

PROJEKT

NEU.rind

Nachhaltigkeit • Effizienz • Umweltwirkung

Digitaler Betriebshelfer zur Bewertung der Nachhaltigkeit, der Effizienz und der Umweltwirkungen am Milchviehbetrieb

METHOD DESCRIPTION

Mit Unterstützung von Bund und Europäischer Union

 Bundesministerium
Land- und Forstwirtschaft,
Klima- und Umweltschutz,
Regionen und Wasserwirtschaft


LE 14-20
Entwicklung für den Ländlichen Raum

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NEU.rind Tool – Method Description

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1 Introduction

1.1 Purpose of the Manual

This manual provides a transparent description of the methodology for the NEU.rind sustainability assessment tool. The tool was developed within the EIP-AGRI project “NEU.rind – Digital farm assistant for assessing sustainability, efficiency, and environmental impacts on dairy farms” from 1.1.2022-31.03.2025. The tool includes Life Cycle Assessment (LCA) elements in addition to other sustainability indicators, which are commonly used to analyse raw milk production and agricultural systems in general. Besides the LCA impact categories *global warming potential* (GWP₁₀₀; assessing greenhouse gas emissions in CO₂-eq), *terrestrial acidification* (in kg sulphur-dioxide equivalents, SO₂-eq) and their most relevant source of ammonia (NH₃) emissions, fossil energy use (as *cumulative energy demand* in MJ), and estimates on potential nitrate (NO₃⁻) emissions, biodiversity is assessed with potential losses of species and proportions of the farmland, which are ‘high nature value farmland’, are assessed. Furthermore, the NEU.rind-tool considers protein production per ha and protein efficiency, a high number of animal health indicators, and – regarding farm profitability – the gross margin per cow per year as well as direct cost-free revenue per ha and per kg energy corrected milk (ECM).

The NEU.rind-tool is designed for farmers, researchers, policymakers, farm advisors, and industry stakeholders who aim to quantify and improve the environmental and economic performance of dairy farming. The methodology ensures a holistic view of milk production by considering all relevant resource inputs, emissions, and sustainability indicators along the entire life cycle of dairy cows. It follows standardized LCA principles and includes biophysical allocation methods to fairly distribute environmental impacts among milk and co-products (e.g., meat from culled cows and calves).

This manual is structured to provide clear step-by-step instructions for calculating the sustainability indicators and interpreting results, ensuring that findings are comparable, reproducible, and actionable.

1.2 Scope, System Boundaries and Functional Unit of the NEU.rind tool’s assessments

The assessment focuses on the production of raw milk, including all activities related to feed cultivation, animal husbandry, and manure management. The system boundaries extend from on-farm resource inputs (e.g., fertilizers, feed, energy) to the farm gate (‘cradle to farmgate’), ending when milk (for processing in dairies) is collected.

The environmental assessment (mainly the LCA part) and the farm economic assessment accounts for direct and indirect inputs, their costs and revenues, as well as emissions related to:

- Feed production (on-farm and external sources, i.e. purchased feed)
- Manure and fertilizer application (including internal nutrient flows)
- Enteric fermentation and methane emissions

- Energy and material input use for dairy farming
- Milk and growth performance of cows, biological data, animal health
- Infrastructure (milk production-related machinery and buildings on farms)

Not included in the assessment are transportation and processing of milk beyond the farm gate, retail and consumption phases, or on-farm environmental effects which are not related to dairy production.

To ensure comparability and meaningful impact assessment, results are expressed in two functional units: (1) per hectare (ha) farmland which is related to milk production in terms of feed or fertilizer nutrient flows, and (2) per kilogram of energy-corrected milk (kg ECM) – to account for differences in milk composition and correct for varying fat and protein contents. The ha-based analyses are particularly relevant for assessing land-use efficiency, but also a consistency with natural flows and sufficiency (regarding e.g., nutrient balances, and biodiversity effects). Milk-based analyses (impacts per kg ECM) are important to assess efficiency of the raw milk production. The ECM unit standardizes milk output based on fat and protein content, allowing for better comparisons between farms with different breeds and production systems.

The ECM calculation formula used herein:

Equation (1):

$$\text{kg ECM} = (\text{kg milk yield}) * [0.38 \times (\text{fat \%}) + 0.21 \times (\text{protein \%}) + 1.05] / 3.28$$

1.3 Overview of Sustainability Indicators in the NEU.rind tool

This manual evaluates key environmental, economic, and animal welfare indicators relevant to dairy farming sustainability. The following ones, see Figure 1, are assessed and described in the following paragraph. Proposals for more than a dozen indicators were developed by the scientific partners and assessed for their practical applicability on dairy farms. The final selection and ordering of the indicators were determined by the extended Operational Group within the NEU.rind EIP-AGRI project.

	Indicator	per kg milk (consideration of co-products, allocation)	per ha utilised area or per farm
1	Global warming potential (GWP)	kg CO ₂ -eq	kg CO ₂ -eq
2	Human edible feed conversion efficiency / Protein production	heFCE factor	kg CP / ha
3	Biodiversity	Potentially disappeared fractions of species	% High nature farmland; Rare/Endangered crops / breeds
4	Fossil energy demand	MJ	GJ
5	Ammonia and acidification	kg SO ₂ -eq	kg NH ₃
6	Nitrate emissions	kg N-eq	kg N-eq
7	Animal health aspects	Scores	
8	Gross margin	€	€

Figure 1. LCA and sustainability indicators used in the NEU.rind tool.

a. Environmental Impacts

- Greenhouse gas (GHG) emissions: GWP₁₀₀ in CO₂-equivalents per ha and per kg ECM (including enteric methane, manure emissions, energy and material inputs, infrastructure and feed-related emissions).
- Protein production and feed (protein) conversion efficiency: Yield of human-edible protein per ha and efficiency of the conversion of potentially human-edible protein into milk and beef protein.
- Biodiversity impact: Proportion of High Nature Value (HNV) farmland in total farm area. Potential species loss per kg ECM, based on Chaudhary & Brooks (2018) biodiversity assessment method. Keeping (rare and) endangered cattle breeds.
- Fossil energy demand: Total energy consumption in MJ per ha and per kg ECM.
- Air pollution and Acidification: Ammonia (NH₃) emissions per ha and terrestrial acidification emissions per kg ECM.
- Water contamination risks are assessed by nitrate (NO₃⁻) emissions per ha and per kg ECM. (In comparison to other indicators, these results are rather rough estimates as the NEU.rind method does not query fertilizer amounts crop- and field-specific but only on a farm level.)

b. Animal Health and Welfare Indicators

- Animal Health Metrics: Q-check (Thünen Institute; <https://www.thuenen.de/de/fachinstitut/oekologischer-landbau/arbeitsgruppen/arbeitsgruppe-tierwohl/q-check-tierwohl-in-der-milchviehhaltung-mit-system>). Evaluation of 16 key indicators affecting cows' and calves' health, including longevity, and productivity summarized under the topics of udder health, metabolism, cow losses and calf losses.

c. Economic Performance

- Farm Profitability: Gross margin per cow per year and per kg milk as well as direct cost-free revenue per ha.

1.4 Allocation

The Allocation follows the more sophisticated procedure described in IDF (2022), referencing to Nemecek and Thoma (2021) as well as Ineichen et al. (2022). It is a biophysical type of allocation (avoidance), using (i) the amount of feed net energy required to produce milk versus (ii) the amount of feed net energy required for body growth to distinguish between impacts allocated to the product milk and impacts allocated to the beef by-products cull cow and calves.

1.5 Data in the NEU.rind tool and links to databases

One key requirement during the development of the NEU.rind digital farm assistant was to minimize the data collection burden on farmers by utilizing existing data rather than requiring duplicate entry. To ensure efficient and user-friendly data input, as many parameters as possible are prefilled with farm-specific parameter values or default values sourced from established data interfaces.

