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Finanziato nell'ambito del Piano Nazionale di Ripresa e Resilienza PNRR. Missione 4, Componente 2, Investimento 1.3 Creazione di "Partenariati estesi alle università, ai centri di ricerca, alle aziende per il finanziamento di progetti di ricerca di base"

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1.3.3 Environmental footprint national and regional datasets for the main Italian production systems – section b: Cattle breeding supply chain

Document data	
Title	Spoke 1 Work Package 3 D1.3.3 ENVIRONMENTAL FOOTPRINT NATIONAL AND REGIONAL DATASETS FOR THE MAIN ITALIAN PRODUCTION SYSTEMS – section b: Cattle breeding supply chain
Owner	Ionian Department of Law, Economics and Environment, University of Bari Aldo Moro, Taranto, Italy
Contributor/s	Ionian Department of Law, Economics and Environment, University of Bari Aldo Moro, Taranto, Italy
Document version	D1.3.3 – v1
Last version date	30/04/2026

Executive summary

This document develops national and regional datasets on the environmental footprint of the Italian cattle supply chain, with a specific focus on the main life cycle stages: feed production, livestock farming, and slaughtering. The analysis is grounded in a Life Cycle Assessment (LCA) framework, integrating both Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA), and applying the Environmental Footprint 3.1 (EF 3.1) methodology for impact normalization and weighting.

The dataset construction reflects the high structural heterogeneity of the Italian livestock sector, which is characterized by variability in breeds, age classes, gender, production purposes, and management systems (intensive, extensive, and mixed). This variability translates into significant differences in feeding regimes, nutritional requirements, and manure management practices, ultimately influencing emission profiles and input–output flows across the system.

Within the agricultural phase, the production of forage, hay, and silage emerges as a critical contributor to the overall environmental footprint. Water use represents the dominant impact category, strongly influenced by the high water stress conditions characterizing the Italian context. Among the analyzed crops, permanent grassland and waxy maize exhibit the highest overall impacts. Land use and climate change also constitute significant impact categories, primarily driven by agricultural yields and emissions associated with fertilizer application and fuel consumption.

In the processing stage, haymaking practices reveal substantial differences between natural and mechanical drying systems. Mechanical drying leads to significantly higher environmental impacts, particularly in terms of climate change and fossil resource use, due to increased energy consumption. However, the predominance of natural drying in Italy contributes to mitigating the overall environmental burden of hay production.

Regarding concentrated feed production, grain cultivation—especially soybean and maize—represents one of the most impactful stages. These impacts are largely associated with water consumption, as well as ecotoxicity and particulate matter emissions in specific cases. The inclusion of imported raw materials further alters the environmental profile, highlighting the importance of global supply chains and international transport in shaping overall impacts.

The modular structure of the developed inventory datasets enables their application to site-specific assessments, supporting detailed case studies and tailored environmental evaluations. As such, this work provides a robust analytical tool for comparing environmental performances within the cattle supply chain and supports the development of targeted strategies to enhance sustainability in the Italian agri-livestock sector.

TABLE OF CONTENTS

Index of Tables

Index of Figures

1. LIFE CYCLE IMPACT ASSESSMENT

The Life Cycle Inventory (LCI) datasets were developed by defining specific data sources, methodologies, and assumptions tailored to different life cycle stages. These include feed rations (agricultural and processing phases) subdivided into forage, silage, and concentrates; cattle categorized by breed, aptitude, age group, and gender (farming phase); and end-use (slaughtering phase) at both national and regional levels. In practice, individual farms are characterized by highly heterogeneous herds in terms of age, gender, breed, and purpose. This heterogeneity results in significant distinctions in animal diets, nutritional intakes, and customized feed ration management. Furthermore, farming systems vary from intensive to extensive, including hybrid forms (semi-intensive and semi-extensive). Since no standard herd exists, as farms are often composed of mixed livestock, these characteristics lead to substantial variability in the inputs and outputs associated with the analysed system.

Environmental impacts also vary significantly based on the management of manure, wastewater, and slurry. These variations can be accurately assessed by utilizing the developed inventories as modular building blocks to conduct site-specific impact analyses of the actual stable/farm/company under study, leveraging the datasets available on the AMELIA platform. This approach was implemented to define the environmental profile of three distinct case studies, based on on-field data collection, which are detailed further in the research.

This section presents the LCIA (Life Cycle Impact Assessment) results for the most significant and representative inventories of this project. The environmental performance of the various production stages is described schematically, grouped by their respective functional units (FU):

- *Agricultural products*: 1 kg of product.
- *Farming phase*: 1 kg of live weight (LW) and the average weight per animal within a specific class.
- *Slaughtering phase*: 1 kg of carcass weight.

The impact assessment was conducted using the Environmental Footprint 3.1 V1.01 (EF 3.1) normalization and weighting set method. In addition to the characterization of impacts, the results are illustrated through histograms expressed *via* a weighted eco-indicator.

1.1 LCIA: Production of feed rations for cattle in Italy

The impact assessment of the agricultural phase is critical for quantifying the environmental footprint of various crops and their subsequent processing stages, including the production of forage, silage, milled products, and concentrates. These elements are essential for defining the diverse feed rations analyzed within the scope of this study.

1.1.1 Cultivation of crops for forage and silage

This section analyzes the environmental impact assessment of the cultivation phase for crops intended for the production of forage, hay, and silage. The characterization factors are presented in **Table 1**. Particular emphasis is placed on the Climate Change category, expressed in kg CO_2 equivalent, which describes the Global Warming Potential (GWP). **Table 2** reports the impact assessment values expressed via the eco-indicator (µPt), broken down by impact category for each analyzed crop. **Figure 1** provides a graphical representation of the impact per category for the crops used in forage and silage production. The results show that for 1 kg of cultivated product, the most impactful crop in absolute terms is permanent grassland (24.7 µPt), followed by waxy maize (18.2 µPt), other grass (17.6 µPt), and clover (12.0 µPt). For these crops, the most significant impact category is Water Use (accounting for 63.9% to 72.3%) due to high water consumption. Other crops require significantly lower water inputs for irrigation or fertilizer application. It should be noted that Water Use has a substantial contribution to the overall eco-indicator when using the EF 3.1 methodology, as water carries a high characterization factor. Furthermore, water consumption was associated with the dataset "*water well, IT*"; under the EF 3.1 method, Italy is classified as a high water-stress territory. Consequently, for the same amount of water consumed, using well water in a European country with higher water availability (e.g., France) would result in a lower contribution to the Water Use category. Beyond this category, the most relevant impact for all crops, albeit with varying percentage contributions, is Land Use (ranging from 8.5% to 15.2% for high-water-demand crops, and from 21.0% to 62.2% for others). This impact is higher for crops with lower yields, such as pasture, sainfoin, and monophyte cereal forage. The next major category is Climate Change (between 3.7% and 14.3%), with the highest values recorded for monophyte cereal forage, waxy maize, permanent grassland, and pasture. These impacts primarily depend on CO_2, CH_4, and N_2O emissions resulting from diesel combustion during agricultural operations and direct emissions from the application of organic and mineral fertilizers.

Table 1: Characterization of crops used for the production of forage and silage required for cattle feeding in Italy for each impact category

Category	**Unit**	**Alfalfa**	**Sulla**	**Sainfoin**	**Clover**	**Ryegrass**	**Permanent lawn**	**Grassland**	**Monophyte herbaceous plant**	**Monophyte cereal herbaceous bed**	**Mixed grassland**	**Other grasses**	**Other legumes**	**Mixtures**	**Waxy corn**
Acidification	mol H^+ eq	1.75E-04	1.51E-04	1.30E-04	1.27E-04	1.31E-04	2.39E-04	2.23E-04	1.31E-04	4.19E-04	1.04E-04	2.09E-04	1.99E-04	1.40E-04	2.82E-04
Climate change	kg CO_2 eq	2.23E-02	1.91E-02	1.59E-02	1.59E-02	1.78E-02	3.15E-02	3.05E-02	1.79E-02	6.10E-02	1.33E-02	2.89E-02	2.64E-02	1.97E-02	3.78E-02
Ecotoxicity, freshwater	CTUe	6.76E-01	7.07E-01	1.21E+00	4.06E-01	3.34E-01	5.69E-01	8.62E-01	3.23E-01	1.14E+00	3.54E-01	3.31E-01	2.92E+00	1.60E+00	2.14E+00
Particulate matter	disease inc.	1.24E-09	1.14E-09	1.07E-09	8.23E-10	1.06E-09	8.63E-10	1.11E-09	1.06E-09	4.38E-09	6.68E-10	1.11E-09	2.43E-09	1.55E-09	1.31E-09
Eutrophication, marine	kg N eq	1.29E-04	9.35E-05	5.86E-05	2.13E-04	1.37E-04	3.64E-04	4.18E-04	1.37E-04	6.91E-04	1.28E-04	3.44E-04	1.41E-04	1.06E-04	6.85E-04
Eutrophication, freshwater	kg P eq	1.65E-05	1.81E-05	1.37E-05	1.64E-05	1.01E-05	4.95E-06	9.44E-06	1.01E-05	2.90E-05	1.06E-05	8.38E-06	1.70E-05	1.01E-05	1.46E-05
Eutrophication, terrestrial	mol N eq	6.08E-04	4.81E-04	5.38E-04	4.27E-04	4.72E-04	1.06E-03	9.09E-04	4.73E-04	1.69E-03	3.68E-04	8.17E-04	1.04E-03	6.38E-04	1.13E-03
Human toxicity, cancer	CTUh	4.37E-10	3.69E-10	5.58E-10	2.60E-10	1.03E-10	6.28E-10	7.74E-10	9.11E-11	3.33E-10	1.96E-10	7.36E-11	3.91E-10	2.27E-10	7.67E-11

Human toxicity, non- cancer	CTUh	8.18E-10	2.25E-09	1.14E-09	1.47E-09	2.03E-09	6.24E-10	4.88E-10	1.90E-09	4.75E-09	3.00E-10	1.37E-09	1.36E-10	1.04E-10	1.82E-09
Ionizing radiation	kBq U-235 eq	4.20E-04	4.40E-04	3.28E-04	3.29E-04	3.59E-04	2.67E-04	3.80E-04	3.59E-04	1.31E-03	2.43E-04	4.09E-04	5.76E-04	4.30E-04	4.32E-04
Land use	Pt	2.03E+01	3.29E+01	4.93E+01	1.88E+01	1.79E+01	2.80E+01	5.22E+01	1.79E+01	3.91E+01	1.42E+01	1.76E+01	3.03E+01	1.72E+01	1.61E+01
Ozone depletion	kg CFC11 eq	1.07E-09	8.01E-10	6.74E-10	6.52E-10	7.39E-10	8.73E-10	1.01E-09	7.39E-10	2.71E-09	4.82E-10	1.02E-09	1.23E-09	9.20E-10	1.25E-09
Photochemical ozone formation	kg NMVOC eq	1.37E-04	9.77E-05	1.02E-04	1.01E-04	9.17E-05	2.82E-04	2.28E-04	9.19E-05	2.56E-04	8.53E-05	1.97E-04	1.44E-04	9.63E-05	2.96E-04
Resource use, fossils	MJ	3.08E-01	2.74E-01	2.11E-01	2.22E-01	2.64E-01	4.61E-01	4.59E-01	2.64E-01	9.28E-01	1.91E-01	4.44E-01	3.34E-01	2.75E-01	5.72E-01
Resource use, minerals and metals	kg Sb eq	2.02E-08	2.02E-08	1.86E-08	2.39E-08	1.73E-08	1.21E-08	1.65E-08	1.73E-08	6.78E-08	1.01E-08	1.88E-08	1.96E-08	2.56E-08	2.00E-08
Water use	m^3 depriv.	7.72E-03	8.89E-03	4.41E-03	1.03E+00	1.03E-02	2.41E+00	1.65E-02	1.03E-02	4.64E-02	4.56E-01	1.70E+00	7.48E-03	9.91E-03	1.54E+00

