”, “Family income” and “Probability of dramatic yield loss”. “Income variability” and “Invested capital” remain in the same rating class as the BS strategy (Fig. 12). Thus, the economic improvements of AS1 affects the most economic attributes.

The AS2 strategy shows exactly the same ratings for all economic sub-attributes (Fig. 12).

The IS strategy improves the “income variability” for one rating class compared to the AS2 strategy (Fig. 12). All other attributes remain with the same ratings than AS2.

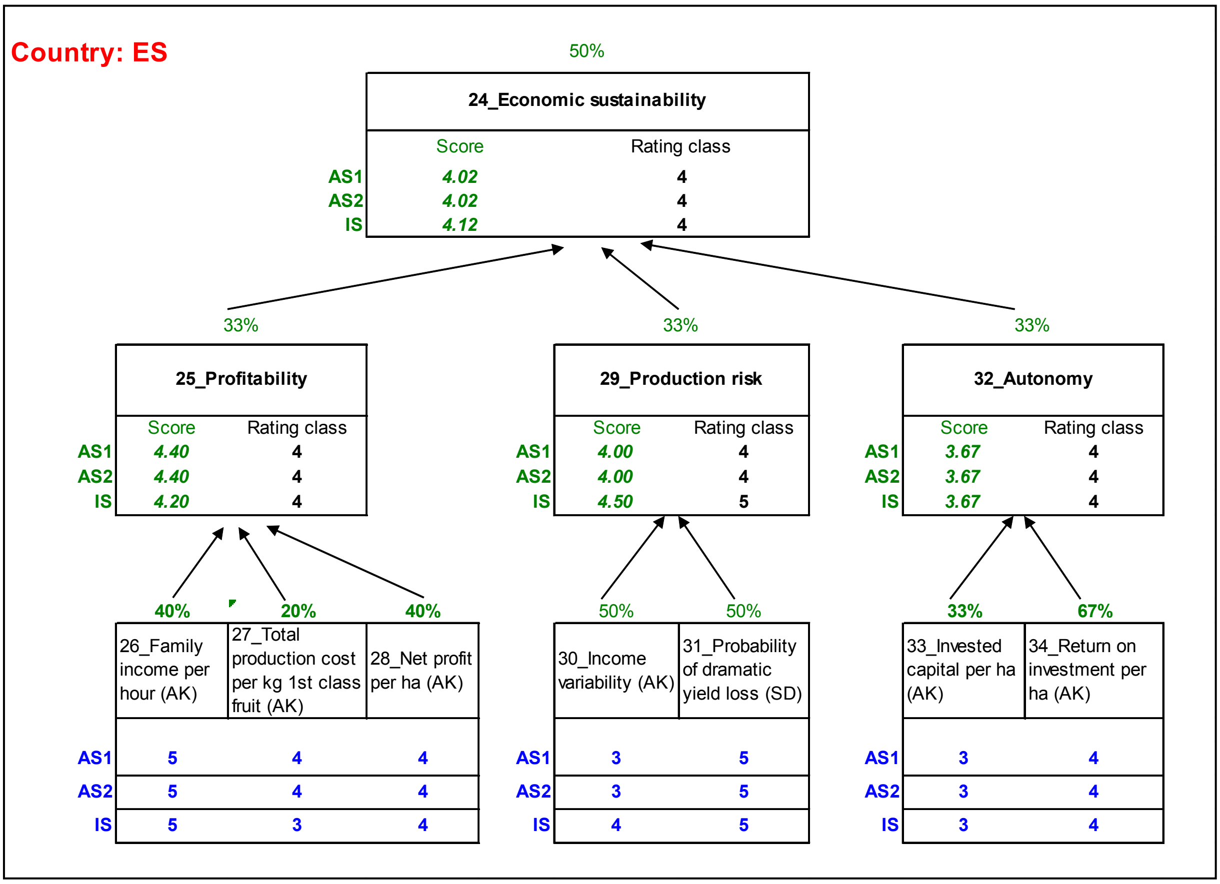

Figure 12. Economic sustainability rating for three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, 3 = similar to BS, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System. Scores: Weighted mean value of ratings of direct sub-attributes.

8.6. Optimising economic attributes

For the AS1 strategy the revenue side is higher as for the BS strategy due to the same higher portion of 1st class fruit (Fig. 14), since for all strategies the amount of yield (Fig. 13) and fruit prices are the same. The production cost side of the AS1 compared to BS strategy is characterised by much lower investments for irrigation but higher investments due to hail net and exclosure netting. Overall, the "Invested capital" for AS1 is slightly lower than for BS (Fig. 15). For AS1 the costs of pesticide products plus their application are equivalent to the costs of non-chemical tools. As a result, the "Total production costs per kg" of AS1 is about 10% lower than for BS. The "Family income per hour" (Fig. 15) of AS1 is increased for more than 40% compared to BS.

The AS2 strategy shows advantages on the cost side compared to AS2. The "Family income per hour" of AS2 is about 30% higher than for AS1 (Fig. 15).

The IS strategy overcompensates the higher "Invested capital" compared to AS2 by an increased portion of 1st class fruit. The "Family income per hour" is even slightly higher than for AS2 and more stable indicated by a 30% reduced "Family income variability" (Fig. 15).