Through integration with the Rinderdatenverbund (RDV), NEU.rind accesses a wide range of routinely collected data relevant to sustainability assessment. These include herd data and

data on breeding, milk (milk yield records) and beef production data, animal health and longevity, calving and insemination data, information on feed diets, and farm infrastructure information. With the farmer's consent, NEU.rind can use these datasets directly without additional input effort.

The tool also integrates data from other major sources:

- IACS-data (Invekos) by the Agrarmarkt Austria (AMA): Farm structure, land use, animal numbers, and participation in agri-environmental programs (ÖPUL)
- Österreichische Fleischkontrolle (ÖFK): Slaughter body masses, carcass weights, and slaughter categories
- Bundesanstalt für Agrarwirtschaft und Bergbauernfragen (BABF): Farm-specific economic standard values from the IDB system (interactive gross margin calculator; <https://idb.agrar-forschung.at/verfahren/konventionell/milchkuhhaltung>)
- Feed analysis results from the Feed Laboratory Rosenau
- Health monitoring data from veterinarians

To ensure legal compliance, the necessary data protection and technical frameworks were established, particularly for sensitive data such as those from IACS (INVEKOS) and economic figures from BABF.

Additionally, NEU.rind adopted the Q-Check Animal Welfare Assessment (developed by the Thünen Institute in Germany) to systematically map animal health parameters in dairy herds. Default values drawn from these sources are automatically displayed in the NEU.rind data input tables and can be manually overwritten by users, where needed. Each default value is transparently linked to its source, and it is recorded whether a default or a user-specific input was used.

Importantly, while high-quality default values are available, they cannot capture all farm-specific nuances, particularly in economic assessments and feed management. Thus, for maximum accuracy, the use of individual farm parameters is recommended wherever possible.

The following Figure 2 displays the data sources used in the NEU.rind tool.

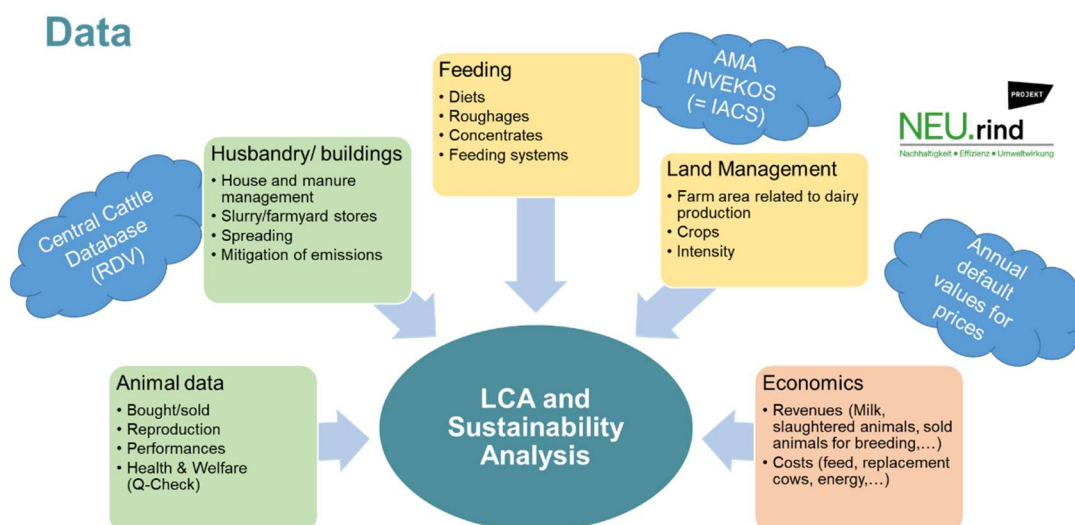


Figure 2. Data sources used in the NEU.rind tool to ensure efficient and user-friendly data input.

All data entering NEU.rind, either by manual insertion by the farmer or from the diverse databases, is automatically checked concerning correct and appropriate numbers. Warnings are provided, if data is not within typical ranges or if no primary data from a farm was inserted (Figure 3).

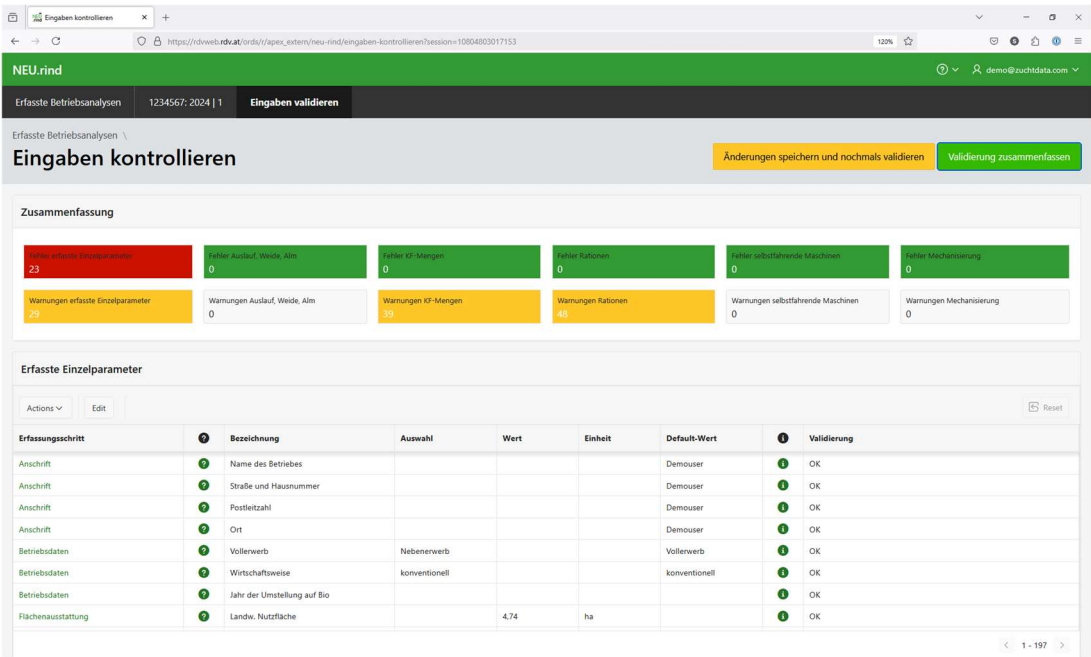


Figure 3. Under the headings ‘Check data entry’ (‘Eingaben kontrollieren’) and ‘Zusammenfassung’ (‘Data Summary’) warnings related to various data inputs are displayed.

2 Detailed method description for environmental impact assessment, animal health and farm profitability

2.1 Global warming potential – GHG emissions

Greenhouse gas (GHG) emissions are assessed from various sources, as outlined in Table 1. For emission factors (EFs) related to manure management systems, NEU.rind primarily relies on Austria's national factors (see Umweltbundesamt, 2024ab), supplemented by selected IPCC (2019) EFs. An overall aim of NEU.rind was to ensure that the calculations align as closely as possible with those used in the national inventory for both GHG and NH₃ emissions. A list of EFs and correction factors (CFs) is given in the annex.