Table 2: Impact assessment of crops used for the production of forage and silage expressed as a single score (eco-indicator in µPt) for each impact category

Category	Unit	Alfalfa	Sulla	Sainfoin	Clover	Ryegrass	Permanent lawn	Grassland	Monophyte herbaceous plant	Monophyte cereal herbaceous bed	Mixed grassland	Other grasses	Other legumes	Mixtures	Waxy corn
Acidification	µPt	1.95E-01	1.68E-01	1.45E-01	1.42E-01	1.46E-01	2.67E-01	2.49E-01	1.46E-01	4.68E-01	1.16E-01	2.33E-01	2.22E-01	1.56E-01	3.15E-01
Climate change	µPt	6.22E-01	5.33E-01	4.44E-01	4.43E-01	4.96E-01	8.78E-01	8.51E-01	4.98E-01	1.70E+00	3.71E-01	8.05E-01	7.36E-01	5.51E-01	1.06E+00
Ecotoxicity, freshwater	µPt	2.29E-01	2.39E-01	4.11E-01	1.37E-01	1.13E-01	1.93E-01	2.92E-01	1.09E-01	3.85E-01	1.20E-01	1.12E-01	9.89E-01	5.41E-01	7.26E-01
Particulate matter	µPt	1.86E-01	1.72E-01	1.61E-01	1.24E-01	1.59E-01	1.30E-01	1.67E-01	1.59E-01	6.59E-01	1.01E-01	1.66E-01	3.66E-01	2.33E-01	1.97E-01
Eutrophication, marine	µPt	1.96E-01	1.42E-01	8.88E-02	3.23E-01	2.07E-01	5.51E-01	6.33E-01	2.07E-01	1.05E+00	1.94E-01	5.22E-01	2.14E-01	1.60E-01	1.04E+00
Eutrophication, freshwater	µPt	2.87E-01	3.15E-01	2.39E-01	2.87E-01	1.77E-01	8.62E-02	1.64E-01	1.77E-01	5.06E-01	1.85E-01	1.46E-01	2.97E-01	1.76E-01	2.55E-01
Eutrophication, terrestrial	µPt	1.28E-01	1.01E-01	1.13E-01	8.96E-02	9.90E-02	2.23E-01	1.91E-01	9.93E-02	3.56E-01	7.73E-02	1.71E-01	2.18E-01	1.34E-01	2.37E-01
Human toxicity, cancer	µPt	5.40E-01	4.55E-01	6.89E-01	3.21E-01	1.27E-01	7.75E-01	9.56E-01	1.12E-01	4.11E-01	2.42E-01	9.09E-02	4.83E-01	2.80E-01	9.48E-02
Human toxicity, non-cancer	µPt	1.17E-01	3.22E-01	1.63E-01	2.11E-01	2.90E-01	8.92E-02	6.98E-02	2.72E-01	6.80E-01	4.29E-02	1.96E-01	1.94E-02	1.48E-02	2.60E-01
Ionizing radiation	µPt	4.99E-03	5.23E-03	3.90E-03	3.91E-03	4.27E-03	3.16E-03	4.52E-03	4.26E-03	1.55E-02	2.88E-03	4.86E-03	6.84E-03	5.10E-03	5.13E-03

Land use	µPt	1.97E+00	3.19E+00	4.77E+00	1.82E+00	1.73E+00	2.71E+00	5.06E+00	1.73E+00	3.79E+00	1.38E+00	1.71E+00	2.94E+00	1.66E+00	1.56E+00
Ozone depletion	µPt	1.29E-03	9.66E-04	8.12E-04	7.86E-04	8.90E-04	1.05E-03	1.22E-03	8.90E-04	3.27E-03	5.81E-04	1.23E-03	1.48E-03	1.11E-03	1.51E-03
Photochemical ozone formation	µPt	1.60E-01	1.14E-01	1.20E-01	1.19E-01	1.07E-01	3.30E-01	2.67E-01	1.07E-01	3.00E-01	9.98E-02	2.30E-01	1.69E-01	1.13E-01	3.47E-01
Resource use, fossils	µPt	3.94E-01	3.51E-01	2.70E-01	2.85E-01	3.38E-01	5.90E-01	5.88E-01	3.38E-01	1.19E+00	2.45E-01	5.68E-01	4.27E-01	3.52E-01	7.32E-01
Resource use, minerals and metals	µPt	2.40E-02	2.40E-02	2.21E-02	2.83E-02	2.05E-02	1.44E-02	1.95E-02	2.05E-02	8.05E-02	1.20E-02	2.23E-02	2.33E-02	3.04E-02	2.38E-02
Water use	µPt	5.73E-02	6.60E-02	3.27E-02	7.67E+00	7.63E-02	1.79E+01	1.23E-01	7.63E-02	3.44E-01	3.38E+00	1.26E+01	5.55E-02	7.35E-02	1.14E+01
Total	**µPt**	**5.11E+00**	**6.20E+00**	**7.67E+00**	**1.20E+01**	**4.09E+00**	**2.47E+01**	**9.63E+00**	**4.06E+00**	**1.19E+01**	**6.57E+00**	**1.76E+01**	**7.16E+00**	**4.48E+00**	**1.82E+01**

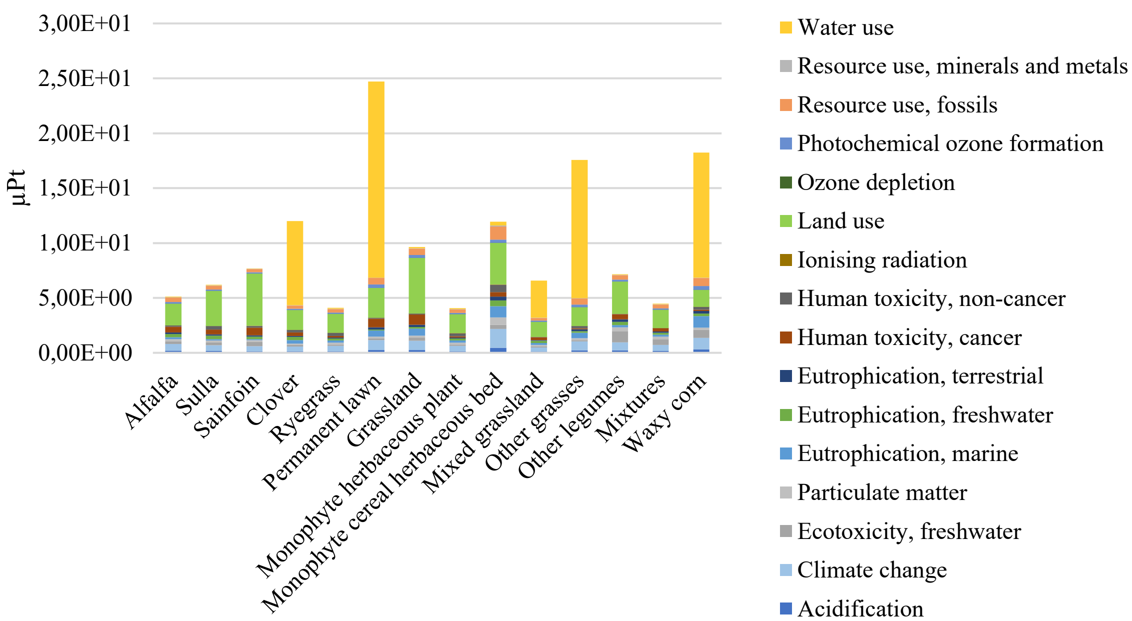

Figure 1: Impact assessment, expressed in eco-points and distinct for each impact category, of crops for the production of forage and silage

1.1.2 Haymaking and silage

Once agricultural products are harvested, some undergo a drying process necessary for hay production (haymaking). This process can occur through either natural (sun-drying) or mechanical (dehydration) methods. Beyond the resulting Dry Matter (DM) content, the primary difference lies in the consumption of heat and electricity, which are significantly higher for mechanical drying, inevitably leading to a greater environmental impact.

The haymaking process for each crop was modeled considering that the relative contribution of natural versus mechanical drying varies by crop and is typically site-specific across different Italian regions. Generally, natural drying is preferred at lower latitudes in Southern Italy, while mechanical drying is more prevalent in the North Italy.

To illustrate the disparity between these two processes, the environmental impact results for alfalfa hay subjected to both treatments are summarized below. On a national average, Italian alfalfa hay is typically obtained from a mix consisting of 82.5% natural-dried hay and 17.5% mechanically dried hay. The average yield for the alfalfa haymaking process is approximately 20%. **Table 3** and **Table 4** present the characterization factors and the overall eco-indicators broken down by impact category. **Figure 2** displays the total impacts of the analyzed systems categorized by impact type.

As hypothesized, mechanical drying shows increased impacts in the Resource use, fossils category (28.3 µPt for mechanical; 2.2 µPt for natural; 6.8 µPt for the mix) and Climate change (39.8 µPt, 4.1 µPt, and 10.4 µPt, respectively). These increases are driven by higher diesel consumption for mechanical operations (180.8 MJ for mechanical vs. 76.8 MJ for natural), thermal energy derived primarily from natural gas (150 kWh for mechanical vs. zero for natural), and electricity consumption (100 kWh vs. 1 kWh). Mechanical processing also results in a slight increase in Photochemical ozone formation and Particulate matter.

Due to the dominant contribution of natural drying (82.5%) typically preferred in Italy, the environmental impact of 1 kg of the Italian alfalfa hay mix (42.7 µPt) is much closer to that of the natural process (29.3 µPt) than to the significantly higher impact of the mechanical process (105.8 µPt).

Table 3: Characterization for each impact category of the haymaking typologies for alfalfa

Category	**Unit**	**Hay - natural drying**	**Hay - mechanical drying**	**Medium hay (85% nat, 18% mec)**
Acidification	mol H^+ eq	1.44E-03	2.85E-03	1.69E-03
Climate change	kg CO_2 eq	1.48E-01	1.43E+00	3.72E-01
Ecotoxicity, freshwater	CTUe	4.50E+00	4.89E+00	4.57E+00
Particulate matter	disease inc.	8.09E-09	3.58E-08	1.29E-08
Eutrophication, marine	kg N eq	8.04E-04	1.44E-03	9.15E-04
Eutrophication, freshwater	kg P eq	8.00E-05	9.62E-05	8.28E-05
Eutrophication, terrestrial	mol N eq	6.04E-03	1.17E-02	7.03E-03
Human toxicity, cancer	CTUh	2.24E-09	2.68E-09	2.32E-09
Human toxicity, non- cancer	CTUh	5.51E-09	5.99E-09	5.59E-09
Ionizing radiation	kBq U-235eq	1.84E-03	6.72E-03	2.69E-03
Land use	Pt	9.91E+01	1.16E+02	1.02E+02
Ozone depletion	kg CFC11eq	5.22E-09	5.87E-08	1.46E-08
Photochemical ozone formation	kg NMVOCeq	1.18E-03	4.21E-03	1.71E-03
Resource use, fossils	MJ	1.72E+00	2.21E+01	5.29E+00
Resource use, minerals and metals	kg Sb eq	1.23E-07	1.41E-07	1.26E-07
Water use	m^3 depriv.	2.93E-03	5.89E-02	1.27E-02

Table 4: Impact assessment for each impact category by type of alfalfa haymaking process, expressed as a single score (eco-indicator in µPt)