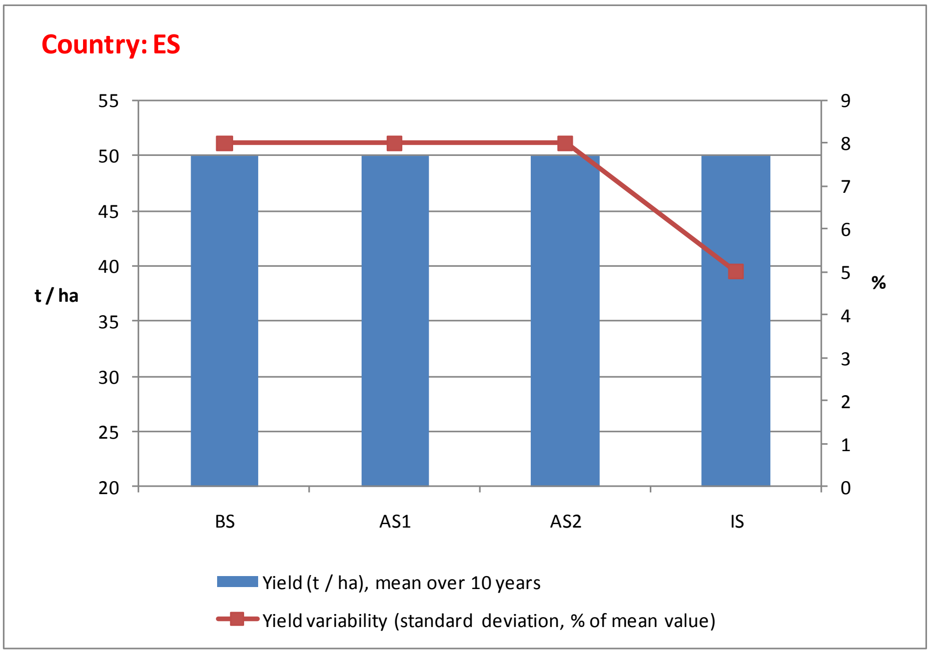

Figure 13. Target values for mean (left scale) and standard deviation (right scale) of yield for four crop protection strategies in apple orchard systems.

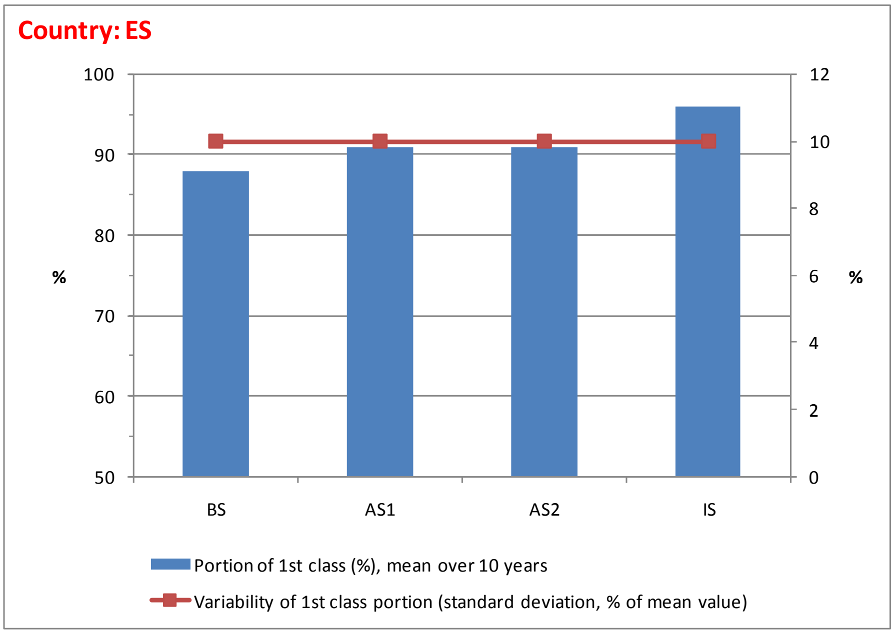

Figure 14. Target values for mean (left scale) and standard deviation (right scale) of the portion of 1st class fruits for four crop protection strategies in apple orchard systems.