Table 1. Emissions sources covered in the NEU.rind-tool and its most important calculations and parameters per cow and year.

kg CH ₄ enteric fermentation	Gross energy per cow & day * 0.065 * 365 / 55.65
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kg CH₄ manure management system	VS_{excr} per cow & day * 365 * 0.24 * 0.67 * EFs [see Table 1]
kg N₂O manure management system	N_2O manure management _{direct} + N_2O manure management _{indirect}
kg CH₄ enteric fermentation as CO₂-eq (GWP₁₀₀)	CH ₄ enteric fermentation * 27.9
kg CH₄ manure management system as CO₂-eq (GWP₁₀₀)	CH ₄ manure management system * 27.9
kg N₂O manure management system as CO₂-eq (GWP₁₀₀)	N_2O manure management system * 273
kg N₂O soil as CO₂-eq (GWP₁₀₀)	(N_2O soil _{direct} from manure application + N_2O soil _{direct} from additional/synthetic fertilizers + N_2O soil _{indirect}) * 273
kg CO₂-eq (GWP₁₀₀) roughages and straw	Sum of all kg roughages _i / cow & year * (GWP _{100i} / kg roughage _i)
kg CO₂-eq (GWP₁₀₀) concentrates	Sum of all kg concentrates _i / cow & year * (GWP _{100i} / kg concentrate _i)
kg CO₂-eq (GWP₁₀₀) electric energy and fuels	Sum of kWh electricity _i / cow & year * Electricity GWP _{100i} / kWh + Sum of kg fuels GWP _{100i} / cow & year * Fuels GWP _{100i} / kg
kg CO₂-eq (GWP₁₀₀) synth. fertilizers	Sum of all kg fertilizers _i / cow & year * (GWP _{100i} / kg fertilizer _i)
kg CO₂-eq (GWP₁₀₀) infrastructure	Buildings _i per cow & year * (GWP _{100i} / building _i) + machinery _i requirement per cow & year * (GWP _{100i} / machinery _i)
Sum kg CO₂-eq (GWP₁₀₀) / cow & year	kg CH ₄ enteric fermentation + kg CH ₄ manure management system + kg N ₂ O manure management system + kg N ₂ O soil + roughages and straw + concentrates + electric energy and fuels + synthetic fertilizers + infrastructure (all in CO ₂ -eq)

As shown in Table 1, CH₄ emissions from enteric fermentation are estimated based on gross energy (GE) intake. The daily GE intake per cow is calculated from total feed intake and its nutrient composition – specifically crude fat (CL), crude protein (CP), crude fibre (CF), and ether extracts (EE). These values depend on the cow's average body weight, growth rate, and milk production performance, as described by Ineichen et al. (2022), a study relating to IDF (2015) and relevant to IDF (2022). Ineichen et al. (2022) outline the IPCC (2019)-based methodology for deriving parameters such as net energy (NE) per kilogram of milk, NE requirements for pregnancy, maintenance, and growth. The total amount of feed (in kg per average cow and year) was determined based on this sum of NE requirement per cow per year; first, the primary data on the quantity of concentrate feed per cow per year were calculated, and then the difference to the total NE requirement per cow per year, according to IPCC (2019) and Ineichen et al. (2022), was used to calculate the amounts of different roughage feedstuffs, based on the percentage distribution of the forage ration. Once daily feed demand is calculated, the daily GE intake per cow is assessed using the following equation 2 and the heating values of CL, CP, CF and NfE:

Equation (2):

$$\text{GE intake per cow and day} = \sum (\text{kg roughage}_i / \text{cow} \cdot \text{day} \times \text{MJ GE} / \text{kg roughage}_i) + \sum (\text{kg concentrate}_i / \text{cow} \cdot \text{day} \times \text{MJ GE} / \text{kg concentrate}_i)$$

Volatile solids (VS) excreted per cow per day (VS_{ex}) are estimated using IPCC (2019, Equation 10.24), which incorporates factors such as GE intake, feed digestibility, urinary energy, and ash content.

Annual nitrogen excretion (N_{ex}) per cow, a key variable for estimating NH₃ and N₂O emissions, is calculated as:

Equation (3):

$$N_{\text{ex}} \text{ per cow and year} = [\sum (\text{kg roughage}_i / \text{cow} \cdot \text{day} \times \text{kg CP}_i / \text{kg roughage}_i) + \sum (\text{kg concentrate}_i / \text{cow} \cdot \text{day} \times \text{kg CP}_i / \text{kg concentrate}_i)] \times 365 - (\text{kg ECM produced per year} \times \text{protein content} / 100 / 6.25)$$

Volatile solids (VS_{ex}) and N_{ex} are allocated according to the manure management system (MMS) in which they occur, including different types of slurry-based and solid manure housing systems, pasture, and yards. Nutrients contained in straw are accounted for following the guidelines from EMEP/EEA (2023).

N_2O emissions are derived from three main sources: Direct soil-related emissions, direct emissions from MMS ($N_2O_{\text{manure management-direct}}$), and indirect emissions ($N_2O_{\text{manure management-indirect}}$) resulting from NH_3 , nitrous oxide (NO_x), and NO_3^- losses (see section 2.5). All these emissions are estimated according to the methodologies outlined in Umweltbundesamt (2024ab). CH_4 emissions from MMS are calculated based on VS_{ex} values and also follow the national inventory approach (Umweltbundesamt, 2024ab). Further methodological details on housing and manure management systems are provided in Umweltbundesamt (2024ab) and Hörtenhuber (2025).

Additionally, the CO_2 -equivalent emissions (expressed in $kg CO_2\text{-eq}$, using GWP_{100} values) associated with various inputs are reported in Table 3. These include emissions from:

- ingested roughages and straw (sum of all roughages_i per cow per year $\times$ EF_i)
- concentrates (sum of all concentrates_i per cow per year $\times$ EF_i)
- electricity and fuel use (with current EFs from the Austrian Environment Agency, Umweltbundesamt, 2024a)
- synthetic fertilizers
- infrastructure (e.g., machinery and building construction for milk production).

Generally – also for other impacts – (GWP_{100}) environmental impacts from inputs (Table 3) are assessed by:

Equation (4):

$$GWP \text{ per cow \& year} = \sum (\text{Input}_i \text{ per cow and year} \times EF_i)$$

Emission factors (EF) for all inputs are derived from secondary data sources, notably adapted datasets from established life cycle assessment (LCA) databases, especially the Ecoinvent database (version 3), and values published in papers such as Ruckli et al. (2021). The impact assessment for those database-related factors followed the Product Environmental Footprint (PEF) methodology of the European Union, using the respective characterization factors provided therein (and which are the same as shown above). Finally, the total CO_2 -equivalent emissions per dairy farm (branch) are normalized by the average number of cows per year, and impacts per average cow and year are allocated to 1) the average amount of milk per cow and year, and 2) to the area of farm land needed per cow and year. This allows for the calculation of greenhouse gas emissions (in CO_2 -equivalents) per kilogram of energy-corrected milk (ECM) and per hectare of agricultural land.

Table 2. Emission and characterization as well as correction factors, e.g., for NH₃ emissions, used in the NEU.rind-tool, inter alia for manure management systems.

