Assessment of sustainability indicators on farms under real-life conditions

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Abstract: *Despite the widespread acceptance of the 'three-pillar' model for sustainability – environmental, social and economic – there is still a serious lack of technically and practically feasible data-collection solutions for use in conducting a quantitative sustainability assessment of agricultural holdings. Various methods intended to provide a comprehensive assessment of sustainability at the farm level are available. However, most of them suffer from either a failure to provide a clear conceptual framework, insufficient thematic coverage (e.g., ignoring animal welfare or landscape quality) or both.*
Therefore, Agroscope has recently completed a project that aimed to develop a scientifically sound set of indicators of the most relevant aspects of sustainability, following a life-cycle approach (Roesch et al., 2017). The developed method, SALCASustain, includes a comprehensive evaluation of the following impact categories: resource use, global warming, eutrophication and acidification, ecotoxicity, biodiversity, soil quality, economic sustainability, and social sustainability. Serious gaps remain, particularly in the development of feasible indicators for the socio-economic dimension of sustainability, as well as some environmental indicators.
Therefore, we placed a special focus on advancing the following aspects of sustainability: (1) social sustainability: physical and mental workload and the aesthetic value of the agricultural landscape; (2) ecotoxicity, biodiversity and soil quality and (3) economic indicators, which reflect the long-term economic viability of agricultural holdings.
In order to test this set of sustainability indicators under real-life conditions, the SustainFarm project was launched in 2016. This project aims to determine the scientific soundness and feasibility of the indicator system on ten farms in Switzerland, including data acquisition, the computation of the sustainability indicators, the analysis and the feedback to the individual farmer.
This paper discusses the first results of the entire process, i.e., the experience gained during data collection, the communication with the farmers and the computation of the indicators, as well as the significance of the indicator set for estimating the overall sustainability of the investigated farms. Based on these results, ways to improve the SALCASustain method and its implementation will be discussed and implemented.
At the current stage of the work, we can conclude the following: (1) the computation of indicators requires a great deal of manpower due to the demanding data preparation process; (2) timely data acquisition at a reasonable accuracy is a demanding process and requires a well-developed data flow between farmers, the parties collecting the data and indicator specialists and (3) the interpretation of the results provides deep insights into the relationships between the various sustainability indicators.

Keywords: *Sustainability of farms, indicators, data acquisition, sustainability assessment tools*

Introduction

The comprehensive assessment of the sustainability of farms is gaining increased importance for all actors in the value chain (producers, processors, traders and consumers). In order to gain an overall view, it is important not only to include the environmental impacts of farming but also to assess the economic viability of a given farm, as well as its social structure. The explicitly equal status of these three dimensions is first found in the 'Triple Bottom Line' concept, formulated by 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 in the agricultural sphere.
Consequently, two methods termed RISE (Response-Inducing Sustainability Evaluation; Grenz et al., 2012) 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. Because these two methods focus on the simple and rapid evaluation of farms throughout the world, a set of indicators has been recently developed for a more in-depth analysis of Swiss farms (Roesch et al., 2017). These indicators are based on quantitatively measurable criteria.

In order to apply and evaluate these indicators under real-life conditions, the *SustainFarm* project was launched in 2016. This project was used to test the framework, including data acquisition and communication with the farmers. For this purpose, ten pilot farms were selected that belonged to the IP-Suisse association, a federation of farmers whose aim is to produce in an environmentally sound manner according to integrated production (IP) standards. These farms must follow guidelines concerning animal welfare, crop rotation, plant protection and biodiversity.

The project runs from 2016 to 2019 and consists of two phases with two data collection years. In this paper, we present the results of the first project phase.

Our first experiences show that a data collection process based on Excel spreadsheets, including a plausibility control, is appropriate for a limited number of farms. However, the large number of input variables (up to several thousands, depending on farm type and size, equipment and management practices) requires that we reduce the manual work of the data acquisition and preparation.

The statistical analysis of the computed indicators is complicated by the small sample size of ten farms. Nevertheless, the results of the initial test phase provide reasonable and interpretable results. Furthermore, a correlation analysis has been performed in order to identify synergies and trade-offs between the indicators. The derivation of composite indicators was, however, not an aim of this study and will be treated in detail during the 2018–2021 working program.

The set of indicators is also well-qualified for monitoring purposes because they are mainly based on quantifiable input variables and also capture fairly small changes in a farm's operational setup due an adequate and complete description of the main factors of influence. In the future, the Swiss association IP-Suisse and a leading Swiss retailer aim to apply a selected subset of the indicators to a large sample of farms for monitoring purposes.

Methods

Within this study, the following aspects of sustainability were considered: social sustainability: work load, landscape; economical sustainability: economic situation; and environmental sustainability: resource use, climate change, nutrient management, ecotoxicity, biodiversity and soil quality. The method includes a total of 34 individual indicators (see Roesch *et al.*, 2017). In this paper, we present the results for the indicators listed in Roesch *et al.* (2017). These indicators are further detailed below.