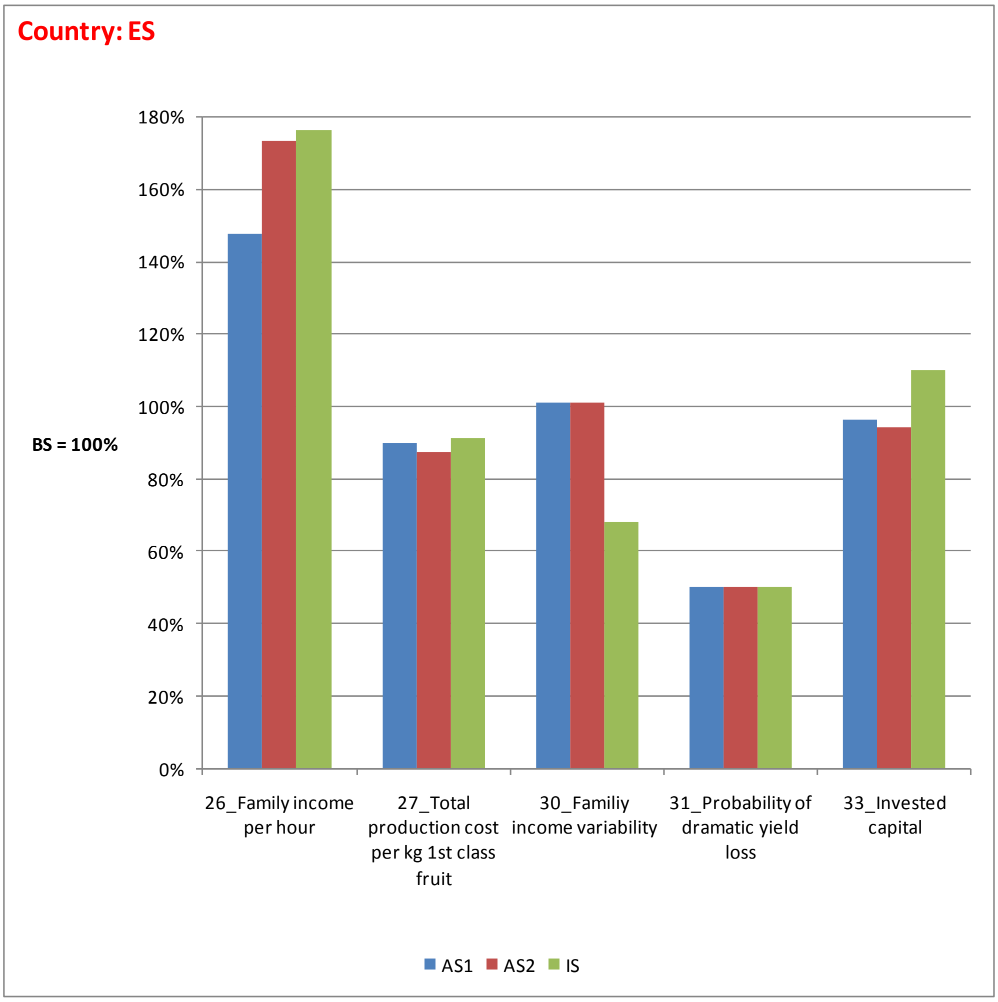

Figure 15. Income, production cost and economic risk for four crop protection strategies in apple orchard systems in relation to the BS.

8.7. Conclusion on optimising crop protection strategies

The score of the Ecological-economic sustainability increased from AS1 to IS, but the increase was higher for the Ecological sustainability than for the Economic sustainability.
The detailed analysis of the scores of the Ecological sustainability shows that the score of its three sub-attributes (Resource use, Environmental quality and Human toxicity) improved already for AS1, but that it produced a change of the rating class only for AS2 and IS. The improvement of the Resource use rating was mainly due to the increase of the Water use efficiency, as flooding irrigation in the BS is substituted by drip irrigation in AS and IS, and the decrease of Energy use per ha, as the number of driving through the orchard to apply plant protection chemicals is reduced from BS to IS. The improvement of the Environmental quality is due to the improvement of Ecotoxicity and of Impact on beneficial organisms. Both facts are a direct consequence of the changes in the criteria used to select plant protection measures from BS to IS. These criteria include not only the selection of the plant protection chemicals taking into account their human toxicity and environmental impact, but also, and more important, the priority use of non-chemical methods. In the Lleida fruit growing area, as in the rest of the European Southern fruit production areas, arthropod pests are much more important than diseases; in consequence, the Terrestrial and Aquatic ecotoxicity of the plant protection systems are mostly due to the use of insecticides and acaricides. As the many non-chemical plant protection methods for arthropod pests are available (biological control, ethological control, cultural control), it is possible to reduce greatly the Ecotoxicity of the plant protection systems, reducing both the acute and the chronic risks. The improvement of the Human toxicity is mostly due to the change in the plant protection methods used, and in the human toxicity of the insecticides – acaricides used. It is not possible to further reduce it, as an important component is the machinery use and the production of fertilisers.

The detailed analysis of the scores of the Economic sustainability shows that the score of its three sub-attributes (Profitability, Production risk and Autonomy) improved already for AS1. Profitability is a special case, as the IS score is smaller than the AS's scores, due to the increase of the Total production cost per kg of 1st class fruit. This fact should be taken into account, as the total production cost might be perceived by the growers as an obstacle for the adoption of the new technologies.
In conclusion, AS's strategies permit an important decrease of human toxicity and ecotoxicity without a great impact on the Economic sustainability.

9. Overall conclusions

The sections 4. - 8. present the *region-specific* potential for optimising crop protection strategies for the five countries under study. Based on these region-specific results some general conclusions can be derived:

9.1. General potential to improve the "Ecological sustainability"

The AS1 strategy in all countries shows an improvement of the "Ecological sustainability" compared to the BS strategy, indicated by a score that is higher than 3.0 (Fig. 16). This relative progress is stronger in Germany, France and Switzerland than in Spain and The Netherlands. The AS2 strategy compared to the AS1 shows a relatively strong improvement in the case of The Netherlands, France and Spain, whereas for Germany this progress is relatively little and for Switzerland the AS2 strategy shows no progress compared to AS1. In contrast, for Switzerland the improvement of the IS strategy is strong compared to the AS2, while in Germany and The Netherlands this progress is only moderate and for France and Spain the IS strategy brings nearly no improvement compared to AS2.

Over all, AS1 and AS2 demonstrate that in all five countries the “Ecological sustainability” can be improved using alternative measures that are available on the present market. We like to point out that the proposed strategies are optimised strategies. The optimisation was mainly achieved by using the SustainOS tool in an integrative process including several experts per country. Through that it was possible to make use of the information provided by LCA and SYNOPS for each active ingredient concerning the “Environmental quality” and “Human toxicity”. Often the toxicity was caused by only one or few active ingredients. Thus the optimisation process was based on the following three optimisation approaches:

- To replace active ingredients (A.I.) which have the highest impact with A.I. with a lower impact if possible.
- To replace or to reduce the number of applications of A.I. by alternative crop protection measures (e.g. exclosure netting, resistant cultivar)
- To enhance drift reduction measures to more than 75% (e.g. special sprayers, hedges).