CH ₄ characterization factor GWP ₁₀₀	kg CO ₂ eq	27.9
CH ₄ characterization factor GTP ₁₀₀	kg CO ₂ eq	5.38
N ₂ O characterization factor GWP ₁₀₀	kg CO ₂ eq	273
N ₂ O characterization factor GTP ₁₀₀	kg CO ₂ eq	233
NH ₃ characterization factor Acidification Potential AP	kg SO ₂ eq	1.88
kg indirect N ₂ O per kg NO ₃ -N-loss	N ₂ O EF	0.011
kWh per person in a household subtracted from overall electric energy values	kWh	600
Deep litter CH ₄ emission factor	CH ₄ EF	0.17
Solid manure CH ₄ emission factor (frequent removal)	CH ₄ EF	0.02
Slurry, stored during summer, CH ₄ emission factor (Amon et al. 2006)	CH ₄ EF	0.3277
Slurry, stored during winter, CH ₄ emission factor (Amon et al. 2006)	CH ₄ EF	0.0097
Nitrate-losses Arable land (Eder et al. 2015)	NO ₃ EF	0.277
Nitrate-losses Permanent grass land (Eder et al. 2015)	NO ₃ EF	0.027
Direct N ₂ O-N losses from soil	N ₂ O EF	0.01
Nitrous oxide (NO _x) losses – at and after manure application	NO _x EF	0.04
Nitrous oxide (NO _x) losses from solid manure – from animal houses and storage	NO _x EF	0.1
Nitrous oxide (NO _x) losses from liquid manure – from animal houses and storage	NO _x EF	0.001
NH ₃ -N-losses from synthetic fertilizers	NH ₃ EF	0.1
NH ₃ -N-losses from urea	NH ₃ EF	0.16
Correction factor (CF): (Always) observing favorable weather conditions during manure and fertilizer application	NH ₃ CF	0.9
Solid manure: rapid incorporation after 4 hours and before 12 hours	NH ₃ CF	0.5
Solid manure: rapid incorporation within 4 hours	NH ₃ CF	0.45
Liquid manure: (always) favourable weather conditions for spreading	NH ₃ CF	0.9
Slurry: rapid incorporation after 4 hours and before 12 hours	NH ₃ CF	0.7
Gülle: rasche Einarbeitung innerhalb 4 Stunden	NH ₃ CF	0.45
Slurry: rapid incorporation within 4 hours	NH ₃ CF	0.7
Deep slurry injection	NH ₃ CF	0.2
Shallow slurry injection	NH ₃ CF	0.35
Trailing hose	NH ₃ CF	0.5
Trailing shoe	NH ₃ CF	0.7
Separation of slurry with low-emission storage	NH ₃ CF	0.7
Separation of slurry without low-emission storage	NH ₃ CF	0.8
Acidification of the slurry only when spreading	NH ₃ CF	0.5
Acidification of the slurry during storage (and spreading)	NH ₃ CF	0.4
Aeration of slurry	NH ₃ CF	1.1
Storage of solid manure under plastic film	NH ₃ CF	0.7
Storage of solid manure enclosed on 3 sides with roof	NH ₃ CF	0.85
Composting of solid manure	NH ₃ CF	1.2
Slurry storage with natural crust	NH ₃ CF	0.6
Slurry storage with straw cover	NH ₃ CF	0.4
Slurry storage with plastic film, hexacover, etc.	NH ₃ CF	0.4
Slurry storage with solid cover (from concrete or wood)	NH ₃ CF	0.2
Cleaning robot for slatted floors	NH ₃ CF	0.85
Grooved floors for rapid urine drainage	NH ₃ CF	0.75
NH ₃ emission from solid manure spreading (related to Nex)	NH ₃ EF	0.1185
NH ₃ emission from liquid slurry spreading (related to Nex)	NH ₃ EF	0.25
NH ₃ emission from storage of solid manure (related to Nex)	NH ₃ EF	0.045
NH ₃ emission from storage of liquid slurry (related to Nex)	NH ₃ EF	0.075
NH ₃ emission from pasture (related to Nex)	NH ₃ EF	0.05
NH ₃ emission from loose house in a solid manure system (related to Nex)	NH ₃ EF	0.118

NH ₃ emission from loose house in a slurry system (related to Nex)	NH ₃ EF	0.118
NH ₃ emission from tied housing, in a solid manure or a slurry system (related to Nex)	NH ₃ EF	0.04

Table 3. Impacts per unit of selected (exemplary) feed- and other inputs-related ‘emission factors’ used in the NEU.rind-tool. Other impacts, e.g., for organic feedstuffs can be found in the annex.

	MJ NE _L feed energy	kg CO _{2eq}	kg SO _{2eq}	MJ fossil	kg N-eq	m ² Land Use	Potentially human-edible fraction (hef-PQR)
Conventionally produced feed, purchased (impacts per kg)							
Compound concentrate feed (<17% CP)	7.67	0.357	0.0040	2.56	0.0100	2.13	0.30
Barley	8.16	0.357	0.0040	2.56	0.0100	2.13	0.31
Oats	6.97	0.348	0.0037	2.45	0.0113	3.03	0.31
Rye	8.44	0.348	0.0037	2.45	0.0113	2.63	0.32
Wheat	8.53	0.445	0.0042	3.08	0.0108	2.17	0.32
Triticale	8.29	0.396	0.0040	2.76	0.0111	2.22	0.31
Corn	8.38	0.331	0.0046	1.79	0.0095	1.15	0.34
Peas	8.51	0.616	0.0133	2.95	0.0151	5.56	0.52
Field/faba (horse) beans	8.59	0.610	0.0115	2.48	0.0158	4.35	0.52
Soybeans	9.9	0.512	0.0035	2.65	0.0149	3.70	0.90
Soybean meal extracted	8.66	0.539	0.0048	3.55	0.0131	3.40	0.71
Rapeseed cake & extracted meal	7.13	0.467	0.0065	3.64	0.0069	2.33	0.42
DDGS (ActiProt)	8.01	0.695	0.0037	8.22	0.0041	1.33	0.46
Wheat bran	5.9	0.246	0.0024	1.79	0.0060	2.17	0.05
Dried pulp from sugarcane	7.39	0.405	0.0030	4.51	0.0045	0.83	-
Mineral feed incl. limestone (mix)	0	0.227	0.0029	3.93	0.0005	0.04	-
Conventionally produced roughages, on-farm (impacts per kg)							
Pasture (Dauerweide)	6.03	0.076	0.0075	-	0.0006	1.81	-
Hay dried outside	5.3	0.067	0.0080	-	0.0017	2.61	-
Grass silage high quality	6.05	0.076	0.0063	-	0.0012	1.12	-
Maize silage	6.46	0.093	0.0029	-	0.0045	0.74	0.12
Electric energy (impacts per kWh)							
Austrian average energy mix		0.226	0.00015	0.13			
Austrian certified ‘green’ energy		0.014	0.00015	0.11			
Fuels (impacts per kg)							
Diesel (including combustion)		3.03	0.0160	41.98			
Fertilizers (impacts per kg nutrient)							
Calcium ammonium nitrate (per kg N)		8.14	0.0389	52.54			
Urea (per kg N)		3.12	0.0150	55.65			
Super phosphate (per kg P ₂ O ₅)		1.32	0.0170	24.30			
Buildings							
Cubicle housing, cattle, wood construction, non-insulated (per animal place, over e.g. 30 years)		5048.13	301.34	100849.6			
Machinery							
Tractor (per 1 kg)		5.44	0.352	83.98			

Besides the calculation of the GWP₁₀₀, the NEU.rind tool also allows for a calculation of the Global Temperature Potential (GTP₁₀₀) using the same data and the respective characterization factors by IPCC (2021). However, to avoid confusion, the results of this additional climate change-related indicator are currently not shown in the tool.

GWP₁₀₀ results and all other indicators' results are expressed in terms of relevant emission sources (e.g. enteric fermentation CH₄, manure management CH₄ and N₂O, feed production CO₂ and N₂O) and the sums per individual substance (e.g. greenhouse gases CO₂, CH₄, N₂O, air pollutant NH₃, etc.)