Category	**Unit**	**Hay - natural drying**	**Hay - mechanical drying**	**Medium hay (85% nat, 18% mec)**
Acidification	µPt	1.61E+00	3.18E+00	1.88E+00
Climate change	µPt	4.13E+00	3.98E+01	1.04E+01
Ecotoxicity, freshwater	µPt	1.52E+00	1.66E+00	1.55E+00
Particulate matter	µPt	1.22E+00	5.38E+00	1.95E+00
Eutrophication, marine	µPt	1.22E+00	2.17E+00	1.39E+00
Eutrophication, freshwater	µPt	1.39E+00	1.68E+00	1.44E+00
Eutrophication, terrestrial	µPt	1.27E+00	2.46E+00	1.48E+00
Human toxicity, cancer	µPt	2.77E+00	3.31E+00	2.86E+00
Human toxicity, non- cancer	µPt	7.88E-01	8.57E-01	8.00E-01
Ionizing radiation	µPt	2.18E-02	7.98E-02	3.20E-02
Land use	µPt	9.61E+00	1.13E+01	9.90E+00
Ozone depletion	µPt	6.29E-03	7.08E-02	1.76E-02
Photochemical ozone formation	µPt	1.38E+00	4.93E+00	2.00E+00
Resource use, fossils	µPt	2.20E+00	2.83E+01	6.77E+00
Resource use, minerals and metals	µPt	1.46E-01	1.67E-01	1.49E-01
Water use	µPt	2.17E-02	4.37E-01	9.43E-02
Total	**µPt**	**2.93E+01**	**1.06E+02**	**4.27E+01**

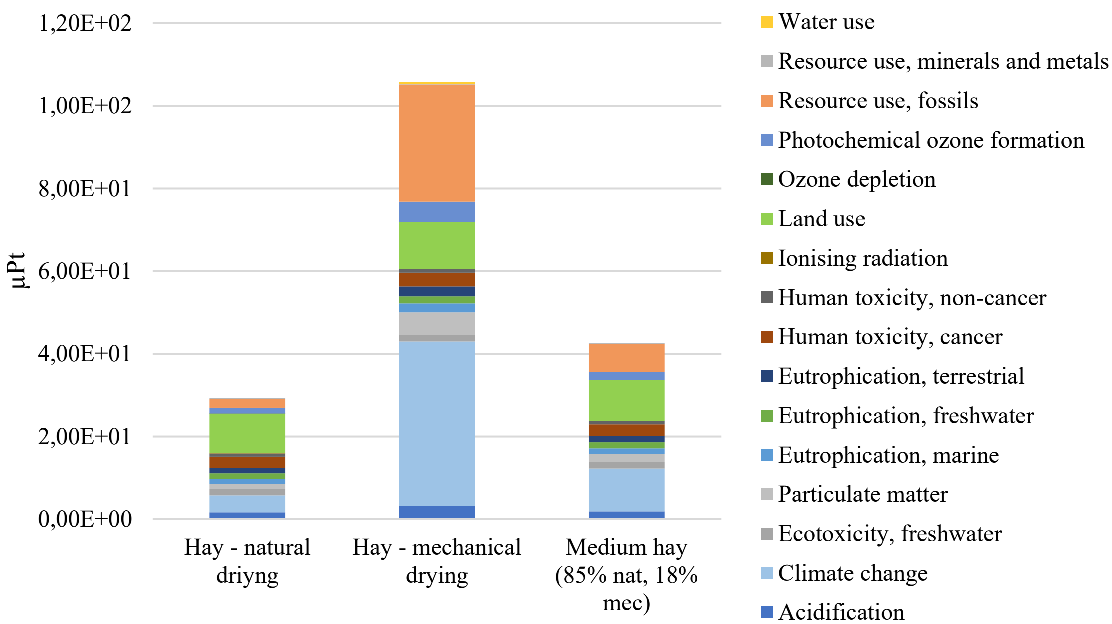

Figure 2: Impact Assessment, expressed in eco-points and divided into each impact category, by type of haymaking process (alfalfa)

For all other crops intended for drying, an average haymaking process was modeled, incorporating the respective percentage contributions of mechanical and natural treatments. Hay products are derived from the cultivation processes described in Section 1.1.1; notably, pasture was excluded from this stage as it is consumed in situ. Conversely, an average hay mix was included, representing the weighted contribution of all other selected hay types.

Table 5 presents the characterization factors for the haymaking processes representative of all selected crops. Additionally, the ensiling process for waxy maize is included. **Table 6** details the impact assessment for each selected product, expressed in µPt.

Finally, **Figure 3** provides a graphical representation of the environmental contributions broken down by impact category. The data show that the upstream agricultural phase remains the primary differentiator; products requiring significant water volumes during cultivation continue to exhibit the highest impacts. It should be noted that both haymaking and ensiling processes involve a reduction in moisture content. The impact contribution from electricity, thermal energy, and diesel consumption is relatively minor when compared to the cultivation phase, primarily due to the process yield. Consequently, to produce 1 kg of final product, a significantly larger quantity of fresh biomass input is required. As shown in **Table 7**, yields range from 17% to 23%.

In descending order, the most impactful products (using a cut-off > 50 µPt) are: Alfalfa hay: 138.8 µPt (20% yield); Other grass hay: 85.5 µPt (23% yield); Clover hay: 80.1 µPt (17% yield); Average forage mix: 60.4 µPt (20.7% yield); Monophyte cereal forage hay: 58.9 µPt (22% yield). Conversely, the products with the lowest environmental impact are Italian ryegrass hay (20.7 µPt; 23% yield), maize silage (21.6 µPt), and mixed forage hay (23.9 µPt; 20.5% yield).

Table 5: Characterization for each impact category of the haymaking process for the different selected crops

Category	**Unit**	**Alfalfa**	**Sulla**	**Sainfoin**	**Clover**	**Ryegrass**	**Permanent lawn**	**Monophyte herbaceous plant**	**Monophyte cereal**	**Mixed grassland**	**Other gramineous**	**Other legumes**	**Mixtures**	**Waxy corn silage**	**Forage mix**
Acidification	mol H+ eq	1.69E-03	1.35E-03	1.34E-03	1.85E-03	9.62E-04	2.17E-03	1.43E-03	2.33E-03	7.23E-04	1.39E-03	1.28E-03	9.72E-04	3.98E-04	1.44E-03
Climate change	kg CO_2 eq	3.72E-01	1.37E-01	1.27E-01	1.88E-01	1.01E-01	2.48E-01	1.53E-01	3.29E-01	7.33E-02	1.82E-01	1.44E-01	1.18E-01	5.05E-02	2.09E-01
Ecotoxicity, freshwater	CTUe	4.57E+00	5.22E+00	8.08E+00	3.82E+00	2.75E+00	4.30E+00	3.60E+00	5.40E+00	1.31E+00	1.72E+00	1.56E+01	7.58E+00	2.58E+00	4.45E+00
Particulate matter	disease inc.	1.29E-08	8.42E-09	8.16E-09	7.86E-09	6.72E-09	7.22E-09	9.17E-09	2.09E-08	2.40E-09	5.88E-09	1.20E-08	7.27E-09	2.83E-09	7.99E-09
Eutrophication, marine	kg N eq	9.15E-04	6.65E-04	5.04E-04	1.65E-03	6.66E-04	2.24E-03	9.52E-04	3.32E-03	7.72E-04	1.70E-03	9.42E-04	6.79E-04	7.92E-04	1.20E-03
Eutrophication, freshwater	kg P eq	8.28E-05	1.03E-04	7.57E-05	9.64E-05	4.41E-05	2.60E-05	5.87E-05	1.32E-04	5.08E-05	3.66E-05	9.33E-05	4.86E-05	1.65E-05	5.44E-05
Eutrophication, terrestrial	mol N eq	7.03E-03	5.34E-03	6.24E-03	8.23E-03	3.96E-03	1.03E-02	6.00E-03	9.80E-03	3.40E-03	5.94E-03	7.40E-03	4.93E-03	1.64E-03	6.54E-03
Human toxicity, cancer	CTUh	2.32E-09	2.21E-09	3.22E-09	1.66E-09	5.52E-10	3.44E-09	6.69E-10	1.53E-09	9.50E-10	3.43E-10	2.16E-09	1.11E-09	8.82E-11	1.84E-09
Human toxicity, non- cancer	CTUh	5.59E-09	1.41E-08	7.91E-09	1.18E-08	9.56E-09	5.79E-09	1.24E-08	2.28E-08	2.69E-09	7.35E-09	2.12E-09	1.77E-09	2.10E-09	5.25E-09
Ionizing radiation	kBq U-235 eq	2.69E-03	2.28E-03	1.57E-03	1.75E-03	1.59E-03	1.41E-03	2.17E-03	6.14E-03	4.65E-04	1.96E-03	2.14E-03	1.64E-03	5.32E-04	1.74E-03

Land use	Pt	1.02E+02	1.88E+02	2.74E+02	1.11E+02	7.78E+01	1.48E+02	1.03E+02	1.78E+02	6.92E+01	7.67E+01	1.68E+02	8.37E+01	1.80E+01	1.04E+02
Ozone depletion	kg CFC11 eq	1.46E-08	4.38E-09	3.65E-09	4.60E-09	3.23E-09	5.37E-09	4.62E-09	1.32E-08	1.72E-09	5.36E-09	5.69E-09	4.30E-09	7.34E-09	6.76E-09
Photochemical ozone formation	kg NMVOC eq	1.71E-03	9.38E-04	1.09E-03	1.80E-03	5.94E-04	2.46E-03	1.00E-03	1.72E-03	8.79E-04	1.48E-03	1.29E-03	9.76E-04	4.02E-04	1.50E-03
Resource use, fossils	MJ	5.29E+00	1.62E+00	1.34E+00	2.20E+00	1.24E+00	3.27E+00	1.91E+00	4.92E+00	8.09E-01	2.67E+00	1.48E+00	1.46E+00	7.33E-01	2.81E+00
Resource use, minerals and metals	kg Sb eq	1.26E-07	1.39E-07	1.30E-07	1.71E-07	1.04E-07	9.10E-08	1.38E-07	3.15E-07	3.31E-08	8.92E-08	8.42E-08	1.16E-07	1.58E-07	9.88E-08
Water use	m3 depriv.	1.27E-02	1.58E-02	-1.46E-02	6.04E+00	3.09E-02	1.27E+01	4.19E-02	2.14E-01	2.16E+00	7.39E+00	-4.37E-02	5.81E-03	1.73E+00	3.71E+00

Table 6: Impact assessment for each impact category of the haymaking process for the different selected crops, expressed as a single score (eco-indicator in µPt)