Figure 17 shows that that among the three sub-attributes that refer to the “Ecological sustainability” it is “Human toxicity” that has the highest potential for improvements in all countries. Also the “Environmental quality” has high potential of optimisation in all countries. In contrast, “Resource use” is not much affected by the optimisation of the plant protection strategies in all countries. Further improvements concerning the “Resource use” could be possible as well. For example Spain demonstrates that an improved irrigation system has a strong positive effect on lowering the water use. But the optimisation of “Resource use” was not the focus of our study.

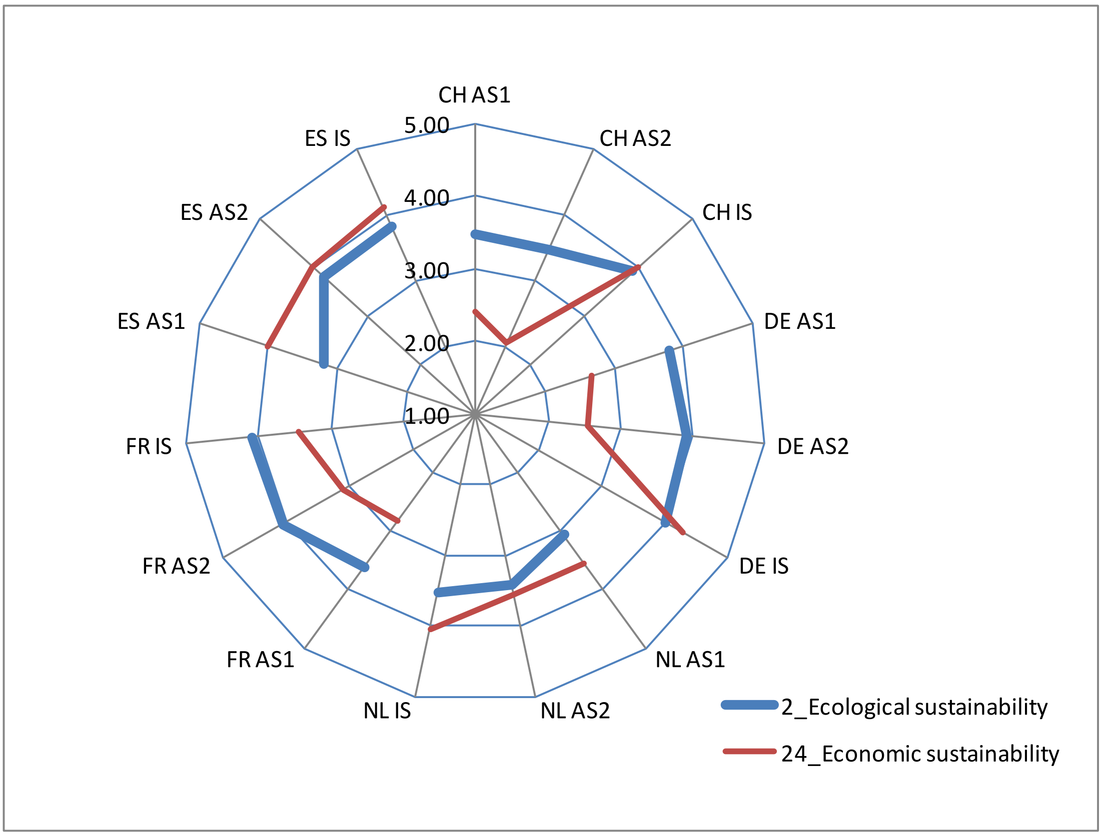

Figure 16. Ecological-economic sustainability rating for five countries and three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, 3 = similar to BS, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System of the respective country.

