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Comprehensive Farm Sustainability Assessment

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Summary

Sustainable agricultural production is the sine qua non of future-proof food production and the provision of food to the population. Numerous research projects show that it is not sufficient to focus exclusively on the environmental components of sustainability; rather, it is becoming increasingly important to look at sustainability from a holistic perspective, based on the three dimensions of society, economics and the environment.

This study provides scientific bases for assessing the sustainability of farms, bearing in mind the three dimensions of sustainability where the following aspects were considered: social: human well-being, animal welfare and landscape; economics: economic situation; environment: resource use, climate change, nutrient management, ecotoxicity, biodiversity and soil quality. Based on a suitable set of quantitative impact indicators, the evaluation follows the dictum of an optimal combination of scientific accuracy and practicality, which above all involves efficient data acquisition at the lowest possible cost. Wherever possible, concepts and indicators were designed so as to allow the implementation of a life cycle analysis (LCA)-based methodological approach. Since the various aspects of social sustainability have not yet been investigated to a great extent, this study pays special attention to the social dimension. Besides a discussion and synthesis of the results obtained, this report discusses various options for the aggregation of the indicators.

The most important findings of the study are summarised below. An overview of the aspects of sustainability analysed in this study is given in Table 1.

Table 1: List of the aspects of the farm sustainability evaluation explored in the study. The last column suggests how to implement the evaluation.

Dimension	Subject	Aspect	Implementation
Social	Well-being	Financial and working conditions	Survey form: 3 questions
		Living conditions	Survey form: 1 question
		Health	Survey form: 4 questions
		Work/life balance	Survey form: 5 questions
		Education and skills	Survey form: 2 questions
		Social connections	Survey form: 3 questions
		Civic participation and governance	Survey form: 4 questions
		Subjective well-being	FOAG Well-being Survey (importance of/satisfaction in different spheres of life)
		Workload in terms of time	Ratio of needed to available labour units
	Animal Welfare	Absence of prolonged hunger and thirst	Credit point system (additional services above the minimum stipulated by the Swiss Animal Protection Law)
		Resting comfort	
		Thermal comfort	
		Freedom of movement	
		Absence of injury, disease and farm-management-related pain	
		Expression of social and other behaviours	
		Good human-animal relationship	

Dimension	Subject	Aspect	Implementation
		Positive emotional state	
	Landscape	Landscape diversity and aesthetics	Shannon Index, calculated from AGIS structural data
Economic	Profitability	Earned income per family labour unit	Direct calculation from accounting data
		Total return on capital	
	Liquidity	Cashflow-turnover rate	
		Dynamic gearing ratio	
	Stability	capitalisation ratio	
		equity-to-fixed-assets ratio	
Environmental	Resource use	Non-renewable energy resources	Cumulative energy demand (ecoinvent method)
		Phosphorus and potassium	CML2001 method
		Water requirement (fresh water)	Method of Pfister *et al.* (2009)
		Land use	Indicators on three levels: Land occupation (e.g. CML 2001 method) Biomass production potential, foodstuff potential (e.g. protein production potential)
	Climate change	Greenhouse gases (CO_2, CH_4 and N_2O)	Global warming potential according to IPCC 2013 (100-year time horizon)
	Nutrient-related environmental impacts	Eutrophication (aquatic and terrestrial)	Eutrophication potential (EDIP2003 method)
		Acidification (aquatic and terrestrial)	Acidification potential (e.g. ReCiPe or 'accumulated exceedance' method for terrestrial acidification)
	Ecotoxicity	Ecotoxicity of pesticides	PestLCI for Life Cycle Inventory (LCI) USETox for Life Cycle Impact Assessment (LCIA)
	Biodiversity	Genetic diversity	SALCA-BD or biodiversity points according to IP-SUISSE
		Species diversity	
		Habitat diversity	
		Habitat linkage	
		Diversity of agricultural crops	
		Potentially natural habitat	
		Plant-protection products	
		Fertiliser use	
		Irrigation	
		Use intensity, management technique	
		Functional aspects	
	Soil Quality	Erosion	SALCA-SQ

Dimension	Subject	Aspect	Implementation
		Humus content (organic carbon content)	
		Soil hydrology	
		Soil compaction	
		Impact of pesticides	

Social Dimension

The social dimension of sustainability deals with the three aspects of well-being, animal welfare and landscape. A separate chapter is devoted to defining an indicator for estimating workload.

The analysis of various concepts has shown that the concept of well-being developed by the Organisation for Economic Co-operation and Development OECD constitutes a sound basis for developing and classifying indicators for describing well-being. This concept distinguishes between economic capital, natural capital, human capital and social capital, which together contribute to sustainable well-being. The advantage is that it makes use of the so-called 'basic-needs concept' as well as of the concept of social capital, thereby taking important components of social sustainability into account. The OECD Well-being Framework, which chooses to subdivide well-being into three material and eight non-material dimensions, was modified slightly in this study, since e.g. the aspect of personal security (criminality, war, terrorism) is of little relevance in the Swiss agricultural sector. A set of indicators – as quantitative and as easily measurable as possible – were developed on the basis of the OECD well-being concept and the analysis of various existing evaluation instruments. This indicator set covers the various dimensions of the OECD concept as completely as possible whilst bearing in mind the most important internal and external stakeholders (farm manager's family, employees, suppliers, consumers). The indicators were established on the basis of a questionnaire with 24 questions concerning the following aspects according to an adapted OECD version: (i) financial and working conditions; (ii) living conditions; (iii) health; (iv) work/ life balance; (v) education and skills; (vi) social connections; and (vii) civic participation and governance. For each question, the form states the stakeholders concerned, a range of possible responses, and suggestions for a performance reference point. Present-day social research ascribes a very high importance to the components of subjective well-being. To determine these components, the approach developed by Radlinsky *et al.* (2000) for measuring quality of life in the Swiss agricultural sector, which is also used in the Federal Office for Agriculture FOAG's Well-being Survey, is recommended. The method is characterised by the fact that it not only determines satisfaction in various spheres of life, but also the importance of these spheres. A critical point, however, is that due to the stipulation that the questionnaire is to be completed exclusively by the farm manager, the questionnaire does not take the subjective well-being of the remaining internal stakeholders (family members, non-family employees) into account.

Especially in agriculture, where high weekly working hours frequently occur, workload represents an important component of social sustainability. The proposed indicator is based on the practical approach of comparing the theoretically deduced working-time requirement to the actual work units available on the farm. The widely used 'ART Work Budget' software developed by Agroscope is an ideal tool for determining the working-time requirement of a farm on the basis of models. The work units actually available on the farm can be deduced from the AGIS structural database (at least approximately, since the number of work units is only collected for three workload categories). The workload indicator is based on the ratio of work units needed to those actually available on the farm, with values above 1 indicating a potential overload. The needed work units are estimated by simulating the required working time. A lack of information on the degree of mechanisation and the extent of the work carried out by contractors will adversely affect the accuracy of the indicator.

The study shows that there can be no single indicator for describing animal welfare, since its assessment requires a multidimensional analysis, as well as being inextricably bound up with certain ideals and values. A holistic evaluation of animal welfare must include all three perspectives (natural behaviour, health and physiology, emotional state) formulated by Fraser (2008), which are covered by the 'Five Freedoms', such as e.g. freedom from pain caused by housing (Brambell 1965). In order to develop a comprehensive animal welfare indicator, it is essential to bear in mind the twelve aspects of animal welfare dealt with in the Welfare®

Quality Protocol (e.g. freedom of movement and the absence of pain) (Welfare Quality® 2009b). For reasons of feasibility, Welfare® Quality Protocols are not suitable for wide-scale use and/or a large number of farms. Consequently, we propose a pragmatic solution: In a first step, measures having a positive effect on one of the twelve aspects of animal welfare and which go beyond the minimum legal requirements of the Swiss Animal Protection Law are determined for each species of animal. In the present study, a list of parameters is proposed for the two livestock species ‘dairy cows’ and ‘fattening pigs’. Scores are awarded to each of these measures. In addition, a scoring system is used to assess the added value of the two ethology programmes PAS (particularly animal-friendly stabling) and ROEL (regular outdoor exercise for livestock) vis-à-vis the twelve aspects of animal welfare. The authors stress that much remains to be done in terms of research before the assessment of animal welfare can become operational, either for evaluating additional livestock species, or for verifying whether the proposed measures can be confirmed by animal-based measurements and/or other animal-welfare assessment methods.

The aesthetics of landscape is allocated to the social dimension of sustainability. An indicator for evaluating landscape must satisfy many demands. Besides being easy to operationalise, the indicator must cover a wide variety of landscapes, as well as doing justice to special and rare landscapes (e.g. those dominated by high-stem orchards). To this end, from the nine concepts for developing landscape indicators described in the conceptual framework of Tveit *et al.* (2006), the following three were chosen: (i) diversity; (ii) naturalness; and (iii) seasons. Diversity was determined in various studies with the help of the Shannon Diversity Index, which repeatedly showed ample correlation with landscape preferences. Since greater diversity does not necessarily lead to a higher-rated (‘more beautiful’) landscape, preference values for types of usage served as a reference for evaluating the landscape’s naturalness and calculating a weighted Shannon Index. Season can be determined via an accumulated seasonal diversity. The latter can be calculated via the sum of the differences, since the preference values for different stages of development of the crops and areas reserved for promoting biodiversity are available for the landscape elements at two-week intervals between March and October. The present report stresses that a further refinement of these concepts is necessary to prevent farms with an increase in surface area of high-rated landscape elements from being assessed with a lower Shannon Index value. We therefore propose that for a group of farms yet to be defined, the area-weighted preference value be borne in mind as an indicator for landscape aesthetics. The other farms will be divided into the three following groups, with certain landscape elements being aggregated before the diversity index is calculated: (i) ‘beautiful agricultural landscape’, with the accent on especially attractive landscape elements; (ii) ‘varied arable landscape’, with a stress on arable farming; and (iii) ‘varied grassland landscape’, with a focus on grassland. Allocating the farms to the different groups remains a major challenge.

Economic Dimension

The economic sustainability of a farm is determined via broadly accepted indicators enabling the appropriate assessment of both capital- and labour-intensive farms. In addition, the set of indicators must allow the adequate evaluation of farms with a wide range of focal activities, and allow conclusions on the future existence of the farm to be drawn. Finally, the indicators must possess high practical relevance, and be deducible from common accounting data.

A study of the literature on both the existing evaluation instruments and the project stipulations showed that the economic situation of a farm can be effectively characterised with two indicators from each of the three spheres of profitability, liquidity and stability. For profitability, which designates the ratio of an economic result to the utilised production factors, the two indicators proposed are ‘earned income per family labour unit’ and ‘total return on capital’. For liquidity, i.e. the availability of sufficient means of payment, the two indicators of ‘cash flow-turnover rate’ and ‘dynamic gearing ratio’ are recommended. The stability of a farm estimates risk with respect to profitability and liquidity, thereby underscoring the long-term component of economic sustainability. Investment intensity and investment coverage represent plausible and practical indicators for assessing the stability of a farm. Particularly where data acquisition is concerned, practical implementation requires technical monitoring and careful harmonisation of the indicators. Moreover, the scrupulous separation of farm and private household is essential in order to ensure the comparability of the different farms.

Environmental Dimension

In order to evaluate the ecological sustainability of farms, this study analyses resource use, effects on climate change, and nutrient-related environmental impacts, as well as biodiversity and soil quality. The aim here was not to develop new indicators, but rather to evaluate the SALCA methodology and the available impact indicators within the context of the latest developments on the international scene. In-depth studies were undertaken in order to estimate the ecotoxicity of pesticides used on agricultural land. A methodological comparison deals with the effects of agricultural production on biodiversity and soil quality.

Regarding natural resources, within the context of a life cycle analysis, the following aspects are important: abiotic resources (energy, metals, minerals), biotic resources (wood, biomass), water (especially freshwater) requirement, and land. To evaluate the sustainability of all the resources, the use of so-called 'exergy' (useful energy or ability to produce work) is recommended, since this allows all resources to be evaluated with the same method while using the same unit. For estimating the impact of anthropogenic climate change, the global warming potential is suggested, since it can be thoroughly and precisely described by means of factors characterising the main greenhouse gases, and has gained acceptance as a standard indicator for assessing climate impact. The most important environmentally relevant nutrients in agriculture are nitrogen (N) and phosphorus (P). Eutrophication caused by N and P input is captured by eutrophication potential, with a distinction being made between aquatic and terrestrial potentials. Since the terrestrial acidification potential and the terrestrial eutrophication potential are both strongly influenced by ammonia emissions and are therefore closely correlated, only one of the two categories is included in the overall analysis of sustainability. Analysis of the various midpoint indicators shows that EDIP2003 is the most suitable method for assessing the impact of aquatic and terrestrial eutrophication.

Bearing in mind that – put in simplistic terms – all pesticides spread on crops end up in the soil, a special sub-project was put in place for ecotoxicity. In order to qualify as appropriate, the chosen method must take account of pesticide emissions to the different environmental compartments (groundwater, surface water, air). The 'PestLCI' method has proven to be particularly suitable for use in the life cycle inventory. For the impact assessment, we recommend using the USEtox model. Supported by a broad consensus, this model determines the characterisation factors in different environmental compartments (natural/agricultural soil, freshwater, sea, air). Various sensitivity studies have demonstrated that the combined use of the PestLCI and USEtox models should lead to a reasonable impact assessment. Nevertheless, users are advised to continue to exercise great caution when interpreting the results, since, despite their detailed simulation, both methods still exhibit significant uncertainties.

In order to estimate the effects of an agricultural activity on biodiversity, a comparison of different models was conducted. For biodiversity, the three evaluation methods of IP-SUISSE credit point system, SALCA Biodiversity, and the RISE (Response-Inducing Sustainability Evaluation) model developed at HAFL were compared. The evaluation includes the assessment of (i) completeness on the basis of 13 different criteria (such as genetic diversity, species diversity or habitat linkage); (ii) robustness and uncertainty; (iii) transparency and reproducibility; (iv) communicability and practicability. To meet the requirements of this study (such as simplification of both the data survey and operationalisation), the authors recommend using the IP-SUISSE credit point system, despite being aware that this method does not allow conclusions to be drawn at plot scale. The impact of agricultural management on soil quality was analysed in the same way as biodiversity. The following five methods were considered for the evaluation: (i) SALCA soil quality; (ii) RISE; (iii) MASC ('Multi-Attribute Assessment of the Sustainability of Cropping Systems'); and the two dynamic models (iv) LCA-SOL (= 'Life Cycle Assessment- SOIL') and (v) EPIC ('Environmental Policy Integrated Climate'). Here, the SALCA Soil Quality model is recommended, since it scored best in terms of completeness, and responded with the desired degree of sensitivity to type of management. The problem with the SALCA method is that it requires a relatively detailed data survey.

Abbreviations

ACC	Agricultural Concept Classification
AFWU	Annual Family Work Unit
AGIS	Agricultural Information System
APEX	Agricultural Policy/Environmental eXtender
ARPB	Area(s) Reserved for Promoting Biodiversity
AWI	Animal Welfare Index (rating system for cruelty-free animal husbandry)
awPv	Area-Weighted Preference Value
CED	Cumulative Energy Demand
CF	Characterisation Factor
CFC	Chlorofluorocarbon
CHF	Swiss francs
CORINE	Coordination of Information on the Environment
CPG	Civic Participation and Governance
CSSA	Criteria System for Sustainable Agriculture
CTU	Comparative Toxic Unit
DAYCENT	Daily Century Model
DF	Distribution Factor
DIN	German Industrial Standard (= 'Deutsche Industrienorm')
DLG	German Agricultural Society
DPO	Direct Payment Ordinance
EC	Effect Concentration
EC10	Concentration at which effects occur for 10% of test organisms (Effect Concentration)
EC50	Concentration at which effects occur for 50% of test organisms (Effect Concentration)
ECA	Ecological Compensation Area
EEA	European Environment Agency
EF	Effect Factor
ENDURE	European Network for Durable Exploitation of Crop Protection Strategies
ENVASSO	Environmental Assessment of Soil for Monitoring
EPIC	Environmental Policy Integrated Climate
EQO	Environmental Quality Ordinance
ES	Education and Skills
FADN-AEI	Farm Accountancy Data Network – Agri-Environmental Indicators
FAO	Food and Agriculture Organization of the United Nations
FOAG	Federal Office for Agriculture
FOEN	Federal Office for the Environment
FW	Financial and Work Conditions
GIS	Geographic Information System
GTP	Global Temperature Potential
GW	Groundwater
GWP	Global Warming Potential
H	Shannon Index
ha	Hectare
HAFL	School of Agricultural, Forest and Food Sciences
HANPP	Human Appropriation of Net Primary Productivity
HC	Hazardous concentration
HE	Health
IDEA (FSI)	Farm Sustainability Indicators
ILCD	International Reference Life Cycle Data System
ILO	International Labour Organization

IS	Impact score
KABO	Canton of Aargau Soil Monitoring Network
LC	Living conditions
LCA	Life Cycle Assessment
LCA-SOL	Life Cycle Assessment-Soil
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCM	Life Cycle Management
LC50	Lethal Concentration for 50% of test organisms
LMU	Livestock Manure Unit
LU	Livestock Unit
LUE	Land Use Efficiency
LUI	Land Use Intensity
MASC	Multi-attribute Assessment of the Sustainability of Cropping Systems
MEA	Millenium Ecosystem Assessment
MJ	Megajoule
MOTIFS	Monitoring Tool for Integrated Farm Sustainability
NAV	Regular Working Contract
NOEC	'No Observed Effect' Concentration (highest concentration at which no effect on the test organism is observed)
NPP	Net Primary Productivity
OCIS PG	Organic Conversion Information Service, Public Goods
OECD	Organization for Economic Cooperation and Development
PAF	Potentially affected fraction
PAS	Particularly Animal-Friendly Stabling
PEP	Proof of Ecological Performance
PPP	Plant protection product
PSE	Producer Support Estimate
PSMV	Plant Protection Products Ordinance
QBA	Qualitative Behaviour Assessment
RE	Residual Error
RG	Research Group
RISE	Response-Inducing Sustainability Evaluation
RLU	Roughage-consuming Livestock Unit
ROEL	Regular Outdoor Exercise for Livestock
RothC	Rothamsted Carbon Model
SFSO	Swiss Federal Statistical Office
SALCA	Swiss Agricultural Life Cycle Assessment
SALCA-SQ	SALCA-Soil Quality
SC	Social connections
SEJ	Solar Energy Joules
SIW	Sustainability Indicator for Workload
SLU	Standard Work Unit
SMART	Sustainability Monitoring and Assessment Routine
SNB	Swiss National Bank
SR	Systematic Collection of Swiss Laws
SUS	Sustainability
SW	Subjective Well-being
TSchG	Swiss Animal Protection Law
UAA	Utilised Agricultural Area
UN	United Nations
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
USLE	Universal Soil Loss Equation

WBCSD	World Business Council for Sustainable Development
WEPP	Water Erosion Prediction Project
WHO	World Health Organization
WL	Work/Life Balance
WQ	Welfare Quality
WTO	World Trade Organization
WU	Work Unit
XF	Contact Factor

1 Introduction

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This report develops the scientific basis for a methodology for a comprehensive sustainability assessment at farm level. The assessment is based on a suitable set of quantitative impact indicators for each of the three dimensions of ecology, economy and social aspects. The following chapter provides a brief outline of the history of sustainability, by way of introduction.

The origin of the concept of sustainability lies in the 18th century, with the German mining administrator Hans Carl von Carlowitz employing the concept as early as 1713 in his forest management instructions that no more timber must be felled than can regrow. Latter-day discussion of sustainability begins with the famous essay of Meadows *et al.* (1972), which concluded that, given the current trends in population growth, industrialisation, food production and resource consumption, the limits of growth would be reached “within the next hundred years”. A subsequent important milestone in this development was the Brundtland Report (UN 1987), which formulated the following mission statement: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs and choose their lifestyle”. At the environmental conference in Rio de Janeiro (1992), the famous Agenda 21 expanded on the concept of sustainability. Besides the long-term protection of the environment and resources, sustainable development likewise encompasses the achievement of social and economic objectives: the principle of the three dimensions of sustainability – environmental, economic and social – was thus firmly anchored in the environmental-policy action programme for the 21st century. In the numerous subsequent climate summits, it was repeatedly stressed that sustainability targets could not be achieved without the contribution of agriculture. Despite this, the main focus continued to be placed on the ecological dimension, particularly in the sustainability assessment of agricultural production. The explicit equal status of these three dimensions is first found in the ‘Triple Bottom Line’ concept formulated by John Elkington (1999), which postulates that sufficient sustainability can only be achieved in one dimension when a minimum level of sustainability is reached in the other two dimensions (McKenzie 2004). Today, the three-pillar model of sustainability is widely applied, and not only in the agricultural sphere, but in industry and in the evaluation of businesses as well. Here, the aim is to simultaneously improve environmental and socioeconomic sustainability. Often, however, the optimal achievement of all objectives is not possible. For this reason, it is important to carefully analyse the existing trade-offs and to keep them to a minimum. Only in this way can we prevent a focusing on individual objectives which might lead to the long-term disregarding of risks.

1.1 Initial Situation

The comprehensive assessment of the sustainability of farms is increasingly gaining importance for all actors in the value chain (producer, processing, trade, consumers). In order to gain an overall view, it is important not only to include the environmental impacts, but also to assess the economic viability of the farm as well as its social structure. Consequently, the two methods of RISE (Response-Inducing Sustainability Evaluation; Grenz *et al.* 2012c) and SMART (Sustainability Monitoring and Assessment RouTine; Schader *et al.* 2016) were developed in Switzerland for the holistic assessment of the various aspects of farm sustainability. Designed for international use, SMART and RISE include various quality-assurance procedures. SMART covers a large number of impact mechanisms with over 300 indicators, and has already been employed on more than 1000 farms worldwide. RISE is based on 10 indicators, and has been in use for over a decade, during which time it has been utilised to assess well over 1000 farms worldwide. The strengths of the already-existing SMART and RISE methodologies should also to be borne in mind to the extent possible when developing new quantitative sustainability indicators. As described in Schader et al. (2014), there is no ‘one size fits all’ solution for assessing the sustainability of farms. Consequently, the focus in both the SMART and RISE methods is on the simple and rapid evaluation of farms throughout the world, whilst the indicator set developed within the context

of this study is based as far as possible on quantitatively measurable criteria, and is specially adapted to Swiss conditions.
M-Industry and the Migros Cooperative Association (MGB), which had provided financial support for this project, developed a new sustainability strategy based on a scientifically supported assessment of all three dimensions of sustainability. Migros' strategy thus satisfies an important objective of Agroscope's, viz., a more comprehensive assessment of sustainability through the incorporation of the social and economic dimensions. Already-concluded projects that aimed to determine environmental impacts, such as the Farm Accountancy Data Network Project on Farm Life-Cycle Assessments (Hersener *et al.* 2011) form an outstanding starting point for this. In addition, competition of ideas and innovations among the researchers is key for scientific progress. We may assume that complementary methodologies will continue to exist in parallel, with a lively exchange between the various groups of researchers naturally being of crucial importance. This is one of the main reasons why this project was initiated, with aim of enabling the development of scientifically supported indicators under the leadership of Agroscope.

1.2 Aims and Target Groups of the Study

The aim of this project is to present the current state of knowledge on sustainability assessment methods in Switzerland in as complete and clear a manner as possible, making use of already existing and newly acquired findings provided by various Agroscope research groups as well as two private-sector agencies (Gruppe Agéco (www.groupeageco.ca) and jch-consult). Important in addition to the scientific accuracy of the methodology are a high level of practicability and the ability to apply the calculation of the indicators to a large number of farms. The aim is to use the indicator system to comprehensively monitor farm sustainability (for the time being in Switzerland).
The target groups of the present report are manifold, encompassing all actors along the food value chain (producer/farmer, suppliers, wholesalers and retailers, consumers), and in addition agricultural extension services as well as (agricultural) cooperatives, associations, and sector organisations. The aim is that a better understanding of the different aspects of sustainability will motivate farmers to organise their production along more sustainable lines. The Agroscope 'Production2020' research initiative therefore provides for the testing and pooling of measures intended to improve the sustainability of commercial farms. In this context, measurable and easy-to-interpret indicators are urgently needed to help decision-makers form opinions during the decision-making process; however, sustainability research will also benefit from the results, since this report has placed great importance on the clear derivation of underlying concepts.

1.3 Project Organisation

The project was jointly supervised by Agroscope and the MGB. The project team consisted of various research groups from Agroscope's Institute for Sustainability Sciences, from the Agéco Group, and from the private-sector agency jch-consult. Strategic management was exercised by those in overall charge of the project, with representatives from Agroscope, the Migros Cooperative Association (MGB) and Micarna. The project was monitored by a scientific advisory group composed of internationally recognised researchers in the field of sustainability research.

1.4 Structure of the Report

After a short introduction to the topic of sustainability as well as to the chosen methodology, the report presents the indicators for the various aspects of sustainability. The report was designed in such a way that all subchapters follow a common structure, viz., after an introduction and a description of the relevance of the topic in terms of sustainability, an overview of the most important methods is given. The indicators (or models) are then accurately described and evaluated according to the following criteria: (i) completeness; (ii) robustness and uncertainties; (iii) transparency and reproducibility; (iv) applicability; and (v) communicability and practicality. Depending on the topic, there may be a slight deviation from this scheme. With its introduction to each chapter, the structure allows individual chapters to be read without the necessity of reading the full report. The report is therefore also highly suitable as a reference work, whether as an introduction to the relevant subfield or for an in-depth discussion. Following the various chapters on methodology is a chapter discussing the complex subject of the aggregation of individual indicators. Here, once the aims of the project have been outlined, a rough introduction to the subject is given and several simple concepts are formulated. The report ends with a discussion, the conclusions, and an outlook.

2 Approach

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2.1 Introduction

The operationalisation of sustainability is usually based on the 'three pillars' model (Buckwell et al. 2014) or the related 'three dimensions' concept (Interdepartmental Commission on Sustainable Development, 2012) with the pillars or dimensions of 'environment', 'economy' and 'social aspects'. Alternative concepts do exist, but have not gained currency to date.

There are various ways to operationalise sustainability which vary according to the context (e.g. consideration of the product versus the company) and the level under consideration (e.g. company level versus an entire country) (Singh *et al.* 2009); this also holds true for the agricultural sector (Lowrance *et al.* 1986; Christen 1996; Schader *et al.* 2014).

Numerous methods for evaluating sustainability at the sectoral, farm and product level are described in the literature. A number of these either limit themselves to just one dimension – most frequently it is the environmental impacts that are considered – or even aspects of a dimension, such as soil quality (Oberholzer *et al.* 2012) or animal welfare (Botreau *et al.* 2007b). Moreover, the aims of the developed approaches differ markedly. Schader *et al.* (2014) identify 35 approaches from the literature evaluating the environmental components of sustainability as a minimum, and categorise these on the basis of the following six criteria:

- Primary purpose
  (Eight different purposes are distinguished, e.g. information from consumers, farm advisory or monitoring services);
- Level of assessment
  (e.g. farm vs. agricultural sector, or product vs. value chain);
- Geographical scope
  (Application of the approach at global, national or regional level);
- Sector scope
  (All farms, or just farm activity or product);
- Thematic scope
  (Environmental, economic and social dimension); as well as
- Perspective on sustainability
  (Farm- or company-specific, social perspectives).

Of the 35 approaches to sustainability assessment studied, most serve to investigate research issues or provide policy advice. Only a few are geared to concrete application at farm level, and contain a sustainability assessment for all three dimensions (Schader *et al.* 2014). Of the total of seven assessment approaches that consider the farm, three focus on individual countries: the certificate of the German Agricultural Society (DLG Certificate for short) is awarded to farms in Germany and Austria (DLG 2015). The Sustainable Agriculture Criteria System (KSNL) (Breitschuh and Eckert 2008) is used in Germany, and the Farm Sustainability Indicators approach (IDEA method) (IDEA, Zahm *et al.* 2008) in France. Two systems – MOTIFS (Monitoring Tool for Integrated Farm Sustainability, Meul *et al.* 2008) and OCIS PG (Organic Conversion Information Service Public Goods, Lillywhite *et al.* 2012) – are aimed at use in Europe, whilst a further two systems, RISE (Response-Inducing Sustainability Evaluation, Grenz *et al.* 2009) and SMART (Sustainability Monitoring and Assessment Routine, Jawtusch *et al.* 2013), are designed for the sustainability assessment of farms worldwide (Schader *et al.* 2014, Schader *et al.* 2016). Global sustainability assessment tools such as RISE and SMART rely on publicly available databases, surveys or self-declaration to capture the necessary data (Zapf and Schultheiß 2013). The data for RISE and SMART are collected within the context of a farm visit by methodologically well-trained experts with wide professional experience. This means that expert observations are also included in the assessment.

The scope of the input data varies significantly between the various systems, with e.g. KSNL placing significantly higher demands on data availability than RISE. Marchand *et al.* (2014) compared the time spent collecting the necessary MOTIFS and OCIS PG input data (a few hours vs. more than two days, respectively). In order not to jeopardise the practical implementation of the sustainability evaluation on a large number of farms, the system developed in this study must take this issue into account.

2.2 Methodology

This chapter describes the methodology recently developed by the project to assess the sustainability of farms by means of six criteria as well as several principles. It also addresses the problem of different system boundaries underlying each of the indicators to be evaluated.
The approach chosen in this study can be classified on the basis of the six criteria formulated in Chapter 2.1 as follows:

- Primary purpose: The focus is on monitoring and information for consumers, but the farm advisory aspect may become more important if the tools are successfully implemented.
- Level of assessment: Farm
- Geographical scope: Switzerland: Adaptation to other countries possible, but not entirely straightforward owing e.g. to different accounting systems and different data-acquisition approaches
- Sector scope: The whole farm, including all farm activities but excluding household and sideline
- Thematic scope: All three dimensions of sustainability
- Perspective on sustainability: Mixed (the intention is both for the farm to contribute to the sustainable development of society, as well as for it to be on a sound financial footing and to produce in a resource-saving manner).

The approach chosen for this study is based on the following six principles:

(1) The various aspects of farm sustainability are evaluated with the help of measurable and communicable indicators.
(2) Where possible, quantitative indicators are to be preferred to qualitative ones; however, for certain aspects of sustainability such as subjective well-being, qualitative indicators are indispensable.
(3) None of the three dimensions of sustainability is to be given preference (i.e. they are all on a par).
(4) The data required for the calculation of the indicators must be based on data which is either already routinely collected at individual-farm level, or which can be acquired from the farm manager via questionnaire or web interface. Thus – except for verification of the results on selected farms – for reasons of cost and capacity, interviews and farm visits are to be refrained from. Also for reasons of cost and time – at least within the scope of the current project – there are no plans to extend the sample of those surveyed to third parties (in addition to the farm manager).
(5) The concepts and indicators are developed by recognised experts in the relevant field. For purposes of quality control, the manuscripts of at least two other experts in the field in each case were read and annotated.
(6) The life-cycle approach is implemented, to the extent permitted by limited resources and feasibility.

Principle (4) clearly differs from the selected survey methodology of both the RISE and SMART methods, which are based on an on-site interview conducted by an expert.
The sustainability assessment method developed in this study is based on **indicators**[1]. An indicator is a quantitative or qualitative measure that is derived from a series of collected data, and which illustrates the state of a particular aspect of sustainability in summary form. The OECD (1993) supplies a precise definition: "A parameter, or a value derived from parameters, which points to/provides information about/describes the state of a phenomenon/environment/ area, with a significance extending beyond that directly associated with a

[1] With the exception of the social dimension, where scant resources did not permit the development of any indicators.

parameter value". Indicators serve to summarise the large quantity of information on the various aspects of sustainability (Ciegis *et al.* 2015), with indicator systems helping e.g. policy decision-makers and industry organisations to gain a quick overview of the current situation and of various sustainability criteria trends. Indicators also enable the early identification of problem areas. Indicators cannot satisfy all expectations: they arise from a trade-off between technical feasibility (reasonable time required for the data collection) and completeness of the captured processes. Depending on the objective (highlighting the current state of affairs, monitoring, quality assurance, certification, training), different demands are placed on indicators in terms of professionalism, practicability and utility/acceptance. In this context, the connection between decision-making processes and indicators formulated in Sterman (2000) is especially important for practitioners, with decisions capable of influencing reality, and hence, in turn, of influencing the indicators, being made on the basis of indicators (so-called 'information feedback'). With the help of indicators, we can track how agriculture influences sustainability, and how new measures affect individual components of sustainability.
The following criteria were defined for this study: Indicators must…

- have been developed on a scientific basis;
- be capable of being measured (on a scale);
- be transparent (users' access to in-depth information on type of calculation);
- be practicable (in terms of data availability, calculation method and total time expenditure);
- be easily interpretable;
- be reproducible and clearly defined (no ambiguous interpretations);
- be capable of describing a state as aptly as possible;
- be sensitive (e.g. vis-à-vis change in the management method);
- highlight trends over time;
- be anchored in a superordinate concept;
- enjoy good acceptance (among farm managers, policy decision-makers and sector organisations);
- pursue a clear purpose, such as the provision of information for policy decision-makers (to enable them to make informed decisions) or the certification of farms;
- allow a definition of their importance (on the basis of an appropriate threshold or reference value).

In order to increase the utility for different users of indicator systems, it is important to invest the requisite time in the quality of results presentation. Well-prepared results with clear, easily interpretable statements are the key to good communicability and high target-group acceptance. Owing to the focus on the development of the indicators, however, the (graphic) presentation of the results is not dealt with in this study.

Working methodology: The working methodology of the participating project partners varied considerably, not least of all because of the major differences in the current state of knowledge on the development of suitable indicators. After the project launch, the partners were appointed and informed in detail by the project managers about both the work to be carried out and the general conditions. Most of the project team chose the literature analysis tool in order to acquire detailed information about the development of indicators, methods and models. In February 2015 all project employees were invited to a joint workshop with the aim of getting to know one another and introducing their own area of expertise. In addition, sufficient time was allowed for the clarification of questions of detail. The subsequent concrete work showed that various additional workshops were necessary in order to develop the desired scientific foundation, particularly in the preparation of the social dimension of sustainability, as well as in the analysis of models for calculating ecotoxicity. The project report as well as the minutes were produced by experts in the field, in order to meet the requirement for a well-constructed, scientifically sound concept. The project partners were tasked with structuring the final report in a table-of-contents format to allow the reader to locate the desired information more quickly. The provisional results were presented to senior project management at a full-day event in early May 2015, in order to identify and correct criticisms at an early stage. The presentation of the final results followed in September 2015; one week later, the results were critically examined by the scientific advisory group. The first draft of this report was delivered to senior project management in mid-November 2015. In conclusion, it should be mentioned that this ambitious project required an intensive exchange between the individual project partners and the project leader during the entire project phase.

System boundaries: The same system boundaries cannot be chosen for all three dimensions of sustainability. The environmental impacts (excluding biodiversity and soil quality) are determined on the basis of the life-cycle analysis (EC-JRC-IES 2011) using the SALCA ('Swiss Agricultural Life Cycle Assessment') life-cycle assessment method developed by Agroscope, which provides the necessary calculation tools at whole-farm level. Here, the system boundary encompasses agricultural production with all upstream stages up to the farm gate, i.e. excluding the downstream processes of transport, storage, processing and consumption. For the impacts of agricultural activity on biodiversity and soil quality, only the farm is considered.
The life-cycle analysis developed for the environmental dimension can also be applied to socioeconomic spheres, but would obviously violate the above-formulated Principle 4 (Data collection via farm manager only). Thus, for example, for a social life-cycle analysis, the social networks and relationships between the feed producers or tractor manufacturers would need to be included, and thus ascertained. The questions on the social dimension listed in Chapter 3.4, however, are not limited to the farm manager's family, but also include the employees' situation. Certain questions, such as those pertaining to social networks and product traceability, also take account of the so-called indirect external stakeholders (local community and consumers), i.e. the social impacts along the value chain are also included to a certain extent.
The assessment of economic sustainability deliberately only includes the "actual agricultural activities" (i.e. excluding para-agriculture in particular). Hence, the focus lies on the farm, and key economic figures can thus be calculated from the information available in a farm's accounts.

Boundaries: There are no clear lines of demarcation between the three dimensions of sustainability: environment, economy and social aspects interact with and influence one another. In positive cases, economic, social and environmental aspects support one another, but they can also compete with one another. Thus, a functioning social network is scarcely possible in a farm lacking economic viability. The intersection model illustrating the three dimensions of sustainability with three overlapping circles shows that certain criteria cannot always be unequivocally allocated to a single dimension. Hence, the income of employees can be allocated to either the economic or social pillar. In this study, the income situation of employees is assigned to the social dimension, since the situation of the entire household is the prime concern here, whilst the economic pillar focuses on the performance of the farm, evaluating on-farm activities only. With this approach, we follow the convention of the Agricultural Report of the FOAG, which is published annually.
In addition to the social sustainability categories such as employment situation and social integration (Chapters 3 and 4), this report also includes quality of the appearance of the landscape (Chapter 6) and animal welfare (Chapter 5) as part of the social dimension.
Different environmental impacts can have the same cause. Diesel consumption, for instance, depletes finite resources whilst contributing to greenhouse-gas emissions, thereby influencing both resource use and global-warming potential. It is important to point out that the SALCA method estimates the toxic effect of pesticides on earthworms and microorganisms as part of soil quality, whilst the input of heavy metals into the soil through the application of fertilisers and pesticides is allocated to terrestrial ecotoxicity. Human toxicity and ozone formation are not taken into consideration in the present report, since they both have a high correlation with the environmental impact 'global-warming potential'. The two aspects 'odour emissions' and 'noise' are also disregarded.

Part I: Social Dimension

3 Human Well-being

Jonas Isenring, Jacques Chavaz, Jean-Michel Couture, Christine Jurt, Andreas Roesch

3.1 Introduction

This chapter demonstrates how social sustainability can be ascertained on Swiss farms. The focus here lies on the human component of sustainability. Aspects of work/life balance are discussed not only in this part of the report, but in Chapter 4 (Workload) as well. Animal welfare (Chapter 5) and appearance of the landscape (Chapter 6), which are also part of social sustainability, are likewise addressed in their own chapters, although the latter in particular contains human components. By contrast, economic components are only considered a part of social sustainability when they affect the household and not the farm. The economic sustainability of the farm is addressed in Chapter 7.

The present chapter aims to highlight what is meant by sustainability in the context of Swiss agriculture, and how this sustainability can be ascertained. Starting with a description of the relevance of the social dimension for sustainability, the chapter then gives a detailed overview of which theoretical and practical concepts are conducive to achieving this aim. This overview also specifies what data are to be gathered, and what criteria are important in making the selection. In the next step, the proposed indicators for ascertaining social sustainability are described, then evaluated. Chapter 3 closes with a recommendation and conclusions.

3.2 Relevance of the Topic for Sustainability

Assuming a concept of ecological sustainability that focuses on the fair distribution of environmental resources, over the past few decades it has become generally accepted that the social and economic dimensions must also be included when considering sustainability.

Particularly important milestones in this development were the Brundtland Report (UN 1987) as well as the Rio Declaration and Agenda 21 arising from the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992. Although these sustainability concepts postulated the link between environmental, economic, social and institutional aspects of social development, the primary focus remained on the ecological dimension. The sustainability of the other two dimensions was mainly intended to serve the environment, since it was recognised that environmental protection without simultaneous consideration of these dimensions is not possible (Littig and Grießler 2004).

Developed by John Elkington (1999), the “triple bottom line” concept was the first to explicitly award equal status to these three dimensions, postulating that it is impossible to achieve sustainability in one of the three dimensions without achieving at least a minimum level of sustainability in the other two (McKenzie 2004). Frequently used nowadays, the three-pillar model of sustainability derives from Elkington’s concept, and assumes the equal status of environmental, social and economic sustainability postulated by him.

The equal status of the pillars is justified by the argument that the satisfaction of human needs may not only be reduced to an ecologically stable environment that is compatible with human health, but that there are also legitimate economic, social and cultural human needs whose fulfilment must be ensured in a sustainable society. Social and cultural conditions, services and values are therefore also viewed as resources which, according to the sustainability postulate, also require a fair inter- and intragenerational distribution (Littig and Grießler 2004).

3.3 Overview

This chapter aims on the one hand to present a conceptual derivation of social sustainability, and on the other to highlight which aspects are captured and ascertained by the indicators. For this, both theoretical and practical concepts are introduced and discussed in a first section. By reference to the findings of the first section, a second section shows what aspects are to be ascertained, and defines the criteria which indicators must fulfil in order to measure these aspects. A subsequent third section describes approaches to compiling the indicator set.

3.3.1 Conceptual Derivation

Before an indicator set is compiled for ascertaining social sustainability, we must define precisely what is meant by the term. To achieve this aim, the topic is conceptually processed. Based on a general theoretical conception of social sustainability, the focus is placed on concepts that allow us to ascertain social sustainability in a business context.

Social Sustainability

Taking as a basis the definition of sustainability in the Brundtland Report (UN 1987) – viz., sustainable development must meet the needs of the present without depriving future generations of the means to do the same – the needs and the resources required to meet them are at the heart of a consideration of social sustainability (Empacher and Wehling 1999). Within the scope of social sustainability, the 'basic need' concept and the concept of social capital lend themselves to the consideration of these two aspects.

The 'basic need' concept is closely linked with the name Maslow and the latter's needs pyramid. Maslow (1943) identifies five basic needs which he arranges hierarchically, i.e. higher-level needs develop when lower-level needs are satisfied. The basic needs and their hierarchy are as follows:

1. Physiological needs, which maintain the functioning of the organism;
2. Safety needs, such as the craving for safety and stability;
3. Social needs, which relate to the desire for community and emotional exchange;
4. Esteem needs, e.g. the striving for self-affirmation and self-confidence, as well as recognition;
5. The need for self-actualisation.

Although the 'basic needs' concept lost importance in the early 1970s, it was taken up again in the context of the development theory of the 1980s to define the minimum requirements for socially sustainable development. Even if no general definition of basic needs exists, there is a consensus on what basic needs are essential. These can be broken down into basic material needs (food, shelter, clothing, sufficient clean drinking water, sanitation facilities, health care, educational institutions) and the following basic non-material needs: (i) Satisfactory employment opportunities at a reasonable wage; (ii) Participation in individually relevant decisions at local level; (iii) Participation in political power; (iv) Political liberty; (v) Economic equality at the outset; and (vi) Safeguarding of fundamental human rights (Mutlak and Schwarze 2007).

Thanks to new emphases, further concepts have developed based on the 'basic need' concept. Particularly interesting are the concept of human development of the United Nations Development Programme (UNDP), and the capability concept of Amartya Sen (1999). Unlike the 'basic need' concept, these two concepts focus not on specific objects of need-satisfaction, but on the expansion of the trading potential of the actors to allow them to meet their own needs independently and to safeguard their livelihood in the long run (Empacher and Wehling 2002; Mutlak and Schwarze 2007). Sen (1999) defines 'capabilities' as "*the chances or comprehensive abilities of people to live a life that they have good reasons to choose, and that does not call into question the basics of self-esteem.*"

Of interest for a theory of social sustainability is the 'basic need' concept and its further development as an attempt to define minimum social and political criteria – and hence the aims of socially sustainable development – on an explicit ethical basis. Although primarily formulated from the perspective of fighting poverty in the third world, this concept is also of key importance for a global discussion of sustainability, i.e. one which includes the industrial and threshold countries. It is important to stress that from the viewpoint of sustainability, the aim is not solely to ensure "sheer survival", but to create the conditions for taking an active and productive part in social, economic and political processes. One difficulty with this concept, however, lies in the task of defining the needs of future generations without having the appropriate knowledge of the changes that will have taken place (Empacher and Wehling 2002).

A second concept that lends itself to the description of social sustainability is the concept of social capital. 'Social capital' is taken to mean the fund of social networks, trust, and cooperation-promoting values and norms of a society (Mutlak and Schwarze 2007).

This concept was taken up in the 1980s by two sociological trends in particular: by Coleman (1988, 1992) with his theory of rational action, and by Bourdieu (1983) with his class theory.

Coleman (1992) bases his explanation of social capital on the observation that people instrumentalise their social contacts in order to achieve certain goals, so that social ties develop as a private fortune. In contrast to human capital, which manifests through the skills and abilities of the individual, social capital refers to the relationship structure of two or more people (Empacher and Wehling 2002; Mutlak and Schwarze 2007).

Bourdieu's concept of social capital derives from his general theory of the reproduction of capital. He identifies three types of capital, economic, cultural and social, defining the latter as follows: "*Social capital is the totality of the current and potential resources associated with the possession of a permanent network of more or less institutionalised relationships of mutual acquaintance or recognition; or, expressed differently, it is about resources based on belonging to a group"* (Bourdieu 1983). According to Bourdieu, the amount of social capital depends on how far the network of relationships extends, and how much economic, cultural and social capital is possessed by those with whom an individual has a relationship. Seen from this perspective, social capital cannot be viewed as the only component of the social dimension, or independently from economic and cultural capital (Empacher and Wehling 2002; Mutlak and Schwarze 2007).

Unlike Coleman, Bourdieu does not assume that profits from belonging to a group are necessarily deliberately striven after, but rather that relationships and lasting commitments can also be formed by chance. A further important difference between the two concepts is that Bourdieu for the most part remains on the individual level – i.e. the microstructure – when considering the matter, and unlike Coleman does not also describe the origins and benefit of social capital on a meso- and macrostructure. For Coleman, in addition to individual social networks, superordinate, group-specific (mesostructural) or pan-societal (macrostructural) norms and values are also part of social capital, since these structures facilitate the common achievement of individual operational targets. Coleman (1988) also found that groups, communities, networks and organisations generate social capital in particular when they are close-knit communities and closed, as well as when they contain a high frequency of interaction and unifying norms. Consequently, Coleman assumed that the danger of a decrease in social capital lies in particular in the disappearance of close-knit communities viewed by stakeholders as manageable. From his point of view, the decrease in strong traditional family structures also represents a problem in this respect (Gefken 2012).

Putnam – another important representative of the social-capital concept – focuses even more strongly than Coleman on the effects of social capital on society as a whole. Putnam (1995) thus defines social capital as follows: *"Social capital refers to features of social organization such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit*". Putnam's approach shows that social networks interest him primarily as civic engagement networks. It is precisely in these networks, as, for example, in associations, that reciprocity norms, trust and solidarity of action flourish especially well (Gefken 2012).

As can be seen, the social capital concept is multidimensional, and can arise on an individual or group-specific level, or on the level of society as a whole, as well as bringing benefit on all of these levels.

Since the 1990s, the concept of social capital has been addressed in sustainability research. Expectations have been high: on the one hand, the hope has been aroused that the application of this concept will enable the social dimension of sustainability to be partially, if not fully described; on the other hand, the use of the term 'capital' suggests that social capital has analogies with other types of capital such as physical or natural capital, and can thus be measured as an asset base in the social dimension of sustainability. It turns out, however, that although the concept of social capital furnishes important starting points for a definition of social sustainability, which should on no account be ignored, it does not represent a suitable tool for theoretically capturing and measuring social sustainability. Thus, the criticism has been raised that the analogy with other types of capital cannot be drawn automatically, since – unlike physical or natural capital – social capital is not used up, but rather increases the more it is used. Another criticism is that the social capital concept only describes social resources, whilst resources not described here are also important for social sustainability. It is also demanded that social capital not be limited to its economic meaning, but be recognised as primarily representing a civil-society intervention resource of key importance e.g. for the regulation of a civil, violence- and conflict-free social coexistence (Empacher and Wehling 2002; Mutlak and Schwarze 2007).

From the above findings with respect to social sustainability as well as the Brundtland definition of sustainability, it follows that:

- There is no generally valid definition of social sustainability.
- The social needs of the current generation are to be met in such a way that there is no risk of future generations not being able to meet their own social needs.
- The 'basic need' concept only defines fundamental needs, and social sustainability cannot be achieved through the satisfaction of these needs alone. Instead, social sustainability means that individuals meet their needs, and can thus take an active and productive part in social, economic and political processes.
- Needs are not static, i.e. the needs of the current generation may, but need not be, the same as the needs of future generations.
- To satisfy needs, resources are essential.
- The social capital concept names individual as well as social resources that are important for the social dimension of sustainability.
- Social capital must not be limited to its economic meaning, but also has an important non-monetary meaning.
- The resources mentioned in the social capital concept are not sufficient for social sustainability; rather, resources from physical, natural and human capital must also be drawn on here.[2]

Well-being

Having shown how the concept of social sustainability has developed and identified the important points for explaining it, we must now find a way to actually ascertain social sustainability. The ideal approach here is to use the well-being concept, which is viewed as an integral component of social sustainability. Thus, Ross (2013) defines social sustainability as "[…] an ideal state of well-being which might be expected to occur when social, economic, and environmental interactions foster intergenerational equality and longitudinal equilibrium. That is, social sustainability refers to equality, well-being, and balance across quality of life indicators between sociocultural groups over time and from one generation to the next." Likewise, Magis and Shinn (2009) identify individual well-being – in combination with social equality, a democratic government and a functioning civil society – as a fundamental requirement of social sustainability.

On the one hand, this serves to show the importance of well-being for social sustainability; on the other, however, it also highlights the fact that social sustainability cannot be equated with well-being, but contains additional components. This project's focus on the well-being concept can be justified by the fact that we are dealing here primarily with an individual component, whilst the other components relate more to society as a whole. True, the other components are also shaped by the action of individuals, but generally to a much smaller extent than is the case where one's own well-being, as well as that of people with whom one has a close personal or professional relationship, is concerned.

In addition, a functioning democracy and civil society constitute a component of the OECD Well-being Framework used in this project (see following chapter), which means that this component is also taken into account. Moreover, social equality – though not explicitly mentioned – can be viewed, at least in some instances, as a requirement for social sustainability, thanks to the inclusion of the capitals in the OECD Well-being Framework.

Well-being research has become well established over the past few decades, but as with social sustainability, we are still missing a general definition of the concept. A great diversity of definitions and descriptions of this concept therefore exist, not least of all owing to its inherent complexity. In addition, the well-being concept is dealt with by different academic disciplines and schools of thought, and is consequently viewed from a variety of perspectives. This complexity on the one hand and the various perspectives on the other frequently lead to the term being defined either in a very broad (and hence unclear) or too narrow a manner, disregarding important aspects of the concept. Hence, well-being is sometimes employed as a synonym for happiness,

[2] Depending on definition, cultural capital and knowledge should also be mentioned here. Bourdieu names these explicitly, whilst the other definitions include them as part of the (other) named capitals.

quality of life or life satisfaction, which according to current wider definitions are not synonymous with well-being, but merely constitute subaspects of it (Forgeard *et al.* 2011; Dodge *et al.* 2012; La Placa *et al.* 2013).
Despite this occasional focus on subaspects of the concept, the realisation that the well-being concept is a versatile and multidimensional construct has increasingly caught on. The view that it encompasses emotional, social and functional components is widespread. What remains unclear, however, is what components are to be included in a valid theory of well-being, and in its measurement. This leads us to conclude that a comprehensive evaluation of well-being must take into account both objective and subjective components – neither of which are, however, defined in a uniform way (Forgeard *et al.* 2011; Dodge *et al.* 2012; La Placa *et al.* 2013).
Definitions of objective components often rest on needs-oriented concepts and theories, like the capability concept of Sen (1999), the 'primary goods' approach of Rawls (1999), or definitions of basic needs as with e.g. Doyal and Gough (1991). However, such combinations do not lead to a formal theory of well-being, but merely offer a selection of qualities and characteristics that contribute to well-being. Although they vary, these combinations generally encompass concepts such as economic resources, political liberty, good health and good education (Forgeard *et al.* 2011).
In current research there is a consensus that well-being cannot be adequately illustrated with objective indicators alone. The main reason given for this is that objective indicators do not take account of the fact that needs are individual in nature, and hence cannot be specified in absolute terms. This weakness of objective indicators can be offset by supplementing them with subjective components (Forgeard *et al.* 2011).
As with the objective components, there are various approaches to defining the subjective components of well-being. General happiness, positive emotions, engagement, meaning and purpose of life, life satisfaction, relationships and social support, and accomplishment and competence are often mentioned (Forgeard *et al.* 2011).

OECD Well-being Framework

A topical and broad definition of well-being is furnished by the Well-being Framework of the OECD (2011a), which is based on recommendations of the Commission for the Measurement of Economic Performance and Social Progress (Stiglitz-Sen-Fitoussi Commission).
Based on a set of macro-indicators (e.g. employment rate, household expenditure, etc.), this concept was developed to measure the well-being of the population at national and regional level. Although the concept was not developed for the micro-level and its indicators can therefore only be directly applied on this level to a limited extent, it provides a sound definition of well-being, and hence a good basis for developing indicators for measuring well-being at the individual level. Particularly bearing in mind the connection between social sustainability and well-being, this concept is the ideal approach for the following reasons:

- The definition is based on the 'capability' concept, and picks up on an important concept of social sustainability research.
- Both material and non-material conditions are included.
- Objective and subjective components are combined, which is in line with current research.
- Not only the well-being of the current generation is considered, but the sustainability of well-being for future generations is also taken into account.
- Aspects of social, economic and environmental sustainability dimensions are incorporated, and it is stressed that their interactions are important for people's living conditions.
- Natural, physical and human capital are included in addition to social capital, in line with the precept that merely considering social capital is inadequate for measuring social sustainability.

Based on the capability concept, the OECD identified eleven dimensions for this framework which would enable people to shape their lives according to their own goals and values. As can be seen in Figure 1, these 11 dimensions are subdivided into material conditions and quality of life. These are supplemented with the types of capital that are necessary for ensuring well-being in terms of sustainability for future generations as well.

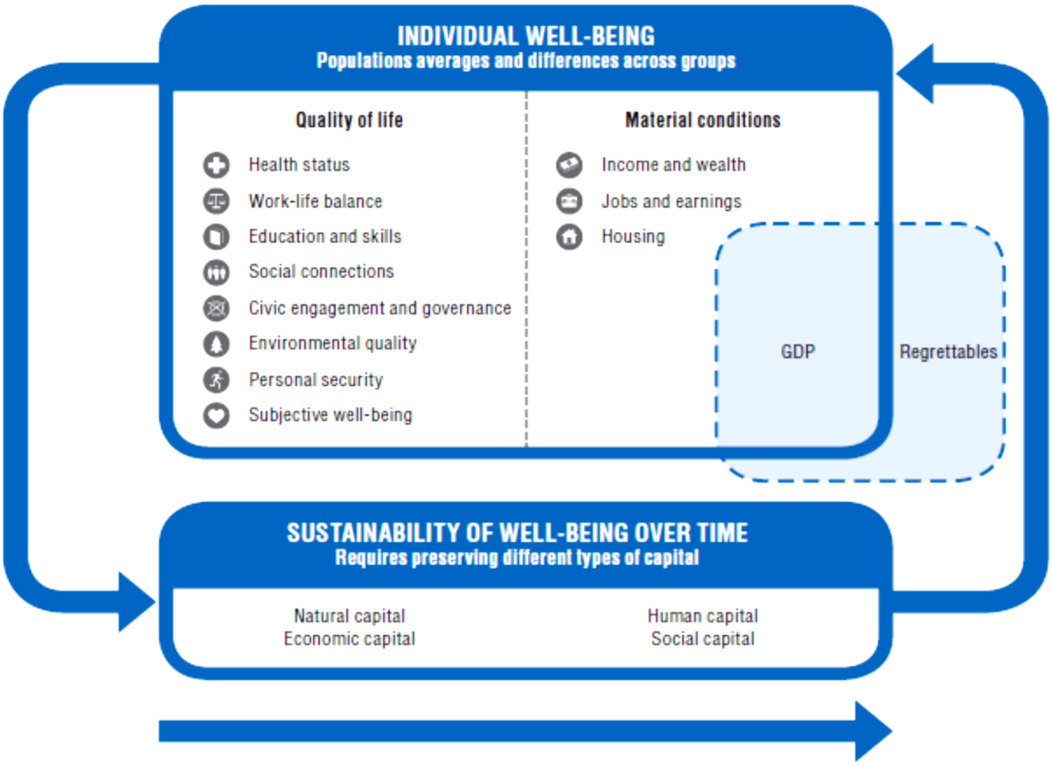

Figure 1: OECD Well-being Conceptual Framework (2011a).

'Income and wealth', 'jobs and earnings' and 'living conditions' number among the material conditions in this conceptual framework.

'Income and wealth' is used to ascertain current and future consumption opportunities. Available consumption opportunities not only allow basic needs to be covered, but enable further goals to be met. Economic resources increase individual freedom of choice, allowing people to shape their lives according to their own ideas and desires. Moreover, sufficient assets offset economic risks, providing a cushion against unexpected changes in income. The preservation of assets is one of the determining factors for safeguarding material living conditions over longer periods of time.

With 'Jobs and earnings', both availability and quality are key factors. Not only are jobs and earnings important for maintaining control of resources, but they also enable people to develop skills, to feel they are making a useful contribution to society, and to build self-confidence. In addition, work can contribute to a sense of personal identity and help to create social connections. By contrast, unemployment often has a negative effect on health (Wilson and Walker 1993) and on subjective well-being (Clark and Oswald 1994). The consequences of unemployment are therefore not limited to the associated loss of income.

People generally spend a significant proportion of their time at work, which is why working conditions are likely to affect people as strongly as the mere availability of work. There are various approaches to defining and measuring job quality, such as that used by the International Labour Organization (ILO) (2003) or the United Nations Economic Commission for Europe (UNECE) together with Eurostat (UNECE 2010). These approaches identify safety at work, a good workplace ethic, social security, a social dialogue at the company, social connections at the workplace and work motivation as important points for high job quality.

Living conditions are identified as a further component of the material standard of living. Good living conditions are essential for meeting basic needs, such as protection from extreme weather and climatic conditions as well as other risks. What's more, good living conditions convey a feeling of general security and personal privacy. Poor living conditions such as inadequate sanitation facilities or overcrowding are a major cause of poor physical and mental health (OECD 2008b, 2009, 2011b), and can contribute to domestic violence, as well as to unsatisfactory academic achievement in children (OECD 2009). Poor living conditions can also adversely affect participation in social life (entertaining guests, etc.), thereby leading to lower social capital (Glaeser and Sacerdote 2000).

The OECD assigns the non-material well-being components of health status, work/life balance, education and skills, social connections, civic engagement and governance, environmental quality, personal security, and subjective well-being to the category of 'quality of life'.
'Health status' is one of the most important life components, influencing not only the length of our lives, but whether they can be lived as free as possible from illnesses, disease and disabilities. Of course, health status also influences our opportunities for continuing our education, taking part in the labour market, or cultivating social connections. The WHO (1948) defines health as "*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity"*. This definition shows that the concept of health is understood in a broad sense, and that health has a bearing on many aspects of our lives. It also highlights the fact that both objective and subjective aspects of health are important.
Health status is influenced by numerous factors. Genetics, addiction habits, and overweight play a role, for example, but so do living and working conditions, income, and whether or not the individual can afford health care and preventive treatment. Health status is therefore a consequence of the interaction of social, socioeconomic, environmental and biological factors, as well as lifestyle. Many of these factors are influenced by health care and other preventive strategies. These lifestyle and preventive factors are critical in determining whether an individual becomes ill or remains healthy.
'Work-life balance' describes the balance between a person's working and private life. Achieving such a balance is crucial for human well-being. Too little work can lead to too little being earned to maintain a desired standard of living, as well as to the meaningfulness of life being called into question. Too much work can have a negative effect on well-being, causing e.g. one's health or personal life to suffer. The ability of a person to arrange their working life in a balanced manner is not only important for their own well-being, but also for that of every other member of the household. The well-being of children is particularly strongly dependent on the work/life balance of the parents, which among other things affects the time both spend together. Likewise, the well-being of older parents in need of care can be adversely affected by a poor work/life balance of the employed family members. On a social level, it is also important for members of society to have enough leisure time to cultivate their social connections and participate in social life.
'Education and skills' are not just considered to be crucial for the prosperity of nations, but are also seen as key for a better life for individuals. Resulting from one the most basic human aspirations – namely, the desire to constantly learn new things – skills development is vitally important for people. Many skills are essential for leading a good and autonomous life. Moreover, activities which give people pleasure, such as reading a book or visiting an exhibition, often go hand-in-hand with education.
Education also leads indirectly to greater well-being. Because higher education generally leads to greater opportunities on the labour market as well as higher earnings (OECD 2010), education has a strong positive effect on material living conditions. Moreover, educated people frequently have better health status, since they often cultivate a healthier lifestyle and have greater chances of securing a job in a lower-risk environment (La Fortune and de Looper 2009; Miyamoto and Chevalier 2010). Education also increases civic awareness, promotes political participation (Borgonovi and Miyamoto 2010) and provides people with skills enabling better integration in society.
The quality and quantity of an individual's social connections are considered to be important determinants of well-being in two respects: not only does spending time and sharing experiences with others give one pleasure (Kahneman and Krueger 2006), but social connections also represent important resources in the form of social networks. These networks can be called upon when a person is need of support. In addition, they can open up job opportunities as well as other spheres to which access would otherwise be difficult, if not impossible. Well developed social connections create trust, standards, and collective action, and encourage good information exchange. Social connections are a fundamental component of social capital, and usually have positive effects not only on the well-being of the individual, but on the functioning of society as a whole.
'Civic engagement and governance' refers on the one hand to the activities of the population when participating in political processes, and on the other to the manner in which the political institutions function. Civic engagement and good governance contribute to the well-being of people who are able to participate constructively in political processes, thereby exerting political influence on the shaping of the environment in which they live. Good and effective public governance also creates trust in politics and the administration,

whilst civic engagement encourages a feeling of belonging to the community and social integration as well as trust, all of which likewise contributes to well-being.

The well-being of people is strongly correlated with the environmental quality of their habitat. A healthy physical environment affects the quality of life of residents in health terms, with environmental pollution caused by contaminants and noise considered to be an important determinant (Prüss-Üstün and Corvalán 2006). In addition, a healthy physical environment is also important for the well-being of residents, given that a sense of well-being can more easily develop in an aesthetically pleasing and intact habitat. Moreover, a habitat with green spaces, woods, healthy waters and clean air offers plenty of opportunities for leisure and recreational activities, which are also essential components of well-being. Because it can also exert a positive effect on income and wealth, good environmental quality leads directly to greater well-being. Not only are the influences of environmental quality on well-being manifold – the concept of environmental quality is also broadly defined, encompassing both objective components such as pollutant concentrations and emissions as well as subjective components such as perception and assessment of beauty and intactness.

The concept of personal security should also be broadly defined, encompassing *inter alia* the dangers of war, political and ethnic conflicts, terrorism, environmental and natural dangers, and industrial or farm accidents. The OECD concept focuses on criminality, which is one of the greatest dangers for personal security. Moreover, criminality itself is multidimensional, including *inter alia* physical attacks, theft, burglaries and assaults, as well as fraud or corruption. Criminality can have both physical and mental short- or long-term consequences for the victim. What's more, criminality also has an indirect impact on people's well-being, since the mere worry and anxiety about potential criminality can make daily activities difficult, or prevent them altogether, as well as putting psychological stress on residents. Consequently, not only living in objectively safe surroundings, but also subjectively experiencing these surrounding as safe, is important for human well-being.

Subjective well-being reflects the belief that how people perceive circumstances and the effects exerted by them is of the utmost importance. The three components life satisfaction, positive affects and negative affects are taken into consideration in the assessment of subjective well-being. Life satisfaction is captured by means of a reflective assessment of general living conditions. This represents a useful addition to assessment by means of objective criteria, since it allows us to illustrate a total picture of well-being based on individual preferences rather than on generally defined well-being components. Positive and negative affects measure emotions at a specific point in time. Positive affects include, among others, happiness, joy, enthusiasm and love, whilst anger, pain and sadness are considered negative affects. Unlike life satisfaction, which focuses on the general feeling, positive and negative affects provide information on the impacts of specific daily activities, such as commuting or getting together with friends.

The above-described dimensions of well-being were identified by the OECD for the current generation, and from a present-day perspective. They cannot automatically be applied to future generations, however, since it is unknown how these generations will define their own well-being. In order to consider the sustainability of well-being, it is therefore not sufficient to ensure the eleven dimensions in the long-term: rather, the factors underlying the dimensions of well-being must be examined.

Here, the obvious solution is the capital approach. This approach focuses on the resources, which are assigned a value for well-being. Also referred to as 'capital', the resources link the present with the future by remaining available in both the present and future, depending on use. The choice and behaviour of a generation thus influence the opportunities of the next generation.

When applying the capital approach to determine the sustainability of well-being, it is important to identify the underlying factors influencing well-being, and to observe the changes in these factors.

The OECD Well-being Framework distinguishes between economic, natural, human and social capital, which together contribute to sustainable well-being.

Economic capital can be subdivided into produced capital and financial capital. Tangible assets such as buildings, machines, roads, semi-finished and finished goods, as well as non-material goods such as software or art fall into the first category, whilst cash, bank balances, stocks and shares, retirement assets and policyholder funds fall into the second.

Natural capital consists of a wide range of naturally occurring goods that may or may not be tradeable. Within the context of sustainability, natural capital may be further subdivided into the categories of environmental goods and ecosystems. Whereas the former comprise the individual components of the environment, the latter designate the interactions and common functioning of the individual components. To determine the sustainability of natural capital within the context of well-being, not only must stocks of environmental goods as well as changes in these stocks be investigated, but the ability of the ecosystem to provide services for the economy and other important components of human well-being must also be studied.

The OECD (2001) takes human capital to mean the knowledge, skills, competencies and qualities of individuals supporting personal, social and economic well-being. These components are varied, and also include motivation and behaviour, as well as the physical, emotional and mental health of individuals (OECD 2001). Although the human capital of institutions and science is predominantly defined in terms of its relevance for economic productivity, it is important to recognise that both education and health are important inherent values. What's more, they make a major contribution to other, non-economic well-being dimensions (OECD 2011c). Investment in human capital can take different forms, i.e. through upbringing, formal education, informal training, health behaviour or healthcare provision. Unlike economic and natural capital, human capital does not generally get used up more quickly the more often it is used, but rather tends to be reinforced through use. Since human capital resides in the individual, it disappears as soon as the individual dies. Nevertheless, knowledge, skills and other components of human capital can be passed on to other individuals, and especially to the next generation. The preservation of human capital depends on a range of factors such as investment in education, training or health, but also on migration and demographic change. The family and the social capital of individuals both play a vital role in the transfer of human capital to succeeding generations.

As the 'Social Sustainability' chapter demonstrates, social capital consists of different components. In this respect, the OECD (2013) distinguishes between personal relationships, support from the social network, civic engagement, and trust and cooperative norms. The first two of these components are closely linked with one another. On the one hand, they refer to the networks of friends, relatives, etc. as well as to the social behaviour that these networks create and maintain; on the other, they highlight the direct effects of these networks, such as the emotional, material, practical, financial, intellectual or professional support that can be called upon when needed. The third component comprises the activities by means of which people contribute to community life, examples of which are volunteer work, political participation, membership in organisations, and various forms of joint initiatives. The fourth component refers to common values, norms and expectations that are essential as a pillar of social functioning and that facilitate mutual advantageous cooperation. As with human capital, social capital tends to increase rather than diminish with use. Unlike human capital, however, social capital does not reside *in* individuals, but between them. This makes it difficult to identify (sub-) components of social capital that can be transferred inter- and intragenerationally to other individuals. Whilst all four of the mentioned components are important for the well-being of the current generation, the OECD (2013) considers trust and cooperative norms to be the most important aspects for the sustainability of well-being: in the first place, they accumulate gradually and remain similar over fairly long periods of time, thereby lending themselves to transfer over generations; and secondly, they are vital for the functioning of the social system as well as for establishing cooperative ventures, both of which are crucial for economic performance and other key elements of social progress.

A common feature of all four types of capital is that their creation generally takes a fairly long time, whilst their loss can occur very quickly. For this reason in particular, it is important to handle these resources carefully and in a sustainable manner.

Social Impact

Now that we have shown what social sustainability is taken to mean and how the OECD Well-being Framework can be used to define and determine it, it is time to place individual well-being in a business context. For this, the concept of 'social impact' will come in handy. This term also has a variety of definitions[3], distinguished *inter alia* according to the cause of the impact. In a business context, social impact can be described in general terms as the amount of all positive and negative, long- and short-term, intentional and non-intentional effects on human well-being caused by specific business activities (Clark and Oswald 1994; WBCSD 2013).

[3] See Mass and Liket (2010) for an overview of the existing definitions.

Such effects can be based on various business activities that we can subdivide into the following three groups: business behaviour (the manner in which a company operates, and how this manifests itself *inter alia* in the working conditions of its employees or the living conditions of the local residents); product features (characteristics of products or services such as quality, safety or nutritional value which lead *inter alia* to impacts on the customers); and business activities (e.g. the economic contribution of the company to society, *inter alia* in the form of employment, investment or taxes).
A central component of the social impact concept is the results chain (also called, among others, *logical framework*, *log frame* or *causal chain*). This consists of the five successive levels of input, activity, output, outcome and impact (see Figure 2).

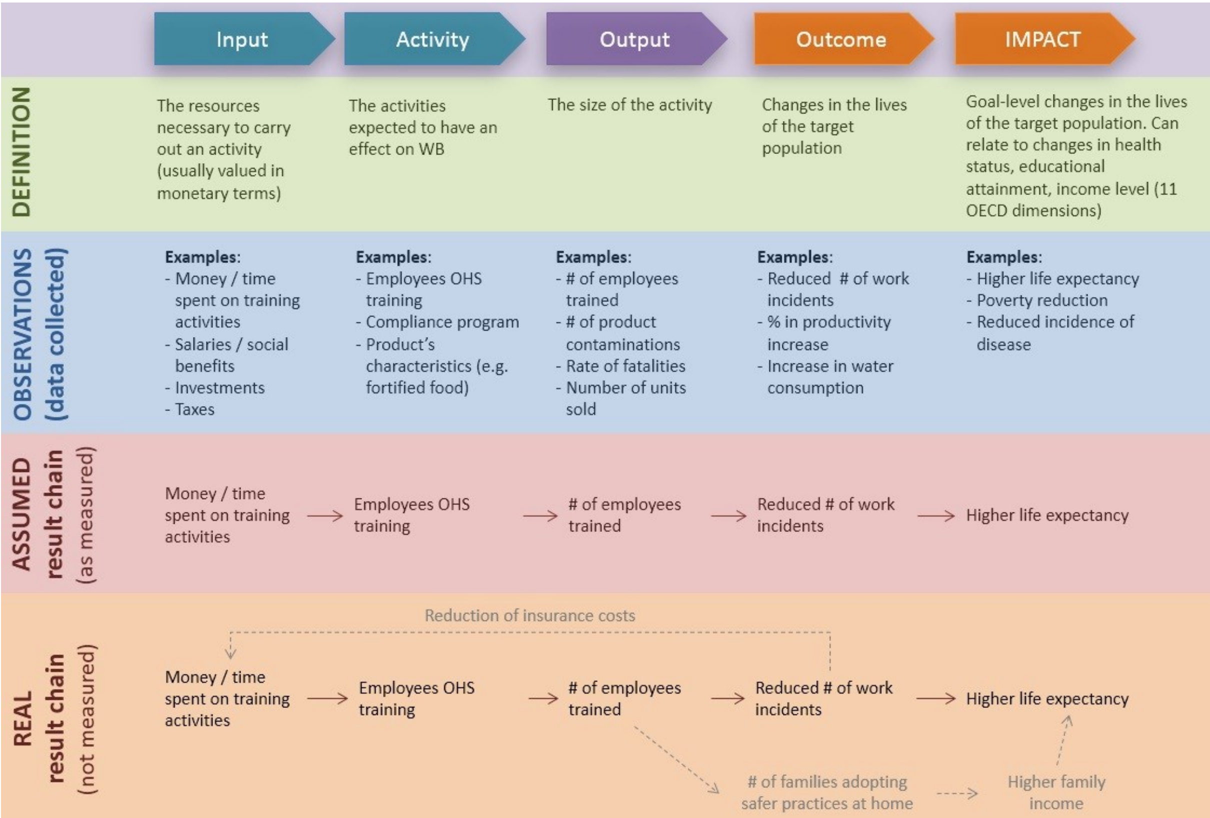

Figure 2: Example of a results chain (Agéco 2015).

The results chain is based on the assumption that an input – e.g. in the form of money and time – is provided at the beginning of the chain, allowing a specific activity which in turn elicits a quantifiable output. This output leads to changes in the target persons in the form of outcomes and impacts. The distinction between outcomes and impacts is usually not clear-cut, although impacts are generally viewed as longer-term and more-broadly defined goals arising from the more-narrowly defined, short-term outcomes. (WBCSD 2013).
The simultaneous strength and weakness of the results chain is that it links the different levels whilst simultaneously viewing them as independent from one another. The strength is that the dependencies highlighted by the results chain are for the most part there. The weakness is that a causality is suggested that often exists only in part, or which can seldom be proven.
As shown in Figure 2 results chains work with hypothetical and therefore unreal causalities. External effects are disregarded, as are positive and negative feedback within the results chain. Results chains are therefore not meant to suggest real causalities, but to show that there are connections between the different levels, and that social sustainability can be measured on different levels of the results chain.
The choice of measuring level depends on the aim of the evaluation and the available data. Whereas indicators on the ‘activity’ level show what concrete activities a company carries out, those on the outcome/impact level measure the effects of these activities on the well-being of stakeholders. The former implicitly assume the existence of a linear path between good business practices (e.g. safety training) and their positive contribution to the well-being of individuals (e.g. health status). The latter document the well-being of individuals (e.g.

through complaints triggered by accidents at work) without being able to unequivocally trace this well-being to an activity (e.g. the extent to which better safety training leads to fewer complaints triggered by accidents at work). Both of these perspectives are complementary, since they contemplate the business activities from two different angles.

Many linked variables must be taken into account in order to assess social impact. Thus, not only must well-being be defined, but which activities can affect this well-being, and how, must also be identified. That is why there is no 'right' set of indicators for describing specific impacts, but rather a variety of possible advice, symptoms or suggestions allowing us to observe, measure or recognise impacts with varying degrees of accuracy (Mayoux 2002). The choice or development of a relevant set of indicators therefore always depends on what is to be evaluated and how.

3.3.2 Defining What Is to Be Measured

What is to be measured is defined by the aim of the evaluation (Mayoux 2002). In this project, the primary aim is to assess the social impacts of agricultural activities, in order to maximise their positive and minimise their negative effects on stakeholders.

As shown in the previous chapters, the OECD Well-being Framework with its eleven dimensions offers a practicable definition of what it sets out to measure, viz., the social impacts of business activities. Because these dimensions cannot be adopted directly within the scope of the present project, however, several adjustments and restrictions are necessary.

Thus, the dimensions of income and wealth as well as jobs and earnings cannot be clearly demarcated, although the former dimension focuses more strongly on the immediate financial conditions, whilst the latter devotes more attention to the consequences of met and unmet material conditions, as well as to the circumstances in which the material conditions are produced. Because of the overlaps and unclear demarcation, these two dimensions are summarised under the single dimension of 'financial matters and working conditions', without ignoring the various perspectives on this topic.

The OECD (2011a) primarily interprets the 'personal security' dimension to mean actual and perceived criminality, whose existence can, of course, also adversely affect people's well-being in the context of Swiss agriculture, but which does not represent a direct impact of business activities. In the context of this project, personal safety at work is of far greater importance, which is why the focus is placed on this. Since this type of safety is closely associated with the dimension of health, the corresponding impacts are allocated to the 'health' dimension, and the 'personal security' dimension is omitted.

By contrast, the dimension of civic engagement and governance expands its focus somewhat. Whereas the OECD (2011a) adopts an exclusively political perspective, we expand this dimension through the addition of a business perspective.

Since it is discussed in other subprojects (Chapters 8–13), the 'environmental quality' dimension is not dealt with in this part of the report, which only looks at economic aspects of the entire household. The economic situation of the actual farm is set out in Chapter 7.

In addition, we must specify the stakeholders for which the various well-being dimensions are to be measured. As a rule, stakeholders can be defined as "*those groups and individuals that can affect, or are affected by, the accomplishment of organizational purpose*" (Freeman 2010), or – to put it differently – stakeholders are all individuals whose well-being can be influenced by business activities. What stakeholder groups must be included in the 'social impact' concept is dependent in each case on the context in which the company or sector operates (location, size, activities, etc.). The existing classifications generally encompass both internal (e.g. labour, managers, partners) and external stakeholders (local community, consumers, business partners, etc.).

The stakeholder mapping shown in Figure 3 was developed for the identification and grouping of stakeholders.

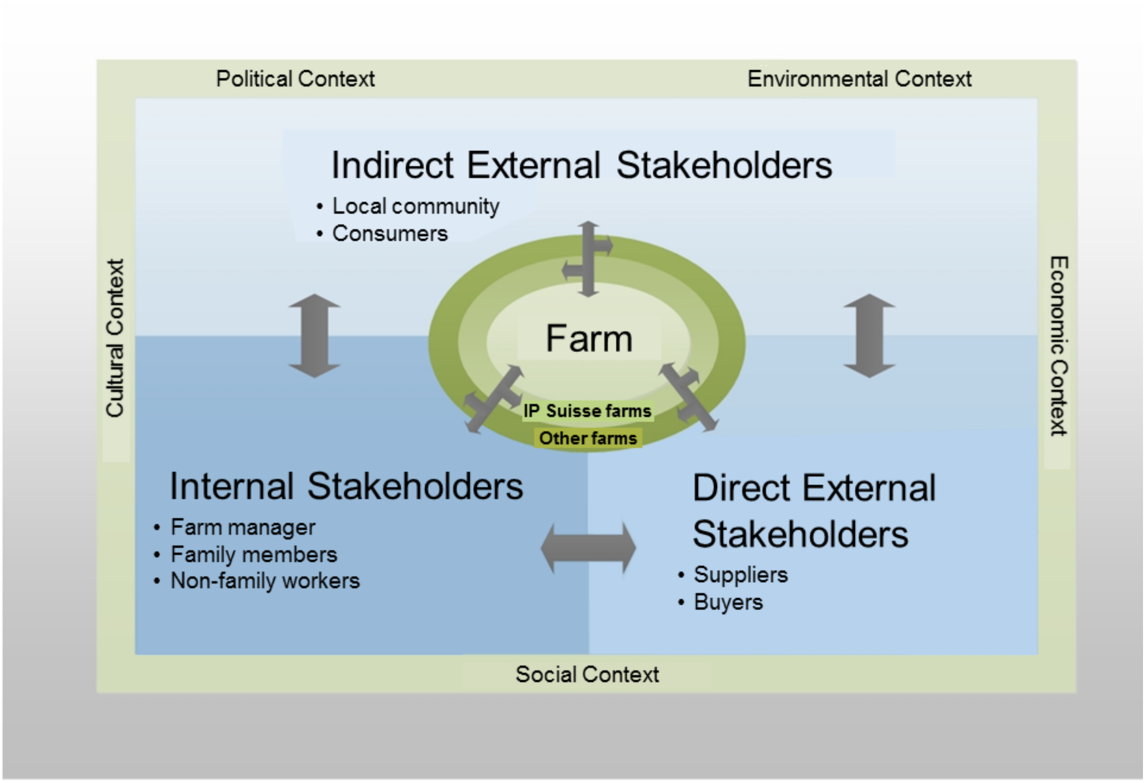

Figure 3: Stakeholder mapping. Source: Own presentation.