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

<table>
<tr><th>Dimension</th><th>Subject</th><th>Indicator</th><th>Implementation</th></tr>
<tr><td rowspan="2">Social</td><td>Well-being</td><td>Workload in terms of time</td><td>Ratio of needed to available labour units (Roesch et al., 2017, Chap. 3)</td></tr>
<tr><td>Landscape quality</td><td>Landscape diversity and aesthetics</td><td>Shannon Index, calculated from AGIS structural data (Roesch et al., 2017, Chap. 6)</td></tr>
<tr><td rowspan="2">Economic</td><td rowspan="2">Profitability</td><td>Earned income per family labour unit</td><td rowspan="2">Direct calculation from accounting data (Roesch et al. 2017, Chap. 7)</td></tr>
<tr><td>Total return on capital</td></tr>
</table>

Dimension	**Subject**	**Indicator**	**Implementation**
	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 Centre, 2007)
		Phosphorus and potassium	CML 2001 method (Guinée *et al.,* 2001)
		Water requirement (fresh water)	Method of Pfister *et al.* (2009)
		Land use	CML 2001 method (Guinée *et al.*, 2001).
	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, Hauschild et al., 2006)
		Acidification (aquatic and terrestrial)	Acidification potential: 'accumulated exceedance' method for terrestrial acidification, see Seppälä *et al.*, 2006 and Posch *et al.*, 2008.
	Ecotoxicity	Ecotoxicity	CML2001 method (Guinée *et al.,* 2001)
	Biodiversity	Genetic and species diversity	IP-Suisse credit point system (Birrer *et al.*, 2014)
		Habitat diversity and linkage	
		Diversity of agricultural crops	
		Potentially natural habitat	
		Plant-protection products	
		Fertiliser use	
		Irrigation	
		Use intensity, management technique	
		Functional aspects	
	Soil Quality	Physical indicators: rooting depth, macropore volume, aggregate stability	SALCA-SQ (Oberholzer *et al.,* 2012)
		Chemical indicators: organic carbon, heavy metal content, organic pollutants	
		Biological indicators: microbial activity, microbial biomass, earthworm biomass	

Social Dimension

Temporal workload

The sustainability indicator for workload (*SIW*) is comprised of only a temporal aspect and is computed by the ratio of the required workforce to the workforce available on the farm:

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

The required workforce will be calculated according to the Global Work Budget (ART Work Budget) developed at Agroscope (Schick *et al.,* 2007). The labour actually available on the farms will be retrieved from the Agricultural Information System (AGIS) Database of the Federal Office for Agriculture (FOAG).

Visual quality of the landscape

The landscape indicator reproduces certain aspects of the findings presented in Tveit *et al.* (2006), whose concept of landscape summarises several visual dimensions, such as complexity and naturalness. The newly developed indicator (Schüpbach *et al*., 2018, in prep.) is calculated as the equally weighted mean of two sub-indicators. The first sub-indicator covers naturalness, or visual quality, and is computed as an area-weighted mean of the so-called 'preference values' of the landscape elements of a farm. The preference values reflect the preference of the general public for various land-use types. The second sub-indicator covers the aspect of complexity and the "ephemera" of the landscape and is approximated by the Shannon diversity index. The seasonal variation is accounted for using biweekly data for the preference values during the vegetation period (end of March to middle of October).

In order to compare the results for different farms, the indicators were normalised using the mean landscape indicator results of comparison groups of Swiss farms.

Economic Dimension

The economic situation of a farm is characterised with two indicators from each of three fields: profitability, liquidity and stability (Roesch *et al*., 2017).

For profitability, which is designated as the ratio of an economic result to the utilised production factors, the two indicators proposed are 'earned income per family labour unit' (IFLU) and 'total return on capital' (ROC).

The IFLU value is derived from agricultural income as remuneration for the family's own labour and capital. The ROC value is a very common measure of profitability, and it is computed as the ratio of net income to capital. It thus compares the farm's profit for a particular period with the capital invested.

For liquidity, i.e., the availability of sufficient means of payment, the two indicators of the 'cash flow rate' (CFR, also known as 'cash flow-turnover rate') and the 'dynamic gearing ratio' (DGR) are recommended.

The CFR is defined by the ratio of the cash flow and the turnover and thus indicates the farm's efficiency in its use of cash for the generation of sales revenue.

The DGR compares the farm liabilities with the cash flow. The farm liabilities include both the short- and long-term debts. The DGR measures how many years the current cashflow must be generated in order to pay all the debts.

The stability of a farm estimates risk with respect to profitability and liquidity, thereby underscoring the long-term component of economic sustainability. The two indicators of 'investment intensity' (ININT) and 'capitalisation ratio' (CR, also called 'investment coverage') were selected to describe a farm's stability. The ININT is the ratio of fixed assets (machinery and buildings) to total assets. The CR is computed by dividing the own capital (or farm equity) by the fixed assets.

Environmental Dimension

The estimation of the environmental impact is based on the SALCA (Swiss Agricultural Life Cycle Assessment) method (Nemecek et al., 2003).

The direct field and farm emissions are computed as follows:

- *Methane emissions* from the digestive systems of animals, on pasture, and through farmyard-manure management are calculated with the IPCC (2006) emission factors (detailed in Tier 2 methodology).
- The losses of *ammonia* (NH_3) from animal husbandry; manure management, including manure application, and grazing are calculated according to the Agrammon model (HAFL

2013a, 2013b). Emissions from mineral nitrogen fertilisers are calculated using emission factors according to the EEA (2013).

- Nitrate *(NO_3^-)* leaching is estimated on a monthly basis by accounting for N mineralisation in the soil and N uptake by the vegetation, as detailed in the SALCA-nitrate model (Richner *et al*., 2014).

- Nitrous oxide *(N_2O)* emissions from grazing cattle are differentiated between urine and dung because *N_20* emissions from urine are considerably higher than those from dung (Nemecek and Alig, 2016).