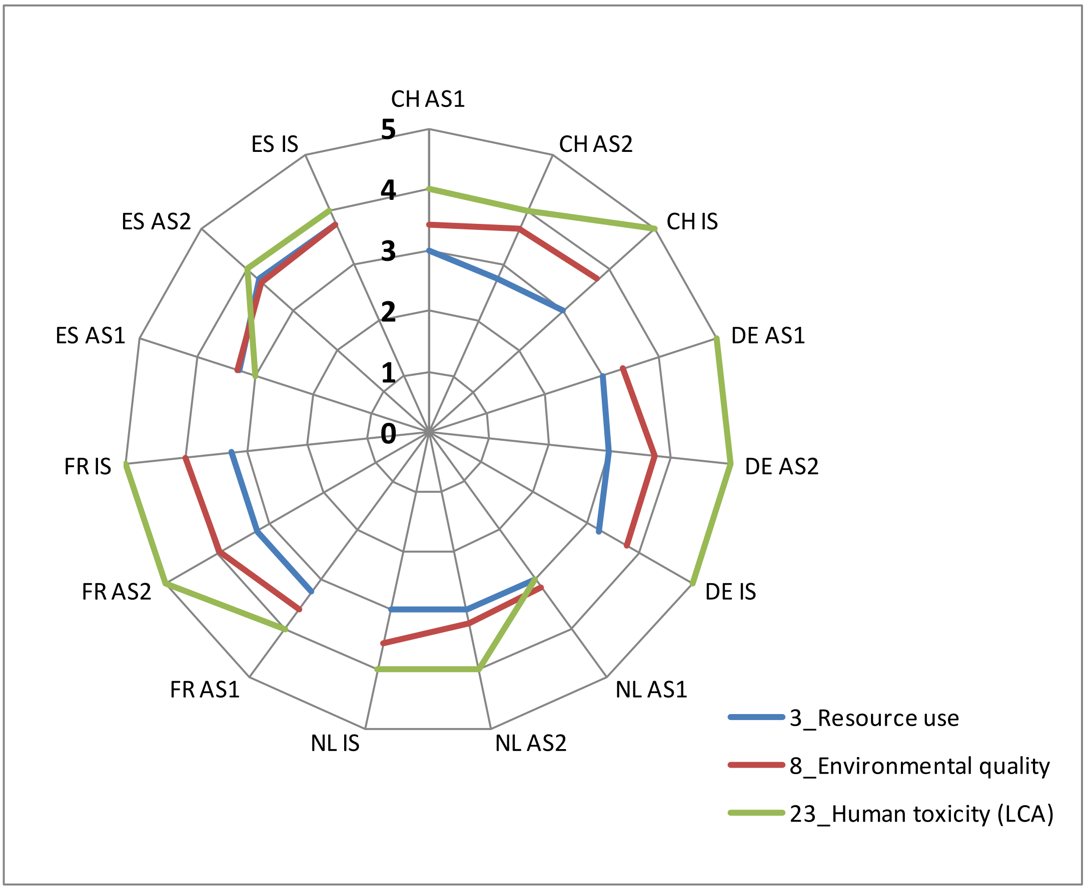

Figure 17. Ecological sustainability rating for five countries and three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, 3 = similar to BS, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System of the respective country.

9.2. General potential to improve the "Economic sustainability"

Economic disadvantages are the price for the ecological progress for AS1 and AS2 strategies in the case of Switzerland, Germany and France (only for AS1) as Fig. 16 shows. In contrast, for The Netherlands and Spain a win-win situation is indicated between ecology and economy not only for the AS1 strategy but also for AS2 and IS (Fig. 16). However, the IS strategy shows an improved economic situation compared to the BS strategy for all countries (Fig. 16), based on *higher or more stable yield and portions of 1st class fruits*. While the economic sub-attributes "Profitability" and "Autonomy" for all countries show a parallel improvement among the strategies, the "Production risk" might by over proportionally increased like in the case of The Netherlands or decreased like in the case of Germany (Fig. 18). Further improvements of the "Ecological-economic sustainability" can be expected if the innovations presumed for the IS strategy become commercially available. One example is the breading of new cultivars with multigene resistance against several major pests. Experts estimate a time horizon of 30 years for a genetic solution for apple scab, fire blight, powdery mildew and aphids integrated in the same cultivar. In addition, it takes at least 10 years till a new cultivar is established in the apple market to a relevant portion. The assumed higher yield per hectare and the higher portion of 1st class fruit for the IS strategy are the prerequisites for the economic success.

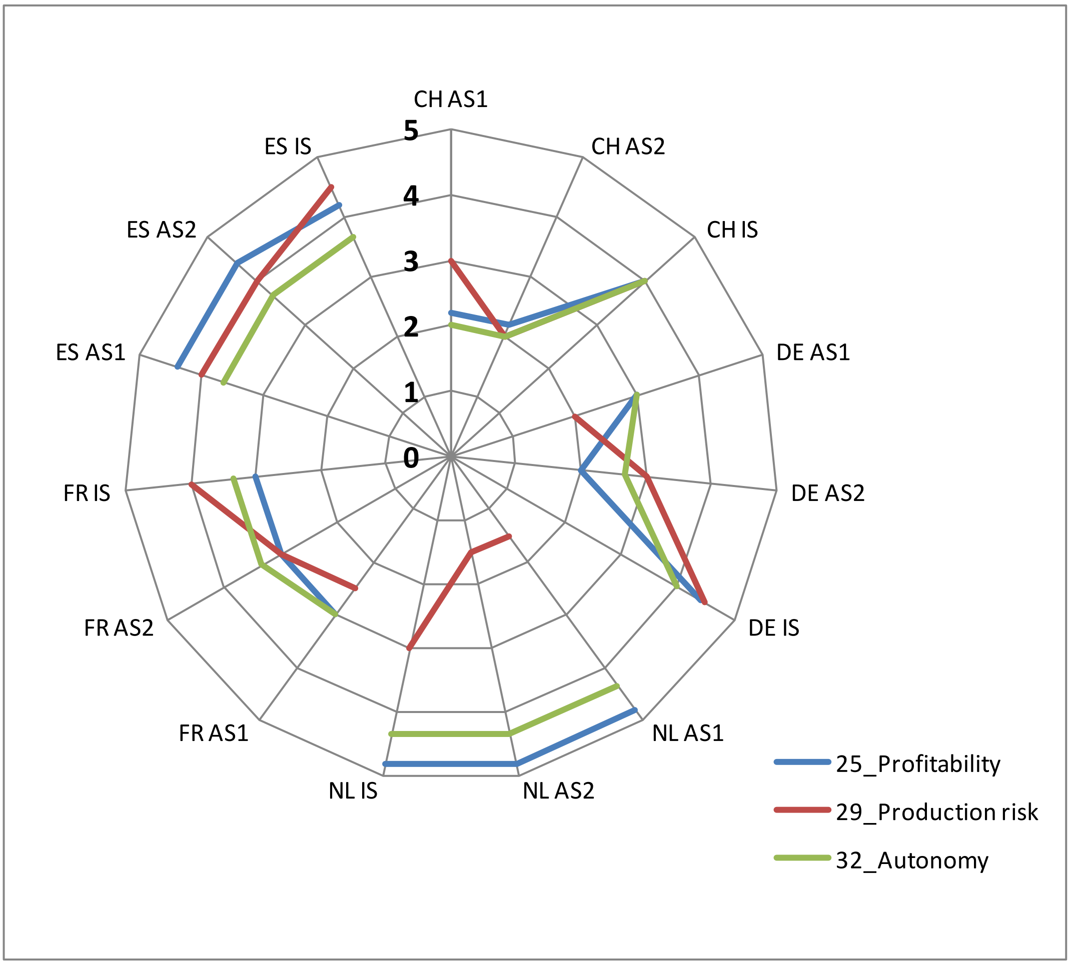

Figure 18. Economic sustainability rating for five countries and three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, 3 = similar to BS, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System of the respective country.