2.2 Protein Production & Efficiency

The amount of crude protein (CP) produced through milk per hectare of utilized agricultural area is calculated by multiplying the total milk yield of the cows by the average protein content of the milk and dividing this product by the land area used for the dairy cows. This represents a milk-based gross CP production per hectare. It does not differentiate between whether the milk is fed to animals or processed into products in the dairy, for example. The proteins contained in the cow feed that are potentially suitable for human consumption are also not deducted. The following formula is used:

Equation (5):

$$\text{kg CP per ha} = \text{Cow number} \times \text{kg milk amount per cow-year} \times \% \text{CP}_{\text{milk}} / \text{ha on-farm for cows}$$

In the context of human food protein provision, an additional indicator is evaluated: the human-edible protein feed conversion efficiency. This metric does not assess the production intensity per hectare, which is often a function of the primary production (feed harvest amounts) at a given location, but rather focuses on the efficiency of scarce resources, namely the conversion efficiency of potentially human-edible protein in the feed. This second indicator is calculated following the approach described by, among others, Ertl et al. (2015, 2016) and takes into account protein quality through the application of the Digestible Indispensable Amino Acid Score (DIAAS). The calculation is based on the following formula:

Equation (6):

$$\text{heFCE} = 0.034 \times \text{DIAAS}_{\text{milk}} / \sum (\text{kg concentrate}_i \text{ per kg ECM} \times \text{hef-PQR}_i)$$

The hef-PQR_i represents a factor, which combines the protein content of a specific concentrate *i*, its fraction that is potentially human-edible and in addition the quality of the protein measured in DIAAS compared to the DIAAS of milk. The factors for selected feedstuffs are shown in Table 3.

2.3 Biodiversity Impact Assessment

Within the broad field of biodiversity, the NEU.rind tool focuses on selected indicators to assess the potential contribution of cattle farming to biodiversity conservation. While the authors and developers of the NEU.rind-tool acknowledge that biodiversity is a complex and

multi-dimensional concept, which ideally should be assessed through a broader set of indicators, the tool focuses on three representative metrics within the scope of a comprehensive sustainability analysis.

2.3.1 High Nature Value (HNV) Farmland Proportion

Based on IACS (Invekos) data from the participating farms, the proportion of High Nature Value (HNV) farmland in relation to the total farm area is calculated. HNV farmland is recognized for its importance in supporting biodiversity and valuable landscape structures and reflects habitat diversity as well as nature conservation potential at the farm level.

2.3.2 Potential Species Losses per kg ECM

As a proxy for biodiversity impact along the feed supply chain, the potential species losses per kilogram of ECM are estimated. This indicator is based on the biodiversity assessment method developed by Chaudhary & Brooks (2018). The effects of land occupation were assessed. Effects of land use (category) changes were not assessed, as such changes with negative impacts are rarely existent on dairy farms, because there is for instance a ban on ploughing permanent grassland *de jure*, especially when public funds are received. Specific impact factors for individual feed components can be found in Table 3 of the documentation. This indicator links feed composition and origin to global biodiversity threats via land-use-related species loss potentials.

2.3.3 Use of Rare and Endangered Breeds

As a third indicator, NEU.rind evaluates whether a farm contributes to the conservation of genetic diversity by keeping (rare and) endangered cattle breeds. The preservation of such breeds plays a crucial role in maintaining livestock genetic resources and long-term resilience of production systems.

Together, these indicators address multiple levels of biodiversity:

- Species diversity and land use efficiency through potential species loss assessment
- Habitat and landscape-level diversity via the HNV farmland proportion
- Genetic diversity through the identification of rare and endangered breeds (ÖNGENE list: <https://www.oengene.at/seltene-erhaltungswuerdige-nutztierrassen>)

It is important to note that not all indicators are currently included in the reporting output (provided to farmers), but they form an integral part of the tool's analytical framework and can be reported in future versions.

2.4 Fossil Energy Demand

This section describes the methodology used to evaluate the fossil energy demand associated with dairy farms in the NEU.rind tool. The evaluation is carried out both per kg ECM and per hectare of agricultural land utilized by the dairy branch. This dual perspective provides a robust basis for assessing energy efficiency and identifying hotspots for energy input reductions.

The analysis includes all direct and indirect fossil energy inputs relevant to milk production at farm level. Fossil energy demand is expressed in megajoules (MJ) and refers to the cumulative fossil energy input from upstream production and delivery of farm inputs (system boundaries from 'cradle to farm gate').

Input data are mainly sourced from farm-specific records and sometimes take national average values into account (e.g., for electric energy mixes), with consideration of inputs (e.g., fuel, fertilizer, feed) relevant for the milk branch. As for all other indicators related to ha of farm land area, the land was limited to the area directly contributing to milk production (e.g., forage cultivation, pasture, feed cropping areas and other area receiving relevant amounts of dairy cattle manure).

The following input categories were included in the calculation:

- Production and transport of mineral fertilizers (e.g., N, P, K) on-farm: detailed list of different fertilizers in Annex, which can be selected in the NEU.rind tool
- Production, transportation and combusted diesel or gasoline fuel (for field operations and machinery) on-farm
- Electricity (Austrian average energy mix, Austrian certified 'green' electricity, photovoltaic energy, biogas electricity) and natural gas or liquid heating on-farm
- Purchased feedstuffs (e.g., soybean meal, maize silage, compound concentrate feed)
- Pesticides
- Production of infrastructure, that means machinery and buildings

The fossil energy demand per unit of input is based on standardized energy factors as presented in Table 3. These include upstream processes (e.g., production, processing, and transport of inputs).

Total fossil energy demand was calculated using the following equation:

Equation (7):

$$\text{Total FED per cow \& year} = \sum(\text{Input}_i \times \text{EF}_i)$$

Where:

Input_i = Quantity of input i (feed, energy like fuel or electricity, or fertilizer) used per cow and year

EF_i = Overall fossil energy demand of input i (MJ/unit)

This sum per cow and year is then allocated to 1 kg ECM and 1 ha of utilized farm land, as this is done for other indicators. The results provide insights into energy efficiency of milk production via the product-related result, overall (absolute and) land-related impacts, thereby identifying opportunities to optimize input use regarding fossil energy dependency by emphasizing the contribution of specific inputs with high fossil energy demand.

2.5 Acidification & Ammonia Emissions

As for other indicators (GHG emissions in section 2.1 or fossil energy demand in section 2.4) acidifying SO_2 -eq emissions as well as ammonia (NH_3) emissions are assessed within the NEU.rind tool per kg ECM and per ha of utilized farm land.

The assessment of NH_3 losses, based on Umweltbundesamt (2024ab), differentiates N_{ex} occurring in animal housing systems – distinguishing between tied and loose housing, yards

and pasture. NH₃ emissions are adjusted using correction factors depending on storage type, treatment, and manure spreading practices (e.g., incorporation into the soil). Mitigation measures include, among others:

- solid and plastic covers, straw coverings, etc.
- slurry separation
- incorporation into the soil
- acidification either during storage or at application.

Factors used in the NEU.rind tool can be found in the annex, and further methodological details on housing and manure management systems are provided in Umweltbundesamt (2024ab) and Hörtenhuber (2025). Emissions from synthetic fertilizers are also included in the NH₃ calculations.

The procedure to calculate SO₂-eq from feed, fuels, fertilizers and other inputs is comparable to those of CO₂-eq (GWP₁₀₀) or MJ (FED) and incorporates the factors provided in Table 3. It is calculated as:

Equation (8):

$$\text{Total SO}_2\text{-eq per cow \& year} = \sum(\text{Input}_i \times \text{EF}_i)$$

2.6 Nitrate Emissions

Nitrate emissions from leaching and runoff per ha and per kg ECM are estimated for feed, fuels, fertilizers and other inputs following other indicators' procedures, see e.g., the previous section 2.5 on NH₃ and using NO₃ factors from Table 3. No NO₃ emissions from manure management systems are assumed, as regulations prevent them; only barn surfaces and manure storage facilities that are sealed against soil and water infiltration are permitted, with the exception of pastures and unpaved outdoor areas.