Starting from the farm in the center of the stakeholder mapping, three stakeholder categories were identified. A first category comprises the internal stakeholders, who live and/or work on the farm. These include the farm manager, his or her family members, and non-family employees. The second category comprises the direct external stakeholders. These maintain a direct business relationship with the farm, without living or working on it, and include the farm's suppliers and customers. The third category are the indirect external stakeholders, who are affected by the farm's activities, but neither live nor work on it. These include the local community, as well as the consumers of the farm's produce and products. The definition of this category is not clear-cut, however, since consumers can also maintain a direct business relationship with the farm (e.g. via direct marketing), and the geographical boundaries of the local community are not entirely straightforward. Likewise, other farms or farmers could number among the direct or indirect external stakeholders, depending on whether business relationships exist with them or not.

Stakeholders do not exist in a vacuum, but act and interact within a specific political, environmental, economic, social and cultural context which on the one hand influences them and which they in turn can influence and shape.

Ideally, a social sustainability assessment takes account of all stakeholders, together with the context in which they act and interact, but this requires a complex evaluation. A crucial condition regarding the inclusion of stakeholders in the survey is directly derived from the restriction – specified in the project – that only the farm manager is to be included in the data survey. Consequently, external stakeholders can only be included in the survey indirectly. For this reason, the selected indicators focus primarily on the internal stakeholders, whilst covering only some of the external stakeholders. The eventual expansion of the evaluation to directly include external stakeholders should, however, be the aim here.

As has been pointed out with regard to the social impact concept, measurements are carried out on different levels of the results chain. Whereas the OECD's Well-being Framework focuses on the outcome/impact level, the sustainability assessment tools analysed in this project (see Chapter 3.3.4) concentrate primarily on the 'activities' and 'output' levels. Since we are dealing here with complementary perspectives, the choice of a measuring level is not essential. Consequently, complementary indicators can be measured on different levels.

An important component of the OECD Well-being Framework is its combination of objective and subjective perspectives on the well-being of individuals. This manifests itself in the ‘subjective well-being’ dimension, as well as in further subjective criteria complementing the objective parameters of the remaining well-being dimensions. The inclusion of subjective criteria is also of vital importance in the business context, since it discloses how the stakeholders perceive and assess the different business activities. For this reason, both objective and subjective indicators are proposed for this project. Subjective indicators can only be collected directly from the stakeholder concerned in each case, however. With the given restrictions, this is only possible for the farm manager.

3.3.3 Measurement Approach

Now that we have shown what is to be measured and have thus specified the framework of the indicator set to be developed, this chapter describes how the measuring is to be carried out. Whilst the last chapter focused on the conceptual variables, this chapter pays particular attention to practical considerations and any constraints on operationalisability. This is important, since a relevant indicator must be both conceptually sound as well as practical. Both of these conditions can be formally expressed by selection criteria that an indicator must possess in order to be considered ‘relevant’ in a specific measuring context.
The criteria listed in Table 2 were drawn up for this project on the basis of the foregoing statements, talks with Migros, and Mayoux and Meul *et al.* (2008).

Table 2: Indicator criteria. Source: AGECO and jch-consult, based on Meul et al. (2008) and Mayoux (2002).

Criterion	Definition
Impact-oriented	There should be a clear and obvious connection between what the indicator measures and the dimensions of well-being.
Measurable and clear-cut	Indicators should: Be precisely defined, so that their measurement variables and interpretations are clear-cut; Be independent, so that they do not correlate too strongly with one another; Provide factual data that are independent of how the data are collected; Be comparable between farms, so that performances can be compared and aggregated; Permit a performance evaluation by setting performance reference points enabling a comparison of the farm’s activities.
Quantitative	Indicators should measure information and provide quantitative results.
Achievable and sensitive	Indicators should be achievable by the farm, and should therefore react sensitively to changes on the farm.
Operationalisable	Indicators should be relevant for the Swiss agricultural context, and be easy to document on the farm.
Time-bound	Indicators should capture activities/outcomes that are time-bound.

The criterion of impact-orientedness arises from the previous discussion regarding the results chain perspective and the OECD Well-being Framework. In order to meet the aim of the evaluation, indicators must be selected that can be assigned to one of the eleven OECD well-being dimensions. According to the results chain perspective, these indicators can be on any level of the results chain. This criterion is crucial for ensuring that the focus is placed on data that are meaningful in the context of social sustainability.
Indicators must also furnish clear and unambiguous results. To avoid double counting, indicators should be as independent of each another as possible.[4] Since an outcome is generally the consequence of several activities,

[4] There are, of course, both objective and subjective indicators that measure the same components of well-being and which are independent of each another, since they consider these components from different perspectives.

it is necessary to verify that the measured outcomes or activities do not correlate significantly with one another, or form part of the same results chain. Thus, for example, social networks and earned income may be viewed as two relatively independent outcomes, whilst earned income and household assets are too dependent on one another. Regardless of whether indicators are based on objective or subjective criteria, they should be defined so as to allow a factual assessment: in other words, the surveys must be reproducible. Only in this way can we ensure that the results allow comparisons over time and between farms. Consequently, indicators must furnish results that can be directly or indirectly interpreted as a sum. This criterion is particularly important for working with performance reference points. These performance reference points can be recognised social standards, norms, practices or benchmarks serving as limits for assessing the performance of a farm relative to a comparison group. The use of explicit performance reference points is essential for assessing a performance, and hence for taking the step from pure reporting to an evaluation.

A further criterion for selecting the indicators is the condition that indicators must provide quantitative results, or results that are as quantitative as possible. This criterion is too restrictive, since most social phenomena are qualitative in nature. This dilemma can be solved in two ways: firstly, by establishing the measurements at the beginning of the results chain, since activities and outputs are generally quantitative in nature (e.g. yes/no, a certain percentage or absolute numbers); secondly, by transforming measurements at the end of the results chain on the outcome/impact level – which are generally qualitative – into semiquantitative results, by means of rating scales.

With regard to operationalisability, it is important for the indicators to be sensitive and achievable. This means that all indicators collected on the farm should respond sensitively to changes in business activities, and the optimum target size of every farm should be theoretically achievable. In terms of operationalisability, it is also important for the indicators to be relevant in the context of the Swiss farming sector, and for their documentation at farm level to be a straightforward matter. This last criterion is also crucial inasmuch as the indicators are useless if the required data are not available, or cannot be collected under the given conditions.

The final criterion to be noted is that indicators must be time-bound. This means that for every indicator, we must define the point or period in time of its intended validity.

3.3.4 Procedure for Developing an Indicator Set

The first step in developing an indicator set for assessing social sustainability in the Swiss agricultural sector was to collate and analyse existing sustainability assessment tools and their indicators. As the analysis showed (see following chapter), although these tools furnished a good basis for an indicator set, the search for suitable indicators would clearly have to be expanded in a further step, or else we would have to develop our own indicators.

Analysis of Existing Sustainability Assessment Tools

Over the past few years, an increasing number of general and specifically agricultural sustainability assessment tools have been developed. Whilst these tools often have the selfsame social components of sustainability (working conditions, connections to the local community, etc.), they differ greatly in terms of their indicator sets. Consequently, there were a large number of indicators at our disposal whose suitability for use in this project needed to be tested with the help of the criteria formulated above.

In order to analyse the indicators belonging to different available methods, various sources were examined by AGÉCO and jch-consult. In the first instance, four current reviews were consulted (cf. Godard 2008; Terrier *et al.* 2010; Le Houérou 2012; Zahm 2013), and an internet search was conducted for further tools. Not all methods were relevant in the context of this project, and therefore worth testing. Hence, only tools for detailed analysis that included the social dimension of sustainability, whose methodology was publicly available, which contained an internally developed indicator set[5], and which consisted of indicators supplying both factual and quantitative data and results, were selected.[6]

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[5] Whilst many tools contain their own indicators that are specifically tailored to the aim of assessment, others contain only indicators that are based on other tools. This is the case e.g. with SMART, which is based on SAFA.

[6] An overview of the analysed tools are available in the form of an Excel table (*Indicators_Classification)* upon request. The tools highlighted in grey meet the criteria formulated for the project, and were thus analysed in detail.

As described in Chapters 3.3.2 and 3.3.3, the indicators were classified in a first step according to the following categories[7]:

- Position within the results chain (input, activity, output, outcome or impact)
- Objective or subjective
- Involved stakeholders.

In a second step, in order to gain an overall picture of the indicators of the selected assessment tools and to analyse the extent to which the indicators were suitable for this project, said indicators were classified according to subject area[8]. Table 3 provides an overview of the stakeholders with their assigned subject areas that are used to classify the indicators. Derived from various assessment tools used in the agricultural sector, this list provides an overview of the main subject areas. It does not claim to be exhaustive, but serves merely to provide a structured analysis of indicators from various assessment tools.

Table 3: Stakeholders and Subject Areas. Source: Agéco 2015 and jch-consult.

Stakeholder Category	Affected Subject Areas
Worker (non-family employee)	Employment relationship Working hours Wages and fringe benefits Professional development Safety and health at work Young employees Equal opportunities Work environment Quality of life
Local community	Neighbourhood relationships/Coexistence Local engagement Local employment opportunities Landscape stewardship (1)
Consumers	Food safety and quality Product availability Product information Feedback mechanism/Dialogue
Business Partners	Purchasing practices Business relationships Networking
Farm Manager/Family Members	Financial well-being (2) Safety and health at work Quality of life
Remarks: (1) This topic is discussed in greater detail in Chapter 6. (2) Personal financial well-being; the economic sustainability of the farms is discussed in Chapter 7.	

Although there are many indicator systems, the analysis showed that only a few indicators meet in full the criteria outlined in Table 2.
In addition, the following limitations were identified:

Performance Reference Points

Missing performance reference points represent a major limiting factor. Just two assessment tools (PRés *Social Footprint* guidelines and SAFA) systematically propose performance reference points for each indicator.

[7] More-precise details are available in the form of an Excel table (*Indicators_Inventory)* upon request.

[8] More-precise details are available in the form of an Excel table (*Indicators_Classification)* upon request.

Although activities, outputs and outcomes of the other assessment tools are measured, they are not compared with explicit reference values to enable their performance to be ranked.
Whilst implicit performance reference points can be assumed for certain indicators (e.g. zero hours forced labour or 100% of workers have a written employment contract), they must in most cases be defined. Performance reference points can be either ‘objective’ or ‘relative’, i.e. context-specific. Whereas many indicators on the outcome/impact level refer to objective performance reference points (e.g. number of fatal accidents equals zero, or 100% of employees are satisfied with their job), most of the indicators on the activities level are based on context-specific performance reference points. Thus, for example, social norms or standards are often used as performance reference points. These can be taken e.g. from the United Nations (UN) Universal Declaration of Human Rights, or from the International Labour Organization (ILO) Conventions. National laws or standards can also be used as performance reference points. Particularly in the context of agricultural production in industrial countries, however, these performance reference points are not always relevant, or sufficiently restrictive. Thus, average or past performances can be used as an alternative means of assessing current performance. Although such performance reference points are not objective per se, depending as they do on past performances, or on the performances of other farms (e.g. in the case of average values), they do provide practical and meaningful reference values. This method is therefore the obvious choice when no ‘more objective’ performance reference points can be formulated.

Impact-orientedness

From a results chain perspective, it is important to recognise what factors lead to a particular outcome/impact. With most assessment tools the ability to do this is not a given, since they focus on documenting the activities rather than on capturing their impacts. This leads to numerous indicators on the activities level with, by contrast, only a few indicators on the outcome/impact level, the majority of which are subjective in nature. This is to be expected, since in many cases it is difficult to trace an indicator on the outcome or impact level back to a specific activity. Moreover, indicators on the outcome/impact level correspond to only a few of the areas listed in Table 2; these are the ones most closely associated with an impact at the end of the results chain (e.g. presence of health and safety, or quality of life).
Considerably more subject areas are covered by indicators on the activities level, though these are often not able to capture social impacts in concrete terms, and by doing so, provide relevant information on the social sustainability of a farm. To give an example, for reporting on marketing it can be relevant to know whether a farm has invested in distribution points, but possessing this information hardly allows us to deduce a connection with impacts on the well-being of stakeholders. This holds true for many socioeconomic indicators, such as ‘working hours per unit produced’, which allows us to make a statement on productivity, but not on the social sustainability of productivity.

Operationalisation

Although most of the analysed indicators stem from assessment tools developed for the agricultural sector, many proved unsuitable for the Swiss agricultural context. Thus, for instance, indicators such as ‘Number of programmes for capacity development in the population’ or ‘Presence of an anti-discrimination policy’ do not make sense in the context of this project. Other indicators are only meaningful on a sectoral level (e.g. % of production taking place within the country) or for certain categories of farm (size, location, sector, etc.), and hence are not applicable for the assessment of a wide variety of farms.
The analysis of the existing assessment tools shows a wide variety of indicators. This underscores the great importance of clear selection criteria for the development of an indicator set.
Over half of the analysed indicators fail to meet at least one of the criteria, rendering them unusable for the indicator set in this study. Despite this, they provide a solid basis upon which to develop an indicator set that meets the conditions formulated in Chapters 3.3.2 and 3.3.3.

Search for and Development of Further Indicators

Based on the results formulated above, the search for indicators was expanded in a second step. Whilst the first step had consisted in the analysis of indicators from assessment tools used in the agricultural sector, we were now mainly searching for general indicators which would better cover the OECD Well-being Dimensions.

To this end, we first analysed the indicators developed by the OECD. The advantage of these indicators is that they can be directly allocated to the appropriate well-being dimensions. It turned out, however, that most of the indicators used by the OECD are based on statistical data collected at national or regional level, and hence not suitable for the individual-farm level. Despite this, the analysis of these indicators gave us a good insight into what aspects of the individual dimensions the OECD focused on, and what questions were used to create the necessary data resource. These findings were included in the development of new indicators, and are therefore closely based on the indicators suggested by the OECD.
Since many indicators turned out to be unsuitable for the Swiss context, we next concentrated our search on indicators already used in Switzerland which could be allocated to the OECD Well-being Dimensions. For this, we analysed assessment tools adapted to Switzerland (e.g. SwissGap), as well as questions from various Swiss surveys (e.g. Swiss Health Survey, Swiss Income and Living Conditions (SILC), FOAG State of Mind Survey).
The indicators and questions determined by this approach were analysed using the criteria from Table 2. Here, some of the indicators/questions could be incorporated unchanged in the questionnaire compiled by us, whilst others had to be adapted to meet the criteria. Furthermore, some of the questions or response options were also adapted and expanded, in order to compel answers that were more precise.
Particularly when analysing surveys, it was observed that appropriate performance reference points were often missing. For this reason, internally developed performance reference points were proposed in this study for each question. Here, both ‘objective’ and ‘relative’ performance reference points were defined, with the context of the Swiss agricultural sector being taken into account as far as possible in the latter case. It is important to note here that this is simply a recommendation that needs to be tested or analysed in a pilot phase, and adapted if necessary.

3.4 Description of the Indicators

This chapter gives a detailed description of the indicators for assessing social sustainability, which were developed with the help of the approach formulated above. The classification of the indicators follows the dimensions of the OECD Well-being Framework.

3.4.1 Financial Resources and Working Conditions

The dimensions of income and wealth on the one hand and jobs and earnings on the other – summarised in this report under the dimension ‘financial resources and working conditions’ (FW) – form two key material components of the OECD Well-being Framework (see Chapter 3.3.2). Although the OECD presents these dimensions on the material side of its framework, they also contain a wide range of non-material working conditions that are likewise important for people’s well-being.
Since these dimensions contain economic components, a clear demarcation from the economic dimension of sustainability (see Chapter 7) is necessary. According to the FOAG (2014), when dealing with the economic dimension of sustainability income is chiefly of interest as a measure of the performance of the farms, whilst with the social dimension the income situation of farm households is of prime importance. This definition applies *mutatis mutandis* for further financial aspects, such as assets. This leads to the general rule that with the economic dimension of sustainability the farm is paramount, whilst with the social dimension the financial aspects at household level are of most interest.
According to current well-being research, both objective and subjective components should be included (see Chapter 3.3.1). For various reasons, however, this is not always possible. It is difficult for the farm managers and their families to compile a detailed and objective survey of their financial circumstances, since farm income/assets often cannot be tidily separated from household income/assets; moreover, we are dealing here with very sensitive data. For this reason, an objective indicator is proposed that can be collected with reasonable effort and expense, and which is based on data gathered in a manner not considered to be particularly sensitive. This indicator is supplemented with the subjective indicators for satisfaction with one’s income and general living standard (see indicator FW1).
No subjective indicators can be used with employees, since, as stipulated by the project guidelines, data is collected from the farm manager alone.

Table 4: Indicator FW1

Name of indicator:	FW1
Components of FW dimension	Retirement provision
Affected stakeholders	Farm manager/Family
Question asked	How much money (CHF) has your household paid into/invested in retirement provision over the past year? Please list the amounts separately for unrestricted retirement provision (e.g. saving deposits, shares/funds, pillar 3b) and restricted super-mandatory retirement provision (e.g. pillar 2, pillar 3a, life insurance policies) as separate figures.
Possible responses	For both categories: 'CHF 0', 'CHF 1-1500', 'CHF 1501-5000 ", 'CHF 5001-15,000', 'CHF15,001-30,000', 'CHF 30,001-45,000', 'over CHF 45,000'
Proposed performance reference point	Defining a performance reference point is difficult. Whether retirement provision leads to longer-term financial well-being or is inadequate depends on many individual factors. The indicator gives us no information about e.g. how much money has been set aside for retirement provision in the past, i.e. it allows no conclusions to be drawn about built-up pension-plan assets. Neither does it show the relationship between existing retirement provision and future need. A general rule is that the amount should lie within the positive range, since saving is an important component of financial well-being. Thus, sufficient assets can minimise economic risks. They also ensure the maintenance of the material standard of living, at least for a certain length of time, even when there are unexpected fluctuations in household income or expenditure (OECD 2011a).
Reason for choice of indicator	Income and consumption are crucial parameters for assessing social position in the agricultural sector (FOAG 2014). This indicator shows the relationship between household expenditure and household income, and hence the potential for saving, without surveying sensitive data. This indicator not only provides an aggregate-level snapshot of the relationship between income and expenditure for all respondents, but when collected over several years also enables an assessment of the longer-term financial trend of the household. Differentiating between payments into unrestricted and restricted pension plans seems a reasonable approach, since unrestricted pension funds are available at short notice, whilst restricted pension funds only benefit longer-term financial well-being (old-age, survivors' and disability pension plans). In the case of restricted pensions only the super-mandatory portion is to be ascertained, since the mandatory portion must in any case be paid by all households.

Table 5: Indicator FW2

Name of indicator:	FW2
Components of FW dimension	Employee wages
Affected stakeholders	Employees
Question asked	Please select a job description and enter the current gross monthly wages for each of your non-family employees. (For part-time employees, wages must be extrapolated to full-time for comparison with the reference wages; for employees paid by the hour, the hourly wage including holiday allowance must be extrapolated to the monthly wage; Wages in kind may be credited to a maximum of CHF 990.)
Possible responses	Job descriptions: See 'Reference Wages 2015', Annexe 3 (in German) Gross monthly wage: Amount in CHF

Name of indicator:	FW2
Proposed performance reference point	Agreed between the Swiss Farmers' Union, the Swiss Association of Farm Women and the ABLA (= Swiss Working Group of the Professional Associations of Agricultural Employees), *Wage Guidelines for Non-Family Employees in the Swiss Agricultural Sector, including Agricultural Home Economics* (see Annexe 3, only available in German) serve as good performance reference points for fair salaries. Wages above the reference wages are likely to have a positive effect on well-being.
Reason for choice of indicator	An adequate and fair wage is a fundamental component of both the material and non-material well-being of employees. Not only does an adequate wage allow employees to enjoy a reasonable standard of living and to save, which offsets economic risks; it also provides a feeling of being appreciated for the work done, and can therefore contribute to greater job satisfaction (Warr 1999; UNECE 2010; OECD 2011a).
Remarks	This question is to be answered in an input screen together with indicators WL1 and WL2 (see Table 19).

Table 6: Indicator FW3

Name of indicator	FW3
Components of FW dimension	Employment contract and payslip
Affected stakeholders	Employees
Question asked	Do all non-family employees regularly receive a payslip, and are they in possession of a valid written employment contract?
Possible responses	'Yes', 'No'
Proposed performance reference point	A valid written employment contract and a regular payslip are both important components of a working relationship. This question should therefore be answered 'yes'.
Reason for choice of indicator	A written employment contract and a payslip lead to greater legal security for the employee, and protect him or her from abusive dismissal. In addition, they ensure that rules and agreements are better adhered to. This has a direct impact on the material well-being of employees, since wage payments – at least for a certain period of time – are guaranteed and can be checked. An employment contract also influences non-material well-being by increasing employee security (Warr 1999; UNECE 2010; OECD 2011a).

3.4.2 Living Conditions

Living conditions (LC) constitute a further material dimension of the OECD Well-being Framework. They should not only meet certain objective minimum requirements, but should also lead to subjective satisfaction (OECD 2011a). Since – as already mentioned – subjective satisfaction can only be determined for the farm manager, the only parameter ascertained for employees is whether the minimum requirements were met.

Table 7: Indicator LC1

Name of indicator:	LC1
Components of LC dimension	Employee housing
Affected stakeholders	Employees

Name of indicator:	LC1
Question asked	In the event that employee housing is available on the farm: Is the employee housing on the farm currently habitable, and equipped with the basic facilities (i.e. roof, windows and doors, drinking water, toilets and drains)?
Possible responses	'Yes', 'No', 'No employee housing available'
Recommended performance reference point	Employee housing must have all of the enumerated basic facilities in order to merit the 'yes' performance reference point.
Reason for choice of indicator	This indicator ascertains whether basic facilities essential for shelter, privacy, safety and hygiene are available. These are important requirements which, according to the OECD (2011a), define adequate housing.
Remark	This indicator need only be ascertained by farms that are not SwissGAP-certified. SwissGAP-certified farms must meet this performance reference point. It is therefore essential to determine at the outset of the questionnaire whether the farm is SwissGAP-certified. This applies to all indicators in Chapter 3.4.2.

Table 8: Indicator LC2

Name of indicator	LC2
Components of LC dimension	Satisfaction with living conditions
Affected stakeholders	Farm manager/ Family
Question asked	How satisfied are you with your current living conditions in terms of the following criteria: Location of the house/flat; general state of repair of the house/flat; sanitary facilities; furnishings; available space; cost
Possible responses	'Very satisfied', 'Fairly satisfied', 'Unsure', 'Fairly dissatisfied', 'Very dissatisfied'
Recommended performance reference point	For positive well-being, this question should always be answered either with 'very satisfied' or 'fairly satisfied'.
Reason for choice of indicator	Since satisfaction with one's living conditions consists of a number of components, a detailed survey is preferable to a query as to general satisfaction. This indicator draws heavily on OECD (2013).

This question's input screen could be structured more or less as follows:

Table 9: Living Conditions input screen

How satisfied are you with your living conditions in terms of the following criteria?					
	Very satisfied	Fairly satisfied	Unsure	Fairly dissatisfied	Very dissatisfied
Location of house/flat					
General state of repair					
Sanitary facilities					
Furnishings					
Available space					
Cost					

3.4.3 *Health Status*

One of the key social topics (FOAG 2014), health status (HS) (FOAG 2014) is affected by many factors. Some of these factors are biological in nature, whilst other depend on the individual's behaviour or external impacts (OECD 2011a). The focus here is on the behaviour patterns and impacts at the workplace which exert a direct influence on safety at work, and hence on the health of the people working on the farm. Inadequate on-the-job safety can lead to bad accidents at work and occupational diseases, with serious consequences for those affected. On-the-job safety is particularly important in agriculture, since – owing to the use of dangerous substances and machinery, as well contact with animals – the health impacts in this sphere are relatively high compared to those in other sectors. Loss of working days generally impacts not only those directly affected, but also family members, since they have to bear a share of the financial consequences. Likewise, one person's loss of working days can lead to an additional burden on other employees. Particularly for family farms, the financial and personal consequences of accidents at work can be very high, and in extreme cases can jeopardise the continued existence of the farm (Parent-Thirion *et al.* 2007; Grenz *et al.* 2012c; FAO 2014).

Table 10: Indicator HS1

Name of indicator:	HS1
Components of HS dimension	Safety at work
Affected stakeholders	Farm Manager/Family, Employees
Question asked	Are safety-at-work specialists (according to EKAS Guidelines 6508) consulted on the farm, or is the farm a member of an industry solution (e.g. AgriTOP or SRF)?
Possible responses	'Yes', 'No'
Recommended performance reference point	'Yes'
Reason for choice of indicator	An important measure for increasing safety at work and thereby reducing work-related accidents and occupational diseases consists in prevention on the farm. According to Swiss law (EKAS Guidelines 6508), all farms with employees must either consult a safety-at-work specialist, or alternatively join an industry solution. Although there is no obligation to implement them, these preventive measures are also recommended for farms without employees (see www.agritop.ch).
Remarks	This indicator need only be ascertained by farms that are not SwissGAP-certified. SwissGAP- certified farms must either be members of an industry solution (AgriTop or SRF), or carry out a risk analysis compiled by SwissGAP. For SwissGAP-certified farms, the performance reference point is deemed to be met.

Table 11: Indicator HS2

Name of indicator:	HS2
Components of HS dimension	Safety at work
Affected stakeholders	Farm Manager/Family, Employees
Question asked	Do all persons working with dangerous substances and equipment possess the appropriate qualifications for their field of activity, or have they received appropriate (on-farm or external) training within the past 5 years?
Possible responses	'Yes', 'No'

Name of indicator:	HS2
Recommended performance reference poin:	'Yes'
Reason for choice of indicator	In addition to the farm manager or a person nominated by the farm manager undergoing advisor-administered awareness-raising (see Indicator HS1), it is important for safety at work that all persons exposed to an increased risk be appropriately trained. It is also important that their knowledge be regularly updated.
Remarks	This indicator was derived from the corresponding SwissGAP indicator, but was supplemented by the time requirement (5 years). We therefore recommend that this indicator also be ascertained for farms that are already SwissGAP-certified.

Table 12: Indicator HS3

Name of indicator:	HS3
Components of HS dimension:	Safety at work
Affected stakeholders:	Farm Manager/Family, Employees
Question asked:	Is appropriate protective gear such as suitable footwear, waterproof clothing, protective suits, rubber gloves, protective masks, appropriate respiratory, ear and eye protection, etc. available to the workforce, and is this equipment always in good condition?
Possible responses:	'Yes', 'No'
Recommended performance reference point:	'Yes'
Reason for choice of indicator:	A further important requirement for greater safety at work is the appropriate protective equipment, which should be both suitable and in good condition. Inadequate and defective equipment can lead *inter alia* to contact with harmful substances such as chemicals, pesticides and dust, which in turn can lead to acute or chronic health problems (Grenz *et al.* 2012c).
Remarks:	This indicator need only be ascertained by farms that are not SwissGAP-certified. SwissGAP-certified farms automatically meet this requirement regarding protective equipment.

Table 13: Indicator HS4

Name of indicator:	HS4
Components of HS dimension:	Traceability
Affected stakeholders:	Consumers
Question asked:	Can every product sold by or via your farm over the past 12 months be traced from the supplier to the customer? (Based on delivery documents, invoices, or purchasing and sales ledgers)
Possible responses:	'Yes', 'No'
Recommended performance reference point:	'Yes'

Name of indicator:	HS4
Reason for choice of indicator:	The traceability of foodstuffs is an integral component of food safety. It is the only way of ensuring that the producers, processers, distributors, carriers, etc. over the entire value chain are known for each product. This is particularly important where consumers have been exposed to risk, since it is only through e.g. product recalls that they are optimally protected (Wallace *et al.* 2010).
Remarks:	This indicator need only be ascertained by farms that are not SwissGAP-certified. SwissGAP-certified farms must meet the product traceability requirement.

3.4.4 Work/life balance

Work/life balance (WL) refers to the balance between one's working life and private life. It is a particularly important issue in agriculture, where long working hours are the rule rather than the exception. This manifests *inter alia* in the fact that considerably more (self-employed) people in this sector than in others claim to work long hours (Parent-Thirion *et al.* 2007). Excessively long working hours and too little leisure time can adversely impact the health of those directly affected if too little time remains for sufficient physical and mental relaxation (Grenz *et al.* 2012c). Moreover, overwork can greatly impair concentration, which in turn increases the risk of accidents (FAO 2014). Moreover, a poor work/life balance also affects one's family and social life, when work does not leave enough time for them. This not only impacts those directly affected, but also affects the well-being of family members and other people in one's social environment (OECD 2011a; Semmer and Kottwitz 2011). The indicators presented below address important aspects of the work/life balance of individual stakeholders. In addition to the considerations above, the indicator discussed in Chapter 4 measures the workload of the farm as a whole.

Table 14: Indicator WL1

Name of indicator:	WL1
Components of WL dimension	Employee working hours
Affected stakeholders	Employees
Question asked	How many hours per week do each of your non-family employees work, as an annual average?
Possible responses	Number of hours per week, as an annual average

Name of indicator:	WL1
Recommended performance reference point	Defining a reasonable performance reference point is difficult, since there are different recommendations. The OECD (2011a), for example, rates working weeks in excess of 50 hours as having a negative effect on well-being (the general, non-country-specific limit); the International Labour Organization (ILO) sets 48 hours/week as a reasonable limit (ILO Convention 1, Art. 2, with the agricultural sector being exempted from the ILO Conventions). Cantonal standard employment contracts (SECs) for agricultural employees usually define 55 hours/week as the maximum number of working hours, with lower (48 hours/week) as well as higher figures (66 hours/week) also being proposed. The maximum number of working hours specified in the Swiss SECs is significantly higher than for other European countries. In most European countries, a 40-hour working week is considered the norm, and although individual countries allow flexible increases in weekly working hours, in almost all of these countries said increases must not be in excess of 48 hours (EFFAT 2007). RISE uses the ILO definition as a performance reference point, since according to Grenz *et al.* (2012c) there are no medical grounds for treating the agricultural sector differently from other sectors. This is due in no small part to the above-average impacts caused by agricultural activities. Because of the different recommendations, we have refrained from expressing a reference point in numerical terms – rather, we would encourage users to define a performance reference point together with IP-SUISSE and selected farmers.
Reason for choice of indicator	As explained above, long working hours can lead to both health and social problems, for which reason the objective measurement of working hours is essential.
Remarks	This indicator is only ascertained on farms with at least one employee. For farms with many employees, this process is likely to be quite time-consuming. For this reason, it might make sense to stipulate the maximum number of employees to be surveyed. This question is to be dealt with together with indicators FA2 and WL2 (see Table 19).

Table 15: Indicator WL2

Name of indicator	WL2
Components of WL dimension	Employee holidays
Affected stakeholders	Employees
Question asked	How many weeks' holiday does each of your non-family employees have per year? (With employment durations of under a year, holidays must be extrapolated to an entire year; for employees working for an hourly wage, this question need not be answered.)
Possible responses	'0 weeks', '1 week', '2 weeks', '3 weeks', '4 weeks', '5 weeks', '6 weeks', 'Over 6 weeks'

Name of indicator	WL2
Recommended performance reference point	Holiday allowance recommendations in '*Wage Guidelines for Non-Family Employees in the Swiss Agricultural Sector, including Agricultural Home Economics'* are based on cantonal standard employment contracts for the agricultural sector (see Annexe 3). These provisions stipulate five weeks' holiday for employees up to the age of 20 – and depending on the canton, after the age of 50 – and four weeks' holiday for all other employees. Since cantonal differences are not to be taken into account (well-being does not depend on one's place of work), five weeks' holiday is recommended as a performance reference point for all employees under 20 or over 50, and four weeks for all others.
Reason for choice of indicator	In addition to weekly working hours that are not unduly high, sufficient holidays are a further important requirement for protecting oneself from overwork, recuperating, and having enough leisure time to indulge in one's hobbies (Semmer and Kottwitz 2011).
Remarks	This question is asked together with indicators FA2 and WL1 (see Table 19).

Table 16: Indicator WL3

Name of indicator	WL3
Components of WL dimension	Employee overtime
Affected stakeholders	Employees
Question asked	Is the overtime worked by non-family employees always shown on their payslips, and can they take compensatory time off, or charge a premium of at least 25% over their normal wages for working overtime? ('Overtime' is taken to mean all work performed in the interests of the employer in excess of the agreed or usual working hours.)
Possible responses	'Yes', 'No'
Recommended performance reference point	'Yes'
Reason for choice of indicator	Seasonal fluctuations in workload and the weather dependency of certain jobs mean that employees in the farming sector must be flexible, and prepared to work overtime when necessary. This is in keeping with Law OR Art. 321c, according to which employees must work overtime as required. Compensatory time off or entitlement to a premium of at least 25% over the normal wage when working overtime is also provided for in law. Written documentation and identification of overtime on the payslip is important, since it can serve as a check for employees and protect them better in the event of a dispute. Such identification on the payslip is also stipulated in '*Wage Guidelines for Non-Family Employees in the Swiss Agricultural Sector, including Agricultural Home Economics'* (see Annexe 3).

Table 17: Indicator WL4

Name of indicator	WL4
Components of WL dimension	Working hours of farm manager/family
Affected stakeholders	Farm manager/Family

Name of indicator	WL4
Question asked	How many hours do you and your family workforce work per week, as an annual average? Only those hours spent on family-farm-related work should be included in the total.
Possible responses	Number of hours per week, as an annual average
Recommended performance reference point	As for WL1
Reason for choice of indicator	As for WL1; This indicator is also interesting in combination with subjective satisfaction in terms of leisure time, since the length of the working week need not necessarily correlate with satisfaction with leisure time. Long working hours can be mentally stressful for certain people and therefore have a negative effect on subjective well-being, whilst other people do not experience long working hours as stressful, and may even rate them as positive. What should not be ignored with all people, however – regardless of how satisfied they are with their leisure time – is the physical stress that can be caused by long working hours.

Table 18: Indicator WL5

Name of indicator	WL5
Components of WL dimension	Farm manager's holidays
Affected stakeholders	Farm manager/Family
Question asked	How many weeks' holiday do you and your family workforce take on average per year?
Possible responses	'0 weeks', '1 week', '2 weeks', '3 weeks', '4 weeks', '5 weeks', '6 weeks', 'Over 6 weeks'
Recommended performance reference point	As for WL2
Reason for choice of indicator	As for WL2; As for WL3, here too it is also interesting to compare the response with the respondent's rating of subjective satisfaction with leisure time.

The following common survey is proposed for indicators WL1 and WL2, as well as indicator FW2 of the dimension 'Financial resources and working conditions':

Table 19: FW2, WL1 and WL2 input screen

	Age	Job	Monthly Wage	Weekly Hours Worked (Annual Average)	No. of Weeks' Holiday per Year
Employee 1*					
Employee 2*					
Employee 3*					
…					
*Employees need not be mentioned by name					

3.4.5 Education and Skills

Promoting the education and skills (ES) of the people working on the farm is important from both an economic and psychological perspective.
For farms aspiring to high economic sustainability, it is therefore important to create stable employment conditions and offer professional development opportunities for employees. Adequately supported employees are often more motivated, and thus contribute to the success of the company. Support and encouragement of employees is easier on larger farms than on smaller farms with low numbers of (seasonal) employees. Despite this, even smaller farms must be in a position to provide further education and training for their employees. Moreover, it is not just the support and further education of employees that forms the basis of a successful future; the farm manager must also undergo regular further training to acquire new skills (FAO 2014). This is also crucial for subjective well-being, since it takes account of the major human need to continue to learn new things (OECD 2011a).

Table 20: Indicator ES1

Name of indicator	ES1
Components of ES dimension	Further education of employees
Affected stakeholders	Employees
Question asked	How many of your employees have received vocational support/further education over the past 12 months? Please answer this question for each of the following three categories: Support through being assigned new areas of responsibility Participation in internal training to learn new skills Participation in external training to learn new skills
Possible responses	Number of employees per category
Recommended performance reference point	It is almost impossible to define an absolute performance reference point for the individual categories, since further education and skills promotion occur in different ways and in different combinations. It is likely, however, that a situation where only a small percentage of employees attended further education courses over a fairly long period of time would have a negative impact on the well-being of the employees (and hence on the economic sustainability of the farm).
Reason for choice of indicator	Employees are supported in their careers by being assigned new areas of responsibility, and by acquiring new knowledge through internal or external training sessions. Ideally, employees should be prepared for new duties through training. Training can also be useful even when new areas of responsibility are not being assumed, however.

Table 21: Indicator ES2

Name of indicator	ES2
Components of ES dimension	Further education of farm manager
Affected stakeholders	Farm Manager/Family
Question asked	Have you upgraded your skills in terms of your farm in the past 12 months? Please answer the question for each of the following categories: Through courses Through agricultural extension Through trade or specialist journals Through discussions with colleagues With the help of the Internet

Name of indicator	ES2
Possible responses	‘Yes’, ‘No’ for each category
Recommended performance reference point	As with ES1, it is almost impossible to define an absolute performance reference point for the individual categories, since here too various combinations are possible. If all categories are answered with ‘no’, however, this will certainly have an adverse affect on well-being. When analysing the responses, it makes sense to include subjective importance and satisfaction regarding further education (see indicator SW1).
Reason for choice of indicator	The vocational support/further education of employees is important for the farm, as well as for the individual well-being of both the employees and the farm manager. Since self-advancement is almost impossible to determine, the question for the farm manager is limited to formal and informal further education courses. The advantage of this categorisation is that the query can be more precise, enabling a more-detailed analysis of the results.

3.4.6 Social Connections

Social connections (SC) are a crucial component of human well-being, and hence also a key component of social sustainability. Social connections are complex, and have heterogeneous and individual causes and consequences (OECD 2011a). The proposed indicators focus on the farm manager’s family. Since social connections (Weber 2015) are never a one-side affair, but always affect a number of individuals, the social connections of farm managers and their families frequently affect those of other members of the local community. Because of the aforementioned strictures of the survey, however, the positive effects on the well-being of the latter can only be surmised rather than measured.

Table 22: Indicator SC1

Name of indicator:	SC1
Components of SC dimension	Social life
Affected stakeholders	Farm manager/Family, Local community
Question asked	How often in the past 12 months have you and your family members taken part in events put on by a society, club, political party, cultural association or other groups (including religious ones) in your immediate vicinity?
Possible responses	‘Almost daily’, ‘About once a week’, ‘1–3 times a month’, ‘Every couple of months’, ‘Rarely’, ‘Never’
Recommended performance reference point	A performance reference point is not explicitly recommended here, since the values of this indicator provide little information on the social impacts. Instead, it is the chosen values in combination with further indicators that should be considered.
Reason for choice of indicator	This indicator illustrates participation in social life. Such participation is important for one’s integration in the local community, but, viewed in isolation, has only limited significance for the social situation of the farm manager and his family, as well as for other members of the local community. For one thing, only formal contact is ascertained, and informal contact is therefore ignored; for another, only the quantity and not the quality of this contact is depicted. Nevertheless, this frequently used indicator gives a good insight into social interactions, without being nearly as cumbersome to survey as, for instance, time-budget studies (OECD 2011a). The important thing is for this indicator not to be viewed in isolation, but rather in combination with the two other indicators of the ‘Social connections’ component, as well as with the indicator SW1, which deals with the importance of and satisfaction with one’s social environment.

Table 23: Indicator SC2

Name of indicator:	SC2
Components of SC dimension:	Social networks
Affected stakeholders	Farm manager/family, Local community
Question asked	Decide whether the following three statements on social aspects are very true, fairly true, fairly untrue, or not at all true for you: We are well integrated in the community in our village. We have good relationships with farming circles. We have good relationships with non-farming circles.
Possible responses	'Very true', 'Fairly true', 'Fairly untrue', 'Not at all true'
Recommended performance reference point	Since good integration is considered to be an important requirement for a good social network (OECD 2011a), this first question should be answered with 'very true' or 'fairly true'. Whether or not this integration is the result of good relationships with farming circles, non-farming circles or both, is likely to be of secondary importance. Since integration and the resulting social network have an individual subjective importance, we recommend analysing the responses together with the question on the importance of and satisfaction with the social environment (indicator SW1).
Reason for choice of indicator	As a supplement to indicator SC1, which captures the frequency of formal contact with other members of the local community, as well as how well the individuals concerned are integrated in society, this indicator shows how strongly the farm manager and his family are integrated in the local community. This creates a distinction between farming and non-farming circles in the examination of social integration. Although this distinction is of secondary importance in terms of the statement regarding integration, it can nonetheless provide important reference points for subsequent analyses of integration. The same question is asked by the FOAG in its Well-being Survey, conducted every four years among Swiss farmers. This allows a later comparison with already existing results.

Table 24: Indicator SC3

Name of indicator:	SC3
Components of SC dimension	Support through social networks
Affected stakeholders	Farm manager/Family, Local community
Question asked	If you were in trouble, are there people in your community who would help you out?
Possible responses	'Yes', 'No'
Recommended performance reference point	Support that can be called upon in case of need is considered to be a very important pillar of well-being, so it should be possible to answer this question with 'yes'.

Name of indicator:	SC3
Reason for choice of indicator	In addition to enabling interactions with other people, to mostly positive effect, a social network is also beneficial in that it can be used as a resource when necessary (OECD 2011a). This indicator is therefore the ideal supplement to indicator SC2, which despite focusing on integration in the local community does not deal with whether or not the latter can be asked for support in case of difficulties. Moreover, the local community is merely a part of this resource, since friends and relatives living outside of the local community can come to one's aid. This indicator only ascertains general support: should the need arise, however, the question could be formulated more specifically, and the type of support offered (financial, practical, psychological, etc.) could be ascertained. The composition of the circle of individuals could also be stated more precisely (e.g. relatives, friends, within or outside of the local community).

3.4.7 *Civic Engagement and Governance*

In its Well-being Concept, the OECD (2011a) defines civic engagement and governance (CG) as the activities of the population when involved in political processes, as well as the manner in which the political institutions function. Unlike the OECD dimension, the present well-being dimension expands the focus in terms of civic engagement from a purely political to a political, social and business perspective. In terms of governance, the focus lies wholly on business governance in the sense of good corporate governance according to the definition of the FAO (2014). This is because this specific concept of civic engagement and governance lays greater stress on business activities. In this way, and through their activities, the farms gain more influence on social sustainability than the original OECD definition would have allowed.
The FAO (2014) takes 'good corporate governance' to mean decision-making and -implementation processes involving the consideration of the environmental, economic and social sustainability of all affected stake-holders. A business that commits to sustainability must therefore have a sustainability-oriented management structure. Contradictory sustainability principles will not lead to business activities that are sustainable in the longer term.

Table 25: Indicator CG1

Name of indicator:	CG1
Components of CG dimension	Participation in government agencies
Affected stakeholders	Farm manager/Family, Local community
Question asked	Over the past five years, how long have you been actively involved in a local or regional non-agricultural organisation (e.g. local council, school board, fire brigade)?
Possible responses	'Not at all', 'Less than 1 year', '1 to 2 years', 'Over 2 years'
Proposed performance reference point	Defining an absolute performance reference point here is a challenge. In general, it should hold true that the longer the engagement, the greater the contribution to a functioning society.

Name of indicator:	CG1
Reason for choice of indicator:	This indicator can be used to describe the civic, political and social engagement of farm managers. The original OECD definition of civic engagement, which was purely political in nature, has been expanded to include the concept of general social engagement. Hence the focus is no longer solely on political participation and its consequences for individual well-being, but also on the contribution made by the individual to the functioning of the overall social system (Münzel et al. 2004), and thus to collective well-being. Focusing on local/regional organisations is justified by the stakeholder 'local community', since local/regional commitment affects this group more directly than service at a higher level (e.g. cantonal or federal government agency level). Consideration should be given as to whether this question should distinguish between type of organisation (e.g. political or non-political).

Table 26: Indicator CG2

Name of indicator:	CG2
Components of CG dimension	Participation in agricultural organisations
Affected stakeholders	Farm manager/Family, Other farmers
Question asked	Over the past 5 years, how long have you been actively involved in at least one agricultural organisation?
Possible responses	'Not at all', 'Less than 1 year', '1 to 2 years', 'Over 2 years'
Proposed performance reference point	Longer engagement (and hence longer experience) is likely to have a positive impact on the functioning of professional organisations.
Reason for choice of indicator	This indicator expands civic engagement with the addition of a professional component. In order to exercise their roles, professional organisations are dependent upon active members. Functioning agricultural organisations are crucial for the Swiss agricultural sector, and should therefore have a positive impact on the well-being of farmers. As with CG1, consideration should be given as to how to capture the agricultural organisation more precisely.

Table 27: Indicator CG3

Name of indicator:	CG3
Components of CG dimension	Purchase of means of production
Affected stakeholders	Business partners
Question asked	In the past 12 months, were social criteria (based on labels or certification) borne in mind when purchasing means of production?
Possible responses	'Always', 'Usually', 'Often', 'Sometimes', 'Rarely', 'Never'
Proposed performance reference point	Defining an absolute performance reference point is difficult, but it is certainly safe to say that the response 'always' impacts the well-being of the business partners or their affected stakeholders in the most positive way, whilst the response 'never' has the most negative impact on their well-being.

Name of indicator:	CG3
Reason for choice of indicator	This indicator allows the social sustainability perspective to be expanded to include upstream areas. Ideally, this perspective is captured directly from the supplier of the means of production, an approach unfortunately associated with the expenditure of much time and effort. Simplifying matters, farm managers state what social criteria were also borne in mind when choosing the suppliers, since this contributes to social sustainability in the upstream areas (Krause et al. 2009). The specification “based on labels or certification” allows this practice to be objectively queried, even if these labels and certifications are not further defined. Consideration should be given to querying labels and certifications, although this makes detailed listing and analysis necessary.

Table 28: Indicator CG4

Name of indicator	CG4
Components of CG dimension:	Sustainability management plan
Affected stakeholders	Farm manager/Family, Employees, Business partners, Local community, Consumers
Question asked	Does your farm currently have a management plan focusing on all three pillars of sustainability (economic, environmental and social)?
Possible responses	‘Yes’, ‘No’
Proposed performance reference point	It is worthwhile for all farms to create a sustainability management plan, since it requires the farms to actively engage with the topic of sustainability, and to formally adhere to the aims laid down. However, this approach is also associated with a fair amount of time and effort, as well as requiring expert knowledge. Consequently, small farms can scarcely be compelled to create a sustainability management plan. It is therefore recommended that such a plan only be made compulsory from a particular size of farm onwards (e.g. from a certain number of employees or a certain managed area), and that the remaining farms be encouraged to create such a plan voluntarily.
Reason for choice of indicator	A sustainability management plan is considered to be an important component of a holistic management approach. A holistic management approach is characterised by as balanced a weighing-up as possible of short- and long-term interests, economic, social and environmental matters, and the different interests of the various stakeholders (FAO 2014). These balanced considerations should therefore also form an integral component of the sustainability management plan. The formal incorporation of sustainability considerations into management plans is a relatively new concept, but is increasingly becoming the norm in Western companies (FAO 2014).

3.4.8 Subjective Well-being

According to the current state of research, capture of the subjective aspect is a fundamental component in the assessment of individual well-being (SW; see Chapter 3.3.1).
This indicator is meant to supplement subjective indicators proposed for other well-being dimensions. Whereas with the other dimensions subject elements only exert a tangential influence, here, the topic of subjective well-being is to be considered in detail.
For this, we propose the approach developed by Radlinsky *et al.* (2000) for measuring quality of life in the Swiss agricultural sector. Used in the well-being survey carried out on behalf of the FOAG, this approach is also employed in a modified form in the RISE model (Grenz *et al.* 2012c).

The subjective assessment of quality of life is at the heart of quality-of-life research (Radlinsky *et al.* 2000), with quality of life being determined by different factors. The components of quality of life do not have uniform scientific definitions. We are dealing here with the physical, mental and social well-being of an individual (Grenz *et al.* 2012c).

In their baseline survey, Radlinsky *et al.* (2000) developed a methodology for defining and measuring quality of life in the context of the Swiss agricultural sector. To this end, they first identified the relevant areas of life for Swiss farmers, then developed a method for surveying satisfaction in these spheres. An important feature of their proposal consists in the fact that it does not just survey satisfaction with the individual spheres of life, but also determines how important these life spheres are. This pays even more attention to the subjective evaluation of quality of life.

Over the course of time, several life areas of the well-being survey carried out on behalf of the FOAG have been slightly adapted, renamed, or replaced by others. Although the reasons for this are not known, it is proposed that the life areas be defined according to the latest FOAG Well-being Survey.

As mentioned, each of the identified life spheres is assigned a statement on importance as well as one on satisfaction. To calculate the so-called life satisfaction index, these two responses are encoded, then multiplied together for the individual life spheres (see

Figure 4). The results can be presented separately for the individual life spheres. General satisfaction is determined by summing together the results of all life spheres. The presentation of individual life spheres is particularly recommended when these supplement objective indicators. The objective and subjective indicators of a specific life sphere complement one another, and can be used to reveal paradoxical results (Grenz *et al.* 2012c).

Thus, for example, long working hours need not necessarily go hand-in-hand with a subjective negative rating of leisure. This shows that well-being cannot be defined by objective indicators alone, but that subjective indicators must also always be included, owing to the individual assessment of importance and satisfaction.

Table 29: Indicator SW

Name of indicator:	SW1
Components of SW dimension:	Importance of and satisfaction with specific areas of life
Affected stakeholders:	Farm manager/Family
Question asked	How important are the individual areas of life to you? Are they very important, important, unsure, unimportant, or completely unimportant? How would you rate your current satisfaction with these individual life areas? Are you very satisfied, satisfied, unsure, dissatisfied, or very dissatisfied in terms of the following life spheres: Paid employment Training (e.g. completed apprenticeship) Further education (e.g. courses) Income General standard of living (e.g. home furnishings) Family Social environment Stable political and economic conditions Leisure Health Having enough time Cultural offerings

Name of indicator:	SW1
Possible responses	Importance: 'Very important', 'Important', 'Unsure', 'Unimportant', 'Completely unimportant' Satisfaction: 'Very satisfied', 'Satisfied', 'Unsure', 'Dissatisfied', 'Very dissatisfied' The values must then be encoded (see Figure 4)
Proposed performance reference point	The absolute performance reference point for both the individual life spheres and the aggregation of all life spheres is equal to zero, since this value defines the threshold between satisfaction and dissatisfaction. Higher values indicate a higher quality of life. New surveys can be compared with the results from the well-being survey, and thus also be used as reference values. This allows newly acquired results to be compared both with general values from the agricultural sector and with the reference population (see FOAG 2013).
Reason for choice of indicator	The approach for measuring quality of life presented above has already been used several times in practice with success, which is suggestive of a high significance. In addition, regular surveys on behalf of the FOAG have provided us with comparative data from other farmers and from a reference population, which can be used as relative performance reference points.

Calculation of Quality-of-Life Index

Code Conversion of Importance		Code Conversion of Satisfaction	
Very unimportant	0.2	Very dissatisfied	-3
Unimportant	0.4	Dissatisfied	-1.5
Unsure	0.6	Unsure	0
Important	0.8	Satisfied	1.5
Very important	1	Very satisfied	3

The quality-of-life index is the sum of the products over all 12 life spheres: the respective code or value for rating the importance of a life sphere is first multiplied by the respective code or value for rating satisfaction with the same, then these 12 results are summed.

The quality-of-life index is equal to a maximum of 36 points when all 12 life spheres are rated 'very important' and 'very satisfied', and to a minimum of -36 points when all 12 life spheres are rated 'very important' and 'very dissatisfied' by somebody. If someone rates their satisfaction in all 12 life spheres as 'unsure', their quality-of-life index stands at 0.

Figure 4: Calculation of the quality-of-life index (FOAG 2013).

3.5 Evaluation of the Indicators

3.5.1 Completeness of Scope

As described above, defining the social dimension of sustainability is no easy task. Nor, therefore, is the objective measurement and assessment of the same. This study recommends using the OECD Well-being Concept to measure social sustainability. Although well-being is a very important – if not *the* most important – component of social sustainability, these two concepts must not be equated with one another. Thus, the proposed indicators cannot fully capture social sustainability, but only its (nevertheless very) important well-being components.

For reasons of operationalisability, it is not possible to capture the overall well-being of the stakeholders. This is due one the one hand to the limitations of the dimensions of the OECD Well-being Concept, but on the other to the emphasis of specific aspects within the well-being dimensions. Again for reasons of operationalisability, this focus is unavoidable. It therefore remains important to stress that although the proposed indicators highlight important components of well-being, they can never capture all aspects of social sustainability.

Since only farm managers are questioned, the well-being of other stakeholders must be ascertained indirectly; however, this is only possible for objective and not subjective indicators. Since research has identified subjective well-being as a crucial component, well-being can therefore only be adequately captured at the level of the farm manager.

To ensure feasibility, the number of proposed indicators must be limited. For this reason, the proposed indicator set relates first and foremost to internal stakeholders, whilst external stakeholders are only taken account of in passing. Moreover, the well-being of external stakeholders can only be determined to a limited extent at best, since the project specification only allows for questioning of the farm manager. There are also differences within the group of internal stakeholders, however. The well-being of non-family employees is better portrayed than that of the family workforce, since wages, working hours and holidays of non-family employees are generally regulated contractually, which is often not the case for the family workforce. To determine the well-being of the family workforce, the latter would have to be questioned directly, using subjective indicators.

The OECD Well-being Framework not only considers the well-being of the current generation, but also seeks to incorporate the well-being of future generations by means of the ‘capital’ approach. Although the proposed indicators cover the well-being of the active generation first and foremost, some of them (e.g. further education, social connections, pension plan) definitely have a certain influence on future generations. For a more meaningful survey of the well-being of future generations, indicators that address the idea of various types of capital (e.g. economic, cultural and social) must be developed. For reasons of scope and operationalisability, however, these cannot be taken into account within this study.

3.5.2 Assessment of Robustness and Uncertainties

An understandably formulated question on robustness is very important. Only if the question is posed sufficiently clearly is it understood the same by different farm managers. To optimise the questions, it is therefore strongly recommended that the indicators be tested in practice, and be further optimised and adapted where necessary.

In addition to the questions being phrased unambiguously, it is important for them to be answered honestly. Since the farm managers collect the data themselves, there is a certain risk of them presenting a distorted picture of the social situation. This problem can be avoided – at least in part – by clearly communicating the purpose of the survey. Negative findings must not entail any negative consequences. In the case of objective indicators, it is appropriate for these to be checked on a random basis on the farm.

The proposed performance reference points are to be used with great care and require further clarifications, especially since it is difficult to determine absolute performance reference points and to use them as threshold values for social sustainability. Performance reference points must always be developed conceptually. In addition, there are certain interactions between the individual reference points. Some social sustainability indicators are subjective in nature, and therefore cannot be depicted on an absolute scale. Whereas reference values can quite easily be defined for indicators with the possible answers of ‘yes’ or ‘no’ (a question answered in the positive often points to a positive contribution to the well-being of the stakeholder), this is a less straightforward matter for questions with several possible responses. Although the relative contribution to stakeholder well-being can be highlighted – it is plausible, for example, that the more frequently an activity having a positive impact on well-being is performed, the greater the increase in well-being – it is nonetheless difficult to determine how often an activity must occur in order to be rated as socially sustainable. This task is also exceptionally challenging for indicators with a continuous pattern (such as e.g. earned income).

We therefore recommend using performance reference points with caution, and refraining where possible both from defining absolute threshold values and using them in studies.

3.5.3 Reproducibility

With quantitative and semi-quantitative indicators, reproducibility should be a given. In the case of subjective indicators, reproducibility of results is generally likely to be difficult to achieve. This should not be interpreted as a weakness, but rather is in the nature of subjectivity. Since it is important to take subjective criteria into account when evaluating well-being, the absence of reproducibility must not lead to the exclusion of subjective indicators from the assessment.

3.5.4 Applicability: Communicability and Practicability

When selecting the indicators, care was taken to ensure that they were easy to operationalise and could be captured without disproportionate effort or expense. Most of the questions are easy to answer, since they simply require a binary (yes/no) response, or are categorical in nature. Only for a very few indicators are precise numerical values requested, making the survey more complex. This holds particularly true for capturing monthly wages on farms with a great many employees.
Because of the different topics and response options (yes/no, scales, numerical values), social sustainability is not easily communicated. The aggregation of individual questions and the necessary weighting and standardisation via performance reference points are particularly demanding, and could only be approached in this study in a rudimentary fashion (see Chapter 14.7). We strongly advise against the definition of absolute threshold values to assess whether or not a farm can be classified as socially sustainable.

3.6 Recommendation

The proposed indicator set allows fairly complete coverage of the farm manager’s well-being. Because of the project’s specification that the indicators be collected exclusively via farm managers, assessing the well-being of the other internal stakeholders is less straightforward, with subjective well-being in particular being impossible to determine. Because of the crucial importance of subjective well-being it is recommended that the other internal stakeholders (also) be directly included in future surveys, despite this being associated with greater effort and expense. Assessing the well-being of external stakeholders is even more difficult, since this can only be ascertained on farm-manager level in a very incomplete fashion. Here, we suggest questioning the important external stakeholders at the very least, or questioning the external stakeholders of a small subsample by way of example.
All indicators must be tested in a well documented and carefully monitored pilot phase. Here, it is important for the indicators to be evaluated with the stakeholders in a participatory process, and adapted if necessary. This is especially true for the comprehensibility of the questions and the definition of the performance reference points.

3.7 Conclusions

Whereas sustainability used to be considered solely from an environmental perspective, in recent years the realisation has dawned that the social and economic dimensions must also be included as equal pillars in any comprehensive assessment of sustainability.
That being said, there are different definitions of social sustainability. From the Brundtland definition of sustainability, it follows that a consideration of social sustainability must focus not only on the needs, but on the necessary resources for meeting these needs. This aim can be achieved with the help of both the ‘basic needs’ concept (including the refinement of the same) and the concept of social capital. Key points of these concepts are taken up by the ‘well-being’ concept. Although well-being must not be equated with social sustainability, it is nonetheless an important – if not *the* most important – component of social sustainability. That is why it is wise to use a concept that focuses on well-being.
A current and broad definition of well-being is provided by the OECD Well-being Framework. This framework subdivides well-being into three material and eight non-material dimensions, with both objective and subjective indicators being utilised to capture well-being. Moreover, it is not just the well-being of the current generation that is considered, but – through the ‘capital’ approach – the well-being of future generations. Whilst the OECD Well-being Framework furnishes a good basis for capturing general well-being, it does not allow a direct

correlation to be drawn between business activities and their effects on the well-being of the stakeholders. The 'social impacts' concept, however, is capable of describing this correlation sufficiently accurately.
After conceptually deriving a usable system for assessing social sustainability, this study determines which aspects of social sustainability are to be incorporated in the assessment. To this end, the involved stakeholders are identified via stakeholder mapping. Next, criteria are defined which must be met by the selected indicators. A critical review of various indicator systems based on the criteria list showed that only a few indicators fully met the established criteria. For this reason, new indicators had to be developed or existing ones adapted and modified in order to create a suitable indicator set for Swiss farms.
Because of conceptual difficulties and the given restrictions (questioning via farm managers only), the indicator set developed in this study does not allow a full survey of social sustainability. Nevertheless, the proposed indicators give a broad and accurate insight into the social sustainability of a number of important stakeholders, and serve as a good basis for future refinement of the indicator set by e.g. extending the survey to further stakeholders.
In conclusion, it should again be emphasised that the developed indicators, and the performance reference points in particular, represent an initial well-thought-out suggestion which must nevertheless undergo practical testing. It is only this pilot phase which allows us to check the operationalisability of the indicators and engineer any necessary adaptations and improvements.

4 Workload

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4.1 Introduction

For an adequate depiction of social sustainability, we also have to take the workload in the agricultural sector into account. A good work/life balance has a positive effect on the mental and physical constitution of the individual. Despite this, workload in the agricultural sector is constantly increasing. Although a regular working contract in the canton of Zurich provides for a 55-hour working week in agriculture, actual working hours may be quite a bit higher owing to flexibility in working hours during peak periods (AGRIMPULS 2014). The Swiss Federal Statistical Office discovered that Swiss farmers worked an average of around 60 hours a week (FOAG 2013). Rossier and Reissig (2014) suggest a similar figure in their time-budget study.

Swiss farm women surveyed in the 'Women in Agriculture' study (FOAG 2012) name current agricultural policy, the economic situation and time pressure as the three most stressful factors faced by them. When such stress factors occur over the long term, stress can become chronic and cause illness or disease. Those affected may suffer *inter alia* from back pain and headaches or facial pain (FOAG 2010a).

But it is not just the adverse consequences for people's health caused by insufficient recovery time that has a major impact on the sustainability of farms; the lack of buffer periods between times of intense activity can also reduce the resilience of a farm. For this reason, a 'workload' sustainability indicator was developed as part of this project, as a basis for the assessment of farms. This indicator needed to be easy to ascertain, whilst also being generally valid and informative. A possible approach to capturing the indicator is set out below.

4.2 Relevance of the Topic for Sustainability

As Chapter 3 made clear, the different spheres of social sustainability can be discussed and depicted in a very wide-ranging manner. Here, so-called work/life balance is especially important for a socially sustainable working environment. A sustainable workload is the basis of a healthy work/life balance.

An excessive workload on a farm has a negative effect on recovery times and holiday entitlement. In various regular working contracts for the agricultural sector used in different cantons, 4–5 weeks, depending on age, is mandated for employee holidays. Although self-employed farm managers do not fall within the scope of this regulation, recovery times are just as important for people in this position. In a study from Austria, only 20% of dairy farmers stated that they went on holiday for at least one week a year (Wiesinger 2005). This situation could be depicted within the scope of the Swiss agricultural sector via Indicator WL5 'Farm manager's holidays' (see Chapter 3.4).

In addition, a study by Wagner (2011) found that 58% of the 195 surveyed farmers experienced psychosocial stress in the form of 'burn-out'. The lack of a chance to recuperate together with job dissatisfaction, worries about the economy / market prices and family concerns are given as the main reasons for 31% of farm-manager burn-out cases in the aforementioned study.

A further worrying factor is the high suicide rate among farmers compared to other occupational groups. In his book, Watzka (2008) described how farmers are the most at-risk occupational group, with an annual suicide rate of 53 per 100,000 persons. This is contrasted with an annual rate of 8–18 suicides per 100,000 persons recorded for men employed in the services sector, and internationally, with an annual suicide rate among farmers in southern Australia of 33.8 per 100,000 inhabitants (Miller and Burns 2008).

The results of the different studies highlight the great need for action in the social sustainability sphere. The following chapter therefore examines an indicator for assessing workload as a specific component of the social dimension.

4.3 Overview

There are two different types of methods for recording working hours – final methods and causal methods. With final methods, working hours are estimated with the best possible results, whilst with the causal method they are measured. This provides us with a more accurate overview of the actual working-time requirement, or working-time demand. The disadvantage of the causal method lies in the high time requirement of the survey, as well as in a possible distortion caused by the employee feeling observed, and thus possibly performing the task more correctly and more quickly, or even deliberately slower. With the final method, there is generally a distortion owing to the under- or overestimation of workload.

ART Work Budget Software (Agroscope; Ettenhausen, Switzerland) is a work-economics calculation system based on work-economics parameters. The Work Budget Software uses models to help calculate the working-time requirement for farms. This gives an indication of the size of workforce required on the farm. Here, however, it must be remembered that it is the working-time requirement, and not the actual working-time demand, that is being calculated by models. Working-time requirement refers to the standardised working hours needed for work processes to be carried out according to the modelled working-time elements. The actual working-time demand is then obtained by taking into account additional irregularities (e.g. technical problems, speed in completing work) that are not considered in the work-element model.

The statistical analysis of AGIS (Agricultural Information System Database) data provides a further method for obtaining an overview of the current availability of labour. Whilst collecting the farm data, farmers also provide details on the availability of labour on the farm, stating workforce numbers in various categories and workload categories in %. With the once-yearly independent input of information, however, there is the risk of data not being updated, or of a discrepancy in the personal assessment of workload. According to AGIS specifications, details concerning workload are to be based on a full-time workload corresponding to 51 working hours per week.

A further variable for evaluating work is the standard labour unit (SLU). It is defined such that the SLU is a dimension for measuring farm size. Through the indirect route of labour, the various agricultural activities (plant production, animal husbandry) are made comparable, and above all summable. Here, it is not just field and stable work, but also special and farm-management tasks that are taken into account (FOAG 2015a).

The additional consideration of the SLU factor – based on the different working-time requirements of different units of a farm (e.g. utilised agricultural area or number of dairy cows) – allows a more accurate measurement of farm size to be obtained. One SLU relates to 2800 working hours per annum. From 2016 onwards, due to a reform based on technical progress, a new figure of 2600 hours per SLU will be enforced. Hence, 2600 hours per SLU was assumed below for the calculation.

4.4 Description of the Indicators

Three potential parameters stipulated in the project application were used to calculate the sustainability indicator for workload in the agricultural sector:

- Labour actually available on the farms, according to the AGIS Database
- Calculated working-time requirement according to the Global Work Budget (ART Work Budget)
- SLU figures according to the FOAG calculator

The raw data for calculating working-time requirement as well as for determining the actual available manpower on the farms was provided in anonymised form by the Agricultural Information System (AGIS) database of the Federal Office for Agriculture (FOAG).

To determine actual workforce numbers on the farm, the AGIS Database categories were merged. Accordingly, only the stated working time was taken into account, and not type of labour (e.g. farm manager, women family members). Information on workload was stored in the database in class ranges of > 50%, 50–74% and < 74%. For the calculations, the percentage range was averaged (Annexe 4).

The working-time requirement of the farms was calculated using the Global Work Budget (Riegel and Schick 2007). To this end, it was necessary to classify the animal population listed in the AGIS Database in the following streamlined categories: dairy cows, suckler cows, rearing cattle, fattening cattle and calves. Classification was performed in a standardised manner on all farms (Annexe 5). Land management was also included in the calculation of the total working-time requirement. Here, an average degree of mechanisation was assumed for the management of the farms. The categories of the individual land areas also had to be adapted for the calculations (Annexe 6).

For land which did not fit into the categories of the Global Work Budget, figures on working-time requirement were drawn from various sources (Meier *et al.* 2012; AGRIDEA 2015; Wirth *et al.* 2015). These values were manually added up to the calculated number of LU h/year. Land not belonging to the utilised agricultural area,

such as e.g. private gardens or land to be used in the near future as a building site, was not taken into account in the calculation. Other land deemed irrelevant owing to its negligible size was also excluded from the calculation of the model farms' working-time requirement (Annexe 7).
The sum of the calculated working-time requirement and the manually added number of working hours per area not available in the software therefore led to the calculated working-time requirement. To enable the calculated values to be related to one another, the calculated working-time requirement is then divided by 2600 hours. The value '2600 hours' draws on the recently defined annual working hours of a farmer from 2016 onwards to define a standard labour unit (SLU). In addition, the weekly working time of 50 hours is more or less comparable with the workload assumed when recording workforce numbers in the AGIS Database.
The SLU figures were calculated with the aid of the FOAG's SLU calculator (status as at 1/1/2014). For this, the data from the AGIS Database were categorised using the FOAG's enforcement tool, Data Sheet No. 6 ('Land Catalogue/Entitlement to Subsides 2015' – status as at 30/10/2014) (see Annexe 8). A further subdivision ensued into utilised agricultural area (UAA), special crops, forest or vine growing. Fruit trees were also taken into account. In the case of organic farms, utilised agricultural area was increased by 20% (LBV 1998, Art. 3, 2c 3).
For mountain farms, a standardised methodology for taking account of hillside and/or steep-slope allowances was developed, since the AGIS Database does not inform us which areas of the farm in question are in receipt of said allowances. Here, the SLU figure was first calculated without any hillside or steep-slope allowance, then with the maximum area entitled to a hillside allowance, and after this with the maximum area entitled to a steep-slope allowance, according to the classification stipulated in the enforcement tool in each case. From these three different values we then determined the average, which in each case corresponded to the value for supplementing the SLU figure whilst bearing in mind the maximum area entitled to a hillside allowance.
After this, the correlations between the individual calculated parameters – necessary workforce numbers according to the Global Work Budget, actual workforce numbers according to AGIS data, and the SLU figure– were determined (Table 30).

Table 30: Spearman's rank correlation coefficient (ρ) for the various workforce parameters

Required LUs vs. Actual LUs		
All data	**Lowland**	**Mountain (incl. allowance)**
0.39	0.44	0.42
Required LUs vs. LUs		
All data	**Lowland**	**Mountain (incl. allowance)**
0.91	0.91	0.91
Actual LUs vs. LUs		
All data	**Lowland**	**Mountain (incl. allowance)**
0.38	0.49	0.27

Despite the high rank correlation of ρ=0.91 between required work units and SLU figures, the SLU figures were not taken into further consideration when developing the sustainability indicator, since they are calculated solely on the basis of the complete utilised agricultural area, resulting in a reduction of information and accuracy.

Development of an Indicator

To determine a simple, easily captured sustainability indicator, we suggest using the ratio of required workforce to workforce available on the farm. This sustainability indicator for workload (SIW) gives an indication of the situation on the farm in terms of temporal workload.

$$SIW = \frac{Required\ workforce}{Workforce\ available\ on\ the\ farm} \qquad 1$$

Analysis of the Indicator

In a first analysis of the feasibility of the sustainability indicator, 30 lowland and 30 mountain farms involved exclusively in dairying were selected as focus farms. Among the mountain farms were six organic farms. All other farms in both the lowland and mountain areas were managed according to PEP guidelines. Location in different mountain zones was not taken into further consideration.

When calculating the indicator for all 60 dairy farms, an average of the sustainability indicator (SIW) = 1.09 was determined ranging between 0.56 and 3.29. We may assume that with an SIW of 1, an equal ratio exists between required workforce according to working-time requirement and workforce available on the farm. Here, however, it should be noted that this is not the ideal situation. The number of work units required only reflects the working-time requirement, not working-time demand. Accordingly, a buffer of at least 20% should be budgeted for in order to head off any eventualities such as technical problems or absence owing to illness. The balanced ratio of actual to required LUs is given in Figure 5 and Figure 6 in the 'critical situation' category. Since a bias should be budgeted for when performing the calculation with the Global Work Budget, a buffer of 20% over 1 was also assigned to the 'critical situation' range. The indicator was subdivided into a total of three categories to illustrate the approach. The limits between the categories are not yet conclusively set, but are merely for demonstration purposes (Table 31).

Table 31: Overview of a possible classification of the indicator

Classification	Exemplary Limit (SIW)
'Sustainable state' to 'Potential for growth'	< 0.8
'Critical situation'	0.8 - 1.2
'Potential overload'	> 1.2

Figure 5 and Figure 6 graphically represent the distribution of the workload indicator, with Figure 5 referring to the lowland farms whilst Figure 6 portrays just the mountain farms. What stands out here is the different distribution of farms at different altitudes. Based on the classifications defined here, a large proportion of the lowland farms would appear to be in the 'potential overload' range. This category is less common in the mountain area. One possible explanation for this could be the hidden unemployment in the mountain area. Furthermore, it is conceivable that the calculation does not take sufficient account of technical progress in the lowland zone. As a result, progressive mechanisation on lowland farms means that assuming an 'average degree of mechanisation' does not adequately portray the reality, leading to an overestimation of the working-time requirement on many lowland farms. When calculating the lowland farms with a high degree of mechanisation, an average of 14% lower working-time requirement was noted.

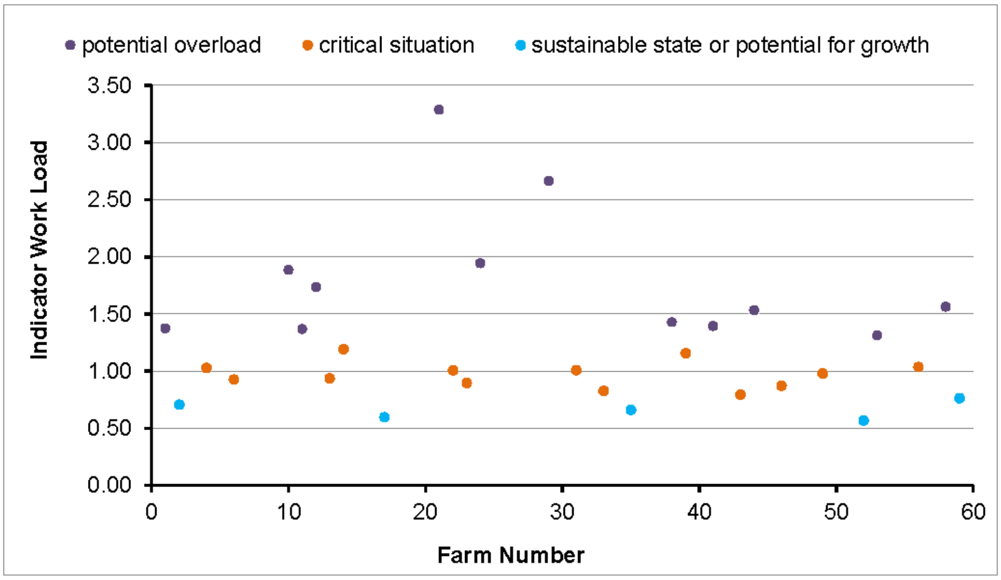


Figure 5: Distribution of the workload indicator for 30 lowland farms, with classification ('Sustainable' to 'Potential for growth'< 0.8; 'Critical situation' = 0.8 - 1.2; 'Potential overload'> 1.2).

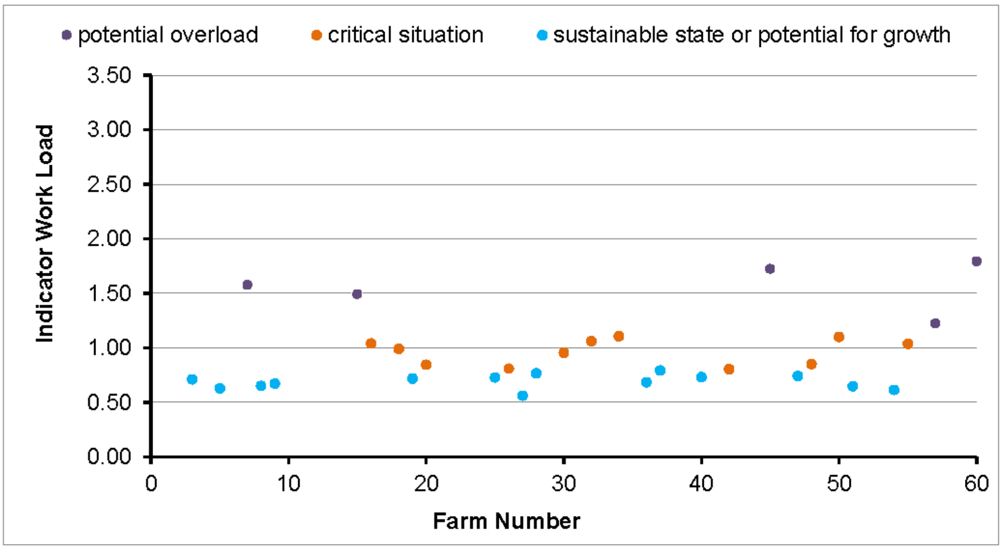


Figure 6: Distribution of the workload indicator for 30 mountain farms, with classification ('Sustainable to Potential for growth' < 0.8; 'Critical situation' = 0.8 - 1.2; 'Potential overload' > 1.2).

Figure 7 shows a boxplot of the distribution of the 'workload' indicator. What is striking here is that the variation for the mountain farms is considerably lower than for the lowland farms, and that the median, which stands at SIW = 0.81, is in a more sustainable range. Moreover, with SIW values between 0.56 and 3.29, the range for lowland farms is substantially wider than for mountain farms. One explanation for this is the possibly more heterogeneous distribution in the lowlands, with its different levels of mechanisation and farm structures, than in the mountain area.

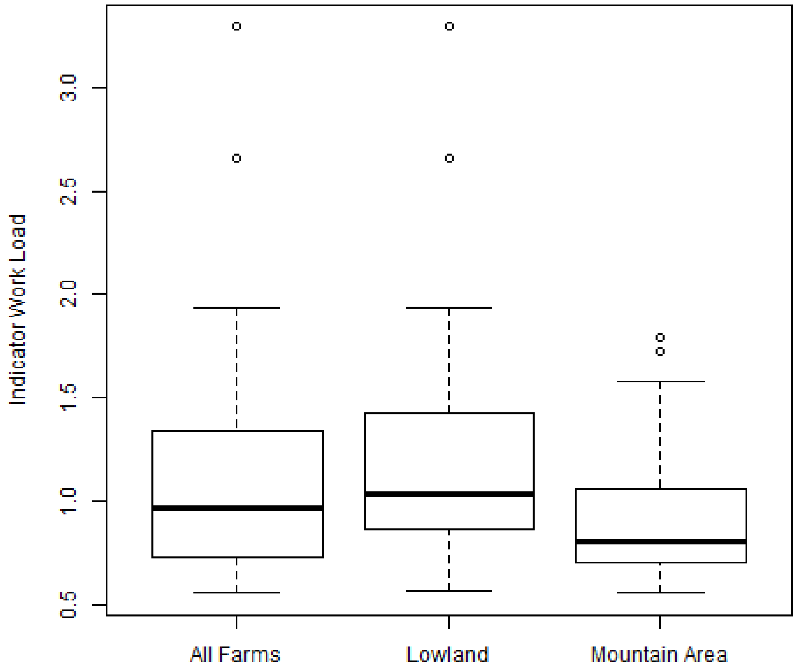


Figure 7: Boxplot of workload indicator for the three following groups: all farms; lowland farms; mountain farms

Validation Study

To check the significance of the indicator, in addition to an initial indicator feasibility analysis based on AGIS data, a pilot validation study was conducted on ten randomly selected commercial dairy farms in the canton of Thurgau.

The survey comprised the following data:

- In a face-to-face interview with the farm manager, workforce numbers available on the farm at the time of the interview as well as their workload in % was ascertained. These data were collected in addition to the AGIS data for purposes of comparison.
- The parameter 'workforce numbers available on the farm' – equivalent to the AGIS Database – was also ascertained during the face-to-face interview. The classification and calculation of the 'workforce numbers actually available on the farm' corresponds to the details in the 'Description of the Indicators' chapter.
- To calculate the working-time requirement, the farm datasheet was obtained from each farm. The farm datasheet lists all the data required to apply for direct payments (livestock numbers, types and sizes of cultivated area). These data correspond to the AGIS data, and are used for the calculation of the sustainability indicator in accordance with the process described in Chapter 4.4.

The sustainability indicator was calculated on these ten commercial farms in accordance with Formula 1. Figure 8 graphically portrays the results of the distribution of the sustainability indicator of the validation study. Here, the only two categories are 'potential overload' and 'critical situation'. During data collection, it was noticed that three of the farms have a milking robot which is not taken into account when determining the degree of mechanisation. The SIW statement does not apply for these farms, since the working-time requirement is significantly lower. Since seven of these ten farms have a milking parlour, and three have a milking robot, all ten farms were additionally calculated with the high degree of mechanisation, in order to check the extent to which this changed the value of the indicator (Figure 8).