- Nitrous oxide emissions after the application of mineral and organic N fertilisers are modelled using a quadratic function of the N fertiliser rate to correct the IPCC EFs (Tier 1).

- *NO_x* emissions are modelled according to the EEA (2013) and Bystricky *et al.* (2014).

- Three phosphorus emissions pathways to water are included, namely surface run-off as phosphate and erosion as phosphorus to rivers, as well as leaching to ground water as phosphate (Prasuhn, 2006).

- The heavy metal emissions were calculated via SALCA-heavy metal (Freiermuth, 2006). Inputs into farm land and outputs to surface water and groundwater were calculated on the basis of heavy metal input from seed, fertilisers, plant protection products and deposition. The amount of eroded soil is calculated as P-emissions using the method described in Oberholzer (2006).

The life-cycle impact assessment (LCIA) methods are based on mid-point categories, mainly derived from the EDIP2003 (Hauschild *et al.,* 2006) and CLM01 methods (Guinée *et al.,* 2001).

The following LCIA mid-points have been applied in this study:

- The computation of the global warming potential over 100 years follows the recommendation of the IPCC (2013).

- The demand for non-renewable energy resources (oil, coal and natural gas) is computed according to the ecoinvent Centre (2007) data.

- Eutrophication potential (impact of the losses of N and P to aquatic and terrestrial ecosystems) is calculated according to the EDIP2003 method (Hauschild and Potting 2005). The method provides indicators of terrestrial eutrophication (dominated by NH_3), aquatic N eutrophication (dominated by NO_3) and aquatic P eutrophication (all emissions of P to water). In order to interpret the total eutrophication potential, these three indicators have been normalised and aggregated.

- Acidification potential (impact of acidifying substances released into ecosystems) is estimated as recommended in ILCD 2011 (EC-JRC-IES 2011). It is based on the accumulative exceedance method (Seppälä *et al.,* 2006; Posch *et al.,* 2008).

- Terrestrial and aquatic ecotoxicity and human toxicity potentials are computed according to the CML01 method. Characterisation factors for about 400 active ingredients in pesticides were included (Kägi *et al.* 2008; Hayer *et al.* 2010).

- Land competition (in m^2a) is assessed via the CML 2001 method (Guinée *et al.* 2001). It is an unweighted sum of all land areas occupied.

- Water use is assessed via the sum of consumptive water use (in m^3) and includes only blue water (water extracted from water bodies). The water stress index is computed according to Pfister *et al.* (2009).

- The use of phosphorus and potassium resources is assessed at the inventory level, without applying a characterisation factor.
- The SALCA soil quality method assesses the impacts of management practices on nine soil quality indicators representing the physical (rooting depth, macropore volume and aggregate stability), chemical (organic C content, heavy metal content and organic pollutants) and biological properties (earthworm biomass, microbial biomass and microbial activity) of the soil (Oberholzer *et al.,* 2006; Oberholzer *et al.,* 2012).
- Biodiversity: The usage types of all biodiversity promotion areas, 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, the upgrading of forest edges, rare livestock breeds and plant varieties, target species, and resource-protection measures, are rated with a credit point system.

Note that a farm's level of biodiversity has not been assessed via SALCA-biodiversity but rather by the IP-Suisse credit point system.
The acidification potential is largely caused by ammonia (NH_3), nitrous oxides (NO_x) and sulphur dioxide (SO_2). After nitrification, ammonia has an acidifying effect in the soil. Because, in agricultural systems, NH_3 clearly dominates acidification, this measure is closely related to terrestrial eutrophication (Roesch *et al.,* 2017). Thus, terrestrial eutrophication has been omitted in the presentation of the results and the discussion.

Farm sample

The data for ten farms were sampled for the 2015/16 business year. Some key variables concerning land use and livestock are listed in Table 2. Each farm belongs to one of the three following groups:

(i) MOUNT: Mountain dairy farms composed primarily of grasslands in the "Emmental" and "Entlebuch" communities situated in the Swiss mountains.

(ii) ARAB: Arable farms in the western part of Switzerland (fraction of cropland above 75% of utilised agricultural area (UAA), with less than 20 livestock units (LUs).

(iii) PIG: Lowland fattening farms in the canton of Lucerne with predominantly pigs (more than 3 LU/ha and LU of pigs > 8).

Table 2: List with some key characteristics of the ten analysed Swiss farms within this study. AUU: Agricultural utilised area, EFA: Ecological focus area; LUs: Livestock units. Data are for the year 2016.

Abbreviation	AUU [ha]	Fraction of arable land [%]	Grassland fraction [%]	EFA fraction [%]	LU (total)	Animal species
MOUNT1	30.9	0	95.5	13.4	79.2	Dairy cows/ young cattle/ poultry
MOUNT2	23.2	0	96.1	19.9	25	Dairy cows/ fattening calves
MOUNT3	53.4	2.2	86.1	11.7	77.5	Dairy cows/ mother cows/horses
MOUNT4	50.1	0	64.1	62.3	44.8	Mother cows, horses/llamas
MOUNT5	13.4	10.1	83.6	8.9	21.2	Mother cows
ARAB1	33.7	61.2	14.9	27.7	4.5	Horses
ARAB2	50.7	90.1	6.9	8.7	11.4	Dairy cows
ARAB3	22.7	73.8	0.8	17.3	0	No animals
PIG1	22.9	27.7	65.3	9.6	57.3	Pigs/mother cows, young cattle
PIG2	22.8	11.2	82.6	10.7	95.5	Pigs/beef cattle
Mean	32.4	27.6	59.6	19.0	41.6	
Median	27.1	10.7	74.0	12.6	34.9	
Standard deviation (SD)	14.2	34.4	37.6	16.3	34.3	
Coefficient of variation (VAR)	0.44	1.25	0.63	0.86	0.82	