Equation (9):

$$\text{Total NO}_3\text{-N-eq per cow \& year} = \sum(\text{Input}_i \times \text{EF}_i)$$

2.7 Animal Health and Welfare Metrics

For the evaluation of Animal Health in NEU.rind the system Q-Check, that was elaborated by the "Thünen Institut für Ökologischen Landbau", is used. It is recognized for national animal welfare monitoring in Germany. See: <https://www.thuenen.de/de/fachinstitute/oekologischer-landbau/arbeitsgruppen/arbeitsgruppe-tierwohl/q-check-tierwohl-in-der-milchviehhaltung-mit-system>

The following Q-Check indicators are calculated for dairy cattle on the farm based on data from milk recording tests, focusing on udder health, metabolism, cow losses, and calf losses. The results in the four categories are derived from the average ranking of the individual parameters across all NEU.rind farms within the benchmarking group.

1) Udder Health:

- Proportion of cows with healthy udders (somatic cell count ≤ 100,000/ml of milk)

- Proportion of cows with somatic cell count > 400,000/ml of milk
 - New infection rate during lactation
 - Number of first-lactation cows with somatic cell count > 100,000
 - Proportion of chronically ill animals with poor healing prospects
 - New infection rate during the dry period
 - Healing rate during the dry period
- 2) Metabolism:
- Proportion of animals with FEQ (Fat-to-Protein Ratio) ≥ 1.5 within the first 100 days of lactation
 - Proportion of animals with FEQ < 1.0 within the first 100 days of lactation
- 3) Cow Losses:
- Proportion of cullings
 - Cow mortality
 - Average productive lifespan of culled cows in months
- 4) Calf Losses:
- Proportion of early calf losses in first-lactation cows
 - Proportion of early calf losses from the second calving onward
 - Proportion of calf losses between days 8–28
 - Proportion of rearing losses between days 29–180

For detailed information on the indicators and their calculation see: <https://infothek.q-check.org/download-category/merkblaetter/>

2.8 Economy – Farm Profitability

To assess a part of (potential) farm profitability, within the NEU.rind tool a gross margin (direct cost-free revenue) per cow per year, per ha and year as well as per kg ECM are calculated. The calculation follows the Austrian interactive gross margin calculation tool IDB ('Interaktive Deckungsbeiträge und Kalkulationsdaten' <https://idb.agrarforschung.at/verfahren/konventionell/milchkuhhaltung>) and uses their default values in the background, which differentiate between conventionally and organically managed dairy farms. However, all relevant costs are based on the farm-individual amounts of inputs required per average cow and year and default values are used just in such cases, when farmers did not insert farm-specific data.

3 Benchmarking and Farm-Specific Recommendations in the NEU.rind Tool

Benchmarking in the NEU.rind tool enables farms to compare their sustainability performance with that of similar or specifically selected groups of other farms. Through this comparative analysis, farms can identify disadvantages and recognize areas with potential for improvement. Benchmarking thus serves as a valuable starting point for targeted sustainability enhancements. Benchmarking results can be displayed within tables, as this is known by

farmers from other analysis, e.g., milk recording data (see Figure 4). Furthermore, two different types of graphical illustration of the results' benchmarking are provided, see Figures 5 and 6

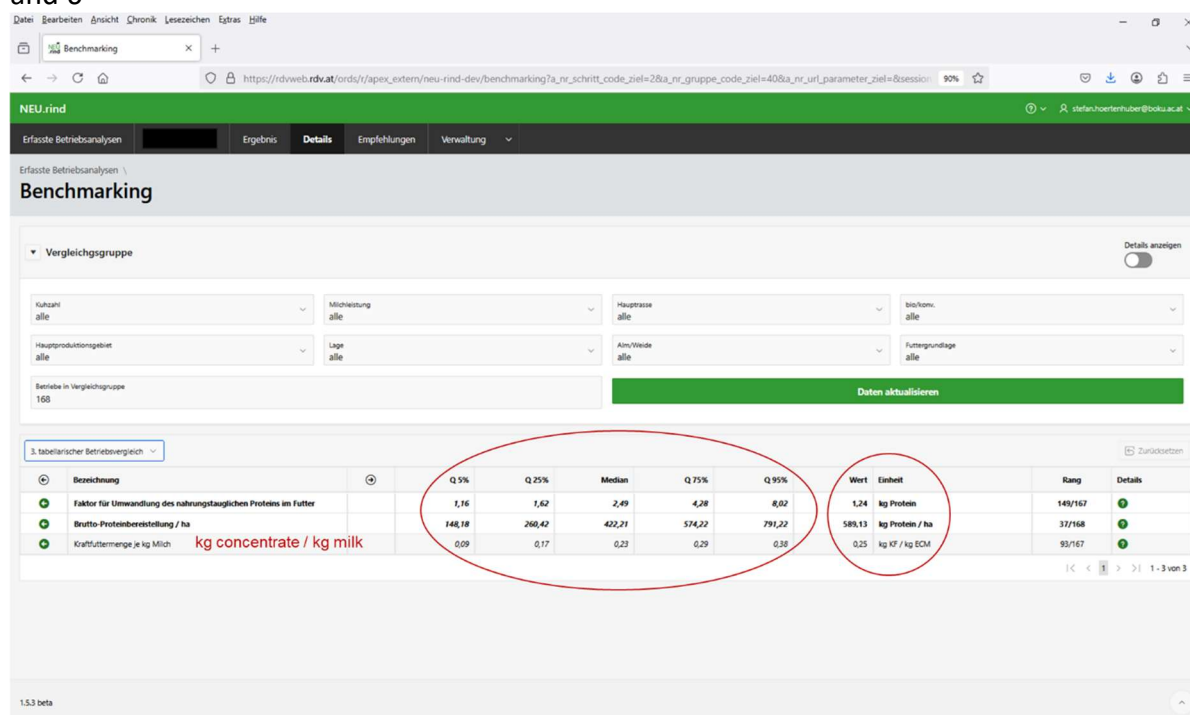


Figure 4. Screenshot from the NEU.rind tool showing results from benchmarking (the example of protein production and the indicator 'kg concentrate per kg ECM') displayed within tables.

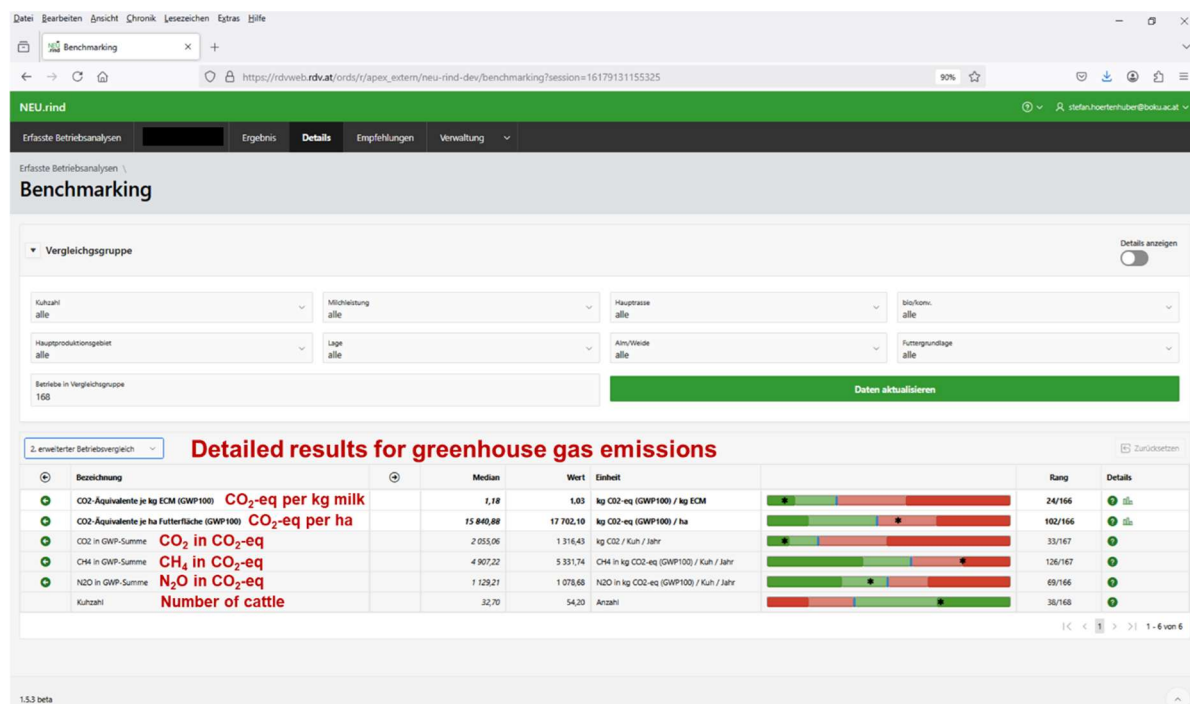


Figure 5. Screenshot from the NEU.rind tool showing results from benchmarking (the example of greenhouse gas emissions) in an illustrative form. The asterisks indicate the individual