Category	Unit	Alfalfa	Sulla	Sainfoin	Clover	Ryegrass	Permanent lawn	Monophyte herbaceous plant	Monophyte cereal	Mixed grassland	Other gramineous	Other legumes	Mixtures	Waxy corn silage	Forage mix
Acidification	µPt	1.88E+00	1.51E+00	1.50E+00	2.07E+00	1.07E+00	2.42E+00	1.59E+00	2.60E+00	8.07E-01	1.55E+00	1.43E+00	1.08E+00	4.44E-01	1.61E+00
Climate change	µPt	1.04E+01	3.81E+00	3.55E+00	5.25E+00	2.81E+00	6.93E+00	4.25E+00	9.17E+00	2.04E+00	5.07E+00	4.01E+00	3.30E+00	1.41E+00	5.83E+00
Ecotoxicity, freshwater	µPt	1.55E+00	1.77E+00	2.74E+00	1.29E+00	9.31E-01	1.46E+00	1.22E+00	1.83E+00	4.43E-01	5.81E-01	5.27E+00	2.57E+00	8.73E-01	1.51E+00
Particulate matter	µPt	1.95E+00	1.27E+00	1.23E+00	1.18E+00	1.01E+00	1.09E+00	1.38E+00	3.14E+00	3.62E-01	8.84E-01	1.81E+00	1.09E+00	4.25E-01	1.20E+00
Eutrophication, marine	µPt	1.39E+00	1.01E+00	7.63E-01	2.50E+00	1.01E+00	3.39E+00	1.44E+00	5.02E+00	1.17E+00	2.57E+00	1.43E+00	1.03E+00	1.20E+00	1.81E+00
Eutrophication, freshwater	µPt	1.44E+00	1.79E+00	1.32E+00	1.68E+00	7.69E-01	4.53E-01	1.02E+00	2.30E+00	8.85E-01	6.37E-01	1.63E+00	8.47E-01	2.88E-01	9.48E-01
Eutrophication, terrestrial	µPt	1.48E+00	1.12E+00	1.31E+00	1.73E+00	8.31E-01	2.16E+00	1.26E+00	2.06E+00	7.13E-01	1.25E+00	1.55E+00	1.04E+00	3.45E-01	1.37E+00
Human toxicity, cancer	µPt	2.86E+00	2.73E+00	3.98E+00	2.05E+00	6.82E-01	4.25E+00	8.26E-01	1.89E+00	1.17E+00	4.24E-01	2.67E+00	1.37E+00	1.09E-01	2.27E+00
Human toxicity, non-cancer	µPt	8.00E-01	2.01E+00	1.13E+00	1.68E+00	1.37E+00	8.28E-01	1.77E+00	3.26E+00	3.84E-01	1.05E+00	3.03E-01	2.53E-01	3.00E-01	7.50E-01
Ionizing radiation	µPt	3.20E-02	2.71E-02	1.86E-02	2.07E-02	1.89E-02	1.68E-02	2.58E-02	7.29E-02	5.52E-03	2.33E-02	2.54E-02	1.94E-02	6.31E-03	2.07E-02

Land use	µPt	9.90E+00	1.82E+01	2.65E+01	1.07E+01	7.53E+00	1.43E+01	1.00E+01	1.72E+01	6.71E+00	7.43E+00	1.63E+01	8.11E+00	1.75E+00	1.01E+01
Ozone depletion	µPt	1.76E-02	5.29E-03	4.40E-03	5.55E-03	3.90E-03	6.48E-03	5.56E-03	1.59E-02	2.07E-03	6.46E-03	6.85E-03	5.18E-03	8.85E-03	8.15E-03
Photochemical ozone formation	µPt	2.00E+00	1.10E+00	1.28E+00	2.11E+00	6.95E-01	2.88E+00	1.17E+00	2.01E+00	1.03E+00	1.73E+00	1.51E+00	1.14E+00	4.71E-01	1.76E+00
Resource use, fossils	µPt	6.77E+00	2.08E+00	1.71E+00	2.82E+00	1.59E+00	4.18E+00	2.44E+00	6.29E+00	1.04E+00	3.42E+00	1.90E+00	1.87E+00	9.38E-01	3.60E+00
Resource use, minerals and metals	µPt	1.49E-01	1.65E-01	1.55E-01	2.02E-01	1.23E-01	1.08E-01	1.64E-01	3.74E-01	3.93E-02	1.06E-01	9.99E-02	1.37E-01	1.87E-01	1.17E-01
Water use	µPt	9.43E-02	1.17E-01	-1.09E-01	4.48E+01	2.29E-01	9.42E+01	3.11E-01	1.58E+00	1.61E+01	5.48E+01	-3.24E-01	4.31E-02	1.28E+01	2.75E+01
Total	**µPt**	**4.27E+01**	**3.87E+01**	**4.71E+01**	**8.01E+01**	**2.07E+01**	**1.39E+02**	**2.89E+01**	**5.89E+01**	**3.29E+01**	**8.15E+01**	**3.96E+01**	**2.39E+01**	**2.16E+01**	**6.04E+01**

Table 7: Yield of the haymaking process

	Alfalfa	Sulla	Sainfoin	Clover	Ryegrass	Permanent lawn	Monophyte herbaceous plant	Monophyte cereal	Mixed grassland	Other gramineous	Other legumes	Mixtures	Forage mix
Yield (%)	**20.0**	**17.5**	**18.0**	**17.0**	**23.0**	**18.9**	**17.3**	**22.0**	**20.5**	**23.0**	**18.0**	**20.5**	**20.07**

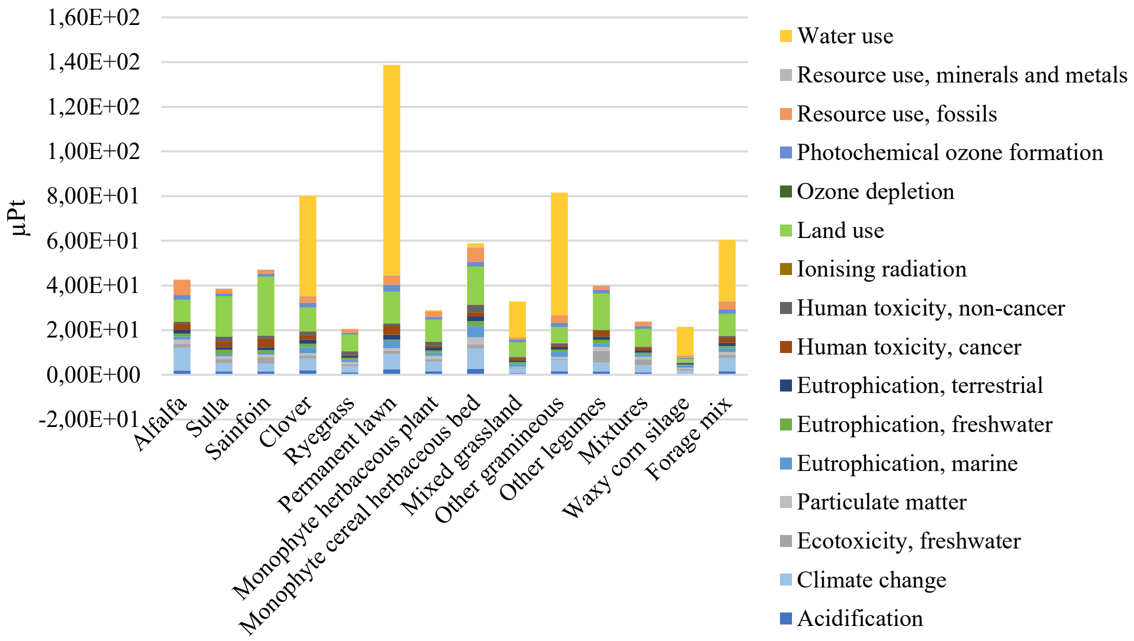

Figure 3: Impact assessment for each impact category of the haymaking process for the different selected crops, expressed in eco-points and distinct for each impact category

1.1.3 Cultivation of Grains and Imported Mixes

In addition to fresh forage, hay, and silage, cattle feed includes grains and milling by-products essential for producing concentrates. Unlike silage and forage, these products are not delivered directly to the farm but are sent to a flour mill for further grinding and processing (a stage detailed in the following section). Characterization factors for the impact assessment are described in **Table 8**, while **Table 9** tabulates the environmental impact results for each category across all selected products. The graphical representation is provided in **Figure 4**. The analysis shows that soybean grain is the most impactful process (187.7 µPt), slightly higher than maize grain production (176.7 µPt). For both systems, Water Use is the most significant category, accounting for 65.2% and 38.1%, respectively. Additionally, Ecotoxicity (26.9%) is significant for maize grain production. All other categories contribute less than 10% individually, as the substantial relevance of water consumption during the agricultural phase (0.36 m^3/t for soybeans and 0.19 m^3/t for maize) compresses the other percentage contributions. Physiologically mature maize also requires considerable water during cultivation (0.1 m^3/t), though other process inputs are lower. Furthermore, the high agricultural yield of sugar beet results in a lower environmental burden when using 1 kg of product as the functional unit. Conversely, the lower yield of soybeans leads to a higher environmental impact per kilogram of cultivated product. Regarding sunflower seed production (128.4 µPt), the most significant impact categories are Particulate Matter (22.2%), Climate Change (19.2%), and Terrestrial Eutrophication (13.2%). Water use is notably lower here, as no irrigation water is required; water is only used for the application of fertilizers and plant protection products (pesticides).Fuel consumption for agricultural operations is also a significant contributor for soybeans (0.06 kg/t), sunflowers (0.05 kg/t), and maize grain (0.03 kg/t), while it is considerably lower for sugar beet (0.005 kg/t). Additionally, maize grain requires a drying stage (fuel consumption of 7,745 MJ and electricity of approximately 117.2 kWh *per* tonne of harvested maize), which is absent for the other crops in this section. These products are then transported to the mill; on average, transportation impacts vary, with higher values for soft wheat (0.11 tkm/t), soybeans (0.12 tkm/t), and sugar beet (0.10 tkm/t).Finally, since a portion of the raw materials for grain production is sourced from abroad, the environmental performance is inevitably affected by international transport and different agricultural practices. Consequently, import mixes were modeled, accounting for the specific road, rail, and sea transport distances involved.

Table 8: Characterization for each impact category of the grain production process

Category	Unit	Corn for grain	Corn for animal feed	Sunflower	Soybean	Common wheat	Barley	Oats	Sugar beet
Acidification	mol H^+ eq	2.99E-03	1.60E-03	5.06E-03	3.38E-03	2.12E-03	2.11E-03	1.81E-03	4.33E-04
Climate change	kg CO_2 eq	4.94E-01	2.97E-01	8.86E-01	4.46E-01	3.81E-01	3.54E-01	2.91E-01	6.33E-02
Ecotoxicity, freshwater	CTUe	1.41E+02	1.05E+01	1.95E+01	1.21E+01	1.29E+01	1.17E+01	1.84E+01	1.57E+00
Particulate matter	disease inc.	9.88E-08	9.54E-08	1.89E-07	3.68E-08	8.86E-08	7.48E-08	5.46E-08	7.70E-09
Eutrophication, marine	kg N eq	3.89E-03	3.23E-03	3.54E-03	1.64E-03	1.68E-03	1.61E-03	1.37E-03	2.48E-04
Eutrophication, freshwater	kg P eq	6.64E-05	5.68E-05	7.28E-04	8.10E-04	4.07E-04	3.98E-04	4.60E-04	4.36E-06
Eutrophication, terrestrial	mol N eq	4.59E-02	4.08E-02	8.06E-02	2.29E-02	3.70E-02	3.33E-02	2.42E-02	4.33E-03
Human toxicity, cancer	CTUh	5.99E-10	7.54E-10	5.11E-09	1.63E-09	1.85E-09	2.55E-09	1.36E-09	1.18E-10
Human toxicity, non- cancer	CTUh	1.59E-08	5.45E-08	1.38E-08	2.41E-08	6.94E-09	8.23E-09	1.54E-08	1.03E-09
Ionizing radiation	kBq U-235 eq	3.72E-03	1.67E-03	9.17E-03	4.71E-03	4.19E-03	3.25E-03	3.34E-03	4.71E-04
Land use	Pt	1.17E+00	6.80E-01	2.90E+00	1.04E+01	6.77E+00	6.25E+00	1.32E+01	1.01E-01
Ozone depletion	kg CFC11 eq	1.03E-08	4.77E-09	2.25E-08	1.39E-08	1.18E-08	8.73E-09	9.41E-09	1.54E-09
Photochemical ozone formation	kg NMVOC eq	2.88E-03	1.26E-03	3.91E-03	3.57E-03	1.51E-03	1.83E-03	1.52E-03	5.01E-04
Resource use, fossils	MJ	4.96E+00	2.22E+00	8.97E+00	5.45E+00	3.67E+00	3.49E+00	3.00E+00	7.22E-01
Resource use, minerals and metals	kg Sb eq	1.75E-07	8.67E-08	4.13E-07	3.57E-07	2.84E-07	2.02E-07	2.66E-07	2.21E-08
Water use	m^3 depriv.	9.08E+00	3.90E+00	3.73E-01	1.65E+01	1.74E-01	1.34E-01	1.72E-01	1.16E+00