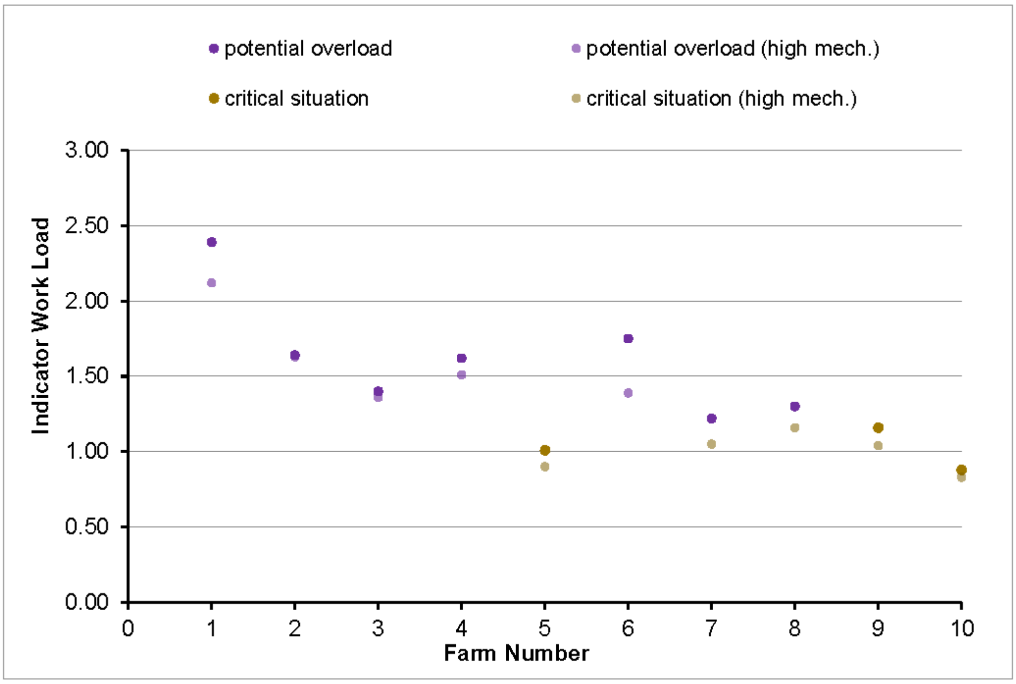


Figure 8: Distribution of the workload indicator of the ten validation farms, with classification ('Sustainable to Potential for growth'<0.8; 'Critical situation' = 0.8 - 1.2; 'Potential overload'> 1.2) with different degrees of mechanisation of the milking proc.

4.5 Evaluation of the Indicators

4.5.1 Assessment of Robustness and Uncertainties

The sustainability indicator for workload depicts working-time requirement in relation to the workforce which, according to AGIS data, is available on the farm. Working-time requirement is calculated on the basis of the data concerning the cultivation of the individual acreages and livestock numbers, which are ascertained in the application for direct payments. The available AGIS data do not make it clear which activities are performed by a contractor. Since, however, disregarding the use of a contractor would distort the results, there should be an option for indicating that cultivation of the individual acreages has been outsourced to contractors.

A further uncertainty in the calculation of working-time requirement is the consideration of all relevant influencing factors. All values determined for the 60 pilot farms as well as the ten validation farms were calculated with the Global Work Budget, which models working-time requirement based on area and livestock-population data as well as a roughly defined degree of mechanisation. However, no further details such as hillside/slope location, shape of plot or individual degree of mechanisation can be taken into account. When calculating the indicator, all farms were assumed to have an average degree of mechanisation. This means e.g. pipeline milking plant, slurry channel and grating as a basis in the dairying sector, or a mower working width of 2.8 m and a self-loading waggon volume of 17 m^3 in forage production. Sometimes, or even frequently, however, these values do not depict the actual circumstances. When collecting information on the land, it would therefore make sense to also ask about the degree of mechanisation of management.

Furthermore, some land types are not represented in the Global Work Budget, although they are also managed by the farmer. To remedy this situation, and as part of the calculation, the estimated working-time requirement from other sources was added manually to the total working-time requirement (all details listed in Annexe 7). In the overall calculation, however, this addition only amounted to 4% of all working hours.

Once yearly, as part of the data in the application for direct payments, the farm manager self-assesses the number of employees available on the farm. This survey method also has a high potential for error, since changes might have occurred during the year that are no longer taken into consideration. Moreover, the data are adopted automatically every year, so the farmer need not actively enter any changes. Consequently, this is possibly neglected in practice. The validation study attempts to depict these discrepancies between the

AGIS data and workforce numbers currently available on the farm by calculating a Spearman's rank correlation of $\rho = 0.80$. Thus, the AGIS data provide a relatively accurate snapshot of the ten validation farms. Nevertheless, it should be borne in mind that the various percentage categories to which the workforce is assigned have a fairly wide range, and that the subjective assessment of the farmers regarding working time can also lead to inaccuracies. One farmer, for instance, stated that the farm manager worked about 90% on-farm and 20% off-farm. The percentage figures should relate to a 51-hour working week. Whether this is always the case is difficult to check. However, a more accurate measurement of the actual working time in agriculture is no easy matter.

4.5.2 Transparency and Reproducibility

The indicator is simple to calculate and easy to understand. Provided that the AGIS data on land management and livestock population are available, and with the help of the ART work budget software, the calculation based on the above-described methodology can be repeated at any time.

4.5.3 Applicability: Communicability and Practicability

The data from the AGIS Database are easily available, and the calculations can be performed quickly with the help of the Global Work Budget. Here, too, an automated solution is also conceivable. A further step would be a benchmarking system allowing each farmer, once he has entered the data, to see directly how his farm is doing in comparison with other years or other farms, and where there might be a need for optimisation or action. To ensure the significance of the indicators, however, additional parameters concerning the use of contractors and the degree of mechanisation of the farm activity should be collected.

4.6 Recommendation

A sustainability indicator for workload on farms, based on the AGIS Database and the Global Work Budget, can be categorically recommended. Here, additional information concerning land management by contractors and degree of mechanisation should also be collected. Furthermore, this would provide participating farmers with a tool for assessing their farm against other farms in the spirit of a benchmarking, and discovering opportunities for optimisation.

4.7 Conclusions

All in all, we may conclude that the indicator should be developed in such a way as to allow the collection of valuable information regarding working-time requirement. The pilot comparison between mountain and lowland farms has already produced interesting findings, and has thus given a valuable indication in terms of applicability. Looking ahead, the extent to which such an indicator can be automatically captured should now be analysed. The legal situation as well as the technical options for combining the AGIS Database with the ART Work Budget must still be clarified. Furthermore, we have yet to investigate how the information on degree of mechanisation and use of contractors can be collected automatically.

5 Animal Welfare

Christina Rufener, Nina Keil

5.1 Introduction

The status of animals in a society is dependent on the latter's culture and education level as well as further sociological factors. As regards livestock, initial discussions on the conflicting demands of production on the one hand and the welfare and well-being of animals on the other (henceforth, for simplicity's sake, subsumed in this text under the heading of 'animal welfare') were first broached in 1964, when Ruth Harrison questioned the then-prevailing attitude to animals as existing solely to provide us with food in her book, *Animal Machines* (Harrison 1964). The following year, the Brambell Report (Brambell 1965), commissioned by the British Government, was published. In it, concrete demands concerning the entitlements of animals kept under human care were asserted for the first time. In the 1980s, these were framed as the 'five freedoms', and comprised:

- Freedom from hunger and thirst
- Freedom from discomfort
- Freedom from pain, injury and disease
- Freedom to express natural behaviour
- Freedom from fear and distress.

The term *animal welfare* was only introduced later, however, and was defined as the ability of an animal to adapt to its environment (Broom 1986). This laid the cornerstone for initial research work on the measuring and assessment of animal welfare, and hence for the creation of a separate field of research.

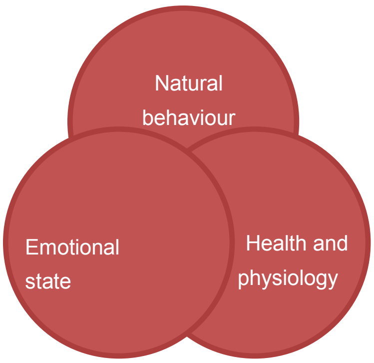


Figure 9: Three perspectives as a framework for animal-welfare assessment according to Fraser (2008).

Values and ideals play an important role in animal welfare, which can therefore not be dissociated from personal and social values and ideals, and can thus neither be clearly defined nor conclusively measured by science(Mason and Mendl 1993; Fraser 1995; Appleby and Hughes 1997). In order to render animal welfare describable within the scope of various conceptions, Fraser *et al.* (1997) described three perspectives which are relevant in terms of the definition of the quality of life of animals: natural behaviour, health and physiology, and emotional state (Figure 9). Here the Five Freedoms defined in 1965 cover all three perspectives, and today still serve as the basis of a holistic and multidimensional animal welfare assessment. The placing of the focus on one of the three perspectives is up to the viewer, and is primarily dependent on personally or vocationally determined values and ideals. Nevertheless, these perspectives cannot offset one another, and must therefore be viewed as a general multi-dimensional picture (Botreau *et al.* 2007a; Botreau *et al.* 2007b; Marchant-Forde 2015). Thus, for example, an animal raised within a low-input system has full freedom of movement and is able to behave relatively naturally, but any diseases or injuries to which it is subject will be more difficult to treat; and conversely, an animal kept under intensive conditions can be in fine fettle and optimally fed, yet have little opportunity within this husbandry system of expressing natural behaviour.

Since – unlike people – animals cannot be directly questioned, animal welfare can only be assessed indirectly via suitable parameters. Whereas a wide variety of parameters have already been used to ascertain health, physiology and behaviour in both science and practice, the capture and assessment of emotions and the emotional state of the animals has not long been the focus of research (Marchant-Forde 2015).

5.2 Relevance of the Topic for Sustainability

Nowadays, ensuring animal welfare within the context of livestock production is a social concern. More and more people define their lifestyle through their attitude to nutrition, and hence to food and animal production (Broom 2010). Of course, animal welfare is perceived and defined differently by different sections of the

population (Lassen *et al.* 2006). Whilst producers associate animal welfare in particular with state of health and provision with food and water, consumers prioritise the opportunity for the animals to express natural behaviour patterns (Sørensen and Fraser 2010). Moreover, the gender as well as the origins (town vs. country) or eating habits (vegetarian vs. carnivore) of the consumer influences his or her rating of the various animal-welfare aspects within an assessment system (Tuyttens *et al.* 2010).
Furthermore, various spheres of animal welfare may conflict with productivity and profitability, as well as with environmental aspects. Thus, for example, intensive dairy-cattle farming, with its high percentage of concentrates in the ration, is cost-efficient (high feed-conversion ratio, good balance between basal metabolic rate and performance) and eco-friendly (reduced methane emissions compared to the ration with a high proportion of roughage), but can lead to health problems (particularly metabolic disorders and lameness), increased veterinary costs and a shortened useful life owing to non-livestock-friendly feeding. By contrast, exclusive pasture rearing guarantees behaviourally appropriate feed intake and adequate freedom of movement, as well as reducing ammonia emissions in comparison with indoor rearing, but owing to increased parasitic infections may be associated with a high use of medication and the development of resistance to antiparasitics; moreover, the high proportion of roughage leads to increased methane emissions.
Animal welfare therefore affects all three pillars of sustainability: society, the environment and profitability. Thus, it is important to develop a socially accepted system for assessing animal welfare that is both cost-effective and environmentally sustainable. Here, covering all aspects of animal welfare is indispensable for meeting the expectations of all sections of the population (Rushen and Passillé 1992).

5.3 Overview

As explained above in the introduction, animal welfare can only be described in multidimensional terms, which is why it is essential to include a number of parameters for its assessment (Fraser 1995; Botreau *et al.* 2007c). The elaboration of aspects within a definition of animal welfare (e.g. the Five Freedoms) enables the allocation of parameters to function groups, which are easier to describe – and hence measure – than animal welfare as an umbrella term (Fraser 1995). The definition of animal welfare – which is broken down into aspects – and the choice of parameters per aspect, are dependent upon the intended purpose and aim of the assessment system (Main *et al.* 2003). In order to obtain an overview or arrive at an overall assessment ('Animal Welfare Index'), the results of the chosen parameters must then be aggregated on various levels, weighted against one another based on their relative importance, and offset against each another. The weighting of the individual parameters here is usually based on expert surveys, and as such is subjective(Spoolder *et al.* 2003).
The main criteria for practical applicability, and hence for the choice of the parameters, are validity, reproducibility and feasibility of the individual variables (Scott *et al.* 2001; Waiblinger *et al.* 2001; Minero *et al.* 2009). Here, three different types of parameters with different advantages and disadvantages can be distinguished (see Table 32).

Table 32: Advantages and disadvantages of the three types of parameters (animal-based, management-based and resource-based)

Parameters	Advantages and Disadvantages
Animal-based parameters	Are captured directly on the animal, but are usually rather laborious to obtain, and often can only be qualitatively captured Examples: injuries, nutritional status (Body Condition Score), occurrence of behavioural disorders
Management-based parameters	Are often qualitative in nature, or non-measurable; must usually be collected via observation on the farm, or by questioning the farmer Examples: Castration procedure, feeding process, looking after animals
Resource-based parameters	Are recorded in the housing environment, and are directly measurable, and hence can be quantitatively described Examples: size of exercise area, slat width, number of resting cubicles

Depending on the orientation or focus of the animal welfare assessment, other types of parameters should be chosen (Main *et al.* 2003). For all types of parameters, validity in terms of animal welfare must be the sine qua non. Resource-based parameters are recommended for performing an assessment with maximum reproducibility, but these are dependent on the husbandry system. Management-based parameters are frequently difficult or onerous to check. Because they are collected by questioning the farmer, they are particularly suitable if no farm visit is to be undertaken. Animal-based parameters allow us to assess the impact of husbandry conditions directly on the animal. Their great advantage is that they are therefore independent of the husbandry system, so results are comparable between systems. Despite this, there is disagreement as to the extent to which the focus on purely animal-based variables is sensible, particular in terms of practicability. The use of both resource- and management-based parameters as well as animal-based parameters could ensure broader support of an index, thereby providing a more valid depiction of animal welfare. In addition, a number of animal-based parameters could be captured via resource-based parameters, just as e.g. minimum dimensions for housing ensure the animals' freedom of movement (Bracke 2007).

Studies on animal welfare and its influencing factors must find a method for determining animal welfare that is adapted to the relevant research objective both in terms of expense/effort and significance. The upshot of this is that there are practically as many animal welfare indices as there are animal welfare studies, and that there are only a few standardised evaluation systems for assessing animal welfare. The three best-known systems, which follow very different approaches, are compared and contrasted in Table 33 in terms of various criteria. The criterion 'offsetting' describes how individual parameters are aggregated into aspects, and aspects are aggregated into a total value. The possibility of 'compensation' is in turn dependent upon the type of offsetting, which – depending on the system – allows the inadequate results of a parameter or aspect to be offset by the better values of another parameter or aspect. 'Completeness' refers to coverage of the underlying definition of animal welfare by the parameters used in the protocol. Assessment of the 'validity' of an index is based on how the relationship with actual animal welfare is protected, and is usually directly dependent on the parameters used. The 'reproducibility' of an animal welfare index is all the higher when both the same observer ('intra-observer reliability') and a number of different observers ('inter-observer reliability') reach the same conclusions on the same farm. The assessment of 'feasibility' relates to the effort required for data collection, regardless of the purpose (research, farm assessment).

Table 33: Overview of three different animal-welfare assessment systems: the Animal Welfare Index (AWI), Welfare Quality® (WQ) and Qualitative Behaviour Assessment (QBA). For a comprehensive description, see Annexe 9, Annexe 10 and Annexe 11.

	Animal Welfare Index (AWI)	**Welfare Quality® (WQ)**	**Qualitative Behaviour Assessment (QBA)**
Animal species	Cattle, pigs, laying hens1)	Cattle, pigs, poultry2)	All
Aggregation level	Farm activity, farm	Farm activity	-
Application	Practice	Science (practice)	Science
Focus	Resource-based parameters	Animal-based parameters	Animal-based parameters
Basis	Expert survey	Scientific studies, expert survey	Other approach to defining animal welfare
Type of parameters	Mostly quantitative	Mostly qualitative	Purely qualitative
No. of parameters	30–37 (depending on animal species)	9 –35 (depending on animal species & availability)	To be determined by the observer
Offsetting	Point system	Complex, mathematical	-
Compensation	Possible & desirable	Made more difficult through type of offsetting	Not possible within the scope of the definition

	Animal Welfare Index (AWI)	Welfare Quality® (WQ)	Qualitative Behaviour Assessment (QBA)
Completeness	As far as possible within the scope of the definition	As far as possible within the scope of the definition	Complete within the scope of the definition
Validity	Assessed by experts	Validity of individual variables assessed (in part experimentally)	Confirmed within the scope of the definition
Reproducibility	OK	OK	OK
Feasibility	OK, training necessary	Very time-intensive; intensive training necessary	OK, experience necessary

1) Specific protocols for dairy cows, calves, sows, fattening pigs and laying hens
2) Specific protocols for fattening cattle, dairy cows, sows, fattening pigs, piglets, fattening chickens and laying hens

The Animal Welfare Index (AWI; Bartussek 1995a, 1995b, 1996), which focuses on resource-based parameters, was developed for the assessment of Austrian organic farms, and is thus dependent on husbandry systems studied in Austria. Here, the focus on practicability is at the expense of scientificity, since the choice of parameters was pragmatically and in some cases politically motivated. Because of these restrictions the AWI has not gained acceptance outside of Austria for assessing animal welfare in practice, but is used as a reference value in various studies on account of its simplicity.

To develop the Welfare Quality® Protocols (WQ; Welfare Quality® 2009d, 2009e, 2009a), between 2004 and 2009, and with a research funding volume of EUR 17 million, expert groups from 44 universities in 13 countries in Europe and Latin America scrutinised each individual eligible animal-based parameter in terms of validity, reproducibility and feasibility (Welfare Quality® 2009f, 2009c, 2009b). Thanks to the focus on animal-based parameters, WQ can be captured regardless of the husbandry system. Because it is as scientific as possible, it is often used at present in animal welfare research to assess animal welfare. A major drawback of WQ, however, is that the surveying process – especially on large farms – is very laborious, since a certain percentage of the animals must be individually and intensively observed or examined (e.g. while resting, or to check for injuries). Furthermore, the individuals conducting the survey must undergo intensive training.

A completely different approach that avoids this set of problems by definition is the Qualitative Behaviour Assessment (QBA; Wemelsfelder *et al.* 2000; Wemelsfelder *et al.* 2001; Wemelsfelder and Lawrence 2001). Here, the qualitative assessment of the behaviour as opposed to the observation of the behaviour itself is meant to reflect the extent to which adapting to its housing environment overtaxes an animal, and hence to encompass the result of all influences on the animal (housing environment, state of health). This assessment is conducted by people undergoing just a short training, who describe and assess the animals' behaviour in their own words (e.g. calm vs. nervous, apathetic vs. curious). Although not yet ready for practical application, this approach is highly promising, particularly in terms of reproducibility and feasibility. On the whole, acceptance in practice could be problematic, since QBA does not evaluate animal welfare in terms of predefined aspects, and therefore cannot serve as a standardised method.

5.4 Description of the Indicators

According to the present-day perception and definition of animal welfare, an animal welfare index is complete when both the Five Freedoms and three perspectives defined according to Fraser *et al.* (1997) (see Chapter 5.1) are fulfilled in equal measure. Ideally, the surveying of the aspects thus generated would be based on as many parameters as possible which are both valid and reproducible. Since the Welfare Quality® Protocols were developed with an emphasis on these criteria and therefore consider all twelve animal welfare aspects (Health and Physiology → thirst, hunger, injuries, diseases; Natural Behaviour → comfort when resting, thermal comfort, freedom of movement; social behaviour, other behaviours; Emotional State → management-related pain, good human/animal relationship, positive emotional state),they can be at present be deemed to represent the best state of knowledge in terms of a scientifically sound animal welfare assessment. Because, however, being based on as many parameters as possible is not reconcilable with feasibility of use in a non-scientific context, we must of necessity lower our sights in this respect for an index that is applicable in practice. There are only a few studies dealing with how to suitably reduce the number of parameters, i.e. as far as possible without sacrificing validity, whilst retaining coverage of all aspects – and these have pursued different approaches. One approach consists in evaluating the correlation of individual parameters with the overall result of an animal welfare assessment. Heath *et al.* (2014a), for example, used logistical models to investigate whether individual aspects of a WQ protocol could predict the overall assessment of a dairy farm. Surprisingly, 'absence of prolonged thirst' allowed the proper classification of 88% of the farms. The ability to reduce the multidimensionality of the WQ to a single binary (yes/no) parameter must above all be interpreted as an obviously non-optimal weighting of the aspects within the WQ, however. Moreover, with such a reductive approach, there is generally a risk that producers will be encouraged to focus primarily on covering this particular aspect, causing the correlation with the sum total of all aspects of animal welfare to disappear.

Other researchers investigated whether the results of an animal welfare assessment based either on data to be collected via an automated process or data available at herd level can be predicted(Johnsen *et al.* 2001; de Vries *et al.* 2011; de Vries *et al.* 2014; Knage-Rasmussen *et al.* 2015). Several parameters would appear to be promising for the early recognition of problem farms, but are not suitable for general use in practice as stand-alone indicators. Other studies also showed that other, even multifactorially influenced parameters could not cope with the multidimensionality of animal welfare. Thus, for example, the occurrence of stereotypies, mortality, productivity, or the use of medication could not serve on their own as valid indicators for comprehensively describing animal welfare (Mason and Latham 2004; Ortiz-Pelaez *et al.* 2008; Coignard *et al.* 2014; Knage-Rasmussen *et al.* 2015).

Moreover, taking the example of antibiotic use, we note that the significance for animals and the significance for humans must be viewed as two separate issues, and that even choosing a suitable measurement parameter is difficult. The occurrence of resistant bacteria ('superbugs') is above all a problem for 'human sustainability', whilst for sick animals, the use itself is relevant. What's more, the resistance situation is not necessarily proportional to antibiotic use – although specialised calf-rearing farms with high animal movement may have high antibiotic usage, they may still in certain circumstances have a better resistance situation than small farms with low antibiotic usage (Reist *et al.* 2013). Regardless of usage, another study showed that superbugs occurred less on pig-fattening farms classified as 'animal-friendly' than on conventional farms, although admittedly the correlation with the actual level of animal welfare on the farm in question was not determined (Regula *et al.* 2003). Furthermore, not just healthy animals, but also untreated and sick animals – and therefore ones which would be given a low rating in an animal welfare assessment –make little use of antibiotics. Thus, a correlation between antibiotic use, superbugs and animal welfare cannot be assumed without further studies.

Besides the question of indicator suitability and validity, there is still also the issue of data availability. Although nowadays a great deal of data is collected for animals, the existing databases – the Animal Movement Database, to mention one – have a different focus (animal disease control, traceability of foods), so it is no easy matter to obtain the relevant data for assessing animal welfare. The suitability or validity of the indicator would first have to be demonstrated in scientific studies. Here – as mentioned above – the current state of knowledge does not yet allow us to make any safe assumptions.

Already available data that are gathered specifically with respect to animal welfare are only available in Switzerland for animal welfare inspections within the context of the Proof of Ecological Performance (PEP). Here, animal welfare subsidies for 'particularly animal-friendly housing systems' (PAS) and 'regular outdoor exercise for livestock' (ROEL) are established as incentives for increasing animal welfare above the level of the Swiss Animal Protection Law. PAS differs from the Animal Protection Law in particular in its stipulation of group stabling and provision of bedding material, and RAUS requires regular outdoor exercise (cattle, pigs

Table 34: Percentage of WUs participating in PAS or ROEL programmes according to species (FOAG 2014).

	Percentage of WUs	
	PAS	**ROEL**
Cattle	47%	79%
Pigs	66%	50%
Laying hens	90%	73%
Fattening chickens		8%
Total	51%	74%

and poultry), and grazing (cattle and poultry). Whereas the minimum requirements of the Animal Protection Law must be met in order to be eligible for direct payments, participation in an animal welfare programme is voluntary. Moreover, PAS and RAUS subsidies may be drawn independently of each another, and for individual animal species. PAS and RAUS form the basis for various quality labels (e.g. TerraSuisse), and are implemented for 51% and 74% of all livestock units (LUs), respectively (FOAG 2014). Participation in one or both programmes is dependent on the species (Table 34), since the effort required to implement the guidelines varies massively from one species to another (loose housing for cattle under PAS; minimum 56 days' fattening for fattening chickens under ROEL).For Switzerland, therefore, it would be possible to assess animal welfare on the basis of participation in PAS and ROEL. The correlation of PAS and ROEL with higher animal welfare than on conventional farms was demonstrated at the very outset for pigs and cattle(Krieter *et al.* 2004; Regula *et al.* 2004; Cagienard *et al.* 2005); however, these studies primarily recorded health parameters and a few behavioural observations which no longer correspond to the multidimensionality of the present-day definition of animal welfare.

5.5 Evaluation of the Indicators (Assessment Criteria)

Below, we therefore take a practical approach to assessing animal welfare under Swiss conditions. Based on the assessment of animal husbandry experts (the authors of this report and additional animal husbandry experts at Agroscope), we determine the extent to which a farm that complies with the requirements of the Animal Protection Law as well as with PAS and ROEL conditions already covers the twelve animal welfare aspects of the Welfare Quality Protocol:

- Absence of prolonged thirst
- Absence of prolonged hunger
- Comfort when resting
- Thermal comfort
- Freedom of movement
- Absence of injury
- Absence of disease
- Absence of management-related pain
- Expression of social behaviour
- Expression of other behaviours
- Good human/animal relationship
- Positive emotional state

In the present project, this assessment is carried out using dairy cows and fattening pigs as examples (Table 35). The system boundary is the farm; a separate assessment would need to be undertaken for transport and slaughter. The aim of this assessment is to indentify, for the various aspects, areas in which there is still potential for improving animal welfare above and beyond the PAS and ROEL requirements. A list of parameters which in any case could be captured through self-declaration by the farmer or by using farm checks is compiled for these inadequately covered aspects (see Chapter 5.3, QBA).

5.5.1 Completeness of Scope

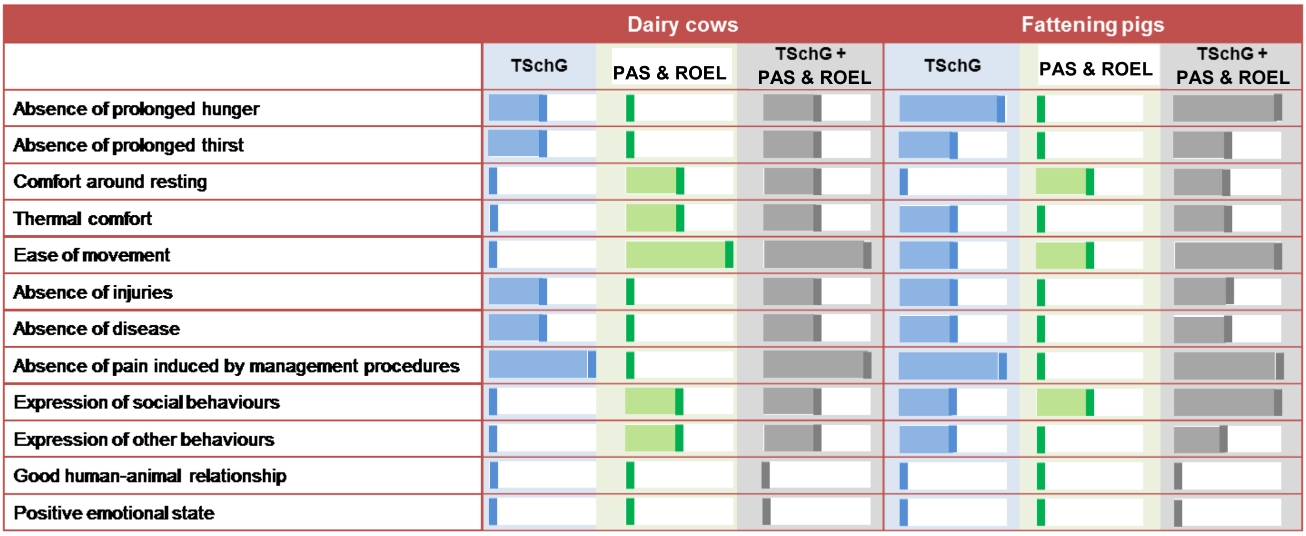
Different animal species have different needs, and therefore place different demands on their housing environments. Moreover, both the Animal Protection Law and the requirements of the PAS and ROEL ethology programmes vary hugely according to animal species. For dairy cows, according to the requirements of the Animal Protection Law, tied housing with a defined number of days access to an outdoor exercise area is the minimum standard. The main difference between this and compliance with PAS and ROEL is that the latter two programmes stipulate freestall housing with nearly daily outdoor exercise and grazing in the summer. The housing of fattening pigs in partially slatted pens will be mandatory after expiry of the phase-out period in 2018. A farm participating in PAS and ROEL programmes will also provide pigs with an outdoor run, outdoor access, and straw litter in the resting area.

The evaluation of the coverage of the twelve animal welfare aspects by the relevant legal bases (described in greater detail below), undertaken as part of this report, is displayed in Table 35. The rating per aspect of the legal situation is as follows:

(0) minimal coverage of the aspect
(1) partial coverage of the aspect
(2) reasonably good coverage of the aspect in animal welfare terms.

The initial situation consisted of the minimum requirements according to the Animal Protection Law (dairy cows: tied housing; fattening pigs: partially slatted pen).A rating of (0) with respect to the Animal Protection Law means that the minimum requirements for animal-friendly housing are met; for PAS and ROEL, that no specific requirements have been formulated in terms of this aspect. A rating of (1) or (2) indicates that further, more precisely stated specifications concerning an aspect are to be found in the Animal Protection Law and for PAS and ROEL. Here, a rating of (2) represents reasonably good conditions within the context of present-day housing systems and the current state of knowledge for animal-friendly housing, but need not yet be the optimum. A three-tier rating system is deliberately used here, and is applied jointly to both PAS and ROEL requirements. A separate statement for both would be scientifically untenable, and ultimately not appropriate for the stated objectives.

Table 35: Coverage of the 12 animal welfare aspects by the Animal Protection Law (TSchG) (in blue) and the PAS and ROEL ethology programmes (in green) as well as combined (in grey) for dairy cows and fattening pigs. The bigger the bar, the better the aspect is c covered by the legislation in question (0–2). A full bar does not represent the optimum, but rather a reasonable situation within the context of present-day housing conditions.



Absence of prolonged thirst

According to the Animal Protection Law, cattle must be watered at least twice daily (1). Under PAS and ROEL, the flooring in the water trough and feeding area must also be solid, which does not represent a substantial improvement for this aspect (0). Water ad libitum and guaranteed access to water thanks to an adequate flow and an appropriate animal/trough ratio would further contribute to the absence of prolonged thirst.

By contrast, the Animal Protection Law stipulates that pigs must have round-the-clock access to water, and the number of troughs per animal is specified (2). Apart from solid flooring around the water trough and feed areas, The PAS and ROEL guidelines for pigs make no further stipulations (0). Further optimisation of conditions would require guaranteed functioning of the troughs and an adequate flow of water to them.

Absence of prolonged hunger

The absence of prolonged hunger in cattle is regulated in the Animal Protection Law via general articles as well as the definition of feeding-place size and animal/feeding-place ratio (1). Although ROEL stipulates grazing and defines the minimum state for the grass sward, grazing only serves as an additional source of fodder during the summer period, and need only cover one-quarter of basic-ration consumption (0). Feed ad libitum, and in particular a species-appropriate ration, and hence a high proportion of roughage, should be offered with a view to optimising dairy-cow welfare in terms of feeding. Nutritional status per se can be reliably evaluated via the regular assessment of a so-called body condition score.

The Animal Protection law also regulates the animal/feeding-place ratio for pigs (1), whilst no further require-ments in terms of feeding are made by PAS and ROEL (0). For pigs too, nutritional status per se can be reliably evaluated via regular assessment of a so-called body condition score. Because of the required high daily weight gains, a needs-based ration is the norm on most pig-fattening farms. A diet geared exclusively to energy and protein content is not necessarily animal-friendly, however, whilst the provision of roughage would lead to a greater feeling of satiety as well as a slower and therefore physiologically more favourable passage through the intestine, which would in turn have a positive effect on animal welfare (Wenk 2001).

Comfort when resting

The Animal Protection Law prescribes minimum bedding for dairy cows. In addition, the dimensions of the resting area as well as the resting-area ratio is regulated. Nevertheless, tied housing is suboptimal in terms of the animals' ability to lie down and stand up unimpeded, as well as restricting the animals in terms of synchronisation of resting behaviour and the choice of resting partners (0). Freestall housing and stricter provisions concerning the materials in the resting area as well as grazing in the summer enable greater resting comfort for dairy cows in PAS and ROEL housing, particulary since they have a preferred surface to lie on (soft and malleable; 1) at their disposal. Because they mimic natural resting conditions, permanent access to pasture and the exclusive use of straw mattresses or deep litter in the resting area would encourage natural resting behaviour, thereby further increasing resting comfort. Selected resting-cubicle dividers could ensure even better freedom of movement.

The Animal Protection Law does not specify litter bedding for fattening pigs; fully slatted flooring will be prohibited after expiry of the phase-out period in 2018. The distinction between a resting and activity area in the exercise yard – made possible by PAS and ROEL – should separate active from inactive animals, allowing pigs to lie undisturbed. The required litter is still not sufficient to offer the pigs adequate resting comfort, however (1). For this, rubber mats below the litter or deep litter would be needed. In hot weather, however, bedding may even be contraindicated, and heat-dissipating resting areas would be needed.

Thermal comfort

The Animal Protection Law contains almost no provisions concerning thermal comfort in dairy-cow housing (0). In PAS and ROEL housing, dairy cows can choose between different housing areas owing to their freedom of movement, but there are no regulations concerning the climate in the housing (e.g. ventilation) (1). Permanent access to an outdoor exercise area or pasture would provide the cows with more options, and would thus have a positive impact on thermoregulation. Where non-year-round grazing is the case, however, shelters are not specified – and these are essential for preventing heat stress. Heat stress in the housing can be reduced via facilities such as sprinklers or fans.

The Animal Protection law formulates precise guidelines for avoiding heat and cold stress in pigs. Individual thermoregulation owing to free choice of housing area is already in place, thanks to mandatory group housing (1). The explicit distinction between littered and non-littered areas in PAS and ROEL farms only offers the pigs a clearer distinction between two thermal zones. The as-a-rule permanently accessible outdoor exercise area offers additional space, which should be an advantage in hot weather (0). Nevertheless, installed cooling facilities (shower, wallow) in hot weather as well as additional rubber mats in the littered resting area, or even deep litter for insulation in cold weather, would be important provisions to allow substantial improvement in the thermoregulation of pigs. Installing a shade net in the outdoor area for the prevention of sunburn should also be essential.

Freedom of movement

Although the Animal Protection Law stipulates access to an outdoor exercise area for all cattle on a total of 90 days a year (30 days in winter, 60 days in summer), no minimum duration is specified. Consequently, tethered dairy cows are currently ensured only minimal freedom of movement (0). Loose housing guarantees freedom of movement within the housing. Depending on their dimensions, outdoor exercise area and pasture offer additional space, and hence freedom of movement. In addition, PAS and ROEL specify different minimum areas according to horn status (2). Permanent access to an outdoor exercise area and/or 24-hour access to pasture would ensure optimal freedom of movement, provided the cows were not restricted owing to poor soil quality or hoof and limb ailments. The Animal Protection Law only minimally regulates flooring quality in the housing; in addition, the quality of cattle tracks should also be borne in mind here.

The stipulation of group housing and minimum dimensions as well as a ban on fully slatted floors as per the Animal Protection Law ensure freedom of movement for fattening pigs (1), with an outdoor exercise area creating additional space, and hence enabling more movement (1). Permanent access to an outdoor exercise area of appropriate dimensions, or to pasture, as well as minimum requirements for soil quality with good hoof and limb health would have a further favourable impact on freedom of movement.

Absence of injury and disease

Among dairy cows, the prevalence of injury and disease is strongly management-related. Although there is no specific regulation in the Animal Protection Law, there is a duty of prevention and treatment on the part of the livestock owner. In addition, mass-produced housing and control facilities for cattle are only approved after thorough testing, with the aim of reducing the risk of injury (1). Increased comfort while resting and freedom of movement, as encouraged by PAS and ROEL, can have a positive effect on specific health parameters (e.g. hock and teat injuries), whilst other problems such as lameness or hoof health are unlikely to be affected one way or the other (0). Monitoring of the herd by the cattle health service would lead to improvements here, both as prophylaxis and with already existing problems.

The health of pigs is also strongly management-related, and is only regulated by general articles in the Animal Protection Law. Here too, there is a duty of prevention and treatment on the part of the livestock owner. The testing and authorisation process for mass-produced housing and control facilities for pigs reduces the risk of injury in the housing to the greatest extent possible, however (1). PAS and ROEL have no further requirements here; their effects on health parameters are not unequivocally positive (0). In addition to ailments – particularly of the lungs – related to the climate in the housing, the main problem with injuries in pigs frequently consists of manipulative behaviour towards conspecifics, such as tail-biting. Although this is a multifactorial problem, its severity can be reduced by deliberately keeping the animals occupied, e.g. by providing a wallowing area (deep litter, pasture,) rooting area. Monitoring of the herd by the pig health service would be helpful, both as prophylaxis and for already existing problems.

Absence of management-related pain

With cattle, the Animal Protection law only permits procedures to be carried out on the animal if analgesia is used (2). This aspect is therefore covered for cows with respect to acute management-related pain. To be able to rule out any long-term adverse effects from the improper performance of the procedure in question, the dehorning of cows, for example, would have to be prohibited.

With pigs too, painful procedures may only be undertaken under analgesia (2). Here, additional improvements might be achieved with provisions for the treatment of postoperative pain after castration. In order to completely rule out management-related pain in pigs, castration would have to be categorically banned.

Expression of social behaviour

Although the opportunity for cattle to express social behaviour is governed by general provisions in the Animal Protection Law, the conditions are only minimally met in tied housing (0). Loose housing ensures social behaviour (1), but cramped conditions or non- or poorly structured housing can lead to an increase in agonistic behaviour, and thus stress. Increased space provided by a permanently available outdoor exercise area or pasture would therefore make sense. A management approach leading to a stable herd with as few changes as possible, as well as distinguishing between the space requirements of horned and unhorned animals and a suitable structuring of the areas would help to prevent excessive hierarchical fighting.

A housing system as required for fattening pigs in the Animal Protection Law enables social behaviour in stable groups (1). However, unstructured, still relatively cramped conditions make it hard for pigs to avoid other animals or withdraw. PAS and ROEL call for an additional outdoor exercise area, which has a positive effect in this respect (1). A lower animal density and specific infrastructure for diversion (rooting behaviour, exploration), or the housing of pigs in mixed-age family groups, as in nature, would be further optimisation possibilities.

Expression of other behaviours

Tied housing also prevents, or at least strongly limits, other behaviour in cattle (0).By contrast, freestall housing, an outdoor exercise area and pasture offer an enriched environment and increased space, thus allowing explorative behaviour, comfort behaviour such as grooming, and natural feeding behaviour (1). Since grazing is only possible in summer, an appropriate ration for the species in question, with a high percentage of roughage with a view to rumination and proper insalivation of the food, can meet the demands of natural feed consumption. Comfort behaviour can be encouraged by offering rotating scratching brushes. As the present-day production system completely suppresses the cow-calf relationship, mother-bonded calf rearing offer the most humane solution for cow and calf in this respect.

According to the Animal Protection Law, manipulable materials must be made constantly available to fattening pigs (1). However, the need to root and explore, which is very strong in pigs, cannot be adequately met either by these materials or by the bedding specified in PAS and ROEL (0).For this, deep litter, pasture or a rooting area would be necessary. These infrastructures keep pigs suitably occupied, as well as offering the chance to express exploratory behaviour. Here, keeping the pigs in family housing offers the appropriate infrastructure.

Good human/animal relationship and positive emotional state

Neither the Animal Protection Law nor the PAS and ROEL regulations contain explicit provisions concerning the human/animal relationship or the emotion state of an animal (0).A good human/animal relationship leads to reduced stress during handling (milking, hoof care, medical treatments, transport) and in certain circumstances also represents intensiveness of care. Unlike dairy cows, fattening pigs are scarcely handled, and can therefore be more prone to stress, e.g. when they are transported.

The emotional state of an animal highlights the extent to which its resilience is overtaxed, and thus reflects the animal's current overall state, in which all aspects of animal welfare play a part. Research into animal emotions is still in its infancy, however, and their survey is not yet possible within a practicable framework (see Table 36).

The animal welfare aspects not adequately covered by the Animal Welfare Law or PAS and ROEL are summarised in Table 36. The parameters proposed to capture them could be surveyed e.g. by self-declaration, or alternatively as part of a farm inspection.

Table 36: Proposed list of parameters for the further coverage of the twelve animal welfare aspects for dairy cows and fattening pigs

Aspect	Dairy Cows	Fattening Pigs
Absence of persistent thirst	Water *ad libitum*[1)] Animals: water troughs[2)] Functioning water troughs[1)]	Functioning water troughs[1)]
Absence of persistent hunger	Feed *ad libitum*[1)] Roughage: concentrate[2)] Body condition score[2)]	Roughage[1)] Body condition score[2)]
Comfort when resting	Deep litter or straw mattress[1)] All-day access to pasture[1)]	Rubber mats in the resting area[1)] Deep litter[1)]
Thermal comfort	Fans, sprinkler, air conditioning[1)] Housing system (Open, cold, warm stable)[3)] Insulation[1)]	Rubber mats in the resting area[1)] Deep litter[1)] Sprinkler, shower, wallow[1)] Nets in the outdoor exercise area for protection from the sun[1)]
Freedom of movement	Permanently accessible outdoor exercise area[1)] Soil/Flooring / Cattle-track quality[3)] Hoof-care frequency[2)]	Pasture[1)] Soil quality[3)] Hoof and limb health[3)]

Absence of injury	Herd monitoring[1] Hoof-care frequency[2]	Herd monitoring[1] Deep litter[1]
Absence of disease	Herd monitoring[1]	Herd monitoring[1]
Absence of management-induced pain	Dehorning[1]	Castration[1]
Social behaviour	Structuring of housing and outdoor exercise area[1,3] Herdmanagement[3] Space conditions[2]	Pasture[1] Structuring of housing and outdoor exercise area[1,3] Deep litter[1] Housing in family groups[1]
Other behaviours	Opportunity to graze[1] Roughage: concentrate[2] Space conditions[2] Permanently accessible outdoor exercise area[1] Permanently accessible pasture[1] Scratching brush[1] Mother-bonded calf rearing[1]	Pasture[1] Wallow[1] Deep litter[1] Wallow area[1] Roughage[1] Housing in family groups[1]
Human/animal relationship	?	?
Positive emotions	?	?

[1] yes / no
[2] numerical
[3] qualitative

5.5.2 Assessment of Robustness and Uncertainties

The process outlined in this project is a first step towards an animal welfare assessment that would be feasible for a large number of farms operating under Swiss conditions. For a scientifically well supported and technically correct process, it would be necessary (1) to check whether farms that comply with PAS and ROEL actually receive a better animal welfare assessment than those that only comply with the requirements of the Animal Protection Law, and (2) to determine how aspects that are lacking can be surveyed in a valid and reliable manner. This would require further steps to be undertaken, and we would undoubtedly run up against various uncertainties and methodological weaknesses.

In terms of the demands made by an animal species on animal-friendly housing, it must be borne in mind that the components of PAS and ROEL have a different meaning for animal welfare depending on the species in question. Whilst for dairy cows litter primarily serves to increase resting comfort, for fattening pigs it is also a material to be manipulated and to satisfy rooting behaviour (Tuyttens 2005). This could result in the animal welfare evaluation via PAS and ROEL not being equally suitable for all animal species. Moreover, the legal requirements of the Animal Protection Law, PAS and ROEL differ for individual farm activities in terms of infrastructure and management. Litter must be made available to dairy cows, whilst for fattening cattle slat rubber flooring already counts as “malleable material”. Furthermore, the minimum fattening period of 56 days for ROEL fattening poultry or the construction of loose housing for PAS dairy cows entails greater effort than setting up a covered outdoor area for laying hens, and thus probably also has other effects on the animal. The precise clarification of the coverage of all animal welfare aspects for each individual animal species / farm activity is therefore a requirement for being able to confirm PAS and ROEL as animal welfare indicators. In the last analysis, the assessment made here for dairy cows and pigs is currently no more than a hypothesis that would have to be verified with data surveys. For other farm activities and animal species (e.g. poultry (laying hens, fattening poultry), breeding sows, suckling piglets, calf rearing and fattening, cattle fattening, goat and sheep husbandry, rabbit breeding and fattening), this assessment does not yet exist.

Moreover, animal welfare assessment based on PAS and ROEL is chiefly resource-based, which could limit the validity of its provisions. No animal-related parameters are collected, and the factor 'management' is scarcely taken into account. This can definitely cancel out the positive effect of a resource (e.g. wet, soiled litter; outdoor exercise area with inadequate dimensions). Thus, the previous evaluation of PAS and ROEL for dairy cows and fattening pigs also yielded inconsistent results, which could be traced back to the management effects. An indication of this is that PAS and ROEL for fattening pigs which are kept for a relative short time in for-the-most-part standardised systems and with little direct contact with people had a more positive impact on health and behaviour(Cagienard *et al.* 2005) than was the case for dairy cows (Regula *et al.* 2004). The latter have a much longer useful life than pigs and are in daily close contact with humans (e.g. during milking), which therefore significantly increases influenceability by management factors.
The simplest and most efficient way to collect additional animal welfare parameters would be as part of a self-declaration that would be spot-checked. Because of the individual definition and perception of animal welfare (see Chapter 5.2), the self-declaration requires very specific questions with as little wiggle room for interpretation as possible, which is why it is primarily questions that must be answered with a yes or no that should be incorporated in the list of parameters for self-declaration (Table 36). The extent to which these parameters are valid and reliably measurable, and whether and how a self-declaration would work, would also still have to be tested, however.
At present, there are still no practical methods for assessing a good human/animal relationship or the positive emotional state of an animal. These aspects can therefore not be covered, which translates into a data gap. Whereas the emotional state could represent the overall well-being of an individual and could thus in certain circumstances be suitable as a sole indicator, at least for the current situation, the importance of a good animal/human relationship is a matter of debate. On small farms with a great deal of interaction between human and animal, a good relationship demonstrably reduces stress; on large or low-input farms, animal welfare might depend considerably less on the human/animal relationship. Because of the high research interest in these areas, however, new findings are to be expected here in the next few years.

5.5.3 Transparency and Reproducibility

PAS and ROEL are transparent animal welfare indicators, since specific requirements apply for each animal species, allowing their effect on each individual aspect of animal welfare to be assessed for each individual species. The resource-based parameters on which PAS and ROEL are mainly based are clearly defined, understandable, simple to check, and thus presumably easily reproducible. To ensure that the additional parameters to be surveyed via self-declaration also remain transparent, they must be clearly defined. To ensure reproducibility, management-based parameters for self-declaration should ideally be phrased as binary questions, whilst a clearly defined selection of response options should be provided for questions requiring a numerical or qualitative response.

5.5.4 Applicability: Communicability and Practicability

A good level of acceptance can be assumed for the method proposed here for the evaluation of areas not yet covered by PAS and ROEL. Since the twelve Welfare Quality® aspects contain all three approaches according to Fraser (see Chapter 5.1), they also cover all the expectations of the various population groups and involved stakeholders. Here, it should be borne in mind that Table 36 only contains suggestions for a more comprehensive animal welfare assessment. For the selection of the parameters, in addition to considering feasibility, validity and reproducibility, we must clarify how high the specific criteria and aspects should be rated in order to determine what the strategy deems to be a maximum animal welfare rating (full bar in the diagram shown here). The undertaken assessment only reveals which areas contain more or less potential. As set out in the introduction, the awarding of the points and the number of points to be attained can be based not only on scientific knowledge about animal welfare, but also on the values and ideas of the stakeholders in each case.
PAS and ROEL are already established on many Swiss farms (Table 34). Since they are tested as part of the PEP inspections, evidence of their implementation is already available on an individual-farm basis. When ascertaining additional requirements, it should be checked whether these are not already covered by other

programmes. If, for example, specifications on the roughage/concentrate ratio for dairy cows are to be established, this could be accomplished through participation in the 'Contribution for grassland-based milk and meat production (GMM)' programme. Most data is probably not already available, however, and would have to be collected anew. Data to be self-declared, for instance, could be incorporated in the IP Suisse database upon collection. The data declared by the farmer would have to be checked via a survey on the farm, and ideally included in the already performed checks. Violations would need to result in a downgrading in the animal welfare assessment.

5.6 Recommendation

Animal welfare is dependent upon values and ideals, and from a scientific point of view cannot be conclusively defined or evaluated. The approach pursued here of checking and supplementing the completeness of already available data on animal welfare assessment is above all useful in terms of its broad application in practice. The process described here is intended to illustrate how the completeness of an indicator can be assessed in a relatively pragmatic manner. Nevertheless, this should only be viewed as the first step of an animal welfare assessment within the context of a sustainability concept. Considerable research is still needed in this field.
For one thing, the correlation of the resource-based indicators PAS and ROEL with actual animal welfare ought to undergo further scientific testing. Since there is no gold standard for animal welfare assessment, the question of a suitable reference value is a pressing one. In addition to an evaluation of the extent to which the individual animal welfare aspects are covered, an evaluation of the correlation with other animal-welfare assessment methods is needed. The comparison of Welfare Quality®, QBA and AWI findings with the animal welfare standard followed on the farm in question would be apt here. Furthermore, the additional suggested parameters should also be validated and examined as to their feasibility before being included in the animal welfare assessment. For this, a species- and farm-activity-specific analysis is essential. The areas 'positive emotional state' and 'good human/animal relationship' require further research.

5.7 Conclusions

The current state of knowledge precludes a conclusive definition of animal welfare, and thus the derivation of a scientifically sound, generally valid animal welfare index. A reduction to just a few indicators, or even a single indicator (e.g. antibiotic use) for the assessment of animal welfare is presumably not possible, since it could not do justice to the complexity and multidimensionality of this subject; furthermore, the relevant data for this, at least at present, are not available in suitable form.
Given the current state of knowledge, reliance on a multitude of parameters that cover the twelve mentioned animal welfare aspects as thoroughly as possible is essential. Although the choice of parameters as well as their offsetting and weighting is ultimately always subjective, it can and should be based as far as possible on expert opinions and specialist knowledge. In the final analysis, each animal welfare index is simply created specifically for a particular audience and purpose: animal welfare is what the animal welfare index measures.
For practical reasons as well as to limit costs, we propose using already-available data to define the parameters of this project. For Swiss conditions, the ideal approach here at present is to include data that had already been collected for PAS and ROEL Here too, however, the question of valid, feasible and reproducible parameters remains unsettled. Furthermore, the proposed parameters for examining the aspects of animal welfare not covered by PAS and ROEL should also be defined, and their suitability scientifically clarified.

6 Visual quality of the landscape

Beatrice Schüpbach, Andreas Roesch

6.1 Introduction

Agriculture (including summer grazing areas) occupies just under 36% of Switzerland's surface area (BFS 2013), thus leaving its mark on large parts of the country. According to the Millennium Ecosystem Assessment (MEA), aesthetic and spiritual 'services' form part of the 'cultural ecosystem services' (MEA 2005). This means that, aside from producing food, a sustainable agricultural sector contributes with a beautiful landscape to both cultural identity and to human well-being. The area used for agriculture is often also a recreational area for the population. Recreation and well-being are components of the social dimension of sustainability.

Research on landscape perception has led to various theories to explain landscape preferences. Bourassa (1991) has studied these theories in depth, and summarised them into three levels. The first level – the 'biological level', encompasses the so-called habitat theories (e.g.Kaplan and Kaplan 1989; Orians 2001). The habitat theories explain landscape preferences with evolutionary-biological arguments. A landscape that made it easier for early humans to survive is also still preferred today. Such a landscape offers e.g. variety and easy orientation in space, but also opportunities for concealing oneself. The landscape preferences explained by the 'biological level' are stable over time as well as over different cultures, population groups and social strata. People like park-like (savanna-like) landscapes and landscapes with stretches and bodies of water. The second level – the social level – explains the symbolic content of a landscape with social and cultural arguments. Thus, landscapes that trigger feelings such as 'being at home', 'identification' and ''place attachment' are preferred. As these preferences are related to the social and cultural background of the individual, they may change over time, as well as between different cultures, population groups and social strata. The third level posited by Bourassa (1991) is the individual level, which explains a portion of landscape preferences through individual experience, knowledge and desires.

In summary, we can state that landscape perception encompasses both objective and subjective aspects. In addition, there is a wide range of models allowing the visual quality of the landscape to be measured.

6.2 Relevance of the Topic

The rating of the visual quality of the landscape as a component of the social dimension of sustainability is often neglected when assessing sustainability, as shown by an overview of various life-cycle assessment and LCA-like methods (Biewald and Schumacher 1991; Brosson 1999; Wetterich and Haas 1999; Oppermann 2003a; Braband 2006; Westbury *et al.* 2011; Louwagie *et al.* 2012). In these methods, the visual quality of the landscape is frequently not explicitly considered as an environmental category, but as a component of biodiversity (Wetterich and Haas 1999;Braband 2006; Grenz *et al.* 2012c). Blumentrath (2010) developed a comprehensive methodology for assessing the landscape which he termed the 'aesthetic farm inventory'. Focusing exclusively on the visual quality of the landscape, it is based on various landscape inventories and the input of landscape elements by the farmers via a GIS Web interface. The aim is to show farmers where they could improve their environmental services. Owing to the extensive data input, this methodology is too complex for an assessment of overall sustainability.

The inclusion of visual quality of the landscape in a sustainability assessment is important for two reasons. Firstly, it also takes account of the needs of the non-agricultural population, whereas Chapter 3 presents methodologies for assessing the well-being of the farmers. The population not only supports the agricultural sector indirectly via government direct payments, but also via the purchase of its products. If it can be shown that certain products lead to a more attractive landscape, this is a (further) argument for a more sustainable agricultural sector. The second reason has to do with the assessment of the dairy and meat industry. With previous life-cycle assessment methods (e.g. SALCA), farms with low-input pasture-based cattle husbandry (e.g. suckler-cow production) often possess greater biodiversity, but have a worse climate balance than intensive indoor operations, and achieve lower yields. That is why low-input cattle farming is frequently rated in LCAs as less advantageous than intensive (housing-based) cattle farming. When considering visual quality of landscape, it becomes clear that such low-input areas, which often occur in low-input pasture-based cattle farming, are highly rated. This also applies for grazing cows (Schüpbach *et al.* 2009). Thus, inclusion of visual quality of landscape could lead to a differentiated picture, particularly in cattle farming. Here, however, a suitable indicator must be developed.

6.3 Overview

6.3.1 Theoretical Background to Landscape Indicators

Interest in visual quality of the landscape as a 'by-product' of agriculture and its importance for the population's leisure and recreation continue to increase. Also associated with this is the acknowledgement, by means of direct payments in both Switzerland and the EU, of the stewardship services rendered by agriculture. Accordingly, scientists are endeavouring to supplement the studies examining the effect of direct payments (EEA 2005, 2006; Dramstad and Fjellstad 2011; Paracchini and Capitani 2011; Paracchini *et al.* 2012; Kienast *et al.* 2013) with appropriate indicators.

A comprehensive tool for defining indicators for measuring landscape quality was developed byTveit *et al.* (2006). The tool comprises nine concepts for rating the various aspects of landscape preferences, and proposes landscape quality assessment indicators for this purpose. The nine concepts are summarised in Table 37.

Table 37: The nine concepts according to Tveit et al. (2006) with descriptions and potential indicators

Concept	Description	Potential Indicators
Stewardship	Measures the degree of order in the landscape, and the extent to which the landscape is cared for.	Percentage of land invaded by scrub or gone fallow, Maintenance of buildings
Coherence of the landscape	Measures the adaptation of land use to environmental conditions, or the unity of a landscape through repeating patterns.	Repeating patterns of colours and structures, the matching of land use and natural potential
Disturbance of the landscape	Measures the opposite of the foregoing. A 'disturbed landscape' lacks coherence. Non-matching elements occur side by side.	Number and visibility of disturbing and foreign elements
Historicity	Measures historical continuity and the visibility of history in the landscape.	Number and age of cultural elements (buildings, fountains, wayside crosses, walls, fences, etc.) in the landscape
Visual scale	Describes the spatial structure of the landscape.	The topography, the openness of the landscape or the degree of patchwork structure
Imageability	Measures the uniqueness of the landscape through landmarks, vantage points or other special landscape elements.	Number of vantage points, historic elements, unique elements; number of still or flowing bodies of water
Complexity	Describes the variety and diversity of the landscape.	Diversity or dominance indicators, variety of forms and boundaries
Naturalness	Measures the proximity of the landscape to a state defined as 'natural'.	Land-use intensity, differentiation into permanent and temporary land-use forms

Concept	Description	Potential Indicators
Ephemera Weather phenomena, or the visibility of the changing seasons in the landscape	Weather-related and seasonal changes in the landscape are grouped together under the heading of ephemera (short-lived phenomena). This concept measures the extent to which landscape elements or forms of land use can render weather-related or seasonal changes visible.	Percentage of landscape elements that show seasonal changes

Of these nine concepts, it is mainly the concept of 'complexity' that has heretofore been the most used in the development of landscape indicators. The diversity of the landscape can be measured relatively easily with diversity indices, which use the number and percentage of landscape elements within a landscape to measure the latter's diversity. Thanks to its simple calculation method, this approach has already been frequently applied (Hunziker and Kienast 1999; Dramstad *et al.* 2006; Ode and Miller 2011; Frank *et al.* 2013; Plexida *et al.* 2014). Individual studies have demonstrated a correlation between landscape preference and diversity (Dramstad *et al.* 2006; Ode and Miller 2011). However, these studies also show that more diversity need not necessarily lead to a higher preference. Both Tveit *et al.* (2006) and Kaplan and Kaplan (1989) remark that more diversity does not perforce equate with a 'more beautiful' landscape.

In the past, the concept of 'naturalness' has only been used in landscape aesthetics in isolated cases (Hoisl *et al.* 1987). The aesthetic concept of naturalness must be clearly distinguished from the environmental approach to naturalness. The aesthetic concept rates standard orchards highly, even when they are sprayed with pesticides several times a year, because they represent a permanent crop and an original form of a tree-populated meadow. Hoisl *et al.* (1987) define the concept of naturalness along these lines.

The concept of 'ephemera' has probably been the least-considered concept in landscape assessment to date, despite the seasons being an important feature of the temperate climate zones (Brassley 1998; Jones 2007). It has been demonstrated that cultivation clearly influences the visibility of seasonal change in the agricultural landscape (Stobbelaar *et al.* 2004; Stobbelaar and Hendriks 2007). Seasonal changes are therefore an ideal way to measure the effects of different management on the visual quality of the landscape.

6.3.2 Preliminary Work for Developing an Indicator

The most important foundation for developing an indicator for the consideration of visual quality of landscape in the SALCA life cycle assessment method consists of the preference values for the seven most important crops and the seven most important types of Areas Reserved for Promoting Biodiversity (ARPB) in the Swiss Midlands. The preference values were collected by means of an extensive survey (Schüpbach *et al.* 2009). A selection of four pictures of different crops at different stages of development were rated by 1500 participants and 280 farmers. The preference values are available for the following crops and Areas Reserved for Promoting Biodiversity (ARPB): maize, sugar beet, (winter) wheat, high-input permanent meadow, grass-clover ley, high-input pasture, low-input meadow, wet meadow, field margin, wildflower strip, hedgerow, and standard fruit trees on high-input meadow.

Preference values for the four to six most important stages of development are available for each of the listed elements. These preference values were interpolated with a temporal weighting to a series of preference values between March and October with an interval of two weeks (Figure 10). This yields thirteen preference values per evaluated crop, which can be summarised into a time-weighted average preference value.

The preference values represent a possible assessment of 'naturalness'. Since preference values for different developmental points in time (i.e. different seasons) are available for each evaluated landscape element, the seasonal variability of a landscape element can also be portrayed via these preference values.

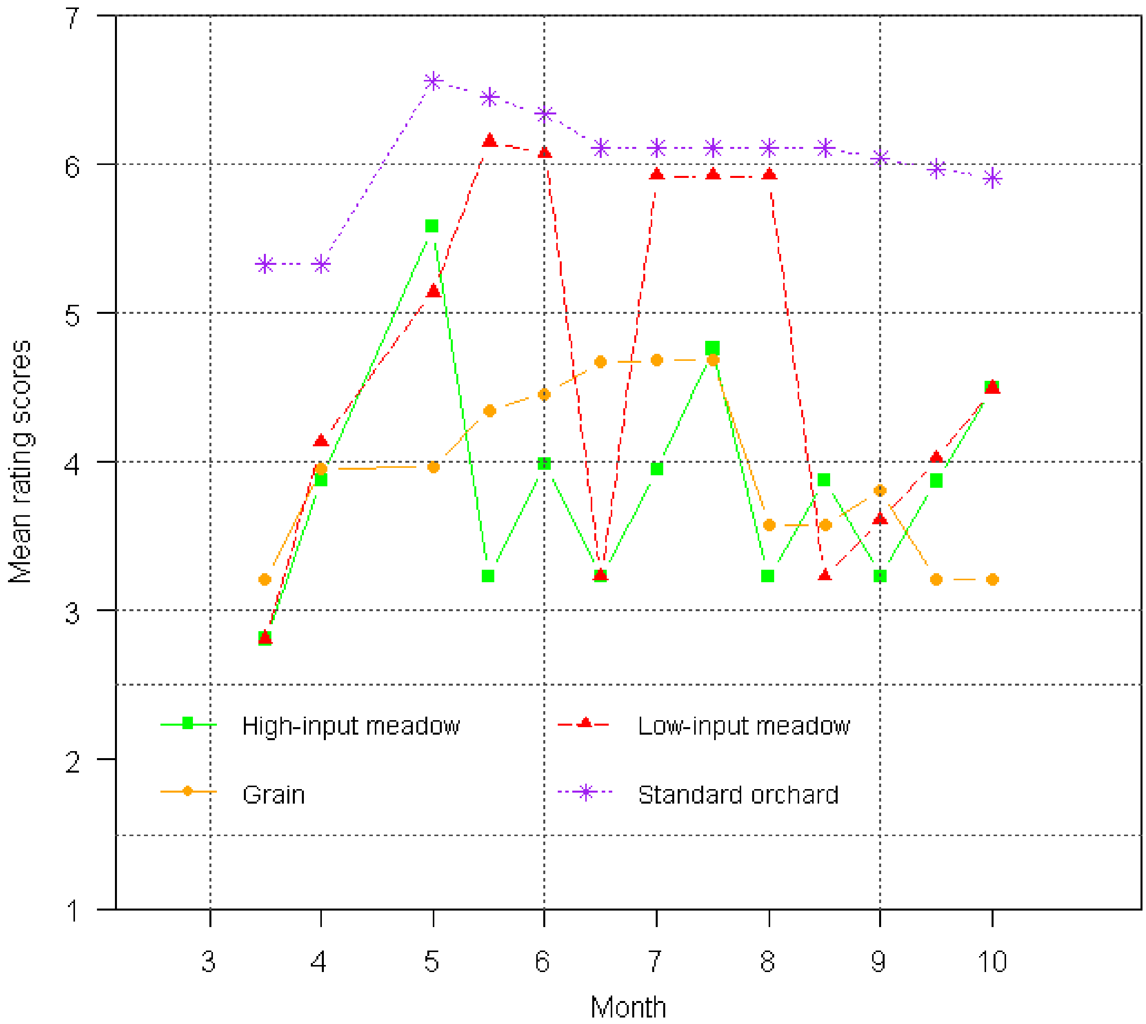


Figure 10: Trend of the preference values for 'high-input meadow', 'grains' ,'low-input meadow 'and 'standard orchards' between March and October (Schüpbach et al. 2016).

In a first trial, we examined whether an indicator for visual quality of landscape could be derived based on the farm data (percentage of crops per farm) available from the Swiss Federal Statistical Office (SFSO) and the preference values. For this, the surface areas of the individual crops per farm were multiplied by the preference values and divided by the sum of all weighted (considered) surface areas. This yielded an area-weighted preference value. It became apparent that this particularly distinguished special landscapes (e.g. landscapes dominated by standard orchards) from other landscapes. Because these remaining landscapes (dominated by arable farming or grassland) were not further differentiated, however, this easy-to-calculate, transparent indicator does not take account of the diversity of arable-crop and grassland landscapes (Figure 11).

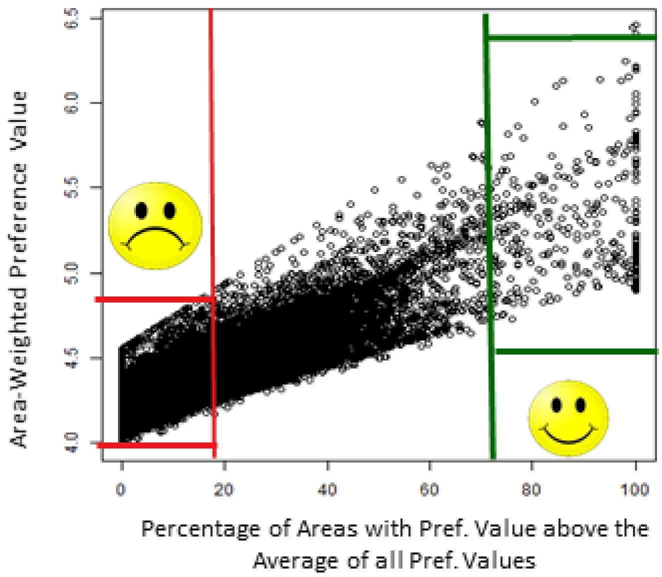


Figure 11: Area-weighted preference value as a function of the percentage of elements with preference values over the average of all preference values (percentage of ARPB). Farms with a low percentage of ARPB (below, right) are poorly differentiated; farms with a

Since the simplest version of an area-weighted indicator does not lead to the desired result, the inclusion of diversity indices (Shannon Index and Inverse Simpson Index) was tested. Based on the example of 27 landscape details of 1km^2 with land-use mapping, diversity indices with a seasonally different weighting (preference values) were calculated (Schüpbach *et al.* 2016). At first, only the weighting with preference values was used, to offset the 'more elements leads to higher diversity' effect. It appeared, however, that the weighting alone was not enough to prevent this undesired effect. We therefore attempted to modify the calculation so that changes in the landscape leading to a decrease in the surface area of highly rated landscape elements would also cause a decrease in the diversity index. For this, the 'beautiful landscape' aggregation type described below was defined. The results showed that this form of aggregation is strongly geared to the highly preferred landscape elements, and does not take account of the reality of arable farming and cattle husbandry with various grassland types (Schüpbach *et al.* 2016). For this reason, the additional two aggregation types also described below – 'diverse arable landscape' and 'diverse grassland landscape' – were developed.

- 'Beautiful landscape' aggregation type: After multiplication of their surface area by the preference value in question, all elements whose preference value lies below the average of all considered landscape elements are aggregated into a single element (i.e. all elements are only entered into the calculation formula with a probability of p_i). All remaining elements lying above the average of all considered landscape elements ARPB) are left as individual elements. Table 38 shows the average values of the individual elements. Figures in bold mean that the preference value lies above the mean of 4.857.
- 'Diverse arable landscape' aggregation type: The various types of meadow (high-input meadow, high-input pasture and grass-clover ley) are aggregated into an element. In the same way, low-input meadows/pastures and wet meadows are aggregated into an ecoelement. By contrast, all arable crops are entered individually into the calculation. Wildflower strips, field margins and hedgerows as well as standard orchards are also treated as individual elements.
- 'Diverse grassland landscape' aggregation type: For this aggregation type, all arable crops (including wildflower strips and field margins) are aggregated into an element after weighting the surface area with the relevant preference value. All of the different sorts of grassland use as well as all ARPB meadows (low-input meadow, low-input pasture and wet meadow), standard orchards and hedgerows are left as individual elements.

Table 38: Time-weighted average preference values for the individual landscape elements. Elements and values printed in bold are ARPB whose time-weighted preference value lies over the average of all preference values.

Description of Landscape Element	Average Value over the Analysed Period (March to October)
Grass-clover ley	3.994
High-input meadow	4.109
Beets	4.189
Winter cereals	4.246
Maize	4.337
Oilseed rape	4.43
High-input meadow	4.556
Wet meadow (ARPB)	4.8957
Low-input meadow (ARPB)	4.983
Wildflower strip (ARPB)	5.034
Margin (ARPB)	5.359
Hedgerow (ARPB)	5.65
Low-input meadow (ARPB)	5.77
Standard orchards (ARPB)	6.456

Figure 12 shows the land-use percentages and the modified Shannon value according to the 'beautiful landscape' aggregation type for simulated farms with different percentages of ARPB, standard orchards, meadows and arable fields. The simulated farm with the highest percentage of standard orchards achieves the lowest value of the modified Shannon Index. This means that the Index value also rises with the aggregation of the landscape elements if standard fruit trees are replaced with grassland or arable crop fields, although this would impair the original character of a special and generally prized landscape.

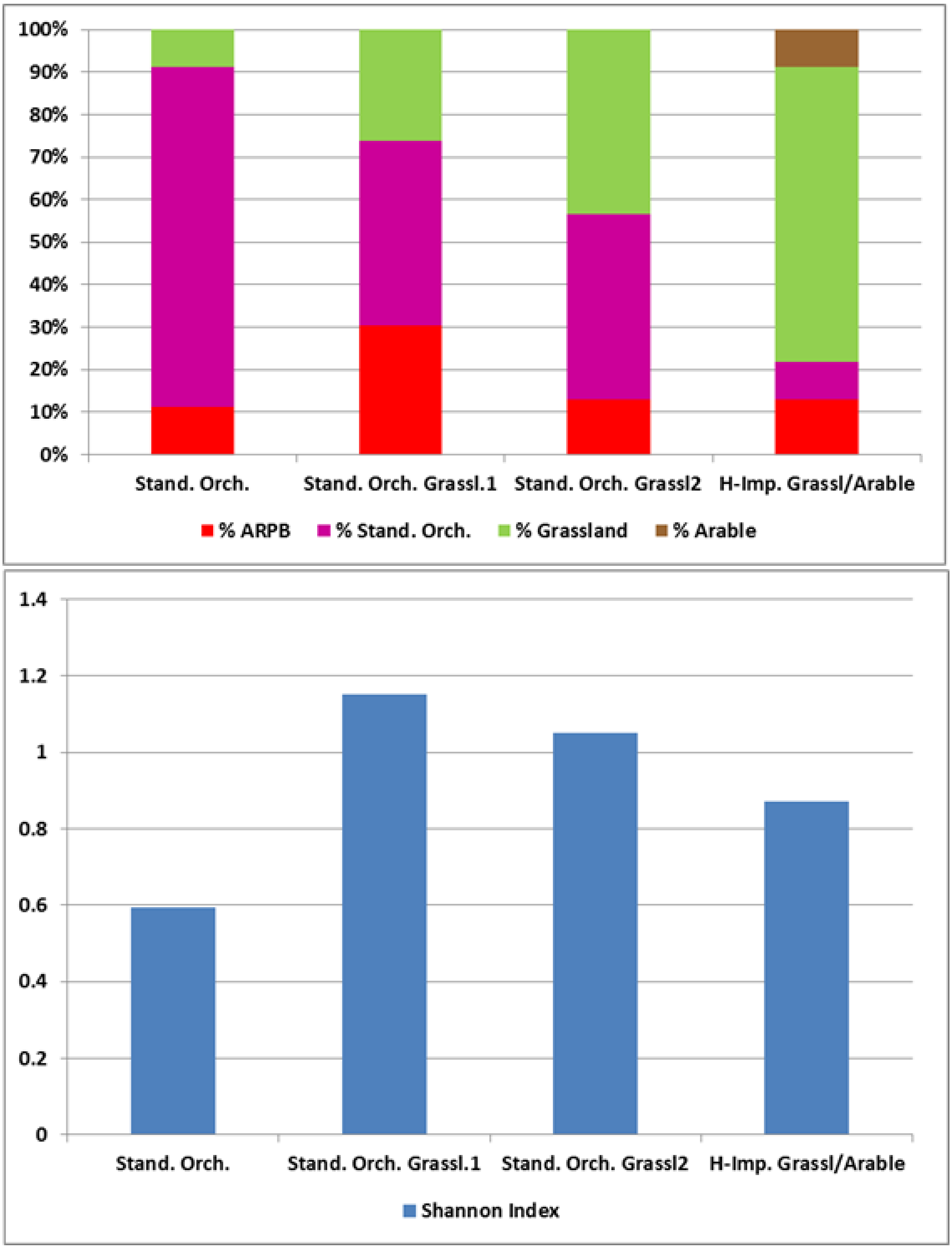


Figure 12: Land-use percentages and corresponding values of the Shannon Index weighted with the preference value, calculated according to the 'beautiful landscape' aggregation type for four different farms.

The inclusion of the preference values as a weighting has an advantageous effect, since the modified diversity indices can be calculated not only over the months of March to October with the time-weighted average, but also separately for all time steps, thereby yielding 13 additional index values. Subtracting the temporally adjacent weighted diversity indices from each other and then adding up their absolute difference results in the accumulated seasonal diversity for each unit evaluated (landscape or farm). This accumulated seasonal diversity is also to be included in the future index. In order to reduce the two indicator values (diversity of the elements and seasonal diversity) to a single value, the Euclidean distance can be calculated from the two values (cf. Figure 13).

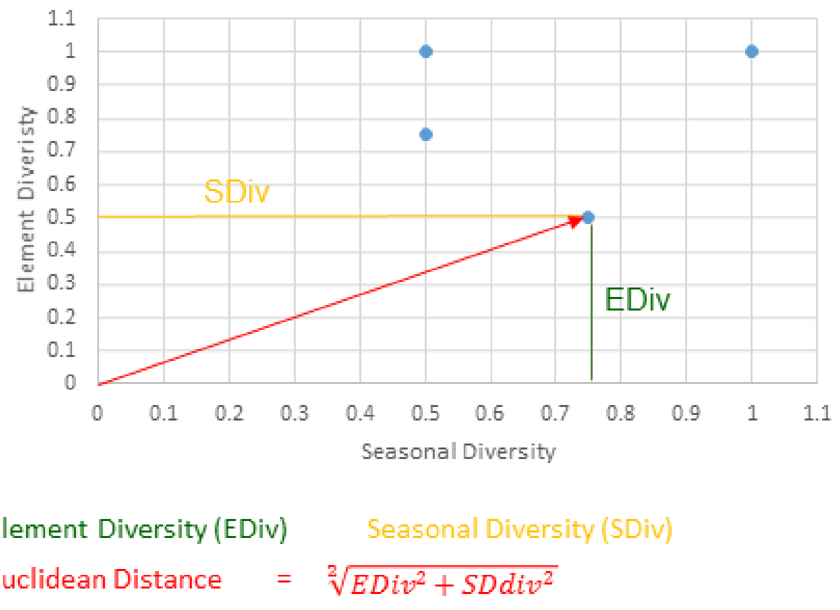


Figure 13: Calculation of the Euclidean distance for the aggregation of element diversity and seasonal diversity.

A comparison of the index values (Shannon and Simpson) showed the two indices to be strongly correlated. Since a correlation between index value and landscape preference has already been demonstrated for the Shannon Index, it make sense to use the Shannon index for the future indicator.

6.4 Description of the Indicators

6.5 Aim of the Indicator

The indicator developed here is intended both to identify the farms with a high proportion of especially beautiful landscape elements (standard fruit trees, hedgerows and other ARPB), and to measure the contribution to landscape and seasonal diversity of the remaining (arable and grassland) farms. This two-step process ensures that farms with a high proportion of ‘beautiful’ landscape elements but with low diversity are preserved, since they contribute to a special landscape type, thereby increasing landscape diversity at regional level. At the same time, however, the ‘normal’ farms (arable and grassland) can be more readily assessed with a description of their contribution to spatial and temporal diversity within the landscape of their region. Consequently, the indicator consists of two sub-indicators: an area-weighted preference value and a spatiotemporal landscape diversity index based on preference values and the methodology of a Shannon index.

6.5.1 Data Preparation

The calculation of the indicator values in this project is based on the farm data from the Swiss Federal Statistical Office (SFSO) from 2013. These data had first of all to be prepared in such a way that a preference value could be assigned to the individual land-use types. As mentioned above, preference values are only available for the most important crops and ARPB. Values for sunflower, potatoes, vegetables, berries, intensive fruit production and viticulture have been missing to date.
Since preference values are not available for all land-use types, each non-assessed land-use type had to be allocated to a land-use type with a preference value. Thus, for example, the values for beets were assigned to the missing preference values for potatoes, and wildflower-strip values were assigned to rotational fallow. For summer grain, the interpolated preference range for winter grain was adapted with the help of sowing and harvest times, and the different grain varieties (barley, oats, etc.) were summarised. A table mapping the crops to land-use types with preference values can be found in Annexe 12. No preference values are available for special crops such as vegetables, viticulture and intensive fruit production (bush trees).

The calculation of both sub-indices is only performed for farms for which a preference value, or alternatively the preference value of a replacement element or of a similar element, is available for at least 75% of the area. Forest and summer-grazing areas are not assessed, and are excluded from the farm acreage to be assessed, firstly because they do not form part of the UAA, and secondly because the summer-grazing areas are only listed in the database if the farm itself possesses summer-grazing land. This does not, however, mean that other farms would not also graze livestock on mountain pastures, thereby also contributing to stewardship in the summer-grazing area.

6.5.2 Methodological Approach

Based on the conclusions in Chapter 6.3, two indicators were calculated: the area-weighted preference value, and the spatiotemporal landscape diversity index based on preference values and the Shannon Index.
The area-weighted preference value (AwPv) is calculated from the surface areas of the individual crops and the corresponding preference value according to the following formula:

$$AwPv = \frac{\sum f_j * s_j}{\sum f_j} \qquad 2$$

where
f_i= Area of landscape element *i*
s_i= Preference value of landscape element *i*.

As described above, the spatiotemporal landscape diversity index is based on a Shannon Index H. Before calculating the index, the areas of the individual landscape elements are multiplied by the respective preference value. This yields the following formula:

$$H = -\sum_{i=1}^{n} f_i \cdot s_i \cdot \ln(f_i \cdot s_i) = -\sum_{i=1}^{n} p_i \cdot \ln(p_i) \qquad 3$$

where
f_i = Area of landscape element *i*
s_i = Preference value of landscape element *i*
n = Number of landscape elements of the farm
p_i =f_i*s_i.