9.3. Recommendation

The current situation for apple growing systems is a mixture of farms with BS, AS1 or AS2 strategies. The portion of these three strategies might be different from country to country. It would be very likely that an increase of AS2 strategies in all countries, except for Switzerland, would improve the "Ecological sustainability". In the case of Switzerland the increase of AS1 strategy is recommended since the AS2 strategy shows not relevant ecological advantages compared to AS1 strategy, while AS1 brings a clear advantage compared to BS. In the case of The Netherlands and Spain this could be done more easily since an ecological-economic win-win situation can be expected. For the other countries the economic disadvantages of AS2 and AS1 need be overcome.

Since the IS strategy has the most promising potential for improving the overall sustainability we recommend to shorten the time to market for alternative measures that are today only working in trials or laboratories.

Introducing crop protection strategies on a region-specific base makes sense, since the sustainability potentials are based on advanced strategies that differ in many details from region to region. A tool like SustainOS could be very helpful for defining and optimising advanced systems. Since the assessments are base on methods like LCA, SYNOPS and Arbokost, joint project including fruit growers and assessment specialists are needed.

10. Discussion on the SustainOS methodology

We discuss the SustainOS methodology according to the goals of our study that are:

(a) Reach TRANSPARENCY in order to optimise crop protection strategies
i.e.:
- tracks cause-effect
- shows if a modification is relevant
- can be communicated clearly

(b) Cope with UNCERTAINTIES of assessments
(c) Be REGION-SPECIFIC

We experienced that a proper system description is fundamentally important. An adequate system description is the first step to reach **transparency** and a prerequisite to optimise crop protection strategies with an iterative process. The system description sheets can also be seen as the storage of crop protection knowledge of a higher order according to Scholz (1987, p. 147-154): "Knowledge of a higher order is different from directly accessible knowledge because it is attained by a series of reconstructive steps and can often only be gained by tutored activity or formal education." The SustainOS methodology scheme is a iterative process since data for system description are gained by experts who have considered assessment results of previous data settings. We think that three runs are fine to optimise crop protection strategies. Workshops and phone conferences bringing together experts from different regions are very useful for optimising system description data. Keeping target and context parameters fixed for each system, reflecting the region-specific conditions, helps to focus on optimising crop protection parameters. It is crucial that the crop protection parameters are defined for each active ingredient with dosage and week of application since this might strongly influences the "Ecotoxicity" results. Since SustainOS provides also the results of LCA, SYNOPS, Arbokost it is possible to **track the cause-effect** of different crop protection strategies. SustainOS also provides the information if a change of assessment results due to a change in the system description, is a **relevant modification** or not. This is the case if an attribute of interest changes the sustainability rating class. We think that five rating classes are suitable balancing robustness and sensitivity in a practical way. Also the rating results are easy to **communicate** with five rating classes. For some countries the "Ecotoxicity" of the AS1 strategy reached already the highest rating class. As a consequence an improvement of AS2 or IS strategy cannot be differentiated by the sustainability rating. Anyhow, reaching the highest rating class means that this strategy is "much better" than the BS strategy and that the "Ecotoxicity" is relatively low. Furthermore, such an improvement can be proved by studying the SYNOPS results directly (i.e. Fig, 11). If the aquatic or terrestrial risk of AS2 or IS strategy belongs to a lower risk class as AS1 or BS, the improvement can be considered to be relevant. SustainOS methodology copes with the **uncertainty** of the assessment methods by defining asymmetric rating scales (Fig. 4) that reflect the sensitivity of the robustness of the assessment methods and input data. The higher the uncertainty the wider the rating scale is defined.

The SustainOS methodology highly supports defining and optimising **region-specific** crop protection strategies. SustainOS therefore has the potential to be useful for finding and evaluating region-specific action plans as forced from the European community in order to implement IPM by the year of 2014. With small adjustments (e.g. adapting the list of active ingredients) SustainOS could be used also for other tree fruit crops like pear, cherry and plum orchards. For assessing crop rotation systems of annual crops the scheme of the methodology could be applied as it is but the structure of the system description parameters would need to be modified completely. Also complementary assessment methods could be included into the scheme without problems. Especially social assessments would be of interest to refer to a triple bottom line of sustainability instead of an ecological-economic approach. We think it is very important that **established assessment methods** are included into the SustainOS methodology. On one hand this helps to keep the attribute tree slim which is essential for a clear communication. On the other hand it means that the assessments

need to be conducted by specialists. The region-specific input data derived from the system description parameters can be analysed for all regions by one institution or one specialist. A **network** as we established during the Orchard system case study is very effective. Such a network is a secure way to cope with the complexity of crop protection optimisation in order to discover the relevant points for improving the sustainability of orchard systems.

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12. Appendix 1: Risk assessment with SYNOPS and aggregation of the results for region specific scenarios.