Table 9: Impact assessment for each impact category of the milling process for the production of grains, expressed as a single score (eco-indicator in µPt)

Category	Unit	Corn for grain	Corn for animal feed	Sunflower	Soybean	Common wheat	Barley	Oats	Sugar beet
Acidification	µPt	3.34E+00	1.78E+00	5.64E+00	3.77E+00	2.36E+00	2.35E+00	2.02E+00	4.83E-01
Climate change	µPt	1.38E+01	8.28E+00	2.47E+01	1.24E+01	1.06E+01	9.87E+00	8.11E+00	1.76E+00
Ecotoxicity, freshwater	µPt	4.76E+01	3.57E+00	6.61E+00	4.10E+00	4.38E+00	3.97E+00	6.23E+00	5.32E-01
Particulate matter	µPt	1.49E+01	1.44E+01	2.85E+01	5.54E+00	1.33E+01	1.13E+01	8.22E+00	1.16E+00
Eutrophication, marine	µPt	5.90E+00	4.90E+00	5.35E+00	2.49E+00	2.54E+00	2.44E+00	2.07E+00	3.75E-01
Eutrophication, freshwater	µPt	1.16E+00	9.89E-01	1.27E+01	1.41E+01	7.09E+00	6.94E+00	8.01E+00	7.60E-02
Eutrophication, terrestrial	µPt	9.62E+00	8.56E+00	1.69E+01	4.80E+00	7.76E+00	6.98E+00	5.09E+00	9.10E-01
Human toxicity, cancer	µPt	7.39E-01	9.30am-01am	6.30E+00	2.02E+00	2.28E+00	3.15E+00	1.68E+00	1.46E-01
Human toxicity, non- cancer	µPt	2.28E+00	7.79E+00	1.97E+00	3.44E+00	9.91E-01	1.18E+00	2.20E+00	1.47E-01
Ionizing radiation	µPt	4.42E-02	1.98E-02	1.09E-01	5.60E-02	4.98E-02	3.86E-02	3.96E-02	5.59E-03
Land use	µPt	1.13E-01	6.59E-02	2.81E-01	1.01E+00	6.56E-01	6.05E-01	1.27E+00	9.74E-03
Ozone depletion	µPt	1.24E-02	5.74E-03	2.71E-02	1.67E-02	1.42E-02	1.05E-02	1.13E-02	1.85E-03
Photochemical ozone formation	µPt	3.37E+00	1.48E+00	4.58E+00	4.17E+00	1.77E+00	2.14E+00	1.78E+00	5.86E-01
Resource use, fossils	µPt	6.35E+00	2.84E+00	1.15E+01	6.97E+00	4.70E+00	4.46E+00	3.84E+00	9.23E-01
Resource use, minerals and metals	µPt	2.08E-01	1.03E-01	4.91E-01	4.24E-01	3.37E-01	2.40E-01	3.16E-01	2.62E-02
Water use	µPt	6.74E+01	2.89E+01	2.77E+00	1.22E+02	1.29E+00	9.93E-01	1.28E+00	8.63E+00
Total	**µPt**	**1.77E+02**	**8.46E+01**	**1.28E+02**	**1.88E+02**	**6.02E+01**	**5.66E+01**	**5.22E+01**	**1.58E+01**

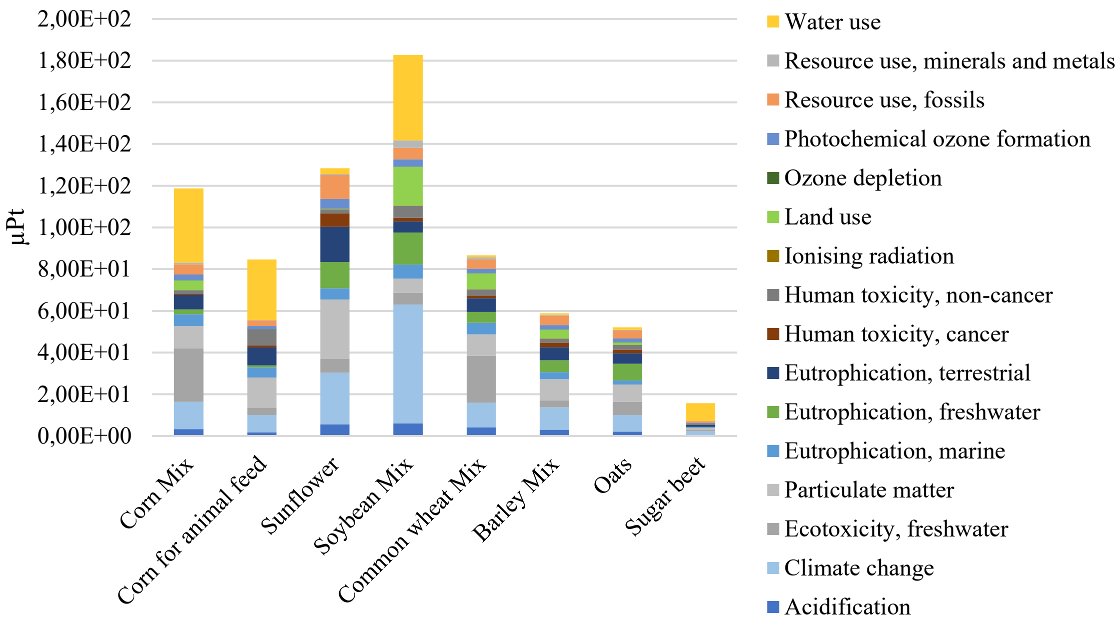

Figure 4: Impact assessment for each impact category of the milling process for the production of grains, expressed as a single score, expressed in eco-points and distinct for each impact category

Sourcing from international markets plays a pivotal role in the supply chain, particularly for maize, soybeans, soft wheat, and barley. While the primary processing and milling of these grains typically occur within Italy, soybean represents a notable exception; for this crop, the importation of crushed meals and associated by-products is also significant.

To accurately quantify the influence of international sourcing, the following analysis incorporates market mixes for products with substantial import shares. These results replace the domestic-only datasets previously discussed to provide a more representative environmental profile.

The LCIA characterization factors are detailed in **Table 10**, while **Table 11** presents the environmental impacts expressed in micro-points (µPt). For clarity, products modeled using an import-adjusted mix are highlighted in italics. Furthermore, **Figure 5** illustrates the total eco-indicator for each selected product, highlighting the shifting importance of specific impact categories when global supply chains are factored into the inventory.

Table 10: Characterization for each impact category of the grain production process including imports and related mixes

Category	Unit	Corn Mix	Corn for animal feed	Sunflower	Soybean Mix	Common wheat mix	Barley Mix	Oats	Sugar beet
Acidification	mol H^+ eq	2-98E-03	1-60E-03	5-06E-03	5-49E-03	3-68E-03	2-65E-03	1-81E-03	4-33E-04
Climate change	kg CO_2 eq	4-67E-01	2-97E-01	8-86E-01	2-04E+00	4-25E-01	3-88E-01	2-91E-01	6-33E-02
Ecotoxicity, freshwater	CTUe	7-58E+01	1-05E+01	1-95E+01	1-71E+01	6-63E+01	1-00E+01	1-84E+01	1-57E+00
Particulate matter	disease inc.	7-11E-08	9-54E-08	1-89E-07	4-44E-08	6-90E-08	6-66E-08	5-46E-08	7-70E-09
Eutrophication, marine	kg N eq	3-77E-03	3-23E-03	3-54E-03	4-50E-03	3-58E-03	2-26E-03	1-37E-03	2-48E-04
Eutrophication, freshwater	kg P eq	1-34E-04	5-68E-05	7-28E-04	8-77E-04	3-00E-04	3-31E-04	4-60E-04	4-36E-06
Eutrophication, terrestrial	mol N eq	3-26E-02	4-08E-02	8-06E-02	2-57E-02	3-17E-02	2-96E-02	2-42E-02	4-33E-03
Human toxicity, cancer	CTUh	4-49E-10	7-54E-10	5-11E-09	1-33E-09	9-32E-10	1-79E-09	1-36E-09	1-18E-10
Human toxicity, non- cancer	CTUh	1-24E-08	5-45E-08	1-38E-08	4-02E-08	2-11E-08	1-28E-08	1-54E-08	1-03E-09
Ionizing radiation	kBq U-235 eq	4-83E-03	1-67E-03	9-17E-03	8-18E-03	5-60E-03	4-26E-03	3-34E-03	4-71E-04
Land use	Pt	4-79E+01	6-80E-01	2-90E+00	1-93E+02	7-93E+01	4-53E+01	1-32E+01	1-01E-01
Ozone depletion	kg CFC11 eq	1-55E-08	4-77E-09	2-25E-08	2-46E-08	2-02E-08	1-37E-08	9-41E-09	1-54E-09
Photochemical ozone formation	kg NMVOC eq	2-34E-03	1-26E-03	3-91E-03	3-06E-03	1-87E-03	1-87E-03	1-52E-03	5-01E-04
Resource use, fossils	MJ	3-84E+00	2-22E+00	8-97E+00	4-29E+00	3-44E+00	3-38E+00	3-00E+00	7-22E-01
Resource use, minerals and metals	kg Sb eq	6-79E-07	8-67E-08	4-13E-07	2-91E-06	8-62E-07	4-42E-07	2-66E-07	2-21E-08
Water use	m^3 depriv.	4-81E+00	3-90E+00	3-73E-01	5-52E+00	1-36E-01	9-34E-02	1-72E-01	1-16E+00

Table 11: Impact assessment for each impact category of the grain production process including imports and related mixes, expressed as a single score (eco-indicator in µPt)