The Shannon Index H describes the farm's contribution to landscape diversity. As described in Chapter 6.3, the modified Shannon Index is calculated both for the temporally weighted average preference value and for each of the 13 individual stages of the preference value between March and October. The accumulated seasonal diversity is calculated from these 13 individual stages. The two indices are aggregated into a single index via the Euclidean distance (Chapter 6.3.2).
The preference value from Schüpbach *et al* (2009) is used as a weighting for calculating both the area-weighted preference value and the various Shannon Indices (cf. Chapter 6.3.2). In addition, the landscape elements are aggregated as described above. Although the areas of the landscape elements per farm are taken from the SFSO farm data, they can also be derived from the AGIS data of the farm structure survey.

6.6 Evaluation of the Indicators

6.6.1 Completeness of Scope

With regard to the theory of Tveit *et al.* (2006) and its nine concepts (cf. Chapter 6.3), it becomes obvious that the consideration of naturalness, diversity and seasonality only takes into account a small part of the features that comprise the visual quality of the landscape. Aspects such as the comprehensibility of the history (historicity) of the landscape, its uniqueness, or its well-tended appearance (stewardship) are not included. Surveying all of these aspects for the whole of the Swiss agricultural landscape would entail a considerable expenditure of time and effort; however, it would not be possible to survey some of these aspects based solely on farm data, since cultural elements or fallow land are not available in the farm database. In order to survey further aspects, a significantly higher expenditure of time and effort would be necessary not only for data collection, but also for developing a ready-to-use indicator.

With respect to the suggested approach, it must again be emphasised that no preference values are yet available for some crops. Thus, the preference values are missing for special crops such as vegetable production, viticulture, intensive fruit production, berries, and even potatoes and sunflower. We recommend ascertaining these values with similar methods to those used to survey the first preference values (Schüpbach *et al.* 2009).

6.6.2 Assessment of Robustness and Uncertainties

The allocation of the preference values is fraught with uncertainties, since the preference values for the ARPB meadows and pastures on the photographs in Schüpbach *et al.* (2009) are based on ARPB areas of botanic quality. Of the ARPB areas existing in 2013, 123,994 ha are low-input meadows and pastures and litter meadows. Of these, however, only 41,457 ha (33.4%) are registered as meadows, pastures or wet meadows of botanic quality. The same is true for low- and fairly-low input meadows and pastures that are not managed as ARPB. Despite this, they may – though need not necessarily – be of good botanic quality, i.e. colourful and full of flowers. When calculating the indicators, all ARPB areas as well as the low-input meadows and pastures that are not ARPB areas were assigned to the preference value of the appropriate ARPB area. Were the farm data to contain information on the botanic quality of meadows and pastures, this would significantly improve the quality of the indicators.

With the stipulation that 75% of the UAA must be assigned to a preference value, the problem of data gaps in the preference values is largely taken into account. None of the farms with less than 75% of their UAA assigned to a preference value were included in the assessment.

6.6.3 Transparency and Reproducibility

With suitable data preparation and indicator calculation, the various indicators can be calculated in a transparent and reproducible manner. The important basics here are Access (or another database) for data storage, and R (or another script-oriented program) for calculation of the indicators.

6.6.4 Applicability: Communicability and Practicability

Ease of data collection and relative ease of calculation are the advantages of combining the two indices of area-weighted preference value and spatiotemporal landscape diversity index. Although some crops still lack preference values, it was possible to assess 86% of the total of 50,553 farms. A prerequisite for this was that a preference value be available for 75% of the UAA. The percentage of farms assessed is also dependent on farm type, however. Only 12% of the ‘special crop’ farms (fruit, vegetables and viticulture) and 63% of the ‘finishing’ farms (pigs and poultry) were assessed, whilst between 89% and 98% of the remaining farms were evaluated.

The necessary differentiation between farms with special, aesthetically highly rated land-use forms somewhat impairs the simplicity of application, since a definition of thresholds is essential for the application of the various indices.

6.7 Recommendation

Two sub-indicators and a three-step process are proposed for use as an indicator for visual quality of the landscape in the sustainability assessment. The three steps differ in terms of thresholds, some of which have yet to be defined. Figure 15 shows a design for a decision tree. This decision tree is meant to help in choosing the ‘right’ indicator for the individual farm, so that ‘special farms’ are preserved on one hand, whilst on the other a differentiation is also possible within the remaining farms.

In a first step, the aim is to separate farms with few but highly rated landscape elements (e.g. standard orchards) from the rest. An obvious threshold for this is the stipulation that the area-weighted preference value should be higher than the average of all of the preference values, since this of course would mean that a large proportion of the landscape elements on this farm have above-average ratings. In our experience, we are dealing here with farms with a high percentage of standard orchards, hedgerows, and in some cases ARPB.

Although farms with a high percentage of standard orchards are not particularly diverse, they nevertheless contribute to a special and valuable quality of the visual landscape. The loss of landscapes with large-scale standard orchards means a loss of landscape diversity at national level in Switzerland.

The second threshold is harder to define. It is clear, however, that the average of all preference values cannot represent an absolute limit. Although farms whose area-weighted preference values lie just below this first threshold can no longer be directly described as 'beautiful', they generally contain a relatively high proportion (significantly over 7%) of ARPB, which does make them 'special'. This percentage of ARPB should, however, be rated in conjunction with farm type and zone. Thus, an arable farm in the lowlands with 20% ARPB should be rated differently from a mountain farm also having 20% ARPB. A feasible approach would be to base these limits on biodiversity thresholds.

If the area-weighted preference value of a farm lies below this second threshold, the spatiotemporal landscape diversity index based on the Shannon Index is calculated. In order to take account of farm type (arable, grassland or mixed), the arable percentage must first be determined. If this lies below 20%, for example, the index for 'diverse grassland' could be used. An arable crop production percentage of between 20 and 40% would allow the landscape diversity index for both 'diverse grassland' and 'diverse arable crop production' to be calculated. For farms with an arable crop production percentage of at least 40%, the landscape diversity index of 'diverse arable crop production' could be calculated. This is meant to be merely an initial suggestion for the choice of thresholds which will need to be verified more precisely in test phases. Figure 14 shows the index values as a function of the relationship of arable production to grassland. The general aim is to find the type of aggregation that best reflects each farm's positive contribution to the visual quality of the landscape.

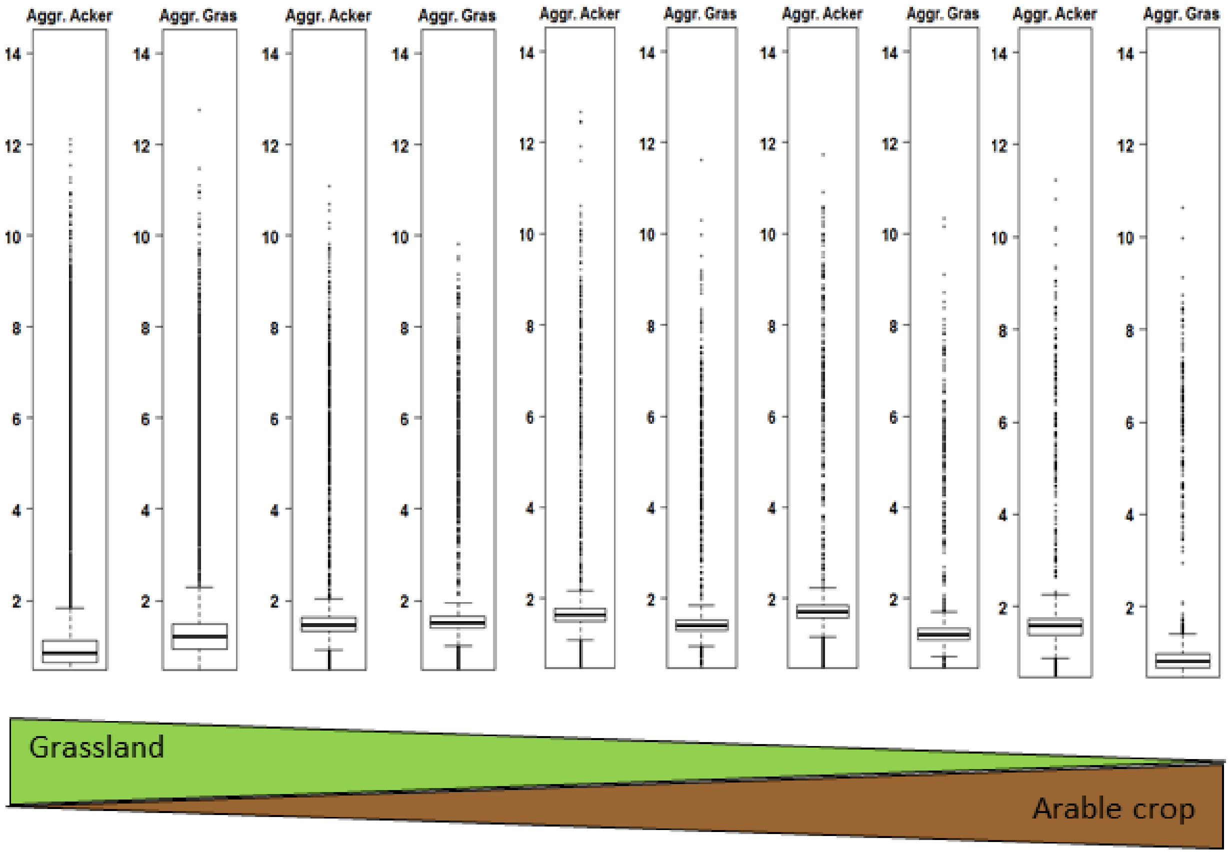


Figure 14: Distribution of the index values (based on Shannon) according to the aggregation types 'diverse arable landscape' and 'diverse grassland landscape' as a function of the arable and grassland conditions

The definitive form of this decision tree (see Figure 15) should be refined in a test phase with farms that differ in terms of land use (arable production / grassland) and are located in different zones (lowland / hill / mountain). Further thoughts on assessing the temporal evolution of the index values are to be addressed within the scope of a test phase. Thus, for example, empirical values for several years could be used to formulate target values based on the farms with higher index values. Then again, it is also to be expected that land use on a farm may change. The assessment of such changes must also be reflected upon more carefully. Ultimately, it is conceivable that the completion of the preference values (viticulture, vegetable production, etc.) will alter the average of all the preference values. This means that the definition of the average of all preference values must be reconsidered, since it fulfils the function of identifying farms with few yet highly rated landscape elements (e.g. standard orchards) and protecting the associated visual quality of their landscape. The same mechanism could potentially also apply for (selected) vineyard landscapes.

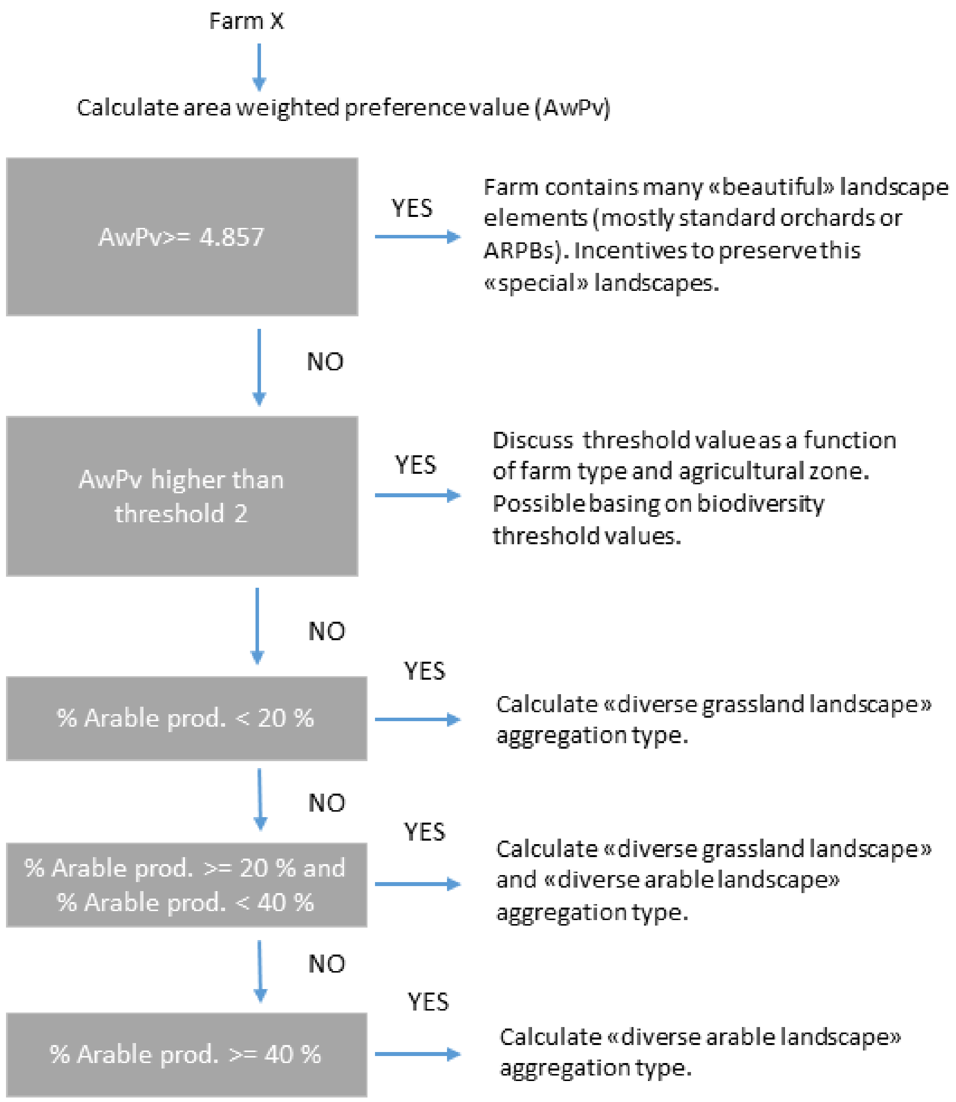


Figure 15: Design of a decision tree for calculating a suitable indicator for visual quality of the landscape.

6.8 Conclusions

This study highlights the possibility of incorporating the aspect of 'visual quality of the landscape' into the life cycle assessment, and hence into a sustainability assessment. Despite the absence of preference values, at least 75% of the utilised agricultural area of 86% of all farms in the SFSO structural database was assessed. The advantage of the two proposed sub-indices (area-weighted preference value and spatiotemporal diversity value based on the Shannon Index) is that they are based on the latest findings, as well as taking several aspects of a concept for the definition of landscape indicators into account. Another advantage is that the index can be calculated on the basis of structural data. Although the lack of stipulation of the two threshold values delays rapid implementation, the said values are important for the inclusion of the agricultural context. A test phase with 50 to 100 farms selected according to defined criteria is essential both for determining the threshold values and for clarifying various questions of detail.

7 Economic Indicators

Alexander Zorn, Andreas Weber, Markus Lips

7.1 Introduction

The level of observation of this analysis is the individual farm (microeconomic level). On this level, economic sustainability is frequently defined as the (long-term) viability of the farm (e.g. Christen 1996; Landais 1998; Heissenhuber 2000). The viability of a farm depends both on the latter's current economic situation and on the development of its economic, political and institutional framework conditions. The farm manager and his or her entrepreneurial skills have a substantial influence on viability (Heissenhuber 2000). An introductory overview of the "economic pillar in farm assessment systems" is given by Zapf *et al.* (2009b).

Entrepreneurs, farmers and even banks use key figures to assess the current economic situation of a farm and its expected short- and medium-term development. These key figures are based on data from the balance sheet or income statement of previous financial years or tax periods. Key figures summarise information, thereby allowing a simple comparison between years, i.e. the trend on the farm itself as well as a comparison with other farms. The aim of this chapter is therefore to develop a quantitative set of economic indicators for Swiss farms based on accounting data, in order to assess the economic dimension of sustainability.

In order to develop this indicator set, the literature on existing approaches to the assessment of sustainability was then examined, focusing on approaches aimed at practical application on the farms, either for farm extension or certification, as opposed to primarily scientific or socio-political issues. General key figures for evaluating the economic situation and creditworthiness of farms were also taken into account. In this way, various key figures and indicators for assessing sustainability on a farm were identified before a preliminary selection was discussed with experts. Finally, using data from the Farm Accountancy Data Network, the influence of important farm characteristics on the proposed key figures was investigated.

7.2 Relevance of the Topic for Sustainability

The economy is one of the three dimensions of sustainability. The implementation of sustainability according to the dimensions defined in this report shows various possible interactions between the dimensions. Thus, increased animal welfare is generally associated with costs which, unless these can be accordingly recouped on the market, will affect the profitability of a farm activity. Reducing the negative environmental impacts of agricultural production is also generally associated with costs (which may also include lower yields). This parallel and balanced relevance is expressed in the image of the three pillars, which – if not taken equal account of – can lead to a non-sustainable result.

7.3 Overview of Available Methods

There are numerous approaches to assessing economic sustainability in agriculture. Here, the parameters of economic sustainability are set in different ways in the sustainability-assessment approaches mentioned in Chapter 2.1. Thus, a study of the literature (Buckwell *et al.* 2014) identified a total of 95 indicators used to capture the economic dimension (on a number of observation levels).

Farm accountancy data suggest themselves as a basis for assessing economic sustainability. At national level, they are generally acquired in a uniform manner; a consistent evidence base of this nature allows the approaches with a national focus to make use of accountancy data (the Sustainable Agriculture Criteria System (KSNL) and the detailed testing level of the DLG Certificate). For the recording of economic data, global sustainability assessment tools such as RISE and SMART use accountancy data which must, however, be considered and analysed together with the farmer during a farm visit (Zapf and Schultheiß, 2013). The quality (accuracy) of accountancy data is rated as significantly better than that of data acquired by means of a survey or self-declaration (Zapf *et al.* 2009b).

Both national and global approaches assess the economic sustainability of a farm on the basis of key operational figures such as cashflow-turnover rate or equity ratio. Key figures represent a consolidation of the data contained in the accounts (Bardt 2011). Based on key figures, farms with similar structures can be compared with one other, and business-management strengths and weaknesses alike can be identified

(Dabbert and Braun 2012). The balance-sheet analysis distinguishes financial and performance ratios (Wöhe and Döring 2010). The key figures can also be broken down into the spheres of profitability, liquidity and stability (Heissenhuber 2000; Manthey 2007; Dabbert and Braun 2012).

The success of the business is reflected in the indicators for profitability, which are usually expressed by the ratio between the ordinary result and the used production factors (in the agricultural sector, chiefly labour and capital). Liquidity indicators are meant to express the ability of a business to meet its payment obligations on time. The stability of a business is defined as its ability to maintain both profitability and liquidity in the face of unforeseeable risks (Manthey 2007; Dabbert and Braun 2012).

The costs, the time required for documentation and data acquisition, and the concern that originally voluntary sustainability assessment systems could be transformed into general legal requirements, are all invoked as reasons why the existing approaches have heretofore failed to become significantly widespread (Doluschitz *et al.* 2009).

7.4 Description of the Indicators

Profitability, liquidity and stability are the indicators used to represent the economic sustainability of Swiss farms on the basis of accounting data. These indicators are captured by means of key business figures. Essential criteria when selecting the key figures were to keep data acquisition simple and to portray sustainability as compactly as possible. At the same time, it was essential for indicators to be precise and scientifically sound. Finally, the key figures also had to have a practical relevance for the farmer, i.e. needed to be readily comprehensible and interpretable.

In this context, the allocation of the key figures to a specific indicator is not always a straightforward matter, owing to the close dependencies between the key figures. Thus, high profitability promotes a correspondingly good liquidity, and hence also the stability of a farm. Standard textbooks allocate e.g. the dynamic gearing ratio to the analysis of liquidity (Wöhe and Döring 2010; Mußhoff and Hirschauer 2011), whilst a sustainability approach as well as a bank (the Deutsche Kreditbank) use this key figure to assess stability (Zapf *et al.* 2009b; Hein 2015).

7.4.1 Profitability Indicator

Profitability represents the relationship of a performance indicator to the production factors used. From 2012–2014, a Swiss-wide average of 1.71 work units and around CHF 900,000 of capital were used on an ‘active’ farm. Farm assets include the land in the farm property (Hoop and Schmid 2015). Labour represents the essential production factor on a Swiss farm: If we compare remuneration of the factors ‘labour’ and ‘capital’ on the basis of their opportunity costs, the opportunity costs of the farm family’s labour at current interest rates come to around 20 times the opportunity costs of capital (Hoop and Schmid 2015, Tables E).

The ratio of capital used per labour unit does, however, vary significantly between different farm types. The key figure ‘net profitability’ (also referred to as ‘relative factor remuneration’) allows us to consider farms of different factor structures by relating performance to the sum of the imputed remuneration of labour and capital (Blanck and Bahrs 2010). In order to adequately illustrate both the different capital intensities and different property forms of farms, however, the combined use of the key figures ‘earned income per family work unit’ and ‘total return on capital’ is proposed for determining the profitability indicator.

7.4.2 Earned Income per Family Work Unit

The majority of work performed on a Swiss farm is done by family members, who for the most part are not remunerated. The percentage of family farms in Switzerland in 2010 stood at 88% (SFSO 2014)[9]. Earned income per family work unit constitutes an essential criterion for the existence and long-term continuation of family farms in Switzerland. Significant differences exist between farm types, with an average 0.88 family work units (FWUs) active on an arable farm from 2012–2014, whilst an average 1.32 FWUs were employed on a commercial dairy farm over the same period (average value is 1.21, Hoop and Schmid 2015).

[9] The Swiss Farmers‘ Union considers 99% of farms to be family farms “from a legal perspective”, with the legal entities ‘natural person’ and ‘simple partnership’ being deemed family farms (Swiss Farmers’ Union 2013, p.12).

Earned income per family work unit is calculated on the basis of accounting data as well as supplementary data from the tax return. First, there is a harmonisation or adjustment of business outcome (e.g. with respect to the allocation of old-age provision to 'farm' vs. 'private' and the employment of the spouse), in order to obtain the comparable success factor 'harmonised agricultural income'. Agricultural income (AI) represents the annual outcome achieved by the farm, which is available for the reimbursement of the invested equity capital and the remuneration of family labour. In order to obtain the farm-wide earned income – i.e., that of all family work units – we must therefore also deduct the remuneration for the invested equity capital[10] from the AI. Dividing the earned income by the number of family work units[11] yields the earned income per family work unit, see Table 39.

Table 39: Calculating earned income per family work unit (notional values)

Agricultural income (harmonised)	**CHF 58,000**
– Return on equity	CHF 5000
= Earned income per family work unit (FWU) in CHF	CHF 53,000
/ Family work units (FWUs, number)	1.2
= Earned income per family work unit (CHF/FWU)	CHF 44,167

A degree of uncertainty is associated with the accurate capture of the working hours invested by the family workforce on the farm. These working hours are not gathered in a standard manner for the accounts. Since working hours are generally not documented in detail, they must be estimated or roughly calculated for the year in question by the farm manager.

To determine the interest rate for equity capital (including land), government bonds are used in accordance with the Ordinance on the Assessment of Sustainability in Agriculture (LwG 1998b). This is based on the assumption that farm managers wish to invest their capital safely and over the long term. This approach – the use of 10-year government bonds – is also applied in other European countries (Vrolijk *et al.* 2010). The use of an interest rate means that fluctuations in the interest rate have, *ceteris paribus* (i.e. under otherwise identical conditions) a direct effect on earned income. Recently, the interest rate of 10-year government bonds has been negative (months of July and August 2015), whilst in 2009 the interest rate still stood at over 2%.

The assessment of land in the balance sheet may differ as a function of type of purchase: with farm transfers within the family, the associated land is generally transferred at its productive value, whilst land purchased outside of the family is shown in the balance sheet at purchase price (commercial value), and can be evaluated at a figure many times higher than this as part of the legal provisions (Swiss Federal Law on Rural Land BGBB, SR 211.412.11). In extreme cases, this can lead to higher capital investment and a correspondingly lower remuneration of labour. As a rule, it can be assumed that on a family farm, the majority of the land owned was acquired as part of the transfer; for this reason, and because of the low capital investment with regard to labour, no major effect of the assessment approach is expected.

Finally, individual, subjective perception – of both remuneration and workload – is key for the question of the continued operation of the farm, which is in turn crucial for the latter's long-term existence (Heissenhuber 2000).

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[10] To calculate the interest rate for equity capital, the average interest rate of the corresponding year of government bonds with a maturity period of 10 years is used in the Basic Report of the Farm Accountancy Data Network (as per Art. 5 of the Ordinance on the Assessment of Sustainability in Agriculture, SR 919.118) (Hoop and Schmid 2015, p. 18). In the 2014 calendar year, the average was 0.69% (Swiss National Bank (SNB) 2015).

[11] When determining the number of family work units, the work capacity of the latter (based on the labour unit LU and bearing in mind reductions for younger and older members of the workforce) should be used. According to the Basic Report of the Farm Accountancy Data Network, 280 days form the basis of one family annual labour unit (Hoop and Schmid 2015). According to the 'Agricultural Ordinance Package, Autumn 2015', the mandated standard working hours for calculating a standard labour unit is to be reduced from the then-current 2800 hours (in 2015) to 2600 hours (FOAG 2015b).

7.4.3 Total Return on Capital

Capital investment differs according to farm type. On fairly high-input livestock farms (e.g. the 'combined finishing' type with CHF 1.18 million assets) it is relatively high, on arable- and special-crop farms it is more or less average, and on fairly low-input livestock farms (e.g. the 'other cattle' type with around CHF 650,000 assets), capital investment is below average (Hoop and Schmid 2015). Taking account of total return on capital thus enables the adequate depiction of capital-intensive farms, as well as farms with a high proportion of non-family employees, for which capital investment per labour unit is very high.
For this, the remuneration of the family workforce is deducted from the harmonised agricultural income and the interest on borrowed capital is added on. This yields the profit after compensation of the family workforce. Relating this profit to the capital invested yields the farm's return on capital.

Table 40: Calculating total return on capital (notional values)

Agricultural Income (Harmonised)	**CHF 58,000**
- Wages for family work units (FWUs)	CHF 89,150
+ Debt interest	CHF 6700
= Profit after remuneration of family workforce	CHF –24,450
/ Farm assets	CHF 850,000
= Total return on capital (in percent)	-0.029 (-2.9%)

The result is strongly dependent on the assumed remuneration of family labour. According to the Federal Law on Agriculture (Article 5, SR 910.1, LwG 1998a), "sustainably managed, economically efficient farms" are meant "[…] to be able to achieve incomes comparable to those of the remaining working population in the region". To this end, the Swiss Federal Statistical Office conducts an annual survey of comparative wages differentiated according to lowland, hill and valley regions. On average, the comparative wage per annual labour unit in the lowland region from 2011–2013 was CHF 74,232[12] (Hoop and Schmid 2014).
When considering total return on capital, the structure of the capital – i.e. the question of the ratio of equity capital to borrowed capital – is disregarded. The KSNL approach therefore also includes equity-capital profitability in addition to total return on capital.

7.4.4 Liquidity Indicator

The ability of a farm to meet its payment obligations at any time is termed liquidity. In principle, a distinction is drawn between 'point in time' and 'period of time' liquidity. Point-in-time-related key liquidity figures refer to the balance-sheet date. Thus, they are influenceable in the short-term, as, for instance, with farms receiving their contributions (direct payments) mainly at the end of the year. This could affect e.g. the frequently used key figures 'degree of liquidity 1' (also referred to as 'cash ratio') and 'degree of liquidity 2 (also called 'quick ratio'), which relate liquid resources or current financial assets to short-term liabilities.
With time-period-related liquidity, cashflow assumes an essential role, depicting the deposits and disbursements over a period of time. If deposits exceed disbursements, solvency is ensured. Cashflow depicts internal financing power, and thus the ability of the farm to fund investments and repay debts (Manthey 2007; Wöhe and Döring 2010).

[12] The comparative wage is the median of the gross annual wages of all secondary- and tertiary-sector employees of the region in question. In the period 2011-2013, the comparative wages in the hill and mountain regions were CHF 67,855 and CHF 63,170, respectively. The policy aim is for one-quarter of the farms to be able to achieve the comparative wage on average over several years (FOAG 2009).

7.4.5 Cashflow-Turnover Rate

The cashflow-turnover rate is yielded by the ratio of cashflow to turnover over a period of time, e.g. the calendar year. Relating cashflow to turnover yields a key figure which is also comparable for farms of different sizes, and which indicates what percentage of the turnover is available for internal financing (financing via resources from the farm turnover process, Wöhe and Döring 2010). Other reference values are documented in the literature, such as e.g. cashflow per ha of utilised agricultural area (Heissenhuber 2000). Relating cashflow to turnover allows for broader applicability, since it enables e.g. specialised finishing farms to be captured more accurately. Banks use the cashflow-turnover rate to assess the creditworthiness of farms (Hein 2015).
To calculate the cashflow-turnover rate, we add the depreciations to the harmonised outcome from agriculture for the calendar year – adjusted for farm particularities in terms of old-age provision and employment of spouse – which yields the cashflow for agriculture. To this we add the additional income of the farm, and then subtract private expenditure. The resultant cashflow is divided by the operating profit to give us the cashflow-turnover rate. The higher the cashflow-turnover rate, the higher the surplus generated in a given period.

Table 41: Calculating the cashflow-turnover rate (notional values)

Outcome from agriculture (harmonised)	**CHF 55,000**
+ Depreciations	CHF 35,000
= Cashflow for agriculture	CHF 90,000
+ Additional income, farm	CHF 2000
– Private expenditure	CHF 60,000
= Cashflow (business-private cashflow)	CHF 32,000
/ Operating profit	CHF 260,000
= Cashflow-turnover rate	0.123

7.4.6 Dynamic Gearing Ratio

Based on the cashflow achieved, the dynamic gearing ratio (also referred to as the ‘debt factor’ or ‘imputed amortisation period’) indicates how many years this cashflow will have to be generated in order to settle the farm’s debts. This is another key figure used by banks to evaluate the creditworthiness of a farm (Hein 2015). The calculation of the dynamic gearing ratio is based on net liabilities; these are calculated by deducting the liquid assets and receivables from borrowed capital. If we then divide net liabilities by cashflow, this yields the number of years necessary to offset the liabilities. The smaller this (positive) number is, the better. A dynamic gearing ratio of less than 5 is deemed to be good for Swiss farms (‘good adaptability to changing market conditions’, Landwirtschaftliche Lehrmittelzentrale (=Centre for Agricultural Educational Material) 2000, p. 165).

Table 42: Calculating the dynamic gearing ratio (notional values)

Borrowed capital	**CHF 420,000**
– Liquid assets + receivables	CHF 100,000
= Net liabilities	CHF 320,000
/ Cashflow (Business-private cashflow)	CHF 32,000
= Gearing (debt-equity ratio)	10.0

In given years, farms may well experience negative cashflows (so-called 'cash drain'). This can point to a highly problematic situation. When calculating averages, e.g. via farm types, this can lead to a distortion of the results.

7.4.7 Stability Indicator

'Stability' refers to the ability of a farm to safeguard both profitability and liquidity over the long term in the event of unforeseen risks (Manthey 2007). Balance-sheet ratios are frequently used to assess stability. These can be broken down into four groups: ratios for analysing capital structure (e.g. equity ratio), assets-and-liabilities structure (e.g. investment intensity), coverage structure (e.g. investment coverage), and equity-capital formation (Manthey 2007). For the stability indicator, a choice from the "multiplicity of different key factors" (Mußhoff and Hirschauer 2011, p. 100) was required; said choice attempted both to depict the above-mentioned range of key figures for stability analysis and to look out for as low a congruence as possible within the key figures.
Investment intensity (for analysing the asset-and-liabilities structure) and investment coverage (for analysing the coverage structure) were selected as key figures for representing the stability indicator. Equity-capital formation (Schmid and Kurmann 2013) was not taken into account, since this key figure correlates strongly with both cashflow and cashflow-turnover rate: the equity ratio (percentage of equity capital out of total capital) can be determined by multiplying together the selected key figures (Investment coverage x Investment intensity).

7.4.8 Investment Intensity

Investment intensity is calculated by dividing fixed assets by the total assets of the farm. The fixed assets consist of farm assets that are not intended for sale, but rather serve the object of the farm in the longer term: among these are e.g. buildings and machines (Landwirtschaftliche Lehrmittelzentrale 2000). This key figure shows what percentage of the assets is tied up in investments. A high investment intensity (values close to 1) is rated critically, since it is associated with high fixed costs as well as a high risk of devaluation of investments through technical progress (Manthey 2007). Moreover, the expected backflow of funds from investment in installations lies in the possibly distant future (Wöhe and Döring 2010). Low investment intensity can be interpreted as high financial flexibility.

Table 43: Calculating investment intensity (notional values)

Fixed assets (excluding livestock assets)	**CHF 600,000**
/ Capital (assets)	CHF 900,000
Investment intensity	0.667

Livestock assets are not taken into account in the calculation, since they occupy a special position: depending on useful life (short useful life for fattening livestock as opposed to a long useful life for breeding stock), they can either be allocated to investment or working capital. In the Basic Report of the Farm Accountancy Data Network, livestock assets are recorded separately. Similarly, with the proposed calculation of the key figure for investment intensity, livestock assets are not considered investment assets.

7.4.9 Investment Coverage

Investment coverage represents the percentage of fixed assets covered by equity capital. The greater the extent to which fixed assets are covered by equity capital, the greater the farm's stability. This is reflected in the 'golden balance rule', which calls for the financing of long-term tied assets by long-term assets. According to a specifically agricultural interpretation of this rule, long-term assets in land and building assets should be completely financed by equity capital, so that land and buildings can be leased out free of debt in the event of farm exit (Manthey 2007).

Table 44: Calculating the degree of investment coverage (notional values)

Equity capital	**CHF 480,000**
/ Fixed assets	CHF 600,000
Degree of investment coverage	0.800

7.5 Evaluation of the Indicators

Three indicators, each of which are meant to be determined on the basis of two key figures, are proposed for the assessment of economic sustainability. Note that certain correlations exist within both the indicators and the key figures, viz., a high liquidity results in a certain profitability, and stability for its part is defined as the ability of the farm to ensure profitability and liquidity over the long term. In principle, when selecting a limited number of key operational figures, care was taken to specify key figures that are as independent of one another as possible.

7.5.1 Completeness of Scope

The proposed key figures depict the profitability, stability and liquidity of the farm, thereby covering the major present-day prerequisites for the latter's continued existence. They do not, however, allow for a reliable medium-term, let alone long-term, forecast of a farm's viability.

The intention of this paper was to make data acquisition easy, and to identify a manageable range of key figures for assessing sustainability. Because of the selection of a small number of key figures, however, we cannot rule out the possibility of certain sub-aspects not being sufficiently well illustrated. The completeness of the proposed indicators and of the key economic sustainability figures on which they are based should therefore be examined critically at the same time as they are implemented. This is all the more important since the actual implementation was not conclusively clarified when this report was being drawn up.

The existence of many farms in Switzerland depends heavily on government payments (Jarrett and Moeser 2013). According to the Organization for Economic Cooperation and Development (OECD), the percentage of state support out of total farm income in Switzerland is around three times as high as in the European Union (OECD 2015)[13]. The evolution of this support is characterised by a number of uncertainties. Changes in agricultural policy (e.g. the opening up of the milk market, or the so-called 'white line') are currently being discussed. These sorts of policy changes and the form of their implementation can strongly influence the economic framework of the entire agricultural sector, or certain branches thereof. This aspect, or its relevance for the sustainability assessment, is also discussed in the literature as the autonomy (Lebacq *et al.* 2013) or independence (Zahm *et al.* 2008) of the farm. This aspect could also be captured via the additional recording of the direct payments received by the farm and their consideration in an additional indicator (e.g. the sum of the direct payments in relation to the operating profit or business outcome).

The ability of a business to adapt to major changes in the policy- or economic framework is termed resilience (Günther 2015). Stability covers this aspect from an economic perspective by using classic key figures. Besides this, the diversity in agricultural income ('diversification') is also deemed to be a relevant criterion in this context (Lebacq *et al.* 2013). The diversity of production or diversification of a farm could be determined by means of a Shannon Index, e.g by means of the farm activities and their share of turnover (Spellerberg and Fedor 2003). In agriculture, resilience plays a vital role not only in terms of social support, but also in connection with climate change.

[13] To quantify the total state support received by the agricultural sector of a country, the OECD uses the Producer Support Estimate (PSE), which gives the percentage of all direct and indirect state support out of total farm income. Viewed in an international context, the Swiss agricultural sector is highly subsidised; its PSE currently stands at around 55%, whilst the figure for the European Union (EU 28) stands at just under 20%.

7.5.2 Assessment of Robustness and Uncertainties

The key figures for profitability, stability and liquidity can be reliably captured in the event of existing accounts. The calculation of the key figures illustrated in Chapter 7.4 essentially aims to capture detailed data in order to determine the key figures in as uniform a manner as possible (instead of using aggregated data, e.g. a key figure generated from the accounts). This approach reduces uncertainties in data collection (cf. the allocation of livestock assets discussed in Chapter 7.4), thereby increasing the reliability of the resultant key figures.

When implementing a sustainability assessment system, important characteristics of the farm influencing the economic key figures should be taken into account. With a benchmarking system (DLG Certificate) or the use of critical limits (KSNL), sustainability should be assessed by being broken down into different essential characteristics which can influence the key figures used. Thus, farm types differ in terms of the ratio of the factors labour to capital. Furthermore, a certain regional differentiation should be undertaken (Zapf *et al.* 2009a), since the natural and economic conditions that are important for agriculture (e.g. the different options and compensation of off-farm activities) can differ significantly from one region to another. Lastly, we must also assume an effect on the key figures stemming from farm size.

The influence of farm type is portrayed comparatively for three specialised farm types and the six key figures in Table 45. Significant differences are to be noted between the farm types for all key figures except investment intensity.

Table 45: Average values of the key figures for specialised farm types (FADN data; average values for the years 2009-2013).

	Farm Type		
Characteristic	**Arable**	**Commercial Dairy**	**Finishing**
Earned income (CHF/FWU)	65,966	39,924	59,820
Total return on capital	0.0 %	-5.0 %	- 0.9 %
Cashflow-turnover rate	0.19	0.25	0.19
Dynamic gearing ratio*	2.8	7.0	7.3
Investment intensity	0.69	0.72	0.72
Degree of investment coverage	2.1	1.4	0.8
No. of observations	617	5894	389

* For didactic reasons, the 5% lowest and highest values in each case were excluded when calculating the key performance indicator 'dynamic gearing ratio', in order to correct excessively strong distortions.

Table 46 shows that the key figures also differ significantly between the usually differentiated lowland, hill and mountain regions. The recognisable differences are doubtless also largely attributable to the different extents to which the various farm types are represented in each of the regions.

Table 46: Average values of key figures for the lowland, hill and mountain regions (FADN data; average values for the years 2009-2013).

	Region		
Characteristic	**Lowland**	**Hill**	**Mountain**
No. of observations	6399	4791	4045
Earned income (CHF/FWU)	54,878	42,692	31,921
Total return on capital	-2.1 %	-4.0 %	-6.7 %
Cashflow-turnover rate	0.20	0.24	0.26

Characteristic	Region		
	Lowland	Hill	Mountain
Dynamic gearing ratio*	7.4	8.0	9.7
Investment intensity	0.70	0.72	0.73
Degree of investment coverage	2.0	0.9	1.1
* For didactic reasons, the 5% lowest and highest values in each case were excluded when calculating the key performance indicator 'dynamic gearing ratio', in order to correct excessively strong distortions.			

Finally, Table 47 compares the key figures of the smaller 50% of commercial dairy farms to those of the larger 50% (the grouping is based on the number of livestock units of the farm, and was done separately for each year.) Here too, and as expected, there are clear differences as a function of farm size.

Table 47: Average values of the key figures of smaller vs. larger commercial dairy farms (FADN data; average values for the years 2009-2013).

Characteristic	Farm Size (Classified according to Livestock Units)	
	Smaller Commercial Dairy Farms	Larger Commercial Dairy Farms
No. of observations	2948	2946
Earned income (CHF/FWU)	29,770	50,085
Total return on capital	-8.0 %	-1.9 %
Cashflow-turnover rate	0.27	0.24
Dynamic gearing ratio*	7.4	1.7
Investment intensity	0.71	0.72
Degree of investment coverage	1.0	1.7
* For didactic reasons, the 5% lowest and highest values in each case were excluded when calculating the key performance indicator 'Dynamic gearing ratio', in order to correct excessively strong distortions.		

Comparison of the key figures on the basis of the different farm types, region, and farm size (using the example of the commercial dairy farm) reveals a significant influence of the characteristic in question in each case. In the event of the use of absolute reference values as well as relative references in the assessment of operational sustainability on the basis of the key figures proposed in Chapter 7.4, the three criteria of farm type, region, and farm size should be taken into account at minimum. Bearing in mind key factors influencing profitability is crucial for the reliable evaluation of a farm and its economic opportunities.

Owing *inter alia* to their dependence on the weather, agricultural markets are characterised by yield and price fluctuations which have increasingly been observed over the last few years. These fluctuations are also reflected in the indicators. The sustainability rating should therefore be based on average values over several years, so that short-term extreme situations do not dominate the assessment.

Finally, it should be noted that accountancy data are historical data. Deriving statements on the long-term existence of a farm from retrospective data is fundamentally associated with uncertainty. The existence of a business can be jeopardised e.g. by the unexpected death of its manager, or changes in product prices or production costs. The assessment of a farm's operational sustainability should therefore be understood as no more than an estimate.

7.5.3 Transparency and Reproducibility

The indicators mentioned in Chapter 7.4 were selected on the basis of an in-depth analysis of the literature. The indicators and the key figures proposed for their evaluation are generally used for both business and sustainability assessments. Both the selection of the indicators and key figures as well as their calculation, set out in Chapter 7.4, can therefore be deemed transparent and reproducible.

The assumptions for the remuneration of both capital (interest rate used) and labour (opportunity-costs used) made in order to assess profitability should be stated and explained, and additionally, in the event of extreme values (e.g. negative interest rates), critically discussed.

7.5.4 Applicability: Communicability and Practicability

The indicators and key figures are documented in the business administration literature, as well as in various sustainability assessment sources. The use of accounting data limits applicability to farms that keep accounts; this is not deemed a major constraint, however, since full-time farms, which account for 72% of farms and 88% of the utilised agricultural area (SFSO 2015b), almost without exception have an accounts department.

When applying the indicators, care must be taken to comply with the following assumptions so that the key figures may be compared with one another:

- The farm is an individual operation with properties in business assets; joint farm operations or legal entities cannot be captured reliably with the proposed approach.
- A critical lower limit for family workforce numbers (e.g. at least 0.1 family work units) should be available on a farm; otherwise, the comparability of the key figures could be limited by extreme values (e.g. in the case of the ‘labour profitability’ indicator).
- The calculation of the key figures is based on the assumption that the balancing of farm accounts is carried out according to accounting law, and corresponds to the common AGRO-TWIN accounting framework ‘KMU-Landwirtschaft’ (= ‘SME Agriculture’), or a balancing that is the same in terms of content; major deviations from this approach may have a negative impact on the comparability of the calculated key figures.
- The boundary between the farm and the private household corresponds to that of the financial accounting.
- The imputed rental value of the farm manager’s residence is contained in the business results as an earnings item, provided that said residence is reported on the balance sheet and its costs are recorded as operating expenses.
- The agricultural income and further key figures must be harmonised before the data can be compared.
  - A differentiation is made between agricultural and non-agricultural activities via the separation in the accounts of a non-agricultural part-time business, or the boundary is appropriately determined elsewhere.
  - Any wages paid to the spouse are to be taken into account in a consistent manner.
  - Pension contributions to the farm manager’s first pillar old-age provisions are charged to the agricultural result.
  - Fifty per cent of the farm manager’s contributions to the second pillar old-age provisions are charged to the agricultural result. Second-pillar purchases made by the farm manager are not considered as operating expenses.

The proposed indicators and key figures are highly relevant for economic assessments of farms. Restriction to a manageable number of key figures increases acceptance, thereby ensuring practicability. Business knowledge is a prerequisite for understanding and interpreting the key figures, however; should a farm manager lack this knowledge, it could be provided via brief explanations of how to calculate and interpret the key figures and indicators.

The requirement that comparative data – which should be differentiated according to the abovementioned criteria of farm type, region and farm size – be used in the evaluation of the key figures, means that these data must be easily accessible. Here, the data acquired by the Farm Accountancy Data Network – published annually by Agroscope (Hoop and Schmid 2015) – could be used.

7.6 Recommendation

The practical implementation of a sustainability assessment system based on the proposed key figures should be done carefully and monitored critically. The present results are based on an analysis of the literature, the analysis of harmonised and aggregated accounting data, and talks with experts. Because a testing in practice was not previously possible, expert monitoring is recommended in the event of implementation. This is all the more important as no information is available on essential points for designing a sustainability assessment approach, such as the actual application of the key figures (e.g. what standards the assessment is to be based on) and the implementation of the sustainability assessment (e.g. the aggregation of key figures into an indicator).

Following the initial aim of this paper, sustainability should refer exclusively to primary agricultural production, or to the production of foodstuffs. Agriculture-related activities (referred to at the Farm Accountancy Data Network as 'para-agriculture'), such as e.g. agrotourism or direct sales should explicitly not be taken into account. As the term 'agriculture-related' makes clear, we are dealing here with "agricultural activities, which [nevertheless] are not immediately associated with agricultural production" (Agroscope 2014, p. 2-2). In the bookkeeping records, however, agriculture-related activities along the lines of para-agriculture are assigned to the farm.

When calculating the key figures described in Chapter 7.4, the differentiation of primary agricultural production therefore represented a major challenge. Additional data would have to be collected for the differentiation. Moreover, it must be assumed that the reliability of the differentiation will not be very high.

If we use accounting data to consider the share of agriculture-related activities out of gross agricultural output (hereafter, gross output from agricultural production, including direct payments as well as para-agriculture, is counted as part of this), we see that the average share at farm level comes to just 5.7 % (data from 2009–2013, 15,235 observations from the Farm Accountancy Data Network). The presentation of the percentiles[14] in Table 48 shows that for 90% of farms, the share of agriculture-related activities out of gross output (turnover) is less than 16.5%.

Table 48: Percentage of agriculture-related activities ('para-agriculture') out of total gross agricultural output (sum of gross output from agricultural production, direct payments, para-agriculture; data from the Farm Accountancy Data Network; average value of the years 2009–2013).

Percentiles	Turnover Share of Para-agriculture
1	0.0%
10	0.0%
25	0.1%
50	1.2%
75	5.6%
90	16.5%
99	61.2%

Although the percentage of agriculture-related activities and the influence of this on the key economic figures can be high in the case of individual farms, for the farms as a whole this influence can be seen as marginal. Because of the challenges described above, we recommend forgoing the complicated and laborious differentiation of agriculture-related activities.

[14] Percentiles indicate what percentage of the farms achieve a turnover share up to the indicated value.

7.7 Conclusions

Based on analyses of the literature and expert discussions, six key figures are suggested for carrying out a farm sustainability assessment using the indicators profitability, liquidity and stability. The indicators selected should ensure a high accuracy and reliability; moreover, implementation should be possible with reasonable expense and effort (costs and time spent on data collection and sustainability assessment).

Analysis of the literature on approaches to sustainability assessment has shown that there are different approaches to evaluating agricultural sustainability at farm level. Given the number of projects – some of them longstanding – with different objectives regarding the level of detail and their application, the question arises as to why no dominant or convincing approach has managed to take shape in Europe to date. An explanatory approach might be an imbalance between costs and benefit: without a doubt, the expenditure of time, money and effort required to reliably assess the dimensions of sustainability is very high. If this effort, and hence the accuracy is reduced, it will be to the detriment of the meaningfulness of a sustainability assessment; thus, we may assume that heavily simplified data capture will result in less accurate key figures, which in extreme cases could lead to a loss of credibility. Furthermore, when designing a sustainability approach, strategic considerations on the non-discriminatory treatment of certain farms or ways of doing business might well also constitute a hurdle (Doluschitz *et al.* 2009). In order for an approach to be widely accepted and implemented in the agricultural sector, both the admission requirements for the farms (stringency of the criteria, data requirements, costs) and the expectations in terms of the fulfilment of sustainability targets must be weighed against one another.

The focus on selected key business indicators for assessing economic sustainability addresses the relationship of costs and benefit. The existence of accounting data that are of high quality when considering a country such as Switzerland enables the calculation of valid and resilient key figures. The underlying idea of sustainability assessment approaches is to make statements on the future existence of a farm on the basis of these key figures. The existence of a farm also depends heavily on non-influenceable and unforeseeable factors, however, with the result that a degree of uncertainty regarding the usability of the key figures and their resilience for this purpose cannot be ruled out. Nevertheless, the key figures can readily be used to assess the development of a farm, and as an early-warning system. Accounts-based key figures provide the farmer with a means of reviewing his results, and possibly also conducting an inter-farm comparison of said results. Thus, a reliable means of rating the economic situation can increase the farm manager's awareness of business-management matters, as well as providing the farm manager with practical points of reference for the steering and further optimisation of the farm.

The practical implementation of an assessment approach should be carefully tested beforehand. Here, the concept of a purely quantitative approach enables sound analyses of the collected data. Thus, for example, the correlations and possible interactions within the indicators could be investigated. This could ultimately contribute to a deeper understanding of sustainability efforts.

In the national economy sphere, economic development is also interpreted as a process of "creative destruction". Generally attributed to Schumpeter (2005), this term is meant to express the idea that inefficient farms are edged out. This edging out or the change in the economic structure is a consequence of innovations and the more or less successful adaptation of farms to new situations. From this economic perspective, the requirement of farming more sustainably virtually implies that not all farms will be able to accomplish this equally successfully. In this relativising point, the economic dimension of sustainability undoubtedly distinguishes itself at farm level from other dimensions dealt with in this report.

Part III: Environmental Dimension

8 Resource Use

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8.1 Introduction

Three so-called ‘areas of protection’, i.e. natural resources, environmental quality and human health, are distinguished in the life cycle assessment (Dewulf *et al.* 2015). Natural resources are at the interface between the natural environment and the economic system (Figure 16).

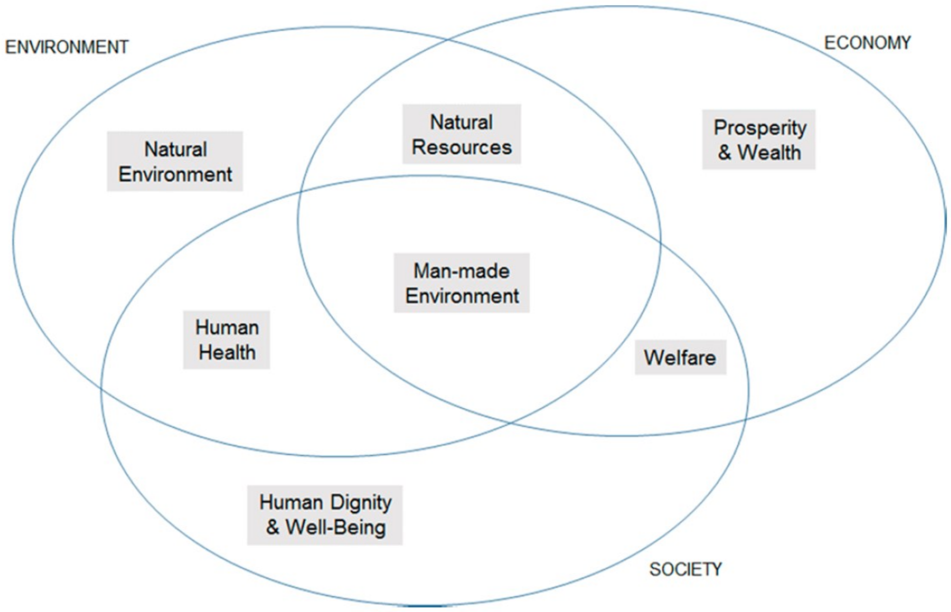

Figure 16: Areas of protection in the life cycle assessment according to Dewulf et al. (2015).

In a life cycle assessment, natural resources are inputs from the environment (the ecosphere) into the economic system (the technosphere). By contrast, emissions represent outputs from the technosphere into the environment.
The following resource areas are targeted from the point of view of the life cycle assessment (EC-JRC-IES 2010):

- Abiotic resources: These include energy resources (non-renewable and renewable with the exception of biomass), metals and mineral resources. Because of their importance, energy resources are often listed and analysed separately.
- Biotic resources: Wood, fish, game.
- Water: Here, it is generally only freshwater that is taken into consideration.
- Land area: The term ‘land use’ is also often used in life cycle assessments, and is take to mean a wide variety of impacts from human activities, i.e. the effects of the use of an area or of a change in use (land transformation) on e.g. biodiversity and soil quality.

Figure 17 shows how the use of natural resources is associated with impacts on ecosystem quality and human health.

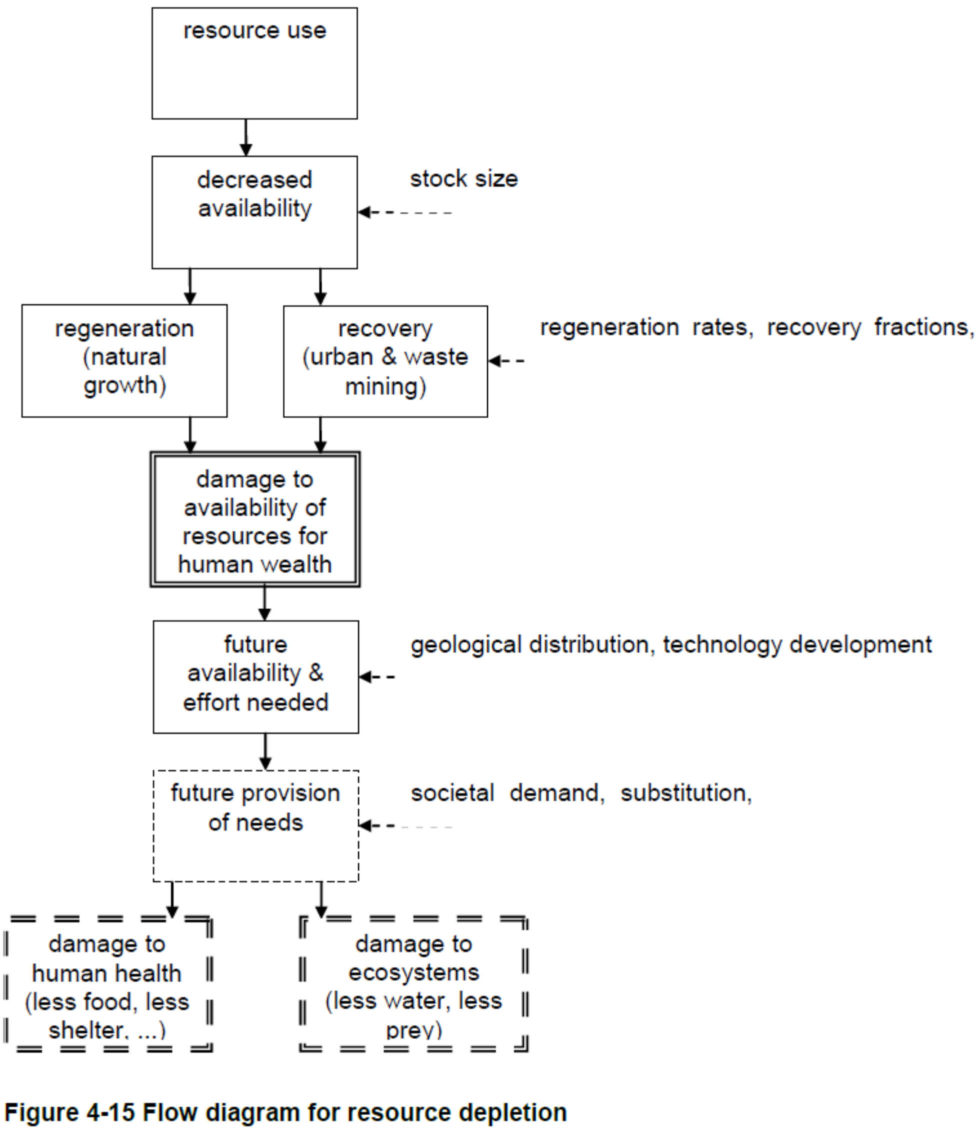

Figure 17: Impact of resource use on the areas of protection of human health and ecosystem quality according to EC-JRC-IES (2010).

EC-JRC-IES (2011) discerns four categories of methods for the assessment of resource requirements:

- Category 1: Impact assessment based on a common characteristic of the evaluated resources. An example of this is the cumulative energy demand. Here, various energy resources are characterised with their calorific values, enabling them to be summarised in an impact category.
- Category 2: Methods based on current consumption or current use of resources on the one hand, and on available reserves on the other hand.
- Category 3: Methods for the assessment of water resources, which are dealt with separately owing to their high importance for agriculture and their special characteristics.
- Category 4: Endpoint methods.

Endpoint indicators describe the end of a cause-and-effect chain, i.e. harmful effects on a protected resource. By contrast, midpoint indicators are situated on a level between emissions/resource requirements and the endpoint level (EC-JRC-IES, 2011). Categories 1 to 4 are characterised on the one hand by an increasing relevance and significance, but on the other by increasing uncertainty.

Klinglmair *et al.* (2014) observed major methodological differences in resource impact analysis in life cycle assessments. Not only are there often substantial gaps in various resource areas in the impact assessment, but in some cases very different characterisation factors are applied. In general, life cycle assessments pay little attention to biotic resources. Klinglmair *et al.* (2014) categorise the methods for the evaluation of natural resources as follows:

- Methods that are based on the available reserves and mining rates, and which therefore characterise the scarcity of the resource;
- Methods that are based on exergy;
- Methods that evaluate the effort (*'surplus energy'*) involved in the mining of a resource;
- Methods that take into account the marginal costs of mining a resource;
- Methods that characterise the *"willingness to pay"* for a specific resource;
- Methods that evaluate the *"distance to target".*

In the following chapters, natural resources are summarised into three groups:

- Abiotic resources: Energy resources, metals and mineral resources fall into this category. In the latter, phosphorus and potassium, the reserves of which are limited, may be cited as particularly important nutrients for agriculture.
- Water: Also an extremely important production factor in agriculture.
- Land area: This category describes a very important production basis for agriculture.

No particular attention is paid to biotic resources, with the exception of energy from biomass, which can be characterised via indicators for renewable energy sources (cumulative energy demand, see below).

8.2 Abiotic Resources

8.2.1 Energy Resources

The fossil fuels (petroleum, coal, natural gas) as well as uranium as the basis for nuclear power generation are subsumed under the heading of non-renewable energy resources. Fossil fuel reserves are limited; assuming mining rates that remain constant, for example, coal, crude oil and natural gas will remain available for approx. 120, 56 and 55 years, respectively (World Energy Council 2013). The estimation of the future availability of resources is fraught with uncertainty, however, since not only is the exact extent of the reserves unknown, but availability also depends on the mining technique, prices and mining costs. Moreover, uncertainties exist with respect to future mining rates.

Fossil fuel use is closely associated with climate change, since burning fossil fuels produces CO_2 as a greenhouse gas. If all fossil fuel supplies were burnt, CO_2 concentrations would rise steeply enough to result in a global temperature increase of 9°C with respect to the preindustrial era (Greenstone 2015). For this reason, the impact of fossil fuels on the climate should be viewed as a more strongly limiting factor than the exhaustion of fossil fuel reserves.

Solar and wind power, geothermal energy, hydroelectric power and biomass all fall under the heading of renewable energy resources. These differ from non-renewable energy resources in that it is not their reserves, but rather their annually available (in the case of solar and wind power) or annually renewed quantities (in the case of geothermal energy, hydroelectric power and biomass) that are limited.

8.2.2 Mineral Resources Phosphorus and Potassium

Phosphorus (P) and potassium (K) are two important macronutrients that are essential for agricultural production. These elements are only available in limited quantities. According to Fixen and Johnston (2012), at current mining rates, phosphorus reserves will last for another 93–291 years, potassium reserves for 235–510 years (on the basis of the 2007–2008 mining rates). The lower number in each case applies for the mining of raw materials under present-day economic conditions, whilst the higher number applies for reserves which are minable with higher prices, lower costs compared to the present, or new technologies. Since these two nutrients are irreplaceable in agriculture, it is imperative for them to be used economically, bearing in mind that the phosphorus reserves do not last as long as the potassium reserves, with the result that the phosphorus requirement must be weighted more heavily.

The situation is different for nitrogen (N). This nutrient is at least as important for plant growth as P and K, and the nitrogen cycle is associated with a multiplicity of environmental problems. For the reasons listed below, however, N need not be considered a scarce resource:

- Using the Haber-Bosch process, atmospheric nitrogen (N_2) can be converted into ammonia, and from there into further N-compounds such as nitrate or urea. This process is very energy-intensive; nowadays, natural gas is generally used for it, which is why the impacts associated with the production of N-fertilisers are depicted using the 'fossil fuel requirement' and 'global warming potential' categories. Here, there is more than enough atmospheric nitrogen available, which is continuously replenished by the N-losses during denitrification (conversion of NO_3 into N_2). After the use of N-fertilisers, further emissions result from reactive nitrogen (N_2O, NH_3, NO_3, NO_x), which are taken into consideration via impact categories such as global warming potential, eutrophication or acidification.
- In addition, there are further sources which supply reactive nitrogen to agriculture. Here, mention should be made of biological nitrogen fixation by legumes, and inputs via N-deposition from industry, households, traffic and lightning strikes.

Additional macronutrients such as calcium, magnesium and sulphur are also essential for agricultural production; however, their reserves are so large that they will not constitute a limitation for agricultural production in the foreseeable future.

8.2.3 Assessment Methods

A range of methods are available for assessing the demand for abiotic resources. An overview with a detailed assessment of the individual methods and a recommendation can be found in the ILCD Report (EC-JRC-IES 2011) in the chapter on Resource Depletion, on which the following analysis is based:

- **Exergy** (Dewulf *et al.* 2007): Exergy represents the amount of 'useful work' that can be performed with a resource. Thus, for example, electricity or mechanical energy can be used in a great variety of ways to perform 'useful work'; both, for instance, can be completely converted into heat. By contrast, heat energy can only be partially converted (i.e. with losses) into electricity or mechanical energy; the efficiency depends on the temperature gradient. The method is highly comprehensive, and allows the assessment of numerous resources: fossil fuels, uranium, renewable fuels (solar, wind and hydroelectric power, biomass energy), metals, mineral resources (including P and K) and water. The method was applied to the ecoinvent Database (Bösch *et al.* 2007), and allows us to express resource depletion or resource use in a common unit, namely MJ of exergy.
- **Emergy**: The method for assessing emergy (which stands for '**em**bodied en**ergy**') allows a variety of different resources to be evaluated. The criterion here is the energy directly or indirectly required to create these resources. The unit used is 'solar energy joules' (SEJ). A special focus is placed here on natural resources like sunlight, wind, rain, water or soil. Markussen *et al.* (2014) present an application of the emergy method to vegetable production farms in England; parallel to this, the same farms were also analysed by means of established life cycle assessment impact categories. Although the emergy method has many similarities to life cycle assessment, there are several fundamental differences. Rugani and Benetto (2012) showed how the emergy method could be incorporated in the life cycle assessment context. In its current state, however, the emergy method is not developed enough to be used routinely in life cycle assessments.
- The **cumulative energy demand (CED)** method permits the assessment of the energy resources. Here, both the non-renewable resource categories of fossil and nuclear fuels as well as the renewable energy resources of biomass, wind, solar energy, geothermal energy and hydroelectric power (rivers, reservoirs, tides and waves) can be taken into account. This is the most commonly used method for estimating energy demand, and was also implemented in the ecoinvent Database (Frischknecht *et al.* 2007). With fossil fuels, the higher heating value (gross calorific value) is used, since it characterises the totality of the energy contained in the fuel, including the evaporation energy of water vapour in the combustion gases. To date, this has also been the default method used in the SALCA methodology (Nemecek *et al.* 2010), with only the non-renewable energy resources (fossil and nuclear) being taken into account. The assessment of the renewable fuels constitutes a particular challenge. Basically, there

are two approaches: '*energy harvested'* and '*energy harvestable'* (Frischknecht *et al.* 2015). In the former, the quantity of energy effectively extracted is accounted for (e.g. in the harvested biomass); in the latter, the much greater total quantity of energy that impinges upon the energy production facility (e.g. global radiation on the field). Frischknecht *et al.* (2015) compared five different methods for calculating the CED by means of a case study. The methods differ chiefly in terms of how they evaluate uranium and renewable fuels. Frischknecht *et al.* (2015) recommend the cumulative energy demand method according to the '*energy harvested'* approach, since the latter produces a consistent characterisation of the fuels when they exceed the limit between ecosphere and technosphere. This method was also implemented in ecoinvent.

- The **Swiss Ecological Scarcity** method (Frischknecht and Büsser Knöpfel 2013) takes account of the following resources: Non-renewable energy resources (fossil and nuclear); renewable energy resources (biomass, solar power, hydroelectric power, wind, geothermal energy); land use; mineral resources (including phosphorus but excluding potassium); metals, gravel and sand; and water. The assessment is conducted on the basis of Swiss environmental policy targets, and the greater the distance of a particular environmental problem to the target value, the higher the weighting *('distance to target'* method). The assessment is consistently conducted by means of environmental pollution points; we are dealing with a single-score methodology here.
- **CML** (Guinée *et al.* 2001): This method takes account of the consumption of abiotic resources (*'abiotic depletion potential*') and land occupation (*'land competition'*, in m^2a). In the case of the abiotic resources, energy resources, metals and mineral resources (including phosphorus and potassium) are taken into account. The resources are evaluated on the basis of the ratio of the annual depletion rates to the availability of the resource in Earth's crust (squared). They are then expressed relative to the reference substance (antimony (Sb) equivalents).
- **EDIP2003** (Hauschild *et al.* 2006): The 'Resources' impact category encompasses fossil energy resources, uranium and metals. This implies the disregarding of P and K resources, which are important for agriculture, rendering this method less suitable for the analysis of agricultural systems. The assessment is made exclusively on the basis of the available – and from a present-day perspective, economically minable – resources.
- **ReCiPe** (Goedkoop *et al.* 2009): This method considers the occupation of agricultural and urban land (m^2a), the conversion of natural land (m^2), water requirement (m^3), metal consumption (iron equivalents) and the fossil fuels (oil equivalents) on the midpoint level. On the endpoint level, the impacts are converted into the unit Species*Year (land use) and into a monetary unit (abiotic resources). The raw materials are evaluated on the basis of the marginal costs of mining them.

Since the publication of the ILCD Report (EC-JRC-IES 2011), there has been little progress in the sphere of abiotic resources; unlike the cited report, the above compilation takes only the updated Swiss Ecological Scarcity method of 2013 into account.

Schneider *et al.* (2015) present a new methodology for estimating metal resources based on the available reserves. Because this is only applicable to metals, however, it is not particularly suitable for use in agriculture, since neither the mineral resources P and K nor energy resources are taken into consideration.

8.3 Water Requirement

Water is a crucial resource for agricultural production. Seventy per cent of freshwater consumption by humans goes to the irrigation of agricultural crops (The Crop Site 2015). Because of its relatively high precipitation levels, Switzerland currently usually has sufficient high-quality freshwater available. Annual precipitation stands at 60 km^3; added to this are inflows of 13 km^3 from other countries. Evapotranspiration comes to 20 km^3, whilst the remaining 53 km^3 corresponds to the outflow to other countries (Swiss Hydrological Survey 2003). With climate change, we can expect more frequent hot, dry summers, with the result that water will increasingly become a scarce commodity for Swiss agriculture (Fuhrer *et al.* 2013). If the glaciers in the Alps melt, rivers will carry less water in the summer, thereby aggravating the water shortage.

A number of the methods discussed above take account of the use of the resource water. The ILCD (EC-JRC-IES 2011) recommends the use of the Swiss Ecological Scarcity method. At the time of the ILCD's analysis, the 2006 version of this method was available, the method having not changed in terms of water use with the 2013 update (Frischknecht and Büsser Knöpfel 2013). The Swiss Ecological Scarcity method takes account of the current extraction of freshwater, and relates this to critical flow (this yields so-called 'ecofactors'). Critical flow is assumed to be 20% of those water resources that are renewed annually. These ecofactors are available for all countries.

The method of Pfister *et al.* (Pfister *et al.* 2009; Pfister *et al.* 2011) was not taken into account in the ILCD analysis, since it was not yet available. This method calculates a water-stress index from the ratio of current water consumption to renewed freshwater over the same period. The water-stress index values are made available worldwide, both for individual countries and for water catchment areas. This method therefore permits a better differentiation. Both the Swiss Ecological Scarcity method and the use of the water-stress index according to Pfister *et al.* (2009) (Figure 18) assume a regionalised impact analysis, i.e. the place where the water is extracted must be determined and differentiated according to country or water-catchment area. If, however, the bulk of water consumption occurs in the same place (e.g. on the farm), and contributions from upstream are marginal, the same factor can be used for overall water consumption, as an approximation.

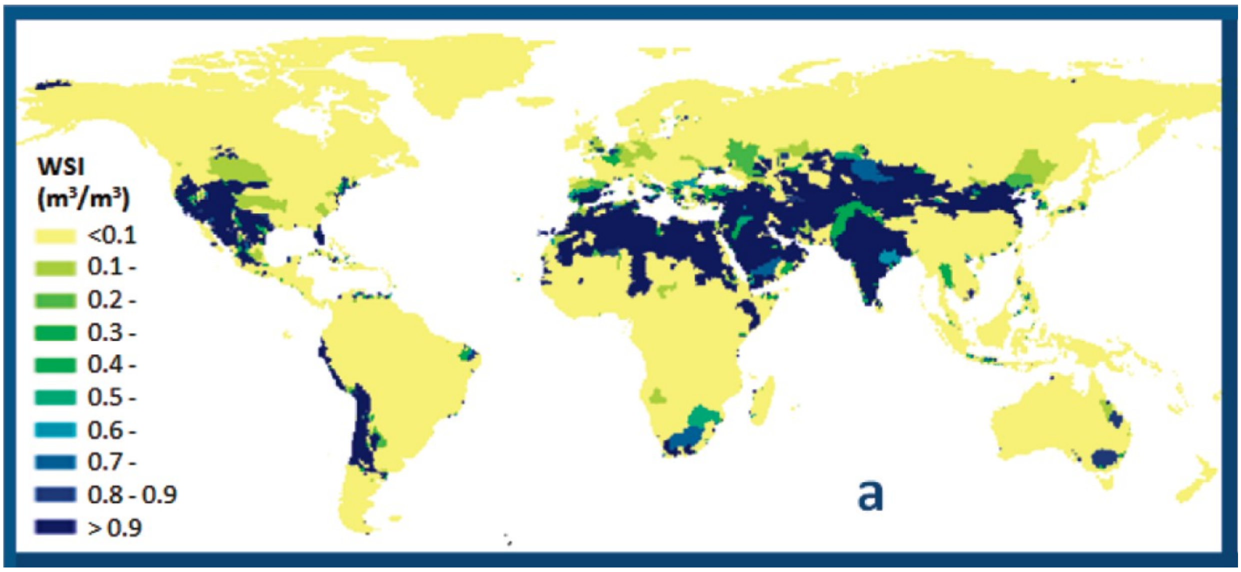

Figure 18: Global values for the water-stress index according to Pfister et al. (2009)

8.4 Land Use

Useful agricultural area is the prerequisite for agricultural production. The concept of 'land use' is very comprehensively applied in life cycle assessment (Milà i Canals *et al.* 2007a), taking into consideration aspects such as the mere use of the land, the biomass production potential of land, the effects of use on soil quality, biodiversity, and also – in some cases – landscape. In this report, the effects on biodiversity, soil quality and landscape aesthetics are covered by means of separate indicators. Consequently, the focus here lies on the remaining aspects. These are, first and foremost, *land occupation* per se, land-use change (*land transformation*), and the *biomass production potential* aspect.

From the above overview of the impact assessment methods, it is clear that several methods take specific aspects of land use into account. ILCD (EC-JRC-IES 2011) recommends the method of Milà i Canals *et al.* (2007b), in which soil organic matter is proposed as a robust indicator for soil quality. This indicator, however, is already taken into consideration in the soil-quality method, and is not suitable for depicting the aspects listed above.

For the land use assessment, indicators are proposed on three levels:

1. Land requirement,
2. Biomass-production potential,
3. Food-production potential.

- **Land requirement** (measured in m^2 per annum) bears in mind the fact that land area is a finite resource. If a piece of land is supplied for a specific use (e.g. through a building project), it is no longer available for other uses such as agricultural production. The CML2001 method (Guinée *et al.* 2001) proposes the indicator *land competition*, which is also used in the SALCA methodology, for this purpose. The advantage of this indicator is its simplicity. Moreover, common databases such as ecoinvent systematically record land occupation, with the result that calculation with the usual life cycle assessment software is possible. The disadvantage, however, is that the suitability of a piece of land for a particular use is not taken into account. Thus, a hectare of fertile arable land in the Swiss Midlands offers quite different possible uses from a hectare of alpine meadow, or a hectare in the Sahara.
- This lack can be offset with methods that bear in mind the **biomass production potential**. These are based either on *net primary productivity* (NPP), or on *human appropriation of net primary productivity* (HANPP). The former describes the biomass production potential of a piece of land (measured in MJ, kg C or kg dry matter), the latter the use of the biomass production potential by humans (through harvest). Both variables exist in the form of global maps. Alvarenga *et al.* (2013) present a method that expresses land use in MJ exergy (Figure 19). It therefore describes the potential for biomass production, which can be compared and contrasted with actual production. A refinement of the method of Alvarenga *et al.* (2015) is based on the HANPP, and characterises the remaining (non-harvested) biomass production potential. The idea behind this is that the non-harvested biomass is available for other ecosystem functions. These effects, however, are already largely covered in the present concept by biodiversity and soil quality, with the result that this method is less suitable. Both methods require a regionalised impact assessment, which very few LCA software programs are currently able to handle. Biomass production potential is of limited significance for food production, however, since it does not distinguish between renewable resources such as wood, feedstuffs such as grass, and food.

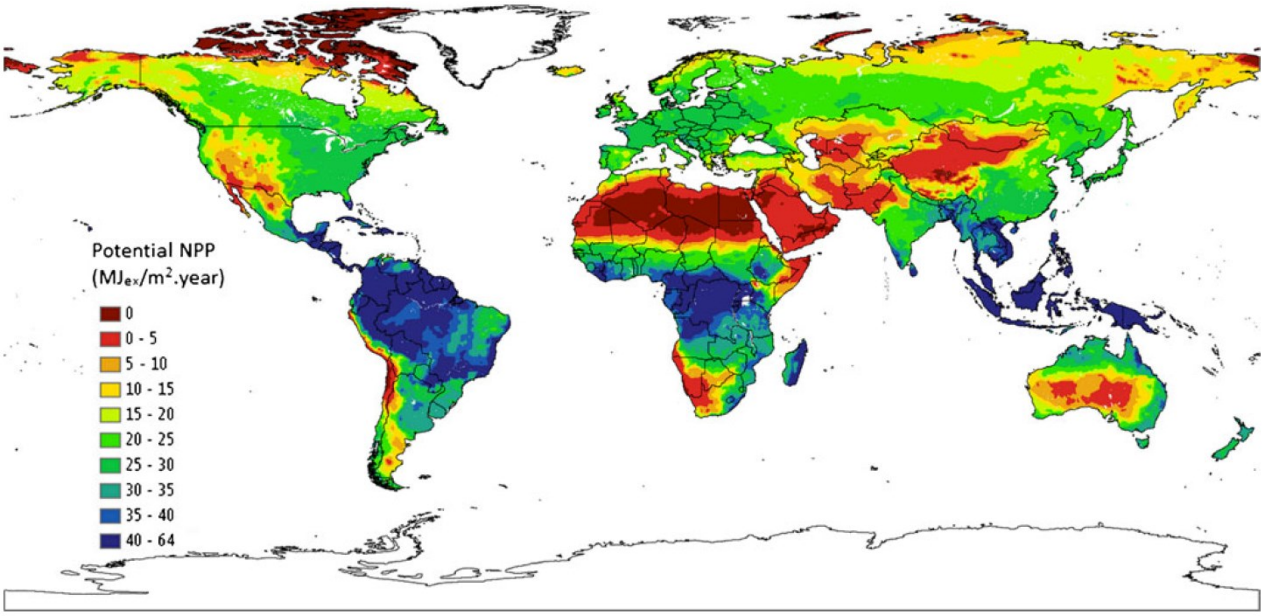

Fig. 2 World map of characterization factors of land resources in human-made systems, based on the potential availability of natural net primary production (in exergy units, MJ_{ex}/m^2year)

Figure 19: Exergy-based characterisation factors for land use (Alvarenga et al. 2013).

- In order to consider the different possible uses and food production in connection with animal production, Mollenhorst *et al.* (2014) developed a method which quantifies **protein production potential** for the human diet. In this method, a *land-use efficiency (LUE) ratio* is calculated as a quotient of the plant proteins which could be produced directly on the forage land for human nourishment, and the animal proteins which are actually produced. This method allows us to clearly highlight e.g. the differences between keeping ruminants on obligatory grassland plots that allow no other agricultural use, and feeding these ruminants forage from the field where foodstuffs could also be produced directly. The use of this methodology requires a regionalised impact assessment. The characterisation factors for world-wide application would also still need to be determined, which means that this methodology is not yet ready for widespread use.

These three approaches have different possible applications and a varying significance. The choice depends on the aim of the study in question. Land requirement is simple and universally applicable, but is of limited significance for agricultural production. The method of Mollenhorst *et al.* (2014) is specifically suited to the analysis of animal production. The method of Alvarenga *et al.* (2013) occupies an intermediate position, since it is globally applicable and covers important aspects of biomass production.

In addition to land occupation alone, **land transformation** is also highly relevant for agricultural systems. In Switzerland, natural regrowth and building projects have brought about a decrease in the utilised agricultural area. Transformation of other land into utilised agricultural area is a very rare occurrence. Despite this, grassland areas can be transformed into arable land, and vice-versa. The topic is far more pressing in other countries: in recent decades in Brazil, for example, large wooded areas have been clear-cut for agricultural use. This factor can be illustrated in the SALCA method with the indicator *deforestation*, which quantifies the net change in forest and bushland in m^2. It is similar to the *natural land transformation* indicator from the ReCiPe method (Goedkoop *et al.* 2009), but also takes the conversion of bushland into account.

8.5 Partial Aggregation of the Resource-Use Indicators

The proposed indicators for resource use relate to very different resources, and are given in different units. For this reason, common characteristics of the resources must be used for the aggregation. The exergy method (Bösch *et al.* 2007; Dewulf *et al.* 2007) allows an aggregation, since the various resources are consistently expressed in MJ exergy. In the ILCD assessment (EC-JRC-IES 2011), the exergy method was rated relatively favourably with the exception of environmental relevance, since scarcity is not taken into account, and acceptance by stakeholders, since the method cannot be communicated very easily.
Exergy can cover the following areas:

- Fossil fuels
- Nuclear fuels
- Renewable resource, wind power
- Renewable resource, solar power
- Renewable resource, hydroelectric power
- Renewable resource, biomass
- Water
- Metals
- Minerals.