The mean AUU value of the ten analysed farms was equal to 32.4 ha. The farms hold, on average, 41.6 LUs. Thus, the farms' mean size is clearly above the Swiss mean of 25.3 ha (Hoop *et al.,* 2017). Crop cultivation is performed on little more than a quarter of the total AUU, while grassland covers close to 60% of the total AUU. A substantial part of the farmland consists of EFAs (Ecological Focus Areas), such as low-input meadows and pastures, moist meadows, wildflower strips, hedgerows or high-stem orchards. MOUNT4 especially stands out: almost two-thirds of the AUU belongs to areas of particular significance from an ecological point of view. This farm has not only substantial strips of extensive meadows and pastures of high ecological value but also more than 14 ha of straw fields.

The ten analysed farms vary significantly in size, animal population and type. This is evident upon inspecting the values for the coefficient of variation (VAR) provided in Table 1. In fact, VAR is a particularly suitable measure for specifying the spread of the data because it specifies the variation in proportion to the sample mean.

The five dairy farms hold dairy cows primarily for the production of milk and fattening, partly supplemented by other farm animals such as poultry (MOUNT1) and horses (MOUNT3). MOUNT2 also rears fattening veal calves, and MOUNT4 raises a few llamas, foals, ponies and goats. The three farms MOUNT1, MOUNT2 and MOUNT4 are pure grassland farms with no crops, while farm MOUNT3 does cultivate silage maize, and MOUNT5 cultivates vegetables, medicinal and aromatic plants and some berries.

The three sampled arable farms are characterised by a high percentage of arable land and little livestock. ARAB1 predominantly cultivates winter wheat, triticale and sunflowers; ARAB2 cultivates grain maize, winter wheat, sugar beet, potatoes and winter rapeseed, while ARAB3 grows summer/winter wheat, sunflowers and sugar beets. Only ARAB2 maintains a significant herd of twelve cattle.

The two pig farms, PIG1 and PIG2, hold – in addition to pigs – a substantial number of young cattle (PIG1) and mother cows (PIG2). PIG1 managed 236 pig places in 2016, while PIG2 raised slightly above 100 breeding sows, 280 weaned piglets and 281 suckling piglets, as well as well as 30 fattening pigs.

Data

Farm structure census: The farm structure census results are compiled annually by the Federal Statistical Office (FSO). The census is comprised of an exhaustive farm inventory regarding crop areas and livestock data and also the labour force. Different types of grassland are differentiated (e.g., intensive/extensive meadows and pastures). Grassland area is given according to the management system used. Furthermore, ecological focus areas (EFAs), such as low-input meadows and pastures, moist meadows, wildflower strips, hedgerows and high-stem orchards, are provided as well.

For this study, the normalisation of the landscape quality indicator was performed using the 2016 farm structure census.

Inventory data for SALCA: Farmers entered most of their management data into a ‘field calendar’, which was made available to us by the IP-SUISSE farming association. For all management data that were still missing afterwards, we compiled an extra data collection sheet using Excel, which every farmer also had to fill in.

Biodiversity: The data that are required for the calculation of the IP-Suisse credit points (biodiversity scores) were compiled by the IP-SUISSE association.

Results

Here, we summarise the main results of the investigated sustainability indicators. We added descriptive statistics despite the relatively small sample size because the findings nevertheless provide some valuable insight into the distributions of the indicators.

Social Dimension

Table 3: Social indicators 'Landscape quality' and 'Workload' for the ten farms described in Table 2.

Farm ID	Normalised landscape quality [ ]	Workload
MOUNT1	1.069	1.36
MOUNT2	0.980	0.72
MOUNT3	1.068	0.77
MOUNT4	1.129	0.62
MOUNT5	1.023	0.90
ARAB1	1.143	0.73
ARAB2	0.993	0.78
ARAB3	0.986	0.34
PIG1	1.117	1.37
PIG2	1.139	0.98
Mean	1.064	0.86
Median	1.069	0.78
Standard deviation (SD)	0.066	0.32
Coefficient of variation (VAR)	0.060	0.32

Table 3 shows that the normalised landscape quality indicator is quite similar for all investigated farms. Because the indicators are normalised, the average of slightly above 1 points to the fact that the farms under study generally contribute to a visually "nice" landscape. The three farms MOUNT4, ARAB1 and PIG1 have a distinctly above-average visual quality, while the two PIG farms and MOUNT3 seem to contribute little to a diverse landscape. The landscape indicator is the arithmetic sum of two sub-indicators (preference for the landscape elements and diversity). A closer inspection reveals that for the two farms MOUNT4 and ARAB1, both sub-indicators contribute equally to the above-average landscape indicator, while PIG1 especially profits from its highly diverse landscape.

The indicator for temporal workload compares the theoretically derived working-time input and the workforce available on the farm. The evaluation reveals large differences between the farms under study (Table 3). While MOUNT1 and PIG1 show a clear tendency toward a potential lack of labour, ARAB3 seems to suffer from distinct underemployment. On average, a mean value of 0.86 points to a slight underemployment on these farms.

