DEXi-Dairy indicator handbook:: Sustainability tree and selected indicators for assessing European specialised dairy farms

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MilKey project: 'Decision support system for sustainable and GHG optimised milk production in key European areas'

DEXi-Dairy indicator handbook

Sustainability tree and selected indicators for assessing European specialised dairy farms

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Summary

The MilKey project aims at assessing the environmental, economic, and social sustainability of European dairy production systems, and at identifying ‘win-win’ farming practices for sustainable and greenhouse gas (GHG) optimised milk production.

In this context, a holistic model was developed to evaluate the sustainability of specialised dairy farms and was entitled DEXi-Dairy. This model has the potential of aiding the identification of GHG and nitrogen (N) emission mitigation options and assessing their effects across multiple sustainability aspects. DEXi-Dairy covers the three sustainability pillars, i.e., environmental, economic, and social. Based on the ‘DEX’ multi-criteria methodology, the model is detailed under the form of a tree structure represented by four main hierarchical layers, i.e., branches, principles, criteria, and indicators. DEXi-Dairy was built following a participatory and interdisciplinary approach by MilKey project partners. It was then tested on three case study farms from Ireland, France, and Germany, respectively, using data from 2020.

The DEXi-Dairy indicator handbook describes the sustainability tree and selected indicators to assess dairy production systems over a production year. Overall, this document can be used as a basis to replicate and expand the sustainability assessment framework developed as part of the MilKey project.

Keywords: Environmental sustainability; Economic sustainability; Social sustainability; Sustainability indicators; Dairy production systems; Multi-criteria assessment.

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List of abbreviations and acronyms

In order of appearance in the text:

GHG	Greenhouse gas
EU	European Union
LCA	Life Cycle Assessment
CML	Centre of Environmental Science, Leiden University
N	Nitrogen
kg	Kilogram
g	Gram
%	Percentage
DM	Dry Matter
L	Litre
km	Kilometre
t DM	tonne of Dry Matter

N_2O	Nitrous oxide
P	Phosphorus
PO_4^{3-}	Phosphate
eq	Equivalent
FPCM	Fat-Protein-Corrected-Milk
IPCC	Intergovernmental Panel on Climate Change
GWP	Global Warming Potential
CO_2	Carbon dioxide
SO_2	Sulfur dioxide
NO_x	Nitrogen (mono/di) oxide
NH_3	Ammonia
ha	Hectare
ESDAC	European Soil Data Centre
1.4-DB	1.4 dichlorobenzene
MJ	Megajoule
PPDB	Pesticide Properties DataBase
LD50	Lethal Dose median
mg	Milligram
FADN	Farm Accountancy Data Network
AWU	Annual Work Units
€	Euro
UAA	Utilised Agricultural Area

1. Introduction

This document describes the indicators selected to assess the sustainability of key European dairy cattle farm systems as part of the MilKey project. The assessment covers the three sustainability pillars, i.e., environmental, economic, and social, and is performed using the 'DEX' multi-criteria methodology over a production year (Craheix et al., 2015).

The DEX method breaks down a decisional problem into smaller, less complex sub-problems represented by four main hierarchical layers, i.e., branches, principles, criteria, and indicators (Craheix et al., 2015). Layers are organised following a tree structure, where higher levels depend on lower levels. Specifically, indicators are located at the lowest level of the tree. They can be either quantitative or qualitative and can have different measurement units. Their values are calculated using raw information from the entities under consideration (i.e., dairy cattle farm systems in this study). They are then aggregated at higher hierarchical levels, which constitute the tree's criteria, principles, and, finally, branches.

To facilitate the aggregation of indicators at higher hierarchical levels, they must take ordered, qualitative values. For this reason, quantitative indicators are assigned qualitative scores based on rating scales. Moreover, while all indicators, criteria, principles, and branches present in the tree must be considered to resolve the overarching decisional problem, weights assigned to each one of them can vary depending on their relative importance.

Based on these premises, a holistic model was developed to evaluate the sustainability of European specialised dairy farms, and was entitled DEXi-Dairy. It has the potential of aiding the identification of greenhouse gases (GHG) and nitrogen (N) emissions mitigation options and assessing their effects across multiple sustainability aspects. The sustainability tree was built with three main branches representing each of the sustainability pillars, i.e., environmental, economic, and social. Indicators, criteria, principles, and corresponding weights were then selected based on expert opinion of MilKey partners following a participatory and interdisciplinary approach. As for rating scales of quantitative sustainability indicators, these were constructed using reference values from the literature or pre-existing datasets.

The diversity of dairy cattle production systems in Europe represented a major challenge in developing the methodology of the multi-criteria sustainability assessment. According to Eurostat (2022), farm specialisation describes the dominant farming enterprise in farm income. A dairy farm is said to be specialised when dairy production provides at least two thirds of the farm's gross output (i.e., production value). Specialised holdings can thus have additional farming enterprises (e.g., cash crop production, beef fattening, commercial forestry), which will affect farm structure, management, and sustainability. Additionally, over 95% of European Union (EU) farms are family farms, managed and operated largely by a household (Eurostat, 2019a). As a result, most of them derive their labour inputs from unpaid family members. These considerations conditioned the development of the tree structure and selection of sustainability indicators. Specifically, the MilKey project adopted a whole system approach to build the sustainability assessment model and evaluate key dairy production systems across the environmental, economic, and social sustainability pillars. The model was tested on three dairy-specialised case study farms from Ireland, France, and Germany, respectively, using data from 2020. The farm data necessary to conduct the DEXi-Dairy sustainability assessment described in this document was collected using the Baillet et al. (2022a) data templates and Baillet et al. (2022b) data collection guide.

The current document gathers the list of sustainability indicators with their definitions and formulas, as well as their DEXi rating scales. In addition, the tree structure is presented. Overall, this document can be used as a basis to replicate and expand the sustainability assessment framework developed as part of the MilKey project.

The remainder of the document is structured as follows. The environmental branch is presented in section 2. The economic branch is detailed in section 3. Finally, section 4 describes the social branch.

2. Environmental branch

The environmental branch of the sustainability assessment is presented in Figure 1. Selected environmental indicators are summarised in Table 1. The branch structure, indicators, and formulas were selected based on expert opinion of the MilKey environmental assessment subgroup and retrieved from a combination of literature sources detailed in this section.

While most environmental indicators were calculated using direct raw information from farms, eutrophication potential, global warming potential, air acidification, and total energy consumption were estimated through the life cycle assessment (LCA) methodology, using the characterization method from the Centre of Environmental Science, Leiden University (CML) (Guinée et al., 2002). The life cycle inventory (LCI) outputs were also used as inputs to calculate several indicators such as heavy metal balance, erosion risk, water use for animal housing, and nitrogen efficiency. The LCI were based on multiple models to estimate the different emission, pollutant, and resource fluxes in the air, soil, and water. Technical and scientific reports were used to build scales that would convert the quantitative values of indicators into qualitative values (please note that these will be specified and detailed throughout this section). The scales were then revised (and readjusted when necessary) by the MilKey environmental subgroup to take into account country specificities.

Overall, the environmental branch includes four principles, i.e., best dairy herd management practices, environmental quality, abiotic resources conservation, and biodiversity conservation. The 'best dairy herd management practices' principle focuses on feeding management of dairy animals, as well as their reproductive performance. The 'environmental quality' and 'abiotic resources conservation' principles are based on the LCA methodology, i.e., on the LCI and the characterisation step of the LCA. These two principles point out the potential damage of farm activity to environmental compartments (i.e., air, water, and soil) and limited resources (i.e., energy and water). Finally, the 'biodiversity conservation' principle assesses the potential impacts of farm activity on biodiversity.