In addition, the method of Alvarenga *et al.* (2013) allows land use to be depicted based on NPP. This means that all resources that are relevant for agriculture can be taken into account. Whilst the use of these resources can be represented with a single figure, it is entirely possible, as well as being useful for purposes of interpretation, to break down the exergy indicator according to the categories mentioned above. Only the land-transformation aspect (deforestation) cannot be included therein, and must be analysed separately, where necessary.

8.6 Evaluation of the Indicators

A detailed analysis can be found in the EC-JRC-IES Report (2011), and is summarised below.

8.6.1 Completeness of Scope

The headings of energy, mineral resources, metals, land use and water use take into consideration all of the natural resources that are important for agriculture. Further aspects are covered by the indicators for bio-diversity and soil quality. Renewable fuels, where they play a particular role, can also optionally be considered. Where relevant, land transformation must also be taken into account.

8.6.2 Assessment of Robustness and Uncertainties

The life cycle inventory data with regard to energy are considered to be relatively robust, since this area has been focused on for quite some time. There are, however, major differences in the literature in the choice of impact analysis method, depending on whether the gross or net calorific value[15] is considered, or whether only non-renewable rather than both non-renewable and renewable fuels are taken into account.

The LCI data for the requirement for metals and minerals are relatively robust. If the quantity and type of fertiliser is known, the need for phosphate ore or potash salt can be estimated fairly accurately. The impact analysis of the available reserves, however, is fraught with major uncertainties. In the first place, nowhere near all deposits are known; in the second place, the estimate of the available reserves depends on prices and mining technique.

With the water-stress index, there are major uncertainties in the upstream chains. True, the quantities of water consumed should be known on well-documented farms, but it is often not known whether irrigation took place, and if so, how much. Although Pfister *et al.* (2011) provide data on water consumption for the most important crops and all countries, experience shows that said data has a high level of uncertainty; moreover, water shortages are often a seasonal problem.

In terms of land requirements, the farm's own land is very well known. Uncertainties exist with regard to the upstream chains. Although the quantities of inputs are generally recorded, yields (e.g. of feedstuffs) can fluctuate considerably, especially since the countries and regions of origin are often not known, which increases the uncertainty regarding land requirement. There are also substantial uncertainties with regard to the land requirement for the production of purchased animals.

As regards land transformation, the estimation of deforestation is fraught with major uncertainties. The change in wooded area in various countries is documented in the statistics, but there is great uncertainty as to how this change is to be allocated to individual products (e.g. soya or beef).

8.6.3 Transparency and Reproducibility

All methods are described in the scientific literature, and most are also implemented in common software tools. Consequently, transparency and reproducibility are good.

8.6.4 Applicability: Communicability / Practicality

The use of abiotic resources is quantified in life cycle inventory databases, with the result that the impact assessment is readily applicable here. In some cases, water requirement and land use require a regionalised impact assessment, which the current LCA software tools cannot yet handle as a matter of course.

In the case of cumulative energy demand communicability is good, since these factors have been known for years and are often discussed. The water-stress index is also readily communicable, as are land requirement and deforestation. With abiotic resources, the CML2001 method unit (antimony (Sb)-equivalents) is scarcely known to laymen. The concept of exergy is difficult for laymen to grasp, and therefore difficult to communicate. In the case of uncommon units, however, there is always the possibility in communication of speaking of (and correspondingly, of documenting) e.g. resource points, and only using the original units for scientific communication.

8.7 Recommendation

The choice of indicators depends on the objective of the study. For life cycle assessment studies with a scientifically or otherwise technically trained audience, we recommend working with several individual indicators, as shown in Table 49. Indicators that are not relevant for the systems considered may be omitted; for example, the indicator 'deforestation' is largely irrelevant for an analysis of Swiss arable farming, and can thus be ignored. The number of indicators can be reduced further by using the CML2001 method '*abiotic resource depletion*' for fuels as well, which means that the indicator 'cumulative energy demand' (CED) can

[15] The higher heating value (gross calorific value) quantifies the total amount of energy chemically bound in the fuel, whilst the net calorific value (lower heating value) describes only the energy released, excluding the evaporation heat of the water contained in the combustion gases.

be dispensed with. However, fuels are then expressed in the highly uncommon unit of antimony-equivalents, which adversely affects communication and comparability with other studies.
For the assessment of overall sustainability, we recommend working with the indicator ‘exergy’. This allows all important resource areas to be taken into account with the same method and unit. The exception is logging, which must be considered additionally, if need be. The individual resource areas can and should be distinguished when presenting the results, in order to make interpretation easier.

Table 49: Overview of the proposed indicators for the ‘use of environmental resources’ category

Environmental Resource	Individual Indicators	Unit	Aggregated Indicator	Unit
Non-renewable fuels	Cumulative energy demand (CED): fossil and nuclear	MJ	Exergy	MJ
Renewable fuels	Optional: Cumulative energy demand (CED): biomass, wind, solar, geothermal, hydroelectric power	MJ	Optional: Exergy for biomass, wind, solar, geothermal, hydroelectric power	MJ
Metals and minerals	CML2001 ‘abiotic resource depletion’ (without fuels)	kg Sb-Eq.	Exergy: Metals Exergy: Minerals	MJ
Water	Water-stress index, Pfister et al. (2009)	m^3	Exergy: Water	MJ
Land use	1. Land competition (CML2001) 2. Exergy: Land use (Alvarenga et al. 2013) 3. Protein production potential	m^2a MJ LUE	Exergy: Land use (Alvarenga et al. 2013)	MJ
Land transformation	Deforestation	m^2	Not available	-

9 Climate (Global Warming Potential)

Thomas Nemecek, Maria Bystricky, Gérard Gaillard, Andreas Roesch

9.1 Introduction

Anthropogenic climate change has numerous effects on ecosystems, as well as on human health (Figure 20).

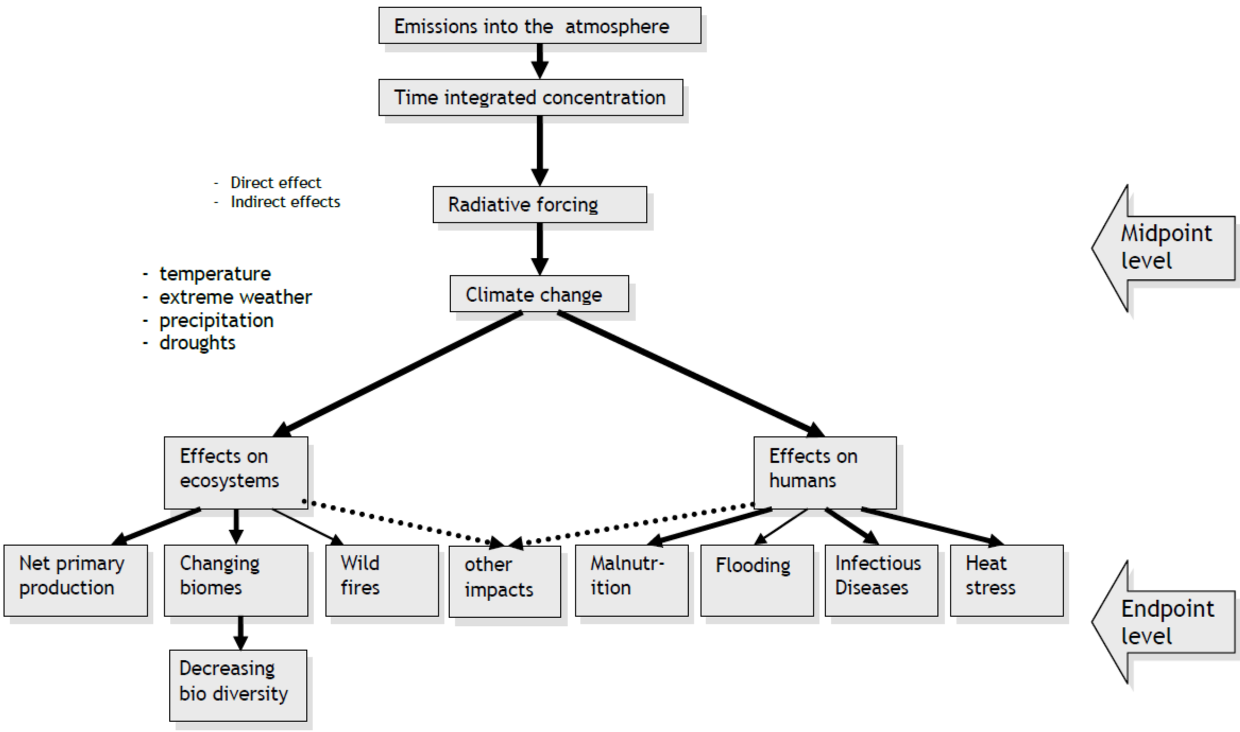

Figure 20: Connections between climate change and its effects on ecosystems and human health (source: EC-JRC-IES 2010).

In 2013, the Swiss agricultural sector generated 11.5% of Switzerland's greenhouse-gas emissions (FOEN 2015). In recent years, this percentage has fallen; in 1990, it was still at 13.3%. In this regard, however, it should be noted that in the national greenhouse-gas inventory, not all emissions caused directly and indirectly by the agricultural sector are assigned to the latter. Greenhouse-gas inventories follow a sectoral rather than a life cycle approach as with life cycle assessments, and are therefore not directly comparable with one another. Moreover, various agricultural inputs such as mineral fertilisers or foodstuffs are imported, which means that the corresponding emissions are not contained in the national territorial inventories. All in all, the contribution of agriculture is thus likely to be greater (SFSO 2009; Bretscher *et al.* 2014).

9.2 Life Cycle Inventory

The most important greenhouse-gases in agriculture are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O, Figure 21). Other greenhouse gases such as chlorofluorocarbons (CFCs) may occur in the upstream chains, but as a whole are of negligible importance for agricultural systems. The most important sources of greenhouse gases are the following:

- Methane: By far the most important source of methane is animal husbandry. The largest proportions come from the digestive tract of ruminants (enteric emissions) as well as from farmyard-manure management or grazing. Globally, rice production also plays a key role, but is of negligible importance in the Swiss agricultural sector.
- Nitrous oxide is closely associated with the nitrogen cycle. During nitrification (the transformation of ammonium into nitrate) and denitrification (the transformation of nitrate into atmospheric nitrogen N_2),

nitrous oxide can escape as a by-product or intermediate product. Consequently, nitrous oxide is produced during plant production through the use of (mineral and organic) N-fertilisers, the incorporation of harvest residues, and the degradation of soil organic matter.

- Nitrous oxide is also produced in animal husbandry through the management of farmyard manure and on pasture.
- Induced N_2O emissions may arise through the deposition of other reactive N-compounds of agricultural origin such as NH_3 and NO_x from the atmosphere as well as after the discharge of leached nitrate to the surface; these must also be taken into account.
- CO_2 from fossil energy sources (motor fuels such as diesel and petrol, fuels such as heating oil or natural gas, and the use of fossil fuels in the upstream chains).
- Greenhouse gases from land-use change: deforestation, reclamation of wetlands or the transformation of grassland into arable land can lead to the release of large quantities of greenhouse gases. For the Swiss agricultural sector, the import of feedstuffs such as soybeans from Brazil or palm oil and palm kernel meal from Southeast Asia is particularly significant. Thus, the consumption of meat from regions where deforestation takes place, or from animals fed with the relevant feedstuffs, contributes to these greenhouse-gas sources. The greenhouse gases produced are CO_2, as well as nitrous oxide (through the degradation of organic matter) and methane (through the reclamation of wetlands).

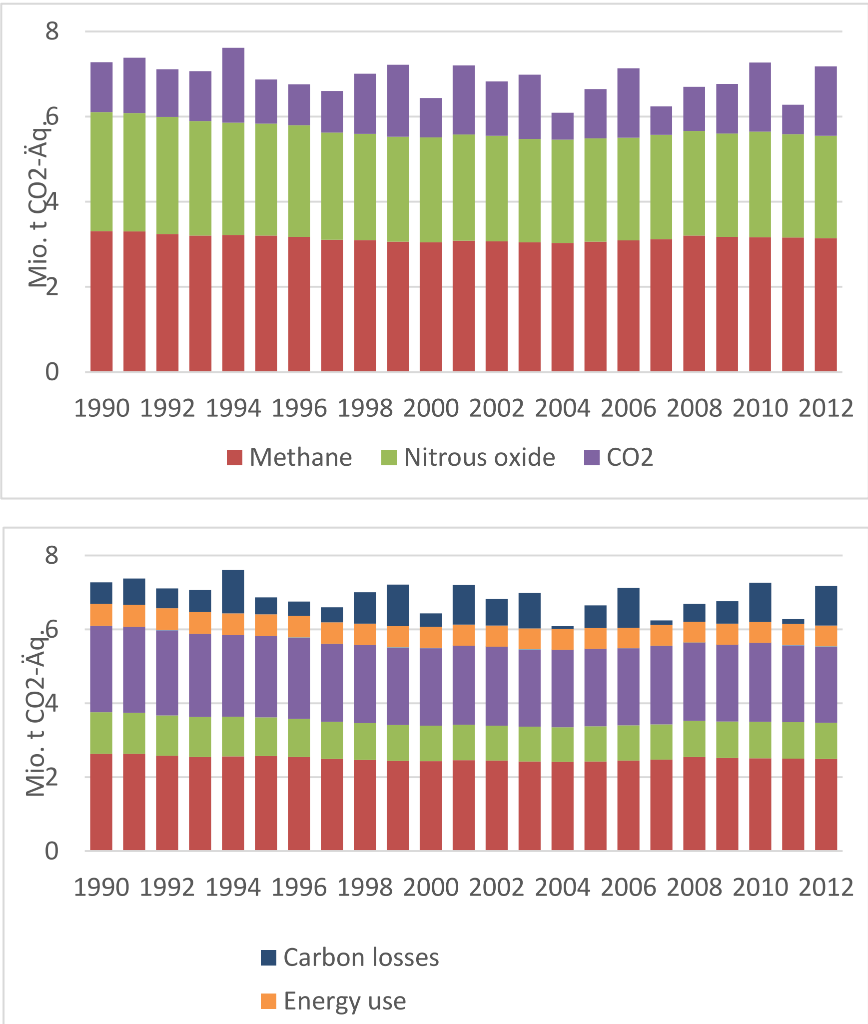

Figure 21: Greenhouse-gas emission trends from Swiss agriculture (above: according to emission; below: according to emission source). Source: FOAG (2013)

The following models and data are used to calculate the greenhouse-gas emissions in the life cycle inventory:

- The emissions from the upstream chains as well as from the combustion of fuels on the farm (all greenhouse gases) are obtained from the ecoinvent and SALCA life cycle assessment databases. Where necessary, they are supplemented by other databases such as the World Food Life Cycle Database, AGRI-BALYSE, ACYVIA or Agri-footprint. This also applies for the emissions themselves.
- Methane emissions from the digestive systems of animals, on pasture, and through farmyard-manure management are calculated with the IPCC (2006) emission factors (detailed Tier 2 methodology). An exception is the enteric emissions of dairy cows, which are calculated with the regression equations of Kirchgessner *et al.* (1993), bearing in mind the composition of the feed.
- The emission factors for methane and nitrous oxide from rice production come from IPCC (2006).
- Direct CO_2 emissions on the farm are generated by the use of urea, lime or dolomite. These are calculated in accordance with IPCC (2006) under the assumption that all C is released as CO_2.
- Nitrous oxide emissions from animal husbandry are calculated according to the IPCC methodology (2006) (Tier 2 method), whilst those from plant production are derived from IPCC (2006) (Tier 1 method).
- The calculation of the precursor substances (NH_3, NO_x, NO_3) for the induced nitrous oxide emissions is described in Chapter 10.2. The emission factors for these induced emissions stem from IPCC (2006) and amount to 1% of the N from NH_3 and NO_x, as well as 0.75% of the N from NO_3.
- The emissions from land-use change are calculated with the IPCC (2006) methodology. The calculation is effected with the *Direct Land-Use Change Assessment Tool* (Blonk Consultants 2014).

9.3 Life Cycle Impact Assessment

EC-JRC-IES (2011) recommends using the characterisation factors of IPCC (2007) for '*global warming potential'* for the timescale of 100 years. In the meantime, a new report was published by the IPCC (IPCC 2013). The characterisation factors for methane were increased, whilst those for nitrous oxide were reduced (Table 50). Moreover, a distinction is now drawn between methane from biogenic sources (e.g. animal husbandry) and from fossil sources. The reason for this is that with time, methane oxidises into CO_2, and CO_2 from fossil sources – unlike that from biogenic sources (produced by the assimilation of CO_2 from the air) – is viewed as climate-impacting.

Table 50: Characterisation factors for global-warming potential (GWP), timescale of 100 years, in the fourth (2007) and fifth (2013) IPCC Assessment Report.

GWP100	V2007 kg CO_2-Eq.	V2013 kg CO_2-Eq.	Change
Biogenic CH_4	25	28	+12%
Fossil CH_4	25	30	+20%
N_2O	298	265	-11%

The characterisation factors for the different greenhouse gases depend on the timescale considered. IPCC (2007) published factors for 20, 100 and 500 years, whilst IPCC (2013) only still lists those for 20 and 100 years. Over longer periods of time the factors for the majority of substances decrease, since they are broken down in the atmosphere, after which they are not more-or-less strongly climate-impacting. When considered over a 500-year period, methane and nitrous oxide emissions become less important than CO_2. From a scientific perspective, there is no proper and generally valid timeframe. In practice, the 100-year time frame has become established, as also laid down as standard in the Kyoto Protocol. This renders the results comparable with those of other studies.

IPCC (2013) also gives factors for *global temperature potential* (GTP). The GTP indicates how strongly the temperature on the Earth's surface changes in a base year as a result of a specific emission. Persson *et al.* (2015) discuss the differences between the two metrics using the example of beef production. As well as on the base year, GTP also depends on the timing of the emission. GWP incorporates the impact of a greenhouse gas over the timescale considered, and is thus a more stable metric. GWP corresponds to a midpoint methodology, whilst GTP has characteristics of an endpoint method.

9.4 Evaluation of the Indicator

The indicator ‘GWP over 100 years’ (IPCC 2013) is considered to be very complete, since it contains characterisation factors for all important greenhouse gases.
IPCC 2013 gives the uncertainty for GWP100 as +/-40% for CH_4 and +/-30% for N_2O (5%–95% confidence range). Observing the trend of the GWP factors over time also gives an indication of the uncertainties, with CH_4 and N_2O factors diverging more than 10% from those in the last IPCC report. By definition, the CO_2 value stands at 1, and thus has no uncertainty itself.
Transparency and reproducibility are both high; this methodology is very well documented.
It is used in numerous studies, tools and databases, which bears witness to its high applicability. ‘Climate change’ is the environmental impact which has received the greatest attention, and which is most widely used. Consequently, communicability can also be rated as very good.

9.5 Recommendation

The *global warming potential* (GWP) over 100 years according to IPCC (2013) has become established as the standard indicator for climate impact. As a midpoint indicator, GWP also ensures the uniformity of the recommended indicators in the environmental dimension. It is therefore recommended for use.

10 Nutrient-related Environmental Impacts

Thomas Nemecek, Maria Bystricky, Gérard Gaillard, Andreas Roesch

10.1 Introduction

Plant growth requires a range of nutrients. In order to ensure productivity in the long run and prevent the land degradation, the leached nutrients must be replaced by the application of fertilisers. Nutrients emitted into the air or water can produce undesirable impacts. The most important nutrients with a high environmental relevance are nitrogen and phosphorus. Potassium is not a limiting nutrient in water systems, and consequently K-losses are not considered in life cycle assessments in terms of their environmental impact, although K is accounted for as a limited resource (cf. 8.2.2).

Nitrogen compounds contribute to acidification (NH_3 and NO_x), climate change (N_2O), and the eutrophication of water systems (NO_3 and other N-compounds). Phosphorus is problematic owing to its eutrophying effect on water systems.

10.2 Life Cycle Inventory

The most important N-compounds in the agricultural context are NH_3, N_2O and NO_3. NO_x is of relatively minor importance, owing to the smaller quantities involved. Direct emissions from agriculture are joined by emissions from the upstream chains, such as fertiliser production.

For phosphorus, outputs from agriculture through soil erosion, run-off and leaching are the main contributing factors, with the latter two generally being less important. Added to these are emissions from the mining of phosphate ores and the manufacture of P-fertiliser. What's more, P-emissions from industry into the atmosphere contribute to total outputs, with e.g. the combustion of P-containing coal in coal-fired power stations producing corresponding atmospheric emissions.

The SALCA method uses the following emission models in the life cycle inventory:

- NH_3: The Agrammon Model (Agrammon Group 2009a, 2009b) for the emissions from animal husbandry and from the application of farmyard manures and other organic fertilisers. Because Agrammon is not differentiated enough for the emissions from mineral fertilisers, the emission factors from the EEA (2013) are relied upon here.
- NO_3: SALCA-Nitrate (Richner *et al.* 2014)
- NO_x: Emission factors according to EMEP (EEA 2013)
- P: SALCA-Phosphorus (Prasuhn 2006)
- Emissions from the upstream chains are derived from the ecoinvent and SALCA life cycle assessment databases. If need be, they are supplemented by other databases such as the World Food Life Cycle Database, AGRI-BALYSE, ACYVIA or Agri-footprint. The same applies for the emissions from the combustion of fuels on the farm.

10.3 Impact Assessment

The impacts on eutrophication and acidification are presented here; the impacts on climate were dealt with in Chapter 9.

10.3.1 Eutrophication Potential

Depending on the impact assessment method used, we differentiate between aquatic and terrestrial eutrophication potential. Aquatic eutrophication can be further differentiated into the impact of P and N compounds, as well as into freshwater and marine eutrophication.

In terrestrial ecosystems, the supply of N and P causes nutrient enrichment. The input pathway is via the air, with N emissions clearly predominating. In agricultural production systems the input of N and P is to be regarded as positive, since it reduces the amount of nutrients that must be supplied via the use of fertiliser. The situation is different in semi-natural and low-input systems such as ecological compensation areas, nature conservation areas or forests. Here, the supply of nutrients promotes plant growth and can alter the composition and variety of species. This is because a relatively small number of highly competitive species often predominate in nutrient-rich ecosystems, which generally reduces biodiversity.

In aquatic systems, species composition and diversity is altered, and the growth of algae is promoted. The decomposition of the resultant biomass consumes oxygen, which can lead to oxygen depletion in deep layers of water systems. Often, only one macronutrient is limiting in these water systems. In general, phosphorus is usually limiting in freshwater, and nitrogen in marine waters (EC-JRC-IES 2010). Although Switzerland does not border on the sea, there are two reasons why marine eutrophication must also be considered in life cycle assessments of Swiss systems:

1. Sooner or later, water from rivers and lakes ends up in the oceans.
2. Processes in the upstream chains often take place outside of the country (e.g. fodder production, or the mining of phosphate ores for the manufacture of fertilisers).

The impact pathways leading to eutrophication are shown in Figure 22.

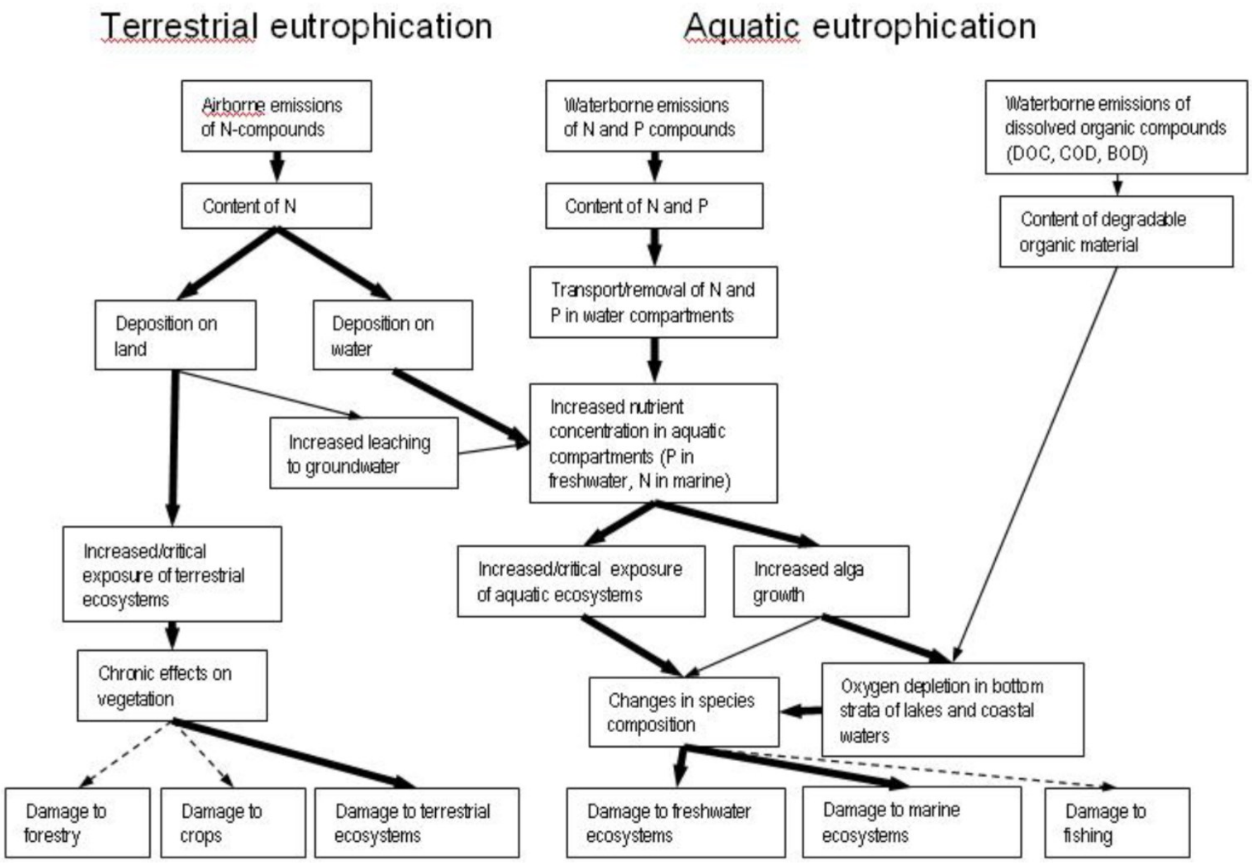

Figure 22: Impact pathways of N and P compounds on aquatic and terrestrial eutrophication (ILCD, 2010).

The ILCD (EC-JRC-IES 2011) compared various impact assessment methods:

- The CML2001 method (Guinée *et al.* 2001) is transparent and easy to use, inasmuch as it takes the entire amount of N and P into consideration. Its main weakness is the lack of a fate model, i.e. the displacement processes of the N and P compounds are ignored. An advantage of this simple model, however, is that overall eutrophication is summarised in a single indicator. Here, it is assumed that 1 mol P contributes as much to biomass production as 16 mol N, so that 1 kg N corresponds to 0.42 PO_4-equivalents (Guinée *et al.* 2001).
- Die EDIP2003 method (Hauschild and Potting 2005) performed relatively well in terms of aquatic eutrophication, and somewhat less favourably in terms of terrestrial eutrophication, though still comparatively well. A strength of the method is its ability to determine regionalised impact factors. Characterisation factors for the European countries are documented in the publication. EDIP2003 is the standard method for calculating eutrophication in SALCA.

- The ReCiPe method (Goedkoop *et al.* 2009) only takes account of aquatic eutrophication. This method performed favourably in the assessment by ILCD. A distinction is drawn between freshwater eutrophication, in which only P compounds play a part, and marine eutrophication, where N compounds alone are considered.
- The *Accumulated Exceedance* method (Seppälä *et al.* 2006; Posch *et al.* 2008) allows an estimate of terrestrial eutrophication and acidification, but does not take the eutrophication of aquatic systems into account. It performed well in comparison with the other documented methods.

EC-JRC-IES (2011) recommends the *Accumulated Exceedance* method for terrestrial and ReCiPe for aquatic eutrophication. Because it makes communication and aggregation more difficult, the use of different methods for terrestrial and aquatic eutrophication appears to be unsuitable for this project.

10.3.2 Acidification Potential

This impact category describes the emissions of acidifying substances into the atmosphere. Although the deposition of these substances on land or in the water causes the release of protons (H^+), which can lead to a decrease in pH value, the impact in the receiving medium is influenced by its buffer capacity. Thus, for example, the impact in the soil depends heavily on its lime content.

Acids such as hydrochloric or sulphuric acid, which are usually only present in agricultural systems in small amounts, have an acidifying effect. Of far greater importance, however, are substances which are converted into acids via chemical or biological processes. Ammonia (NH_3), mononitrogen oxides (NO_x) and sulphur dioxide (SO_2) are largely responsible for the acidification potential. After nitrification, ammonia has an acidifying effect in the soil.

SO_2 is mainly produced when sulphur-containing fossil fuels are burned in industry and in households (chiefly for heating). NO_x emissions are produced at high combustion temperatures from atmospheric nitrogen and oxygen during the combustion of fossil heating and motor fuels, and from biomass from the nitrogen it contains (FOEN 2014). Agriculture also produces direct NO_x emissions, though these are of lesser significance (FOEN 2014).

Thanks to air-pollution control efforts, both SO_2 and NO_x emissions have decreased over the past two decades. Since this does not apply to the same extent for NH_3 emissions, the relative contribution of NH_3 has risen.

In agricultural processes NH_3 usually dominates, accounting for about 80–90% of emissions. NH_3 emissions are primarily associated with animal husbandry, as well as with the use of N-containing fertilisers (Kupper *et al.* 2013).

Since NH_3 is predominantly responsible for acidification in agricultural systems, there is a close correlation with terrestrial eutrophication, which is also largely determined by NH_3.

Figure 23 shows the impact pathways in connection with acidification.

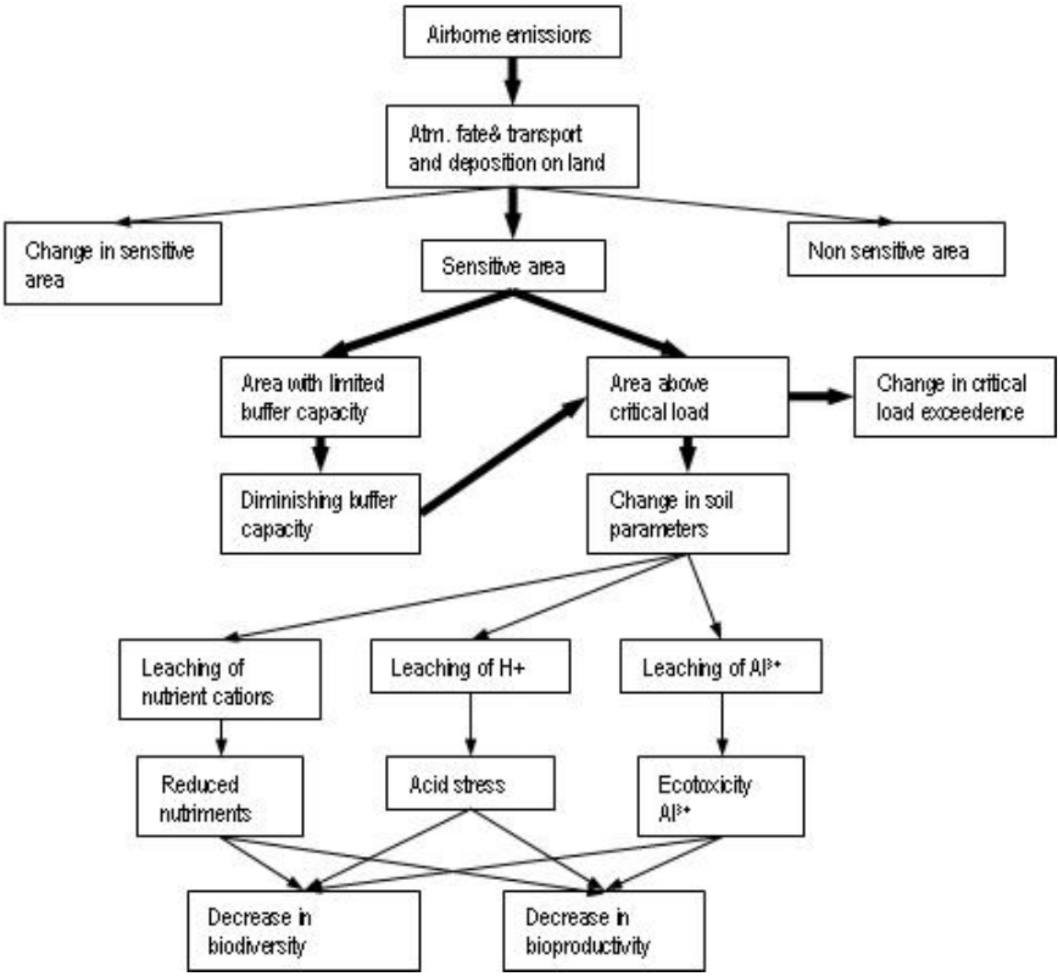

Figure 23: Impact pathways of acidifying compounds (ILCD, 2010).

EC-JRC-IES (2011) presents a comparison and evaluation of different methods for the impact assessment of acidification. This can be summarised in part as follows:

- EDIP2003 (Hauschild and Potting 2005): The modelling of the transport processes is based on the RAINS Model. The method allows a spatial differentiation; there are generic factors and differentiated factors for 44 European countries, with the different buffer capacities of the soils being taken into consideration. EDIP2003 quantifies the change in surface area on which a critical threshold value is exceeded by a specific emission (‘*area of unprotected ecosystem*’ in m^2).
- CML2001 (Guinée *et al.* 2001): This method also uses the RAINS model to model the transport and deposition of the acidifying substances. CML2001 calculates the marginal change in the *hazard index* by comparing the current load with the critical load (Hauschild *et al.* 2006).
- ReCiPe: The EUTREND model is used to model transport and deposition (Goedkoop *et al.* 2009). This method only takes terrestrial ecosystems into account, calculating the change in base saturation per unit of time.
- The *Accumulated Exceedance* method (Seppälä *et al.* 2006; Posch *et al.* 2008) allows an estimate of terrestrial acidification; aquatic systems are not considered. This method performed well in comparison with the other methods analysed.

ILCD recommends using the *Accumulated Exceedance* method, which performed the best in the comparison. CML2001 and ReCiPe received a mediocre rating; EDIP2003’s approach was rated as incompatible with life cycle assessments, with the rationale for this remaining unclear. Consequently, no complete assessment was undertaken for this method.

10.4 Evaluation of the Indicators

The indicators for eutrophication cover all important N- and P-containing substances, with the result that completeness is good.

The uncertainties of the generic characterisation factors are documented in Hauschild and Potting (2005). A value of 101 +/-131 m^2/kg NH_3 (standard deviation), for example, is quoted for terrestrial eutrophication. Since the standard deviation is greater than the value, the uncertainty is high. For emissions into water, 0.59 +/-0.15 kg N-eq./kg N and 0.88 +/-0.15 kg P-eq./kg P are quoted. Consequently, the estimate of aquatic eutrophication is subject to a lower degree of uncertainty. On the other hand, there is the additional uncertainty here as to whether N or P is limiting in an aquatic ecosystem.

Transparency and reproducibility of eutrophication are assured with EDIP2003, since this methodology is well documented.

The EDIP2003 methodology is used time and again in life cycle assessment studies; however, other methods such as CML2001 and ReCiPe can be found more frequently in the literature. For this reason, its acceptance is rated as mediocre.

Furthermore, since the 'Acidification Method' of EDIP2003 performed poorly in the assessment by EC-JRC-IES (2011) (see above), it is not recommended for use here.

10.5 Discussion and Recommendation

The indicators for acidification and terrestrial eutrophication are closely correlated. Experience from numerous LCA studies in the agricultural sphere shows that the conclusions that can be drawn from findings in these two impact categories are almost always identical (cf. e.g. Alig *et al.* 2012; Bystricky *et al.* 2014). The reason for this is that both categories are strongly dominated by ammonia emissions. Consequently, it is sufficient for just one of these two indicators to be included within the scope of a comprehensive sustainability assessment.

The recommendation of the ILCD (EC-JRC-IES 2011) for the category of nutrients is hardly practicable. The *Accumulated Exceedance* method is recommended for acidification and terrestrial eutrophication; the EUTREND model – used in the ReCiPe method – is recommended for aquatic eutrophication. Since we are dealing here with two different approaches, they are difficult to combine as well as to communicate.

Consequently, an alternative suggestion must be developed. The EDIP2003 method can be used for terrestrial eutrophication (unit: m^2) as well as for aquatic N- (unit: N-eq.) and P-eutrophication (unit: P-eq.), and is thus recommended. The ILCD gave this method a relatively high rating. For use on Swiss farms, either the regionalised characterisation factors for Switzerland are applied, or a regionalised impact analysis is carried out, should this be technically feasible.

In order to derive a single key figure for eutrophication from the three indicators, the use of normalised values according to Hauschild and Potting (2005) is proposed. This allows the nutrient-related environmental impacts to be summarised into a single indicator, for use as part of a sustainability assessment. This publication only provides the normalisation factors for total emissions from Europe, which, moreover, are no longer up-to-date. Current normalisation factors for Switzerland have therefore still to be determined for this purpose.

By contrast, it is recommended that the midpoint indicators for terrestrial and aquatic eutrophication through N, aquatic eutrophication through P, and acidification be used for LCA studies. The EDIP2003 method is recommended for eutrophication, whilst the *Accumulated Exceedance* method (Seppälä *et al.* 2006; Posch *et al.* 2008) is proposed for acidification.

11 Ecotoxicity

Tuija Waldvogel, Thomas Nemecek, Andreas Roesch

11.1 Introduction

The aim of this chapter is to test existing methods for assessing the environmental impact 'ecotoxicity' on farms in Switzerland. At the same time, the impacts on the ecosystem of the use of pesticides on farmland are specifically discussed.

The toxic effect of a substance on different species in the environment depends on the one hand on its environmental chemistry, i.e. the behaviour and fate of a substance in the environment (exposure), and on the other hand on the effects of the substance on the organisms that come into contact with it (ecotoxicity). It is therefore essential to model as accurate a distribution of a substance as possible, and to determine the toxicity for the relevant species in various environmental compartments. Important environmental compartments in this context are surface-water systems, groundwater, the air and soil.

The computation of ecotoxicity via the life cycle assessment method follows a set procedure. First of all, the distribution of a substance in the environment ('fate') is modelled as part of a life cycle inventory (LCI). The LCI describes what proportion of the active substance applied ends up in the different environmental compartments. The definition of these environmental compartments is dependent upon the methodology used, as are the distribution and degradation processes taken into account. In the next step of the life cycle assessment – the life cycle impact assessment (LCIA) – the influence of these emissions on the environment is estimated. Here, the toxic effects of a substance on the (eco-)system are quantified, with different environmental compartments being covered depending on the method used.

As can be deduced from this introduction, there are a wide variety of methods used for the life cycle inventory (LCI) and the impact assessment (LCIA). Consequently, one aim of the following assessment is to evaluate the suitability of said methods for calculating ecotoxicity in the context of the sustainability assessment of a farm. The following chapter begins by discussing the relevance of ecotoxicity for sustainability. There follows an overview of the available methods for creating the life cycle inventory and performing the impact assessment. Next, selected methods are described and evaluated, with a focus on the elements of completeness, robustness, the uncertainties, transparency and reproducibility of the methods, as well as their applicability in practice. The chapter concludes with a recommendation and the conclusions of our evaluation in view of the future use of the assessed models.

In addition to pesticides, a range of further harmful substances such as e.g. heavy metals determine ecotoxicity. These substances must also be taken into consideration as part of a life cycle assessment. In this report, however, the analysis is limited to pesticides, since it was in this field that the greatest need for action was identified.

11.2 Relevance of the Topic for Sustainability

Pesticides play an important role in the agricultural production of foodstuffs. A study of de Baan *et al.* (2015), based on data from around 300 Swiss farms shows that for many crops, the number of plots (a cohesive piece of land on which a particular crop is grown) not treated with plant-protection products (PPPs) is very low. In 2013 alone, a total of 2,119 tonnes of pesticide were sold in Switzerland, of which 992 tonnes were fungicides, 748 tonnes were herbicides, and 351 tonnes were insecticides (SFSO 2015a). The quantity and frequency alone, however, are not determining factors for possible ecotoxicological effects; the distribution of an active substance in the environment and its toxicity are also important. Distribution is dependent on different chemical and biological properties of the substance, as well as on climatic parameters (in particular precipitation, wind and temperature) in the system under consideration. A study by Wittmer *et al.* (2014) shows that a large number of pesticides can be detected in natural watercourses in Switzerland. The values in 31 out of 104 cases exceed the limits stipulated by the Water Protection Ordinance, and the ecotoxicological quality criteria are exceeded for 19 pesticides (Wittmer *et al.* 2014). Added to this is the fact that toxicity of PPPs is particularly critical, since pesticides intentionally have negative effects on fungi, insects or plants (Ippolito *et al.* 2015). The ecotoxicological effects of pesticides go hand-in-hand with a decline in biodiversity (Ippolito *et al.* 2015), a topic dealt with in chapter 12.

11.3 Overview

Developed and applied at Agroscope, the SALCA (Swiss Agricultural Life Cycle Assessment) method consists of in-house developments for specific emissions (life cycle inventory) and impact categories (life cycle impact assessment), as well as a range of known impact-analysis models for the application of life cycle assessment to agricultural processes (Gaillard and Nemecek 2009). Because no in-house method has to date been developed by Agroscope for the life cycle inventory of pesticides, the usual methods for assessing impact (e.g. CML, Impact 2002) – based on the assumption that 100% of the pesticide quantities used end up as an emission in agricultural soils (Nemecek and Kägi 2007) – were therefore used. Here, the entire quantity applied is evaluated as an input, and its distribution in the environmental compartments is to be viewed as part of the so-called ‘fate modelling’. The other environmental processes were then modelled in the impact assessment. This, however, is no more than a rough approximation for the modelling of pesticides, and can lead to either over- or underestimates of their ecotoxicological effect. Moreover, the specific conditions during use (climate, soil, application technique or developmental stage of the crop) may not be taken into account. This simplification was therefore also criticised by Rosenbaum *et al.* (2015) in their synthesis report on life cycle assessment. In recent years, improved models and methods for life cycle inventory and impact assessment have been developed with the aim of enabling a more accurate assessment of the distribution and impact of pesticides. Future LCI methods should enable a more accurate depiction of the emissions of an active substance into the different environmental compartments by taking account of important degradation and displacement processes (Linders *et al.* 2000). Developed by Birkved and Hauschild (2006) and refined by Dijkman *et al.* (2012), PestLCI is one such method for calculating the life cycle inventory. Based on physical and chemical models, this method calculates the distribution of a pesticide a short time after its application, as well as the subsequent displacement processes. This yields the emissions into groundwater, surface waters and the air. The soil is not considered an emission compartment, since it is allocated to the technosphere, i.e. the production unit, and hence is not deemed to be part of the environment. This latter assumption is highly contentious, and contradicts the fact that the soil actually does constitute an environmental compartment (see Chapter 11.4).

After the life cycle inventory is compiled, the impact assessment – in which the impact of the emissions of a substance into different environmental compartments is assessed by means of a characterisation factor (CF) – is performed in the life cycle assessment. This CF refers specifically to an active substance in a defined environmental compartment. To calculate the CF, the distribution of the active substance among the environmental compartments, the toxicity of the substance, and the exposure of the affected organisms are all taken into account. The CF therefore describes how harmful the investigated active ingredient is for the organisms in a specific environmental compartment.

Practitioners currently have two options for the life cycle assessment of pesticides: 1) the use of a pesticide emission model such as PestLCI combined with the appropriate CF for emissions outside of the field (groundwater, surface water, air, soil outside of the field); or 2) the applied quantity of the pesticide used is combined with the appropriate CF for emissions within the field (agricultural soil) (Rosenbaum *et al.* 2015).

In SALCA we can choose from different impact assessment methods, with the CML2001 methodology (‘Centrum voor Milieukunde’ (=Centre for Environmental Studies), Institute of Environmental Sciences, University of Leiden), developed by Guinée *et al.* (2001), often being used in agricultural life cycle assessment. The USEtox impact assessment methodology is also frequently referenced in the literature (Dijkman *et al.* 2012; Nordborg *et al.* 2014). USEtox was developed by various research groups as a consensus method. In a report produced by the ILCD (International Reference Life Cycle Data System), a number of common impact assessment methods were compared and evaluated (EC-JRC-IES 2011), *inter alia* the ReCiPe method, which is based in part on the CML methodology. The investigated methods were evaluated by means of the following indicators: i) completeness, ii) environmental relevance, iii) scientific robustness and uncertainties, iv) documentation, transparency and reproducibility, v) applicability, vi) general evaluation of the science-based criteria, and vii) stakeholder acceptance. Four impact assessment methods (USEtox, IMPACT, ReCiPe and TRACI) meet the scientific criteria according to the ILCD, and were therefore considered for a further evaluation. After an in-depth analysis, the ILCD recommended the USEtox methodology as a standard method for calculating freshwater ecotoxicity (EC-JRC-IES 2011). There are several reasons for this recommendation: for one thing, the USEtox model is a consensus model, and its underlying principles thus reflect generally acknowledged and accepted recommendations of experts. Furthermore, the USEtox model has access to all the important parameters in the impact pathway of a substance in the environment (EC-JRC-IES 2011). Based on a comparison of different impact assessment methods carried out by Rosenbaum *et al.* (2008), the accuracy of the USEtox CF for freshwater toxicity lies between 100 and 1000. This precision of two to three orders of magnitude is significantly lower than the variation of up to 12 orders of magnitude between the CFs of other methods.

In different publications dealing with the agricultural life cycle assessment of pesticides, the PestLCI methodology has already been combined with the USEtox methodology (Nordborg *et al.* 2014; Renaud-Gentié *et al.* 2014; Räsänen *et al.* 2015). Moreover, an intensive exchange between LCA researchers regarding the life cycle assessment of pesticides is currently taking place (Rosenbaum *et al.* 2015). One aim of this exchange is better coordination of both the modelling in the life cycle inventory and the impact assessment through a consensus among the involved experts. For these reasons, both the PestLCI and USEtox methods were selected for the present analysis.

In general, it should be noted that there are many other models for environmental behaviour and the ecotoxicology of PPPs outside of the life cycle assessment, which, depending on the issue in question and the available data, meet specific purposes. Examples are models used in the authorisation of the PPPs (Focus, Exposit, GERDA), which are capable of illustrating the spatial and temporal distribution of the risks (Synops), or which aim to predict the actual concentrations and risks of PPPs at a specific location (Aldrich *et al.* in press).

11.4 Description of the Methods

11.4.1 PestLCI 2.0

The PestLCI model is used in the life cycle assessment to create a life cycle inventory. A life cycle inventory is a quantification of the input and output of a process – in this case, the application of pesticides. PestLCI 2.0 subdivides the system under scrutiny into two parts: the technosphere (i.e. the economic system) and the environment. The field up to its edge, including the soil to a depth of one metre and the air column above it to a height of 100 metres, belongs to the technosphere (Birkved and Hauschild 2006; Dijkman *et al.* 2012). The environment is subdivided into three main compartments: air, surface water and groundwater. PestLCI is based on modelling principles from the field of environmental risk assessment, which are used for the analysis of individual chemicals. Unlike a risk assessment, however, an LCA involves the assessment of an average expected impact and not of a risk. In addition, PestLCI can model just one substance, i.e. an active substance of a pesticide, in a single calculation step, but not combinations of different active substances (Dijkman *et al.* 2012). Furthermore, the model can be used to model organic pesticides only, and not inorganic substances (such as e.g. copper), which are also used as pesticides. The model distinguishes 25 climate zones which cover the 16 climate zones of Europe according to the FOOTPRINT project (Centofanti *et al.* 2008; Dijkman *et al.* 2012). The PestLCI soil database contains seven European soil profiles.

Because of its modular construction, the model can be easily adapted (Birkved and Hauschild 2006). Here, the mass flow of the applied PPP follows fixed principles (see Annexe 13) according to the two steps of primary and secondary distribution. Below, the different assumptions for the individual substeps are described in detail.

Primary Distribution

With primary distribution, it is assumed that different proportions of the substance are distributed on the leaves (f_l) and soil (f_s), or carried off by the wind (f_d). Because of the conservation of mass and the model assumptions that pesticides are either deposited on the leaves and soil or are carried off by the wind, $f_d + f_l + f_s = 1$ applies.

For loss by the wind (f_d), the model considers ten application techniques: conventional spraying equipment for large plants (> 1 m) and smaller plants (< 1 m) on the field; spraying via aircraft; the use of conventional

spraying equipment for four plant species (potatoes, flowers, sugarbeet and cereals) and fallow lands, as well as the use of axial fans in orchards for trees with and without leaves (Dijkman *et al.* 2012). The loss curves are validated for wind speeds of up to 4.5 m/s based on the assumption that, owing to the high losses, the farmer will not apply any pesticides at higher wind speeds. In addition, loss via wind only takes into consideration those areas that are less than 110 meters from the field edge.
Distribution of the PPPs between the leaf surface (f_l) and the soil (f_s) depends on the plant species and its developmental stage. The method takes into account 28 plant species with three to four developmental stages according to Linders *et al.* (2000). Here, only the leaf surface and the surface of the topsoil are taken into account, and no other surfaces such as e.g. stalks or stem.

Secondary Distribution

The secondary distribution mechanisms or degradation processes are calculated on the basis of the quantities of pesticide deposited on the plant or soil during primary distribution. Several degradation or displacement processes are taken into consideration here, both for the plants and in the soil.

Plant

As soon as the pesticide reaches the leaf surface, the following three processes take place: evaporation (f_{vl}), absorption (f_{lu}) and degradation (f_{ld}) of the active substances. The proportion of the PPP deposited on the leaf surface in the primary distribution process (f_l) is therefore the sum of these three fractions ($f_l = f_{vl} + f_{ld} + f_{lu}$). The processes are terminated with the first rain event of > 1 mm, with the remainder of the substance leaching out into the soil, but then no longer being taken into account in the further processes in the soil (Birkved and Hauschild 2006).
For the evaporation of the PPP from the leaf surface, the evaporation rate of the chemicals used is calculated for a fixed temperature by means of the evapotranspiration rate, and corrected by means of the average air temperature of the month of application (Birkved and Hauschild 2006).
Absorption of PPPs by the plant is based on the assumption that the PPPs are lipophilic (i.e. have an affinity for fats), and that the substances are absorbed via the cuticle. In the model, the leaf surfaces of all plants are approximated with two species, i.e. pear and lemon, serving as examples. Here, lemon represents all plants with thick, waxy leaves, whilst pear represents all other species (Birkved and Hauschild 2006).
For degradation of PPPs on the leaf surface only photochemical degradation is taken into account, as there is not enough data for direct photolysis. Here, photochemical degradation is modelled by means of OH• radicals, as an approximation of the total degradation of chemical substances on the leaf surface (Birkved and Hauschild 2006).

Soil

The secondary distribution in the soil computes how the fraction deposited on the soil in the primary distribution undergoes different processes in the soil. Here, a distinction is made between topsoil (down to a soil depth of 1 cm) and subsoil (1-100 cm soil depth).

Topsoil

Four processes are taken into account in the topsoil: evaporation (f_{sv}), degradation (f_{sb}), surface runoff (f_r) and macropore runoff (f_{mp}). Below, we explain how these four fractions are calculated. The remaining fraction, which is neither degraded nor removed by the four above-mentioned processes, ends up in the subsoil, and is discussed in the following chapter, ‘Subsoil’.
For the topsoil, we assume that evaporation and degradation are two competing processes. Here, the degradation of PPPs depends first and foremost on the temperature and moisture content of the soil (Dijkman *et al.* 2012). Both degradation and evaporation are interrupted by the occurrence of the first rainfall of over 1 mm. After the first rainfall, the PPPs either end up in the surface water through surface runoff, or are transported directly into the groundwater through macropores (Birkved and Hauschild 2006). The surface runoff is based on the ratio of runoff to rain, and depends on soil type (Dijkman *et al.* 2012). For the definition of macropores, Dijkman *et al.* (2012) distinguish according to Hall (1993) between ‘immobile’ and ‘mobile’ pore water. ‘Mobile’ pore water is in turn subdivided into slowly and quickly flowing water, with the latter corresponding to the macropores. Since macropores lead to a rapid removal of PPPs, it is assumed that the

latter are not degraded on their way to the groundwater. The fraction of macropores in the 'mobile' pores is set by default in PestLCI to 0.3, but this can be adjusted by the user. The volume of water that can drain away through macropores is calculated in PestLCI via the amount of precipitation and the water-storage capacity of the soil. As soon as the soil becomes saturated with water, the water runs off via the macropores (Dijkman *et al.* 2012).

Subsoil

What remains after the degradation and removal processes in the topsoil ends up in the subsoil. The subsoil is defined as the layer of soil between a depth of 1cm and 100cm (Birkved and Hauschild 2006). In PestLCI, the following processes are taken into account for the subsoil: leaching ($f_{sl,i}$), degradation ($f_{sl,g}$) and removal via drainage (f_{dr}).
The most important process in the subsoil is leaching, through which pesticides end up in the groundwater. On the way there, however, substances can be degraded or conducted away via drainage. Soil stratification plays a major role in the leaching of pesticides from the subsoil. In PestLCI, the retention time for each soil horizon is calculated based on the following soil properties: thickness of the soil horizon; average pore-water velocity; diffusion coefficient; pH value; and filtering velocity (Birkved and Hauschild 2006).
Whilst the PPP is retained in the soil, it is degraded via biological processes. The soil-horizon-specific degradation rate is corrected in PestLCI with respect to several criteria: temperature, soil moisture, soil depth and bioavailability. The soil-horizon-specific degradation rate and retention time are used to determine the fraction of pesticide used which passes through all of the soil horizons (Birkved and Hauschild 2006; Dijkman *et al.* 2012).
Before this fraction ends up in the groundwater, a percentage of the pesticides can still be diverted via drainage. If drainage is present, it is assumed that all the PPPs are removed via drainage. The fraction removed via drainage can, however, be smaller than 100%, with the remaining pesticides being further leached out and simultaneously degraded via biological processes. The fraction remaining after drainage and the biological degradation processes is therefore what ends up in the groundwater.

Emission Distribution

The distribution of the emissions to the surface water (f_{sw}), groundwater (f_{gw}) and air (f_{air}) compartments can be determined with the help of the processes described above.
For the emissions into the surface water (f_{sw}), leaching from the topsoil (f_r) and drainage (f_d) are taken into account (see Formula 4):

$$f_{sw} = f_r + f_d \quad (4)$$

For the emissions into the groundwater (f_{gw}), the fraction left over after drainage which remains at a depth of one meter after the biological degradation processes ($f_{sl,\, i=g}$) is taken into account. In addition, the fraction that ends up directly in the groundwater via macropore flow (f_{mp}) is also taken into consideration (see Formula 5):

$$f_{gw} = f_{sl,i=g} + f_{mp} \quad (5)$$

With the emissions into the air (f_{air}), both the losses through drift at the time of application (f_d) as well as the fraction that evaporates on the plants (f_{lv}) and from the topsoil (f_{sv}) are taken into account (see Formula 6).

$$f_{air} = f_d + f_{lv} + f_{sv} \quad (6)$$

Required Input Parameters

For the calculation of the life cycle inventory with PestLCI, various input parameters which must be collected one or more times are required.
A total of 101 PPPs are listed in PestLCI (status as at 14 Sept. 2015) of which, according to our own calculations, 42 are included in the Ordinance on Plant-Protection Products (PSMV) of the Swiss Federal Office for Agriculture (FOAG). There are a total of 332 active substances listed in the PSMV, not including the 75 macro- and microorganisms (PSMV 2010). The PestLCI database therefore covers only a small percentage of the PPPs approved in Switzerland. The important thing here is that PestLCI can only model organic substances. The PSMV of the FOAG, however, contains both organic and inorganic substances. Nevertheless,

future use of Pest LCI will require the addition of several further PPPs to the database. This data collection need only be carried out once per PPP. Table 51 below lists the input parameters required in order to supplement the PestLCI database (16 parameters regarding chemical, biological and physical properties). The parameters listed below are well documented in the Pesticide Properties Database[16] – the database suggested by PestLCI – and can therefore be collected, although the compatibility or otherwise of the existing values with the reference provisions stipulated by the model (e.g. temperature) must be tested individually for each parameter. Here, atmospheric OH rate (hydroxyl radical rate) is a difficult-to-capture parameter, since it is sometimes missing from the above-mentioned main data source of PestLCI. The modelled distribution and degradation processes in the environment are strongly dependent upon the properties of a substance, with certain parameters being more important than others. Table 51 therefore lists how important the collection of the different parameters is according to our own assessment.

Table 51: Required pesticide input parameters for the PestLCI model that must be collected once, with units, explanation and importance according to internal ratings (++ = very important; + = important; o =necessary; - = not necessary).

Parameter	Unit	Explanation	Importance
Name	-		++
Type	-	Herbicide, fungicide or insecticide	+
CAS no.	-	CAS = Chemical Abstracts Service (an international naming standard for chemical substances)	++
SMILES	-	Simplified Molecular Input Line Entry Specification (a chemical structure code)	+
Molecular weight	g/mol		++
Solubility	g/l	Solubility in water	++
Ref. temperature solubility	°C	Usually 20 °C	+
Vapour pressure	Pa		++
Ref. temperature vapour pressure	°C	Usually 25 °C	+
pKa	-	Acidity constant	++
Log Kow	-	Log of the octanol/water partition coefficient	++
Koc	l/kg	Organic carbon partition coefficient	++
Soil t ½ (DT50)	Days	Half-life in the soil	++
Reference temperature for pesticide biodegradation	°C	Usually 20 °C	o
Atmospheric OH rate	cm^3/ (Molecules*s)	OH-radical oxidation rate constant	+
Activation energy for evaporation E(a)	kJ/mol	A default value of 100 kJ/mol is used when no specific E(a) is given	-

PestLCI provides a choice between seven soil types that differ in terms of their relative clay, loam and sand content. It is possible to add new soil types to the model. Table 52 lists the eight required input parameters per soil horizon. Ideally, these parameters are gathered for all soil horizons in the first metre. The sensitivity analysis (see Chapter 11.5.2) highlights the fact that the choice of soil type exerts a major influence on the calculated emissions. Percentages of clay, loam and sand are especially important in this context. Because of

[16] http://sitem.herts.ac.uk/aeru/ppdb/en/index.htm

this sensitivity, the soil input parameters should be as close as possible to real-world conditions. As with the PPPs, future use would therefore require the addition of a few more soil types. The required data need only be collected once, however.

Table 52: Required soil input parameters for the PestLCI model that must be collected once, with units, explanation and importance according to internal ratings (++ = very important; + = important; o =necessary; - = not necessary).

Parameter	Unit	Explanation	Importance
Name		Name of soil horizon	o
Start depth	m	Depth of start of soil horizon	+
End depth	m	Depth of end of soil horizon	+
Clay content	% particle	Particles <2µm	++
Loam content	% particle	2-50µm	++
Sand content	% particle	>50µm	++
Percentage of organic carbon	%		+
pH			+

PestLCI allows the specification of 25 climate zones, only one of which is based on climate data from Switzerland (Lugano). There is thus no distinction between lowlands and Alps, so additional climate zones for Switzerland will be necessary. A total of nine parameters must be collected per climate zone; these are listed in Table 53. These data need only be collected once, and are generally based on climate data that can be obtained from the Swiss Federal Office of Meteorology and Climatology, MeteoSwiss. Data gaps for potential evaporation can be approximated with the help of other data collected (latitude, altitude, minimum and maximum air temperature).

Table 53: Required climate input parameters for the PestLCI model that must be collected once, with units, explanation and importance according to internal ratings (++ = very important; + = important; o =necessary; - = not necessary).

Parameter	Unit	Explanation	Importance
Latitude	°		+
Altitude	m.a.s.l.		+
Solar radiation	Wh/m^2/day	Monthly average	+
Average air temperature	°C	Monthly average	++
Min. air temperature	°C	Monthly average	++
Max. air temperature	°C	Monthly average	++
Precipitation	mm	Monthly average	++
No. of days with >1mm precipitation		Monthly average	+
Potential evaporation	mm	Annual. Alternatively, can also be calculated with the help of minimum and maximum temperature, latitude and altitude.	-

A further important group of input parameters relates to the application of pesticides on the field, and the conditions prevailing during this process. For this category, a further 16 parameters are needed (see Table 54), which are explained in brief below. The crop and its developmental stage – it being possible to select from

28 crops with 3–4 development stages each – are very important, since they have a major impact on the results (see Sensitivity Analysis, Chapter 11.5.2). Furthermore, the application method as well as the quantity used in kg active substance/ha must be specified. The application method is an important input parameter, since the emissions into the air according to the sensitivity analysis of Nordborg *et al.* (2014) are dependent upon it. The sensitivity analysis carried out internally (Chapter 11.5.2) shows that the results respond highly sensitively to the application method and quantity; as precise a recording of these parameters as possible is therefore advisable. An initial assessment can also be based on spraying recommendations, however. The developmental stage can be determined on the basis of crop-specific development processes. In PestLCI the characteristics of the field must also be entered, especially field width and length, width of the buffer zones, slope gradient, and proportion of area drained and its depth, as well as the chosen tillage method. In terms of tillage, there are three predefined methods available: conventional, reduced tillage, or no tillage.
Unlike the pesticide properties, the application-specific parameters in in Table 54 must be collected anew for each application.

Table 54: Required input parameters (with units and explanation) for the PestLCI model regarding the application of pesticide, the crop, and field characteristics, which must be collected anew for each pesticide application. The Importance according to internal ratings (++ = very important; + = important; o =necessary; - = not necessary) is also given.

Parameter	Unit	Explanation	Importance
Crop	-	There are 28 crops to choose from	++
Developmental stage of crop	-	There are 3–4 stages of development per crop to choose from	++
Application method	-	10 application methods to choose from	++
Month applied	-		+
Quantity applied	kg/ha	Quantity of active substance applied	++
Annual irrigation	mm		+
Soil type	-	There are 7 soil types to choose from	++
Climate zone	-	There are 25 climate types to choose from	++
Field width	m	Width of the field	++
Field length	m	Length of the field	+
Buffer zone	m	Width of zone along the field margin in which spraying is not permitted	+
Slope gradient	%		o
Depth of drainage	m	Set to 0.6m by default; may not be greater than 1m	o
Fraction of the soil that is drained	-	The default value is 0.55	+
Tillage method	-	‘Conventional’, ‘reduced tillage’ and ‘no tillage’ are the choices available	+

11.4.2 USEtox 1.01

As already explained in the overview (Chapter 11.3), the USEtox methodology is used for the impact assessment of aquatic ecotoxicity, in order to assess the affect of a chemical on the environment. Since USEtox can be used not only for PPPs, but also, for example, for metals, we will sometimes speak hereafter of ‘chemicals’, in order not to give the impression that this method is only capable of modelling PPPs.

In USEtox, the distribution of chemicals between the following five compartments are considered: agricultural soil, natural soil, freshwater, ocean and air. It is assumed that all compartments are homogeneous, and that a substance is distributed evenly (Rosenbaum *et al.* 2008). Moreover, a distinction is drawn between two geographic levels: the continental and global levels. Both of these levels have the above-mentioned compartments, with the continental additionally containing urban air (see Figure 24). Thus, there are a total of 11 compartments in USEtox. It should be noted that the global and continental levels do not overlap, and hence double counting does not occur. The global level was added in order to complete the mass balance, since otherwise several important sinks would not have been taken into consideration (Fantke 2015a, pers. communication). In USEtox, the ocean is mainly defined as a sink; only in coastal marine waters are exposure and impacts calculated (Rosenbaum *et al.* 2008).

Unlike PestLCI, USEtox does not consider the emissions of pesticides on the field shortly after application (Berthoud *et al.* 2011). These two models are therefore combined by multiplying the emissions calculated via PestLCI with the appropriate characterisation factor (CF) from USEtox. USEtox can be used to calculate aquatic ecotoxicity CFs for the compartments of urban air, rural air, freshwater, marine water, and natural and agricultural soils (Huijbregts *et al.* 2010a). The combination of PestLCI data with the CFs from USEtox will be addressed in even greater detail in a later chapter (see Chapter 11.4.4).

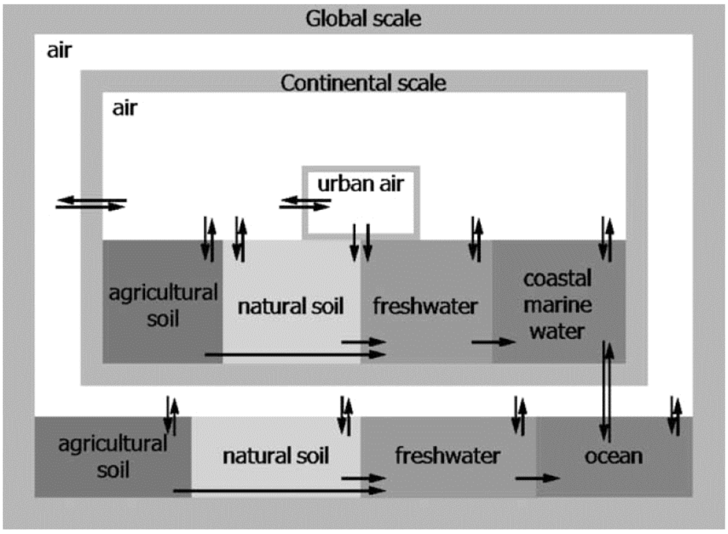

Figure 24: Compartments and geographical distribution in USEtox; Rosenbaum et al. (2008, page 536).

Aquatic Ecotoxicity

The ecotoxicological characterisation factors (CFs) for aquatic ecotoxicity are calculated in USEtox for the continental and global levels with the same formula. This formula contains a fate factor (FF) to describe the persistence of a substance – in this case, the PPPs – in the environment. The exposure factor (XF) reflects the bioavailability of a PPP for aquatic organisms, whilst the effect factor (EF) provides information on the ecotoxicity of the active substance of a PPP for different species. The formula is as follows (Rosenbaum *et al.* 2008):

$$\overline{CF} = \overline{FF} \times \overline{XF} \times \overline{EF}, \qquad 7$$

where

$\overline{FF}$ = Fate factor [day]

$\overline{XF}$ = Exposure factor

$\overline{EF}$ = Effect factor [PAF m^3 kg^{-1}]

$\overline{CF}$ = Characterisation factor.

Fate Factor (FF)

The calculation of the fate factor (FF) takes into consideration the increase in mass of a substance (kg) in a given compartment owing to an emission (kg/day) from another compartment (Henderson *et al.* 2011). The unit of the resultant fate factor is thus the number of days, and reflects the persistence of a substance in an environmental compartment (Huijbregts *et al.* 2010a). The fate factor takes into account various degradation processes, as well as the intermediate transport of PPPs between the 11 compartments (global and continental). With regard to degradation, we consider *inter alia* biodegradation by microorganisms, the transport of chemicals into the sediments, runoff into groundwater (treated the same as degradation) and leakage into the stratosphere (Huijbregts *et al.* 2010a). For intermediate transport, two processes are considered: advective and diffusive transport. With advective transport, a PPP goes unidirectionally from one compartment into the next via an environmental medium, i.e. moves in one direction only. An example of this is when a river transports a PPP from freshwater into the sea, or when the rain conveys a PPP from the atmosphere onto the Earth's surface. Diffusive transport, by contrast, is a passive bidirectional transport between two compartments (Huijbregts *et al.* 2010a). In other words, an active substance can move from one compartment into another, and vice versa. Hence, for a PPP there are 121 individual FFs, i.e. 11 FFs per compartment (Birkved and Heijungs 2011). Both the degradation and the intermediate transport processes depend heavily on the chemical properties of a substance, as well as on the emitting and absorbing compartment (Huijbregts *et al.* 2010a). The exposure time of a chemical in the different compartments is calculated bearing in mind these properties and the associated processes. Here, the mass-balance equation is solved under steady-state conditions (Huijbregts *et al.* 2010a). Below, we deal briefly with the degradation and displacement processes in the three media of water, air and soil considered by USEtox.

In USEtox, the exposure time and hence the FF of a chemical in water is influenced by various processes, some of which are dependent upon specific chemical properties. Four degradation and displacement processes play a role here: adsorption/sedimentation, evaporation, degradation, and advective transport into another compartment. A study by Henderson *et al.* (2011) identified several chemical properties of a substance which play an important role in distribution – viz., the octanol/water partition coefficient and the air/water partition coefficient with regard to distribution, and the substance-specific half-life and the hydraulic half-life of the freshwater compartment with regard to degradation (Henderson *et al.* 2011).

Transfer from the soil compartment to the surface water depends on four processes: degradation, evaporation, leaching into deeper soil strata, and surface runoff into surface waters. With degradation, evaporation and leaching, only the mass dissolved in the pore water is taken into account. With surface runoff, erosion is an additional factor, causing the adsorbed portion to be transported into the surface water as well (Henderson *et al.* 2011). Here too, Henderson *et al.* (2011) have investigated a number of dependencies of the chemical properties of a substance and the above-mentioned processes, and determined that non-adsorbing, mobile chemicals as well as chemicals with very high soil half-lives are transported in significant quantities from soil to water. Chemicals with high air/water partition coefficients evaporate, and hence leave the soil compartment. This reduces the dwell time in the soil (FF), and less substance is transported from the soil into the water (Henderson *et al.* 2011).

Three processes regarding the transport of chemicals from continental air into the soil are modelled: degradation in the air, advection into the global air compartment (see Figure 24), and deposition onto the soil, into surface waters or into the ocean. In their analyses, Henderson *et al.* (2011) noted that transfer from the air into the soil is primarily dependent on deposition and degradation. Here, the partition coefficient between air and water (K_{aw}) is relevant, since chemicals with a low K_{aw} have a longer half-life in the air, and thus tend to leach into the soil with the rain. Moreover, the size of the soil fraction compared to other areas plays a role. As an illustration, the continental compartment comprises 11% sea and freshwater, whilst in the global compartment the sea actually accounts for two-thirds of the area (Henderson *et al.* 2011).

Direct transfer from the air into the surface waters also depends on K_{aw}. Deposition is strongly influenced by the fact that only 2.7% of the continental and only 0.9% of the global area corresponds to freshwater, however. Consequently, substances are mainly transferred from air to water via the soil. This process, however, is only important for substances of which large quantities are transferred from the air into the soil and from the soil into the water (Henderson *et al.* 2011).

Exposure Factor (XF)

The exposure factor (XF) reflects the bioavailability of a PPP for aquatic organisms. In USEtox this is set equal to the fraction of a PPP that dissolves in freshwater ($FR_{w,w}$) (Henderson *et al.* 2011). XF is calculated as follows:

$$\overline{XF} = FR_{w.w} = \frac{1}{1 + (Kp \cdot SUSP + K_{doc} \cdot DOC + BCF_{fish} \cdot BIOmass)/1 \cdot 10^6} \qquad 8$$

K_p stands for the partition coefficient between water and dissolved solids (l/kg), whilst SUSP is the concentration of the dissolved matter, which is set by default in USEtox to 15 mg/l. K_{doc} is the partition coefficient between dissolved organic carbon and water, where DOC corresponds to the concentration of the dissolved organic carbon, set by default in USEtox to 5 mg/l. BCF_{fish} is the bioconcentration factor in fish (l/kg), and BIOmass reflects the concentration of the biota in the water, which is set by default in USEtox to 1 mg/l (Huijbregts *et al.* 2010a).

Effect Factor (EF)

The effect of a chemical is usually denoted in the environmental risk analysis by the PNEC (*predicted no-effect concentration*); however, this value furnishes a very conservative value for describing the toxicity of a substance. Since the purpose of a life cycle assessment is to assess a potential impact, not a risk, a more robust, less conservative effect parameter was recommended for the impact assessment (Henderson *et al.* 2011). The calculation of the effect factor (EF) is based on the assumption of a linear dependency between the concentration and the impact. Here, the gradient is calculated at the point where the fraction of potentially affected species (*potentially affected fraction* = PAF) is equal to 0.5 (see Figure 25).

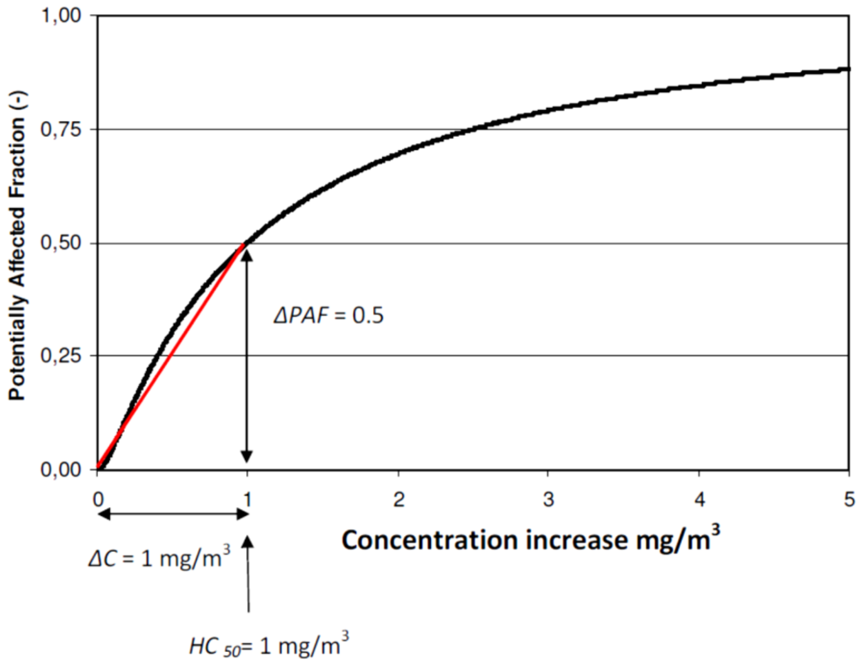

Figure 25: Exemplary illustration of an extrapolation procedure for the EF in USEtox from Huijbregts et al. (2010a, page 16).

The ecotoxicological EF of a PPP is calculated as follows:

$$EF = \frac{0.5}{HC_{50}} \qquad 9$$

The HC_{50} (*hazardous concentration*) stands for the concentration at which 50% of the species are exposed to a concentration greater than EC50 (Huijbregts *et al.* 2010a). The EC_{50} for its part is the concentration at which effects occur (e.g. mortality, acute endpoint) in 50% of the test organisms. The HC_{50} is calculated as follows, where n_s stands for the number of tested species:

$$\log HC_{50} = \alpha = \frac{1}{n_s} \cdot \sum \log EC_{50,s} \qquad 10$$

The calculation of the ecotoxicological EF is therefore based on the geometric mean of experimental EC_{50} data of individual species. Chronic endpoints (e.g. effects on reproduction) have priority, although these are seldom stated. Chronic endpoints derived using an extrapolation factor of acute EC_{50} values have second priority. In USEtox, this factor is set by default to a value of 2 (Rosenbaum *et al.* 2008). The ecotoxicological EF stands for the change in the potentially affected fraction (PAF) of a species owing to a change in the concentration; its unit is PAF m^3 kg^{-1}, also referred to as CTUe (*comparative toxic units*). CTUe is an estimate of the potentially affected fraction of species (PAF = *potentially affected fraction of species*) integrated over the time and volume per mass of the applied PPP [PAF m^3 day kg^{-1}].

LC_{50}	Lethal concentration for 50% of the test organisms (Lethal Concentration)
EC_{50}	Concentration at which effects occur for 50% of the test organisms (Effect Concentration)

Characterisation Factor (CF)

The characterisation factors (CFs) for the global and continental levels are calculated by multiplying the effect factor with the fate factor and the exposure factor (see Formula 7, page 135). Lastly, the continental and global CF for each individual compartment (air, water or soil) are added up. This final CF is measured in CTUe.

$$CF_{final} = CF_{global} + CF_{contin} \quad 11$$

In USEtox, the quality of the calculations is determined via a distinction between two types of CFs. On the one hand, there are *interim* CFs, which exhibit a relatively high uncertainty. Metals, as well as dissociated and amphiphilic substances belong to this group. For all other substances, and hence for PPPs as well, we speak of 'recommended' CFs if they are based on an impact assessment of at least three different species (Rosenbaum *et al.* 2008). If the impact assessment is based on data from fewer than three species, we speak also of *interim* CFs (Rosenbaum *et al.* 2008). This classification into interim and recommended factors cannot be undertaken for all CFs. The additional electronic material of Rosenbaum *et al.* (2008) shows that some substances lack a CF for freshwater ecotoxicity (Henderson *et al.* 2011).

Required Input Parameters

To calculate the CFs with USEtox, several substance-specific input parameters are required. The FF of organic chemicals is particularly dependent on numerous physical and chemical properties. Some parameters are readily available, such as molecular weight (MW) or water-solubility (Sol25); other parameters, such as compartment-specific degradation rates for air (k_{dega}), water (k_{degw}), soil (k_{degsl}) and sediment (k_{degsd}), are more difficult to obtain (Birkved and Heijungs 2011). Further required input parameters are the bioaccumulation factor for fish (BAF_{fish}), the distribution coefficient between suspended solids and water (K_{pss}), the average log EC_{50} for aquatic species (avlogEC_{50}), the octonal/water partition coefficient (K_{OW}), the melting point (T_m), the Henry Constant (KH_{25C}), the partitioning coefficient for organic carbons and water (K_{OC}) and dissolved organic carbon and water (K_{DOC}), the vapour pressure ($Pvap_{25}$), and the first dissociation constant (pKa). The substance-specific parameters need only be collected when a chemical is to be added to the already-existing database with its approximately 3000 pesticides. The list of the above-mentioned input parameters is available in Annexe 14.

In USEtox, it is primarily the EPI Suite™[17] program that is used to collect the physical and chemical properties of a substance (Huijbregts *et al.* 2010b). Should this database contain no values for the above parameters, certain parameters can be calculated via an approximation (Huijbregts *et al.* 2010b). A comparison of the overlapping input parameters of PestLCI and USEtox showed that the two models sometimes make use of different values for the same parameters.

Two databases are used in USEtox for the ecotoxicological data (e.g. EC_{50} values). These two databases encompass 3498 and 1408 chemicals respectively, with the former being based on the RIVM e-toxBase[18] and the latter on data from ECOTOX (2001) or IUCLID (2000) (Huijbregts *et al.* 2010b).

[17] http://www.epa.gov/oppt/exposure/pubs/episuite.htm

[18] http://www.ru.nl/environmentalscience/research/themes-0/risk-assessment/e-toxbase/

For the site-specific data, USEtox has access to standard values. Among these are parameters such as the area of the land and sea, the fraction of the area with freshwater and with natural, agricultural or other soil, and data on ambient temperature, wind speed and annual rainfall. A detailed listing is available in Annexe 15, including the standard values of USEtox 1.01.