Economic Dimension

Economic sustainability will be assessed by two indicators each for three fields: profitability, liquidity and stability (Table 4).

Table 4: Economic indicators for the ten farms described in Table 2. NA: data not yet provided correctly or not plausible. EFWU: earned income per family labour unit, ROC: return on capital, CFR: cash flow ratio (also called cash flow turnover rate), DGR: dynamic gearing ratio, ININT: investment intensity, CR: capitalisation ratio.

Farm ID	Profitability		Liquidity		Stability	
	IFLU [CHF]	ROC [%]	CFR [%]	DGR [ ]	ININT [ ]	CR [ ]
MOUNT1	55630	-1.6	36	11.6	0.91	0.44
MOUNT2	26860	-54.3	-7	NA	0.57	1.74
MOUNT3	16770	-6.6	62	18.3	0.86	0.33
MOUNT4	88850	1.0	119	0.44	0.84	1.02
MOUNT5	35160	-6.9	74	12.5	0.77	0.52
ARAB1	47210	-35.1	NA	NA	0.54	1.57
ARAB2	55150	-13.0	32	NA	0.30	3.12
ARAB3	20070	-21.5	0.26	0.56	0.88	0.95
PIG1	77800	0.4	61	1.35	0.90	0.96
PIG2	38160	-3.3	16	2.87	0.81	0.90
Mean	46170	-14.1	49.1	6.8	0.74	1.16
Median	42690	-6.7	48.5	2.9	0.83	0.96
Standard deviation (SD)	23800	18.1	38.8	7.2	0.20	0.83
Coefficient of variation (VAR)	0.52	-1.28	0.79	1.06	0.27	0.71

The results in Table 4 clearly show that the economic situation of the analysed farms differs significantly regarding profitability, liquidity and stability. The coefficient of variation (VAR) indicates that the variability is lowest for the ININT stability indicator.

The income per family work unit (EFWU) varies between approximately 16'800 CHF (farm MOUNT3) and 88'850 CHF (farm MOUNT4); the average is slightly above 46'000 CH, which is – coincidentally – quite close to the Swiss average EFWU of 47'200 CHF in 2016 (Hoop *et al.,* 2017). The mean ROC is -14.1%, which means that the farm's profit after the remuneration of the family members is negative. Only two farms profit from a slightly positive ROC.

The mean cash flow ratio (CFR) is 49%, meaning that the cash flow is, on average, about half of the turnover. Most of the farms seem to have sufficient liquid means. However, the variation coefficients of 0.79 indicate significant differences between the farms regarding their liquidity levels. The negative CFR value for MOUNT2 is due to negative cashflow, indicating serious liquidity problems for that farm. A closer inspection of this result reveals that the key driver of this negative cash flow is the low annual profit, combined with relatively high private consumption.

The median DGR amounts to 6.8. Again, the differences between the farms regarding the dynamic gearing ratio are large: MOUNT3 needed more than 18 years to pay all its debts with the cash flow generated in 2016, while MOUNT4 needs less than half a year to be debt-free.

The stability of the companies is characterised by the two indicators ININT and CR. The mean ININT is 0.74; i.e., 74% of the total assets are bound to machinery and buildings. A low value of 0.3 was noticeable for ARAB2. A closer inspection reveals that this is related to the low value of that farm's fixed assets (114'700 CHF). The average CR (1.16) is clear evidence that the farms are generally economically stable because their own capital is higher than their fixed assets (machinery and buildings). However, a critical situation in terms of insufficient own capital is found for MOUNT1 and MOUNT3. Crop farming seems to have a favourable effect on the CR stability indicator.

Environmental Dimension

We restrict our tabulations to the values for five important environmental impacts (midpoints) per hectare and year. Values based on the functional unit *MJ digestible energy* are omitted here for reasons of simplicity but are included in the discussion. Nevertheless, the rankings of the farms according to environmental impact differ for the two functional units.

Table 5: Life-cycle impact results per hectare and year for the ten farms described in Table 2. Units are given in brackets.

FARM ID	Energy demand [GJ-eq/(ha a)]	Global warming potential [kg CO2-eq / (ha a)]	Aquatic N Eutrophication potential [kg N / (ha a)]	Acidification potential [m^2 / (ha a)]	Terrestrial ecotoxicity potential [kg 1,4-DB eq /(ha a)]
MOUNT1	92.9	14430	58.0	2313	18.2
MOUNT2	56.5	16390	44.0	3117	6.0
MOUNT3	39.4	8510	36.0	1212	16.0
MOUNT4	39.1	7290	61.4	1291	6.6
MOUNT5	24.5	5020	22.7	818	4.9
ARAB1	15.8	2500	63.3	264	1.6
ARAB2	34.0	6540	80.7	1199	64.3
ARAB3	16.9	1950	44.5	206	7.1
PIG1	129.9	16820	91.3	3180	33.4
PIG2	140.0	26160	136.3	4957	32.4
Mean	58.9	10560	63.8	1856	19.0

Median	39.2	7900	59.9	1251	11.5
Standard deviation (SD)	45.9	7690	32.6	1515	19.5
Coefficient of variation (VAR)	0.78	0.73	0.51	0.82	1.0