Environmental branch

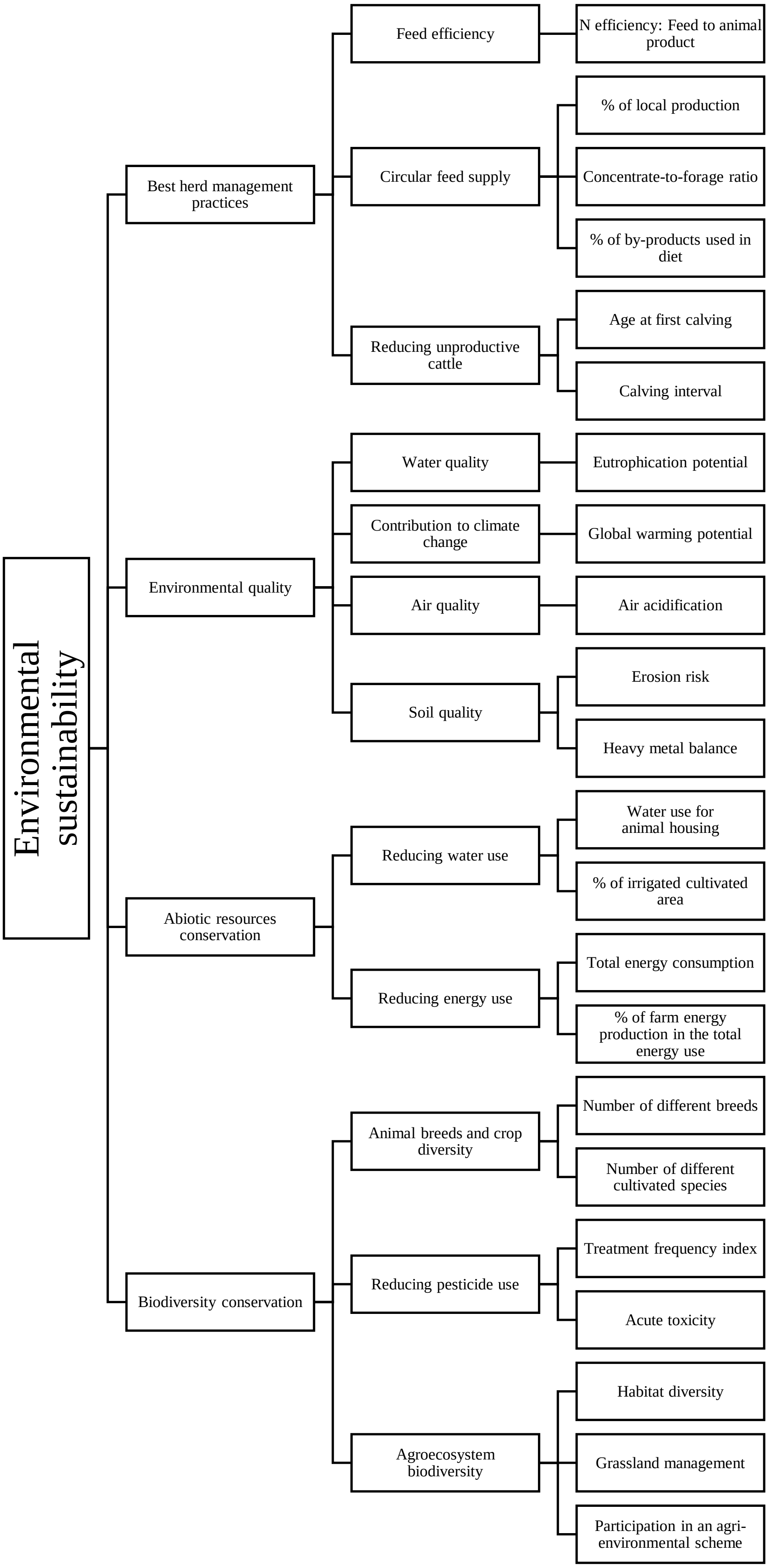

Figure 1: Environmental branch of sustainability assessment

Table 1: List of environmental sustainability indicators

Indicators	**Units**
Nitrogen efficiency: Feed to animal product	Percentage
% of local production	Percentage
Concentrate-to-forage ratio	Percentage
% of by-products used in diet	Percentage
Age at first calving	Months
Calving interval	Days
Eutrophication potential	kg PO_4^{3-}eq/kg
Global warming potential	kg CO_2eq/kg
Air acidification	kg SO_2eq/kg
Erosion risk	t/ha
Heavy metal balance	kg 1.4-DBeq/kg FPCM
Water use for animal housing	L/kg
% of irrigated cultivated area	Percentage
Total energy consumption	MJ/kg
% of farm energy production in the total energy use	Percentage
Number of different dairy cow breeds	Number of dairy cow breeds
Number of different cultivated species	Number of cultivated crops
Treatment frequency index	Score
Acute toxicity	mg/kg
Habitat diversity	Score
Grassland management	Percentage
Participation in an agri-environmental scheme	Yes/No

2.1. Best dairy herd management practices

2.1.1. Feed efficiency

2.1.1.1. Nitrogen efficiency: Feed to animal product

Indicator type: Quantitative

Description: This indicator calculates the percentage of total N inputs recovered in the milk production process, i.e., the percentage of ‘total N ingested’ to ‘total N fixed’. N fixed represents the total N content of the milk produced, while N ingested refers to the total N content of dairy cow diets. This percentage evaluates aspects of the environmental impacts of feed management, largely influenced by N emissions of dairy production (Dulphy and Grenet, 2001; INRA, 2007).

Indicator calculation:

$$\frac{Total\ N\ ingested}{Total\ N\ fixed} * 100$$

Where:

- Total N ingested in kilograms (kg):

$$Total\ N\ ingested = (\sum_{i=1}^{n}(FM_i * \frac{100}{DM_i} * N\ content_i) * \ P_i * N) * 1000$$

n = Number of feed type

i = Type of feed

FM_i = Fresh matter of feed *i* in grams (g)/day/head

DM_i = Dry matter (DM) of feed *i* in g/day/head

$N\ content_i$ = N content of feed *i* in percentage (%)

P_i = Distribution period of feed *i* in days

N = Average dairy herd size

- Total N fixed in kg:

$$Total\ N\ fixed = Total\ milk\ produced * N\ fixed\ per\ weight\ gain\ * \frac{Milk\ density}{1000}$$

$Total\ milk\ produced$ = Total raw milk produced in litres (L)

$N\ fixed\ per\ weight\ gain$ = Total N fixed in g, divided by dairy cow weight gain in kg

$Milk\ density$ = 1.032 kg/L

Unit: Percentage

Indicator interpretation: Higher values are associated with better environmental management practices and are thus expected to lead to enhanced environmental sustainability.

Rating scale:

Reference values (%)	**Scale**	**DEXi interpretation**		**References**
Minimum of 20	>= 30	High	+	Reference values: Aguirre-Villegas et al. (2017) Scale: Expert opinion
Theoretical maximum of 45	[25; 30[	Medium to high		
	[20; 25[	Low to medium		
	<20	Low	-	

2.1.2. Circular feed supply

2.1.2.1. Percentage of local production

Indicator type: Quantitative

Description: The percentage of local production refers to the dependency on external feed supply of the dairy system (i.e., from dairy calves to dairy cull cows). We consider production as local when it is produced within a limited perimeter around the farm. This indicator measures the contribution of the local territory (i.e., an area of land under the jurisdiction of a ruler or state) to the local dairy enterprise. It takes into consideration the transport of off-farm inputs, which plays an important role in GHG emissions from dairy production (Üçtuğ, 2019). The perimeter is limited to a radius of 100-kilometers (km) around the farm.

For concentrates used for dairy animals, only the production's location is considered. Therefore, the origin of feedstuffs included in concentrates is not taken into account.

On-farm production is considered as local.

Indicator calculation:

$$\frac{Total\ local\ feed\ use}{Total\ feed\ use} * 100$$

Where:

$Total\ local\ feed\ use$ = Total amount of locally produced feed use (e.g., concentrates and forage), expressed in tonnes of DM (t DM)

$Total\ feed\ use$ = Total amount of feed use (e.g., concentrates and forage), expressed in t DM

Unit: Percentage

Indicator interpretation: Higher values are associated with better environmental management practices and are thus expected to lead to enhanced environmental sustainability.

Rating scale:

Reference values (%)	**Scale**	**DEXi interpretation**		**References**
55	>= 80	High	+	
45	[60; 80[	Medium to high		Reference values: Adapted from information about concentrate-to-forage ratio (Machado et al., 2014) Scale: Expert opinion
35	[40; 60[	Low to medium		
	< 40	Low	-	

2.1.2.2. Concentrate-to-forage ratio

Indicator type: Quantitative

Description: This indicator refers to the concentrate-to-forage ratio in the diet of dairy animals. It allows for the comparison of concentrate and forage consumptions. It is an indirect measure of the dependency on industrial feed production. This indicator was identified as a key aspect of environmental sustainability based on technical information from Pellerin et al. (2013). Specifically, the Pellerin et al. (2013) report highlights options to reduce protein intake in animal feed and limit N content in effluents and associated nitrous oxide (N_2O) emissions. Please refer to action #8 in Pellerin et al. (2013).

Indicator calculation:

$$\frac{Total\ concentrate\ use}{Total\ forage\ use} * 100$$

Where:

$Total\ concentrate\ use$ = Total amount of concentrates fed, expressed in t DM

$Total\ forage\ use$ = Total amount of forage fed, expressed in t DM

Unit: Percentage

Indicator interpretation: Lower values are associated with better environmental management practices and are thus expected to lead to enhanced environmental sustainability.

Rating scale:

Reference values (%)	Scale	DEXi interpretation		References
35	< 20	Low	+	Reference values: Adapted from Machado et al. (2014) Scale: Expert opinion
45	[20; 35[	Low to medium		
55	[35; 50[	Medium to high		
	>= 50	High	-	

2.1.2.3. Percentage of by-products used in diet

Indicator type: Quantitative

Description: This measure refers to the share of by-products in the diets of dairy animals. It gives an indication of the use of by-products in diets, which is associated with a better use of primary resources. This indicator was identified as a key aspect of environmental sustainability based on technical information from Pellerin et al. (2013). Specifically, the Pellerin et al. (2013) report highlights options to reduce protein intake in animal feed and limit N content in effluents and associated nitrous oxide (N_2O) emissions. Please refer to action #8 in Pellerin et al. (2013).

The by-product content of concentrates bought off farm is not included in this indicator.

Indicator calculation:

$$\frac{\sum_i (Byproduct\ content_i)}{Total\ feed\ use} * 100$$

Where:

$Byproduct\ content_i$ = By-product content in diet i, expressed in kg of DM

$Total\ feed\ use$ = Total amount of feed use (including concentrates, forage, and by-products) in all diets, expressed in kg of DM

Unit: Percentage

Indicator interpretation: Higher values are associated with better environmental management practices and are thus expected to lead to enhanced environmental sustainability.

Rating scale:

Reference values (%)	Scale	DEXi interpretation		References
95	>= 30	High	+	Reference values: Adapted from Condren et al. (2019) and Whelan et al. (2017) Scale: Expert opinion
75	[20; 30[	Medium to high		
55	[10; 20[	Low to medium		
35	< 10	Low	-	

2.1.3. Reducing unproductive cattle

2.1.3.1. Age at first calving

Indicator type: Quantitative

Description: This indicator refers to the average age of dairy heifers at first calving. Delays in age at first calving lengthen the unproductive period of dairy cows. They increase avoidable environmental costs associated with maintaining and feeding unproductive animals. This measure is recorded directly at the farm level. The indicator is based on technical information from Heravi Moussavi and Danesh Mesgaran (2008) and Pellerin et al. (2013).

Unit: Months

Indicator interpretation: Lower values are associated with better environmental management practices and are thus expected to lead to enhanced environmental sustainability.

Rating scale:

Reference values (months)	**Scale**	**DEXi interpretation**		**References**
28	< 24	Low	+	Reference values: Based on the "Reproscope" tool created by IDELE (i.e., French Breeding Institute), which provides data from French dairy farms (2018-2019) (Institut de l'Elevage, n.d.). Quantile method based on 53953 dairy farm and all French breeds Scale: Expert opinion
31	[24; 27[	Low to medium		
35	[27; 30[	Medium to high		
	>= 30	High	-	

2.1.3.2. Calving interval

Indicator type: Quantitative

Description: This indicator refers to the average period from one calving to the next in the dairy herd. Longer calving intervals increase the unproductive period of dairy cows, which is associated with avoidable environmental costs of feeding and maintaining unproductive animals. This indicator is based on technical information from Pellerin et al. (2013).

Unit: Days

Indicator interpretation: Lower values are associated with better environmental management practices and are thus expected to lead to enhanced environmental sustainability.

Rating scale:

Reference values (days)	**Scale**	**DEXi interpretation**		**References**
397	< 390	Low	+	Reference values: Based on the "Reproscope" tool created by IDELE (i.e., French Breeding Institute), which provides data from French dairy farms (2018-2019) (Institut de l'Elevage, n.d.). Quantile method based on 53953 dairy cattle farm and all French breeds Scale: Expert opinion
414	[390; 415[	Low to medium		
437	[415; 440[	Medium to high		
	>= 440	High	-	

2.2. Environmental quality

2.2.1. Water quality

2.2.1.1. Eutrophication potential

Indicator type: Quantitative

Description: This indicator refers to an LCA midpoint impact category. The LCA midpoint method explores environmental impacts at an early stage of natural biochemical processes in the cause-effect chain. In this case, it evaluates the direct impact of excess N and phosphorus (P) inputs on water quality. This measure is given in kg of phosphate (PO_4^{3-}) equivalent (eq) per Functional Unit (i.e., quantitative amount that represents the function delivered by the system). In this study, the selected functional unit is 1kg of fat-protein-corrected-milk (FPCM). Please refer to Guinée et al. (2002) for the detailed method.