Category	Unit	Corn Mix	Corn for animal feed	Sunflower	Soybean Mix	Common wheat mix	Barley Mix	Oats	Sugar beet
Acidification	µPt	3.32E+00	1.78E+00	5.64E+00	6.13E+00	4.11E+00	2.96E+00	2.02E+00	4.83E-01
Climate change	µPt	1.30E+01	8.28E+00	2.47E+01	5.68E+01	1.19E+01	1.08E+01	8.11E+00	1.76E+00
Ecotoxicity, freshwater	µPt	2.57E+01	3.57E+00	6.61E+00	5.80E+00	2.24E+01	3.39E+00	6.23E+00	5.32E-01
Particulate matter	µPt	1.07E+01	1.44E+01	2.85E+01	6.68E+00	1.04E+01	1.00E+01	8.22E+00	1.16E+00
Eutrophication, marine	µPt	5.70E+00	4.90E+00	5.35E+00	6.81E+00	5.42E+00	3.42E+00	2.07E+00	3.75E-01
Eutrophication, freshwater	µPt	2.34E+00	9.89E-01	1.27E+01	1.53E+01	5.23E+00	5.77E+00	8.01E+00	7.60E-02
Eutrophication, terrestrial	µPt	6.84E+00	8.56E+00	1.69E+01	5.40E+00	6.66E+00	6.21E+00	5.09E+00	9.10E-01
Human toxicity, cancer	µPt	5.55E-01	9.3E-01	6.30E+00	1.64E+00	1.15E+00	2.21E+00	1.68E+00	1.46E-01
Human toxicity, non- cancer	µPt	1.78E+00	7.79E+00	1.97E+00	5.74E+00	3.02E+00	1.83E+00	2.20E+00	1.47E-01
Ionizing radiation	µPt	5.73E-02	1.98E-02	1.09E-01	9.71E-02	6.64E-02	5.06E-02	3.96E-02	5.59E-03
Land use	µPt	4.64E+00	6.59E-02	2.81E-01	1.87E+01	7.68E+00	4.38E+00	1.27E+00	9.74E-03
Ozone depletion	µPt	1.87E-02	5.74E-03	2.71E-02	2.96E-02	2.43E-02	1.66E-02	1.13E-02	1.85E-03
Photochemical ozone formation	µPt	2.74E+00	1.48E+00	4.58E+00	3.58E+00	2.19E+00	2.18E+00	1.78E+00	5.86E-01
Resource use, fossils	µPt	4.92E+00	2.84E+00	1.15E+01	5.49E+00	4.40E+00	4.33E+00	3.84E+00	9.23E-01
Resource use, minerals and metals	µPt	8.06E-01	1.03E-01	4.91E-01	3.45E+00	1.02E+00	5.25E-01	3.16E-01	2.62E-02
Water use	µPt	3.57E+01	2.89E+01	2.77E+00	4.10E+01	1.01E+00	6.93E-01	1.28E+00	8.63E+00
Total	**µPt**	**1.19E+02**	**8.46E+01**	**1.28E+02**	**1.83E+02**	**8.67E+01**	**5.88E+01**	**5.22E+01**	**1.58E+01**

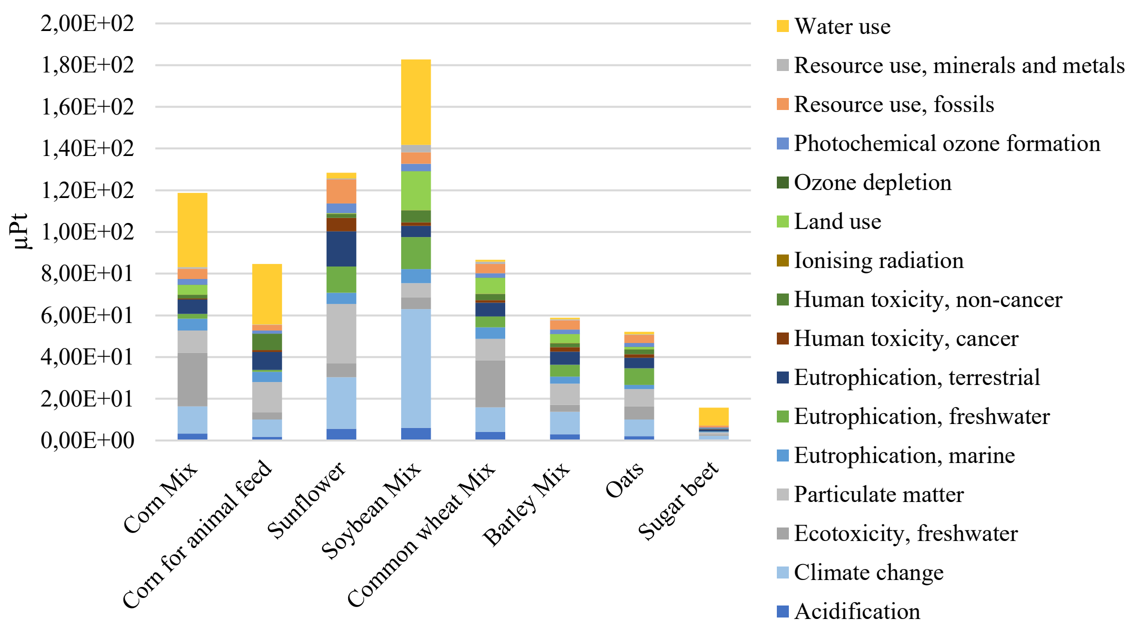

Figure 5: Impact assessment for each impact category of the grain production process including imports and related mixes, expressed as a single score, expressed in eco-points and distinct for each impact category

The results demonstrate that including international transport in the sourcing mix does not automatically result in a higher environmental burden compared to 100% domestic products. Agricultural practices vary significantly between countries and are strictly dependent on local pedoclimatic conditions (e.g., water requirements, nutrient application, and diesel consumption influenced by topography and soil slope). In several cases, international practices prove to be less resource-intensive than domestic ones.

For instance, the maize mix (49% domestic, 51% imported) shows an impact of 118.8 µPt, whereas 100% Italian maize reaches 176.7 µPt. A similar trend is observed for soybeans (30% domestic, 70% imported), with the mix scoring 182.7 µPt against 187.7 µPt for the domestic equivalent. Conversely, the barley mix (67% domestic, 33% imported) remains aligned with the domestic profile (58.8 µPt vs. 56.6 µPt). For common wheat, however, the mix impact is significantly higher than the domestic one (86.7 µPt vs. 60.2 µPt), largely due to the high import share (70%). It is also noteworthy that non-EU countries often employ plant protection products (pesticides) that are banned in Europe due to their high toxicity levels, which can skew toxicity-related indicators.

The following summary highlights the primary shifts in key impact categories:

- ✓ *Maize Mix*: Shows a substantial reduction in Water Use (35.7 µPt vs. 67.4 µPt) and Freshwater Ecotoxicity (25.7 µPt vs. 47.6 µPt), both of which are nearly halved in absolute terms.
- ✓ *Soybean Mix*: While Water Use decreases significantly (41.0 µPt vs. 122.3 µPt), there are marked increases in Land Use (18.7 µPt vs. 1.0 µPt), Marine Eutrophication (6.8 µPt vs. 2.5 µPt), and Climate Change (56.8 µPt vs. 12.4 µPt).
- ✓ *Common Wheat Mix*: Displays increases across Land Use (7.7 µPt vs. 0.7 µPt), Marine Eutrophication (5.4 µPt vs. 2.5 µPt), Freshwater Ecotoxicity (22.4 µPt vs. 4.4 µPt), and Acidification (4.1 µPt vs. 2.4 µPt).

- ✓ *Barley Mix*: The contribution of impact categories shows no statistically significant variations compared to the domestic baseline.

1.1.4 Concentrate

Grains produced both domestically and abroad are transported to flour or oil mills for processing into meals and associated co-products intended for livestock feed. Unlike haymaking, which may occur on-field or at the farm, these transformations take place in dedicated industrial facilities. Each process is characterized by a specific process that significantly influences environmental performance. It should be noted that for each milling process, the upstream environmental burden of the raw material input has been accounted for, as detailed in the previous sections.

Table 12 presents the characterization factors for all impact categories considered for each milled product and co-product. **Table 13** reports the environmental impact values expressed via the eco-indicator, while **Figure 6** provides a graphical representation of these results.

It is important to reiterate that the mills process both domestic and imported raw materials, with the latter including the associated transport impacts modeled in the preceding stage.

The soybean meal mix is the most impactful product (150.0 µPt), followed by domestic de-hulled/solvent-extracted soybean meal (134.6 µPt), maize flour (124.6 µPt), and the sunflower cake mix (102.6 µPt).

- ✓ *Soybean Meal Mix*: Climate Change is the primary impact category (82.4 µPt, representing 54.9% of the total impact), followed by Land Use (17.4 µPt, 11.6%). The milling process yield is 74%. The specific consumption for the milling stage alone includes approximately 1.6 MJ of thermal energy from natural gas, 0.06 kWh of electricity, and 0.02 MJ of fuel for internal operations per kilogram of meal produced.
- ✓ *Defatted (Solvent-Extracted) Soybean Meal*: The most relevant category is Climate Change (42.3 µPt, 31.5%), followed by Water Use (29.2 µPt, 21.7%) and Land Use (13.3 µPt, 9.9%). Starting from one tonne of fresh grain, the process yield is 79.5%. This stage involves significant consumption of natural gas (1.38 MJ/kg), electricity (approx. 0.05 kWh/t), and internal process fuel (approx. 0.02 MJ/kg).
- ✓ *Maize Flour*: Water Use is the most significant impact category (36.9 µPt, 29.6%), followed by Freshwater Ecotoxicity (26.5 µPt, 21.3%), Climate Change (14.1 µPt, 11.3%), and Particulate Matter (11.5 µPt, 9.3%). The milling yield is 62%. Water consumption during the milling phase is negligible compared to the agricultural phase; therefore, this indicator is almost entirely inherited from the maize grain cultivation. Process electricity consumption is approximately 0.1 kWh, with internal diesel use at 0.02 MJ.

The sugar beet pulp extraction process is highly energy-intensive; however, the high agricultural yield of the crop effectively offsets the environmental burden of this feed ingredient.

Table 12: Characterization for each impact category of the grain milling process

Category	Unit	Flour of corn	Corn for animal feed	Sunflower oil cake MIX	Defatted soybean flour IT	Soybean flour MIX	Crushed common wheat	Common wheat bran	Barley grain	Hulled barley	Hulled oats	Oat grains	Dried sugar beet pulp
Acidification	mol H^+ eq	3.15E-03	1.60E-03	2.92E-03	3.99E-03	4.00E-03	3.80E-03	1.43E-03	2.75E-03	3.05E-03	2.71E-03	1.90E-03	4.79E-04
Climate change	kg CO_2 eq	5.07E-01	2.92E-01	5.11E-01	1.52E+00	2.95E+00	4.45E-01	1.72E-01	4.04E-01	4.51E-01	4.44E-01	3.06E-01	1.72E-01
Ecotoxicity, freshwater	CTUe	7.83E+01	1.01E+01	1.19E+02	1.23E+01	1.81E+01	6.70E+01	2.48E+01	1.01E+01	1.11E+01	2.60E+01	1.86E+01	1.99E+00
Particulate matter	disease inc.	7.67E-08	9.09E-08	5.02E-08	3.41E-08	2.92E-08	7.39E-08	2.75E-08	7.14E-08	7.90E-08	8.29E-08	5.93E-08	1.14E-08
Eutrophication, marine	kg N eq	3.90E-03	3.09E-03	2.35E-03	3.23E-03	2.68E-03	3.64E-03	1.38E-03	2.31E-03	2.53E-03	1.97E-03	1.41E-03	2.49E-04
Eutrophication, freshwater	kg P eq	1.39E-04	5.40E-05	2.25E-04	6.24E-04	3.91E-04	3.03E-04	1.14E-04	3.35E-04	3.65E-04	6.44E-04	4.64E-04	6.45E-06
Eutrophication, terrestrial	mol N eq	3.38E-02	3.90E-02	1.82E-02	1.86E-02	1.65E-02	3.24E-02	1.20E-02	3.02E-02	3.31E-02	3.46E-02	2.48E-02	3.92E-03
Human toxicity, cancer	CTUh	4.69E-10	7.17E-10	6.55E-10	9.58E-10	7.59E-10	9.47E-10	3.54E-10	1.81E-09	1.97E-09	1.93E-09	1.38E-09	2.77E-09
Human toxicity, non-cancer	CTUh	1.30E-08	5.19E-08	2.57E-08	2.87E-08	2.25E-08	2.14E-08	8.05E-09	1.30E-08	1.41E-08	2.17E-08	1.56E-08	9.29E-10
Ionizing radiation	kBq U-235 eq	5.60E-03	1.69E-03	1.12E-02	6.23E-03	7.21E-03	5.96E-03	2.57E-03	4.51E-03	5.14E-03	5.53E-03	3.58E-03	1.43E-03