The region specific field related and environmental conditions like slope, soil type and climate data were derived from a spatial database which was developed within the EU-Project HAIR (2007). This database includes evaluated data on 10 * 10 km grid level for the orchard area, the average slope of the agricultural area and the dominant soil types. In addition long term climate data for precipitation and temperature on monthly basis were available on 50* 50 km grid level. This spatial database covers all orchard system case study regions except the Swiss orchard region Lake Constance. Therefore the data of the German orchard region Lake Constance was used as a substitute in the Swiss region.
In Addition to the input data which was derived from the HAIR database, fixed values were assumed for the input parameters which were not included in the HAIR database like distance to the surface water, surface water type and drift reduction measures.
For the minimal distance from the orchard two scenarios: a) directly adjacent orchards with 3 m distance and b) orchards with a distance of 20 m to the edge of the surface water were assessed. It was further assumed that, the orchards could be linked to flowing and standing surface waters. The drift reduction measures were calculated for fixed values of 0%, 50%, 75% and 90%.
The number of 10*10 km Grids in combination with the fixed scenarios used for the environmental and field based input parameters of SYNOPS are listed in Table 1.

Table 1. Combination of the environmental input parameters for GIS database with the fixed scenarios.

	Input parameters related to GIS data-base derived from 10*10 km grids			Fixed scenarios			
Orchard region	Total orchard area (ha)	N Grids	N Grids with OA>0	Type of SW	Distance to SW [m]	Drift reduction %	
Lake Constance (DE)	7979	58	17	standing / flowing	3, 20	0,50,75,90	17*2*2*4 =272
Lake Constance (CH)	-	32	17	standing / flowing	3, 20	0,50,75,90	17*2*2*4 =272
Lleida (ES)	50690	31	27	standing / flowing	3,20	0,50,75,90	27*2*2*4 =432
Rhone Valley (FR)	21220	22	18	standing / flowing	3,20	0,50,75,90	18*2*2*4 =288
Kromme Rijn (NL)	798	10	4	standing / flowing	3,20	0,50,75,90	4*2*2*4 =64

The risk potentials for the assumed scenarios were assessed with SYNOPS for each of the 10 *10 km grids. Therefore for each grid 16 different parameter combinations, which correspond to the assumed scenarios for the distance to the surface water, the surface water type and the drift reduction measures were assessed (step 2, Fig.1). For each parameter combination of the assumed scenarios the orchard area of each grid was used as weight and the weighted mean was calculated for all 16 fixed scenarios (step 3, Fig.1).

The result of the environmental risk assessment with SYNOPS were collected and made available to the partners of the sub-activity in form of an excel sheet for all 16 fixed scenarios and each defined orchard System. For each orchard region a table with the SYNOPS results was prepared.
These results could be used by the partners of the sub-activity to improve the environmental performance of the orchard by replacing products with high risk potential or by reducing drift mitigation measures. The aim of the optimisation was to reduce the environmental risk of the defined orchard systems. The categorisation of the calculated risk scores is given in table 2.
In total 3 circles of optimising the orchard systems were conducted and the SYNOPS results were recalculated each cycle for the optimised orchard systems.

Table 2. Classes of the calculated acute and chronic risk indices which were calculated with SYNOPS

risk classes of SYNOPS results	acute risk	chronic risk
very low risk	ETR<0.01	ETR<0.1
low risk	0.01<ETR<0.1	0.1<ETR<1
medium risk	0.1<ETR<1	1<ETR<10
high risk	ETR >1	ETR >10