Indicator calculation: Based on Koch and Salou (2016)

$$\frac{\sum_i e_i * CF_i}{FPCM}$$

Where:

e_i= Emission of substance i in kg

CF_i = Associated characterisation factor of substance i in kg PO_4^{3-}eq

$FPCM$ = Total FPCM produced in kg, calculated by the following equation (International Dairy Federation, 2015):

$$FPCM = Total\ milk\ produced * Milk\ density * (0.1226 * Fat\% + 0.0776 * Protein\% + 0.2534)$$

$Total\ milk\ produced$ = Total milk produced in L

$Milk\ density =$ = 1.032 kg/L

$Fat\%$ = Fat content of the milk produced in %

$Protein\%$ = Protein content of the milk produced in %

Unit: Kg PO_4^{3-}eq / kg FPCM

Indicator interpretation: Higher values indicate larger negative impacts on the environment.

Rating scale:

Reference values (kg PO_4^{3-}eq/kg FPCM)	Scale	DEXi interpretation		References
0.0027	< 0.003	Low	+	Reference values: Based on three 'cradle to farm-gate' LCA studies of dairy farms using the United Nations Intergovernmental Panel on Climate Change (IPCC) method, the ecoinvent database, and other sources in the literature (Basset-Mens et al., 2009; Cederberg and Mattsson, 2000; Thomassen et al., 2008) Scale: Expert opinion
0.0061	[0.003; 0.005[	Low to medium		
0.0066	[0.005; 0.007[	Medium to high		
0.011	>= 0.007	High	-	
0.0070				

2.2.2. Contribution to climate change

2.2.2.1. Global warming potential

Indicator type: Quantitative

Description: This indicator is based on the global warming potential (GWP) measure developed by the IPCC (Intergovernmental Panel on Climate Change, 2006). It refers to an LCA midpoint impact category and quantifies GHG emitted by the dairy system. This measure is given in kg of carbon dioxide (CO_2) equivalent per kg of FPCM produced during the production year. Please refer to Guinée et al. (2002) for the detailed method.

Indicator calculation: Based on Koch and Salou (2016)

$$\frac{\sum_i e_i * CF_i}{FPCM}$$

Where:

e_i = GHG emission *i* in kg

CF_i = Associated characterisation factor *i* in kg of CO_2eq

$FPCM$ = Total FPCM produced in kg

Unit: Kg CO_2eq / kg FPCM

Indicator interpretation: Higher values indicate larger negative impacts on the environment.

<u>Rating scale</u>:

Reference values ($kg\ CO_2eq/kg$ FPCM)	**Scale**	**DEXi interpretation**		**References**
0.86	< 0.7	Low	+	Reference values: Based on three ‘cradle to farm-gate’ LCA studies of dairy farms using the IPCC method, the ecoinvent database, and other sources in the literature (Basset-Mens et al., 2009; Cederberg and Mattsson, 2000; Thomassen et al., 2008)
0.95	[0.7; 1[	Low to medium		
1.10	[1; 1.3[	Medium to high		
1.41	>= 1.3	High	-	
1.48				Scale: Expert opinion

2.2.3. Air quality

2.2.3.1. Air acidification

Indicator type: Quantitative

Description: This indicator measures the potential impact of acidifying pollutants through the LCA method. Acidifying pollutants have a wide variety of impacts on soil, groundwater, surface water, biological organisms, ecosystem, and materials.

The major acidifying pollutants considered are sulfur dioxide (SO_2), nitrogen (mono/di) oxide (NO_x), and ammonia (NH_3). Please refer to Guinée et al. (2002) for the detailed method.

Indicator calculation: Based on Koch and Salou (2016)

$$\frac{\sum_i e_i * CF_i}{FPCM}$$

Where:

$e_i =$ Emission of substance *i* in kg

$CF_i =$ Associated characterization factor *i* in kg of SO_2eq

$FPCM$ = Total FPCM produced in kg

Unit: Kg SO_2eq / kg FPCM

Indicator interpretation: Higher values indicate larger negative impacts on the environment.

Rating scale:

Reference values ($kg\ SO_2eq/kg$ FPCM)	Scale	DEXi interpretation		References
0.0075	< 0.009	Very low	+	Reference values: Based on three 'cradle to farm-gate' LCA studies of dairy farms using the IPCC method, the ecoinvent database, and other sources in the literature (Basset-Mens et al., 2009; Cederberg and Mattsson, 2000; Thomassen et al., 2008) Scale: Expert opinion
0.018	[0.009; 0.01[	Low		
0.016	[0.01; 0.015[	Medium		
0.0095	[0.015; 0.02[	High		
0.011	>= 0.02	Very high	-	

2.2.4. Soil quality

2.2.4.1. Erosion risk

Indicator type: Quantitative

Description: Erosion risk refers to potential of eroded soil per hectare (ha) of the farm under study over the production year. Erosion is taken into account in the LCA due to its influence on pollutant runoff. Moreover, erosion affects crop productivity due to soil damage. It is influenced by precipitation, soil type, crop management, and topography (Renard et al., 1991).

Indicator calculation: Based on Koch and Salou (2016)

$$\frac{\sum_i^n \frac{R * K * LS * C * P_i * f}{CS_i}}{n}$$

Where:

R = Run-off factor retrieved from the European Soil Data Centre (ESDAC) (Panagos et al., 2015)

K = Soil factor retrieved from the ESDAC (Panagos et al., 2015)

LS= Topography factor: 0.377 (Koch and Salou, 2016)

C = Cover management factor

P_i = Cultural practice of crop *i*

f = Acre factor: 2.47 (Koch and Salou, 2016)

CS_i = Surface area of crop *i* in ha

n = Number of farm crops

Unit: t of eroded soil / ha

Indicator interpretation: Higher values have larger negative impacts on the environment.

Rating scale:

Reference values (t of eroded soil/ha)	**Scale**	**DEXi interpretation**		**References**
0.2	< 0.5	Very low	+	Reference values: Adapted from Gassman et al. (2006) and Vadas and Powell (2013) Scale: Expert opinion
1.5	[0.5; 1.5[	Low		
2.2	[1.5; 2.5[	Medium		
5	[2.5; 4.5[	High		
	>= 4.5	Very high	-	

2.2.4.2. Heavy metal balance

Indicator type: Quantitative

Description: This indicator calculates the difference between inputs and outputs of heavy metals. It takes into account the atmospheric feedback of heavy metal components from fertilisers, seeds, and phytosanitary products. This measure represents the remaining heavy metals in the soil and is thus an indirect indicator of soil toxicity. In high concentrations, heavy metals are toxic for biodiversity in aquatic and terrestrial biospheres, and affect crop fertility.

Indicator calculation: Based on Koch and Salou (2016)

$$\frac{\sum_i^n (HM\ input_i - HM\ output_i) * \ F_i}{n * FPCM}$$

$HM\ input_i$ = Heavy metal input *i* in kg

$HM\ output_i$= Heavy metal output *i* in kg

F_i = Allocation factor in kg of 1.4 dichlorobenzene (1.4-DB)eq / kg

$FPCM$ = Total FPCM produced in kg

Unit: kg 1.4 dichlorobenzene (1.4-DB)eq / kg FPCM

Indicator interpretation: Higher values indicate larger negative impacts on the environment.

Rating scale: The ranking of the soil contamination potential of heavy metals is based on the CML characterisation factor Guinée et al. (2002).

Reference values (kg 1.4-DBeq/kg FPCM)	**Scale**	**DEXi interpretation**		**References**
0.086955	< 0.086955	Low	+	Adapted from Guinée et al. (2002) and Tóth et al. (2016)
0.15504	[0.086955; 0.15504[	Medium		
	>= 0.015504	High	-	

2.3. Abiotic resources conservation

2.3.1. Reducing water use

2.3.1.1. Water use for animal housing

Indicator type: Quantitative

Description: This indicator estimates water consumption of the dairy herd per kg of FPCM produced. It includes drinking and cleaning water during housing and grazing periods. As water is a limited resource, it is an important parameter to consider when evaluating abiotic resources conservation efforts. This indicator can be directly recorded at the farm level. Alternatively, it can be estimated with the LCA method based on recorded diets and information about the farm's milking parlour. It is adapted from Van Calker et al. (2004).

Unit: L / kg FPCM

Indicator interpretation: Higher values indicate larger negative impacts on the environment.

Rating scale:

Reference values (L/kg FPCM)	Scale	DEXi interpretation		References
3.65	< 3.5	Low	+	Reference values: Based on Krauß et al. (2016) Scale: Expert opinion
3.94	[3.5; 3.9[	Low to medium		
4.23	[3.9; 4.4[	Medium to high		
	>= 4.4	High	-	

2.3.1.2. Percentage of irrigated cultivated area

Indicator type: Quantitative

Description: This indicator is an indirect measure of water consumption at the farm scale. The measure takes into consideration water management in terms of percentage of irrigated cultivated area at the farm level. Permanent grassland area is not taken into account. This indicator is adapted from Van Calker et al. (2004).

Indicator calculation:

$$\frac{Total\ area\ of\ crop\ irrigated}{Total\ crop\ area} * 100$$

Where:

$Total\ area\ of\ crop\ irrigated$ = Area of crop production under irrigation, expressed in ha

$Total\ crop\ area$ = Farm area under crop production, expressed in ha.

Unit: Percentage

Indicator interpretation: Higher values indicate larger negative impacts on the environment.

Rating scale:

Scale (%)	DEXi interpretation		References
0	None	+	Scale: Expert opinion
]0; 25]	Low		
]25; 50]	Medium		
> 50	High	-	

2.3.2. Reducing energy use

2.3.2.1. Total energy consumption

Indicator type: Quantitative

Description: This indicator measures the farm's energy consumption, both direct and indirect, per kg of FPCM produced. It is based on the cumulative energy demand methodology (Frischknecht et al., 2015) and is adapted from Pellerin et al. (2013) and Tailleur et al. (2020).

Direct energy consumption encompasses all energy used for on-farm processes (e.g., crop management, heating in buildings, and electricity in barns). This element is recorded at the farm level during data collection.