11.4.3 USEtox 2.0

The new USEtox Version 2.0 was introduced at the Life Cycle Management (LCM) Conference in Bordeaux on 31 August 2015. The new version features several innovations and improvements. For human ecotoxicity, indoor air in the household and in industry was added (Fantke 2015b). USEtox 2.0 also now considers pesticide residues in plants under the heading of human toxicity. Further regions have been added to the new model, so that there is now a choice from among eight continental and 17 subcontinental regions (Fantke 2015b). Several new features were incorporated for aquatic ecotoxicology, including a number of adaptations to the model concerning the chemical specification of the chemicals. In the coming months, several hundred new chemicals will also be added to the USEtox database, among them pesticides. The half-lives of pesticides in the soil were revised, and general improvements with regard to the distribution data were implemented for all chemicals (Fantke 2015b). A publication is planned which describes the USEtox 2.0 methodology, as well as providing a comparison with the USEtox 1.01 methodology used here.

11.4.4 Synthesis of PestLCI and USEtox

In order to calculate the impact of a pesticide on an aquatic system, the CF of a compartment is multiplied by the emissions (M) into this compartment. In this way, the results of PestLCI (emissions into air, surface water and groundwater) are combined with the appropriate CF from the USEtox model. Here, the impacts on the different compatments are added up into an impact score (IS) for freshwater toxicity. The general formula is as follows:

$$IS = \sum_{i} \sum_{x} CF_{x,i} \cdot M_{x,i} \quad (12)$$

CF stands for the characterisation factor of a substance x which is emitted into the compartment i, and M is the emission of x (kg) into the compartment i. This final CF is measured in CTUs. Since PestLCI only illustrates emissions into the air, groundwater and surface water, the combination of PestLCI and USEtox only allows the two compartments of air and surface water to be taken into account, as there is no CF for groundwater.

11.5 Evaluation of the Methods

The evaluation of the two models PestLCI and USEtox was based on three evaluation elements: 1) A scientific monitoring group[19] investigated the models in depth within the context of two workshops; 2) Sensitivity analyses were carried out; and 3) An intensive exchange took place with the developers of the two models (Teunis Dijkman for PestLCI and Peter Fantke for USEtox).

11.5.1 Completeness

The PestLCI Modell largely takes into account all important distribution and degradation processes. Despite this, several processes are still missing (deposition of emissions and emissions into the soil), or need further improvement (macropore runoff, drainage of the field).

Although macropores, which are responsible for rapid water transport into groundwater, are taken into account in PestLCI, the underlying assumptions are inadequate. The model assumes that macropore runoff only takes place when the soil is saturated with water. This situation usually only occurs in autumn and spring, however. By contrast, in summer the soil is often dried out, and a great deal of rain can fall in a short period of time (storms). In such cases the soil does not first become saturated, since its surface silts up. Moreover, the deposition of the emissions into surface water via drift is missing in PestLCI. Consequently, emissions into the air are not transported into nearby waters or into the soil. The validity of the assumption that 100% of the water that flows through the drainage horizon is carried away via the drainage is also questionable. In practice,

[19] Monitoring group: Employees of the Agroscope Ecotoxicology and Plant-Protection Chemistry Research Group

drainage systems are often old, and therefore no longer fully functional. A further limitation of the PestLCI model is the allocation of the soil to the technosphere. Accordingly, soil is not considered an emission compartment in PestLCI.
In terms of the data situation, PestLCI contains several gaps. For one thing, only 42 active substances from the PSMV of the FOAG are listed in PestLCI. Further data gaps exist concerning climate and soil types available to choose from. The model offers the option of choosing from seven soil and 25 climate types. However, there is only one climate zone based on data from Switzerland (Lugano). The results respond very sensitively for both climate and soil (see Chapter 11.5.2) for which reason the input data must be as realistic as possible. Because of time restrictions, we have not yet been able to clarify how many additional climate zones should be defined in PestLCI for Switzerland. Owing to the high sensitivity, using just the climate zone, and hence the climate data, of Lugano – the only Swiss climate zone in the model – is not recommendable; further clarifications are necessary here. As regards the soil, the extent to which the seven soil types of PestLCI are able to adequately cover Swiss soils needs to be verified. It is to be expected that further soil types will have to be added to the existing ones. In both cases, there is the option of using location-specific data, which would lead to higher accuracy, but whose acquisition would be very time-consuming. As part of a future adaptation of the model to Swiss conditions, these two variants – viz., the addition of either soil and climate types *or* location-specific data – have yet to be tested as to their suitability. The data required to complete the database in terms of pesticides, soil types and climate types are listed in Chapter 11.4.1.
As a rule, the model assumptions of USEtox are presented comprehensibly and are based on scientific findings. Individual criticisms relate to the use of extrapolated EC_{50} values for the chronic assessment. The ecotoxicological risk assessment is usually based on acute toxicity values (e.g. mortality, LC_{50} or EC_{50} values), as well as on chronic toxicity values (e.g. reproductive rates, NOEC, EC_{10} values). Because of the new data requirements, EC_{10} rather than NOEC values will increasingly be used in future for chronic risk assessment, i.e. they will also increasingly be found both in databases as well as in the literature. By contrast, chronic EC_{50} values are seldom found in either the databases or in the literature, since only acute EC_{50} values are used in the risk assessment. Accordingly, the USEtox methodology states that where chronic values are missing, acute data can be converted to chronic values by means of an extrapolation factor. This factor (=2) should be checked. A major weakness of the USEtox model is the fact that it does not deal with terrestrial ecotoxicity.

EC_{10}	Concentration at which effects occur for 10% of test organisms
NOEC	Highest concentration at which no effects on the test organism are yet observed (No Observed Effect Concentration)

With USEtox, a larger proportion of the input parameters are available than for PestLCI, since according to own evaluation, USEtox already contains 135 pesticides that are listed in the PSMV (PestLCI includes 42 pesticides). Hence, around 260 substances have yet to be added in order to take account of all of the pesticides approved in Switzerland. The data required for this are described in Chapter 11.4.2.

11.5.2 Assessment of Robustness and Uncertainties

Robustness

The evaluation of the two methods includes two sensitivity analyses. In the first sensitivity study, different PestLCI input parameters were varied in order to identify any changes in the results, i.e. in the emissions into the air, groundwater and surface water. Here, only the investigated parameter was varied, whilst the others were kept constant. The climate type based on measuring data from Lugano served as a standard. Soil type 1, which featured an even distribution between the fractions of sand, clay and loam, served as a standard for the soil. This sensitivity analysis was carried out for four crops (maize, potatoes, stone fruit and oilseed rape), as well as for four pesticides (atrazin, mancozeb, thiacloprid, iprodione). For each tested input parameter (see **Fehler! Verweisquelle konnte nicht gefunden werden.**), there were at least two values deviating from standard. For the variation, values corresponding to a realistic range were used. To give an example, for the

month of application, the neighbouring months were always taken into account, since a shift by one month is realistic. The detailed list of the analysed sensitivity scenarios is given in Annexe 16.
Next, a sensitivity factor was calculated by subtracting the minimum from the maximum value in each case, and dividing by the average. The larger the quotient obtained, the more sensitively the emissions were deemed to respond to changes in the input parameter. Input parameters whose results responded especially sensitively (value > 1.2) appear in red in Table 58 below, with stone fruits as test crops with the pesticide Iprodione.

Table 55: Results of the sensitivity analysis for stone fruits with the pesticide Iprodione for different input parameters and sensitivity values. Sensitivity factors were calculated as follows: (maximum-minimum)/average [-].Sensitivity is especially high for values over 1.2, which are shown in red.

	Emissions		
Input Parameter	**Air [-]**	**Surface Water [-]**	**Groundwater [-]**
Soil	0.00	3.91	1.72
Climate	0.00	2.93	1.32
Irrigation	0.00	0.98	0.13
Developmental stage	0.25	2.99	2.41
Month	0.00	0.12	0.37
Tillage	0.00	0.00	1.62
Macropore fraction	0.00	0.00	0.44
Buffer zone	0.44	0.14	0.01
Buffer zone (without drainage)	1.50	1.05	0.01
Drainage	0.00	1.73	0.05

We can see that in this example, it is primarily the emissions into the water compartment that react sensitively. This also applies for other test crops (maize, potatoes), as well as other pesticides. If, however, a pesticide with a high vapour pressure (e.g. Pendimethalin) that evaporates quickly is used, the emissions into the air also respond sensitively to changes in the input parameters (e.g. variation of the buffer zone). The results show that the emissions into the water react sensitively for variations of the input parameters ‘soil’, ‘climate’ and ‘developmental stage’, and somewhat more weakly for drainage and tillage. Currently, it is unclear which climatic parameters (e.g. precipitation, air temperature) are responsible for the model’s sensitivity to the parameter ‘climate type’. This aspect should be clarified as part of further investigations. If, for example, even small variations in rainfall lead to large differences in the results, more climate types ought to be included in the model, depending on whether we are dealing with a parameter that varies strongly in Switzerland. The results concerning the width of the buffer zone, which was set to 0, 3 and 6 metres in the sensitivity study, are nevertheless striking. Dijkman (2015) suspects that the drainage influences the results too strongly. For this reason, the drained fraction was set to zero, which leads to an increased sensitivity. In terms of the field width, Nordborg *et al.* (2014) have discovered that the results respond very sensitively to a change in this parameter, which is based on the assumption that the wind always blows parallel to the field width in PestLCI.
In summary, it can be said that the results for some parameters (or groups of parameters) respond strongly to changes. This applies particularly for the following input parameters:

- The active substance used (PPP)
- The crop, including developmental stage
- The application method and quantity applied
- Soil type
- Climate

- Field width
- Drainage.

As regards the background data to the PPPs, the soil and the climate, closer analyses are to be carried out to allow the formulation of a concluding statement. By contrast, the results respond less sensitively to month of application (in the case of deviations by one month), irrigation, field length, buffer zone, slope gradient and tillage. According to the scientific monitoring group, the results obtained in the sensitivity studies are essentially transparent.

In order to assess the robustness of the findings after the amalgamation of the results of the life cycle inventory (PestLCI) and the impact assessment (USEtox) via an impact score (IS), a further sensitivity analysis was carried out. Only the 'freshwater' and 'air' compartments were taken into account for the calculation of the IS, since it is only for these two compartments that both emissions from PestLCI and CFs from USEtox are available. Here, the IS's for each combination of crop and substance are added up across all the compartments. Here too, a sensitivity factor was determined from the quotients of range and the average. The sensitivity values for the different test crops are listed in **Fehler! Verweisquelle konnte nicht gefunden werden.** As with PestLCI, the results respond sensitively to the input parameters of soil, climate, developmental stage and drainage, as well as the buffer zone, when drainage does not enter into the calculations.

Table 56: Results of the sensitivity analysis of the IS for different crops and pesticides when the listed input parameters are varied. Sensitivity factors were calculated as follows: (Maximum-Minimum)/Average. Sensitivity is especially high for values over 1.2, which are shown in red.

	Impact Score (IS) [-]		
Input Parameter	**Maize (Atrazin)**	**Potatoes (Mancozeb)**	**Stone Fruit (Iprodione)**
Soil	2.48	0.00	3.17
Climate	2.39	0.00	1.58
Irrigation	0.26	0.00	0.57
Developmental stage	1.62	0.00	1.20
Month	0.03	0.00	0.05
Tillage	0.47	0.00	0.00
Macropore fraction	0.02	0.00	0.00
Buffer zone (without drainage)	0.71	2.43	1.47
Drainage	2.23	0.00	1.66

According to the scientific monitoring group, further calculations for a wider range of substances and examples of usage could contribute to the assessment of plausibility, or provide information on parameters with especially high sensitivity, in the case of both sensitivity analyses. Just how detailed such an evaluation should end up being will also be dependent upon the relative importance given to this module in the overall assessment of sustainability.

Uncertainties

In terms of the uncertainties, there are two important findings with regard to the PestLCI model: Firstly, the uncertainties of the model because of model assumptions, and secondly, the uncertainties owing to a lack of accuracy of the input parameters. The uncertainties of the model with respect to the chosen processes and their calculations have already been discussed in part in the previous chapter. Here, the modelling of macropore runoff, the lack of deposition of emissions from the air into the surface water, the modelling of the drainage of the field, and the lack of emissions into the soil are the most important components.

The uncertainties concerning the input parameters arise because of different values in the literature (e.g. vapour pressure, half-life in the soil). Half-lives are usually measured in field experiments, then calculated back to reference conditions. Databases often state the half-lives for different temperatures and humidity, frequently without specifying the conditions precisely. For these input parameters, it would therefore be necessary to clarify how sensitively the results respond to the variation of said parameters. It has not yet been possible to carry out sensitivity tests regarding the properties of PPPs within this study.

In addition to the uncertainties of the chosen parameterisation approaches in both the model and input parameters, programming errors (as detected in PestLCI) must also be expected. To give an example, a bug in the vaporisation function of PestLCI was identified which was only fixed in Version 2 of the model.

With USEtox, there is also the subdivision into model-specific uncertainties, and uncertainties in terms of the input parameters. Regarding the uncertainties of the model, and based on a comparison with other models, Rosenbaum *et al.* (2008) estimate that the accuracy of the CF for freshwater toxicity in USEtox lies between a factor of 10 and 100. This estimate is based on the residual error (RE), and does not take any uncertainties with respect to the input parameters into account. However, this uncertainty range means that a substance with a CF of 100 need not necessarily be more toxic than a substance with a CF of 1 (Nordborg *et al.* 2014). A further model-related uncertainty in USEtox can be traced back to the assumption that all compartments are homogeneous, and that each chemical is immediately distributed evenly within them (Rosenbaum *et al.* 2008). Also important are the uncertainties regarding the input parameters. Henderson *et al.* (2011) point to the high inaccuracy of the half-lives in the different compartments, which leads to data gaps in the compartment-specific degradation rates. Furthermore, the ecotoxicological effect factors are fraught with a number of uncertainties, since they are based on the assumption of a linear relationship between dose and effect. This assumption, however, does not apply for all species, which implies relatively high uncertainties (Henderson *et al.* 2011). In addition, the chronic data concerning the toxic effect on different species are marked by a great deal of uncertainty, since chronic data were rarely derived from experiments, but were often approximated by acute data (Rosenbaum *et al.* 2008). This inaccuracy leads (*inter alia*) to the subdivision into interim and recommended CFs.

Moreover, the fact that PestLCI and USEtox obtain their data from different databases is likely to be critical. PestLCI primarily sources its data from the Pesticide Property Database[20], whilst USEtox mainly obtains its data from EPI Suite[21] (Huijbregts *et al.* 2010a; Dijkman *et al.* 2012).

11.5.3 Transparency and Reproducibility

The USEtox model can be downloaded free of charge from the USEtox website (http://www.usetox.org/). All of the important information is also available on this website, including instructions, a user forum, online tutorials, and a publicly accessible manual by Huijbregts *et al.* (2010a). Because the USEtox model was programmed in Microsoft Excel®, it allows all formulae to be looked at individually. The method works with matrices and the calculations are documented in detail in a relatively complex but transparent manner, rendering them easily reproducible.

PestLCI is also available free of charge. Information on the model and its acquisition can be found on the website of the Technical University of Denmark (http://www.qsa.man.dtu.dk/ Research/PhD-projects/LCA-of-GMO-crops/PestLCI). In order to work with the model, an additional software program (Analytica by Lumina, http://www.lumina.com/) must be installed. However, a version of this software with slightly limited capabilities can be downloaded for free. The PestLCI model as well as the underlying assumptions are documented in detail in Birkved and Hauschild's publication (2006). The modifications to the model (Version PestLCI 2.0) have also been published (Dijkman *et al.* 2012).

Both methods can be installed and used on one's own with the aid of the manual (USEtox) or the documentation in the program (PestLCI). If anything is unclear, the model's developer can also be contacted (Teunis Dijkman for PestLCI). In the event of problems with USEtox, questions can be posted on the user forum.

[20] http://sitem.herts.ac.uk/aeru/footprint/index2.htm

[21] http://www.epa.gov/oppt/exposure/pubs/episuite.htm

11.5.4 Applicability: Communicability and Practicability

The evaluation of the PestLCI and USEtox methods revealed that neither can yet be used routinely. Both methods still require additional clarifications before they are ready for practical application. First and foremost, this has to do with the data gaps that still exist. For both models, pesticides still need to be added to the database. Moreover, for PestLCI it has to be clarified how the input parameters of soil and climate type are to be specified. Depending on whether one is working with a small number of soil types, or whether the data is gathered plot-specifically, the amount of effort involved varies. Moreover, certain input parameters are relatively difficult to collect (e.g. chronic EC_{50} values), or subject-specific background knowledge is required for choosing the right values; examples for this are degradation rates or soil data. In addition, it must be pointed out that both methods are still in need of refinement (and for certain applications, simplification). As part of further sensitivity analyses, the point of whether simplifications are possible should be clarified. Said simplifications can lead e.g. to a reduction in the data to be gathered, which would increase practical applicability.

The results of an analysis with the PestLCI methodology and the USEtox model can be communicated with ease, although certain prior knowledge of the methodology is assumed.

11.6 Recommendation

The following recommendation is based on internal clarifications of the Agroscope Institute for Sustainability Studies ISS (e.g. via sensitivity analyses) and two internal workshops with the scientific monitoring group consisting of employees from the Agroscope IPS Plant-Protection Chemistry and Ecotoxicology Research Group, as well as on recommendations from the literature.

The analysis of the impact assessment methods carried out by the European Commission’s Institute for Environment and Sustainability shows that the USEtox methodology boasts decisive advantages over other methods (EC-JRC-IES 2011). It is advantageous that, with a factor of 10 to 100, the uncertainties in the USEtox methodology are much smaller than with the other methods, for which uncertainties are higher by up to the tenth power of 10 (Rosenbaum *et al.* 2008). Furthermore, the USEtox methodology was deliberately developed as a consensus method, and the underlying principles of the model therefore reflect generally recognised and accepted recommendations from experts (EC-JRC-IES 2011).

The internal evaluation of the methods has shown that both methods still require further development if they are to be used for the broad assessment of the ecotoxicity potential of pesticide applications. Thus, for example, further pesticides must be added to both methods in order to cover the pesticides approved in Switzerland according to the PSMV. Moreover, a number of sensitive input parameters (e.g. active substance, crop and developmental stage, application method and quantity) were identified for the PestLCI methodology. Both soil type and climate type are missing the evaluation as to which simplifications are possible for adequately covering the soil and climatic conditions in Switzerland.

A new, improved version was developed for both methods in 2015 to supplement their further evaluation. For a comprehensive analysis of the impacts of pesticide usage, human toxicity must be taken into account.

11.7 Conclusions

This chapter discusses two methods that are to be used to calculate the ecotoxicity of pesticide applications. Specifically, the PestLCI 2.0 model (life cycle inventory) was evaluated, as well as the impact assessment method USEtox 1.01. The combination of these two methods has already been used in several life cycle assessments of pesticides (Nordborg *et al.* 2014; Renaud-Gentié *et al.* 2014; Räsänen *et al.* 2015). Moreover, an intensive exchange is currently taking place between LCA researchers regarding the life cycle assessment of pesticides (Rosenbaum *et al.* 2015). As part of this discourse, the USEtox methodology has also gained acceptance. The sensitivity analysis carried out within the context of this project showed the following input parameters of PestLCI to be especially important: soil type, climate, crop (including developmental stage), application method and quantity, tillage, the buffer zone, and drainage. The site-specific factors such as soil and climate can vary significantly from farm to farm. It is therefore important to gauge the extent to which these two parameters can be simplified without falsifying the results too much. The literature also points to the uncertainties and the high sensitivity of certain input parameters (Rosenbaum *et al.* 2008; Dijkman *et al.* 2012; Nordborg *et al.* 2014).

Most of the assumptions in the two methods of PestLCI and USEtox follow known principles in the fields of ecotoxicology and plant-protection chemistry. Certain critical aspects exist for both models, however. Despite this, we may conclude from the analyses that PestLCI in particular represents a significant improvement of the previously used methods, which assumed that the entire amount of PPPs applied ends up in the soil. In spite of the detailed and largely adequate modelling, caution is advisable: both methods suffer in some cases from major uncertainties, and the results should therefore be judged with care, especially if they are being used as a basis for the evaluation of farms.

The model assumptions of PestLCI and USEtox are generally presented transparently in the literature, and are based on scientific findings. We are dealing here with supported and internationally recognised models. From our point of view, therefore, the models are suitable for use in the life cycle assessment of PPPs.

Nevertheless, there are still a number of uncertainties and unresolved issues to clarify with respect to the models. Further calculations for a wider range of substances and examples of usage could contribute to the assessment of plausibility, or provide information on parameters with an especially high sensitivity to environmental impact. This also includes clarifications regarding the soil compartment, the inclusion of the latest model developments, or the assessment of human toxicity.

12 Biodiversity

Thomas Walter, Andreas Roesch

12.1 Introduction

The term 'biodiversity' refers to the variety of life forms. This includes the variety of genes, species and ecosystems, with their functions and interactions, both with one another and with the non-living environment. Biodiversity is the basis of our existence, and its preservation is not only a moral obligation for humanity, but also an existential necessity. Over the last 200 years, and because of humans, biodiversity has declined dramatically, and we have not yet succeeded in turning this steadily declining trend around – not even in Switzerland. At the Biodiversity Convention, with few exceptions, countries from all around the world committed to stemming the decline in biodiversity, or – like Switzerland – to stopping it altogether (Lachat *et al.* 2010). The inclusion of biodiversity in the assessment of human activities in terms of their sustainability has gained in importance in recent decades; hence, the protection in Switzerland of particularly threatened species and habitats by the Federal Law on Nature and Heritage Protection (NHG 1966) as well as the subsequent ordinances. Based on the Environmental Protection Law (USG 1983), they are, for example, taken into consideration in environmental compatibility reports. In the agricultural sector, loss of biodiversity has been curbed under the banner of ecological compensation since the early 1990s. In Switzerland, agriculture most likely had a positive impact on the diversity of habitats and species until around the beginning of the 19th century. Many species from natural habitats also succeeded in establishing themselves on agriculturally utilised land. With the major land-improvement measures and river-course corrections of the 19th century, the essential natural habitats (water meadows, steppes in alluvial areas, mires) together with their biodiversity were largely destroyed. A percentage of the species managed to survive on agriculturally used land, but with the increased intensity of use in agriculture and the associated land-improvement measures since 1900, many species had disappeared by the early 1990s (Lachat *et al.* 2010). The introduction of ecological compensation, and along with it, increased concern for biodiversity in land improvement, has led once again to a moderately positive trend in the lowland area (Aviron *et al.* 2005). Internationally speaking, however, Switzerland continues to have one of the highest percentages of endangered species.

The aim of this chapter is to test existing methods for assessing the sustainability dimension of biodiversity on farms in Switzerland by comparing existing methods in terms of criteria such as completeness, robustness and uncertainties, transparency and reproducibility, and applicability. In addition, strengths and weaknesses of the methods will be addressed, and recommendations for improvements issued.

Singh *et al.* (2009) give an overview of internationally used methods for assessing sustainability, in which biodiversity according to the United Nations Commission for Sustainable Development (UNCSD) is one of 15 main topics. Moldan *et al.* (2012) also list biodiversity as a key variable for sustainability; however, the indices described in these two publications are generally used to compare countries, and are not suitable for the assessment of farms. No mention is made of the methods developed in Switzerland. From this, we may conclude that internationally, there are still major knowledge gaps in the evaluation of the biodiversity of individual farms. The SALCA-Biodiversity *(Jeanneret et al. 2009)* and IP Suisse credit point system (www.ipsuisse.ch) methods developed in Switzerland either have too low an international profile or – as, for example, in RISE (Grenz *et al.* 2012c) – are too scantily documented to find acceptance in scientific publications. In the present chapter, these three methods are compared with one another on the basis of a list of criteria. The assessment tests whether the methods are suitable for capturing biodiversity, and whether the impacts of agricultural activities performed on the farm enter into the assessment. The rationale for limiting ourselves to these three methods is that all three are suitable for carrying out an assessment at farm level, and in addition have already been used in practice.

The assessments and rationales have been examined by the developers of the methods – specifically, by Simon Birrer (Swiss Ornithological Institute, Sempach) for the IP-SUISSE credit point system, by Christian Thalmann (HAFL) for RISE, and by Philippe Jeanneret (Agroscope) for SALCA.

12.2 Relevance of the Topic for Sustainability

Imagine that no other creatures existed besides human beings. This is unimaginable and impossible, since humans cannot survive without other living creatures. Even if we were to feed ourselves purely synthetically, we would not be able to survive long without other organisms. It is therefore crucial for humankind to value the benefit of biodiversity, and for us to support even those forms of biodiversity which, superficially, seem to be of little use. Just a few decades ago, bogs were dismissed as "useless wasteland"; today, we recognise their great importance as carbon sinks. Moreover, in evolutionary terms we are a young species that developed under previous conditions of diversity; we are scarcely in a position to gauge how our well-being is influenced by a further decline in biodiversity.

Below, we list a few more arguments showing how important it is to preserve and promote biodiversity on farms:

- **Utilisation potential**: According to www.bdn.ch, 83% of plant species in Switzerland are of potential use for humans.
- **Direct source of food**: For human beings, global food security represents the most important direct value of biodiversity (FOEN and FOAG 2008). Out of the plant kingdom alone, with over 300,000 species worldwide, between 30,000 and 80,000 species are rated as edible. Around 7000 species have been used as food over the course of human history, whilst 120–150 species have to date been cultivated on a comparatively large scale (Myers *et al.* 2000; Schauer 2002; FOAG 2008). Both plant and animal diversity are prerequisites for selection and breeding, and thus made feeding the increasing population possible in the first place (Diamond 2002). For humans, agrobiodiversity is therefore the source of a varied and healthy diet.
- **Indirect source of food**: In Switzerland, around 5 to 70 plant species occur on a single meadow or pasture. For the whole of Switzerland, the 'Flora Indicativa' (Landolt and Bäumler 2010), based on the 'red list' of Moser *et al.* (2002), assigns 74 plants to the nutrient-rich grasslands, 357 species to the dry grasslands, and 614 species to the alpine sward. Thus, a total of around 1000 plant species are consumed by our livestock, and subsequently exploited by humans in the form of high-quality dairy products and meat.
- **Medicine:** Worldwide, over 50,000 plant species are designated as medicinal plants (Schippmann *et al.* 2002). In Switzerland, over 150 species fall into this category (Ellenberg 2015, pers. communication). Of these, around 50 species are cultivated on Swiss farms. The Swiss National Database for the Conservation of Plant Genetic Resources lists 111 varieties of medicinal and aromatic plants requiring conservation (www.bdn.ch). Many medicinally active substances from fungi or poisonous animals are also known.
- **Raw materials**: Many species are raw materials, such as e.g. various types of wood, cotton, rattan and bamboo. Familiar raw materials from the animal kingdom are, for example, wool, down and leather.
- **Insurance:** Biodiversity constitutes our insurance for the future (FOAG 2008). In future, for example, diseases may emerge, or production conditions in agriculture may change such that humans will be reliant upon species or genetic resources whose benefits are not even known at present.
- **Functions:** Many ecosystem services, such as the regulation of the water budget, the provision of clean drinking water, the building of fertile soils, the stabilisation of slopes in the mountain region, the pollination of our crops, and natural pest control in agriculture and forestry, are absolutely essential. The value of all these services, which would not be available in the absence of biodiversity, can hardly be estimated, or measured in monetary terms. Despite this, economists have attempted to work out a rough estimate, with e.g. Costanza *et al.* (1998) estimating the value of these services at USD 33,000 billion per annum.
- **Impacts of agriculture on other production systems:** Here, it is primarily water pollution from agriculture that is of significant importance. This is currently still one of the main causes of fish death in Switzerland.

Despite its high relevance, even today biodiversity is not always taken into consideration in farm sustainability assessments. In Switzerland, the Proof of Ecological Performance, which calls for 7% biodiversity promotion areas (ARPB) on the the utilised agricultural area – 3.5% in the case of special crops – sets a baseline value that is met by almost all farms.

12.3 Overview

Below, we describe the three biodiversity assessment systems for evaluating farm sustainability:

12.3.1 IP-SUISSE Biodiversity Credit Point System

The credit point system was developed jointly by the Ornithological Institute and the FiBL in the project 'Mit Vielfalt punkten' (= 'Scoring with Diversity'), and adopted (in a slightly altered form) by IP-SUISSE. In this system, the usage types, all ARPB types including their quality according to the Direct Payment Ordinance, their size and distribution, their structural diversity, biodiversity-promoting measures on arable land and green spaces, upgrading of forest edges, rare livestock breeds and plant varieties, target species, and resource-protection measures are rated with a credit point system. The credit point system was introduced in 2008. Products of farms achieving a total of at least 17 points and 15 points in the category of biodiversity are sold by MIGROS (Switzerland's largest supermarket chain) under the label 'Terra Suisse'. The program for calculating the score is available online, and may be used free of charged by all (www.ipsuisse.ch). In its current form, it can only be used for Swiss farms.

12.3.2 SALCA

SALCA (Swiss Agricultural Life Cycle Assessment) is a method for assessing the impact of agricultural activities on biodiversity for life-cycle assessments (SALCA-Biodiversity) (Jeanneret *et al.* 2009; Jeanneret *et al.* 2014). SALCA-Biodiversity is based on scientific knowledge and expert opinions. For scoring and weighting the impact of agricultural activities on 11 groups of species (meadow- and grove flora, arable companion flora, birds, small mammals, amphibians, snails, spiders, ground beetles, butterflies, grasshoppers, and bees and bumblebees), around 2000 publications and expert opinions on each group of organisms were taken into account. The model can calculate an index for an agriculturally utilised area of any size in Switzerland – i.e. even for an entire farm. The calculation of the SALCA-Biodiversity Index of a farm may take account of detailed information on type of land use (including ARPB), usage intensity, the use of auxiliary substances and the harvest technique, as well as maintenance measures on the various plots. The Index can also be calculated when less-detailed input data are available, however. No field surveys for estimating direct biodiversity indicators, such as the target and character species according to agricultural environmental targets (FOEN and FOAG 2008), are required by the model in order to gather the input data. The calculations are performed by a computer application in Excel, which requires a measures inventory as input. The method was primarily developed for research. The Biodiversity Index according to SALCA can be used for Central Europe in its current form.

12.3.3 RISE

An initial version of RISE (*Response-Inducing Sustainability Evaluation*) was developed in 1999 at the instigation of a Brazilian agricultural entrepreneur at the School of Agricultural, Forest and Food Sciences HAFL (Grenz *et al.* 2012a). A first refinement was launched in 2004, with a second following in 2012. By 2010, the different versions of RISE were being used in 30 countries on over 800 farms. In RISE, biodiversity is evaluated indirectly via the variety of wild and used plants and animals on the farm, and the ecological quality of the landscape. Examples of indirect parameters are the percentage of ecological and land-improvement areas (groves, hedgerows, path margins, etc.), participation in agri-environmental programmes, number of plant species/varieties and animal breeds, the tending of mixed crops, the promotion of typical regional breeds and varieties, and plot size (Christen and O'Halloran-Wietholtz 2002; Oppermann 2003b; Breitschuh *et al.* 2008; Pretty *et al.* 2008; Vilain 2008). Theses parameters are captured partially at farm level, and partially on a large scale, in the landscape where the farm stands. Another indirect parameter that should be classified as relevant to biodiversity is the handling of plant-protection products. In the current model version, according to Grenz *et al.* (2012a), the following aspects are taken into consideration for the assessment of both biodiversity and plant protection: plant-protection management, ecological priority areas, intensity of agricultural production, landscape quality, and variety of agricultural production. RISE is geared to target values derived from national and international standards, such as a 17% share of seminatural areas, which in RISE is awarded the maximum score of 100 points. The biodiversity index calculated by RISE is applied worldwide.

12.4 Description of the Indicators

Below, we list the input data required to calculate the biodiversity index of the analysed methods:

12.4.1 Farm Data

In Switzerland, general farm structural data such as the surface areas of the agricultural crops, meadows and pastures as well as the size of the animal populations are listed by the farmer in the so-called 'farm operations profile' ('*Betriebsspiegel*'). These data can usually be included in sustainability assessments without investing too much time. Since usage intensity and biodiversity are correlated, such data allow an initial rough estimate of the expected biodiversity. In this report, biodiversity promotion areas are dealt with under the headings of 'habitat diversity' and 'species diversity'. The three methods make use of the following input data:

- **IP-SUISSE**: Utilised agricultural area, area of permanent grassland including low-input grassland, open arable land, area of temporary leys, arable land, area of litter meadows, area of permanent crops, other areas, area in the lowland and hill zones, in both mountain zones I–II and mountain zones III–IV, number of livestock manure units (LMUs). These data can generally be obtained from the farm operations profile.
- **SALCA-Biodiversity:** Detailed picture of the management activities on all plots, including the fertilisers, PPPs and further auxiliary materials used. This generally implies a face-to-face interview with the farmers.
- **RISE**: Areas of the various crops, UAA and other areas (courtyard, forest, other areas), area of high quality for biodiversity (ARPB quality levels I and II and the like), feeds, fertilisers and plant-protection products used, number of crops in rotations, number of animals per livestock species (present and absent).

12.4.2 Genetic Diversity, Livestock-Breed Diversity, Crop-Plant Varieties

The conservation of rare breeds and varieties on a farm is considered under this heading. In Switzerland, for example, ProSpecieRara and Fructus are committed to the continued existence of such species and varieties. The various microorganisms that are useful on farms e.g. in the manufacture of dairy products such as cheese or yoghurt are also very important. This aspect of biodiversity is not yet taken into account. The three analysed methods consider the following aspects of genetic diversity:

- **IP-SUISSE**: Number of animal breeds according to the ProSpecieRara list, crop-plant species according to ProSpecieRara, trees according to Fructus.
- **SALCA-Biodiversity:** This aspect is not yet taken into consideration.
- **RISE**: Number of old, endangered varieties of crop-plant species and rare animal breeds; beekeeping.

12.4.3 Species Diversity

The variety of species of wild organisms documented on the farm and farmland is assessed under this heading, as is the impact of agricultural activities on these species. On agricultural land it is especially important to promote the growing of target and character species (FOEN and FOAG 2008). This aspect is considered in the three methods as follows:

- **IP-SUISSE:** Points are awarded for the encouragement of target species and for Area(s) Reserved for Promoting Biodiversity (ARPB), based on vascular-plant species.
- **SALCA-Biodiversity:** This method takes account of the potential impact of agricultural activities on 11 groups of organisms (grassland- and grove flora, segetal flora, birds, mammals, amphibians, land snails, spiders, ground beetles, butterflies, grasshoppers, bees and bumblebees). The importance of these species groups for the preservation and promotion of biodiversity whilst taking account of the food chain was weighted by experts and aggregated into a value.

- **RISE:** This assessment is performed indirectly via ecological priority areas, whilst taking account of ARPB quality levels (based on vascular plant species). The impact of agricultural activities on species is assessed by an intensity indicator, later described under the heading ‘usage Intensity’.

12.4.4 Habitat Diversity

The diversity of the various habitat types is assessed under this heading. Here, those habitat types in particular that the FOEN and FOAG (2008) deem worthy of support should be assigned a higher weighting in a sustainability assessment. In Switzerland, this support is provided via the ARPBs. Recently, a ‘red list’ of Swiss habitats was published, and this too must be incorporated in the assessment. The three methods consider habitats as follows:

- **IP-SUISSE:** Surface area and quality of the ARPB types (14 types according to the DPO), low-input/fairly-low input meadows in high-stem orchards, different usage types.
- **SALCA-Biodiversity:** 13 BPA types according to the DPO pre-2014, nature conservation areas and agricultural usage types are scored.
- **RISE:** The percentage of ecological priority areas is assessed with an evaluation function. Such priority areas are, for example, ecological and land-improvement areas (groves, hedgerows, path margins, etc.), BPAs according to agri-environmental programs, utilised areas of high ecological value according to the protection status of an area (nature conservancy agreements), areas included in eco-programmes (Switzerland: Ordinance on Ecological Quality ÖQV-Q20, IPS21: Areas with project quality), or areas classified as valuable on the basis of comparisons with reference photos.

12.4.5 Habitat Linkage

Habitat linkage serves to preserve and promote wild animal and plant species. It is meant to enable the exchange of individuals between subpopulations of these species, as well as to strengthen vagility and natural repopulation, thereby reducing the risk of species extinction. Linkage projects aim to provide special support to target species, and contain appropriately adapted measures such as e.g. the upgrading of forest edges. Linkage is taken into consideration in the three methods as follows:

- **IP-SUISSE:** Points are awarded for upgraded forest edges (length) and target species.
- **SALCA-Biodiversity:** Participation in a linkage project is scored.
- **RISE:** An evaluation is conducted of how closely the ecologically valuable structural elements in the landscape are interlinked, and how the percentage of such elements has grown or decreased over the past ten years. The percentage of farm area located less than 50 metres from an ecologically valuable habitat serves as a measure.

12.4.6 Diversity of Agricultural Crops

The diversity of the agricultural crops, which is not exclusively geared to the promotion of biodiversity, is assessed under this heading. Said diversity is yielded by the variety of production on a farm. In the three methods, this is taken into account as follows:

- **IP-SUISSE**: Awarding of points for the number of usage plots and usage types (arable crops, hay meadows, pastures, high-stem fruit tree production, grape production, vegetable production, other special crops, litter meadows).
- **SALCA-Biodiversity**: The number of arable crops and cover crops in the rotation are assessed. Summer and winter wheat, maize, potatoes, sown meadows, sugar/fodder beet, grain legumes, oil fruits, cover crops, green manure, margins (non-ECA), fairly unproductive, moderately productive and highly productive permanent grassland, fairly unproductive pasture (e.g. ECA type 2), moderately productive and highly productive pasture are scored.
- **RISE**: The number of land-use types present at an appreciable level (>8 %), the number of links in the rotation as well as the crop-plant species and animal breeds are assessed.

12.4.7 Potentially Natural Habitat

The potentially natural habitat is the habitat that would exist on a site without human influence. Such habitats have the highest priority in biodiversity promotion, since they are at acute risk in Switzerland and worldwide. Examples of potentially natural habitats are primary forests, raised bogs and floodplains. Agriculture is a main cause of their endangerment.

- **IP-SUISSE**: This aspect is not taken into consideration.
- **SALCA-Biodiversity:** This aspect remains unconsidered.
- **RISE:** Area of the cleared forest over the last 20 years. Note that this information is not used for the calculation of the biodiversity index, but is included in the calculation of the greenhouse-gas balance.

12.4.8 Plant Protection and Plant Treatment Products (PTPs)

The use of PTPs adversely affects wildlife biodiversity. For this reason, the three methods are assessed in terms of the inclusion of 'PTP input data'.

- **IP-SUISSE**: Based on IP-SUISSE guidelines concerning the handling of PTPs. The guidelines, which constitute a necessary condition for an evaluation via the credit point system, are regularly updated and are crop-specific, e.g. for maize (IP-SUISSE, 2015a), oilseed rape (IP-SUISSE 2015b), cider fruit (IP-SUISSE 2014) or cereals (IP-SUISSE, 2015c). Additional parameters considered in the credit point system are areas which forgo the use of stalk-reducing substances, insecticides, fungicides ('Extenso') and herbicides in agriculture.
- **SALCA-Biodiversity**: This method evaluates the detailed recordings of quantity, frequency and date of application of fungicides, insecticides, mouse control (traps, bait, gassing), slug control, slug pellets and weed control (herbicide, treatment of individual plants, cleaning cut, thermal).
- **RISE:** RISE considers the use of plant-protection products and management according to the principles of integrated plant protection, which maximises natural regulation in the agroecosystem in order to minimise external control interventions and the use of PPPs. Resistance problems, GMO regulations, participation in biodiversity promotion programmes, optimisation of rotations, the taking into account of damage thresholds as well as the toxicity and persistence index of the pesticides used are considered as measurement parameters for the calculation of indicators.

12.4.9 Fertiliser Use

Different plant and animal communities arise depending on the nutrient content of the soils. Biodiversity is also influenced by type and timing of fertiliser application.

- **IP-SUISSE:** The credit point system does not take fertiliser application into account.
- **SALCA-Biodiversity:** SALCA evaluates 25 different types of fertilisation (quantity and timing).
- **RISE**: RISE assesses biodiversity potential as a function of total nitrogen content.

12.4.10 Irrigation

Irrigation is considered in the three models as follows:

- **IP-SUISSE**: Not considered.
- **SALCA-Biodiversity**: SALCA qualitatively evaluates irrigation in arable crops.
- **RISE:** Water use is recorded as a separate indicator, but no link is made with biodiversity.

12.4.11 Usage Intensity, Management Technique

As a rule, biodiversity decreases along with increasing intensity of usage; however, the spread is significant. Over the past few years, correlations between management technique and biodiversity have been analysed in grassland systems in particular. Below, we assess how these findings are taken into account.

- **IP-SUISSE:** The credit point system evaluates the following aspects: , number of livestock manure units, farm area, biodiversity-promoting techniques in agriculture (e.g. plots of cereals, oilseed rape, sun-flowers or maize), cereals in wide-spaced rows (2 rows undrilled), cultivation of summer cereals, overwintering green manure up to 14 February, maize undersown with clover/grass or maize meadow, cereals undersown with clover/grass, wildflower-strip management (breaking of one-quarter of the area per year), biodiversity-promoting techniques in grassland, use of cutter-bar mowers, forgoing the use of mower-conditioners, staggered meadow use (agreement with the Canton) and forgoing the use of silage.

- **SALCA-Biodiversity**: This method evaluates the detailed information on crops, usage techniques (e.g. mowing technique, large-bale silage, stocking density, animal species, tillage) and dates of use on arable land and grassland.
- **RISE**: The parameter 'intensity of agricultural production' is assessed on the basis of fertilisation intensity, PPP intensity (number of applications, toxicity and persistence), stocking density in LU /ha, as well as the effects of management technique on biodiversity. The latter are based on the IP credit point system and include nurse crop in cereals and maize, animal-friendly cutting techniques (hand, scythe, cutter bars instead of rotary mowers), forgoing the use of mower-conditioners, staggered meadow use, later cut (after the main flush), and forgoing the use of silage.

12.4.12 Functional Aspects

In recent times, functional aspects of biodiversity have increasingly being explored. These include e.g. the pollination function or the natural pest regulation of organism communities, but also soil fertility or the water-retention ability of habitats. In this report, only the inclusion of the pollination function is compared.

- **IP-SUISSE**: Additional points are awarded depending on the number of bee colonies kept on the farm.
- **SALCA-Biodiversity**: SALCA assesses and weights the impact of management measures on wild bees, spiders, ground beetles and birds.
- **RISE:** RISE checks whether bee colonies are kept. This is taken into account in the 'diversity of agricultural production' indicator.

12.5 Evaluation of the Indicators

In this chapter, the methods are scored in terms of various criteria on a scale of 0 to 10. There were no clear limits set for the individual scores, and the individual criteria are all weighted equally.
Hereinafter, the abbreviation 'IP-SUISSE' is used for the IP-SUISSE credit point system, and 'SALCA' is used for the SALCA-Biodiversity method.

12.5.1 Completeness of Scope

It is not possible to capture all aspects in a biodiversity assessment. Accordingly, a 'biodiversity' sustainability indicator can never be 'complete'. The methods described above can therefore only be compared relative to one another. Table 57 gives an estimate of completeness.

Table 57: Relative assessment of completeness in terms of variables taken into account to assess biodiversity in three evaluation methods. 0 = worst score, 10 = best score.

Completeness	**Evaluation**		
Criteria	**IP-SUISSE**	**SALCA**	**RISE**
Farm data	9	10	7
Genetic diversity	7	0	7
Species diversity	7	4	3
Habitat diversity	8	8	6
Habitat linkage	5	5	6
Agricultural crop diversity	6	9	6

Completeness	Evaluation		
Criteria	IP-SUISSE	SALCA	RISE
Potentially natural habitat	0	0	2
Plant protection and treatment products	5	10	8
Fertiliser use	0	10	5
Irrigation	0	3	0
Usage intensity, management technique	8	10	8
Functional aspects	2	4	2
Purchased products relevant for biodiversity (e.g. concentrates, impact on production area)	0	0	0

Below, the number of points awarded in Table 57 are explained in brief.

- **Farm data**: Complete farm data are gathered for the IP-SUISSE method and SALCA – a somewhat lower volume of data is gathered for RISE.
- **Genetic diversity**: IP-SUISSE and RISE take rare crop-plant varieties and livestock breeds into consideration, whilst SALCA does not. None of the methods takes into account the in-situ preservation of fodder-grass varieties, or of meadows and pastures that are kept as donor areas, or which could be used as such.
- **Species diversity**: None of the methods provides for field surveys for the assessment of species. Only the IP-SUISSE method acknowledges the presence of target species. In SALCA, the impact of agricultural activities on 11 groups of organisms according to an assessment by experts and references in the literature is included in the assessment and weighted. RISE lacks such a weighting. All three methods draw conclusions about the promotion of species from the promotion of the BPA.
- **Habitat diversity**: All three methods take into consideration the ecologically valuable habitats according to agroenvironmental programmes. Compared to the other two methods, RISE has a less differentiated assessment of the various habitat types and qualities; a more-detailed field mapping does not take place for any of the three methods, however.
- **Habitat linkage**: Essentially, there is a linkage of habitats in terms of the promotion of specific species. In Switzerland, these are usually target and indicator species according to the agricultural environmental targets. IP-SUISSE acknowledges target species and forest-edge upgrades, as well as the creation of biodiversity-promoting structures. These are generally incorporated into linkage projects. Participation in linkage projects is not directly acknowledged, however. SALCA takes account of the farm's participation in linkage projects according to the DPO. RISE identifies areas of shortcoming in agriculture with respect to structural elements, and also takes account of the development of the habitat network of the past few years on the farm.
- **Agricultural crop diversity**: The diversity of agricultural crops is for the most part ascertained in full in all three methods; however, the degree of detail is higher in SALCA than in the other two methods. Despite this, 'special crops' are also missing in SALCA.
- **Potentially natural habitat**: The potentially natural habitat is the habitat as it would exist without human activity. This aspect is only addressed in RISE, when primary forest is cleared for the purpose of agricultural use. This aspect is not, however, included in the biodiversity evaluation, but is used to calculate the greenhouse-gas balance. Nonetheless, it is not obvious to what extent this aspect is later included in the assessment. It is difficult to include this criterion in the evaluation for an LCA, since the timing of the repurposing of a natural habitat for agricultural production plays the key role. The conversion of natural land into agriculturally used land still continues to be the main cause of threat worldwide, however.

- **Plant protection and treatment products**: This aspect is well-to-very-well taken into consideration in all three methods, with SALCA differentiating the various plant-protection methods the most and the IP-SUISSE method differentiating them the least.
- **Fertiliser use**: In SALCA, fertiliser application and its impact on biodiversity is considered in a very differentiated manner; in RISE, this only applies to nitrogen application. In the IP-SUISSE system, fertiliser application is not taken into account.
- **Irrigation**: The impact of irrigation on biodiversity is only taken into consideration in SALCA. The aspect of water-resource use is captured in SALCA and RISE in separate indicators.
- **Usage intensity, management technique**: All methods treat this aspect very comprehensively, with the differentiation in terms of cut frequency or grazing intensity being highest in SALCA. No method uses a scientifically recognised index for 'land-use intensity' (LUI) in which an overall index is calculated from the various management measures and external inputs (e.g. Herzog *et al.* 2006). Such an index, while calculated in RISE, is not scientifically published.
- **Functional biodiversity:** In the three methods, it is solely via the consideration of honeybees that the pollinator function is taken into account, albeit marginally. Other functions of biodiversity such as e.g. soil fertility, the filtering of pollutants or carbon storage are not taken into account in this subindicator. It must be pointed out at this juncture that SALCA and RISE take the aspects of soil fertility and water into account in other environmental impacts.

12.5.2 Assessment of Robustness and Uncertainties

The aspect of robustness is dealt with here by looking at how strongly the indicator reacts to changes in the input data. Since, however, no analyses of the sensitivity of the various methods could be undertaken within the context of this project, we questioned the developer of the method directly as to whether studies on this topic have been conducted. Generally speaking, we may assume that an indicator which consists of a small number of subindicators tends to react more strongly to changes, but illustrates biodiversity less comprehensively. In addition, the reliability of the data sources for providing the necessary input data was examined.

The necessary input data for the three methods are usually ascertained directly by the farm manager; the uncertainty for the three analysed models will therefore be similar. It can be assumed that, for reasons of self-interest, a user of the IP-SUISSE method has the greatest incentive to make his information as correct and complete as possible. In IP-SUISSE, the collected input data are examined by label checkers. In SALCA, data is collected via the 'AgroTech' program, with the uncertainties being reduced thanks to plausibility tests. Except for farmyard and field inspections, RISE has access to no further quality control of the data.

Validations check whether the overall score or total number of points correlates with the observations of individual subindicators actually collected in the field. As a rule, the spread in such studies is significant, and the correlation rather weak. Nevertheless, field experiments give e.g. a rough estimate of what number of plant, bird or insect species is to be expected with a given overall score or total number of points.

Table 58: Assessment of robustness and uncertainties with respect to the input data for evaluating biodiversity in the three assessment methods IP-SUISSE, SALCA and RISE. Scale from 0 (unsatisfactory) to 10 (very good).

Robustness, Uncertainties	Assessment		
Criteria	IP-SUISSE	SALCA	RISE
Sensitivity	6	8	4
Data sources, data quality	9	9	8
Checks	8	8	8
Validations	8	6	1

Sensitivity

- **IP-SUISSE**: This method is available online for all. It allows e.g. for easy verification of how the various measures affect the total number of points. A systematic sensitivity study was not carried out, however.
- **SALCA-Biodiversity:** A study tested how the input parameters influenced the final score at plot level. It was found that the main indicators (usage type, fertilisation and pesticides) exerted the greatest impact. No sensitivity analysis at farm level was carried out. Based on the weighting of the subindicators, however, it is to be expected that type of habitat has the greatest influence.
- **RISE:** According to the authors of the method, there are no sensitivity analyses. The available bases are not sufficient for carrying out our own analysis, since information on the precise way to calculate the indicator is missing.

Reliability of the Data Sources

- **IP-SUISSE:** The farmer enters the necessary input data into the calculation tool, with the details being checked by inspectors before the label is awarded.
- **SALCA-Biodiversity**: An adviser gathers the data together with the farm manager. Information from the ‘AgroTech’ program and ‘Suisse-Bilanz’ (=‘nutrient balance‘) are used; a farmyard and field inspection takes place.
- **RISE**: The adviser gathers the input data with the farmer directly on the farm. ‘Suisse-Bilanz’ data and information from ortho aerial images are taken into consideration; a farmyard and field inspection is carried out.

Checks

- **IP-SUISSE**: Checks are carried out by advisers conducting farmyard and field inspections.
- **SALCA-Biodiversity**: The ‘AgroTech’ program tests the plausibility of the collected data. Agroscope carries out additional plausibility tests. Farm inspections and interviews were carried out in individual projects.
- **RISE:** All data are collected in situ by a RISE adviser together with the farm manager, and simultaneously checked with a field inspection. The plausibility of the responses can be verified at the same time.

Validations

- **IP-SUISSE:** In an accompanying scientific study, correlations of the overall scores with the bird, butterfly, grasshopper and vascular-plant species on 133 farms were calculated and analysed with data collected in the field (Birrer *et al.* 2014).
- **SALCA-Biodiversity**: Koch *et al.* (2010) checked correlations of the overall scores on 10 farms in the Jura with the grasshopper and vascular-plant species collected in the field. A further validation with data from 12 European case studies (bees and bumblebees, spiders, vascular plants) is currently being carried out.
- **RISE**: No validations have been carried out to date. Certain areas of the methodology were developed based on validated methods and publications (e.g. IP-SUISSE method, intensity index according to Herzog *et al.* 2006).

12.5.3 Transparency and Reproducibility

When assessing the methods in terms of their reproducibility we check whether e.g. studies exist concerning the dependence of the data collection on the case handler in question. Transparency depends on whether the methodology is publicly available and precisely described, and whether the weighting of the individual criteria is disclosed. The transparency of the method is also increased if the reasons for a very low or very high evaluation of a farm can be clearly determined (e.g. with an individual farm but also in comparisons between farms).

Table 59: Relative assessment of transparency and reproducibility with respect to the input data for assessing biodiversity in the three evaluation methods IP-SUISSE, SALCA and RISE. Scale from 0 (unsatisfactory) to 10 (very good).

Transparency, Reproducibility	Assessment		
Criteria	**IP-SUISSE**	**SALCA**	**RISE**
Comprehensibility of the method for outside persons	10	5	2
Accessibility of the method for outside persons	10	4	1
Comprehensibility of the results for farmers	10	5	7
Accessibility of the results for farmers	10	5	8
Variability owing to case handler	9	9	4
Comparability of individual farm on a temporal level	10	10	7
Comparability between farms	10	10	6

Below, the assessments of the three methods with respect to transparency and reproducibility from Table 59 are explained in brief:

- **IP-SUISSE**: The tool, including the precise evaluation, is available for all online, as are the most important publications and reports on the methodology (Birrer *et al.* 2008; Birrer *et al.* 2012, 2013; Jenny *et al.* 2013a); two of the latter have appeared in renowned scientific journals (Jenny *et al.* 2013b; Birrer *et al.* 2014). Variability owing to different case handlers was not checked, but ought to be fairly low on account of the easy-to-collect input data. The tool states precisely what data are to be entered in what form. This enables very good comparability of an individual farm over the course of time, whilst also allowing meaningful comparisons between farms for a particular year.
- **SALCA-Biodiversity**: The methodology report (Jeanneret *et al.* 2009) as well as further reports (Gaillard *et al.* 2001; Alig *et al.* 2012) are available online. Seven articles have been published in peer-reviewed journals (Gaillard *et al.* 2001; Jeanneret *et al.* 2007; Nemecek *et al.* 2008; Koch *et al.* 2010; Deytieux *et al.* 2012; Jeanneret *et al.* 2014; Nemecek *et al.* 2015). The detailed evaluation and weighting scores for calculating the overall score have not heretofore been made available to the public, however. This method also enables a very good temporal and inter-farm comparability of the biodiversity index. No tests were carried out that determined variability owing to the case handler in question.
- **RISE**: The description of the methodology (Grenz *et al.* 2012a) is only furnished upon purchase of a licence. A formulaic description of the subindicators as well as the evaluation functions (accessible for assessed farm managers) are only available for farmers who use the model. Reports and publications (e.g. Häni *et al.* 2008; Grenz *et al.* 2009; KTBL 2009; Grenz and Thalmann 2013; Thalmann and Grenz 2013) are available online. Results from RISE have not been published in peer-reviewed publications to date. Given the wide latitude in the collection of the input data, however, the comparability of results is limited.

12.5.4 Applicability: Communicability and Practicability

Under this heading, not only do we judge the time and effort involved in data collection and the calculation of the indicator; we also assess whether a farmer can verify for himself, from the indicator or from the available set of assessment tools, how measures on one's own farm affect the indicator.

Table 60: Relative assessment of applicability with respect to the input data for assessing biodiversity in the three evaluation methods IP-SUISSE, SALCA and RISE. Scale from 0 (unsatisfactory) to 10 (very good).

Applicability	Assessment		
Criteria	**IP-SUISSE**	**SALCA**	**RISE**
Communicability, farm manager	10	6	8
Communicability, public	10	8	5
Use on farms	10	4	8
Time and effort involved in assessment	10	9	10
Geographical scope of application	3	5	10
Applicability for farm managers	10	2	4
Ease of use for experts and advisers	10	10	7
Possibility of aggregation	7	10	8

Below, the assessments of the three methods are discussed with respect to their applicability from Table 60:

- **IP-SUISSE**: This credit point system is already being used in Switzerland at farm level. For a farm manager, the time expenditure for data input should be approx. 15 to 30 minutes. The Microsoft Excel® program for calculating IP-SUISSE biodiversity points can be used free of charge.
- **SALCA-Biodiversity**: This method can be used for farms in Central Europe at plot and farm level. The time expenditure for surveying basic data is one to four hours, and also includes an interview. The 'AgroTech' tool enables the farm manager to collect the management measures himself. This is a complicated process which requires training. The data from 'AgroTech' and other farm data used are treated in all studies as strictly confidential. Aggregated data can continue to be used in anonymised form. SALCA was used for comparisons of various grassland and farmland usage systems in the context of research projects. In addition, SALCA is used for the national agroenvironmental indicator 'potential impact of agricultural activity on biodiversity'. In a further study of Alig *et al.* (2012), the potential impact on biodiversity of various beef-production systems was compared.
- **RISE**: This method is applied worldwide at farm level. The time expenditure for the collection of basic data comes to about an hour, including feedback. To date (Thalman 2015, pers. communication), RISE has been used on over 2000 farms in 51 countries. The data – collected by advisers – are confidential, and belong to the farm manager. Aggregated data can be used in anonymised form for companies, regional authorities, etc., upon consent of the farm manager. Project findings have also been used regularly for public communication and for interested parties.

12.6 Recommendation

All three investigated methods are suitable for assessing biodiversity on farms. Each method possesses strengths and weaknesses, as well as potential for improvement. The three methods require a similar time investment for collecting the input data. The IP-SUISSE credit point system is optimally geared to conditions in Switzerland. Unlike SALCA and RISE, it precisely follows the biodiversity-promotion measures specified as part of the DPO, and is therefore the most understandable of the three methods for farmers, which simplifies data collection. Because of its high degree of completeness, SALCA is the most suitable tool for scientific comparisons such as e.g. the evaluation of individual measures, or of measures that are not taken into account in the direct-payment system. Because of its flexibility in determining the subindicators, RISE is best suited for a rapid assessment. Compared to SALCA and IP-SUISSE, RISE has the disadvantage that, owing to its flexibility, comparisons between farms are only possible to a very limited extent.

For an assessment of the effects on biodiversity for a large number of farms in Switzerland, the IP-SUISSE credit point system is likely to be the most suitable method. Here, even farms not participating in the IP-SUISSE programme can be evaluated. Because of its substantial completeness, SALCA is better suited for the comparison of different production systems than the other two methods, and RISE is probably best suited for use at a global level.

It is conceivable for a new method to be developed on the basis of the three models presented here. In order to achieve this aim, transparency with SALCA and RISE would have to be considerably improved. A substantially more versatile assessment instrument in comparison to the individual models could be developed with reasonable expense and effort.

The author recommends the following improvements for the individual methods:

- **IP-SUISSE**: Inclusion of fertiliser use and irrigation as well as the potentially natural habitat. The latter would be particularly relevant in terms of the assessment of conflicts with the protection of bogs. In addition, plant-protection products should also be taken into greater consideration. The IP SUISSE points programme is also now being used in a very similar form in Germany (Schleswig-Holstein).
- **SALCA**: It is recommended that (rare) animal breeds and plant varieties be taken into consideration in the evaluation. The extent to which the potentially natural habitat or biodiversity functions should also be taken into account is to be tested. Moreover, functional aspects of biodiversity should be taken into consideration. The scoring (weighting) of the individual assessment criteria as well as the description of the methodology should be made generally available. What's more, it would be desirable to include special crops (fruit, vegetables, viticulture), as well as to adapt the model in terms of its applicability to other countries, or improve it. The possibility of simplifying direct data acquisition for farm managers must be envisaged. The indicators should be validated by means of further field surveys.
- **RISE**: Efforts should be made to achieve a distinct improvement in transparency vis-à-vis the scientific community and the public. At the very least, this requires publication of the manual as well as the scoring system. Although a lack of transparency is understandable for reasons of protection against competition, it could lead to the method being rated as untrustworthy ('Blackbox') and to suggestions for improvement of the method being largely impossible. Moreover, for the further development and acceptance of RISE, publication in scientific journals is also important. In particular, there are possibilities for improvement in the following aspects of RISE: plausibility checks of the input data; connection to species diversity; potentially natural habitats; taking into account of irrigation and functional aspects; validation of the results.

The 'biodiversity footprint' of the resources used on a farm is not included in any assessment method (e.g. what impact do purchased feedstuffs, fertilisers, diesel, etc. have on biodiversity at the site of their production). The potentially occurring natural habitat (including on agricultural land), irrigation and drainage issues, and functional aspects of biodiversity are scarcely included.

It would probably also be highly advantageous if the developers of the three methods analysed in this study jointly developed an improved evaluation method and/or discussed opportunities for improvement of the existing models.

With the IP-SUISSE and SALCA-Biodiversity credit point systems, we must ascertain the extent to which an LUI (land-use intensity) index could simplify or improve the assessment. With RISE, we must check the extent to which the method meets high scientific expectations.

As soon as a method determines a threshold value for defining a sustainability label or certificate, the suitability of the assessment system for evaluating the target values for preserving and promoting biodiversity must be ensured. Thus, for example, for the Lowland Zone in Walter *et al.* (2013), 8–12% of high-quality land (biodiversity-promotion areas of a quality according to the Direct Payment Ordinance; arable-farming-specific BPAs with the exception of beneficial-insect strips) is essential. Here, this raises the issue of whether or not lowland farms with less than 8% high-quality BPAs should be authorised for a biodiversity/sustainability certificate or label. Furthermore, this threshold value ought to be set significantly higher in Mountain Zones III (e.g. 20%) and IV (e.g. 40%).

12.7 Conclusions

The following conclusions must be interpreted with caution, since although the scoring was carried out to the best of our knowledge and belief, it nevertheless contains a subjective component. The scores were submitted to the respective developers of the methods, which led to minor corrections only. The individual scored criteria remain unweighted, i.e. the same importance is ascribed to the various aspects. An examination of the scoring by additional experts would help to further reduce the danger of miscalculations.

The IP-SUISSE, SALCA-Biodiversity and RISE credit point systems represent three available field-tested assessment methods.

The IP-SUISSE credit point system was judged the best in terms of transparency, reproducibility, robustness and uncertainties, as well as communicability and user-friendliness. At present, however, this model can only be used for Swiss farms.

SALCA was judged best in terms of completeness. It is particularly suitable for applied research. For a broad application, it has shortcomings with respect to transparency and comprehensibility. Farm managers without external help are not easily able to use SALCA.

RISE was the only one of the three methods also to be used widely in an international context. The details of the methodology are difficult to verify. Moreover, RISE is fairly unsuitable for inter-farm comparisons, since the case handlers have a rather high degree of leeway in the collection of the input data.

Although the inclusion of the effects of purchased resources on biodiversity at their production location is a very demanding process, it should be incorporated into all three methods studied.

If the method for defining a label or certificate is used, possible target values (including, potentially, regional ones) must be discussed in detail. Here, for example, care can be taken to ensure that these correspond to national target values.

13 Soil Quality

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13.1 Introduction

Soil is a vital resource for humans and animals (Gisi 1997). Although sustainably fertile soil is of crucial importance for food production, fertile soils are increasingly in scarce supply globally. In 1960, 0.44 ha arable land was still available per capita worldwide. In 2000, this had sunk to just under 0.22 ha per capita, and by the mid-21st century, according to the FAO, the figure will stand at around 0.15 ha per capita only (Alexandratos and Bruinsma 2012). In Switzerland too, the surface area of land under cultivation (arable land, pasture, meadows) is declining steadily, with around 0.7 m^2 of cultivated land being lost every second from 1985 to 2009. A further 0.4 m^2 has reverted to forest or bush, a result of fewer and fewer areas in the mountain region being used as meadows and pasture. This state of affairs corresponds to a decrease of 850 km^2 in cultivated land, or 5.4%, within 24 years.

The concept of soil quality was developed in the 1980s. Back in 1993, the FAO considered soil quality in the following five criteria for sustainable farming: (i) productivity, (ii) safety, (iii) protection, (iv) cost-effectiveness, and (v) acceptance (Smyth and Dumanski 1993). The ENVASSO (Environmental Assessment of Soil for Monitoring) Project mentions the following dangers for soils: (i) erosion, (ii) decrease in organic matter, (iii) compaction, (iv) contamination, and (v) salinisation (Huber *et al.* 2007). Owing to the great importance of healthy and fertile soil, the UN declared 2015 the International Year of Soils.

In Switzerland too, the protection of agricultural soils is an important component of national agricultural policy, with the FOAG's discussion paper on future agricultural policy strategy rating soil quality as at risk (FOAG 2010b). In this discussion paper, the FOAG formulates the aim of preserving the fertility of agricultural soils over the long term. In addition, the need to enhance measures for protecting the soil from erosion, compaction and the introduction of contaminants – not least of all to ensure security of supply – is clearly recognised.

The definition of soil fertility in Swiss legislation – namely, in the Ordinance relating to Impacts on the Soil (OIS 1998), forms the basis for the assessment of soil fertility. The ordinance defines a fertile soil very broadly, including economic, social and cultural aspects in addition to measurable soil properties. By contrast, according to Oberholzer *et al.* (2012) and Patzel *et al.* (2000), soil quality includes only those soil properties that are scientifically measurable. Since social sustainability as well as landscape aesthetics form the subject-matter of further chapters of this report, we limit ourselves here to soil quality determined by measurable soil properties.

Below, we restrict ourselves to the medium-term effects of agricultural management measures on agricultural soils. Here, management measures not only include tillage, sowing, fertilisation and harvest, but also the choice of main- and catch crop as well as type and intensity of meadow management. In order to take account of slowly changing soil properties, it makes sense to extend the timeframe of the soil-quality assessment to at least one crop-rotation period (6–8 years).

13.2 Relevance of the Topic for Sustainability

Soil is a necessity for human survival, since in addition to its function as a habitat, it also constitutes the basis for foodstuff production. The long-term safeguarding of a high level of soil fertility is therefore of crucial importance, in particular since adverse effects such as e.g. excessive compaction of the subsoil or high inputs of contaminants can lead to long-term and irreversible damage to the soil.

A sustainable use of the resource soil, which takes millennia to renew itself, is crucial, since in addition to the habitat function, soil fulfils numerous ecological and economic functions that highlight the great importance of a soil-quality assessment. According to Candinas *et al.* (2002), the different functions of the soil can be broken down into four thematic groups: (i) habitat function (hollows for organisms and plant roots, water- and heat stores), (ii) ecological function (e.g. storage of substances and filter effect; diversity of plants and soil organisms), (iii) agronomic and hydrological function (biomass production and water storage), (iv) economic, social and cultural function (source of raw materials, CO_2 sink and landscape diversity).

Because of the facts listed above, the assessment of soil quality is extremely important; however, owing to the high temporal and spatial variability of soil properties and their complex interactions, it is not fully possible (Garrigues *et al.* 2012). Consequently, there is no direct possibility of characterising soil quality in a simple indicator. The following chapter gives an overview of the most important methods for describing soil quality. Here, the challenge not only lies in the complex interactions of soil properties and soil functions, but also in the estimation of the impact of agricultural management on soil properties as well as on soil pollution (such as soil compaction, soil erosion or nutrient overfertilisation. In addition, the measurement of soil properties (such as e.g. structural constitution or activity of the soil life) is often difficult and subject to high uncertainties. Last but not least, it is important to point out that when examining soil quality, applying the life cycle approach in a consistent manner would lead to substantial difficulties, since e.g. in the case of a Swiss dairy farm that fed its cattle concentrates, the soil quality of soybean fields in Brazil would also need to be considered. This factor is not, however, taken into account with most common methods for assessing soil quality. In future, therefore, there should be careful consideration of the approach to be used for the assessment of soil quality on land outside of the farm being studied.

13.3 Overview

In this chapter, we present several methods for assessing the impacts of management on soil quality. A more detailed listing of the indicators used in the methods as well as of the required input variables (or input data) will be found in Chapter 13.4. In Chapter 13.5, the methods are evaluated according to a predetermined list of criteria.

Since several methods only cover subaspects of soil quality, only those methods which at minimum take into account the humus balance (or C-simulation models) as well as erosion, and which can be used at plot and farm level, are included. This is why erosion-oriented methods such as USLE (Universal Soil Loss Equation) (Wischmeier 1978) or the process-based WEPP (Water Erosion Prediction Project) model (Flanagan *et al.* 2007) are not taken into consideration. Also excluded from the evaluation are models which exclusively simulate the humus content in the soil whilst ignoring other aspects. Examples in this category are the Rothamsted C-model, which simulates the C_{org} content in the soil in monthly increments (Coleman *et al.* 1997), and the Daily Century model (DAYCENT), which describes C and N flows between the atmosphere, vegetation and soil with a daily resolution (Parton *et al.* 1998).

The evaluation takes the following five methods into account:

- SALCA- Soil Quality (SALCA-SQ, Oberholzer *et al.* 2012)
- RISE (Response-Inducing Sustainability Evaluation, Grenz *et al.* 2012b)
- MASC (Multi-attribute Assessment of the Sustainability of Cropping Systems, Sadok *et al.* 2009)
- LCA-SOIL (Soil Life Cycle Analysis), Jenkinson and Coleman 2008)
- EPIC (Environmental Policy Integrated Climate), Mitchell *et al.* 1998).

The DEXI-PM model (DEXi-Pest Management, Bohanec and Rajkovic 1999, Pelzer *et al.* 2012), which was developed within the scope of the EU-FP6 Project ENDURE (European Network for Durable Exploitation of Crop Protection Strategies), is not included in the evaluation, since it differs only slightly from the MASC model, and like DEXI-PM, is also based on the DEXi method.

All five models presented below place a clear emphasis – with varying degrees of detail – on the impact on soil properties. The spatial resolution of ‘plot’ can be handled by all models; only the two models MASC and SALCA-SQ allow an evaluation of soil quality at farm level (for EPIC, this is only possible with the model extension APEX). The two models LCA-SOIL and EPIC are dynamic simulation models, whilst the remaining three models are based on static equations. The two dynamic models calculate quantitative indicators, whilst the three static models assess soil quality using qualitative indicators (‘scores’).

13.3.1 SALCA-Soil Quality (SALCA-SQ)

The SALCA-SQ method allows us to determine the influence of agricultural management on soil quality in life cycle assessments (Oberholzer *et al.* 2012). SALCA-SQ is used to gauge the effect of management methods (such as cultivation of a catch crop). The aim is not to illustrate short-term reversible changes, but rather to identify medium-term effects of (agricultural) management processes. The method also enables us to derive starting points for improved management.

SALCA-SQ evaluates soil quality in two steps. In a first step, the impacts of management measures (fertilisation, tillage) are assigned to impact categories. In a second step, the influence of these impact categories on soil properties (=direct indicators) is determined. SALCA-SQ is based on nine indicators (important soil properties such as rooting depth or earthworm biomass) which have been allocated to different impact categories. Here, owing to the different importance of the impact categories for the individual indicators, a weighting is used.

Only soil properties having an impact on certain soil functions (e.g. habitat function, ecological function, agronomic and hydrological function) were chosen as indicators. The soil functions therefore serve indirectly as a basis for assessing soil quality (Oberholzer *et al.* 2006).

For detailed information, readers are referred to Candinas *et al.* (2002) and Oberholzer *et al.* (2012).

13.3.2 RISE

Developed for a holistic assessment of agricultural production at farm level, RISE is currently available in the 2.0 version (Grenz *et al.* 2012a). In it, the assessment of the farm is based on indicators covering all three pillars of sustainability (social, economic, ecological). RISE is a practical tool for promoting sustainable development, which records and assesses, on the basis of concrete and measurable criteria, (i) the contribution of the farm to sustainable global development and (ii) the extent to which agricultural production is sustainable for the environment. Since 2004, when the first version was launched, the model has been continually refined and evaluated by a wide range of experts. Furthermore, RISE has been compared with other indicator systems (see e.g. Breitschuh *et al.* 2008; Zahm *et al.* 2008), and has been used to date in 51 countries on over 2000 farms.

13.3.3 MASC

The MASC method is based on a multi-criteria decision-making system for evaluating ecological, economic and social sustainability (Sadok *et al.* 2009; Craheix *et al.* 2012a). The decision support is based on a hierarchically structured tree which aggregates the so-called input attributes into a single evaluation of overall sustainability. The input attributes (such as e.g. ammonia emissions or the pollution of groundwater with pesticides), which may be qualitative or quantitative in nature, are estimated either by experts or with the help of simple models, then assigned to three to seven different levels (e.g. 'very low', 'low', 'average', 'high', 'very high'). These evaluations are then incorporated in the decision tree, which aggregates the input attributes in substeps into fewer and fewer key figures. The weightings in the decision tree (i.e. for the individual aggregation steps) are either based on utility functions defined by 'if-then' decision rules, or on a rating by farm managers and/or experts. The method allows for a comprehensible evaluation of sustainability, and is easy to implement. In addition, the effects of a modification – for example, an adapted form of management in the investigated system – can be analysed easily. Aspects of MASC viewed as problematic are the roughness of the classification, as well as the different degrees of detail of the three pillars of sustainability in the decision tree (Carpani *et al.* 2012). In addition, there is a considerable margin of discretion when setting the weightings.

13.3.4 LCA-SOIL

LCA-SOIL is a modularly constructed simulation model that determines soil quality on the basis of the following three models:

- ***RUSLE2***: Erosion is calculated by RUSLE2 (Universal Soil Loss Equation, Renard and Ferreira 1993), an improved version of USLE (USDA-ARS 2008). This model estimates annual soil loss with the aid of the following factors: soil erosivity and erodibility, slope length and gradient, soil cover and tillage. The model was last modified in 2014 to achieve an improved prognosis for soil erosion with perennial vegetation (Dabney *et al.* 2014).

- ***RothC***: The RothC model (Rothamsted Carbon Model, Jenkinson and Coleman 2008) serves to estimate the amount of organic carbon in the soil. This model simulates C_{org} in monthly time steps, with the C-content of the following five compartments being modelled separately: decomposable and resistant organic plant material, microbial biomass, and humified and inert organic material. The RothC simulation model has been used both for regional studies with various climates (e.g. Peltre *et al.* 2012; Farina *et al.* 2013) and for global analyses (Gottschalk *et al.* 2012). The model can be used both in 'forward' status for the calculation of C_{org} on the basis of given input variables, and in 'inverse' status for the calculation of the input variables with known temporal progression of C_{org}.
- ***COMPSOIL***: Soil compaction due to machinery is given in the COMPSOIL model (O'Sullivan *et al.* 1999) in the form of changes in subsoil and topsoil porosity (30–50 cm and 0–30 cm, respectively). This model consists essentially of three components: (i) a modelling of the force exerted by the wheels on the soil; (ii) an analytical method for determining the spread of tension in the soil; and (iii) the computation of the change in porosity.

  Here, the impacts in terms of harvest yield (metric tonnes of grain) can be converted per ha. Biological diversity as well as (for the most part) soil chemistry are not taken into consideration in the overall model. Moreover, physical properties are also modelled less accurately than in SALCA-SQ.

13.3.5 EPIC

The EPIC (Environmental Policy Integrated Climate) model is used for the analysis of various agriculture and forestry management systems (Mitchell *et al.* 1998). The model consists of various submodels, with the influence of management on erosion, water availability, and nitrogen and phosphorus content in the soil being calculated with the aid of various submodels. EPIC also allows simulation of the growth in biomass of annual and perennial crop plants. In addition, the model can be used to determine soil organic carbon content. The drawback of this complex, dynamic model is its high input data requirement.
An extension of EPIC (APEX (=Agricultural Policy/Environmental eXtender); Wang *et al.* 2014) allows its use at farm level with different plots, soils and management methods. APEX enables an increase in the number of soil strata from 10 to 30, and can simulate the various chemical processes in the soil up to a depth of around 30 metres.

13.4 Description of the Indicators

13.4.1 SALCA-SQ

Soil properties can be subdivided into physical, chemical and biological properties. Physical properties include e.g. the texture, pore volume or density of the solid soil matter. Chemical properties are described by organic carbon (C_{org}) content, nutrients such as nitrogen (N), phosphorus (P) or potassium (K), or the pH value. Biological properties include *inter alia* microbial biomass and soil respiration.
In SALCA-SQ, the influence on soil quality of the change in the following nine direct indicators (=soil properties) are described (see Figure 26):

- Rooting depth (arable land only): measure of the soil volume accessible to plants dependent on the thickness, composition and structure of the soil. This indicator is particularly negatively affected by erosion.
- Macropore volume: Macropores in the soil serve as conveyor tracks for water and air, and are therefore essential for uninterrupted plant growth. (Intensive) heavy-machinery traffic on wet soils has a particularly unfavourable effect on coarse-pore volume.
- Aggregate stability: The SALCA-SQ method assesses the stability of individual aggregates. Soil organisms (e.g. earthworms) and the supply of organic fertilisers have a particularly favourable effect on this characteristic.

- Organic carbon (C_{org}) content: Organic soil matter (humus) influences most soil functions. Besides the addition of organic fertilisers via a suitable crop rotation, low-impact tillage and the leaving of crop residues on the field promote C_{org}.
- Heavy metal content: Heavy metal content is calculated in the 'terrestrial ecotoxicity' impact category, rather than in SALCA-SQ. Here, the heavy metals cadmium, copper, zinc, lead, nickel, chromium and mercury contributed by fertilisers and plant-protection products are recorded and adopted in SALCA-SQ.
- Organic pollutants: Organic pollutants are organic chemicals that have a toxic effect on soil organisms and plants (plant-protection products and problematic compounds in fertilisers). The input of organic pollutants through management is of particular interest here.
- Earthworm biomass: Earthworms have various important functions, *inter alia* loosening and mixing the soil, decomposing straw, and increasing plant-available nutrients via their excrement. Intensive tillage and the spreading of liquid manure have a particularly negative effect on the earthworm population. Nearly all of the plant-protection products authorised in Switzerland have no impact on earthworms.
- Microbial biomass: Here, microbial biomass refers to the amount of all microorganisms in the soil (in particular bacteria and fungi) which are important e.g. for the degradation of organic matter. Pollutants and compaction have a negative effect on this direct indicator, whilst low-impact tillage, fertilisers and harvest residues have a positive influence. In SALCA-SQ, microbial biomass is also influenced by four other direct indicators (coarse-pore volume, C_{org}, heavy metal content, organic pollutants).
- Microbial activity: this provides information on the 'vitality' of the soil. This activity is promoted *inter alia* by high liquid-manure input and the intensity of tillage.