farm result, while the coloured bars represent the distribution showing how closely or widely the results of each 25% of the farms were found. The figure provided in the middle column displays the farm's own results (per kg ECM and per hectare of land), while on the left-hand side the medians of the selected comparison group are shown. In the right column, the farm's rank within the sample is given. Under "Details," additional visualizations such as histograms of farm result distributions or contribution analyses for emission sources can be accessed.

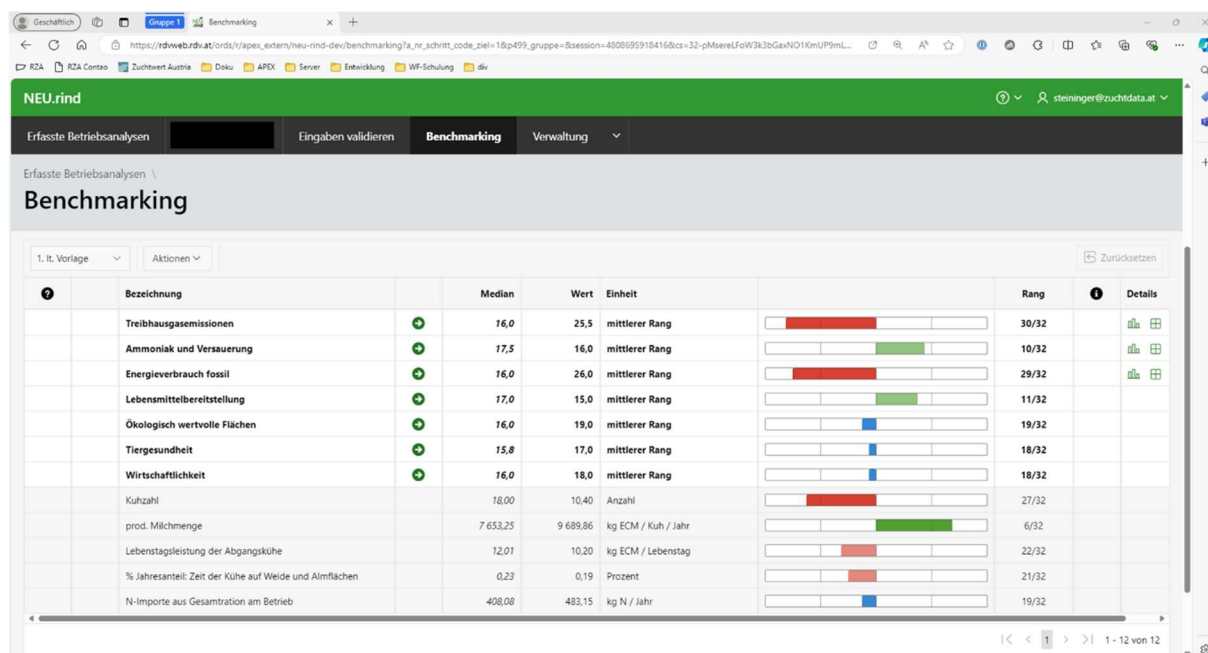


Figure 6. Screenshot from the NEU.rind tool showing results from benchmarking (the example of the sustainability theme overview) in an illustrative, easily understandable form. Coloured result bars extending to the left indicate poorer performance compared to the selected benchmarking group, while deviations from the median to the right indicate better performance. As also shown in Figure 5, the values for the individual farm, the medians, and the farm's ranks are also displayed here.

In such sustainability themes, where indicators show low performance both per ha and per kg ECM, recommendations are provided, see Figure 7.

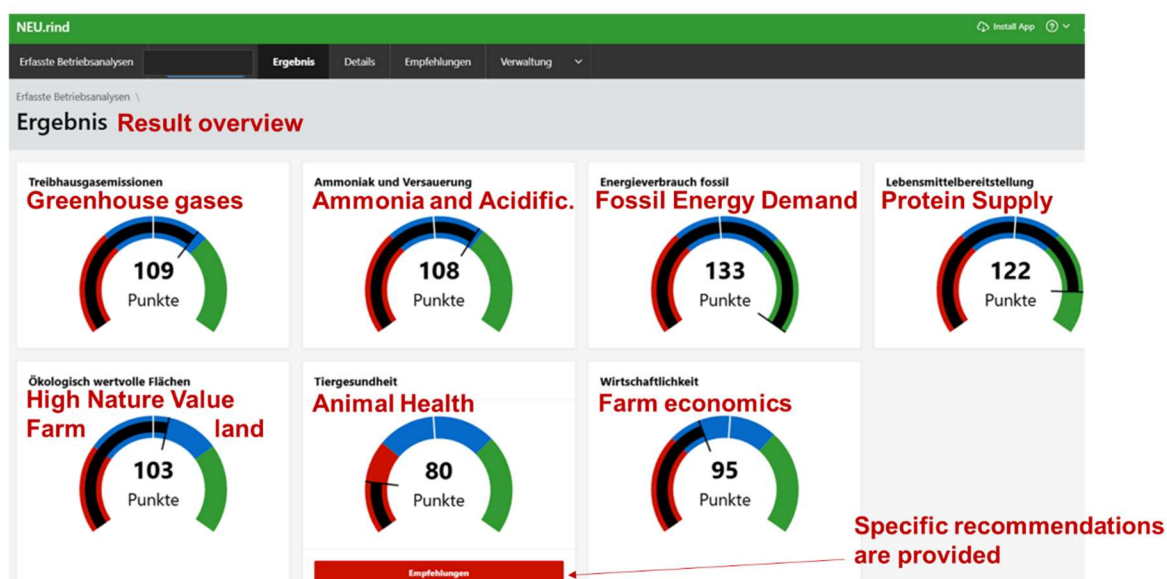


Figure 7. Screenshot from the result overview in the NEU.rind-tool, showing the link to farm-individual recommendations (for this case study farm for the Animal Health theme).

Beyond simple benchmarking, NEU.rind takes the analysis a step further by providing farm-specific recommendations. These are tailored to the individual farm's characteristics, input structures, and management practices. By highlighting specific measures with the greatest improvement potential, the tool supports more effective and individualized strategies for increasing resource efficiency, reducing environmental impacts, and enhancing overall farm sustainability.

4 Methodology Validation, Limitations and Recommendations

The present document provides a preliminary description of the first Version of the NEU.rind tool. As the tool enters routine application, it is expected to evolve further, with both the tool itself and its accompanying documentation being continuously updated and refined over time.

A large proportion of the calculations and assessments implemented in NEU.rind are taken or adapted from validated existing applications, such as the Austrian Air Pollutant Inventory (OLI), the Q-Check Animal Health Assessment, and the IDB gross margin calculations (see section 1.5). Given the robust validation of these underlying sources, a high level of methodological validity is assumed for the NEU.rind tool and its results as well.

Currently, the sensitivity of key methodological elements is being systematically evaluated, including through Monte Carlo simulations, to further strengthen the robustness and transparency of the results.