Indirect energy consumption takes into account all energy used for the production of off-farm inputs (e.g., off-farm feed production, diesel production). This element is obtained through the LCA methodology.

Indicator calculation:

$$\frac{Direct\ energy\ consumption + Indirect\ energy\ consumption}{FPCM}$$

Where:

$Direct\ energy\ consumption$ = Direct energy consumption in Megajoule (MJ)

$Indirect\ energy\ consumption$ = Indirect energy consumption in MJ

$FPCM$ = Total FPCM produced in kg

Unit: MJ / kg FPCM

Indicator interpretation: Higher values indicate larger negative impacts on the environment.

Rating scale:

Reference values (MJ/kg FPCM)	Scale	DEXi interpretation		References
1.39	< 2	Very low	+	Reference values: Based on three 'cradle to farm-gate' LCA studies of dairy farms using the ecoinvent database and other sources in the literature (Basset-Mens et al., 2009; Cederberg and Mattsson, 2000; Thomassen et al., 2008) Scale: Expert opinion
2.51	[2; 4[	Low		
3.10	[4; 8[	Medium		
3.55	[8; 10[	High		
5	>= 10	Very high	-	

2.3.2.2. Percentage of farm energy production in the total energy use

Indicator type: Quantitative

Description: This indicator measures the percentage of energy produced on the farm. It includes direct and indirect energy consumption. Please refer to the previous indicator for further detail on the estimation. This indicator is adapted from the Tailleur et al. (2020) technical report and the Pellerin et al. (2013) action #10.

Indicator calculation:

$$\frac{Farm\ energy\ production}{Total\ energy\ consumption} * 100$$

Where:

$Farm\ energy\ production$ = Total amount of energy directly produced and consumed on the farm, expressed in MJ

$Total\ energy\ consumption$ = Total amount of energy used, expressed in MJ

Unit: Percentage

Indicator interpretation: Lower values indicate larger negative impacts on the environment.

Rating scale:

Reference values (%)	Scale	DEXi interpretation		References
	>= 32	Very high	+	Based on the 2030 targets of the EU climate and energy framework; that is, 20% of energy consumption from renewable energy by 2020 and more than 27% by 2030 (European Commission, 2014a, 2014b).
32	[27; 32[	High		
27	[20; 27[	Medium		
20	[10; 20[	Low		
10	< 10	Very low	-	

2.4. Biodiversity conservation

2.4.1. Animal breeds and crop diversity

2.4.1.1. Number of different breeds

Indicator type: Quantitative

Description: This indicator measures the number of different breeds present in the dairy herd. It represents herd genetic diversity, which is an important aspect of herd resilience against disease and parasitism. This indicator is adapted from Last et al. (2014) and Phocas et al. (2017).

In this indicator, crossbred cows are counted as an additional breed.

Unit: Number of breeds

Indicator interpretation: Lower values indicate larger negative impacts on the environment.

Rating scale:

Reference values (number of breeds)	**Scale**	**DEXi interpretation**		**References**
Minimum of 1	>= 4	High	+	Reference values: Based on the information from Phocas et al. (2017) applied to a Swedish case study in Rodríguez-Bermúdez et al. (2019), and on the “Reproscope” tool which provides data from French dairy farms (2018-2019) (Institut de l’Elevage, n.d.) Scale: Expert opinion
	3	Medium to high		
	2	Low to medium		
	1	Low	-	

2.4.1.2. Number of different cultivated species

Indicator type: Quantitative

Description: This indicator quantifies the diversity of cultivated species at the farm level, thus representing on-farm crop diversity. Farm biodiversity is expected to be enhanced by greater diversity of cultivated species per ha, as it results in higher potential of species shelter. This indicator is adapted from Last et al. (2014).

Unit: Number of crop species

Indicator interpretation: Lower values indicate larger negative impacts on the environment.

Rating scale:

Reference values	Scale	DEXi interpretation		References
Minimum of 1	>= 6	High	+	Reference values: Adapted from the results of a case study analysis performed on 203 farms distributed across 13 European regions (Last et al., 2014) Scale: Expert opinion
Maximum of 16	[5; 6[	Medium to high		
	[3; 5[	Low to medium		
	< 3	Low	-	

2.4.2. Reducing pesticide use

2.4.2.1. Treatment frequency index

Indicator type: Quantitative

Description: The treatment frequency index is an indicator of phytosanitary treatment intensity and product management. This indicator is based on the amount of pesticides applied by farmers on their agricultural plots over the production year. For each phytosanitary product, a certified standard dose is defined per ha and crop type according to the product’s technical guidelines. This indicator gives the number of treatments equivalent to full rates and full field application. It is equal to 1 if the farmer uses the standard dose. This indicator is adapted from Aouadi (2011).

Indicator calculation:

$$\sum_j \frac{\sum_i \frac{Amount\ applied\ of\ PP_i}{Certified\ dose\ of\ PP_i} * \frac{Treated\ area_i}{Total\ area_j}}{Total\ number\ of\ crops}$$

Where:

$Amount\ applied\ of\ PP_i$= Amount of phytosanitary product *i* applied in crop *j*

$Certified\ dose\ of\ PP_i$ = Certified dose of phytosanitary product *i* in crop *j*

$Treated\ area_i$= Treated surface area by phytosanitary product *i*

$Total\ area_j$ = Total surface area of crop *j*

$Total\ number\ of\ crops$ = Total number of crops on the farm

Unit: Score

Indicator interpretation: Higher values indicate larger negative impacts on the environment.

Rating scale:

Reference values	Scale	DEXi interpretation		References
Minimum of 0	0	None	+	Reference values: Based on European and French data collected from several arable crops in Pelzer et al. (2012) Scale: Expert opinion
Maximum of 8	]0; 2]	Low		
	]2; 4.5]	Medium		
	> 4.5	High	-	

2.4.2.2. Acute toxicity

Indicator type: Quantitative

Description: This indicator refers to pesticide toxicity based on the Pesticide Properties Database (PPDB) (University of Hertfordshire, 2007) and technical information from the World Health Organization (Inter-Organization Programme for the Sound Management of Chemicals and World Health Organization, 2010). It averages acute toxicity levels of active substances applied on farms.

The acute toxicity level of a substance is defined by its Lethal Dose median (LD50), i.e., the amount of substance given all at once, which subsequently causes the death of 50% of a group of test animals within a given period. Specifically, the values used in MilKey are for rats as test animals and for a study period of 90 days, with substances being administered orally. Such values are gathered in the PPDB (University of Hertfordshire, 2007).

This indicator is adapted from Aouadi (2011).

Indicator calculation:

$$\frac{\sum_i LD50\ of\ active\ substance_i}{Total\ number\ of\ active\ substances}$$

Where:

$LD50\ of\ active\ substance_i$ = Lethal dose median of active substance i, expressed in milligrams (mg) of active substance administered per kg of bodyweight of tested subjects

$Total\ number\ of\ active\ substances$ = Total number of active substances used on the farm

Unit: mg / kg

Indicator interpretation: Lower values indicate larger negative impacts on the environment.

Rating scale:

Reference values (mg / kg)	Scale	DEXi interpretation		References
5000	>= 5000	Very low	+	Based on Inter-Organization Programme for the Sound Management of Chemicals and World Health Organization (2010)
2000	[2000; 5000[	Low		
200	[200; 2000[	Medium		
50	[50; 200[	High		
	< 50	Very high	-	

2.4.3. Agroecosystem biodiversity

2.4.3.1. Habitat diversity

Indicator type: Quantitative

Description: This indicator represents diversity and prominence of habitats at the farm level. The method used to estimate it is the Shannon Index (Shannon, 1948), which takes the value of zero if there is only one habitat on the farm (i.e., no diversity). The value increases as habitat richness increases. This indicator is adapted from Di Gregorio and Jansen (2000), Herzog et al., (2013), and Walz (2011).

The term "habitat" is defined as categories of habitats (e.g. forest, cropland, and wetlands). It is expected that higher diversity in habitats is strongly linked to a greater biodiversity. This indicator also covers unproductive areas (please see below the different categories). The following table describes all categories taken into account:

No.	Land Cover Class	Land Cover Subclass: Habitat	Examples in this subclass
1	Cultivated and Managed Terrestrial Areas (A11)	Trees	Orchards, other tree plantations
2.	Cultivated and Managed Terrestrial Areas (A11)	Shrubs	Plantations of dwarf trees, shrubs (also vineyard)
3	Cultivated and Managed Terrestrial Areas (A11)	Graminoids	Any grain grasses, maize, and cereal grasses
4.	Cultivated and Managed Terrestrial Areas (A11)	Non-graminoids	Others (e.g. brassicas, any vegetables, other forbs)
5.	Natural and Semi-Natural Terrestrial Vegetation (A12)	Woody	Forests (managed and not managed)
6.	Natural and Semi-Natural Terrestrial Vegetation (A12)	Herbaceous	Grasslands, meadows

No.	Land Cover Class	Land Cover Subclass: Habitat	Examples in this subclass
7.	Natural and Semi-Natural Aquatic or Regularly Flooded Vegetation (A24)	Woody	Swamps = forested wetland areas along stream, river or lake, bogs, and flats
8.	Natural and Semi-Natural Aquatic or Regularly Flooded Vegetation (A24)	Herbaceous	Marshes = wetland at the edges of lakes, streams, rivers dominated by grasses, rushes or reeds, mires, bogs, and fens

Indicator calculation:

$$\sum_i \frac{Habitat\ area_i}{Total\ habitat\ area} * \frac{Ln\left(\frac{Habitat\ area_i}{Total\ habitat\ area}\right)}{Ln(2)}$$

Where:

$Habitat\ area_i$ = Surface area of habitat *i*

$Total\ habitat\ area$ = Total surface of all habitats

Unit: Score

Indicator interpretation: A lower value indicates lower biodiversity and is thus negatively associated with farm environmental sustainability.

Rating scale: The maximum value of the Shannon index is reached when all the habitats are all equally distributed through the farm area. In our assessment, the maximum of the Shannon index is 2.08.