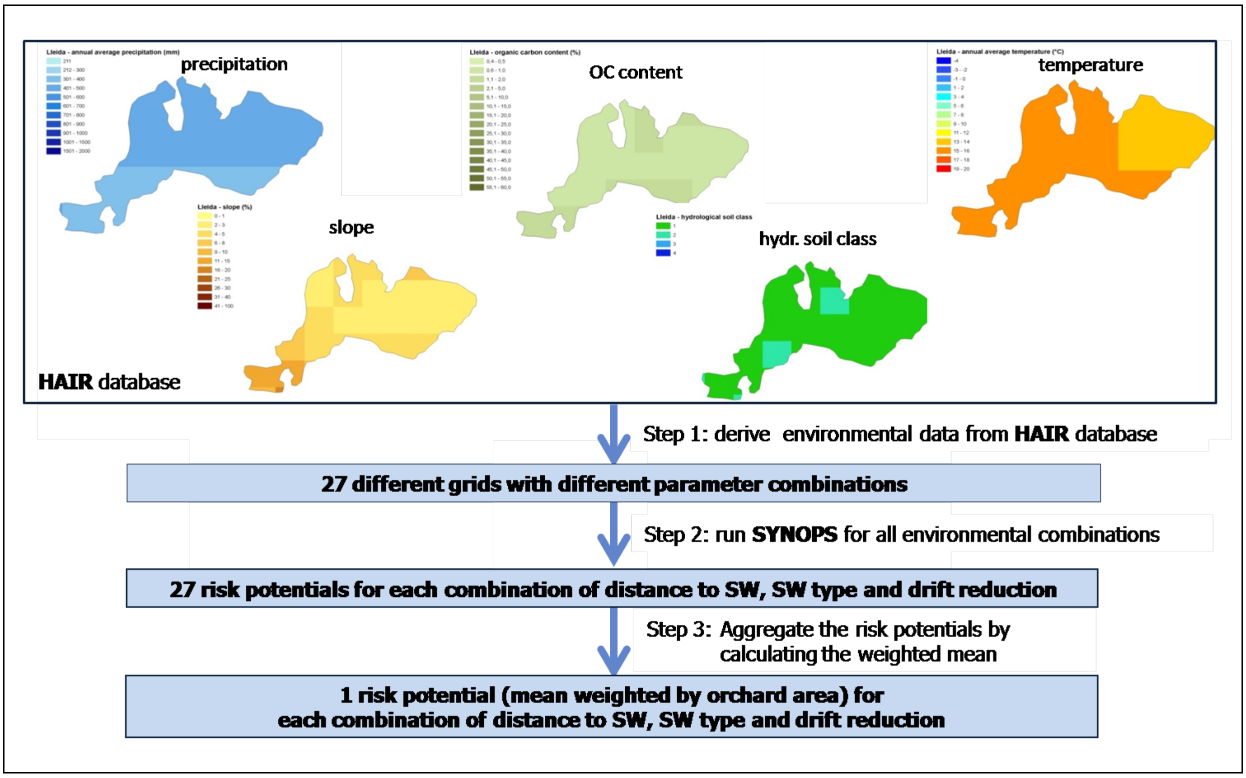

Figure 1. Risk assessment with SYNOPS using the spatial environmental database developed within the EU-Project HAIR.

Region specific aggregation of the assumed scenarios assessed with SYNOPS
The pesticide use of each system was defined with 4-10 different application calendars each describing the pesticide use of one year within the described system. For each of the 16 scenarios all application calendars were assessed with SYNOPS. In table 3 the risk potentials calculated with SYNOPS are listed for the terrestrial risk and the aquatic risk considering the scenarios for distances to the SW of 3 m and 20m and flowing and standing SW. The sample results shown in table 3 are corresponding to the advanced system (AS1) of the Swiss orchard region and were calculated assuming 90% drift reduction.

Table 3. SYNOPS results for the advanced system 1 (AS1) of the Swiss orchard region. In total 6 application calendars were defined for AS1. Listed are the results for the different scenarios of the acute and chronic risk for terrestrial and aquatic ecosystem. For all assessments a drift reduction of 90% was assumed

System	Application calendar	terrestrial risk		aquatic risk					
				3m (near)			20 m (far)		
		acute	chronic	acute	chronic		acute	chronic	
					standing SW	flowing SW		standing SW	flowing SW
AS1	601	0.121	0.598	1.105	3.108	0.067	0.122	0.329	0.007
AS1	602	0.013	0.063	1.105	2.344	0.070	0.122	0.241	0.007
AS1	603	0.069	0.063	1.105	2.313	0.067	0.122	0.237	0.007
AS1	604	0.121	0.598	1.105	3.108	0.067	0.122	0.329	0.007
AS1	605	0.013	0.063	1.105	2.344	0.070	0.122	0.240	0.007
AS1	606	0.069	0.063	1.105	2.313	0.067	0.122	0.237	0.007

In the first aggregation step the scenarios for 3m and 20m distance to the surface water and for standing and flowing surface waters were aggregated by calculating the weighted mean of the SYNOPS results according to the spatial distribution of these parameters in each orchard region. As an example the parameters for Switzerland are shown in (table 4). The functions to aggregate the SYNOPS results are shown in equation 1 and 2.

(1) acute =(acute_near*p_near+acute_far*p_far)

(2) chronic =(chr_near_flow*p_flow+chr_near_stand*p_stand)*p_near +(chr_far_flow*p_flow+chr_far_stand*p_stand)*p_far

Table 4. spatial distribution of orchard which are near (3-20m) and far (>20m) to surface waters and distribution of flowing and standing surface waters for the Swiss orchard region.

probability of distance		probability of surface water type	
p_near	0.276	p_stand	0.055
p_far	0.724	p_flow	0.945

In the next step the results for the scenarios of the different drift reduction measures were aggregated by calculating the weighted mean according to a realistic distribution of the applied drift reduction measures. These values were defined within the context parameters of the assessment tool SustainOS for each orchard region by the responsible person. In Table 5 the values for the drift reduction measures in of the Swiss orchard region are listed an example.

(3) chronic =chronic_dr0* p_dr0+chronic_dr50* p_dr50+chronic_dr75* p_dr75+chronic_dr90* p_dr90

Table 5. Drift reduction measures which were defined fort he Swiss orchard region.

	portion of drift reduction 0% (pdr_0)	portion of drift reduction 50% (pdr_50)	portion of drift reduction 75% (pdr_75)	portion of drift reduction 90% (pdr_90)
BS	0.54	0.42	0.04	0
AS1	0	0.09	0.46	0.45
AS2	0	0	0.18	0.82
IS	0	0	0.09	0.91

Finally the different application calendars of each system were aggregated by calculating the average of all application calendars which were defined for each orchard system (BS, AS1, AS2, IS). The final result of this aggregation procedure is a chronic and acute risk index for terrestrial and aquatic ecosystems. These aggregated risk indices are input parameters of the multicriteria assessment tool SustainOS. In Table 5 the aggregated risk indices for the Swiss orchard region are demonstrated as an example.

Table 4. Aggregated risk indices for the Swiss orchard region. Listed are the results for the different orchard systems of the acute and chronic risk for terrestrial and aquatic ecosystem.

	Terrestrial		aquatic	
	acute	Chronic	acute	chronic
BS	0.192	0.482	3.259	17.402
AS1	0.069	0.243	0.599	0.134
AS2	0.044	0.190	0.307	0.087
IS	0.000	0.000	0.000	0.000