Land use	Pt	4.95E+01	6.50E-01	1.10E+02	1.37E+02	1.80E+02	8.01E+01	3.00E+01	4.57E+01	4.98E+01	1.85E+01	1.33E+01	4.06E-01
Ozone depletion	kg CFC11 eq	1.66E-08	2.83E-08	3.40E-08	2.03E-08	2.39E-08	2.07E-08	7.81E-09	1.41E-08	1.56E-08	1.39E-08	9.72E-09	1.53E-08
Photochemical ozone formation	kg NMVOC eq	2.49E-03	1.27E-03	2.92E-03	2.72E-03	2.65E-03	1.98E-03	7.60E-04	1.97E-03	2.22E-03	2.32E-03	1.62E-03	5.41E-04
Resource use, fossils	MJ	4.35E+00	2.27E+00	4.07E+00	4.18E+00	3.81E+00	3.70E+00	1.52E+00	3.59E+00	4.08E+00	4.75E+00	3.20E+00	2.37E+00
Resource use, minerals and metals	kg Sb eq	7.02E-07	6.29E-07	1.08E-06	2.07E-06	1.73E-06	8.72E-07	3.23E-07	4.48E-07	4.88E-07	3.77E-07	2.70E-07	3.59E-08
Water use	m^3 depriv.	4.97E+00	3.70E+00	1.12E-01	3.94E+00	8.83E-01	1.42E-01	-1.98E-02	9.74E-02	1.09E-01	2.53E-01	1.77E-01	9.15E-01

Table 13: Impact assessment for each impact category of the grain milling process, expressed as a single score (eco-indicator in µPt)

Category	Unit	Flour of corn	Corn for animal feed	Sunflower oilcake MIX	Defatted soybean flour IT	Soybean flour MIX	Crushed common wheat	Common wheat bran	Barley grain	Hulled barley	Hulled oats	Oat grains	Dried sugar beet pulp
Acidification	µPt	3.51E+00	1.78E+00	3.26E+00	4.45E+00	4.47E+00	4.24E+00	1.59E+00	3.07E+00	3.41E+00	3.03E+00	2.12E+00	5.35E-01
Climate change	µPt	1.41E+01	8.15E+00	1.43E+01	4.23E+01	8.24E+01	1.24E+01	4.79E+00	1.13E+01	1.26E+01	1.24E+01	8.52E+00	4.79E+00
Ecotoxicity, freshwater	µPt	2.65E+01	3.43E+00	4.02E+01	4.15E+00	6.13E+00	2.27E+01	8.39E+00	3.44E+00	3.74E+00	8.79E+00	6.31E+00	6.75E-01
Particulate matter	µPt	1.15E+01	1.37E+01	7.56E+00	5.14E+00	4.39E+00	1.11E+01	4.14E+00	1.08E+01	1.19E+01	1.25E+01	8.93E+00	1.71E+00
Eutrophication, marine	µPt	5.91E+00	4.68E+00	3.57E+00	4.88E+00	4.05E+00	5.52E+00	2.09E+00	3.49E+00	3.84E+00	2.98E+00	2.13E+00	3.78E-01
Eutrophication, freshwater	µPt	2.42E+00	9.41E-01	3.92E+00	1.09E+01	6.82E+00	5.28E+00	1.99E+00	5.83E+00	6.35E+00	1.12E+01	8.09E+00	1.12E-01
Eutrophication, terrestrial	µPt	7.10E+00	8.19E+00	3.81E+00	3.90E+00	3.47E+00	6.80E+00	2.52E+00	6.34E+00	6.95E+00	7.27E+00	5.20E+00	8.22E-01
Human toxicity, cancer	µPt	5.79E-01	8.86E-01	8.08E-01	1.18E+00	9.37E-01	1.17E+00	4.38E-01	2.23E+00	2.44E+00	2.38E+00	1.71E+00	3.42E+00
Human toxicity, non- cancer	µPt	1.85E+00	7.41E+00	3.68E+00	4.10E+00	3.22E+00	3.05E+00	1.15E+00	1.85E+00	2.02E+00	3.10E+00	2.23E+00	1.33E-01
Ionizing radiation	µPt	6.65E-02	2.00E-02	1.33E-01	7.39E-02	8.56E-02	7.08E-02	3.05E-02	5.36E-02	6.10E-02	6.56E-02	4.25E-02	1.70E-02

Land use	µPt	4.80E+00	6.30E-02	1.06E+01	1.33E+01	1.74E+01	7.76E+00	2.90E+00	4.43E+00	4.83E+00	1.79E+00	1.29E+00	3.93E-02
Ozone depletion	µPt	2.00E-02	3.42E-02	4.10E-02	2.45E-02	2.88E-02	2.49E-02	9.41E-03	1.70E-02	1.88E-02	1.67E-02	1.17E-02	1.84E-02
Photochemical ozone formation	µPt	2.92E+00	1.48E+00	3.42E+00	3.18E+00	3.09E+00	2.32E+00	8.89E-01	2.30E+00	2.60E+00	2.71E+00	1.90E+00	6.32E-01
Resource use, fossils	µPt	5.57E+00	2.91E+00	5.22E+00	5.35E+00	4.88E+00	4.73E+00	1.94E+00	4.59E+00	5.22E+00	6.09E+00	4.10E+00	3.04E+00
Resource use, minerals and metals	µPt	8.33E-01	7.47E-01	1.28E+00	2.46E+00	2.05E+00	1.04E+00	3.83E-01	5.32E-01	5.79E-01	4.47E-01	3.20E-01	4.26E-02
Water use	µPt	3.69E+01	2.74E+01	8.30E-01	2.92E+01	6.55E+00	1.05E+00	-1.47E-01	7.23E-01	8.11E-01	1.88E+00	1.31E+00	6.79E+00
Total	**µPt**	**1.25E+02**	**8.19E+01**	**1.03E+02**	**1.35E+02**	**1.50E+02**	**8.93E+01**	**3.31E+01**	**6.09E+01**	**6.73E+01**	**7.66E+01**	**5.42E+01**	**2.32E+01**

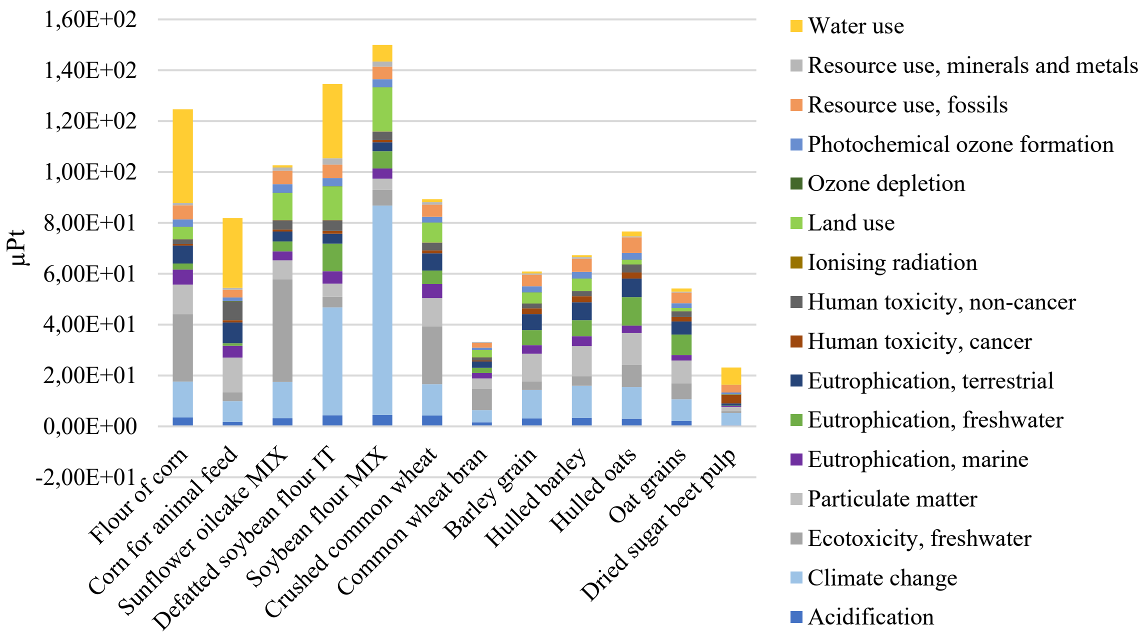

Figure 6: Impact assessment for each impact category of the grain milling process, expressed as a single score, expressed in eco-points and distinct for each impact category

1.1.5 Feed fraction

Feed and ration compositions vary significantly depending on the aptitude and purpose of the cattle (dairy vs. beef). Overall, these rations consist of maize silage, corn-cob mix (CCM) silage, forage mixtures, concentrates (as defined in previous sections), and milk, the latter being exclusively included in the diets of calves aged 0 to 3 months.

Ration compositions are categorized as follows:

- ✓ *FRB (Feed Ration for Beef)*: Comprising 4 distinct formulations based on age group.
- ✓ *FRD (Feed Ratio for female Dairy cattle)*: Comprising 5 distinct formulations.
- ✓ *FRDW (Feed Ratio for Dairy cattle - White Veal)*: Comprising 3 formulations specifically for calves intended for white veal production.
- ✓ *FRDR (Feed Ratio for Dairy cattle - Red Meat)*: Comprising 5 formulations for cattle intended for red meat production.

Table 14 and **Table 15** present the characterization factors, divided into two tables for clarity and legibility. **Table 16** and **Table 17** detail the environmental impact contributions of the various analyzed rations, expressed via the eco-indicator and broken down by impact category.

Table 14: Characterization for each impact category of the different feed rations for the different categories of cattle (part 1)

Category	Unit	FRB				FRD				
		FRB_{3-6}	FRB_{6-12}	FRB_{12-24}	$FRB_{>24}$	FRD_{0-3}	FRD_{3-6}	FRD_{6-12}	FRD_{12-24}	$FRD_{>24}$
Acidification	mol H^+ eq	3.50E-03	4.91E-03	5.06E-03	4.59E-03	5.66E-03	4.10E-03	4.34E-03	4.45E-03	6.00E-03
Climate change	kg CO_2 eq	1.00E+00	1.38E+00	1.23E+00	1.23E+00	6.93E-01	1.04E+00	1.15E+00	1.20E+00	1.76E+00
Ecotoxicity, freshwater	CTUe	5.97E+01	6.62E+01	8.14E+01	7.47E+01	5.83E+01	4.53E+01	4.73E+01	4.66E+01	6.33E+01
Particulate matter	disease inc.	6.73E-08	7.01E-08	7.23E-08	7.27E-08	9.22E-08	7.21E-08	7.57E-08	7.32E-08	8.11E-08
Eutrophication, marine	kg N eq	3.08E-03	3.85E-03	3.72E-03	3.84E-03	3.81E-03	3.16E-03	3.47E-03	3.34E-03	4.63E-03
Eutrophication, freshwater	kg P eq	8.95E-04	1.48E-03	1.59E-03	1.89E-03	1.07E-03	7.10E-04	8.27E-04	7.82E-04	2.55E-03
Eutrophication, terrestrial	mol N eq	2.52E-02	2.80E-02	2.69E-02	2.68E-02	3.56E-02	2.94E-02	3.13E-02	2.99E-02	3.36E-02
Human toxicity, cancer	CTUh	8.44E-10	9.43E-10	9.41E-10	8.79E-10	1.89E-09	1.42E-09	1.27E-09	1.34E-09	1.30E-09
Human toxicity, non- cancer	CTUh	1.70E-08	2.24E-08	2.35E-08	2.16E-08	2.38E-08	1.95E-08	2.06E-08	2.11E-08	2.56E-08
Ionizing radiation	kBq U-235 eq	1.04E-02	1.10E-02	1.48E-02	1.19E-02	1.26E-02	9.19E-03	8.85E-03	9.85E-03	1.18E-02
Land use	Pt	7.15E+01	9.73E+01	9.08E+01	8.61E+01	5.11E+01	7.28E+01	8.27E+01	8.15E+01	1.03E+02
Ozone depletion	kg CFC11 eq	2.33E-08	2.59E-08	3.19E-08	2.62E-08	2.86E-08	2.32E-08	2.27E-08	2.39E-08	2.68E-08
Photochemical ozone formation	kg NMVOC eq	2.65E-03	2.77E-03	2.99E-03	2.86E-03	2.46E-03	2.49E-03	2.63E-03	2.56E-03	3.09E-03
Resource use, fossils	MJ	5.50E+00	5.48E+00	6.43E+00	5.76E+00	6.31E+00	5.46E+00	5.41E+00	5.53E+00	6.31E+00
Resource use, minerals and metals	kg Sb eq	2.12E-06	1.96E-06	3.44E-06	2.28E-06	2.81E-06	1.67E-06	1.49E-06	1.79E-06	2.32E-06
Water use	m^3 depriv.	2.08E+00	1.05E+01	9.18E+00	7.77E+00	1.57E+01	5.66E+00	6.03E+00	7.25E+00	1.46E+01