Reference values	Scale	DEXi interpretation		References
Minimum of 0	>= 1.3	High	+	Expert opinion
Maximum of 2.08	[0.7; 1.3[	Medium		
	< 0.7	Low	-	

2.4.3.2. Grassland management

Indicator type: Quantitative

Description: This indicator evaluates the ecological value of grasslands based on management and surface areas. Depending on these two characteristics, grasslands can be important shelters for biodiversity. For this indicator, grasslands are given two scores depending on the following management strategies:

- Fertilisation:

Fertilisation score	Mineral fertiliser	Organic fertiliser
1F	0	Very occasional
2F	0	Regular
3F	< 80 N units /ha (mowing) < 40 N units /ha (grazing)	Occasional
4F	< 80 N units /ha (mowing) < 40 N units /ha (grazing)	Regular
5F	> 80 N units /ha (mowing) > 40 N units /ha (grazing)	Occasional or regular

- Grassland production types, combined with specific characteristics:

Management score	Type of meadow	Characteristics
1M	Grazed meadow	Wetland
1M	Grazed meadow	Dry environment
2M	Grazed meadow	Medium land
2M	Hay meadow	Rotating or continuous intense grazing

Management score	**Type of meadow**	**Characteristics**
3M	Grazed meadow	Dried hay on the ground, with or without topping
3M	Hay meadow	Silage, haylage, dried hay in a barn, or hay dried on the ground after an early grazing

Then, the fertilisation and management scores are combined to determine if the grassland is a favourable, neutral, or unfavourable area for biodiversity, using the following scoring matrix:

3M	Favourable	Neutral	Unfavourable	Unfavourable	Unfavourable
2M	Favourable	Favourable	Neutral	Unfavourable	Unfavourable
1M	Favourable	Favourable	Neutral	Unfavourable	
	1F	**2F**	**3F**	**4F**	**5F**

After assessing each grassland with the matrix, the results are aggregated at the farm level to obtain a percentage of favourable or neutral grassland surface area to total grassland surface area. This indicator is adapted from Manneville et al. (2014).

<u>Indicator calculation</u>:

$$\frac{Bdv1 + Bdv2}{Bdv0 + Bdv1 + Bdv2} * 100$$

Where:

$Bdv0$ = Neutral grassland surface area in ha

$Bdv1$ = Favorable grassland surface area in ha

$Bdv2$ = Unfavorable grassland surface area in ha

<u>Unit</u>: Percentage

<u>Indicator interpretation</u>: Lower values indicate larger negative impacts on the environment.

Rating scale:

Reference values	Scale	DEXi interpretation		References
45	>= 45	High	+	Adapted from Manneville et al. (2014)
25	[25; 45[	Medium		
0	[0; 25[	Low	-	

2.4.3.3. Participation in an agri-environmental scheme

Indicator type: Qualitative

Description: Agri-environmental schemes are governmental programmes set up to incentivise farmers to manage their land in an environmentally friendly manner (European Environment Agency, 2022). They foster the adoption of specific agricultural practices that support biodiversity. For instance, such schemes could include the implementation of hedgerows, and management of wetlands or other semi-natural habitats. Overall, this indicator points out if a specific management plan dedicated to the protection of biodiversity is in place. It is adapted from Manneville et al. (2014).

Unit: Yes / No

Indicator interpretation: Participation in an agri-environmental scheme is expected to have a positive impact on the environment.

Rating scale:

Scale	DEXi interpretation		References
Yes	High	+	Adapted from Manneville et al. (2014)
No	Low	-	

3. Economic branch

The economic branch of the sustainability assessment is presented in Figure 2. Selected economic indicators are summarised in Table 2. The branch structure, indicators, and formulas were selected based on expert opinion of the MilKey economic assessment subgroup and retrieved from a combination of sources, including EU Farm Accountancy Data Network (FADN) reports and technical documents (European Commission, 2020, 2018a, 2018b), and the Teagasc National Farm Survey (NFS) 2019 sustainability report (Buckley and Donnellan, 2020). The variables used in the calculations were also derived from the EU FADN methodology (European Commission, 2020)[1]. Finally, for all indicators (except loan repayments per farm gross margin and ratio of dairy and dairy animal sales to total sales), the rating scales of qualitative scores were constructed following a quantile method based on the 2016-2018 distribution of FADN country averages for EU specialised dairy farms (European Commission, 2022). The rating scales for loan repayments per farm gross margin and ratio of dairy and dairy animal sales to total sales were derived from the data collected on MilKey case study farms.

Overall, the economic branch is composed of three principles, i.e., profitability, resilience, and efficiency. The profitability principle gathers indicators associated with the farm's ability to generate an appropriate level of earnings, notably to pay unpaid family labour. It incorporates information about the value of farm production before and after farm costs, as well as farm income when accounting for taxes and subsidies. It also includes a dairy-specific indicator to represent the value of dairy production. The resilience principle relates to the farm's ability to cope with external shocks, and covers issues of reliance on subsidies, pressure of farm debts, and diversification. Finally, the efficiency principle gives an indication of the farm's ability to convert farm inputs into outputs. It encompasses three main inputs; that is, costs directly associated with farm production, labour, and dairy cows.

[1] Please note that the farm income measure used in the current study does not take into account asset depreciation due to data constraints. This stands in contrast with farm income indicators used in the EU FADN reporting (European Commission, 2020, 2018a, 2018b).

Economic branch

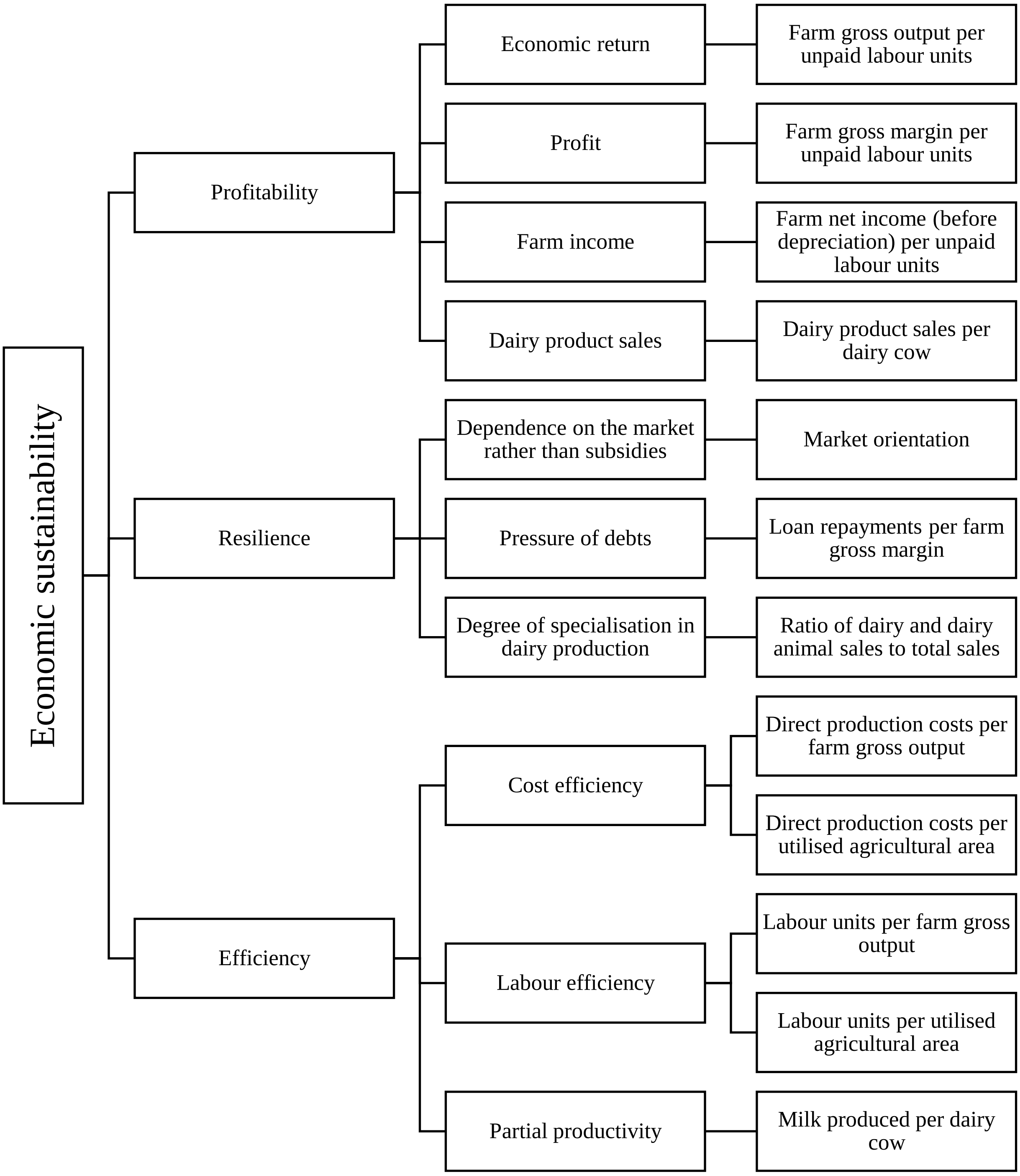

Figure 2: Economic branch of sustainability assessment

Table 2: List of economic sustainability indicators

Indicators	**Units**
Farm gross output per unpaid labour units	€/AWU
Farm gross margin per unpaid labour units	€/AWU
Farm net income (before depreciation) per unpaid labour units	€/AWU
Dairy product sales per dairy cow	€/cow
Market orientation	%
Loan repayments per farm gross margin	€/€
Ratio of dairy and dairy animal sales to total sales	%
Direct production costs per farm gross output	€/€
Direct production costs per utilised agricultural area	€/ha
Labour units per farm gross output	AWU/€
Labour units per utilised agricultural area	AWU/ha
Milk produced per cow	kg/ha

3.1. Profitability

3.1.1. Economic return

3.1.1.1. Farm gross output per unpaid labour units

Indicator type: Quantitative

Description: This indicator calculates the total production value (i.e. gross output), where all farming enterprises are taken into consideration. It is equal to the total value of crops and crop products, livestock and livestock products, and earnings from gainful activities (e.g., commercial forestry).

Farm gross output is divided by unpaid labour units to represent the economic value of unpaid family labour.

Labour units are calculated based on the amount of hours worked on the farm. They are expressed in Annual Work Units (AWU), where 1,800 hours = 1 AWU (Eurostat, 2019b). Following the FADN methodology, the total amount of hours worked by each worker is capped at 1,800 hours per year.

Indicator calculation:

$$\frac{\begin{gathered}[(Sales\ and\ use\ of\ crops\ and\ crop\ products, and\ livestock\ and\ livestock\ products)\\ -(Purchases\ of\ livestock)\\ +(Earnings\ from\ other\ gainful\ actitivies)]\end{gathered}}{Labour\ units\ of\ unpaid\ family\ members}$$

Unit: Euro (€) / AWU

Indicator interpretation: Higher values indicate larger output levels and thus better economic performance.