In terms of data input, NEU.rind is specifically designed to rely on practically accessible and reliable data from individual farms. The methods are aligned with the quality and type of data that can be reasonably expected from farmers. Default values used in place of primary input data are of comparatively high quality, often based on authoritative sources such as IACS (INVEKOS) data, the Rinderdatenverbund RDV routine control data, e.g., on milk ingredients, and other national databases, e.g., regarding feed and other inputs' costs.

In general, we assume that primary farm-specific data are often not inherently more precise than many of the high-quality “default” values provided from the different databases within NEU.rind. However, defaults naturally cannot fully capture all farm-specific characteristics. As a result, many economic outcomes, in particular, become fully valid only when using individualized farm parameters for costs and revenues. Additionally, for specific evaluation areas, such as feeding, NEU.rind analyses should ideally be based on accurate, farm-specific ration compositions, to enable precise calculation of feeding-dependent greenhouse gas emissions, nitrogen excretions, or cost structures.

4.1 Future Research and Opportunities for Improvement

Continuous user feedback and practical experience with NEU.rind are essential to identify further areas for methodological refinement. Future research will focus on:

- Enhancing additional farm branches besides dairy production – as far as possible with precise default datasets, thereby, expanding the capacity for farm-specificities
- Further validating model outputs through independent cross-comparisons with other sustainability assessment tools.

In conclusion, NEU.rind represents a powerful and dynamic system, which is designed to be extended, with a strong foundation in validated methods and a clear pathway for ongoing scientific improvement that helps to improve sustainability on dairy farms.

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Annex

Table A1. List of different fertilizers available in the NEU.rind tool.

Nitramoncal / Kalkammonsalpeter (NAC) - 27% N, 12,5% Ca	Nitramoncal / Calcium Ammonium Nitrate (CAN) – 27% N, 12.5% Ca
Harnstoff / UREA gepirllt od. granuliert - 46% N	Urea, prilled or granulated – 46% N
Ammonium-Nitrat-Harnstofflösung (AHL) - 30% N	Ammonium Nitrate Urea Solution (AHL) – 30% N
Ammonsulfatsalpeter (ASS) - 26% N, 13% S	Ammonium Sulfate Nitrate (ASN) – 26% N, 13% S
Schwefelsaures Ammoniak / Ammonsulfat (SSA) - 21% N, 24% S	Ammonium Sulfate (AS) – 21% N, 24% S
Kalksalpeter streufähig - 15,5% N, 26% Ca	Calcium Nitrate, spreadable – 15.5% N, 26% Ca
Kalkstickstoff / PERLKA - 20% N, 50% Ca	Calcium Cyanamide / PERLKA – 20% N, 50% Ca
anderer N-Dünger (Reinnährstoffmenge anzugeben)	Other nitrogen fertilizer (specify pure nutrient amount)
Hyperkorn - 26% P, 40% Ca	Hyperkorn – 26% P, 40% Ca
Hyperphosphat - 29% P, 40% Ca	Hyperphosphate – 29% P, 40% Ca
Superphosphat - 18% P, 12% S	Superphosphate – 18% P, 12% S
Triplephosphat/Triple-Superphosphat - 46% P	Triple Superphosphate – 46% P
Rohphosphat	Raw phosphate
anderer P-Dünger (Reinnährstoffmenge anzugeben)	Other phosphorus fertilizer (specify pure nutrient amount)
Kalidünger	Potassium fertilizer
Kalkdünger	Lime fertilizer
NP-Dünger 18 46 0 (Diammoniumphosphat - DAP)	NP fertilizer 18 46 0 (Diammonium Phosphate – DAP)
PK-Dünger 0 15 30	PK fertilizer 0 15 30
PK-Dünger 0 18 36	PK fertilizer 0 18 36
PK-Dünger 0 12 20 (DC 45)	PK fertilizer 0 12 20 (DC 45)
PK-Dünger 0 18 18 (Hyperkali)	PK fertilizer 0 18 18 (Hyperkali)
NPK-Dünger 15 15 15	NPK fertilizer 15 15 15
NPK-Dünger 6 10 16 (DC Bor Start)	NPK fertilizer 6 10 16 (DC Bor Start)
NPK-Dünger 20 8 8	NPK fertilizer 20 8 8
NPK-Dünger 12 10 15 (DC 37)	NPK fertilizer 12 10 15 (DC 37)
NPK-Dünger 14 10 20	NPK fertilizer 14 10 20
andere NPK-Dünger - Summe Reinstickstoff anzugeben	Other NPK fertilizer – specify total pure nitrogen
andere NPK-Dünger - Summe Reinphosphat anzugeben	Other NPK fertilizer – specify total pure phosphate
andere NPK-Dünger - Summe Reinkalium anzugeben	Other NPK fertilizer – specify total pure potassium

Table A2: NEU.rind data entry steps

Data entry step		Description
1	Address	Please enter your address.
2	Farm Data	Please enter your farm details.
3	Land Area	Please enter the total farm area. If not all areas are reported to AMA, please adjust accordingly.
4	Storage Facilities	What storage capacity is available on the farm?
5	Other Catt-le	Are cattle other than dairy cows and heifers kept on the farm?
6	Cattle Numbers	The number per category is taken from the latest annual report.
7	Fertility	Information on animal fertility.
8	Annual Milk Production	Data on yearly milk output.
9	Milk Yield	Information on average milk yield.

10	Live Weights	Information on live animal weight for meat production.
11	Meat Output	Information on carcass yield.
12	Animal Welfare	Parameters are taken from the Q-Check system.
13	Slurry Storage	How is slurry from dairy cattle stored?
14	Slurry Treatment	How is slurry treated on the farm?
15	Slurry Stirring	How is slurry stirred before application?
16	Slurry Application	How is slurry applied on the farm?
17	Solid Manure Handling	Storage, treatment, and application of solid manure.
18	Organic Fertilizer Questions	Other questions on the use of organic fertilizers.
19	Housing System	Indicate the stall system
20	Barn Structure	What is the structure of your dairy barn?
21	Lying Area	How are the resting areas for dairy cows designed?
22	Walkways	How are walkways and walking surfaces constructed?
23	Manure System	What is the proportion of solid manure and slurry from dairy cows?
24	Outdoor Access & Grazing	How often do cows use outdoor access, pasture, or alpine grazing?
25	Feedstuffs Used	Define the feedstuffs used on your farm. Ingredients and prices can be adjusted if needed.
26	Purchased Compound Feed	How much compound feed was bought and fed to dairy cattle during the reference year?
27	Purchased Single Feedstuffs	How much single feedstuff was purchased and fed to dairy cattle during the reference year?
28	Self-Produced Compound Feed	How much compound feed was produced and used on the farm in the reference year?
29	Ration Periods	Indicate during which periods the same base ration was fed (e.g., winter and summer).
30	Ration Composition	What feedstuffs were included and at what proportions in the ration?
31	Self-Propelled Machines	List self-propelled machines used (e.g., tractors) with year of manufacture and engine power.
32	Arable Land Mechanization	For each task in arable farming, indicate the vehicle used and whether it is done internally or externally.
33	Grassland Mechanization	Same as above, for standard grassland areas.
34	Mountain Grassland Mechanization	Same as above, for steep mountain grassland areas.
35	Commercial Fertilizer Use	What quantities of commercial fertilizer were used in the reference year?
36	Total Annual Energy Use	Annual energy consumption of the entire farm.
37	Extraordinary Energy Use	Is there significant energy use outside of regular farming or household use (e.g., pig/poultry barn, side business)?
38	Revenue	Adjust the economic parameters if needed.
39	Internal Evaluation	Adjust internal economic evaluation parameters.
40	Costs	Adjust the cost parameters.