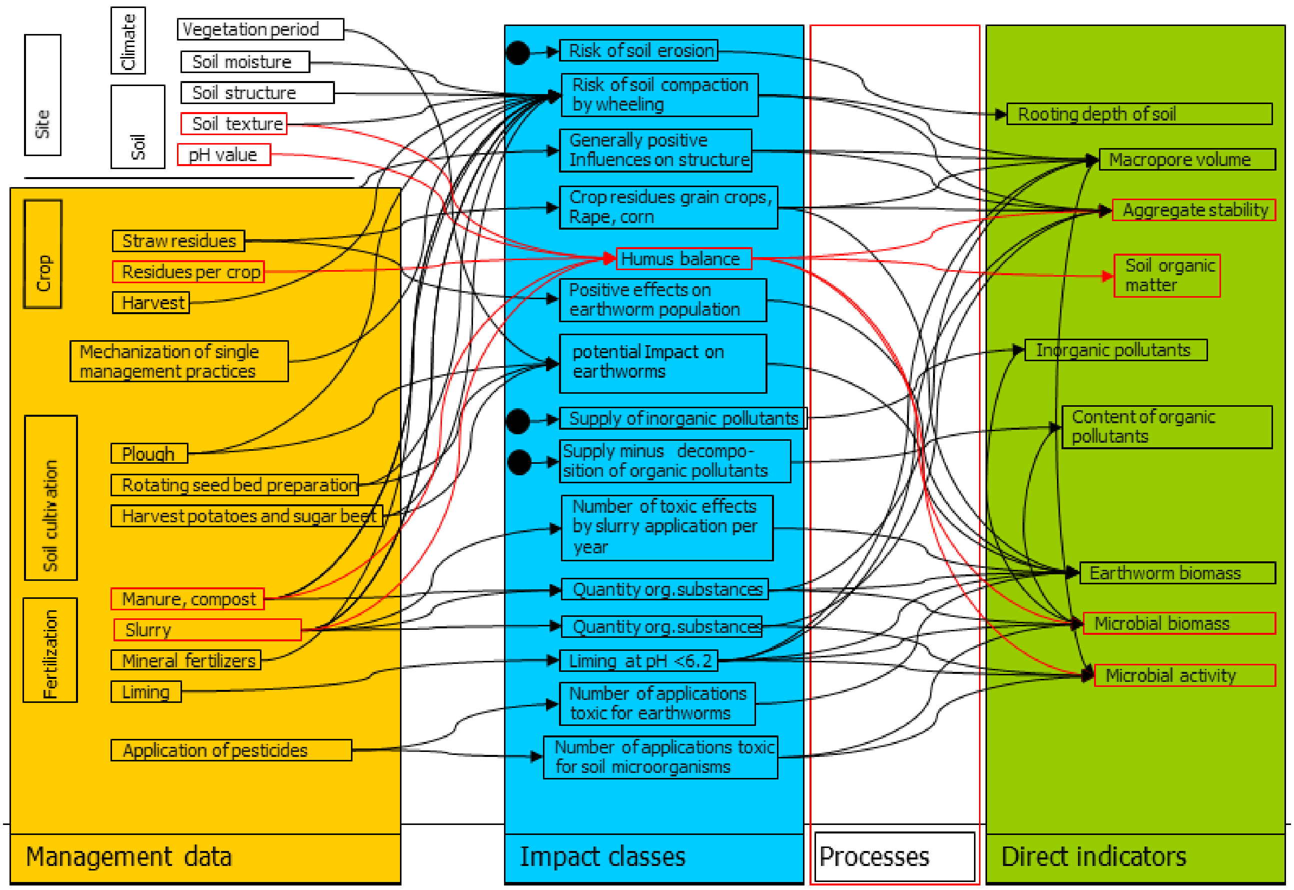

Figure 26: Graphic representation of the impacts on soil quality of management measures evaluated in the life cycle assessment (= indirect indicators) on arable land (from Oberholzer et al. 2006).

The soil properties discussed above are influenced by impact categories, with identical or similar effects of management measures being summarised in the impact categories. As an example, we would mention here the impact category ‘change in humus’, which can be determined by the balance of supplied organic matter (organic fertilisers such as dung and compost) and of humus mineralisation (decomposition of organic matter into inorganic compounds such as CO_2, water, phosphate or nitrate). For a detailed description of the impact categories, see Oberholzer *et al.* (2006). The management measures can influence the impact categories positively (e.g. the impact of intercropping on erosion risk) or negatively (the impact of liquid manure/plant-protection products on earthworm biomass).

The simplified model version of Mosimann and Rüttimann (1995, 1996) serves to estimate annual soil loss through erosion. The average) areal soil loss is determined by multiplying the C-factor (management influences over total rotation) by the S-factor (site dependency). Prior to this, each site is assigned to one of the following five main geographical regions: (i) Lowland zone of the western Swiss Midlands; (ii) Lowland zone of the central and eastern Swiss Midlands; (iii) Hilly zone of the central and eastern Swiss Midlands; (iv) Loess areas; and (v) Hilly zone of the Jura (Oberholzer *et al.* 2006). The C-factor is determined with the help of tables, bearing in mind the following three management aspects:

(i) Percentage by area of specific main crops in the rotation (e.g. winter wheat and oilseed rape); (ii) Use of catch crops before summer crops; and (iii) Use of special cultivation techniques (mulch strips, no-till).

The influence of site on erosion is estimated by the S-factor from the gradient, the flow length of the water, and grain size. Once the number, size and frequency of gullies has been recorded, linear erosion can be assessed and added to the areal soil loss determined above, in order to determine the average overall soil loss.

The humus balance is calculated in SALCA by the humus balance accounting according to Neyroud *et al.* (1997). The humus balance corresponds to the sum of humus loss and humus regeneration. Humus loss (humus mineralisation) is calculated as a function of clay content, pH value and percentage of root crops and temporary leys in the crop rotation. Humus regeneration is determined from the supplied organic matter (organic fertilisers and harvest residues).

Collection of the variables for SALCA-SQ requires considerable time and effort, since the management measures must be recorded in detail plot-by-plot. For the description of the management measures, the following variables in particular must be collected:

- Information on plot/site: Area, percentage of clay and humus content, pH value, soil type, climate, main geographic region (number, size and frequency of gullies) (Oberholzer *et al.* 2006).
- Plot-by-plot arable-crop rotation: Date of sowing/harvest of main crop and catch crop, harvest residues
- Animal husbandry: Grazing, stocking period and stocking density
- Fertilisation: Quantity, type, dilution (for liquid manure only)
- Tillage: Date of ploughing for main and catch crop and tillage by rotary cutter for seedbed preparation
- Wheeled traffic: Vehicle type, machine weight (unladen weight and working weight), axle load distribution, tyre width and diameter.

13.4.2 RISE

In RISE, the state of the soil (soil quality) is captured with the aid of seven parameters which are produced by a normalization on a scale from 0 (unacceptable) to 100 (completely sustainable course of action). The indicator ‘land use’ is determined by an arithmetic averaging of the seven parameters.

An interview with the farm manager is a crucial element for collecting the required input data.

The following seven parameters are determined:

- Soil management: We evaluate whether soil analyses, humus and nutrient balances are calculated and taken into consideration. Furthermore, we record whether the utilised agricultural area has decreased owing to degradation or sealing, or increased owing to a revival of fertility.
- Plant-production productivity: This category analyses yields per unit of area and product quality, including the trend over the past five years. The normalization is based on a comparison with the national average in each case.
- Humus: This parameter is based on an estimate of the humus content, as well as a rough calculation of the humus balance bearing in mind crop rotation and management (tillage, fertilisation, dealing with

harvest residues). If the humus balance is in equilibrium, the parameter 'humus' is given 50 points; a positive balance of 20 kg humus-C per ha and year is awarded 1 point (linear).

- Soil reaction: Evaluates the pH value of the soil and tests the salination and acidification risk, bearing in mind the climate (humid/arid) and the application of fertilisers that reduce the amount of lime.
- Soil pollution: Evaluates the risk of heavy-metal inputs owing to fertiliser application, antibiotics and other harmful substances (e.g. owing to proximity to a motorway or factory)
- Soil erosion: Determines the risk of water and wind erosion bearing in mind climate and topography, and based on observations, soil parameters (e.g. greatest slope gradient and coverage of the topsoil with stones) and global erosion maps (see http://soils.usda.gov/use/). The CORINE (=Coordination of Information on the Environment) method of the European Environmental Agency (EEA) serves to estimate water-erosion risk, and represents a simplified version of the universal soil-loss equation (www.iwr.msu.edu/rusle). The risk of soil erosion is estimated according to the German Industry Standard (DIN) based on soil type and humus content.
- Soil compaction: The risk of soil compaction is estimated by several targeted questions on the weight of the machinery used, the state of the soil, and measures for protecting the soil during management.

13.4.3 MASC

The MASC model uses the following four of the total of 32 available input attributes for determining soil quality:

- Risk of compaction
- Risk of erosion
- Soil organic matter content (SOM indicator)
- Phosphorus fertility.

The risk of erosion is estimated exclusively qualitatively from soil water content, type of soil cover and management, and crust formation. In addition to soil water content and type of management, risk of compaction requires soil type (sand, silt and clay content) and degree of mechanisation as input variables. The MASC Model Version 1.0 performs a qualitative assessment, since the authors were unable to identify any indicators permitting a quantitative assessment (Sadok *et al.* 2009). In the new version MASC 2.0, a qualitative indicator is developed with the aid of so-called 'arbres satellite' (= 'satellite trees') (Craheix *et al.* 2012a).

The INDIGO method (Sadok *et al.* 2009) provides the soil organic matter content. Here, the indicators are given in the form of scores between 0 and 10, with values below 7 being deemed unacceptable. Soil organic carbon (C_{org}) is determined as a function of crop rotation, tillage, handling of harvest residues, and number of fertilisation passes during a four-year period (Sadok *et al.* 2009). The SOM indicator is based on the ratio of input organic matter (minus loss owing to mineralisation) to recommended nitrogen requirement, assuming that SOM=1.72 x C_{org}. The drawback with INDIGO is that it takes only arable and forage production, and not animal husbandry, into account.

The calculation of the phosphorus balance is based on erosion, the quantity of input phosphorus fertiliser, and the date of fertiliser application (see http://wiki.inra.fr/wiki/deximasc/package+MASC). The weighting of the four soil attributes into the aggregated parameter 'soil quality' can easily be adapted by the user (Craheix *et al.* 2012a; Craheix *et al.* 2012b).

13.4.4 LCA-SOIL

The LCA-SOIL model is constructed modularly from various models which estimate soil erosion, change in organic carbon content and soil compaction. In LCA-SOIL, the calculated indicators for soil quality consist of

- annual soil loss,
- change in organic soil carbon content, and
- soil porosity.

The inputs for the three basic models are listed below.

Soil erosion is described by the universal soil loss equation (USLE), which calculates annual soil loss through water via the soil loss equation

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \quad (13)$$

where
A: Average annual soil loss
R: Erosivity factor (rain and surface runoff factor)
K: Soil erodibility factor (erodibility of the soil under standard conditions)
L: Slope length factor
S: Slope gradient factor
C: Soil-cover factors and tillage factor
P: Erosion protection factor.

Calculation of the above factors in LCA-SOIL requires information on climate parameters (temperature and precipitation on a monthly basis), soil properties, organic C-content, slope length and gradient, type of crop, and mechanical cultivation.
The organically bound carbon content in the soil is determined by the RothC (=Rothamsted Carbon) model (Jenkinson and Coleman 2008), which stipulates the collection of the following input parameters:

- Climate data: Long-term monthly mean values for temperature, precipitation and evaporation;
- Soil data: Clay content, initial organic carbon content, thickness of topsoil layer;
- Management: Soil cover, input of organic fertilisers, yield, and plant input (type/quantity/date).

Soil compaction is estimated by the COMPSOIL model (O'Sullivan *et al.* 1999). The following inputs are required by the model for the calculation:

- Soil texture, determined with the aid of five soil types of different granularity from coarse to very fine ('*coarse*', '*moderately coarse*', '*medium*', '*moderately fine*' and '*fine*'), according to the FAO soil classify-cation
- Precipitation (for determining soil water content)
- Type and weight of vehicle, wheel diameter and width, tyre pressure.

Soil compaction is determined via the change in soil porosity modelled in COMPSOIL.

13.4.5 EPIC

EPIC consists of various submodels based on the surface model DAYCENT, a version of the CENTURY SOC model, but with a time step of one day as well as additional soil processes (Parton *et al.* 1998). Consequently, most of the input data must be available on a daily resolution. In addition to modelling soil water content as well as soil organic carbon, nitrogen and phosphorus content, this model is also able to simulate emissions (methane, nitrous oxide and nitrogen oxides) and plant growth. Since the EPIC dynamic model is complex, not all input parameters can be specified in the following chapters. A number of parameters – especially in the EPIC C- and N-model – are assumed to be constant, or are parameterised with a simple approximation (Izaurralde *et al.* 2006). The model requires the following soil parameters for the individual soil layers (a maximum of 10 layers can be given):

- Layer thickness
- Field capacity
- Wilting point
- Root fraction
- Clay/silt and sand fraction
- Hydraulic conductivity at saturation
- Minimum water content
- pH value.

Soil density, porosity and water-retention capacity are explicitly forecasted in EPIC, whilst agricultural machinery traffic does not appear to be taken into account.
For various processes, a number of common climate parameters are required:

- Temperature
- Accumulated precipitation
- Number of rainy days per month
- Relative humidity
- Global radiation (can be approximated by sunshine duration).

Below, we outline the indicators calculated in the models, together with the required input data.

- Erosion: Water-induced erosion is calculated with the USLE soil-loss equation. For the description of the required input parameters, we refer readers to the LCA-SOIL model. EPIC provides the option of using the Onstad-Foster variant of USLE (Onstad and Foster 1975) or MUSLE (Williams 1975). The latter two extensions additionally require the daily surface runoff, as well as the maximum hourly runoff rate.
- Runoff model: This model simulates the surface runoff and the maximum runoff rate. The model provides a detailed resolution of the different processes (interception of water on plants, evaporation, infiltration, transport of water between the individual soil layers). In addition to various soil parameters, this model requires the daily precipitation, surface roughness and fraction of vegetation to be given (Potter *et al.* 1998; Izaurralde *et al.* 2006).
- Wind erosion: This parameter estimates the potential wind erosion for a flat surface. In addition to the average daily wind speed, the model also needs the distribution of wind speed (obtained through a parameterisation) as an input parameter.
- Plant growth: The daily increase in biomass is estimated with the approximation according to Monteith and Moss (1977). Three plant-dependent constants as well as the steam-pressure deficit and atmospheric CO_2 concentration must be given as additional input parameters (Sotockle *et al.* 1992).
- C- and N-model: Calculation of the soil nitrogen and carbon content, as well as emissions of methane, nitrous oxide and NOx. The model is highly detailed, and models humus formation bearing in mind the various functions of microbial biomass and stable ('passive') and 'slow' humus (Izaurralde *et al.* 2006). The calculations require *inter alia* that harvest residues, tillage, and fertilisation measures be stated.

13.5 Evaluation of the Indicators

13.5.1 Completeness of Scope

It is not possible to model all processes in the soil exactly, since some of these processes are very complicated and are not understood in detail. For this reason, even complex models cannot simulate all processes. In addition, complex models frequently require a large number of parameters, some of which are difficult to collect and which in certain circumstances are subject to strong spatial (and temporal) fluctuations. Based on expert knowledge (Oberholzer 2015, pers. communication), completeness was determined using the criteria listed in Table 61. The nitrogen cycle is not evaluated as part of soil quality, since nitrate leaching is dealt with in SALCA-Nitrate. Phosphorus leaching is likewise not included in the list of criteria, since it is more closely linked with soil loss through erosion (avoid double-weighting!). The nitrogen cycle is not assessed here, since leaching/ mineralisation and N-uptake by arable plants is calculated in SALCA-Nitrate.

Table 61: Completeness of the models. The assessment is based on a personal assessment of the main author's. A maximum 10 points are awarded where conditions are ideally fulfilled; '0 points' indicates a massive deficit, i.e. the process or aspect is scarcely taken into account, if at all.

Completeness	**Assessment**				
Criteria	**SALCA-SQ**	**RISE**	**MASC**	**LCA-SOIL**	**EPIC**
Is it possible to evaluate soil quality for a farm?	10	10	6	4	2
Input parameters (scope)	8	5	5	10	10
Erosion model (degree of detail)	7	6	3	9	10
C-model (impact on humus content)*	8	6	6	9	10
Water balance (surface runoff, groundwater)	0	2	3	6	10
Is soil compaction taken into account and estimated?	10	5	4	10	4
Is the influence of ground cover included in the model?	6	7	6	6	8
Is the influence of pesticides (on microorganisms and earthworms) taken into account?	9	4	3	0	2
Total	57	45	36	51	56

The scores in Table 61 are based on the following estimates:

Evaluation at Farm Level

The three models SALCA-SQ, MASC and RISE are designed to evaluate soil quality at farm level. EPIC can only evaluate soil quality at farm level in conjunction with the APEX extension. LCA-SOIL is used primarily at plot level. A disadvantage of MASC is that the model can only be used for arable farms.

Input Parameters

The EPIC model in particular requires a great many input parameters, which in addition to the usual soil and climate parameters, management, and fertilisation plan also include detailed inputs concerning soil cover and the C and N fractions in the harvest residues. Furthermore, the input parameters are required in daily steps. The dynamic model LCA-SOIL also has need of an extensive input dataset, both for climatology and soil structure as well as for cultivation methods. In MASC, ordinal information is often sufficient (attributes are specified categorically, e.g. at three levels with the help of available literature or expert knowledge); climatelogical parameters, slope gradient and soil density are not necessary for the calculations. In order to determine the seven soil indicators in RISE, various questions (often yes/no questions) must be answered by the farm manager. Detailed records are usually not necessary; internal observations are taken into account for the indicator soil erosion.

Erosion Model

In SALCA-SQ, erosion is determined with a simplified version of Mosimann and Rüttimann (1995, 1996), thus neglecting certain aspects (e.g. aggregation of over 20 main regions into the above-specified five main regions). Moreover, a simplified version of the soil-loss equation is used. In RISE, a simplified version of the soil-loss equation is also used. The effect of humus content is not taken into consideration. By contrast, RISE also incorporates observed erosion events in the assessment. MASC assesses erosion risk qualitatively, based on expert knowledge. Tillage is indicated at four different levels (direct sowing (zero-till), minimal tillage, occasional ploughing, regular ploughing). Lack of soil cover during 'critical' periods is weighted heavily. The LCA-SOIL model determines erosion with an adapted soil-loss equation, and takes account of all significant influencing factors of erosion. EPIC determines water-induced erosion and wind erosion. Both types of erosion are modelled in a complex manner, which results in a high input-data requirement (such as e.g. daily surface runoff, maximum hourly runoff rate, or wind-speed distribution).

C-Model (Humus Content)

SALCA determines humus balance (for arable farming) in detail according to Neyroud *et al.* (1997). The degradation ('mineralisation') of organic matter is compared with the input of organic matter (organic fertilisers and harvest residues). Consequently, this method makes no statement on the absolute humus content of the soil, unlike C simulation models. For this reason, the initial quantity of organic matter is also estimated in SALCA. In RISE, a (simplified) humus balance is only calculated on arable land; thus, RISE significantly underestimates humus content on permanent grassland (Kuntze *et al.* 1994). The INDIGO method (Sadok *et al.* 2009) used in MASC for calculating humus content adequately considers the most important influencing factors with the parameters of tillage, crop rotation and frequency of fertiliser application, but simplifies the mechanisms such that feasibility (data input) remains acceptable. The dynamic simulation model RothC (Jenkinson and Coleman 2008), which is applied in the LCA-SOIL model, models all important processes of humus formation and degradation, with C_{org} content being calculated in monthly steps in five different compartments. EPIC calculates organic C and N content in three different compartments with great attention to detail, taking into consideration leaching as well as loss in gaseous form, among others.

Water Balance

SALCA does not determine either soil moisture or surface runoff; nor does RISE model the water balance directly. Nevertheless, there are four parameters on the topic of water usage (water management, water supply, water-usage intensity and risks for water quality) that allow certain conclusions to be drawn regarding surface runoff (e.g. the question of water levels, or of the worsening of water quality over the past 5 years). In MASC, soil water content can be estimated in a very approximate manner from the two indicators 'irrigation during dry spells' and 'water consumption of arable crops'. The LCA-SOIL model calculates soil water content with the COMPSOIL model, by means of soil and precipitation data. EPIC incorporates a runoff model that can simulate surface runoff and the highest runoff rate, with various processes such as interception, evaporation, infiltration and water transport between the various layers being taken into account. This allows the forecasting of both soil water content and surface runoff.

Soil Compaction

SALCA ascribes great importance to the estimation of soil compaction by wheeled traffic and grazing. For each passage of wheeled traffic, soil pressure under the wheels as well as the percentage of the area travelled over is calculated, and a risk deduced therefrom. RISE determines the risk of harmful soil compaction via seven yes/no questions that relate directly to information on compaction. MASC estimates the compaction risk qualitatively based on soil type and moisture, as well as degree of mechanisation; however, no individual passages of wheeled traffic are taken into account. LCA-SOIL estimates soil compaction using a highly developed model: COMPSOIL (O'Sullivan *et al.* 1999) calculates the spread of mechanical tension in the soil through loading, and is therefore in a position to determine compaction (simulated in the model by bulk density) separately for the topsoil (0–30cm) and subsoil (30–50cm). EPIC also forecasts soil density explicitly. Here, however, wheeled traffic does not appear to be explicitly taken into account; rather, changes in density are simulated through the ploughing-in of harvest residues.

Influence of Soil Cover

SALCA-SQ takes into account soil cover when calculating the erosion risk through the inclusion of catch crops before summer crops. When determining the water-erosion risk for each crop rotation, RISE includes soil cover according to the shares of the crops. In the MASC model, soil erosion is also a function of soil cover. Despite being requested from the responsible authors, however, details are not available. In LCA-SOIL, soil cover is included in the calculation of water-induced erosion via the soil-cover factor and the soil-management factor C. In EPIC, soil cover is not only used for water-induced erosion, but also for wind-induced erosion and the humus model.

Pesticides

SALCA-SQ takes account of the quantity, timing and frequency of treatment of plant-protection products (fungicides, insecticides, herbicides) for determining the toxic effect on earthworms and soil microorganisms. RISE deals with the negative effects of plant-protection products in the 'biodiversity and plant protection' indicator, rather than in the 'land use' indicator. Here, in addition to detailed questions concerning plant-protection management (e.g. "Are harmful organisms reliably determined before spraying?") a list of the toxic plant-protection products is called for, with the evaluation being based on a simplified version of the Environmental Impact Quotient (Kovach *et al.* 1992). This method is based on the persistence of active substances, and their toxicity for various groups of organisms. RISE's lower rating can be explained by a rudimentary evaluation of the effects of plant-protection products on soil organisms (especially earthworms). MASC makes a separate calculation for the insecticides, fungicides and herbicides of the so-called Treatment Frequency Index, which gives the number of treatments per year with a standard dose (based on active substances). Since this information is only used for the health risk, MASC is also given a low score. LCA-SOIL ignores the influence of plant-protection products on soil quality. Although EPIC simulates the transport and degradation of pesticides as well as their concentration and aquatic toxicity, it ignores their toxic effect on microorganisms and the earthworm population in the soil.

13.5.2 Assessment of Robustness and Uncertainties

All investigated models are based on mostly rough parameterisations of the physically and chemically highly complex processes in the soil. We must therefore expect all models to have a high uncertainty factor for the results. When estimating uncertainty, however, the focus here is not primarily on the uncertainty in the parameterisations, but rather on the uncertainties arising from the type of data collection and the monitoring of the same. Since the data requirement is high for a number of models, missing values must be replaced by default values, which represents an additional source of errors. Here, sensitivity studies and model validations, i.e. the comparison of model results with direct surveys in the field (measurement, interview of the farm manager) are important tools for estimating robustness and uncertainties.

Data Sources

This aspect covers the quality of data collection. Here, checks on the farm and plausibility tests are particularly important. Moreover, excessive simplification owing to an insufficient volume of data or a lack of precision can lead to errors.

SALCA-SQ

In SALCA-SQ, the input variables for the individual plots such as soil type, crop rotation in arable farming, fertilisation and tillage are collected via a farm survey. Here, we can use the data from the AgroTech tool, which enables the collection of all production-related data of a farm, and which can be used to furnish the Proof of Ecological Performance. We can also use the data from the Suisse-Bilanz, which serve to furnish proof of a balanced nitrogen or phosphorus budget according to the Direct Payment Ordinance (DPO), for fulfilment of the Proof of Ecological Performance (PEP). Additional farmyard and field inspections open up a further source for data collection, but are not strictly necessary. The data from both AgroTech and Suisse-Bilanz are subject to a plausibility check; moreover, the input variables in SALCA undergo a further plausibility test. It may therefore be assumed that the input variables are of a sufficiently high quality. It is also possible to use default values for missing parameters (e.g. missing machine data can be replaced by the machine data from a standard scenario).

RISE

In RISE, input data are for the most part collected via an interview with the farm manager as well as a brief inspection. Except on very complex and large farms, data collection takes under three hours. There is no plausibility check of the input variables. Data on climate (temperature and precipitation conditions) and erosivity (water and wind) as well as soil data can be drawn from databases of institutions such as the FAO and the national statistical offices (Grenz *et al.* 2012a).

MASC

MASC assesses the two indicators 'soil compaction' and 'erosion risk' solely qualitatively; only the indicator for humus content is calculated using the INDIGO method. For this reason, accuracy depends largely on expert knowledge, and cannot be tested for plausibility in a wholly satisfactory manner. With the exception of the Basic Indicators level, the weighting of the individual criteria can be modified by the user (Sadok *et al.* 2009).

LCA-SOIL

LCA-SOIL requires very detailed input variables, both in terms of management as well as soil and climate properties. Where necessary, soil type can be gleaned from global databases, which in the event of high spatial variability of the soil type is likely to lead to an error that ought not to be underestimated. Certain parameters such as e.g. soil water content are calculated by models (in this case, the assessment is made with the help of soil and precipitation data). A plausibility check of the data is not implemented. The data for the 'organic matter content' indicator are collected plot-by-plot via a data entry form; the remaining indicators are based on the assessment of experts.

EPIC

The dynamic model EPIC (and its extension, APEX) – used primarily to calculate the water budget, erosion and C_{org} – requires a highly detailed input dataset, especially with regard to soil properties in different layers of the soil. Data collection thus requires challenging measurements on the various plots studied, whilst no plausibility checks are provided for. Furthermore, an extensive parameter dataset as well as various equation coefficients are required, some of which are difficult to assess (Wang *et al.* 2006). In the case of EPIC, these facts lead to a lower rating than for the other four analysed models.

Validation

This chapter examines the extent to which the model results have been checked and verified (e.g. via interviews or measurements), and whether the model furnishes the results expected by experts, or agrees with measurement results.

SALCA-SQ

The SALCA-SQ results have been verified in various studies. On the basis of 14 farms from the Aargau cantonal soil monitoring scheme (KABO), Marbot (2012) investigated whether the assessment of soil quality with SALCA-SQ can be confirmed by statements from farmers. From the analysis, the study concludes that the SALCA-SQ results can only be verified in part with the farmers' statements. The two indicators 'coarse-pore volume' and 'aggregate stability' can frequently be confirmed, not least of all since farmers can easily estimate the soil compaction problem. From a plausibility check for arable farms for three crop rotations with five fertilisation variants each, Oberholzer *et al.* (2012) conclude that the SALCA-SQ model results largely agree with experts' statements. Genuine validations of the humus balance have been conducted in a master's thesis (Holenstein 2010) and in an international project based on four further humus balances using data from 20 long-term trials in Switzerland, Germany, Sweden and Russia (publication in preparation). Results from Terranimo® served to help estimate soil pressure at 35cm depth (for the compaction risk). Terranimo® is a simulation model for calculating soil-compaction risk when using agricultural vehicles (see https://www.terranimo.ch/). No additional validations comparing direct indicators with observations on the field (e.g. earthworm biomass or coarse-pore volume) were performed.

RISE

No validation of the results has heretofore been undertaken in RISE. Since, however, the model is used worldwide and the questions – as with the other models – derive from practical knowledge and research results, it can be assumed that at least some important aspects of the modelled soil quality agree with observations.

MASC

The qualitative soil indicators of 'soil compaction' and 'erosion risk' used in MASC were not validated. The indicator 'organic matter content' from the INDIGO method (Bockstaller *et al.* 1997) constitutes an exception.

LCA-SOIL

The models implemented in LCA-SOIL for erosion (RUSLE2), humus content (RothC) and soil compaction (COMPSOIL) have been verified and validated in many studies. RUSLE2 (http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm) is globally applicable, and has been tested and validated in numerous studies (Renard and Ferreira 1993; Dabney *et al.* 2006; Ismail and Ravichandran 2008). The same is true for the model 'RothC' (Coleman *et al.* 1997; Jenkinson and Coleman 2008).

EPIC

The model EPIC (and its extension, APEX) have been carefully validated in recent years. Izaurralde *et al.* (2006) compare *inter alia* the humus content calculated with EPIC with other models (including the RothC model used in LCA-SOIL), as well as with longstanding observations.

Sensitivity

This assessment takes into account whether sensitivity studies are available, as well as whether the model reacts sensitively to (expected) changes in soil quality owing e.g. to wheeled traffic.

SALCA-SQ

It is very difficult to capture sensitivity in SALCA-SQ, since soil quality is not determined merely from the sum of the individual components (=direct indicators), but rather by each individual indicator. The model implies a risk to soil quality as soon as an individual indicator lies in the critical range. It is highly advantageous that the direct indicators have an immediate connection with one or more soil functions, and can be influenced in the medium term by the form of management. In a plausibility check for arable farms, Oberholzer *et al.* (2010) investigated which input variables have a decisive influence on the model result, analysing three crop rotations with five fertilisation variants each. The assessment of the impact of the three crop rotations on soil quality on the basis of the model showed that not only the crop rotation itself but the type and quantity of fertiliser applied, as well as harvest-reside management and tillage are crucial factors for the effect. A number of other studies in Oberholzer *et al.* (2010) make it clear that SALCA-SQ generally reacts sensitively to various management forms. Further papers verifying SALCA-SQ in the DOK and Burgrain growing-system trials can be found in Nemecek *et al.* (2005) and Nemecek *et al.* (2011).

RISE

There are no studies from an independent quarter investigating the sensitivity of input variables to the seven parameters characterising the state of the soil in RISE (Grenz 2015, pers. communication). According to Grenz (2015, pers. communication) the following qualitative statements can be made on the sensitivity of the soil model: (i) The relatively large number of seven soil parameters in RISE leads to a strong 'averaging out' of the indicator 'land use'; (ii) Farms in Central Europe tend to receive lower scores for the three parameters of humus, soil erosion and soil compaction, which can be attributed primarily to the root crops.

MASC

Three of the four soil indicators in MASC (compaction risk, erosion risk, P-fertility) were not tested as to their sensitivity. Bockstaller *et al.* (1997) describe the sensitivity of the indicator for humus content to arable-farming data (crop rotation and yield) and soil properties (clay and lime content). In addition, the weighting of the individual indicators (with the exception of the Basic Indicators level) into the aggregated soil-quality indicator can be determined by the user, since MASC is based on a multi-attribute model. Thus, the weighting allows the sensitivity of the aggregated soil-quality indicator to be set to the four specific soil indicators. There are several other papers on the sensitivity of MASC, with Carpani *et al.* (2012) deducing from their studies that MASC differentiates only insufficiently between different arable farming systems. In addition, the study points out that erosion and soil compaction exert the greatest influence on soil quality.

LCA-SOIL

The sensitivity of the various submodels of LCA-SOIL has been tested in numerous sensitivity studies. Garrigues *et al.* (2012), for example, show by means of case studies in various countries that the RothC model reacts particularly sensitively to fertiliser input and plant residues, whilst the sensitivity of the soil compaction calculated by the COMPSOIL model decreases in soils with an increasing percentage of loam, and erosion is strongly influenced by the distribution of precipitation as well as the gradient. From a paper on the C_{org} content of Slovakian soils (Barančíková *et al.* 2010) we conclude that the model is 'sufficiently' sensitive to the input of organic matter and to temperature. Based on a validation of the COMPSOIL model, O'Sullivan *et al.* (1999) conclude that soil compaction is strongly dependent upon soil water content, which can be explained directly by the chosen parameterisation approximations.

EPIC

Various sensitivity studies have been published on the dynamic model EPIC, as well as its extension, APEX (Wang *et al.* 2006; Wang *et al.* 2014). Wang *et al.* (2006) use sophisticated sensitivity models to analyse which input data have a significant influence on the results. The results show that out of the numerous input variables and necessary coefficients in the parameterisation equations, it is often just a few that are important (e.g. for wind erosion, the value of the coefficient in the equation for calculating wind distribution, or the C-factor for calculating water erosion, or the fraction of humus in the 'passive pool' for changing C_{org}). In addition, it is stressed that sensitivity depends on the annual course of the weather conditions. Wang *et al.* (2012) provide a complete overview of the (sophisticated) calibration and validation of the model. Since potential soil compaction through agricultural machinery traffic is not included in EPIC, sensitivity in this respect cannot be assessed.

Table 62: Robustness and uncertainties of the models. The assessment is based on a personal assessment of the main author's. A maximum of 10 points are awarded for ideal fulfilment; '0 points' indicates a massive deficit, i.e. the process or aspect is scarcely taken into account, if at all.

Robustness and Uncertainty	Assessment				
Criteria	SALCA-SQ	RISE	MASC	LCA-SOIL	EPIC
Data sources (survey of the input variables)	8	6	5	6	5
Validation of the model results	7	2	4	9	9
Sensitivity	8	2	5	9	9
Total	23	8	14	25	23

13.5.3 Transparency and Reproducibility

The calculations for all five investigated models are disclosed as a matter of principle.

SALCA

The structure and basics of the SALCA-SQ methodology can be gleaned from Oberholzer *et al.* (2006). A precise description of the specifics of the model and of the input parameters is not available. Experts also lack a summary of the calculations, which can only be understood through detailed analyses of the calculation formulae in Microsoft Excel®. Further information and codings (such as e.g. weighting factors, area percentage of tramlines or humification rates) can be viewed in the form of Excel tables. SALCA allows for trouble-free monitoring of a farm over several years, as well as the comparison of farms among themselves. Susceptibility to errors during data input is limited in SALCA, since the structure of the data input (inventory file) is precisely stipulated.

RISE

A brief description of the seven soil parameters used in RISE can be obtained from Grenz *et al.* (2012a). A detailed description of the calculations is not available for external clients, nor can any complete list of the literature on the methodology be gleaned from the RISE Version 2.0 manual, with the exception of the parameter 'soil erosion'. Indicators normalised to the scale of 0 to 100 allow for the easy comparison of farms. This also applies for time series of an individual farm. With RISE, the uncertainty in the data collection by the experts must be rated as relatively high, since the quality is largely dependent on the quality of the interview with the farm manager.

MASC

MASC is described in various scientific publications in which the two basic components (input for the most part in the form of qualitative attributes; use of a decision tree for an overall aggregation) are well described (Sadok *et al.* 2009; Craheix *et al.* 2012b; Ravier *et al.* 2015), but the details are largely left open. A comparison of farms can be rated as fairly critical, since the decision rules and weightings can/should be adapted according to the farm's focus. The model is also largely unsuitable for studies on the changes in soil quality of an individual farm over time, especially due to the rough qualitative classification ('low', 'average', 'high') of all four attributes taken into consideration in MASC for the calculation of soil quality. The qualitative evaluation of the attributes, and the free (with the exception of the Basic Indicators level) allocation of weightings (Sadok *et al.* 2009) lead to fairly substantial uncertainties or difficulties with data input.

LCA-SOIL

Since LCA-SOIL consists of several submodels that are already well validated and described in detail, the methodologies are also easily understandable for external clients, despite in some cases requiring prior knowledge of physical, chemical and biological processes in the soil. Although comparisons between farms are possible where sufficient data is available, it is particularly problematic in the case of soil compaction (COMPSOIL model), since model output is limited to calculation of the soil density profile. A conversion to the decrease in soil porosity is, however, possible according to Corson (2014).

EPIC

Although the parameterisation equation system implemented in EPIC is itemised in full in the two articles (Williams *et al.* 1998; Izaurralde *et al.* 2006), owing to its high complexity it is most likely difficult for third parties to comprehend. Since this model is freely available (including source code of all subroutines in Fortran), the modelling is completely transparent (see EPIC 2015). Using various case studies conducted over several years, Izaurralde *et al.* (2006) show that the model is suitable for simulating time series of the organic soil-matter content. Data input is judged somewhat more critically: some of the large number of necessary input variables can only be calculated by complicated measurements of, for example, field capacity, distribution of roots in the soil, or wilting point in various horizontal soil layers.

Table 63: Transparency and Reproducibility of the models. The assessment is based on a personal assessment of the main author's. A maximum of 10 points are awarded for ideal fulfilment; '0 points' indicates a massive deficit, i.e. the process or aspect is scarcely taken into account, if at all.

Transparency and Reproducibility	**Evaluation**				
Criteria	**SALCA-SQ**	**RISE**	**MASC**	**LCA-SOIL**	**EPIC**
Is the method (calculation process) comprehensible/accessible for external clients?	7	3	5	8	9
Comparability between farms and comparability of a farm over time	10	8	4	7	8
Susceptibility to error/Uncertainty of data input (admin staff)	8	5	3	7	5
Total	25	16	16	25	20

13.5.4 Applicability: Communicability and Practicability

Here, both feasibility (Are the data accessible for potential model-users? How much time and effort is involved in data collection? Is the program user-friendly?) and communicability (How easily can the results be communicated to third parties? How are the results presented? Can the results be interpreted easily?) are evaluated.

Communicability

This aspect attempts to evaluate whether the results can be communicated to the farm managers as well as interested stakeholders with reasonable effort and expense. This also includes e.g. the option of presenting the results in aggregated form, or whether said results form a basis for certification.

SALCA-SQ

Interpreting the direct indicators calculated in SALCA-SQ requires in-depth familiarisation with the model structure. It is advantageous that – as shown in Marbot (2012) – two 'abstract' indicators can be created for communication purposes: (i) a 'carbon' indicator (from the indicators containing the humus balance as an impact category) and (ii) a 'mechanical load' indicator (containing the two indicators 'earthworm biomass' and 'coarse-pore volume). A simple graphic representation of the results is not implemented.

RISE

Normalisation on a scale of 0 to 100 as well as visualisation of the results in a sustainability polygon means that said results are grasped quickly, even by stakeholders without any in-depth experience in sustainability matters (Grenz *et al.* 2012a). The results of RISE and possible measures for improving soil quality are usually communicated to the farm manager in a feedback discussion. For contracts – e.g. those awarded to public authorities or industrial enterprises – it is mostly farm groups that are evaluated (Grenz *et al.* 2012a), with the utmost care being taken not to disclose the identity of any individual farms during presentation of the results.

MASC

The decision tree in MASC generates a single assessment of the overall sustainability of a farm. Thanks to the simple tree representation (with details on the weightings), the results are easy to understand. By contrast, the calculation of the individual indicators – often also of a qualitative nature – is virtually impossible to grasp. Furthermore, communicability for third parties tends to be complicated by the free choice of the weightings, but offers farm managers the chance to set their own priorities.

LCA-SOIL

The results of the individual models necessary for the assessment of soil quality require expert knowledge, and are therefore difficult for farm managers and people who know little about soil quality to interpret.

EPIC

Although the dynamic model EPIC is available as open source in the programming language Fortran, including a detailed manual, the familiarisation time and the sheer volume of necessary input parameters substantially complicate practical application. Communicability of the results is associated with considerable time and effort, and requires a high degree of expert knowledge and understanding of the model.

User Friendliness

Here, it is mainly the way that data is entered as well as the user-friendliness of the model environment for practical work that is assessed, provided that details on this were available.

SALCA-SQ

Because of the missing graphical tools (input masks with drop-down menu via Web interface), the creation of the input file in Microsoft Excel® for SALCA-SQ is associated with relatively high time and effort. Depending on the complexity of the farm, the time involved in the collection of the basic data ranges from one to four hours. SALCA-SQ is Excel-based, and requires a thorough introduction before it can be used independently.

RISE

Except in the case of very complex farms, data collection on the farm takes up to three hours for a trained adviser. Information on climate, hydrology and soil can be gleaned from various databases, the FAO, and national statistics (Grenz *et al.* 2012a).

MASC

The input data must be made available to the software in an Excel file that is only available in French. A disadvantage is that there is no summary of the permitted versions of the input parameters. MASC is based on the DEXi program, an interactive tool for the development of hierarchical trees (Bohanec 2008).

LCA-SOIL

The input variables to be collected must be recorded in an Excel file. There are no input tools. Missing data – particularly detailed information on management methods – is most easily collected in a personal interview with the farm manager (E. Garrigues, 2015, pers. communication). Due to the model structure (individual models for erosion, soil compaction and humus content), practical application is challenging, since there is no automated process chain. The model for soil compaction (COMPSOIL) is implemented in Microsoft Excel®. It allows a graphic representation of the results, and is also suitable for non-experts. However, since it is only the density profile in the soil that is determined per vehicle wheel in the model, and given that a linkage with coarse-pore volume and aggregate stability can only be determined via a subsequent assessment, the model is of limited practicality only. A disadvantage is that the code of the erosion model (RUSLE2) is not available (Garrigues 2015, pers. communication).

EPIC

It is likely to be advantageous that a graphic interface is available for provision of the input data. The high number of detailed input parameters strongly limits the scope of application of the model for practical studies, however, since provision of the necessary data must be expected to require considerable time and effort.

Geographical Scope

For certain applications, it is important that the model can be used in countries located in different climate zones.

SALCA-SQ

This model was developed first and foremost for central European farms, but with a certain investment of time and effort can be adapted for use in other regions.

RISE

This model is designed for the worldwide assessment of farms. RISE has already been used on over 2000 farms in over 50 countries, not only in Europe but also in equatorial areas of Africa and Central America in particular.

MASC

The two attributes of erosion and soil compaction are qualitatively assessed by experts, and are therefore not tied to a specific region. The INDIGO method (Bockstaller *et al.* 1997; Bockstaller and Girardin 2003), which serves to determine organic-matter content, requires knowledge of the input of organic matter through fertilisers and plant residues (plus in addition the recommended quantity of C_{org}).

LCA-SOIL

The model chain permits worldwide application, provided that the numerous input parameters are available.

EPIC

With EPIC, there is (theoretically) no geographic restriction to use. Because of the numerous input parameters, however, the use of the model is actually very limited. In particular, it would most likely be difficult to determine the soil quality of a large number of farms.

Simplifications

If the model is to be used on a large number of farms, it is important to study whether the soil model can be simplified with reasonable effort and expense.

SALCA-SQ

Marbot (2012) shows that for the SALCA-SQ model, the strong correlation of the two microbial indicators (microbial biomass and microbial activity) means that they can be aggregated into a single indicator. This simplification does not lead to a reduction in the quantity of input data, however. If the use of machine data must be forgone owing to a lack of data, the data of standard machines can be used, although this makes it impossible to evaluate machinery that is easy on the soil, or the (desired!) interference of the farmer.

RISE

No studies exist on the possibility of simplifying the results of RISE. The highest aggregation level is represented by the sustainability polygon, which presents sustainability as the result of ten indicators (energy & climate, water use, nutrient flows, land use, etc.). A further aggregation is not foreseen.

MASC

There is no literature on how the four attributes for assessing soil quality can be simplified. Owing to the low complexity of the attributes, however, such a step would not appear to be strictly necessary.

LCA-SOIL

No simplifications of the three models used can be found in the literature. Sensitivity studies do, however, point to which factors could be ignored with no great loss of accuracy, with e.g. Renard and Ferreira (1993) mentioning in their paper that the RUSLE Erosion reacts much more sensitively to slope gradient than to slope length.

EPIC

With the help of a large number of parameterisations, the dynamic model EPIC captures the processes in and on the soil with great precision (cf. e.g. Izaurralde *et al.* 2006). Simplifying the parameterisations of the model would most likely be difficult, since these require extensive datasets for validation as well as sensitivity studies.

Table 64: Communicability and practicability of the models. The assessment is based on a personal assessment of the main author's. A maximum 10 points are awarded where conditions are ideally fulfilled; '0 points' indicates a massive deficit, i.e. the process or aspect is scarcely taken into account, if at all.

Communicability and Practicability	Assessment				
Criteria	SALCA-SQ	RISE	MASC	LCA-SOIL	EPIC
Communicability of the results (farm managers and public)	7	9	5	4	3
User-friendliness (farm managers/extension staff/experts)	4	9	5	3	3
Geographical scope of application	4	10	8	8	8
Are simplifications possible?	8	5	4	3	2
Total	23	32	22	18	16

13.6 Recommendation

SALCA-SQ possesses the highest degree of detail (completeness) in the description of soil quality. This assertion is also supported by Garrigues *et al.* (2012). Moreover, this model attempts to pick up on the LCA concept. A disadvantage of SALCA is its strong Swiss link; furthermore, it does not take account of indirect influences of agricultural land outside of the farmer's own land (e.g. forage production on another farm). This issue is only taken into account in a limited manner – if at all – in the other models, however. The strong Swiss connection is not a drawback, provided that only Swiss farms are being assessed. The high sensitivity of SALCA-SQ to type of management is advantageous, since this can be influenced by the farm managers. The high degree of detail of the input variables is likely to be critical for practical applications, especially as regards the machinery used. It is a plus that where underlying data is lacking, the model is able to work with default values.

The RISE model scores the highest in terms of communicability and practicability, and is suitable for a quick assessment of the overall sustainability of farms worldwide. There are scarcely any studies on the assessment of uncertainties, however, nor is a precise description of the indicators available. Furthermore, an interview on the farm is absolutely necessary, the quality of which will probably also be dependent on the knowledge and experience of the interviewer. This model is therefore only suitable to a limited extent for assessing the soil quality of a large number of farms. For certain subaspects concerning the specification of indicators as well as implementation (data flow, programming), however, RISE can be of great use.

LCA-SOIL's good rating in the two areas of 'robustness and uncertainties' and 'transparency and reproducibility' is due to the fact that the three models used in LCA-SOIL have been properly described and validated, as well as used in numerous studies. A negative in terms of completeness is the fact that the influence of pesticides is not taken into consideration.

MASC scores by far the worst in the evaluation. This is due on the one hand to the oversimplification of the complex processes in the soil (often only qualitatively described), and on the other to a lack of studies on transparency and uncertainty, e.g. in the form of sensitivity studies. Moreover, with MASC the focus is on the generation of decision trees based on the DEXi methodology, which permits an aggregation of many different qualitative attributes.

Although the dynamic model EPIC is too complex for wide application, it does parameterise various processes in great detail. Where sufficient data is available, parts of the model can be used for an improved understanding of the processes in other models, in order e.g. to significantly improve the quality of the results for humus content. Furthermore, it should be mentioned that the main field of application of EPIC does not lie in the change in soil quality owing to the farmer's management approach, but rather in the precise formulation of the overall water budget, erosion, and the development of biomass.

Table 65: Summary of the overall assessment of the five different models analysed. The assessments can be found in Table 61 to Table 64.

Criteria	**Assessment**				
	SALCA-SQ	**RISE**	**MASC**	**LCA-SOIL**	**EPIC**
Completeness	57	45	36	51	56
Robustness and Uncertainties	23	8	14	25	23
Transparency and Reproducibility	25	16	16	25	20
Communicability and Practicability	23	32	22	18	16
Total	128	101	88	119	115

13.7 Conclusions

The comprehensive assessment of soil quality is extremely difficult, and can be incomplete owing to the complex interrelationships of the physical, chemical and biological processes (some of which are still the subject of research projects), as well as the high spatial and temporal variability of soil quality and the wide range of management methods. None of the models investigated exhibits peak values in all of the evaluated subaspects; the summary in the above table shows the three models SALCA-SQ, LCA-SOIL and EPIC as having fairly similar values.

The evaluation has, however shown that for our purposes, SALCA-SQ is the most suitable model, scoring particularly well in terms of completeness and the desired sensitivity to management measures. For the time being, automatic data collection, intended to ensure the scalability of the model (use on a great many farms with reasonable effort and expense), remains problematic.

In conclusion, it remains to be said that up until now there has been no globally applicable methodology that comprehensively evaluates soil quality with reasonable effort and expense (especially in terms of data collection) whilst also systematically taking into account agricultural soils outside of the area of the farm studied. In future, through a clever combination of the various models – together with intensive measuring campaigns for the validation of the models and a better understanding of the process – significant improvements are highly likely to be achieved. In this context, cooperation between the research institutions is of crucial importance, together with a disclosure of the precise calculation methodology.

14 Aggregation

Andreas Roesch

14.1 Introduction

Agricultural practice generally dispenses with a highly compressed aggregation of the indicators. Here (e.g. in both the RISE and SMART models), a spider web or radar chart is frequently used to represent the individual impacts. This representation prevents interesting information on the individual components of sustainability from getting lost (Meul *et al.* 2008).

For policy, with its need for quick, easily grasped information, or for trade, e.g. for labels or certifications, however, an aggregation of the indicators can yield benefits. Consequently, it is crucially important that we take a closer look at ways of presenting the indicators, or even all three dimensions of sustainability, in compressed form.

According to OECD (2008a), aggregated indicators are constructed in the following ten steps:

(1) Development of the theoretical framework

(2) Selection of indicators

(3) Multivariate data analysis

(4) Estimation of missing values

(5) Transformation and normalisation of the data

(6) Weighting and aggregation

(7) Robustness analysis

(8) Refinement at indicator level

(9) Correlations with other indicators

(10) Presentation and spread.

This chapter limits itself exclusively to the discussion of steps 5 and 6. After some general remarks on normalisation and weighting, a number of methods that are suitable for the compression of the key figures in one dimension of sustainability are presented. After this, several methods for the overall aggregation of all three dimensions of sustainability (social, economic and environmental) are discussed.

14.2 Normalisation

Indicators with different scales and/or units of mass must be normalised before they are aggregated, in order to allow for comparison of the individual values of the indicators. A previous (e.g. logarithmic) transformation of the original data may possibly help, for instance, to lessen the influence of outliers, or to reduce an unwanted skew in the data.

Various methods are available for normalising indicators. A (non-exhaustive) list of the processes is listed below:

- Rank: Ranking is the simplest form of normalisation. The advantage of this method lies in its simplicity and freedom from outliers, whilst the drawback consists in the fact that only the rankings can be compared, since the ranking process causes the loss of the absolute values.
- Standardisation (z-scores): Transformation of the values to a uniform scale with a mean of 0 and a standard deviation of 1. This method avoids a distortion of the mean, but is prone to extreme values.
- Min./Max. normalisation: By means of a normalisation through subtracting the minimum value, then dividing by the range (maximum–minimum), it is ensured that all values lie in the interval [0,1]. The disadvantage of this method lies in the dependence on the minimum and maximum value, which are strongly influenced by the sample size, as well as being subject to annual fluctuations. The scale is therefore not robust.
- Distance to a reference value (‘Distance to target’): Measures the relative position of an indicator vis-à-vis a reference value. Here, for example, the reference value can be the target value that is to be

achieved at a particular point in time (e.g. a 50% reduction in greenhouses gases in Switzerland by 2050), or the average of another country or group of countries.

- Categorical scaling: Assigns a score to each characteristic value of an indicator. The scores can be numerical or qualitative, and are frequently based on the observed distribution (e.g. at national level). Thus, for instance, the best 10% may be assigned a score of 100 and values between the 80th and 90th percentile a score of 90, whilst characteristics between the 70th and 80th percentile receive 80 points, and so on. The problem is that a categorisation of this type causes the loss of a certain percentage of the distribution information.
- A further very simple method consists in coding values 'near' the mean with 0 and those below (above) a certain threshold with -1 (1). Because it does not discriminate sufficiently and it ignores information on the absolute distance from the mean, this method is not recommended. The model's robustness vis-à-vis outliers is seen as advantageous.

In the life cycle assessment, depending on the field of application, individual environmental impacts are normalised according to ISO 14040/44 for well documented environmental impacts such as greenhouse potential. Here, the calculated environmental impact (e.g. greenhouse potential) is divided by the total environmental impact in an area per year (e.g. the greenhouse-gas emissions in Switzerland). If we then divide by the number of inhabitants, the environmental impacts per resident and year can be expressed, and thus depicted on a common scale. However, the normalised results still reveal nothing about the significance of the various environmental impacts.

14.3 Weighting

The compression of the indicators into an overall indicator is done via the weighting. Here, there is generally no single 'proper' weighting of the indicators. The method for determining weightings depends on several factors:

- Context (priorities, value judgements)
- Intended purpose (scientific analysis, communication, benchmarking)
- Subjective preferences (statistical methods, expert advice, simplicity).

When presenting aggregated results, it is important to explain in detail how the weightings were calculated. The literature contains many examples of techniques for determining weightings. Below, we give a brief description of a selection of these:

14.3.1 Equal Weighting

Aggregated indices are frequently based on equal weighting. This means that all indicators are given the same weighting, i.e. each individual assessment has the same influence on the aggregated indicator. This method can also be used when too little information on causal relationships is available, or when a consensus cannot be reached (OECD 2008a). It is important to bear in mind that (highly) correlated variables may lead to a double-counting. This problem can be alleviated by assigning a lower weighting to correlated indicators. A selection of statistical methods for determining the weightings of correlated indicators is given in the following subchapter.

14.3.2 Statistical Methods

There are various statistical methods for determining the weightings of correlated indicators. The advantage of these methods lies in their objectivity, whilst a drawback is that the significance of the underlying indicators is not taken into account. A selection of methods is summarised below.

- Principal component analysis (PCA)/ Factor analysis (FA): PCA presents the original characteristics as weighted sums of the principal components, it only being possible to determine the weightings when certain correlations between the individual indicators exist. PCA allows a reduction in the number of dimensions, as well as an avoidance of the influence of 'overlapping' information between correlated indicators. The method was used e.g. in Mouron *et al.* (2006) to group the various impact categories in the environmental sphere ('midpoints'). The factor analysis takes into account only a limited number of principal components which, taken together, explain a sufficiently high share of the total variability. The indicator weightings are then determined from the squared factor loadings, which correspond to the percentage of total variability explained by the factor in question (OECD 2008a).

- Data envelopment analysis (DEA): DEA is a non-parametric method which has met with great popularity in (national) economic applications (Charnes *et al.* 1978). Based on linear programming, the method enables the determination of an 'efficient' limit as a benchmark, and of the relative measurement of efficiency. Here, efficiency is frequently measured via key output-to-input ratios.
- Regression analysis: Linear regression models can make statements on the relationship of a set of indicators with a single (target) variable. The drawback here is that a linear relationship is assumed, and the correlation between the independent variables ('initial variables') must be as low as possible. The relative weightings correspond to the regression coefficients calculated by the multiple linear regression.

14.3.3 Participatory Approaches

The weightings are determined by the inclusion of various stakeholders – experts, extension workers, politicians, citizens. The discussion should be as broad-based as possible; workshops and questionnaires are useful tools for reaching a good consensus.

The scientific method 'Analytical Hierarchy Process' (AHP) was developed by the mathematician Thomas L. Saaty (Saaty 1990) to support decision-making processes, and has since been used in numerous studies (De Lange *et al.* 2012; Giri and Nejadhashemi 2014; Pradeep *et al.* 2014; Saito *et al.* 2015). AHP breaks down complex decision-making processes into small units, which are then hierarchically structured and compared. This method leads to an evaluation of the 'importance' of indicators through pairwise comparisons. It is important here for the elements on a particular hierarchy level to be as independent as possible, and for the elements of the hierarchy to fully illustrate the problem.

Also recommended for determining weightings is the Budget Allocation Process (BAP), in which experts decide, based on their own experience, how much the individual indicators which are to be aggregated are 'worth' to them (Saisana and Tarantola 2002). The weightings are then determined on the basis of the average budget. This method is easily communicable; moreover, the necessary input data can be collected quickly.

14.4 Aggregation

An aggregation enables an overall indicator to be derived from the individual sub-indicators. Once the weightings of the individual indicators have been determined, the aggregated indicator can be formed using three different methods (Schnell *et al.* 2011).

14.4.1 Additive Aggregation

Additive aggregation involves the summing up of the weighted, normalised indicators. The indicators are therefore proportional to their weightings in the aggregated indicator. This is by far the most common type of aggregation (OECD 2008a). This method allows for complete compensation: indicators with a low rating can be offset by indicators with a sufficiently high rating. This is not desirable in many cases. Equal weighting is a special case of additive aggregation, where $w_1=w_2=\ldots=w_n$ applies for the weighting of the n indicators.

14.4.2 Multiplicative Aggregation

Here, the weighted, normalised indicator values are multiplicatively linked. This method is suitable when the indicators may only partially offset one another. An indicator value of 0 leads to the aggregated indicator being equal to 0, regardless of the values of the remaining indicators in question.

A common variation of this type of aggregation is geometric aggregation, which is calculated as follows:

$$\prod_{q=1}^{n} I_q^{w_q} \qquad (14)$$

where w_q= weight of the indicator I_q, with q=1,…, n. This aggregation allows for only a certain degree of compensation between the indicators. Thus, the incentive to avoid (very) low-rated indicators is greater with geometric aggregation than with additive aggregation.

14.4.3 Multicriteria Aggregation

This method is based on a system of reasoning that allows no compensation between indicators (Podinovskii 1994). Hence, the method does not permit any trade-offs between the individual criteria, i.e. low ratings of a sub-indicator *cannot* be balanced out by good ratings of another sub-indicator. The method is useful when indicators from very different dimensions must be summarised.

14.5 Aggregation of Environmental Impacts

The individual environmental impacts (expressed in midpoint indicators) can be aggregated into so-called endpoint indicators which estimate the deleterious effect on a protected natural resource (human health, ecosystem and resources quality). These are expressed e.g. in the unit 'extinct species per year', or in 'DALY' (disability-adjusted life-years lost).

The existing weighting approaches can be broken down into various groups:

- Focus on **environmental policy targets**:
  (Swiss) Ecological Scarcity Method (Frischknecht *et al.* 2008; Frischknecht and Büsser Knöpfel 2013). Here, environmental impacts are evaluated according to the ecoscarcity method, which calculates the weightings by taking the difference between the current situation and the legal provisions (policy targets). Current emissions and resource extractions are collected by means of measurement data and calculations. National and international regulations and limits can be used to determine target values. The dependence of policy targets as well as the assessment of processes taking place outside of Switzerland can be problematic in the Ecoscarcity Method; moreover, in individual cases a scientific modelling of the environmental impact mechanisms is missing for plant-protection products.
- **Damage-oriented** methods:
  ReCiPe (Goedkoop *et al.* 2009), which is based on a refinement of EcoIndicator 99 (Goedkoop and Spriensma 1999) and CML2002 (Guinée *et al.* 2002), is a damage-oriented method which converts 18 midpoint indicators into the three following endpoint indicators: (i) Damage to health (DALY), (ii) Adverse effect of damage to the ecosystem (reduction in the number of species per unit area over a specific time), and (iii) Damage to natural resources (costs).

  Also forming part of the damage-oriented methodologies are the three methods IMPACT 2002+ (Humbert *et al.* 2005), EDIP2003 (Hauschild and Potting 2005) and LIME (Itsubo and Inaba 2003), which operate primarily on the level of midpoint indicators. LIME provides an endpoint indicator for Japan which assesses potential damage for the four aspects 'human health', 'social welfare', 'biodiversity' and 'production of biomass'.

  Rockström *et al.* (2009) suggest an exciting approach for weighting environmental impacts. They define global resilience limits for nine important system processes such as climate change, loss of biodiversity, and acidification of the oceans. These global threshold values can be applied to the national level and compared with national footprints (= aggregated environmental impact and/or resource use along the production and consumption chain). In a second step, the system processes are subdivided into four categories: 'unequivocally noncritical', 'noncritical', 'critical', and 'unequivocally critical'. The four categories of climate change, acidification of the oceans, nitrogen loss, and loss of biodiversity are rated as critical or very critical on both a global and Swiss level. This classification can be used to weight the processes, with critical processes being weighted more heavily than noncritical ones.
- **Monetarisation approach**: Some methods calculate potential damage in the form of expected costs. The EPS 2000 method (Steen 1999) is based on damage indicators which use the 'willingness to pay' approach K to convert all costs into a monetary unit. Since all indicators are displayed in the same monetary unit, normalisation and weighting are superfluous during the aggregation process. EPS 2000 considers four protected resources as endpoints: (i) human health, (ii) ecosystem production, (iii) biodiversity, and (iv) abiotic resources. The ReCiPe method also enables damage to natural resources to be converted into costs.

Although endpoint applications can be found in the scientific literature, they are particularly favoured when for methodological reasons there is a focus on the concept of environment, as is the case in studies of an interdisciplinary nature (sustainability assessment, environmental sociology).

14.6 Aggregation of Economic Key Figures

The use of key figures entails certain challenges. A sufficiently similar reference group should be used for the comparison or assessment of the key figures of a farm (Annen 2003). On the one hand, this refers to the location of a business and its natural and economic framework conditions (Zapf *et al.* 2009b); on the other hand, farm type and structure, which can strongly influence the key figures, should also be taken into account. Moreover, because of the large fluctuations in agricultural production and producer prices, multi-year averages should be used as a basis for comparison (Breitschuh and Eckert 2008). Various assessment approaches define threshold values for individual parameters (e.g. the 'tolerance threshold' for CSSA ('Criteria System for Sustainable Agriculture') or indicators (e.g. the 'problematic range' in RISE). Because of the diverse influencing factors (e.g. location, farm type and size, form of ownership), this is deemed problematic – *inter alia* on account of personal demands on factor remuneration, which is hard to assess objectively (Zapf *et al.* 2009b).

The first step towards the aggregation of key economic figures consists in the normalisation of said figures, frequently on a scale of 0 to 100 (Dolman *et al.* 2012; Grenz *et al.* 2012a). Here a linear interpolation is usually chosen between the minimum (I_{min}) and maximum (I_{max}) value. The lower limit I_{min} can, for example, be set to the value of the 10th percentile, whilst I_{max} can be set to the 90th percentile value (Dolman *et al.* 2012). A value of 100 is thus assigned to the best 10% of farms, whilst the lowest 10% of farms would receive a value of 0 (Formula 15):

$$Score = 100 \cdot \frac{I - I_{min}}{I_{max} - I_{min}}, \qquad 15$$

where *I* corresponds to the value of the observed indicator. In order to form a sufficiently similar reference group, as mentioned at the outset, it makes sense here to compute the appropriate percentiles on the basis of the group of farms of the same type in the same region.
Owing to missing analyses, it makes sense to weight the three factors profitability, stability and liquidity equally (see Chapter 7.4). Since the said three factors are illustrated by two business indicators apiece, the following weightings can be suggested when equal weighting is imputed (Table 66). It is, however, important to note that an equal weighting is not recommended. For both profitability indicators, Chapter 7 refers to the high importance of payment for work compared to the remuneration of capital. It is therefore reasonable to assign a significantly higher weighting to earned income than to total return on capital.

Table 66: Weightings for overall aggregation of the economic dimension of sustainability where an equal weighting is imputed (not recommended). The six key figures are described in Chapter 7.4

Key Figure	Weighting
Earned income	1/6
Total return on capital	1/6
Gearing	1/6
Investment intensity	1/6
Investment coverage	1/6
Liquidity	1/6

Since certain correlations exist between the six key figures listed in Table 66, the methods mentioned in Chapter 14.3 are suitable for excluding double countings.
Further detailed analyses and clarifications concerning acceptance are to be carried out before the weighting method is used in practice.

14.7 Aggregation of Social Indicators

Various methods are suitable for the aggregation of social indicators. OECD (2008a) emphasises that an aggregated ('composite') indicator can only be meaningfully interpreted when calculations are based on a sound theoretical concept. This concept can be read about in Chapter 3.4 for the social pillar of sustainability, and is based on the OECD Well-being Framework.

Prior to being aggregated the sub-indicators must be normalised, since they are often based on different units. The OECD (2008a) lists numerous normalisation methods, only a few of which are suitable for nominal and ordinal variables – most social indicators are categorical variables. For nominal characteristics, the individual forms must first be recoded, with e.g. the expressions 'very satisfied', 'fairly satisfied', 'uncertain', 'fairly dissatisfied' and 'very dissatisfied' being converted to -3, -1.5, 0, 1.5 and 3, respectively.

The following two normalisation approaches are especially well suited for social indicators (see also the overview in Chapter 14.2):

- Distance to a reference value: The national average could, for example, serve as a reference value for the question "How much money (in CHF) did your household pay into/invest in a pension plan last year?" A further possibility is to rely on so-called performance reference values for the generation of reference values (see overview of the social indicators in Chapter 3.4).
- Categorical scale.

After the normalisation, the sub-indicators can be aggregated into an aggregate indicator by a weighting. Here too, various methods are available for social indicators. In practice, it is frequently assumed that all sub-indicators contribute equally to the overall index, and are therefore given the same weighting. If – as explained in Chapter 3.4 for the OECD Well-being Framework – the social component of sustainability is divided into several dimensions, it is reasonable to assign the same weight to each dimension. If the same weightings are assigned to the individual variables, then a different number of variables per dimension results in an uneven weighting (OECD 2008a).

In the RISE model, the individual indicators are only aggregated up to the level of the sustainability polygon (Grenz *et al.* 2012a); an aggregation of the two social indicators 'quality of life' and 'work conditions', for example, is therefore not carried out. The 'quality of life' indicator is determined by a weighted sum of the associated parameters (such as e.g. social relationships, health, profession and training). At the same time the weighting is performed, the information as to how satisfied the person is with the relevant area of life is included in each case (Grenz *et al.* 2012a). The concrete suggestion for aggregation of the social criteria outlined below also refers to the fact that the statement on importance for all criteria represents a very good tool for assessing the weightings.

As in RISE, the SMART model (Jawtusch *et al.* 2013; Schader *et al.* 2014) also dispenses with the aggregation of the subtopics (e.g. quality of life, competence creation, fair access to the means of production, child labour) for the 'social welfare' dimension.

It should be noted that the weighting process always includes a subjective component, regardless of whether the weightings are based on statistical methods or on the opinion of experts.

From the above-mentioned remarks, as well as from the recommendation of Jean-Michel Couture from the AGÉCO Group (http://www.groupeageco.ca/), the following approach for determining the weighting is proposed for the social indicators introduced in Chapter 3.4; the names here refer to the names of the indicators in Table 4–Table 29 in Chapter 3.4:

- Assignment of each indicator to the most important stakeholder (farm manager/family, employees, consumers, business partners, local community). Exceptions from this are the two OECD well-being categories 'state of health' and 'personal safety', since these are of equal importance for the farm manager and employees.
- Formation of partially aggregated indicators for all combinations of well-being dimension and stakeholder. The sum of the weightings of the indicators which contribute to a partially aggregated indicator must in each case be equal to 1. Moreover, it is recommended that indicators at the end of the results chain ('outcome and impact') be weighted more heavily than those at the beginning of the results chain. FW2 (Table 5) and FW3 (Table 6) can be used as an example: both indicators belong to the

dimension ‘financial matters and work conditions’ and to the stakeholder ‘employees’. Since FW2 lies to the right of FW3 on the results chain, FW2 is assigned a higher weighting, i.e. e.g. w_{FW2}=0.6 and w_{FW3}=0.4.

- Weighting of the individual well-being dimensions for the stakeholder ‘farm manager/family’ according to their importance (if determined); equal weighting is proposed for the employees. The sum of the weightings per stakeholder must be equal to 1.
- The farm manager’s family is to be assigned the highest weighting, closely followed by the employees. The two stakeholder categories ‘consumers’ and ‘business partners’ are significantly underweighted, since they are captured with just one indicator each.

The ideal solution would be to determine the importance of each individual criterium as well, and to calculate the aggregated indicator of social sustainability via the sum of the (normalised) sub-indicators weighted with this importance. This, however, would call for considerable additional effort and expense in the gathering of the extra information.

14.8 Aggregation at the Level of Overall Sustainability

In general, an aggregation of all three dimensions of sustainability is not recommended. Nevertheless, for certain applications it may make sense to carry out an overall aggregation across all three sustainability dimensions.

The simplest way of aggregating the three indicators of the social, economic and environmental pillars of sustainability is an equal weighting, through which the same importance is assigned to all three dimensions. This method, however, is not advisable, since a very poor rating of social sustainability can be offset by a very high rating of ecological sustainability. Moreover, it is hardly sustainable over the long term to offset a farm’s unsatisfactory financial situation with a very low rating for environmental pollution.

Mann and Gazzarin (2004) propose normalising the social, economic and ecological indicators to the value range [0,100], then multiplying the three values thereby determined and applying the logarithm to the result. This will, *inter alia*, prevent a farm in an absolutely unsatisfactory financial situation from achieving a satisfactory or even good rating of overall sustainability owing to very high scores in the social and environmental categories.

Zahm *et al.* (2008) propose using the lowest value in each case of the three (social, economic and ecological) dimensions to assess overall sustainability. This rules out compensation possibilities between the three dimensions of sustainability (‘strong sustainability’, see below).

Participatory methods are generally highly suitable for estimating the importance of (and hence a weighting for) the three pillars of sustainability. The necessary bases for a decision can be developed in the form of expert workshops, or else collected via surveys of the population or affected stakeholders.

Hierarchical decision trees with decision-making rules for the aggregation can be used in particular to aggregate quantitative and qualitative indicators, with e.g. Mouron *et al.* (2012) using a multi-criteria decision tree to derive an aggregated assessment of the environmental and economic sustainability of an apple plantation.

The methods for forming an overall indicator of sustainability can be assigned to either ‘weak’ or ‘strong’ sustainability (Gutés 1996; Ayres *et al.* 1998; Perman 2003). With strong sustainability, no compensation is permitted between the three dimensions of sustainability, whilst with weak sustainability, substitutions remain possible. Thus, the concept of weak sustainability allows for higher greenhouse gas emissions to be offset (substituted) by the farm’s improved financial situation. The equal weighting of the three dimensions is a typical process that can be assigned to weak sustainability. The method applied in IDEA (Zahm *et al.* 2008) is a classic representative of strong sustainability.

In conclusion, it should be noted that even with the aggregation of the three environmental, economic and social indicators into an overall indicator, there is always a subjective component involved.

15 Discussion and Synthesis

Andreas Roesch

The present study was carried out with the primary aim of developing a scientific assessment of overall sustainability at farm level. All three dimensions of sustainability have been taken into account. In particular, this means that none of the three dimensions of sustainability may be disregarded in the analysis, i.e. the indicator set should as far as possible cover all aspects of sustainability, including socioeconomic topics as well as the assessment of landscape aesthetics and soil quality.

The indicators may be subdivided into three groups: The indicators on level 1 are widely supported and accepted, and have already been used in numerous studies; for indicators on level 2, despite the existence of key figures, a sound concept or explicitly Swiss context is largely lacking; and with level 3, approaches for feasible implementation are largely lacking, or fail to satisfy scientific requirements. The determination of the environmental impacts on the basis of life cycle assessments has been examined in detail, and used in numerous studies (level 1), whilst methods for assessing the social situation of farms are in many cases specially suited to countries with low social standards, i.e. developing countries with high criminality and poor working conditions (level 2). In addition, a clear-cut concept that permits e.g. conclusions to be drawn regarding the completeness of the chosen indicator set is frequently lacking, especially for the social and economic dimensions of sustainability. Often, it remains unclear just which questions can and are meant to be answered with the indicators. Where the conceptual framework is missing, it is almost impossible to carry out a (partial) aggregation. The assessment of the visual quality of the landscape must also be assigned to this intermediate category, since a number of questions on the definition of different aggregation types remain to be clarified. Animal welfare is assigned to the lowest level (level 3), since no real-world assessment method is yet available. Owing to these differences in specific knowledge in the individual subject areas, it is obvious that the results developed in the project will also differ significantly. Thus, with the exception of aquatic ecotoxicity, no new models were developed or existing methods modified for the ecological pillar of sustainability; instead, the current state of research was assessed and recommendations were derived (see Chapters 8, 9 and 10). An extensive model comparison was conducted and a recommendation drafted regarding the impacts of agriculture on biodiversity (Chapter 12) and soil quality (Chapter 13). Since total pesticides used have heretofore been considered an emission into the soil, an evaluation of new, more-detailed models for the life cycle inventory (PestLCI) and life cycle impact assessment (USETox), which also take account of other avenues of application, was carried out for aquatic ecotoxicity. Various sensitivity tests were conducted to determine the suitability of these models (Chapter 11). The analyses show that these two models allow for a significantly more realistic modelling of the environmental impact of pesticides, even if not all questions of detail have yet been clarified, and the results obtained must be critically interpreted.

Unlike in the environmental dimension, a great deal of conceptual work had to be done in the social dimension, since research does not yet make many assessment tools available for (sufficiently) impact-oriented, preferably quantitative and easily measurable indicators. In addition, the indicators must be relevant in the context of the Swiss agricultural sector. The analysis showed that the OECD Well-being Framework was particularly well suited for the description of the social components, since (i) its definition is based on the Capability Concept (Sen 1999), and thus picks up on an important aspect of current sustainability research; (ii) both tangible and intangible conditions are taken into consideration; and (iii) both objective and subjective components are included (see Chapter 3.3). In the course of the analysis of existing assessment tools for the social sphere, it became clear that a considerable part of the indicators were either not very well suited for use in the Swiss agricultural context, or else related mainly to the sectoral level. For this reason, and building on existing assessment tools, a suitable set of indicators was developed which illustrated the various dimensions of the OECD Well-being Framework as completely as possible, whilst including the most important internal and external stakeholders (farm manager's family, employees, suppliers, consumers). With certain limitations, the set of around 25 indicators proposed in the report does a good job of covering the social sustainability of a number of important stakeholders. These limitations are not least of all due to the circumstance that, for

reasons of feasibility, the project specification stipulated collection of the necessary data from the farm managers alone.
For the assessment of workload, the quotient of calculated and actually available workforce provides a simple indicator for temporal workload. Here, the actually available workforce is determined directly from the AGIS structural data; the working-time requirement can be calculated with the 'Global Work Budget' developed by Agroscope. A validation based on 30 lowland and 30 mountain farms has highlighted initial interesting results; however, details on the degree of mechanisation as well as on the work carried out by contractors should be available for a meaningful indicator. The proposed sustainability indicator does not take either physical or mental workload into account.
The question of what contribution a farm makes to an attractive and varied landscape is pursued in Chapter 6. This aspect of social sustainability cannot be fully captured either, since only three of the nine aspects of Tveit *et al.*'s concept (2006) are used as a basis for the two sub-indicators. These are (i) diversity, (ii) naturalness, and (iii) seasons. Diversity is taken into account through the use of the diversity index (Shannon Index), naturalness through the use of preference values, and seasons through the inclusion of the seasonal change in the landscape. Thus, for example, 'disruptive elements' (e.g. greenhouses) and the spatial structure of the landscape are ignored. Since, despite the weighting, an increasing diversity leads to an increase in the Shannon index – which, according to Tveit *et al.* (2006) need not necessarily be the case – depending on the percentage of 'beautiful' landscape elements (e.g. Areas Reserved for Promoting Biodiversity), it is proposed that landscape elements with a 'below average' preference value be aggregated before the Shannon index is calculated. A similar concept is proposed for the 'diverse arable landscape' and 'diverse grassland landscape' aggregation types. A clear-cut, justifiable distinction between the three aggregation types represents a particular challenge here.
Developing an animal welfare indicator that could be collected on a large number of farms with reasonable effort and expense, and which at the same time modelled animal welfare as completely as possible, was also particularly challenging. There is a consensus that the animal welfare index should cover all 12 aspects of animal welfare (e.g. comfort when resting or freedom of movement) according to the Welfare Quality Protocols (Welfare Quality® 2009f). It soon became obvious, however, that this is not a workable method, since it would require a certain percentage of the animals to be individually and intensively observed or examined. Owing to the frequently lacking or very low correlation between simple process-based indicators (such as e.g. total mortality or antibiotics use) and animal welfare, a pragmatic approach is recommended in this study: a credit point system rewards measures that go beyond the minimum prescribed in the Swiss Animal Protection Law. The present report introduces this credit point system, using the examples of dairy cows and fattening pigs. The advantage of this method is that further animal species and/or additional measures can be included and evaluated, where necessary.
Assessing the economic situation of a farm – especially when we limit ourselves exclusively to its agricultural production – is easier than rating its social sustainability. Chapter 7 introduces a concept leading to two key operational figures each for the profitability, liquidity and stability of a farm. Here, the key figures were chosen such that both capital- and labour-intensive farms can be reasonably well characterised. Moreover, the proposed key figures allow farms with a wide variety of business activities to be adequately described in terms of their economic performance. The authors clearly point out potential problems and limitations; for example, the various key figures must be harmonised in order to allow the economic situation of different farms to be compared. In addition, differentiation issues (pension contributions, defining the limits between agricultural and non-agricultural activities) must be handled in a consistent manner. And last but not least, during data collection, data security must be strictly respected in order to ensure an optimal relationship of trust between data suppliers and data analysts.
The aggregation of sub-indicators into a single indicator is a very challenging process. For an aggregation, the key figures must first be normalised, then weighted. Although it was not possible to deal in depth with the two topics 'normalisation' and 'weighting' in this study, a few general guidelines as well as several specific approaches are outlined in Chapter 14.
For the environmental dimension, in the past, numerous midpoint and endpoint indicators were developed that allowed environmental impacts (or sub-spheres thereof) to be summarised. Whereas the midpoint approach, via the impact indicator, only describes the potential change in the state of the environment quantitatively,

endpoint approaches attempt to produce the causal links to the real changes to, and impacts on, one or more 'protected resources' (e.g. human health, ecosystem). The question as to whether endpoint indicators can sensibly be used for policy decision-making cannot be answered conclusively, since this is dependent on the question as well as on the client's wishes (Kägi *et al.* 2016). Endpoint indicators are primarily suitable for providing an initial overview or deciding which of two systems is to be given preference, whilst midpoint indicators can be used to answer specific questions. Another point in favour of an aggregation of the individual impact indicators is the fact that a weighting on the basis of socially accepted values (such as e.g. in the ReCiPe method) is in certain cases more suitable than focusing on a single impact, since this implicitly sets the weightings of all other impacts to zero. For resource usage, this study proposes the aggregation by means of the exergy method of the life cycle impact assessments of various resources (with the exception of clear-logging) discussed in Chapter 8.5.

The indicators in the social and economic spheres must also be normalised and weighted for consolidation into a single indicator. Here, normalisation can e.g. be carried out using a regional or national average. The evaluation function serves to scale the key figure to a common scale, e.g. to the interval [0, 1] or [0, 100]. The normalised key figures must then be weighted for the overall aggregation. Chapter 14 provides a number of valuable guidelines on this topic as well. Particularly when normalising key economic figures, it is important always to refer to a similar reference group (e.g. commercial milk farms in the lowland region), since the mean of an economic indicator frequently depends on the focus of the farm. For normalising the characteristic values of the list of questions formulated in Chapter 3.4 to capture the social dimension, we recommend relying on so-called 'performance reference values'. These allow the answers obtained from the survey to be assigned to a rough assessment scheme.

For the interpretation and comparison of key economic figures, normalisation of the results is essential. Particularly in the economic dimension, however, we would advise against the definition of threshold values for the interpretation. Values such as e.g. the 'tolerance threshold' defined for individual parameters in CSSA, or the 'problematic range' of indicators in RISE are likely to be critical, since they depend on many site-specific/ farm-related factors as well as on difficult-to-assess personal demands made of the factor remuneration (Zapf *et al.* 2009b).

In conclusion, it should be stressed here that this project was very helpful for pooling the well-founded knowledge of experts from Agroscope and its partners, and successfully entering the exciting field of indicator development. Here, a high awareness has been developed that precise, meaningful and reliable indicators are a crucial precondition for the comprehensive ascertainment of a farm's sustainability. This is particularly important as regards the assessment of new measures on the farms, either through improved management (work planning), adapted management of the crops, or advances in livestock breeding.

16 Conclusions and Prospects

Andreas Roesch

16.1 Conclusions

The aim of the present project was to develop a scientifically sound indicator system for the holistic assessment of sustainability at farm level. This aim was for the most part achieved, even though a number of challenges remain to be tackled in further projects. Comprehensive studies of the literature were conducted and a proposal for indicators was developed and critically evaluated on the basis of a comprehensive list of criteria for all three dimensions of sustainability. Each subchapter concludes with a recommendation, as well as conclusions which are (also) suitable for gaining a rapid overview of the situation. Consequently, this project has achieved a first important milestone in the development of an ideally quantitative and scientifically sound indicator set for the holistic assessment of the sustainability of Swiss farms.