<u>Rating scale</u>:

Scale	Values (€/AWU)	DEXi interpretation		References
>= 75^{th} percentile	>= 243515.96	High	+	Based on the FADN data distribution for EU specialised dairy farms (European Commission, 2022) Quantile method, 2016-2018 data
[median; 75^{th} percentile[	[131313.42; 243515.96[	Medium to high		
[25^{th} percentile; median[	[41206.30; 131313.42[	Low to medium		
< 25^{th} percentile	< 41206.30	Low	-	

3.1.2. Profit

3.1.2.1. Farm gross margin per unpaid labour units

Indicator type: Quantitative

Description: Farm gross margin describes the farm's profitability by comparing the total production value to the costs directly involved in producing output. It is equal to the farm gross output minus direct production costs, where all farming enterprises are taken into consideration.

Direct production costs include:

- Costs of crop-specific inputs (e.g., seeds and plants, fertilizers, crop protection products, soil analysis);
- Costs of livestock-specific inputs (e.g., feed, veterinary fees and reproduction costs, milk tests); and
- Costs associated with other gainful activities (e.g., biogas production costs, product processing, forestry-specific costs).

Farm gross margin is divided by unpaid labour units to represent the profit available to pay unpaid family labour.

Indicator calculation:

$$\frac{(Farm\ gross\ output) - (Direct\ production\ costs)}{Labour\ units\ of\ unpaid\ family\ members}$$

Unit: € / AWU

Indicator interpretation: Higher values indicate larger margins over operating costs and thus better economic performance.

Economic branch

Rating scale:

Scale	Values (€/AWU)	DEXi interpretation		References
>= 75th percentile	>= 123961.05	High	+	Based on the FADN data distribution for EU specialised dairy farms (European Commission, 2022) Quantile method, 2016-2018 data
[median; 75th percentile[	[75974.07; 123961.05[	Medium to high		
[25th percentile; median[	[20499.77; 75974.07[	Low to medium		
< 25th percentile	< 20499.77	Low	-	

3.1.3. Farm income

3.1.3.1. Farm net income (before depreciation) per unpaid labour units

Indicator type: Quantitative

Description: Farm net income gives an indication of the capacity to remunerate the farm's own production factors such as unpaid family labour, capital, and land. It equals farm gross output minus all farm costs (i.e., direct production costs, overhead costs and external costs), minus farm taxes, plus all direct subsidies. All farming enterprises are taken into consideration.

Overhead costs include:

- Machinery and building costs (e.g., costs of current upkeep of equipment and buildings, costs of land improvements, purchase of minor equipment, car expenses, insurance of buildings);
- Energy costs (e.g., motor fuels and lubricants, electricity, heating fuels);
- Expenditure on contract work (e.g., costs linked to work carried out by contractors and to the hire of machinery); and
- Other costs in the following categories: water, agricultural insurance (except for buildings and accidents at work), accountants' fees, advisory fees, and telephone charges.

External costs include:

- Wages, social security charges and insurance of wage earners;
- Rent paid for farmland and buildings and rental charges; and
- Loan repayments.

Subsidies include:

- Coupled direct payments for crops and livestock;
- Total support for rural development (e.g., environmental subsidies, subsidies on environmental restrictions, subsidies for less favoured areas and areas facing natural or other specific constraints, other rural development payments);
- Subsidies on direct production costs and overhead costs;
- Subsidies on external factors; and
- Subsidies on investments (also known as capital grants).

Farm net income is divided by unpaid labour units to represent the ability to pay for unpaid family labour. This figure is likely to play an important role in the decision to continue operating the farm for members of the farming household.

Indicator calculation:

$$\frac{[(Farm\ gross\ margin) - (Overhead\ costs) - (External\ costs) - (Farm\ taxes) + (Subsidies)]}{Labour\ units\ of\ unpaid\ family\ members}$$

Unit: € / AWU

Indicator interpretation: Higher values indicate greater ability to remunerate unpaid family labour, as well as other production factors (e.g., land, capital) and thus better economic performance.

Rating scale:

Scales	**Values (€/AWU)**	**DEXi interpretation**		**References**
>= 75th percentile	>= 68182.21	High	+	Based on the FADN data distribution for EU specialised dairy farms (European Commission, 2022) Quantile method, 2016-2018 data
[median; 75th percentile[	[48507.38; 68182.21[	Medium to high		
[25th percentile; median[	[18103.89; 48507.38[	Low to medium		
< 25th percentile	< 18106.89	Low	-	

3.1.4. Dairy product sales

3.1.4.1. Dairy product sales per cow

Indicator type: Quantitative

Description: Dairy product sales represents the value of milk and milk products sold off farm, which depends on the quantity and quality (e.g., fat and protein content) of the milk produced. It is specific to the dairy enterprise. The measure is divided by the total number of dairy cows to account for differences in herd size.

Indicator calculation:

$$\frac{Sales\ of\ milk\ and\ milk\ products}{Average\ herd\ size}$$

Unit: € / cow

Indicator interpretation: Higher values indicate larger quantity and quality of dairy production and thus better economic performance.

Rating scale:

Scale	Values (€/cow)	DEXi interpretation		References
>= 75th percentile	>= 2758.59	High	+	Based on the FADN data distribution for EU specialised dairy farms (European Commission, 2022) Quantile method, 2016-2018 data
[median; 75th percentile[	[2505.32; 2758.59 [	Medium to high		
[25th percentile; median[	[1856.53; 2505.32[	Low to medium		
< 25th percentile	< 1856.53	Low	-	

3.2. Resilience

3.2.1. Dependence on the market rather than subsidies

3.2.1.1. Market orientation

Indicator type: Quantitative

Description: This indicator refers to the percentage of farm earnings derived from the market rather than subsidies. It takes into account all farming enterprises and is equal to farm gross output divided by the sum of farm gross output and subsidies.

Indicator calculation:

$$\frac{Farm\ gross\ output}{(Farm\ gross\ output) + (Subsidies)} * 100$$

Unit: Percentage

Indicator interpretation: Higher values indicate greater dependence on the market rather than on subsidies, and thus better resilience capacity and economic sustainability.

Rating scale:

Scale	Values (%)	DEXi interpretation		References
>= 75th percentile	>= 89.94	High	+	Based on the FADN data distribution for EU specialised dairy farms (European Commission, 2022) Quantile method, 2016-2018 data
[median; 75th percentile[	[84.38; 89.94[	Medium to high		
[25th percentile; median[	[77.37; 84.38[	Low to medium		
< 25th percentile	< 77.37	Low	-	

3.2.2. Pressure of debts

3.2.2.1. Loan repayments per farm gross margin

Indicator type: Quantitative

Description: This indicator is equal to the ratio of loan repayments to farm gross margin, where all farming enterprises are taken into consideration. It gives an indication of the share of farm profits utilised to pay off loans.

Indicator calculation:

$$\frac{Loan\ repayments}{Farm\ gross\ margin}$$

Unit: € / €

Indicator interpretation: Higher values indicate larger pressure of debts, and thus lower resilience capacity and economic sustainability.

Rating scale:

Scale	Values (€/€)	DEXi interpretation		References
= 25th percentile	0	High	+	Based on the data from MilKey case study farms (10 farms) Quantile method
]25th percentile; median[	]0; 0.13[	Medium to high		
[median; 75th percentile[	[0.13; 0.22[	Low to medium		
>= 75th percentile	>= 0.22	Low	-	

3.2.3. Degree of specialisation in dairy production

3.2.3.1. Ratio of dairy and dairy animal sales to total sales

Indicator type: Quantitative

Description: This indicator measures the level of farm diversification. It calculates the percentage of gross output coming from the dairy enterprise, i.e., percentage of dairy gross output in farm gross output.

Indicator calculation:

$$\frac{Sales\ of\ dairy\ products\ and\ dairy\ animals}{Total\ farm\ sales} * 100$$

Unit: Percentage

Indicator interpretation: Higher values are generally associated with lower resilience capacity and thus economic sustainability.

Rating scale:

Scale	Values (%)	DEXi interpretation		References
< 25th percentile	< 85.98	High	+	Based on the data from MilKey case study farms (10 farms) Quantile method
[25th percentile; median[	[85.98; 94.98[	Medium to high		
[median; 75th percentile[	[94.98; 98.81[	Low to medium		
>= 75th percentile	>= 98.81	Low	-	

3.3. Efficiency

3.3.1. Cost efficiency

3.3.1.1. Direct production costs per farm gross output

Indicator type: Quantitative

Description: This indicator is equal to the ratio of direct production costs to farm gross output, where all farming enterprises are taken into consideration.

Indicator calculation:

$$\frac{Direct\ production\ costs}{Farm\ gross\ output}$$

Unit: € / €

Indicator interpretation: Higher values indicate lower cost efficiency and thus poorer economic performance.

Rating scale:

Scale	Values (€/€)	DEXi interpretation		References
< 25th percentile	< 0.42	High	+	Based on the FADN data distribution for EU specialised dairy farms (European Commission, 2022) Quantile method, 2016-2018 data
[25th percentile; median[	[0.42; 0.48[	Medium to high		
[median; 75th percentile[	[0.48; 0.54[	Low to medium		
>= 75th percentile	>= 0.54	Low	-	

3.3.1.2. Direct production costs per utilised agricultural area

Indicator type: Quantitative

Description: This indicator is equal to the ratio of direct production costs to utilised agricultural area (UAA), where all farming enterprises are taken into consideration.

Indicator calculation:

$$\frac{Direct\ production\ costs}{UAA}$$

Unit: € / ha

Indicator interpretation: Higher values indicate higher direct production costs per ha and thus poorer economic performance.

Rating scale:

Scale	Values (€/ha)	DEXi interpretation		References
< 25th percentile	< 849.71	High	+	Based on the FADN data distribution for EU specialised dairy farms (European Commission, 2022) Quantile method, 2016-2018 data
[25th percentile; median[	[849.71; 1321.99[	Medium to high		
[median; 75th percentile[	[1321.99; 1972.27[	Low to medium		
>= 75th percentile	>= 1972.27	Low	-	

3.3.2. Labour efficiency

3.3.2.1. Labour units per farm gross output

Indicator type: Quantitative

Description: This indicator is equal to the ratio of total labour units to farm gross output, where all farming enterprises are taken into consideration. Total labour units include the labour units of unpaid and paid workers.

Indicator calculation:

$$\frac{Total\ labour\ units}{Farm\ gross\ output}$$

Unit: AWU / €

Indicator interpretation: Higher values indicate lower labour efficiency and thus poorer economic performance.