The mean energy demand amounts to 58.9 GJ-eq per hectare and year (Table 5). The energy demand for the PIG farms us markedly higher than that for the other farms due to the purchased concentrates and animal. The lowest energy demand per ha was found for the crop farms. The global warming potential shows a similar pattern as that of the energy demand. On average, slightly less than 10.6 tons of CO_2-eq were emitted per unit area in 2016. As for energy demand, the two analysed PIG farms have the highest values for global warming potential.
The aquatic N eutrophication potential was equal to about 64 kg N per unit area, with a range between 22.7 and 136.3 kg N per ha AUU for MOUNT1 and PIG2, respectively.
In agriculture, acidification is largely caused by ammonia (NH_3) emissions. The farm PIG1 has the highest NH_3 emissions, caused primarily by animal husbandry and the production of purchased animals. Animal husbandry outside the farm also causes high emissions on farm MOUNT2, while fertiliser management had a decisive impact on the results for ARAB2.
The median value of terrestrial ecotoxicity potential (the impact of toxic pollutants such as pesticides on soil ecosystems) is 19.0 kg 1,4-DB eq per unit area and year, with a high variability, as indicated by a VAR of 1.0. High values are found for the two farms holding pigs and ARAB2. The high values for the PIG farms originate mainly from the 'purchased concentrated feed' input group, which contributes 75% (PIG1) and 92% (PIG2) to the total terrestrial ecotoxicity. On the crop farms ARAB2 and ARAB3, the use of pesticides contributes almost exclusively to the terrestrial ecotoxicity potential.

The biodiversity scores derived from the biodiversity credit point system as applied by the IP-Suisse association are provided in the following table.

Table 6: Biodiversity scores according the IP-Suisse biodiversity credit point system.

MOUNT1	MOUNT2	MOUNT3	MOUNT4	MOUNT5	ARAB1	ARAB2	ARAB3	PIG1	PIG2
27.6	39.2	33.1	37.3	28.7	34.3	21.9	32.2	23.5	22.9

The farms MOUNT2 and MOUNT4 provide the most beneficial landscape structure in terms of promoting biodiversity. This is primarily due to their high percentage of high-quality ecological compensation areas. The two farms PIG1 and PIG2 rank lowest in potential contribution to biodiversity due to modest fractions of EFAs and few enhancement measures on arable land.

Table 7: Soil quality (overall assessment) based on the SALCA-SQ model. Rating scales are as follows*: -- : very unfavourable; - : unfavourable, 0 : neutral, + : favourable, ++ : very favourable.*

MOUNT1	MOUNT2	MOUNT3	MOUNT4	MOUNT5	ARAB1	ARAB2	ARAB3	PIG1	PIG2
0	--	0	-1	0	+	+	--	-	--

Table 7 shows that the soil quality of the ten investigated farms tends to be negatively influenced by their farming activities. The very unfavourable score for MOUNT2 is due to very unfavourable evaluations for the two physical soil indicators: macropore volume and aggregate stability. The biological soil indicators microbial biomass and activity, which both react positively to the supply of organic matter, also contribute to the adverse effect on MOUNT2's soil quality.

The favourable score for the two crop farms ARAB1 and ARAB2 can be attributed to the positively rated earthworm biomass, which is positively influenced by a sufficient supply of organic matter in the form of solid manure and compost. The very unfavourable soil quality score for ARAB3 is due to its poor ratings for both microbial biomass/activity and two soil physical parameters, macropore volume and aggregate stability. For PIG2, the very unfavourable effect of farm activities on these two soil physical parameters led to a very poor overall assessment.

Discussion

We focus on selected findings of interest such as the correlations between the analysed indicators and the evaluation of the various input groups that contribute to global warming potential.

Correlations

In order to identify potential correlations between the various sustainability indicators, Spearman’s rank correlation coefficients were computed between all variables. Spearman's correlation assesses monotonic relationships and thus not linear relationships. A Spearman correlation of 1 results when the two variables being compared are monotonically related. The reasons for using the non-parametric Spearman approach are (i) the fact that Spearman’s coefficient is appropriate for both continuous and discrete ordinal variables, (ii) the very limited number of samples and (iii) the fact that the distributions are generally skewed.