The differing levels of expertise in the three dimensions of sustainability made it impossible to develop a ready-to-use indicator set for all components of sustainability. Whereas a large number of widely accepted and validated methods for assessing environmental impacts are available in the ecological dimension, the social dimension in particular requires that a concept allowing the drafting of scientifically substantiated indicators first be developed. Here, analyses have shown that the OECD Well-being Concept is especially well suited as a basis for capturing the social dimension. In addition, it was necessary to verify the indicators proposed in existing indicator systems (see Annexe 2) and to adapt them to Swiss conditions. Here, it was also important to formulate questions which did not just refer to the social situation of the farm manager, but which also included further stakeholders (employees, suppliers and consumers) in the assessment, thereby fulfilling an important criterion for the social life cycle assessment (SLCA). As with a life cycle assessment, an SLCA requires that social aspects in the upstream chains as well as in the downstream processes be capable of being determined as systematically as possible. Because of the project specification restricting the collection of data to the farm managers alone, however, it was not possible to fully implement the stipulations of an SLCA. Chapter 14 outlines a rough concept for normalising and weighting the individual questions, whilst recommended performance reference values are described in Chapter 3.4. Nevertheless, practical implementation will require much more detail work.

This study proposes one suitable indicator each for the two impacts ‘workload’ and ‘landscape aesthetics’, both of which are relatively easy to implement in practice. The authors of the chapter on the assessment of animal welfare make it quite clear that there is no one simple ‘animal welfare indicator’, and that even complex approaches such as the Welfare Quality® Protocols are not able to provide a comprehensive description of animal welfare. Moreover, the feasibility of the latter leaves a great deal to be desired – the method is very time-consuming, and thus ill-suited for the assessment of animal welfare on a fairly large number of farms. Consequently, a credit point system for measures going beyond the minimum requirements of the Swiss Animal Protection Law and having a positive influence on one of the twelve animal welfare aspects represents a highly promising approach. To illustrate this method, the two ethology programmes PAS and ROEL were analysed for potential positive effects in terms of the twelve animal welfare aspects for dairy cows and fattening pigs (see Chapter 5.5). The advantage of a credit point system lies in its ease of implementation; moreover, the aggregation of the individual animal welfare aspects through the adding up of the points is straightforward. Here, however, it should be pointed out that this approach may not be appropriate for adequately illustrating the problem of the weighting of the individual aspects.

For the economic dimension, the two key figures for each of the three pillars of profitability, liquidity and stability offer a workable and easily interpretable solution for describing the economic situation of farms. In addition to their practical relevance, the indicators are suitable for providing a sensible assessment of both labour- and capital-intensive farms. In addition, the proposed set of indicators allows the assessment of farms with a wide range of specialisations, as well as the inclusion (at least as far as possible) of the long-term components.

In summary, it may be noted that the aims of the project were largely achieved. It is important that useful follow-up projects be launched in the near future, in order to avoid losing momentum in the addressing of as-yet-unsolved research issues.

16.2 Recommendation

The indicators developed within the scope of this study form a solid foundation for further research projects concerning the holistic assessment of sustainability in agriculture. It is therefore recommended that the findings obtained in this study be borne in mind in the further preparation of a comprehensive sustainability assessment. All of the working groups taking part in the project stress that its practical implementation must be planned carefully and monitored critically. In this context, it is important to conduct several test phases with the active participation of various stakeholders, and with feedback discussions with the farm manager.

Since the method developed here sets other priorities than the two methods SMART and RISE, it is reasonable to combine the different tools in a type of “tool box”. This allows to choose the appropriate tool for the respective issue or target group.

The authors of the chapter on well-being stress that interviewing the farm manager alone is likely to be problematic, since this does not take sufficient account of the great importance of the subjective well-being of various other stakeholders. It is therefore suggested that further internal and external stakeholders be interviewed on (at minimum) a selection of farms.

The calculation of the indicator for workload by means of the quotient of the required (calculated) and available workforce is recommended in principle. Incomplete details on the work carried out by contractors and on the degree of mechanisation should be viewed in a critical light.

Owing to the complex interactions and multidimensionality involved, animal welfare cannot be defined by a simple indicator. The analyses conducted as part of this project clearly show that, owing to their significant data and time requirements, Welfare Quality® protocols are not a feasible solution for determining animal welfare on a large number of farms. Following an analysis of the available assessment tools, implementation of the pragmatic approach of a scoring system is recommended. In this system, points are awarded for measures that go beyond the legal minimum of the Swiss Animal Protection Law in terms of the twelve animal welfare principles. The positive impact on theses aspects of animal welfare should ideally have been documented by scientific studies.

For the assessment of visual quality of the landscape, we propose on the one hand using the area-weighted preference value and on the other determining diversity by means of the Shannon index, with the areas of the individual landscape elements being weighted with the average preference value in question. The influence of the seasonal change in the crops and ARPB on the aesthetics can be determined by adding up the temporal changes in preference values over the period of March to October.

For the economic dimension of sustainability six key figures are proposed – two each in the three spheres of profitability, liquidity and stability. In addition to technical support in the implementation phase, the authors recommend that the calculation of the key figures be based on a farm financial statement in accordance with accounting law, and correspond to the AGRO-TWIN accounting framework ‘KMU-Landwirtschaft’ (=‘SME Agriculture’). Moreover, the reader is advised that the assessed farms should possess a critical lower limit of family workforce numbers, and that a harmonisation of agricultural income and further key figures for a meaningful comparison of different farms is urgently necessary to ensure significant results.

The analysis of the environmental impacts was deliberately kept short in this study, and is primarily limited to minor adaptations and modifications, with the exception of ecotoxicity. For aquatic ecotoxicity, we recommend carrying out the life cycle impact assessment with the USETox method, which is based on a broad consensus of a wide variety of experts and follows internationally recognised principles. For the prior necessity of the modelling of the life cycle inventory, i.e. the distribution of the pesticides in the various environmental compartments, the Pest LCI model is proposed.

For the assessment of total resource efficiency, the use of the variable ‘exergy’ is encouraged, since the latter permits the assessment of various resources such as renewable and non-renewable energy sources, water, land and metals by means of a common variable. For the impact of greenhouse gases on climate, the authors of the study propose the continued use of the widely accepted midpoint indicator ‘greenhouse gas potential’ according to the IPCC, whilst the inclusion of one of the two categories ‘acidification potential’ and ‘terrestrial eutrophication’ in the overall assessment is sufficient for both of these nutrient-related environmental impacts. This is due to the high correlation between acidification and eutrophication, both of which are dominated by the ammonia emissions.

For the two fields of biodiversity and soil quality, and based on a comprehensive model comparison, the use of the following two models is recommended: the IP-SUISSE credit point system developed by the Swiss Ornithological Institute for the assessment of biodiversity, and the SALCA method for the assessment of the impact of agricultural activity on soil quality. It is important to point out that this choice is only valid under the terms of this project (such as e.g. practical relevance, Swiss context).
In conclusion, we would once again draw attention here to the great importance of critically monitoring practical implementation by means of carefully planned test phases and the broad-based acceptance of various involved and interested stakeholders.

16.3 Need for Research

The present study represents an important milestone in the development of a scientifically substantiated indicator set for the holistic assessment of the sustainability of farms. The relatively short project runtime of one year did not allow us to analyse and process all of the important components necessary for the creation of a practicable indicator system. The following section discusses a number of generally valid aspects for which there is still a fairly great need for research. We then turn our attention to specific challenges, each of which can be assigned to a subcomponent of sustainability.
Aggregation: For a (partial) aggregation of indicators, the limited remarks on normalisation and weighting must be developed further. Here, determining reasonable threshold and reference values is particularly challenging. For the weighting of the individual sustainability indicators, there remains a need for innovative ideas which meet with wide acceptance in the research, policy and economic spheres.
Practical Implementation: There is a great requirement for research geared to optimising practical implementation; this applies in particular to both data acquisition and data flow. The practical feasibility of the method can only be verified and improved with intensively supported test phases. Before and during these phases, it is important to closely involve the various stakeholders in the entire process. Here, the participatory approach is a necessary requirement for high acceptance of the sustainability assessment.
Environment: Various environmental impacts are dependent on the region. Thus, with the resources of water and land, it is obvious that regional differences in quality and availability must be taken into account. Acidification depends strongly on soil lime content, or on the pH of the water; the nutrient load in the region influences the eutrophication potential. However, it is also important to include region-specific peculiarities for the two fields of biodiversity and soil quality. Additional research efforts are necessary for the further development and operationalisation of the life cycle assessment methodology into a life cycle impact assessment of ecotoxicity. Admittedly, the present study pointed out the essential suitability of the combined use of the PestLCI model (for determining life cycle inventory) and the USETox model (for the life cycle impact assessment); nevertheless, to allow for operationalised application, several questions of detail remain to be clarified and the underlying data must be supplemented. The life cycle approach, i.e. the consideration of the impacts of the upstream chains and the downstream processes, has not been implemented to date for biodiversity and soil quality: both models only consider land belonging to the farm. Consequently, the influence of e.g. purchased concentrates (at the site of production) on biodiversity and soil quality is still not taken into account.
Social Aspects: In the social dimension, the greatest need for research consists in the normalisation of the key figures by means of reference values, as well as in a widely accepted weighting of the individual sub-indicators that is as objective as possible. For the indicator ‘workload’, there is a need to clarify what information on mechanisation is necessary in order to achieve appropriate precision. For the differentiation of the Shannon index for determining landscape aesthetics, it is important to develop a scientifically substantiated method that classifies farms into the three proposed groups (i) ‘beautiful agricultural landscape’, (ii) ‘diverse arable landscape’, and (iii) ‘diverse grassland landscape’. There are many issues that remain unanswered, preventing the complete development of an animal welfare indicator. Although the suggestion of a credit point system outlined in the study is promising, we are merely dealing here with a list of recommended parameters for dairy cows and fattening pigs that go beyond the minimum prescribed in the Swiss Animal Protection Law. To enable the wide-scale use of an animal welfare indicator, additional animal species and husbandry systems must be included in the assessment catalogue. The authors particularly stress that validation of the results is absolutely necessary, and that this can only be achieved with complex and time-consuming observations at individual

animal level. In addition, the concept that there is still a great need for further research into the two animal welfare aspects of a good human/animal relationship and the positive emotional state of the animal has been ignored, since no practicable methods are currently available for carrying out said research.

Economics: Except for the missing information on aggregation mentioned at the outset of this paper, economic sustainability can be assessed with the information given in Chapter 7. Greater efforts are only needed here if the sustainability assessment is to be extended from farm level to individual products or farm activities. Such an assessment calls for a full-cost accounting for the allocation of overheads (e.g. labour and machines).

Trade-offs: Since data collection and practical implementation did not form part of this study, it was not possible to investigate interactions between the sustainability dimensions and trade-offs. Nevertheless, the analysis of interdependencies and possible trade-offs is of the greatest importance for the provision of advice to farms, especially when concrete measures are to be implemented, or business decisions are in the offing.

In conclusion, it should be noted here that there is still substantial need for research into an improved consideration of the LCA concept. In addition, the various indicators must be adapted at regular intervals when this becomes necessary owing to new developments and findings. It should be mentioned here just in passing (since it was not the subject of this study) that a great many unresolved questions remain to be clarified before the indicators could be used at product or farm-activity level.

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18 Annexe

Annexe 1 Members of the Project Team, (Senior) Project Management, Monitoring Group, and Further Consulted Experts

Project Team

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Annexe 2 Overview of the Sustainability Assessment Tools

Table A. 1: Sustainability evaluation instrument according to Agéco (2015).

Tools	Description	Availability	Specific	Objective	Quantitative	Comments
ARBRE (Arbre de l'exploitation Agricole Durable)	Overall diagnosis of sustainability of a farm to assess projects of individual or collective farms	X	-	-	-	
EDAMA	Assess the sustainability of the activities of agricultural households systems to support installation projects in agriculture	✓	X	-	-	Explicitly based on IDEA and RAD. Tool for supporting dialogue and learning; not an assessment tool per se.
IDEA (Indicateurs de Durabilité de l'Exploitation)	Diagnostic tool that incorporates 3 scales (agro-ecological, socio-territorial and economic) to assess, using quantitative indicators, strengths and weaknesses of the production system, and identify areas for improvement to durability	✓	✓	✓	✓	
RAD (Réseau de l'Agriculture durable)	This is an evaluation method for setting targets and monitoring the sustainability of the farm.	✓	✓	✓	✓	
Impact Measurement Framework (IGD Impact)	IGD provides a list of qualitative and quantitative indicators for some sectors including agribusiness.	✓	✓	✓	✓	

Tools	Description	Availability	Specific	Objective	Quantitative	Comments
DAESE	Agro-Environmental and Socioeconomic diagnostic of farms	X	-	-	-	
MASC (DEXi)	Decision making tool supporting the choice between options according to the fulfillment of stakeholders' expectations	✓	✓	X	-	Social goals are defined by stakeholders
EDEN	Assessing the sustainability of Breton dairy cattle systems	✓	X	-	-	Explicitly based on IDEA and RAD.
Field to market & the Sustainability Consortium	Field to Market is a diverse alliance working to identify supply chain strategies to define, measure and promote continuous improvement for agriculture. The Field to Market 2012 Environmental and Socioeconomic Indicators Report analyzes sustainability trends over time at the national scale for U.S. corn, cotton, potato, rice, soybean, and wheat production.	✓	✓	✓	✓	
RISE (Response-inducing Sustainability Evaluation)	RISE is a computer-supported method developed at HAFL, which facilitates a holistic assessment of agricultural operations. The evaluation is based on ten indicators that reflect environmental, economic and social aspects. The most important data source is a questionnaire-based interview with the farmer.	✓	✓	✓	✓	

Tools	Description	Availability	Specific	Objective	Quantitative	Comments
SMART (The Sustainability Monitoring and Assessment RouTine)	Tool for sustainability assessment of food companies - Farm level assessments are conducted with a special subtool, the SMART-Farm-TOOL	X	X	-	-	Explicitly based SAFA
SAFA (Sustainability Assessment of Food and Agriculture systems)	The Sustainability Assessment of Food and Agriculture systems (SAFA) Guidelines were developed for assessing the impact of food and agriculture operations on the environment and people.	✓	✓	✓	✓	
Diagnostique d'Agriculture paysane	Indicators of peasant agriculture	X	-	-	-	Specific to peasant agriculture
SYSTERRE	Calculator of a set of indicators to assess the technical, economic and environmental of crops on a farm field crop or mixed farming	X	-	-	-	
MOTIFS	Monitoring tool for integrated farm sustainability	✓	✓	✓	X	
SAFE (Sustainability assessment of farming and the environment)	List of 87 performing sustainability indicators specific to the Belgian agricultural context.	✓	✓	✓	✓	
La gestion durable d'une entreprise agricole (COOP fédérée)	Self-diagnosis giving an overall picture of the sustainability of the management.	✓	✓	✓	X	

Tools	Description	Availability	Specific	Objective	Quantitative	Comments
AgBalance – BASF	AgBalance is a method to measure and assess sustainability in agriculture.	✓*	✓	✓	✓	
OFAG	Rapport agricole 2014 de l'Office fédérale de l'agriculture (OFAG)	✓	✓	✓	✓	Not an assessment tool per see, but social indicators are reported in the annual report
PRÉ – Social footprint	Methodology for social impact assessment at product level. The methodology allows reasoned assessment of overall performance by including social topics and performance indicators that reflect positive and negative impacts of the product on three stakeholder groups: workers, consumers and local communities. 19 social topics are proposed, together with their individual performance indicators, including detailed definitions.	✓	✓	✓	✓	
AFAQ 26 000	AFAQ is a method assessing to what level an organisation meets ISO 26 000 requirements	✓*	✓	✓	✓	

Annexe 3 Lohnrichtlinien für familienfremde Arbeitnehmende in der Schweizer Landwirtschaft inklusive landw. Hauswirtschaft 2015

Schweizer Bauernverband
Union Suisse des Paysans
Unione Svizzera dei Contadini
sbv | usp | usc

Schweizerische Arbeitsgemeinschaft der Berufsverbände landwirtschaftlicher Angestellter

Lohnrichtlinie für familienfremde Arbeitnehmende in der Schweizer Landwirtschaft inklusive landw. Hauswirtschaft 2015

In der Schweizer Landwirtschaft werden tausende von Arbeitnehmenden beschäftigt. Es ist von grosser Bedeutung, dass bei deren Beschäftigung geordnete Verhältnisse herrschen. Diese zwischen dem Schweizer Bauernverband (SBV), dem schweizerischen Bäuerinnen- und Landfrauenverband (SBLV) und der Arbeitsgemeinschaft der Berufsverbände landw. Angestellter (ABLA) vereinbarte Richtlinie soll mithelfen, ein gutes Verhältnis zwischen Arbeitnehmenden und Arbeitgebenden zu erhalten. Der Verständlichkeit halber wird in diesem Dokument durchgehend die männliche Form verwendet. Gemeint sind jeweils die männliche und weibliche Form. Die Richtlinie vermittelt einen allgemeinen Überblick. Im Einzelfall sind die Bestimmungen der kantonalen Normalarbeitsverträge sowie allfällig in einem Einzelarbeitsvertrag vereinbarte Regelungen zu beachten.

1. Arbeitsvertrag

Für jedes Arbeitsverhältnis gelten die gesetzlichen Bestimmungen des Arbeitsvertragsrechtes (OR), die Vorschriften der kantonalen Normalarbeitsverträge (NAV) der Landwirtschaft und die im Einzelarbeitsvertrag festgehaltenen Bestimmungen. Für ausserlandwirtschaftliche Tätigkeiten (Gartenbau, Gastgewerbe, Baugewerbe, usw.) sind die bestehenden Gesamtarbeitsverträge der Branchen einzuhalten. Jeder Arbeitgebende und Arbeitnehmende sollte im Besitze des kantonalen NAV der Landwirtschaft oder des Gesamtarbeitsvertrages der betreffenden Branche sein. Diese Verträge sind bei der kantonalen Material- und Drucksachenverwaltung erhältlich.

2. Lohnbedingungen

Dem Arbeitnehmenden ist für seine Tätigkeit eine angemessene Entschädigung (Lohn) auszurichten. Als Richtlinie gelten die auf Seite 3 festgelegten Ansätze.

Vom AHV-Lohn können abgezogen werden:

- 1/2 der Prämie der AHV/IV/ALV/EO-Beiträge;
- die Prämie für die vom Arbeitgebenden bezahlte Krankenpflegeversicherung;
- 1/2 der Prämie der Krankentaggeldversicherung;
- 1/2 der Prämie der Pensionskasse;
- die Prämie für die Nichtberufsunfallversicherung;
- die Quellensteuer (bei ausländischen Arbeitnehmenden ohne Niederlassungsbewilligung);
- der Naturallohn sofern Arbeitnehmende Kost und Logis beziehen.

Vom ersten Monatslohn kann ein Viertel des AHV-Lohnes zurückbehalten werden. Die Rückerstattung erfolgt spätestens bei der ordentlichen Beendigung des Arbeitsverhältnisses.

Ausnahmen: In folgenden Kantonen hat der Arbeitgebende die Hälfte der Krankenpflegeprämie gemäss NAV zu tragen: GL, TI, VS, im Kanton AI hat der Arbeitgebende die ganze Prämie zu tragen.

3. Lohnabrechnung

Der Arbeitgebende ist verpflichtet, jeden Monat eine vollständige Lohnabrechnung inkl. Überzeit- und Freizeitkontrolle zu erstellen. Der Lohn ist spätestens am Monatsende auszuzahlen. Es ist darauf zu achten, dass ein einwandfreier Auszahlungsbeleg (Quittung) vorliegt. Eine Kopie ist dem Arbeitnehmenden auszuhändigen.

Beim Schweizer Bauernverband (Agrimpuls) und den kant. Bauernverbänden kann ein in 15 Sprachen herausgegebener Lohnabrechnungsblock bezogen werden.

4. Arbeitszeit

Die tägliche Arbeitszeit richtet sich nach den Bestimmungen des kantonalen NAV der Landwirtschaft. Im Gemüsebau sind die Bestimmungen des Modellarbeitsvertrages zwischen VSGP und IVAG zu beachten.

5. Überstundenarbeit

Der Arbeitnehmende hat bei Bedarf Überstundenarbeit zu leisten. Im Einverständnis mit dem Arbeitnehmenden kann der Arbeitgebende die Überstundenarbeit durch Freizeit von mindestens gleicher Dauer ausgleichen. Andernfalls hat der Arbeitgebende für die Überstundenarbeit Lohn zu entrichten. Dieser bemisst sich nach dem Normallohn und einem Zuschlag von mindestens 25%.

Die geleisteten Überstunden müssen auf der Lohnabrechnung festgehalten und vom Arbeitgebenden und Arbeitnehmenden bestätigt werden.

6. Freizeit und Ferien

Die Anzahl der freien Tage richtet sich nach den Bestimmungen des kantonalen NAV der Landwirtschaft.

Der Ferienanspruch des Arbeitnehmenden beträgt vier Wochen pro Jahr (bis zum vollendeten 20. und je nach Kanton ab dem 50. Lebensjahr fünf Wochen). Die Ferien sind, wenn sie nicht schon vorher gewährt wurden, bei Vertragsende zu beziehen. Während des Arbeitsverhältnisses nicht bezogene freie Tage sind bei Vertragsende dem Ferienanspruch gleichzustellen.

Der Arbeitgebende hat dem Arbeitnehmenden für die an Freitagen und in den Ferien nicht bezogene Verpflegung eine Entschädigung auszuzahlen.

7. Familienzulagen

Die landwirtschaftlichen Arbeitnehmenden erhalten für jedes Kind bis zum erfüllten 16. Altersjahr eine monatliche Kinderzulage. Um in den Genuss dieser Zulage zu kommen, muss der Arbeitnehmende die Geburtsscheine der Kinder (mit Übersetzung) auf der Gemeindeausgleichskasse des Arbeitsortes abgeben. Für Kinder über 16 Jahre, die noch in Ausbildung stehen, muss zusätzlich zum Geburtsschein eine Schulbestätigung

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(mit Übersetzung) vorgewiesen werden. Arbeitnehmende, die in der Schweiz einen Haushalt führen, haben zudem Anspruch auf die Haushaltszulage (Massgebend sind die Bestimmungen des FLG).

8. Versicherungen

Der Normalarbeitsvertrag (NAV) verpflichtet den Arbeitgebenden sein Personal für Arzt-, Arznei- und Spitalkosten sowie ein Krankentaggeld von 80% des Lohnes zu versichern. In den Kantonen, in denen der Arbeitgebende keinen Anteil an die Krankenpflegeprämien zu entrichten hat, ist er dennoch verpflichtet, zu kontrollieren, ob die Arbeitnehmenden bei einer Krankenkasse angemeldet sind. Ebenfalls müssen die nicht erwerbstätigen Familienmitglieder einer/eines Mitarbeitenden aus einem der neuen EU-Länder (ausser Ungarn) bei dieser Krankenkasse mitversichert werden. Weitere Informationen erhalten Sie bei Ihrer Krankenkasse.

Das Unfallversicherungsgesetz (UVG) verpflichtet den Arbeitgebenden sein Personal für Berufs- und Nichtberufsunfälle zu versichern.

Das Bundesgesetz über die berufliche Vorsorge (BVG) verpflichtet den Arbeitgebenden, das Personal, das länger als 3 Monate beschäftigt wird, einen AHV-Lohn von mehr als CHF 1'762.50 pro Monat bezieht und älter als 17jährig ist, einer Pensionskasse anzuschliessen.
Angestellte, welche die Schweiz definitiv verlassen, müssen sich spätestens einen Monat vor der Ausreise bei der Pensionskasse melden. Dies gilt jedoch nur für Arbeitnehmer, welche älter als 25 Jahre sind.

Auskünfte erteilen die landw. Versicherungsberatungsstellen oder die Agrisano Pencas (ehemals PKSL), Tel. 056 462 51 66.

9. Ungerechtfertigte Entlassung (Art. 337c OR)

Entlässt der Arbeitgebende den Arbeitnehmenden fristlos ohne wichtigen Grund, so hat dieser Anspruch auf Ersatz dessen, was er verdient hätte, wenn das Arbeitsverhältnis unter Einhaltung der Kündigungsfrist oder durch Ablauf der bestimmten Vertragszeit beendigt worden wäre.

Der Arbeitnehmende muss sich daran anrechnen lassen, was er infolge der Beendigung des Arbeitsverhältnisses erspart hat und was er durch anderweitige Arbeit verdient oder zu verdienen absichtlich unterlassen hat.

Der Richter kann den Arbeitgebenden verpflichten, dem Arbeitnehmenden eine Entschädigung zu bezahlen, die er nach freiem Ermessen unter Würdigung aller Umstände festlegt; diese Entschädigung darf jedoch den Lohn des Arbeitnehmenden für sechs Monate nicht übersteigen.

10. Ungerechtfertigter Nichtantritt oder Verlassen der Arbeitsstelle (Art. 337d OR)

Tritt der Arbeitnehmende ohne wichtigen Grund die Arbeitsstelle nicht an oder verlässt er sie fristlos, so hat der Arbeitgebende Anspruch auf eine Entschädigung, die einem Viertel des Lohnes für einen Monat entspricht; ausserdem hat er Anspruch auf Ersatz weiteren Schadens. Erlischt der Anspruch auf Entschädigung nicht durch Verrechnung, so ist er durch Klage oder Betreibung innert 30 Tagen seit dem Nichtantritt oder Verlassen der Arbeitsstelle geltend zu machen; andernfalls ist der Anspruch verwirkt.

11. Lenken von landwirtschaftlichen Motorfahrzeugen

Soll der Arbeitnehmende mit dem Führen von landwirtschaftlichen Motorfahrzeugen beauftragt werden, muss dieser über einen gültigen Führerausweis mindestens der Kategorie G verfügen. Fehlt der gültige Ausweis, können die Motorfahrzeug-Haftpflichtversicherer die gesamten Kosten eines durch den Angestellten verursachten Unfalles beim Arbeitgebenden zurückfordern. Bei den Strassenverkehrsämtern erhält man Informationen über das Ablegen der Führerprüfung für ausländische Arbeitskräfte und die Gültigkeit der ausländischen Führerscheine.

Hält sich ein ausländischer Arbeitnehmer länger als ein Jahr in der Schweiz auf, muss sein ausländischer Führerschein nach einem Jahr in einen schweizerischen Führerschein umgetauscht werden.

12. Schäden durch Krankheiten/Ärztliche Untersuchung

Grundsätzlich kann die Möglichkeit nicht ausgeschlossen werden, dass ein Arbeitnehmender Träger irgendwelcher Viren, Bakterien, Bandwürmer etc. ist. Die Erfahrung zeigt, dass dieses Risiko sehr klein ist. Im Einzelfall können die daraus entstehenden Schäden aber gross sein (z.B. Befall des Tierbestandes mit Bandwürmern). Für solche Schäden bestehen in der Regel kein Versicherungsschutz und kein Haftungsanspruch. Der Arbeitgebende kann das Risiko minimieren, wenn er Arbeitnehmende auf seine Kosten ärztlich untersuchen lässt.

13. Arbeitssicherheit

Alle Betriebe, welche Arbeitskräfte beschäftigen, müssen die EKAS Richtlinie 6508 über den Beizug von Arbeitsärzten und anderen Spezialisten der Arbeitssicherheit erfüllen. Auskünfte über die Branchenlösung AgriTOP erteilt die Beratungsstelle für Unfallverhütung in der Landwirtschaft BUL, 062 739 50 40.

14. Arbeitsbewilligung für ausländische Angestellte

Die Kosten für das Konsularvisum oder die Zusicherung der Aufenthaltsbewilligung gehen zu Lasten des Arbeitgebenden, alle anderen Gebühren oder Kosten gehen zu Lasten des Arbeitnehmenden.

15. Reisekosten für ausländische Arbeitnehmende

Wenn nichts anderes vereinbart wurde, gehen die Reisekosten zu Lasten des Arbeitnehmenden.

16. Fragen

Bei Fragen stehen die kantonalen Bauernsekretariate, der SBLV, die ABLA und Agrimpuls gerne zur Verfügung.

Schweizer Bauernverband
Union Suisse des Paysans
Unione Svizzera dei Contadini

Schweizerische Arbeitsgemeinschaft der Berufsverbände landwirtschaftlicher Angestellter

Richtlöhne 2015

Personal in Landwirtschaft, Obst-, Wein-, Gemüsebau, landw. Haushalt, etc.

Wichtig:

- Massgebend für die Einstufung in die Lohnklassen ist nicht die Ausbildung, sondern die im Betrieb ausgeübte Funktion.
- Die angegebenen Löhne verstehen sich als Monatslöhne inklusive allfällig erbrachter Kost und Logis.
- In der Landwirtschaft sind 12 Monatslöhne üblich. Allfällige 13. Monatslöhne/Gratifikationen sind in diesen Richtlinien nicht enthalten.
- Der Arbeitgebende ist verpflichtet, jeden Monat eine Lohnabrechnung inkl. Kontrolle der Überzeit, Freizeit und Kostgeldentschädigung zu erstellen. Der Ferienzuschlag für 4 Wochen beträgt 8.33% und bei 5 Wochen 10.64% (Stundenlohnabrechnungen).

Lohnklasse	Funktion	Vergleichbare Ausbildung	Berufserfahrung (CH)	Bruttolohn / Monat	
				von CHF	bis CHF
8	**Landw. und bäuerl.-hausw. Betriebsleiter/innen** - Verantwortung für Betrieb /Haushalt - Eigenständige Betriebsplanung	Höhere Fachprüfung HFP Fach-/Hochschulabschluss	Über 5 Jahre	4'580.00	6'190.00
			Unter 5 Jahre	3'990.00	5'210.00
7	**Landw. und bäuerl.-hausw. Betriebszweigleiter/innen** - Verantwortung für Betriebszweig - Eigenständige Planung von Teilbereichen	Berufsprüfung (BLS 1)	Über 5 Jahre	4'210.00	5'575.00
			Unter 5 Jahre	3'750.00	4'940.00
6	**Landw. und bäuerl.-hausw. Betriebsangestellte** - Eigenständige Arbeitsplanung - Kann alle Arbeiten eigenständig ausführen - Gruppenleiter	Fähigkeitszeugnis	Über 5 Jahre	3'825.00	5'040.00
			Unter 5 Jahre	3'610.00	4'670.00
5	**Landw. und bäuerl.-hausw. Betriebsangestellte** - Arbeiten werden gemäss Auftrag selbstständig ausgeführt - Grundkenntnisse vorhanden	Teilprüfung, LAP 1 Eidg. Berufsattest EBA	Über 5 Jahre	3'540.00	4'020.00
			Unter 5 Jahre	3'240.00	3'650.00
4	**Befristete Angestellte oder Angestellte ohne Erfahrung, Hilfskräfte** - Arbeiten werden gemäss Weisungen ausgeführt	Saisonale Arbeitskräfte,		3'200.00	
3	**Aushilfe** - Einfache Tätigkeiten	Keine berufl. Ausbildung, unter 18 Jahre		1'500.00	2'455.00
2	**Praktikanten** im Rahmen eines Programmes von SBV / Agrimpuls	Praktikanten	Über 4 Monate	2'695.00	
			Unter 4 Monate	2'535.00	
1	**Praktikanten** im Rahmen eines Studiums an der HAFL (2014)	Studenten		1'500.00	1'800.00
	Der Minimallohn für Angestellte aus den EU-2 Staaten Bulgarien und Rumänien beträgt CHF 3'200.00.				

Alppersonal

Informationen zu Löhnen auf Alpen sind auf der Internetseite www.zalp.ch oder bei verschiedenen kantonalen Anlaufstellen zu finden.

Grundsätzlich kann auch bei Angestelltenverhältnissen auf Alpen die vorliegende Lohnrichtlinie als Richtlinie beigezogen werden.

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Allgemeine Grundsätze

Die Richtlöhne gelten für voll leistungsfähige Arbeitnehmende. Für Personen deren Leistungsfähigkeit eingeschränkt ist, können die Ansätze entsprechend dem Grad der Einschränkung angepasst werden. Es ist dringend zu empfehlen, dies schriftlich zu vereinbaren.

Allfällige Kinderzulagen sind in jedem Fall zusätzlich auszurichten.

In kantonalen Normal- oder Gesamtarbeitsverträgen festgelegte Lohnregelungen gehen diesen Richtlöhnen vor.

Der Nettolohn ergibt sich nach Abzug der Sozialversicherungsbeiträge (AHV/IV/ALV/EO, Krankenkasse, Krankentaggeldversicherung, Nichtberufsunfallversicherung, Pensionskasse), Quellensteuer, Naturallohn.

Es ist in jedem Fall zu empfehlen, den im einzelnen Arbeitsverhältnis vereinbarten Lohn im individuellen Arbeitsvertrag festzuhalten.

Zusammensetzung des Naturallohn

Leistung	CHF / Tag	CHF / Monat
Logis/Unterkunft	11.50	345.00
Morgenessen	3.50	105.00
Mittagessen	10.00	300.00
Abendessen	8.00	240.00
Total	33.00	990.00
Wird der Naturallohn nicht erbracht, kann er den Arbeitnehmenden nicht vom Lohn abgezogen werden. Zusätzliche Leistungen können separat verrechnet werden.		

Berechnung der Stundenlöhne (gemäss dem Muster-NAV ABLA/SBV)

Die Stundenlöhne ergeben sich durch Teilung des Monatslohnes durch die Anzahl der monatlichen Arbeitsstunden gemäss NAV.

Muster: Bruttolohn CHF 3'200.00, 5.5 Tagewoche, tägliche Arbeitszeit 9.5 Std.

Formel: Lohn pro Arbeitsstunde = $\frac{\text{AHV-Lohn pro Monat}}{\text{Arbeitsstunden pro Monat}}$

Muster: Lohn pro Arbeitsstunde = $\frac{\text{CHF 3'200.00 pro Monat}}{\text{227 Stunden pro Monat}}$ = <u>14.10 CHF pro Std.</u>

Berechnung der Arbeitsstunden pro Monat:

Wochen pro Jahr:	365 Tage : 7 Tage/Woche	=	52.14 Wochen/Jahr
Arbeitstage pro Jahr:	5.5 Arbeitstage/Woche x 52.14 Wochen/Jahr	=	286.79 Arbeitstage/Jahr
Arbeitstage pro Monat:	286.79 Arbeitstage/Jahr : 12 Monate/Jahr	=	23.90 Arbeitstage/Monat
Arbeitszeit pro Monat:	23.9 Tage/Monat x 9.5 Stunden/Tag	=	**227.00 Stunden/Monat**

Entschädigung für Überstunden

Der Arbeitgebende ist verpflichtet eine einwandfreie Aufzeichnung der Überstunden zu führen. Werden die Überstunden nicht durch die Gewährung von Freizeit in gleichem Umfang ausgeglichen, müssen diese mit einem Zuschlag von 25% auf dem Bruttolohn ausbezahlt werden.

Beispiel: Bruttolohn CHF 3'200.00, 5.5 Tagewoche, tägliche Arbeitszeit 9.5 Std., Zuschlag 25% = CHF 17.60
(3'200 : 227 x 1.25 = 17.60)

Hinweis

Diese Richtlinien wurden als sozialpartnerschaftliche Vereinbarung zwischen dem Schweizer Bauernverband (SBV), dem Schweizerischen Bäuerinnen- und Landfrauenverband (SBLV) und der Schweizerischen Arbeitsgemeinschaft der Berufsverbände landwirtschaftlicher Angestellter (ABLA) vereinbart.

Bezugsquellen

Diese Richtlinien sowie der Lohnabrechnungsblock können bezogen werden bei:

Agrimpuls, Laurstrasse 10, 5201 Brugg
Tel. 056 462 51 44, Fax 056 442 22 12
E-Mail: info@agrimpuls.ch, www.agrimpuls.ch

ABLA, Sekretariat, Vordereglezen, 6042 Dietwil
Tel. 041 787 37 14 oder 079 510 09 28
E-Mail: mara.simonetta@bluewin.ch, www.abla.ch

Brugg / Dietwil, im November 2014

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Annexe 4 Recoding of Labour Units

Table A. 2: Recoding of work units from data from the Ordinance on Agricultural Terminology (LBV) into simplified work units (LUs) actually available on the farm.

Actual LUs	LBV Category
0.62	Farm managers, women, 50-74% of working hours
0.87	Farm managers, women, over 74% of working hours
0.25	Farm managers, women, under 50% of working hours
0.62	Farm managers, men, 50-74% of working hours
0.87	Farm managers, men, over 74% of working hours
0.25	Farm managers, men, under 50% of working hours
0.62	Family members of the farm manager, women, 50-74% of working hours
0.87	Family members of the farm manager, women, over 74% of working hours
0.25	Family members of the farm manager, women, under 50% of working hours
0.62	Family members of the farm manager, men, 50-74% of working hours
0.87	Family members of the farm manager, men, over 74% of working hours
0.25	Family members of the farm manager, men, under 50% of working hours
0.25	Non-family foreigners, women, under 50% of working hours
0.87	Non-family foreigners, men, over 74% of working hours
0.25	Non-family foreigners, men, under 50% of working hours
0.62	Non-family Swiss nationals, men, 50-74% of working hours
0.87	Non-family Swiss nationals, men, over 74% of working hours
0.25	Non-family Swiss nationals, men, under 50% of working hours
0.7	Apprentices

Annexe 5 Recoding of Livestock Numbers

Table A. 3: Recoding of livestock numbers from data from the Ordinance on Agricultural Terminology (LBV) into simplified categories in the Global Work Budget (WB).

WB Category	LBV Designation
Rearing cattle	Bovine species and water buffalo, animals 120-365 days old, female Bovine species and water buffalo, animals 365-730 days old, female Bovine species and water buffalo, animals over 730 days old, female
Calves	Bovine species and water buffalo, animals up to 120 days old, male Bovine species and water buffalo, animals up to 120 days old, female
Fattening cattle	Bovine species and water buffalo, animals 120-365 days old, male Bovine species and water buffalo, animals 365-730 days old, male Bovine species and water buffalo, animals over 730 days old, male
Dairy cows	Bovine species and water buffalo, dairy cows
Suckler cows	Bovine species and water buffalo, other cows

Annexe 6 Recoding into the Global Work Budget Categories

Table A. 4: Recoding of the various terms in the Ordinance on Agricultural Terminology (LBV) into the categories of the Global Work Budget (WB).

WB Category	LBV Term
Oats	Oats
Potatoes	Potatoes Seed potatoes (contract farming)
Grain maize	Grain maize
Eco-meadows	Low-input meadows (without pastures)
Rye	Spelt
Silage maize	Silage maize and green maize
Summer barley	Summer barley
Summer oilseed rape	Sunflower for edible-oil extraction
Summer wheat	Summer wheat (excluding feed wheat from the swiss granum variety list)
Scattered orchards	Standard fruit trees
Dessert fruit	Orchards (apples) Orchards (pears) Orchards (stone fruit)
Triticale	Triticale
Forest	Forest
Pasture	Low-input pastures Pastures (home-farm pastures, remaining pastures excluding summering pastures)
Meadows, 2 conservation cuts	Fairly-low-input meadows (without pastures)
Meadows, 3 conservation cuts	Mountain: Temporary leys (without pastures) Remaining permanent meadows (without pastures)
Meadows, 4 conservation cuts	Lowland: Temporary leys (without pastures)
Winter barley	Winter barley
Winter oilseed rape	Winter oilseed rape for edible oil extraction
Winter wheat	Winter wheat (excluding feed wheat from the swiss granum variety list)
Sugar beet	Fodder beet Sugar beet

Annexe 7 Working-Time Requirement

Table A. 5: Manually added working-time requirement (Standard Labour Unit (SLU) requirement) in Standard Labour (SLh), according to terms in the Ordinance on Agricultural Terminology (LBV), based on various calculation bases and sources.

LBV Category	***SLU Requirement per ha in SLh***	***Calculation Bases/Source***
Conservation headland strips, cereals	--	
Wildflower strips	40	Mean value from information from P. Wirth, D. Nyfeler and J. Rohrer, BBZ Arenenberg, as at January 2015: "Wildflower Strips" information leaflet
Christmas trees	1090	North Rhine-Westphalia Chamber of Agriculture, Germany http://www.landwirtschaftskammer.de/landwirtschaft/landservice/buch/4-5-1-0.pdf
Native individual trees and avenues suited to the location	--	Not relevant
Land with no assigned main agricultural purpose	--	Parameters for agriculture not relevant
House gardens	--	Parameters for agriculture not relevant
Hedgerows, copses and wooded river banks (with herbaceous edge)	155	Calculation using Oecocalc (agridea). Parameters: Mountain/lowland, <18-35% lynchet, Distance farm/disposal 20 km, herbaceous edge 30 MPh
Hedgerows, copses and wooded river banks (with buffer strips)	125	Calculation using Oecocalc (agridea). Parameters: Mountain/lowland, <18-35% lynchet, Distance farm/disposal 20 km
Hay fields in the summer grazing area, low-input meadow type	21	Wirz manual 2015: Low-input meadows, 26-35% slope gradient, average mechanisation
Hay fields in the summer grazing area, fairly- low-input meadow type	28	Wirz manual 2015: Meadows, 2 cuts, 26-35% slope gradient, average mechanisation
Perennial berries	4920	Wirz manual 2015: Raspberries
Grapevines	790	Wirz manual 2015: Parameter: Low mechanisation
Region-specific areas reserved for promoting biodiversity (green areas)	19	Wirz manual 2015: Parameters: Low-input meadows, <18% slope gradient, average mechanisation
Ruderal sites, cairns and stone walls	--	No UAA, not included in calculation
Summering pastures	15	Wirz manual 2015: Pastures in the mountain zone
Extensively managed wet areas within the UAA	21.8	Calculation using Oecocalc (agridea): Lowlands <18% slope gradient, 1 mowing, ensilaging, 10 km distance
Extensively managed wet areas within the UAA	23.8	Calculation using Oecocalc (agridea) : Mountain 18-35% slope gradient, 1 mowing, ensilaging, 10 km distance

LBV Category	*SLU Requirement per ha in SLh*	*Calculation Bases/Source*
Tobacco	1329	Wirz manual 2015: mechanised
Remaining areas outside of the UAA	--	
Remaining areas within the UAA, not entitled to subsidy payments	--	
Remaining unproductive areas	--	
Unpaved, natural paths	--	
Ditches, pools, ponds	--	Not relevant according to Agridea information leaftlet; no UAA
Scattered orchards	19.9	Global Work Budget: Add no. of trees manually
Forest	13.9	Global Work Budget; Add no. of hectares manually
Laying hens	0.6	Global Work Budget, add number of animals manually

Annexe 8 Recoding for the Calculation of the Standard Work Unit

Table A. 6: Recoding of the term in the Ordinance on Agricultural Terminology (LBV) for the calculation of the Standard Labour Unit (SLU) with the option of entitlement to slope bonus of mountain farms.

LBV Term	SLU Category	Entitled to Slope Bonus
Oats	UAA	X
Potatoes Seed potatoes (contract farming)	Special crop	X
Grain maize	UAA	X
Low-input meadows (without pastures)	UAA	X
Spelt	UAA	X
Silage maize and green maize	UAA	X
Summer barley	UAA	X
Sunflower for edible-oil extraction	UAA	X
Summer wheat (excluding feed wheat from the swiss granum variety list)	UAA	X
Standard fruit trees	Fruit trees	--
Orchards (apples) Orchards (pears) Orchards (stone fruit)	Special crop	X
Triticale	UAA	X
Forest	Forest	--
Low-input pastures Pastures (home-farm pastures, remaining pastures excluding summering pastures)	UAA	--
Fairly-low-input meadows (without pastures)	UAA	X
Mountain: Temporary leys (without pastures) Remaining permanent meadows (without pastures)	UAA	X
Lowland: Temporary leys (without pastures)	UAA	X
Winter barley	UAA	X
Winter oilseed rape for edible-oil extraction	UAA	X
Winter wheat (excluding feed wheat from the swiss granum variety list)	UAA	X
Fodder beet Sugar beet	UAA	X
Conservation headland strips, cereals	UAA	X
Wildflower strips	UAA	X

LBV Term	SLU Category	Entitled to Slope Bonus
Christmas trees	Special crop	--
Native individual trees and avenues suited to the location	--	--
Areas with no assigned main agricultural purpose	--	--
House gardens	--	--
Hedgerows, copses and wooded river banks (with herbaceous edge)	UAA	--
Hedgerows, copses and wooded river banks (with buffer strips)	UAA	--
Hay fields in the summer grazing area, low-input meadow type	UAA	X
Hay fields in the summer grazing area, fairly- low-input meadow type	UAA	X
Perennial berries	Special crops	X
Grapevines	Viticulture	--
Region-specific areas reserved for promoting biodiversity (green areas)	--	X
Ruderal sites, cairns and stone walls	--	--
Summering pastures	--	--
Extensively managed wet areas within the UAA	UAA	X
Tobacco	Special crop	X
Remaining areas outside of the UAA	--	--
Remaining areas within the UAA, not entitled to subsidy payments	--	--
Remaining unproductive areas (e.g. mulched areas, extremely weedy areas, hedge without buffer strips)	--	--
Unpaved, natural paths	--	--
Ditches, pools, ponds	--	--

Annexe 9 General Survey of the AWI

The AWI ('Animal Welfare Index'), in German 'Tiergerechtheitsindex', hence abbreviated as 'TGI' (35-TGI-L), was originally developed on Austrian organic farms as an official assessment system and a supplement to the Animal Protection Law, and relied on heavily in this context in beef-cattle, fattening-pig and laying-hen husbandry (Ofner 2003). The primary purpose of the AWI is therefore its use as a monitoring tool on farms, which explains its focus on easily collected, resource-based parameters. Nevertheless, a number of management- and animal-based variables are also included. Consequently, the structure of the AWI is based on the Five Freedoms (Table A. 7), whilst dimensions that are essential for the profitability of animal production and which are required in principle for animal welfare (e.g. state of health, hunger and thirst) are thus not collected. Five aspects serve to form function groups, each aspect containing up to eight parameters to be recorded (Table A. 7):

Table A. 7: Aspects and description of the Animal Welfare Index (AWI) parameters

Aspect	Parameter	Type
Movement [2), 3), 4)]	6–7 resource-based parameters	Qualitative & quantitative
Social contact [4), 5)]	5–8 resource-/ management-based parameters	Qualitative & quantitative
Flooring properties [2), 3)]	6–8 resource-based parameters	Qualitative & quantitative
Light, air and noise [2)]	6–7 resource- / management-based parameters	Qualitative & quantitative
Care [2), 3), 5)]	6–7 management- / animal-based parameters	Qualitative

[1)] Freedom from hunger or thirst
[2)] Freedom from discomfort
[3)] Freedom from pain, injury or disease
[4)] Freedom to express (most) normal behaviour
[5)] Freedom from fear and distress

The AWI assesses the circumstances of the 25% most affected animals (Bartussek 1995a, 1995b, 1996). The highest aggregation level for 35-TGI-L is the farm activity, it being possible in principle for the sums of the scores of several species of animal to be further aggregated. The aspects carry no weight in terms of the allocation of the individual parameters, however, since points are awarded per parameter, and these are calculated into a total regardless of the aspect. The possibility of compensating for defects via exceeded animal welfare services in other areas is the intention here, however, since the author of the AWI assumes the ability of an animal to balance out negative effects through positive impacts (Bartussek 1988, 1995a, 1999). At the same time, we distinguish the maximum achievable score per parameter, with weighting automatically applied for animal-welfare-promoting parameters. Based on the total score, an animal husbandry system is rated as 'non-animal-friendly', 'borderline non-animal-friendly', 'not very animal-friendly', 'fairly animal-friendly', 'animal-friendly', or 'very animal-friendly'. Although the derivation of the parameters, the reasons for their choice and their weighting are in principal based on scientific findings, they are also the result of negotiations that are in some cases politically motivated, or of purely pragmatic decisions (Bartussek 1999).
The reproducibility of the AWI was confirmed between observers (Bartussek 1999; Amon *et al.* 2001; Ofner 2003). Since the AWI focuses on resource-based parameters, the immutable nature of these leads us to expect a high level of reproducibility. Moreover, resource-based parameters can also be collected irrespective of climate or season. High reproducibility within an observer can therefore be assumed, although no relevant investigations exist.

Table A. 8: Aspects and associated parameters of the AWI for cattle, pigs and breeding sows, as well as laying hens (h = hours, d = days).

	Movement	Social Contact	Flooring Properties	Light, Air and Noise	Care
Cattle	Space conditions, loose housing • Dehorned dairy cows • Horned dairy cows • Suckler cows • Young stock / Fattening cattle Lying comfort Tied housing • Tie-stall dimensions • Tie-stall partitions Outdoor exercise • Days/year • Alpine grazing / Pasture days/year	Space conditions, loose housing • Dehorned dairy cows • Horned dairy cows • Suckler cows • Young stock / Fattening cattle Herd structure/management Calf management Outside areas • Outdoor access days/year • Grazing days/year	Lying area • Softness • Cleanliness • Slip resistance Activity area, passageways Outside areas Alpine grazing/pasture	Daylight in housing Air quality and airflow Draft in resting area Noise Outside area Days/year Average h/d	Cleanliness of pens and feeding/drinking area Technical state of pen fittings State of skin Cleanliness of the animals State of hooves Technopathies Animal health

	Movement	Social Contact	Flooring Properties	Light, Air and Noise	Care
Pigs/ breeding sows	Space conditions, housing Up to 30 kg/180 kg Up to 60 kg/220 kg Up to 110 kg/260 kg Up to140 kg/>260 kg Manipulable materials Scratching facilities Separate outdoor access Size of outdoor exercise area % of days /cycle Pasture% of growing season	Space conditions, housing Up to 30 kg/180 kg Up to 60 kg/220 kg Up to 110 kg/260 kg Up to140 kg/>260 kg Availability of fittings Delivery of young stock No. of sealed sides around lying area Herd structure/size Mixed-sex Single-sex Separate outdoor access % of days /cycle Passage width of exercise area	No. of flooring types Lying area Malleability and thermal insulation Cleanliness Slip resistance Activity and/or defecation area Separate outdoor access Outdoor wallow	Daylight in housing Air quality and airflow Draft in resting area Showers in pen Noise Outdoor exercise area and pasture h/d Shade net or wallow	Cleanliness of pens and feeding/drinking area Technical state of pen fittings Loss in % State of skin State of hooves/joints Housing accounts Animal health
Laying hens	Walkable surface in housing Area/animal Max. no. animals/area Littered area in % Raised perches Free-range area Area/animal at exits d/year Pasture area Distance pen – pasture area	Animals per group Walkable surface in housing Availability of nests, water, feed Raised perches Cockerels in flock Free-range access/Pasture Width of passageway Distance to housing exit Facilities	Length of perch m^2/animal Max. animals/m^2 Quality of perch Cover of defecation level Scratching area Litter density/type State of litter Flooring in laying area Flooring at the exits Meadow, state of sward	Light in housing Air quality and airflow Draft in resting area Noise Free-range access and pasture d/year h/d Shade structures	Cleanliness of nests and feeding/drinking area Technical state of housing facilities Cadavers in housing State of plumage State of skin Farm records Animal health

Annexe 10 Welfare Quality® Protocol

As part of a major EU project, variables for assessing the welfare of pigs (Welfare Quality® 2009b), cattle (Welfare Quality® 2009f) and poultry (Welfare Quality® 2009c) in terms of the criteria of validity, reproducibility and feasibility were reviewed. Here, the intention was to aggregate the parameters so that they reflected the animals' sensation and perception of the housing environment, without being dependent on one another (Botreau *et al.* 2007c). A wide variety of expert scientific panels from various European countries were involved, which reviewed each potential individual animal-based parameter as to its suitability for inclusion in the Welfare Quality® Protocol on the basis of literature research or practical trials, and issued a recommendation in this regard. Resource- or management-based variables were also evaluated by experts with regard to their suitability, but were only incorporated in the protocol,

- if no animal-based parameters met all the criteria;
- so as to be able to give the farmer direct feedback and suggestions for improvement;
- if such a variable is easier to collect, and can replace one or more animal-based parameters with the same validity;
- If such a variable simultaneously enables epidemiological studies, or
- Is seen as a risk factor for animal welfare, but cannot be depicted in any animal-based parameter (Welfare Quality® 2009f, 2009c, 2009b).

The Welfare Quality® Protocol is based in principle on the Five Freedoms. Owing to a number of inaccuracies and various overlaps, however, four principles with a total of 12 aspects (=criteria) were formulated (Table A. 9). Whereas the principles and aspects are the same for all animal species, there are differences in terms of the variables incorporated in the protocol owing to differing expert opinions or species-specific peculiarities as regards validity, reproducibility or feasibility (Table A. 10 - Table A. 12). The highest aggregation level is an assessment of animal welfare on farm-activity level, this being rated 'not classified', 'acceptable', 'enhanced' or 'excellent'. During the allocation process, overcompensation is to be prevented via the choice of specific operators instead of just weighted sums. Furthermore, the three-stage allocation process (parameters → aspects → principles → total value) is meant to take account of special characteristics and interactions that occur during the level in question, and which are linked with the animal welfare assessment (Botreau *et al.* 2007a). Admittedly, all levels of the allocation process lack adequate transparency (Andreasen *et al.* 2013; Andreasen *et al.* 2014). The Welfare Quality® is scientifically proven as far as possible, and highlights the opportunities and weaknesses of the variables available in current practice.

In order to gain use in practice, an animal welfare assessment must be reproducible, both within an observer (intra-observer reliability) and between various observers (inter-observer reliability) (Battini *et al.* 2014). With the Welfare Quality®, reproducibility was as a criterion for inclusion of a parameter in the protocol, which is why a reproducible overall protocol is assumed (Welfare Quality® 2009f, 2009c, 2009b). Despite this, however, the inter-observer reliability of individual parameters under real-life conditions would appear to be inadequate, or at least strongly dependent upon the training and experience of the observers in question (Heath *et al.* 2014b). Kirchner *et al.* (2014) found that inter-observer reliability was adequate ($\rho > 0.7$) for individual parameters as well as for the overall assessment, but stress the long-term volatility of the results, and thus recommend repeated collection, in order to rule out e.g. seasonal effects.

Table A. 9: Principles, aspects and description of the Welfare Quality® Protocol parameters

Principle	Aspect	Parameter	Type
Good feeding	Absence of prolonged hunger [1)] Absence of prolonged thirst [1)]	Primarily animal-based, but in some cases also resource- and management-based parameters (= 30–50 per animal species) for describing the criteria in question	Qualitative & quantitative
Good housing	Comfort around resting [2), 3), 4)] Thermal comfort [2), 5)] Ease of movement [2), 3), 4)]		
Good health	Absence of injuries [2), 3)] Absence of disease [2), 3)] Absence of pain induced by management procedures [2), 3), 5)]		
Normal behaviour	Expression of social behaviours [4), 5)] Expression of other behaviours [4), 5)] Good human-animal relationship [2), 5)] Positive emotional state [2), 5)]		

[1)] Freedom from hunger or thirst
[2)] Freedom from discomfort
[3)] Freedom from pain, injury or disease
[4)] Freedom to express (most) normal behaviour
[5)] Freedom from fear and distress

Table A. 10: Categories, aspects and associated parameters of the Welfare Quality® Protocol for sows, piglets and fattening pigs.

Category	Aspect	Sows	Piglets	Fattening Pigs
Good feeding	Absence of prolonged hunger	Body Condition Score	Weaning age	Body Condition Score
	Absence of prolonged thirst	Water supply	Water supply	Water supply
Good housing	Comfort around resting	Bursitis Shoulder sores No dung on body	No dung on body	Bursitis No dung on body
	Thermal comfort	Wheezing Huddling	Wheezing Huddling	Shivering Wheezing Huddling
	Ease of movement	Space conditions	-	Space conditions
Good health	Absence of injuries	Lameness Lesions Vulva injuries	Lameness	Lameness Lesions Tale-biting
	Absence of disease	Mortality Coughing Sneezing Laboured breathing Rectal prolapse Abrasions Constipation Metritis Mastitis Uterine prolapse Skin condition Fractures Local infections	Mortality Coughing Sneezing Laboured breathing Rectal prolapse Abrasions Neurological changes Splayed legs	Mortality Coughing Sneezing Laboured breathing Twisted snout Rectal prolapse Abrasions Skin condition Fractures

Category	Aspect	Sows	Piglets	Fattening Pigs
	Absence of pain induced by management procedures	Nose rings Tail-docking	Castration Tail-docking Teeth-clipping	Castration Tail-docking
Appropriate behaviour	Social behaviours	Social behaviours	-	Social behaviours
	Other behaviours	Stereotypies Exploratory behaviour	-	Exploratory behaviour
	Good human-animal relationship	Fear of humans	-	Fear of humans
	Positive emotional state	Qualitative Behaviour Assessment	Qualitative Behaviour Assessment	Qualitative Behaviour Assessment

Table A. 11: Categories, aspects and associated Welfare Quality® Protocol parameters for fattening chickens and laying hens.

Category	Aspect	Fattening Chickens	Laying Hens
Good feeding	Absence of hunger	Body Condition Score	Feeding places
	Absence of thirst	Drinking places	Drinking places
Good housing	Comfort when resting	Cleanliness of plumage Litter quality Dust	Shape and length of perches Incidence of mites Dust
	Thermal comfort	Wheezing Huddling	Wheezing Huddling
	Freedom of movement	Stocking density	Stocking density Perforated flooring
Good health	Absence of injuries	Lameness	Deformation of the sternum Skin lesions Bunions Changes in the toes
	Absence of disease	Mortality Culling	Mortality Culling Enlarged crop Eye injuries Respiratory infections Enteritis Parasites Comb abnormalities
	Absence of management-related pain		Beak trimming
Appropriate behaviour	Social behaviours	No variables	Aggressive behaviour Damaged plumage Comb pecking wounds

Category	Aspect	Fattening Chickens	Laying Hens
	Other behaviours	Free-range area use Free-range area	Nest use Litter use Enrichment Free-range area Free-range area use Covered veranda
	Good human-animal relationship	Avoidance distance	Avoidance distance
	Positive emotional state	Qualitative Behaviour Assessment	Qualitative Behaviour Assessment Novel Object Test

Table A. 12: Categories, aspects and associated Welfare Quality® Protocol parameters for fattening cattle and dairy cows.

Category	Aspect	Fattening Cattle	Dairy Cows
Good feeding	Absence of hunger	Body Condition Score	Body Condition Score
	Absence of thirst	Water supply Cleanliness of drinking troughs No. of animals using the drinking troughs	Water supply Cleanliness of drinking troughs Water flow in drinking troughs Functioning of drinking troughs
Good housing	Comfort around resting	Duration of lying-down process Cleanliness of animals	Duration of lying-down process Bumping into barn fittings when lying down Animals lying outside of lying area Cleanliness of udder Cleanliness of flanks Cleanliness of legs
	Thermal comfort	No variables	No variables
	Freedom of movement	Housing adapted to weight Access to exercise area or pasture Avoidance through retreat	Tied housing Access to exercise area or pasture
Good health	Absence of injuries	Lameness Changes in skin	Lameness Skin changes
	Absence of disease	Coughing Nasal discharge Eye discharge Laboured breathing Diarrhoea Bloating Mortality	Coughing Nasal discharge Eye discharge Laboured breathing Diarrhoea Vulva injuries Somatic cell count Mortality Dystocia Post-parturient hypocalcaemia
	Absence of management-related pain	Dehorning Tail-docking Castration	Dehorning Tail-docking

Category	Aspect	Fattening Cattle	Dairy Cows
Appropriate behaviour	Social behaviours	Agonistic behaviour Cohesive behaviour	Agonistic behaviour
	Other behaviours	Access to pasture	Access to pasture
	Good human-animal relationship	Avoidance distance	Avoidance distance
	Positive emotional state	Qualitative Behaviour Assessment	Qualitative Behaviour Assessment

Annexe 11 Qualitative Behaviour Assessment (QBA)

QBA is based on a so-called 'free-choice profiling' (FCP) approach, in which there are no pre-established parameters. It does, however, require several observers per animal or per farm, whose assessment results are compared with one another.
In a first step, several observers describe the quality of the behaviour of an individual animal or entire herd in their own words (e.g. calm, nervous, playful). In a second step, the observers use their previously compiled list of terms to gauge the occurrence or intensity of said behaviours. For this, observers use a visual analogue scale to rate the occurrence of each term, from 'minimum' (does not occur) to 'maximum' (dominates a social event). The result for each term can be read from the scale as a quantitative value (in cm). Using a relatively complex statistical method (GPA, 'generalised Procrustes analysis'), all of the terms used are summarised across all observers on axes explaining the variation between the animals, e.g. Axis 1: calm to nervous; Axis 2: apathetic to interactive. The calculated values can then also be located on this graph, and hence interpreted. The computation of an overall value per farm or animal, and hence an animal welfare assessment, is not, however, the primary concern here.
In practice, it is not possible for several observers per farm to conduct an assessment, although this would be necessary for implementing the fundamental component of the FCP and its processing by means of GPA. The Welfare Quality® Project makes use of this method for the assessment of the aspect 'positive emotional state' (cf. Annexe 10). For practical application, a modified form of QBA is used for this which stipulates a pre-compiled list of terms that can be collected independently of the observer (Table A. 13). Such lists exist within the context of the WQ specifically for pigs (Welfare Quality® 2009d), poultry (Welfare Quality® 2009a), dairy cows or fattening cattle (Welfare Quality® 2009e). To compute an overall value for QBA within the WQ we work with weighted sums, which then in turn, through the allocation with a pre-defined spline function, yield a score.
The inter- and intra-observer reliability of QBA has been confirmed both within the context of the Welfare Quality® as a tool with specified terms (Welfare Quality® 2009f, 2009c, 2009b) and in various studies with an FCP approach (Wemelsfelder *et al.* 2000; Wemelsfelder *et al.* 2001; Wemelsfelder and Lawrence 2001; Rousing and Wemelsfelder 2006; Minero *et al.* 2009; Andreasen *et al.* 2013; Phythian *et al.* 2013). Nevertheless, the development of the method and its application in its original form (FCP, GPA) in particular are relatively complex, and therefore not very transparent.

Table A. 13: Prescribed terms that can be used in the Welfare Quality® Project for the evaluation of the aspect 'positive emotional state' in fattening cattle, pigs or poultry.

Dairy Cows	Fattening Cattle	Pigs	Poultry (Fattening Chickens and Laying Hens)
Active	Active	Active	Active
Relaxed	Relaxed	Relaxed	Relaxed
Fearful	Uncomfortable	Fearful	Helpless
Agitated	Calm	Agitated	Comfortable
Calm	Content	Calm	Fearful
Content	Tense	Content	Agitated
Indifferent	Enjoying	Tense	Confident
Frustrated	Indifferent	Enjoying	Depressed
Friendly	Frustrated	Frustrated	Calm
Bored	Friendly	Sociable	Content
Playful	Bored	Bored	Tense
Positively occupied	Positively occupied	Playful	Inquisitive
Lively	Inquisitive	Positively occupied	Unsure
Inquisitive	Irritable	LIstless	Energetic
Irritable	Nervous	Lively	Frustrated
Uneasy	Boisterous	Indifferent	Bored
Sociable	Uneasy	Irritable	Friendly
Apathetic	Sociable	Aimless	Positively occupied

Dairy Cows	Fattening Cattle	Pigs	Poultry (Fattening Chickens and Laying Hens)
Happy Distressed	Happy Distressed	Happy Distressed	Scared Drowsy Playful Nervous Distressed

Annexe 12 Mapping of Crops

Table A. 14: Mapping of crops to land-use types with preference values

Code BFS	Crop	CropPhaenology	Allocation
X0501	Summer barley	WintergetrErszSommerG	Replacement allocated
X0502	Winter barley	Winter cereals	Allocated
X0504	Oats	WintergetrErszSommerHa	Replacement allocated
X0505	Triticale	Winter cereals	Replacement allocated
X0506	Mischel (wheat/rye mixture), feed grain	Winter cereals	Replacement allocated
X0507	Feed wheat	Winter cereals	Replacement allocated
X0508	Grain maize	Maize	Allocated
X0511	Emmer/ Einkorn wheat	Winter cereals	Replacement allocated
X0512	Summer wheat (excluding swiss granum feed wheat)	WintergetrErszSommerG	Replacement allocated
X0513	Winter wheat (excluding swiss granum feed wheat)	Winter cereals	Allocated
X0514	Rye	Winter cereals	Replacement allocated
X0515	Mischel (Wheat/rye mixture), bread grain	Winter cereals	Replacement allocated
X0516	Spelt	Winter cereals	Replacement allocated
X0519	Seed maize	Maize	Allocated
X0521	Silage maize & Green maize	Maize	Allocated
X0522	Sugar beet	RübenErszZuckerR	Replacement allocated
X0523	Fodder beet	Beets	Allocated
X0524	Potatoes	RübenErszKartoffeln	Replacement allocated
X0525	Seed potatoes	RübenErszKartoffeln	Replacement allocated
X0526	Summer oilseed rape, edible-oil extraction	Oilseed rape	Allocated
X0527	Winter oilseed rape, edible-oil extraction	Oilseed rape	Allocated
X0528	Soybean	Not available	No allocation
X0531	Sunflower, edible-oil extraction	RapsErszSonnenBL	Replacement allocated
X0534	Flax	Not available	No allocation
X0535	Hemp (according to FOAG)	Not available	No allocation
X0536	Field beans	Not available	No allocation
X0537	Protein peas	Not available	No allocation
X0538	Lupin	Not available	No allocation
X0539	Oil squash	Not available	No allocation
X0541	Tobacco	Not available	No allocation
X0542	Millet	Not available	No allocation
X0545	Annual field vegetables	Not available	No allocation
X0546	Field vegetables for canning	Not available	No allocation
X0547	Chicory roots	Not available	No allocation
X0551	Annual berries	Not available	No allocation
X0552	Annual renewable resources	Not available	No allocation

Code BFS	Crop	CropPhaenology	Allocation
X0553	Annual aromatic and medicinal plants	Not available	No allocation
X0554	Annual horticultural field crops	Not available	No allocation
X0556	Wildflower strip	Wildflower strip	Allocated
X0557	Rotational fallow	Wildflower strip	Similar allocated
X0559	Margin on arable land	Margin	Similar allocated
X0562	Phacelia for seed production	Not available	No allocation
X0563	Other crop for seed production	Not available	No allocation
X0590	Summer oilseed rape, renewable resource	Oilseed rape	Allocated
X0591	Winter oilseed rape, renewable resource	Oilseed rape	Allocated
X0592	Sunflower, renewable resource	RapsErszSonnenBL	Replacement allocated
X0597	Other open arable land, eligible for subsidy payments	Not available	No allocation
X0598	Other open arable land, not eligible for subsidy payments	Not available	No allocation
X0599	Total open arable land	Ignore	Delete
X0601	Temporary leys	Temporary ley	Allocated
X0611	Low-input meadows	Low-input meadow	Similar allocated
X0612	Fairly low-input meadows	High-input meadow	Similar allocated
X0613	Other permanent meadows	High-input meadow	Similar allocated
X0616	Pastures	High-input pasture	Allocated
X0617	Low-input pastures	Low-input pasture	Similar allocated
X0618	Forest pastures	Not available	No allocation
X0619	Pastures for pigs and poultry	Not available	No allocation
X0621	Hay meadows in the summer grazing area, other	Ignore	delete
X0622	Hay meadows in the summer grazing area, low-input	Ignore	delete
X0623	Hay meadows in the summer grazing area, fairly low input	Ignore	delete
X0625	Forest pastures	Not available	No allocation
X0631	Fodder legumes for seed production	Not available	No allocation
X0632	Forage grasses for seed production	Not available	No allocation
X0633	Other forage plants for seed production	Not available	No allocation
X0695	Other green spaces, allowable RLU (=roughage-consuming	Not available	No allocation

Code BFS	Crop	CropPhaenology	Allocation
	livestock units) & ecological compensation areas		
X0697	Other green spaces, allowable RLU	Not available	No allocation
X0698	Other green spaces, non-allowable RLU	Not available	No allocation
X0699	Total green spaces	Ignore	delete
X0701	Grapevines	Not available	No allocation
X0702	Orchards (apples)	Not available	No allocation
X0703	Orchards (pears)	Not available	No allocation
X0704	Orchards (stone fruit)	Not available	No allocation
X0705	Perennial berries	Not available	No allocation
X0706	Perennial aromatic and medicinal plants	Not available	No allocation
X0707	Perennial renewable resources	Not available	No allocation
X0708	Hops	Not available	No allocation
X0709	Rhubarb	Not available	No allocation
X0710	Asparagus	Not available	No allocation
X0711	Mushrooms	Not available	No allocation
X0712	Christmas trees	Not available	No allocation
X0713	Nursery for forest plants outside the forestry zone	Not available	No allocation
X0714	Ornamental bushes, ornamental trees and ornamental shrubs	Not available	No allocation
X0715	Other nurseries	Not available	No allocation
X0716	Maintained groves (chestnut and walnut trees)	Not available	No allocation
X0731	Other orchards	Not available	No allocation
X0797	Other areas of permanent crops, eligible for subsidy payments	Not available	No allocation
X0798	Other areas of permanent crops, not eligible for subsidy payments	Not available	No allocation
X0799	Total area, permanent crops	Ignore	delete
X0801	Vegetable crops, greenhouses with solid foundation	Not available	No allocation
X0802	Other special crops, greenhouses with solid foundation	Not available	No allocation
X0803	Horticultural crops, greenhouses with solid foundation	Not available	No allocation
X0806	Vegetable crops, protected cultivation without solid foundation	Not available	No allocation
X0807	Other special crops, protected cultivation without solid foundation	Not available	No allocation
X0808	Horticultural crops, protected cultivation without solid foundation	Not available	No allocation
X0847	Other crops, protected cultivation without solid foundation	Not available	No allocation

Code BFS	Crop	CropPhaenology	Allocation
X0848	Other crops, protected cultivation with solid foundation	Not available	No allocation
X0851	Extensively managed wet areas	Extensively managed wet meadow	Similar allocated
X0852	Hedgerows, copses and wooded river banks with herbaceous edge, ECAs for which no federal subsidy payments are drawn, but which count towards PEP	Hedge	Allocated
X0857	Hedgerows, copses and wooded river banks with buffer strips	Hedge	Allocated
X0895	Other land within the UAA, ECAs in receipt of federal subsidy payments	Not available	No allocation
X0897	Other land within the UAA, eligible for subsidy payments	Not available	No allocation
X0898	Other land within the UAA, not eligible for subsidy payments	Not available	No allocation
X0901	Forest	Not available	No allocation
X0902	Unproductive land	Not available	No allocation
X0903	Land with no assigned main agricultural purpose	Not available	No allocation
X0904	Ditches, pools and ponds	Not available	No allocation
X0905	Ruderal sites, cairns and stone walls	Not available	No allocation
X0906	Dry walls	Not available	No allocation
X0907	Unpaved natural paths	Not available	No allocation
X0908	Further ecological compensation areas	Not available	No allocation
X0909	House gardens	Not available	No allocation
X0930	Summer grazing pastures	Ignore	Delete

Annexe 13 PestLCI Mass Flow Diagram

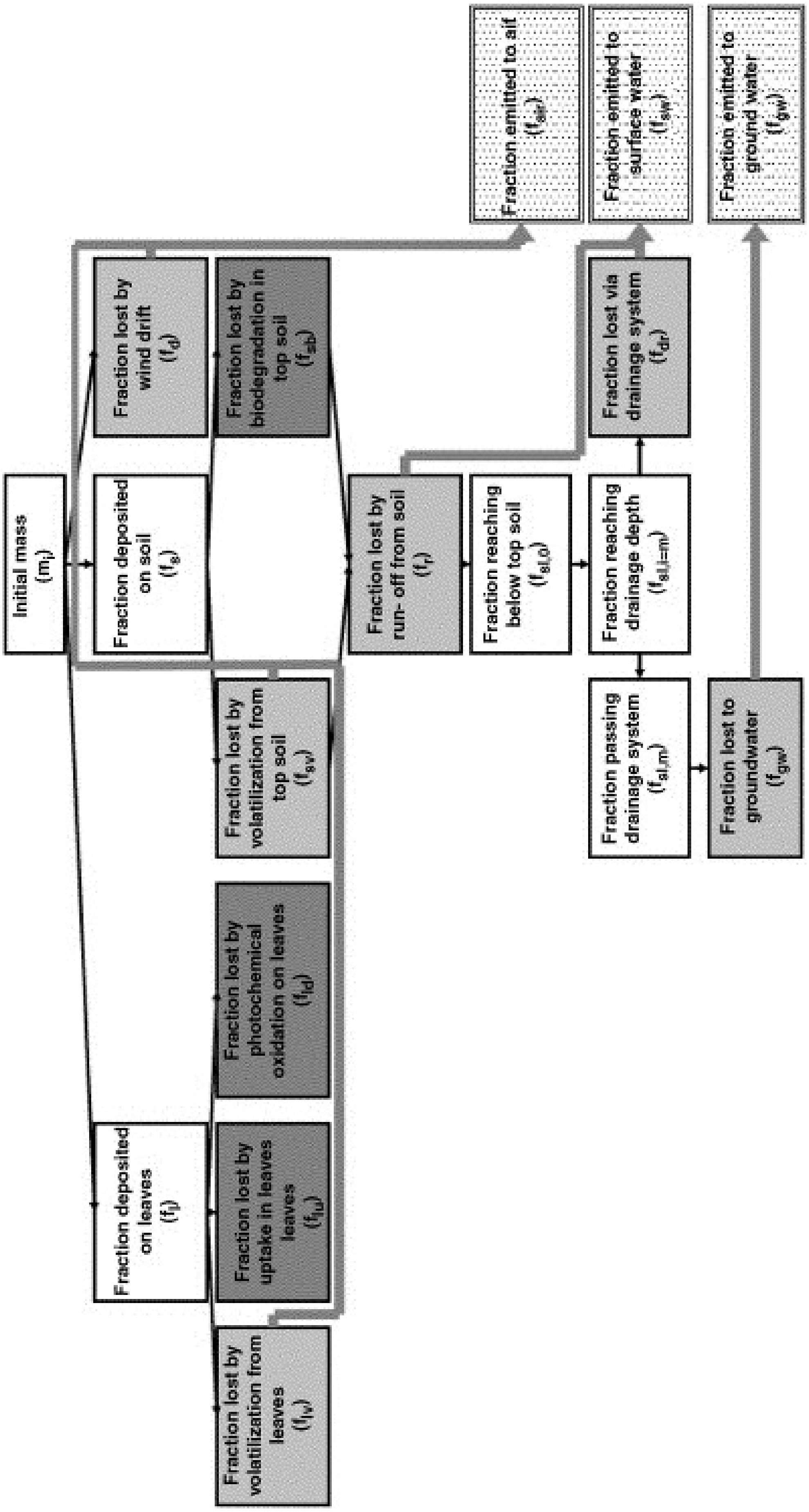

Figure A. 1: PestLCI 2.0 mass flow diagram according to Birkved and Hauschild (2006).

Annexe 14 USEtox 1.01 Input Parameters

Table A. 15: Required input parameters for aquatic ecotoxicity in USEtox, with the additional indication of whether the parameter is required in PestLCI 2.0 (Huijbregts et al. 2010a).

Parameter	Abbreviation	Unit	Approximation possible?	Necessary for PestLCI?
Bioaccumulation factor in fish	BAFfish	l/kg	Yes	
Degradation rate, air	kdega	1/s	Yes	
Degradation rate, water	kdegw	1/s	Yes	
Degradation rate, soil	kdegsl	1/s	Yes	
Degradation rate, sediment	kdegsd	1/s	Yes	
Partition coefficient between suspended solids and water	KpSS	l/kg	No	
Average log EC50 for aquatic species	avlogEC50	mg/l	No	
Molecular weight	MW	g/mol	No	Yes
Partition coefficient, octanol/water	K_{OW}	-	No	Yes
Melting point	Tm	°C	No	
Henry's law constant	KH_{25C}	Pa m^3 mol^{-1}	Yes	
Partition coefficient, organic carbon / water	K_{OC}	l/kg	Yes	Yes
Partition coefficient, dissolved organic carbon/water	K_{DOC}	l/kg	Yes	
Vapour pressure	Pvap25	Pa	No	Yes
Water solubility	Sol25	mg/l	No	Yes
First dissociation constant	pKa	-	No	Yes

Annexe 15 Standard Values for the Site-Specific Input Parameters in USEtox 1.01

Table A. 16: Standard values for the site-specific input parameters in USEtox 1.0 (Huijbregts et al. 2010a).

Parameter	**Unit**	**Standard Value, Continental**	**Standard Value, Global**
Area, land	km^2	$9.01 * 10^6$	$1.41 * 10^8$
Area, sea	km^2	$9.87 * 10^5$	$3.29 * 10^8$
Fraction of area with freshwater	--	0.03	0.03
Fraction of area with natural soil	--	0.49	0.49
Fraction of area with agricultural soil	--	0.49	0.49
Fraction of area with other soil	--	$1.00 * 10^{-20}$	$1.00 * 10^{-20}$
Ambient temperature	°C	12	12
Wind speed	$m\ s^{-1}$	3.00	3.00
Rain	$mm\ yr^{-1}$	700	700
Depth of freshwater	m	2.5	2.5
Fraction of surface runoff	--	0.25	0.25
Fraction of infiltration	--	0.25	0.25
Erosion rate	$mm\ yr^{-1}$	0.03	0.03

Annexe 16 PestLCI Sensitivity Analysis

The following variations were created for the four crops maize, potatoes, oilseed rape and stone fruits, with the pesticide atrazine used for maize, mancozeb for potatoes, thiacloprid for oilseed rape, and iprodione for the stone fruits.

Table A. 17: Varied input parameters in the PestLCI sensitivity analysis.

Input Parameter	**Standard Value**	**Tested Variations**
Soil	Soil type 1	Soil type 2
		Soil type 3
		Soil type 4
		Soil type 5
		Soil type 6
		Soil type 7
Climate	'Alpine: Lugano (CH)' climate type	Climate type: 'North Mediterranean I: Dijon (FR)'
		Climate type: 'Subalpine Continental: Kresmünster (AT)'
Irrigation	100 mm	200 mm
		300 mm
Developmental stage (month)	Maize: Stage I (May)	Stage II (June) Stage III (July) Stage IV (August)
	Potatoes: Stage III (May)	Stage I (March) Stage II (April) Stage IV (June)
	Oilseed rape: Stage II (April)	Stage I (March) Stage III (May)
	Stone fruits: Stage II (April)	Stage I (March) Stage III (May) Stage IV (June)
Month	Maize (May)	April, June
	Potatoes (May)	April, June
	Oilseed rape (April)	March, May
	Stone fruits (April)	March, May
Tillage	Conventional tillage	No-till, reduced tillage
Macropore fraction	0.3	0.2 / 0.4 / 0.7
Buffer zone	m s^{-1}	3.00
Buffer zone (without drainage)	0 m	3 m, 6 m
Drainage	0.55	0 / 0.3 / 1