Rating scale:

Scale	Values (AWU/€)	DEXi interpretation		References
< 25th percentile	< 0.0000078	High	+	Based on the FADN data distribution for EU specialised dairy farms (European Commission, 2022) Quantile method, 2016-2018 data
[25th percentile; median[	[0.0000078; 0.000012[	Medium to high		
[median; 75th percentile[	[0.000012; 0.000027[	Low to medium		
>= 75th percentile	>= 0.000027	Low	-	

3.3.2.2. Labour units per utilised agricultural area

Indicator type: Quantitative

Description: This indicator is equal to the ratio of total labour units worked to UAA, where all farming enterprises are taken into consideration.

Indicator calculation:

$$\frac{Total\ labour\ units}{UAA}$$

Unit: AWU/ha

Indicator interpretation: Higher values indicate larger labour input on the farm per ha and thus poorer economic performance.

Rating scale:

Scale	Values (AWU/ha)	DEXi interpretation		References
< 25th percentile	< 0.026	High	+	Based on the FADN data distribution for EU specialised dairy farms (European Commission, 2022) Quantile method, 2016-2018 data
[25th percentile; median[	[0.026; 0.038[	Medium to high		
[median; 75th percentile[	[0.038; 0.076[	Low to medium		
>= 75th percentile	>= 0.076	Low	-	

3.3.3. Partial productivity

3.3.3.1. Milk produced per cow

Indicator type: Quantitative

Description: This indicator measures milk yield per dairy cow and is equal to the ratio of total milk produced to average dairy herd size. It is specific to the dairy enterprise.

Indicator calculation:

$$\frac{Total\ milk\ produced * Milk\ density}{Average\ herd\ size}$$

Where:

$Total\ milk\ produced$ is recorded in L at the farm level, and

$Milk\ density$ = 1.03 kg/L.

Unit: kg / cow

Indicator interpretation: Higher values indicate larger milk yields and thus better economic performance.

Rating scale:

Scale	Values (kg/cow)	DEXi interpretation		References
>= 75th percentile	>= 7819.23	High	+	Based on the FADN data distribution for EU specialised dairy farms (European Commission, 2022) Quantile method, 2016-2018 data
[median; 75th percentile[	[7167.66; 7819.23[	Medium to high		
[25th percentile; median[	[5921.56; 7167.66[	Low to medium		
< 25th percentile	< 5921.56	Low	-	

4. Social branch

Measuring farm social sustainability is challenging due to complexity in defining the term, as well as in quantifying its different components (Janker et al., 2019; Lebacq et al., 2013). Unlike the environmental and economic dimensions, scientific discourses fail to agree on what constitutes social sustainability and how it can be accurately and exhaustively depicted through standard sustainability assessment tools (Brennan et al., 2021; Gaviglio et al., 2016; Janker and Mann, 2020). The current state of the art is mainly criticised because social sustainability measurements often lack theoretical depth, notably because of the use of vague frameworks (Boström, 2012; Janker and Mann, 2020). However, sustainability by nature cannot be explored without a deeper consideration of social issues revolving around agricultural production (Janker et al., 2019).

In the MilKey project, the social assessment aimed at overcoming common issues pointed out in the literature by integrating the standard DEXi multi-criteria assessment tool with a theoretical framework. To this end, a three-fold approach was followed to build the social branch and define social sustainability indicators. Firstly, a review of the literature on the social sustainability of agricultural production systems was conducted to define the theoretical framework of the social assessment and deduce hierarchical layers in the social branch. Two layers of theoretical concepts were intertwined to form the social branch, with two principles, each comprising three indicators. Secondly, after selecting the theoretical concepts to be included in the social branch, 15 unstructured in-depth interviews were carried out with farmers from Norway, Poland, and Ireland in the fall of 2021. These were based on the grounded theory (Glaser and Strauss, 1967), with the aim of examining what selected concepts entailed for farmers and identifying statements that could represent them. Lastly, based on interviewees' narratives, the theoretical concepts were translated into survey questions for the MilKey social assessment.

Before outlining the social indicators in detail, we describe the theoretical framework and resulting tree structure, which were adapted from the approach proposed in Janker et al. (2019). On the one hand, Parsons' social system theory (Parsons, 1991) was used to define the highest hierarchical layer of the social branch (i.e., principles). In Parsons' theory, social systems are overarching concepts defined as patterned networks of interactions of a 'coherent whole' existing between individuals, groups, and institutions (Parsons, 1991). They are formal structures of role and status that can form a stable group. An individual may simultaneously belong to multiple social systems defined at different levels. For instance, farmers are part of several social systems, such as the farm, farming community, and wider society (Lyon and Parkins, 2013), which are represented in Figure 3. The interactions between these three systems are the focus of the MilKey social assessment because they are key to farmers' quality of life and motivation to farm, and thus social sustainability in agriculture. It is worthwhile to mention that the MilKey sustainability assessment is overall performed at the farm level. Hence, we are merely interested in farmers' perceptions in the social branch, as opposed to perceptions of members of the community or wider society. In this frame, the social branch is divided into two principles: (1) sustainability of farm life, and (2) sustainability of life outside of farming. First, the 'sustainability of farm life' principle focuses on the well-being of farmers in their professional work. This is influenced by on-farm working conditions and relationships with other members of the household and farming community. This also relates to the feeling of security and satisfaction with being a farmer. Second, the 'sustainability of life outside of farming' principle focuses on the well-being of farmers in their private life. This is related to the farmer's quality of life outside of farming.

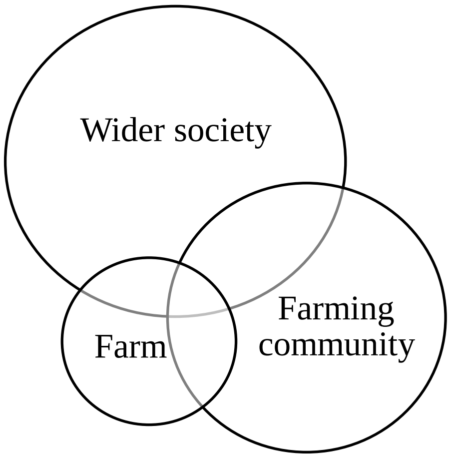

Figure 3: Social systems analysed in the MilKey project

On the other hand, the second layer of the branch (i.e., indicators) was deduced from Maslow's (1943) needs concept, because social sustainability in agriculture is determined by the extent to which farmers' needs are fulfilled. Needs are also consistent with the most widely accepted definition of sustainable development from the Brundtland report, i.e., "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987). In this context, each of the tree's principles are explored through three social sustainability indicators that follow Maslow's hierarchy of needs (Maslow, 1943): (1) physiological and security needs, (2) social needs, and (3) esteem and self-actualisation needs. Physiological and security needs are measured through farmers' perceptions of individual and household physical health and security. Social needs are measured through farmers' perceptions of their social relationships, while esteem and self-actualisation needs are measured through farmers' perceptions of their profession and associated lifestyle. Statements reflecting these perceptions were designed for farmers to express their level of agreement on 5-point Likert scales, ranging from strongly disagree, disagree, neither agree or disagree, agree, to strongly agree. Each social indicator was obtained by averaging farmers' responses to the group of statements that referred to that specific indicator and principle. Rating scales were then deduced based on expert opinion.

The social branch of the sustainability assessment is presented in Figure 4. Selected indicators are summarised in Table 3.

Social branch

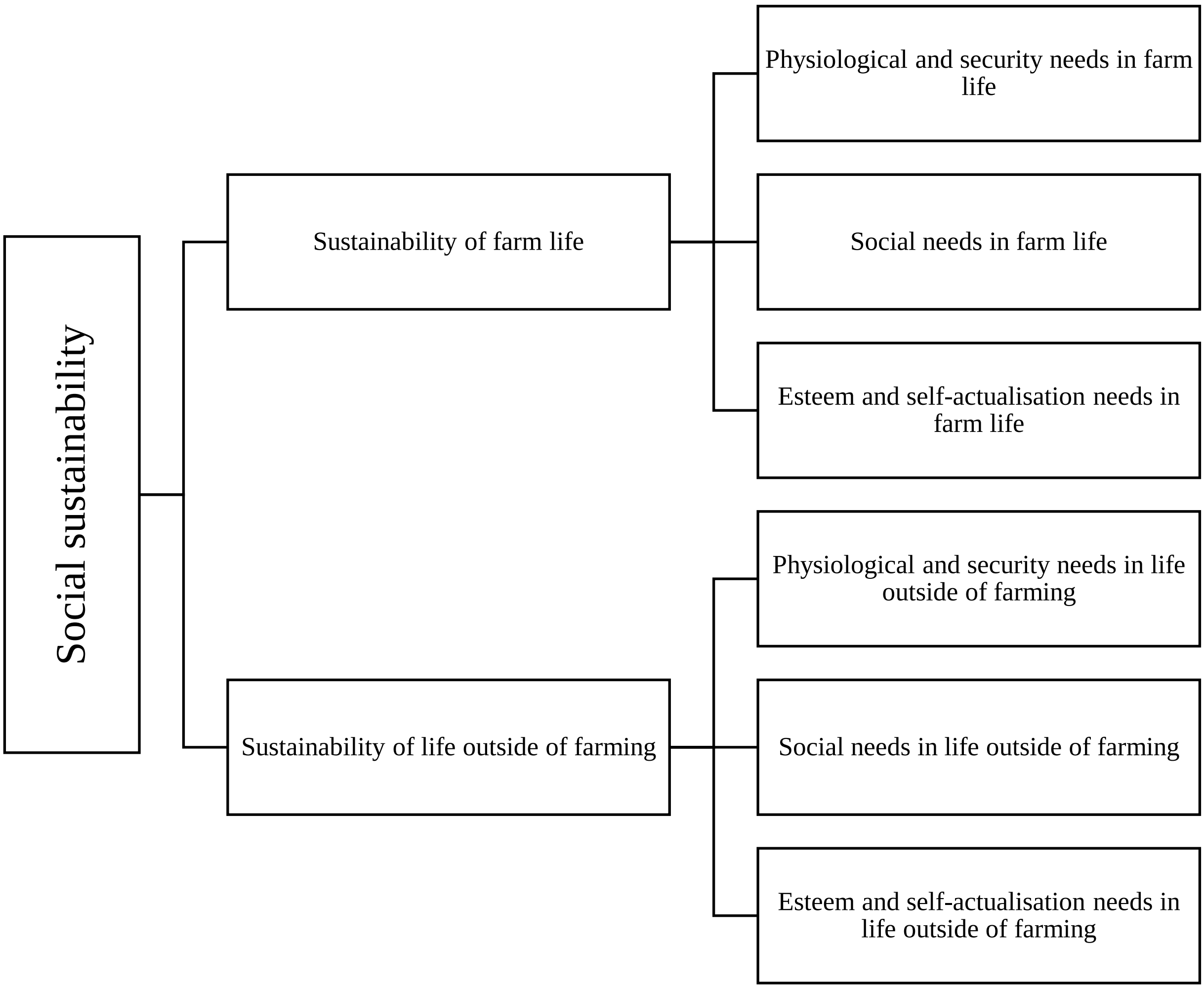

Figure 4: Social branch of sustainability assessment

Social branch

Table 3: List of social sustainability indicators

Indicators	**Units**
Physiological and security needs in farm life	Quantitative score
Social needs in farm life	Quantitative score
Esteem and self-actualisation needs in life outside of farming	Quantitative score
Physiological and security needs in life outside of farming	Quantitative score
Social needs related in life outside of farming	Quantitative score
Esteem and self-actualisation needs related in life outside of farming	Quantitative score

4.1. Sustainability of farm life

4.1.1. Physiological and security needs in farm life

Indicator type: Qualitative

Description: This indicator relates to the quality of life of farmers and their families in terms of meeting their physiological needs and security needs when working on the farm. This is measured through perceptions of working hours, workload, risks at work, availability and access to health services, and the financial performance of the farm.