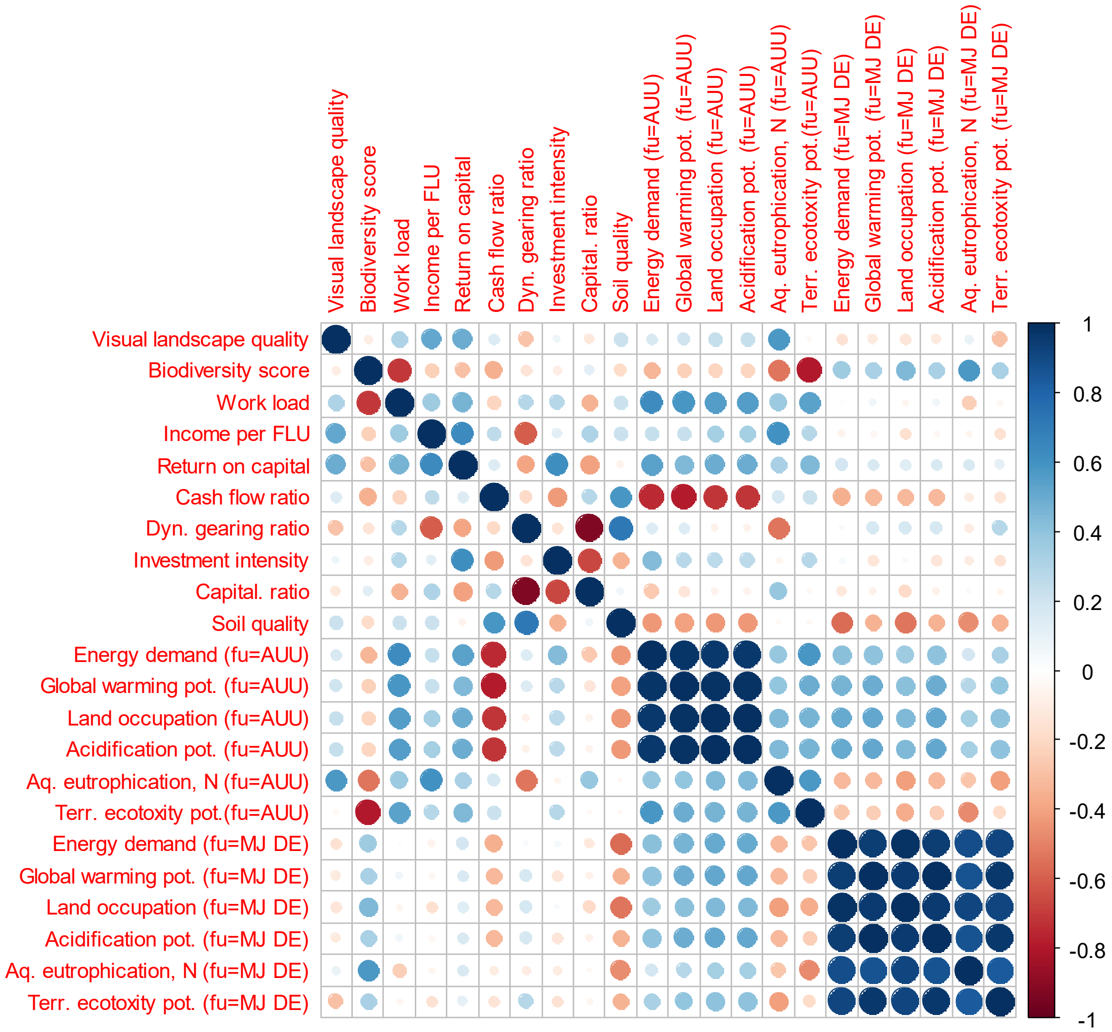

Figure 1: Correlation matrix of sustainability indicators. Results are based on the analysis of ten farms (see Table 2) for the year 2016. fu=AUU: functional unit is hectare AUU; fu=MJ DE: functional unit is MJ Digestible Energy. Positive correlations are displayed in blue, and negative correlations are displayed in red. Color intensity and the size of the circle are proportional to the correlation coefficients. On the right side of the correlogram, the legend color shows the correlation coefficients and the corresponding colors.

From Figure 1 we can conclude that – with some major exceptions – the various surveyed sustainability indicators correlate to only a slight degree. This means that most of the indicators cannot be easily approximated by others and should thus be included to create a comprehensive picture of a farm's overall sustainability. Analysing the distribution of the correlation matrix seen in Figure 1 (excluding the diagonal, i.e., 22 x 22 – 22 = 462 correlation coefficients) reveals that positive correlation coefficients are found more often than negative ones. Specifically, 20% and 10% of the absolute correlation coefficients are above 0.54 and 0.79, respectively. Half of all the absolute correlation coefficients are below 0.32. However, Figure 1 clearly reveals that a large proportion of the environmental impacts are highly correlated. The monotic relationships are even more pronounced when we express the midpoints in the function of MJ digestible energy instead of hectares. The global warming potential shows a very similar pattern to the energy demand. However, the midpoint of 'land occupation' is highly correlated with the global warming potential. The very weak correlation between the environmental impacts given per unit area and per MJ of digestible energy underscores the importance of providing these midpoints in different functional units depending on the specific research question. The reason for the non-existent correlation between the midpoints expressed in the two aforementioned functional units is that the amount of digestible energy produced per unit area varies greatly among the ten analysed farms (by a factor of 35), which means that all other influencing factors are very much diminished.

Economic indicators are generally not highly correlated. The largest positive correlation (*R*=0.64) is found between the two profitability indicators income per FLU and return on capital. It can be thus argued that in computing an aggregated economic indicator, one of the profitability indicators is sufficient to capture the farm's main profitability characteristics. In doing so, we would give priority to income per FLU because this indicator is a very commonly used measure. The largest negative correlation (*R*=-0.93) is between the capitalisation ratio and the dynamic gearing ratio. This is plausible because higher liquidity (i.e., a lower gearing ratio) may lead to higher stability. Liquidity plays a key role in stability in agriculture because it helps to counteract seasonal market fluctuations and external threats (Zhengfei and Oude Lansink, 2006).

Of particular interest are the positive and negative correlations between environmental and economic indicators (Jan, 2012; Torquati *et al.,* 2014; Marton *et al.,* 2016) because they point to potential synergies and trade-offs, respectively. There seems to be a marked trade-off between cash flow ratio and both global warming potential and energy demand. This means that increasing emissions of greenhouse gases per hectare are correlated with an increase in liquidity. The income per FLU is barely correlated with any of the analysed environmental impacts, which are given in both functional unit ha AUU and MJ of digestible energy.