Indicator calculation:

$$\sum_{i=5}^{n} \frac{S_i}{n}$$

Where:

S_i = Farmer response to statement i

n = Total amount of statements taken into account for this indicator

Responses to statements are measured on a 5-point Likert scales, ranging from strongly disagree, disagree, neither agree or disagree, agree, and strongly agree. For all statements, the value 1 indicates the highest level of social sustainability, and 5 represents the lowest level. Hence, the order of the 5-point scale depends on the direction of the statements (e.g., negative or positive expected effect on social sustainability).

Statements taken into account in this indicator and their expected effect on social sustainability are the following:

	Statements	Expected effect on social sustainability
S_1	Working on my farm is straining for my physical health.	-
S_2	Working on my farm often involves dangerous work situations.	-
S_3	I feel the financial performance of my farm is good enough, that I do not have to be worried about the economy.	+
S_4	As a farmer, I experience that both the farm workers here and I have satisfying social welfare and security arrangements.	+
S_5	In case of an illness or injury to me, I am confident that I have people who will help me with the farm work.	+

Unit: Quantitative score, taking values from 1 to 5.

Indicator interpretation: Higher values indicate lower fulfilment of physiological and security needs related to farm work.

Rating scale:

Scale	DEXi interpretation		Reference
[1; 1.5[	High	+	Based on expert opinion
[1.5; 3.5[	Medium		
[3.5; 5]	Low	-	

4.1.2. Social needs in farm life

Indicator type: Qualitative

Description: This indicator relates to the quality of life of farmers in terms of meeting social needs in their professional life. This is measured through perceptions of isolation, and social connection and involvement in agriculture.

Indicator calculation:

$$\sum_{i=3}^{n} \frac{S_i}{n}$$

Where:

S_i = Farmer response to statement i

n = Total amount of statements taken into account for this indicator

Responses to statements are measured on a 5-point Likert scales, ranging from strongly disagree, disagree, neither agree or disagree, agree, and strongly agree. For all statements, the value 1 indicates the highest level of social sustainability, and 5 represents the lowest level. Hence, the order of the 5-point scale depends on the direction of the statements (e.g., negative or positive expected effect on social sustainability).

Statements taken into account in this indicator and their expected effect on social sustainability are the following:

	Statements	**Expected effect on social sustainability**
S_1	I have satisfactory social interactions with colleagues and friends in agriculture.	+
S_2	I often feel lonely in my daily work on the farm.	-
S_3	I am not worried about what will happen to the farm when I stop running it.	+

Unit: Quantitative score, taking values from 1 to 5.

Indicator interpretation: Higher values indicate lower fulfilment of social needs related to farm work.

Rating scale:

Scale	DEXi interpretation		Reference
[1; 1.5[	High	+	
[1.5; 3.5[	Medium		Based on expert opinion
[3.5; 5]	Low	-	

4.1.3. Esteem and self-actualisation needs in farm life

Indicator type: Qualitative

Description: This indicator represents the farmer's desire to be valued and validated by themselves and others (e.g., co-workers and the government) for their work. It is measured through perceptions of self-esteem to uncover the regard and acceptance that individuals have of themselves as farmers.

Indicator calculation:

$$\sum_{i=6}^{n} \frac{S_i}{n}$$

Where:

S_i = Farmer response to statement i

n = Total amount of statements taken into account for this indicator

Responses to statements are measured on a 5-point Likert scales, ranging from strongly disagree, disagree, neither agree or disagree, agree, and strongly agree. For all statements, the value 1 indicates the highest level of social sustainability, and 5 represents the lowest level. Hence, the order of the 5-point scale depends on the direction of the statements (e.g., negative or positive expected effect on social sustainability).

Statements taken into account in this indicator and their expected effect on social sustainability are the following:

	Statements	Expected effect on social sustainability
S_1	Farm work is rewarding and gives me opportunities to realise my full potential as a person.	+
S_2	I feel that the agricultural policy and/or the market forces have made me run the farm in a way that I do not like.	-
S_3	I am confident to further invest time and/or money in the future of my farm given the current situation.	+
S_4	I am optimistic about the future of agriculture in my country.	+
S_5	I feel that the work done by farmers is appreciated by society.	+
S_6	I am proud to be a farmer.	+

Unit: Quantitative score, taking values from 1 to 5.

Indicator interpretation: Higher values indicate lower fulfilment of esteem and self-actualisation needs related to farm work.

Rating scale:

Scale	DEXi interpretation		Reference
[1; 1.5[	High	+	Based on expert opinion
[1.5; 3.5[	Medium		
[3.5; 5]	Low	-	

4.2. Sustainability of life outside of farming

4.2.1. Physiological and security needs in life outside of farming

Indicator type: Qualitative

Description: This indicator relates to the quality of life of farmers and their families in terms of meeting their physiological needs (e.g., bodily requirements like sleep, food, and water) and security needs (e.g., health and financial security) outside of farming. Among others, this is measured through perceptions of leisure time, income security, and access to public good and services.

Indicator calculation:

$$\sum_{i=3}^{n} \frac{S_i}{n}$$

Where:

S_i = Farmer response to statement i

n = Total amount of statements taken into account for this indicator

Responses to statements are measured on a 5-point Likert scales, ranging from strongly disagree, disagree, neither agree or disagree, agree, and strongly agree. For all statements, the value 1 indicates the highest level of social sustainability, and 5 represents the lowest level. Hence, the order of the 5-point scale depends on the direction of the statements (e.g., negative or positive expected effect on social sustainability).

Statements taken into account in this indicator and their expected effect on social sustainability are the following:

	Statements	Expected effect on social sustainability
S_1	I feel that I have both the time and the opportunities to take care of my physiological health in my spare time.	+
S_2	Our household finances (farm income and non-farm income for all household members) are of a level to make us feel financially secure.	+
S_3	I feel that my family and I have satisfactory access to everyday commodities and public services such as grocery, post, bank, education, healthcare, etc.	+

Unit: Quantitative score, taking values from 1 to 5.

Indicator interpretation: Higher values indicate lower fulfilment of physiological and security needs related to social life.

Rating scale:

Scale	DEXi interpretation		Reference
[1; 1.5[	High	+	Based on expert opinion
[1.5; 3.5[	Medium		
[3.5; 5]	Low	-	

4.2.2. Social needs in life outside of farming

Indicator type: Qualitative

Description: This indicator relates to the quality of life of farmers in terms of meeting their social needs (e.g., sense of belonging) outside of farming. This is measured through perceptions of isolation, social connection, and ability to spend quality time with friends and family.

Indicator calculation:

$$\sum_{i=4}^{n} \frac{S_i}{n}$$

Where:

S_i = Farmer response to statement i

n = Total amount of statements taken into account for this indicator

Responses to statements are measured on a 5-point Likert scales, ranging from strongly disagree, disagree, neither agree or disagree, agree, and strongly agree. For all statements, the value 1 indicates the highest level of social sustainability, and 5 represents the lowest level. Hence, the order of the 5-point scale depends on the direction of the statements (e.g., negative or positive expected effect on social sustainability).

Statements taken into account in this indicator and their expected effect on social sustainability are the following:

	Statements	Expected effect on social sustainability
S_1	I feel that I have the time and the opportunities to spend time with my friends and family.	+
S_2	I often feel lonely in my free time.	-
S_3	I feel that I manage to spend quality time with my children, my family and friends in a satisfactory way without it coming into conflict with my tasks as a farmer.	+
S_4	I am concerned that some of my immediate family members may feel lonely and socially isolated.	-

Unit: Quantitative score, taking values from 1 to 5.

Indicator interpretation: Higher values indicate lower fulfilment of social needs related to social life.

Rating scale:

Scale	DEXi interpretation		Reference
[1; 1.5[	High	+	Based on expert opinion
[1.5; 3.5[	Medium		
[3.5; 5]	Low	-	

4.2.3. Esteem and self-actualisation needs in life outside of farming

Indicator type: Qualitative

Description: This represents farmers' perceptions of their feasibility to realise personal plans and aspirations outside of farming.

Indicator calculation:

$$\sum_{i=2}^{n} \frac{S_i}{n}$$

Where:

S_i = Farmer's response to statement i

n = Total amount of statements taken into account for this indicator

Responses to statements are measured on a 5-point Likert scales, ranging from strongly disagree, disagree, neither agree or disagree, agree, and strongly agree. For all statements, the value 1 indicates the highest level of social sustainability, and 5 represents the lowest level. Hence, the order of the 5-point scale depends on the direction of the statements (e.g., negative or positive expected effect on social sustainability).

Statements taken into account in this indicator and their expected effect on social sustainability are the following:

	Statements	**Expected effect on social sustainability**
S_1	I feel that my duties and tasks on the farm hinder me in realising my own wants and interests outside of farming.	-
S_2	I feel that I am able to realise my dreams and visions for the life I want to live next to being a farmer.	+

Unit: Quantitative score, taking values from 1 to 5.

Indicator interpretation: Higher values indicate lower fulfilment of esteem and self-actualisation needs related to social life.

Social branch

Rating scale:

Scale	DEXi interpretation		Reference
[1; 1.5[	High	+	Based on expert opinion
[1.5; 3.5[	Medium		
[3.5; 5]	Low	-	

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