It is well-known that the weekly hours worked by employees who work full-time in agriculture are above the average level for all economic sectors. It is thus interesting to investigate whether a higher temporal work load will at least lead to increased economical success. Figure 1depicts that this relationship cannot be confirmed or, rather, that it can only be confirmed to a very small extent: higher workloads seem to be slightly correlated with higher profitability measures.

Because both the biodiversity score and the landscape indicator increase with increasing EFAs (EFAs provide improved biodiversity scores and have generally higher preference values than other land elements), a certain correlation between these two indicators was expected. However, the evaluation did not confirm this expectation. Obviously, the two indicators will ideally complement one another, pointing to the fact that these two indicators depend on a large number of different influential factors. This implies that both indicators should be retained for a comprehensive assessment of sustainability. The fact that in contrast to the biodiversity score, the landscape indicator is standardised could further contribute to the low correlation coefficient of -0.09.

The soil quality score (given as a discrete ordinal variable) is generally negatively correlated with the other environmental impacts. This means that better soil quality is correlated with decreased environmental burden, thus creating synergy between soil quality and environmental impact.

Because several of the environmental impacts are highly correlated, we focus on global warming potential when analysing the contributions of the various input groups to the total global warming potential. Figure 2 shows that the global warming potential (per ha AUU) is highest for the PIG farms. For PIG2, the main contribution is purchased concentrated feed for the pigs. On PIG1, the purchased livestock and on-farm cattle are the top contributors to a high global warming potential. While the percentage contribution of manure and field emissions is moderate for the MOUNT and PIG farms, this percentage contribution is substantial for the three crop farms (92%, 48% and 64% for ARAB1, ARAB2 and ARAB3, respectively). This is evidently because the three investigated crop farms keep only a little livestock.

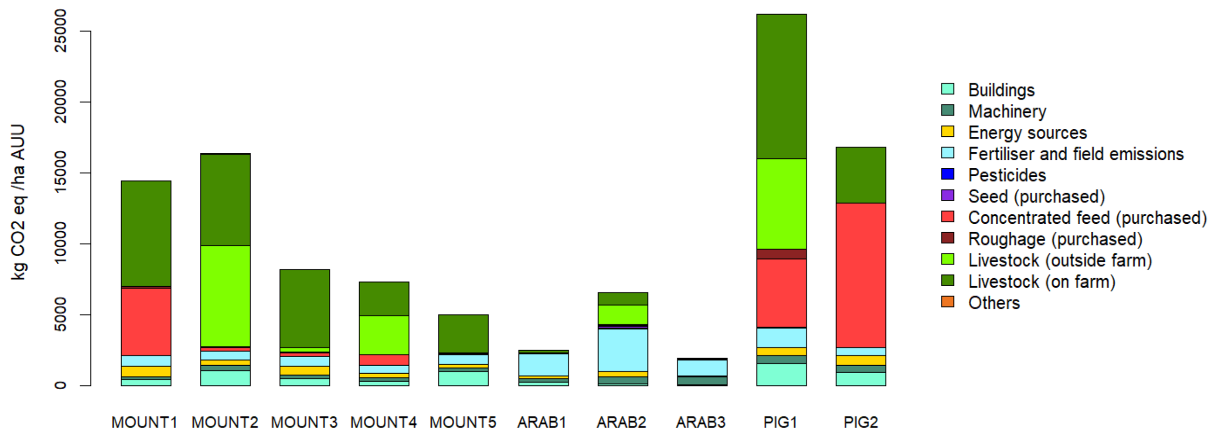

Figure 2: Global warming potential (per unit area) for the ten analysed farms; input groups are given in the legend.

Data acquisition process

Data acquisition for the ten pilot farms was ultimately quite time-consuming. The computation of the environmental impacts, including soil quality, required a large number of input data. The Excel spreadsheets that were distributed to the farmers did not facilitate collecting the large number of variables that are required by sophisticated models. Furthermore, plausibility control is seriously hampered. In order to simplify and speed up data acquisition, Agroscope will develop a sophisticated computer tool during the current 2018–2021 four-year working program. This tool will include a web interface for data acquisition and plausibility control, sophisticated version control and appropriate interfaces with datasets and tools in order to avoid the duplication of any data collection.

Conclusions

We tested the SALCASustain method under real-world conditions, using ten farms of three different farm types. Although the pilot farmers were generally interested in the topic of sustainability in farming, we conclude that the acquisition of the input data for the computation of quantifiable and scientifically reliable sustainability indicators requires quite a great temporal effort.

Despite the fact that the limited sample size hampers the statistical power, some interesting conclusions can be drawn from analysing the correlation pattern among the sustainability indicators. The statistical analysis shows that the various sustainability indicators generally have only slight correlations, with some important exceptions: A considerable number of the environmental midpoints are highly correlated. Some synergies and trade-offs between environmental and economic indicators were confirmed. The evaluation reveals that higher workloads seem to be only slightly correlated with higher profitability measures and do not positively impact on a holding's liquidity or stability. Synergies (indicated by distinctly negative correlations) are found between soil quality and other environmental impacts.

The development of a sophisticated computer tool during the current 2018–2021 working program will allow for the efficient computation of sustainability indicators and also for larger sample sizes due to faster and more user-friendly data acquisition, sophisticated plausibility control and the automated handling of the entire data flow from data compilation to a meaningful graphical and statistical output. Furthermore, the above-mentioned program aims to develop both normalised and aggregated indicators because this is not part of the current investigation.

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