Table 15: Characterization for each impact category of the different feed rations for the different categories of cattle (part 2)

Category	**Unit**	**FRDW**			**FRDR**				
		FRDW$_{0-3}$	**FRDW$_{3-6}$**	**FRDW$_{6-12}$**	**FRDR$_{0-3}$**	**FRDR$_{3-6}$**	**FRDR$_{6-12}$**	**FRDR$_{12-24}$**	**FRDR$_{>24}$**
Acidification	mol H^+ eq	4.59E-03	5.02E-03	3.93E-03	5.04E-03	4.67E-03	4.55E-03	4.85E-03	5.06E-03
Climate change	kg CO_2 eq	8.32E-01	7.77E-01	7.26E-01	8.65E-01	1.02E+00	9.56E-01	8.63E-01	9.43E-01
Ecotoxicity, freshwater	CTUe	4.85E+01	4.58E+01	5.28E+01	4.64E+01	5.52E+01	5.40E+01	6.22E+01	6.26E+01
Particulate matter	disease inc.	8.18E-08	8.62E-08	7.76E-08	8.07E-08	8.00E-08	7.71E-08	8.38E-08	8.19E-08
Eutrophication, marine	kg N eq	3.79E-03	3.98E-03	3.60E-03	3.60E-03	3.90E-03	3.75E-03	4.11E-03	4.14E-03
Eutrophication, freshwater	kg P eq	2.29E-03	1.70E-03	1.15E-03	9.27E-04	1.18E-03	8.12E-04	1.03E-03	1.42E-03
Eutrophication, terrestrial	mol N eq	3.19E-02	3.56E-02	3.13E-02	3.28E-02	3.27E-02	3.23E-02	3.49E-02	3.36E-02
Human toxicity, cancer	CTUh	1.78E-09	1.81E-09	1.34E-09	1.63E-09	1.29E-09	1.27E-09	1.20E-09	1.36E-09
Human toxicity, non- cancer	CTUh	2.15E-08	2.22E-08	1.81E-08	2.13E-08	2.02E-08	1.86E-08	1.96E-08	1.97E-08
Ionizing radiation	kBq U-235 eq	1.00E-02	8.75E-03	8.87E-03	9.61E-03	8.89E-03	8.63E-03	9.14E-03	1.01E-02
Land use	Pt	6.26E+01	6.67E+01	6.46E+01	6.79E+01	7.83E+01	7.15E+01	6.89E+01	6.76E+01
Ozone depletion	kg CFC11 eq	2.29E-08	2.27E-08	2.21E-08	2.45E-08	2.29E-08	2.28E-08	2.31E-08	2.46E-08
Photochemical ozone formation	kg NMVOC eq	2.69E-03	2.62E-03	2.65E-03	2.34E-03	2.59E-03	2.52E-03	2.61E-03	2.62E-03
Resource use, fossils	MJ	5.90E+00	5.62E+00	5.60E+00	5.37E+00	5.36E+00	5.34E+00	5.52E+00	5.76E+00
Resource use, minerals and metals	kg Sb eq	1.78E-06	1.40E-06	1.61E-06	1.90E-06	1.50E-06	1.52E-06	1.61E-06	1.97E-06
Water use	m^3 depriv.	6.68E+00	1.04E+01	3.54E+00	1.21E+01	8.57E+00	9.98E+00	1.11E+01	1.26E+01

Table 16: Impact assessment for each impact category of the different feed rations for the different categories of cattle expressed as a single score (eco-indicator in µPt) (part 1)

Category	Unit	FRB				FRD				
		FRB_{3-6}	FRB_{6-12}	FRB_{12-24}	$FRB_{>24}$	FRD_{0-3}	FRD_{3-6}	FRD_{6-12}	FRD_{12-24}	$FRD_{>24}$
Acidification	µPt	3.91E+00	5.48E+00	5.65E+00	5.12E+00	6.32E+00	4.58E+00	4.84E+00	4.97E+00	6.69E+00
Climate change	µPt	2.79E+01	3.84E+01	3.44E+01	3.42E+01	1.93E+01	2.91E+01	3.21E+01	3.34E+01	4.90E+01
Ecotoxicity, freshwater	µPt	2.02E+01	2.24E+01	2.76E+01	2.53E+01	1.97E+01	1.53E+01	1.60E+01	1.58E+01	2.14E+01
Particulate matter	µPt	1.01E+01	1.06E+01	1.09E+01	1.09E+01	1.39E+01	1.09E+01	1.14E+01	1.10E+01	1.22E+01
Eutrophication, marine	µPt	4.67E+00	5.83E+00	5.63E+00	5.81E+00	5.77E+00	4.79E+00	5.25E+00	5.06E+00	7.01E+00
Eutrophication, freshwater	µPt	1.56E+01	2.58E+01	2.76E+01	3.30E+01	1.86E+01	1.24E+01	1.44E+01	1.36E+01	4.44E+01
Eutrophication, terrestrial	µPt	5.30E+00	5.87E+00	5.65E+00	5.62E+00	7.47E+00	6.16E+00	6.57E+00	6.29E+00	7.06E+00
Human toxicity, cancer	µPt	1.04E+00	1.16E+00	1.16E+00	1.09E+00	2.33E+00	1.75E+00	1.57E+00	1.65E+00	1.60E+00
Human toxicity, non- cancer	µPt	2.43E+00	3.19E+00	3.35E+00	3.09E+00	3.40E+00	2.79E+00	2.95E+00	3.01E+00	3.66E+00
Ionizing radiation	µPt	1.24E-01	1.31E-01	1.76E-01	1.41E-01	1.49E-01	1.09E-01	1.05E-01	1.17E-01	1.40E-01
Land use	µPt	6.93E+00	9.43E+00	8.79E+00	8.34E+00	4.95E+00	7.05E+00	8.01E+00	7.90E+00	1.00E+01
Ozone depletion	µPt	2.80E-02	3.12E-02	3.85E-02	3.15E-02	3.44E-02	2.80E-02	2.73E-02	2.88E-02	3.23E-02
Photochemical ozone formation	µPt	3.10E+00	3.24E+00	3.50E+00	3.34E+00	2.88E+00	2.92E+00	3.07E+00	2.99E+00	3.62E+00
Resource use, fossils	µPt	7.04E+00	7.02E+00	8.23E+00	7.37E+00	8.07E+00	6.98E+00	6.92E+00	7.07E+00	8.08E+00
Resource use, minerals and metals	µPt	2.51E+00	2.32E+00	4.08E+00	2.71E+00	3.33E+00	1.98E+00	1.77E+00	2.12E+00	2.76E+00
Water use	µPt	1.54E+01	7.80E+01	6.81E+01	5.77E+01	1.17E+02	4.20E+01	4.48E+01	5.38E+01	1.08E+02
Total	**µPt**	**1.26E+02**	**2.19E+02**	**2.15E+02**	**2.04E+02**	**2.33E+02**	**1.49E+02**	**1.60E+02**	**1.69E+02**	**2.86E+02**

Table 17: Impact assessment for each impact category of the different feed rations for the different categories of cattle expressed as a single score (eco-indicator in µPt) (part 2)

Category	Unit	FRDW			FRDR				
		$FRDW_{0-3}$	$FRDW_{3-6}$	$FRDW_{6-12}$	$FRDR_{0-3}$	$FRDR_{3-6}$	$FRDR_{6-12}$	$FRDR_{12-24}$	$FRDR_{>24}$
Acidification	µPt	5.12E+00	5.60E+00	4.39E+00	5.62E+00	5.21E+00	5.07E+00	5.41E+00	5.65E+00
Climate change	µPt	2.32E+01	2.17E+01	2.02E+01	2.41E+01	2.84E+01	2.66E+01	2.41E+01	2.63E+01
Ecotoxicity, freshwater	µPt	1.64E+01	1.55E+01	1.79E+01	1.57E+01	1.87E+01	1.83E+01	2.11E+01	2.12E+01
Particulate matter	µPt	1.23E+01	1.30E+01	1.17E+01	1.21E+01	1.20E+01	1.16E+01	1.26E+01	1.23E+01
Eutrophication, marine	µPt	5.75E+00	6.03E+00	5.45E+00	5.45E+00	5.90E+00	5.68E+00	6.22E+00	6.27E+00
Eutrophication, freshwater	µPt	4.00E+01	2.96E+01	2.01E+01	1.62E+01	2.06E+01	1.42E+01	1.80E+01	2.47E+01
Eutrophication, terrestrial	µPt	6.69E+00	7.47E+00	6.56E+00	6.89E+00	6.86E+00	6.77E+00	7.33E+00	7.06E+00
Human toxicity, cancer	µPt	2.19E+00	2.23E+00	1.66E+00	2.01E+00	1.59E+00	1.57E+00	1.49E+00	1.68E+00
Human toxicity, non- cancer	µPt	3.07E+00	3.17E+00	2.59E+00	3.04E+00	2.89E+00	2.65E+00	2.79E+00	2.81E+00
Ionizing radiation	µPt	1.19E-01	1.04E-01	1.05E-01	1.14E-01	1.06E-01	1.02E-01	1.09E-01	1.20E-01
Land use	µPt	6.07E+00	6.47E+00	6.26E+00	6.58E+00	7.59E+00	6.92E+00	6.68E+00	6.55E+00
Ozone depletion	µPt	2.76E-02	2.73E-02	2.66E-02	2.95E-02	2.77E-02	2.74E-02	2.78E-02	2.96E-02
Photochemical ozone formation	µPt	3.15E+00	3.07E+00	3.10E+00	2.74E+00	3.03E+00	2.94E+00	3.05E+00	3.06E+00
Resource use, fossils	µPt	7.55E+00	7.20E+00	7.16E+00	6.87E+00	6.87E+00	6.83E+00	7.07E+00	7.37E+00
Resource use, minerals and metals	µPt	2.12E+00	1.66E+00	1.91E+00	2.25E+00	1.78E+00	1.80E+00	1.91E+00	2.34E+00
Water use	µPt	4.96E+01	7.72E+01	2.62E+01	8.99E+01	6.36E+01	7.40E+01	8.24E+01	9.37E+01
Total	**µPt**	**1.83E+02**	**2.00E+02**	**1.35E+02**	**2.00E+02**	**1.85E+02**	**1.85E+02**	**2.00E+02**	**2.21E+02**

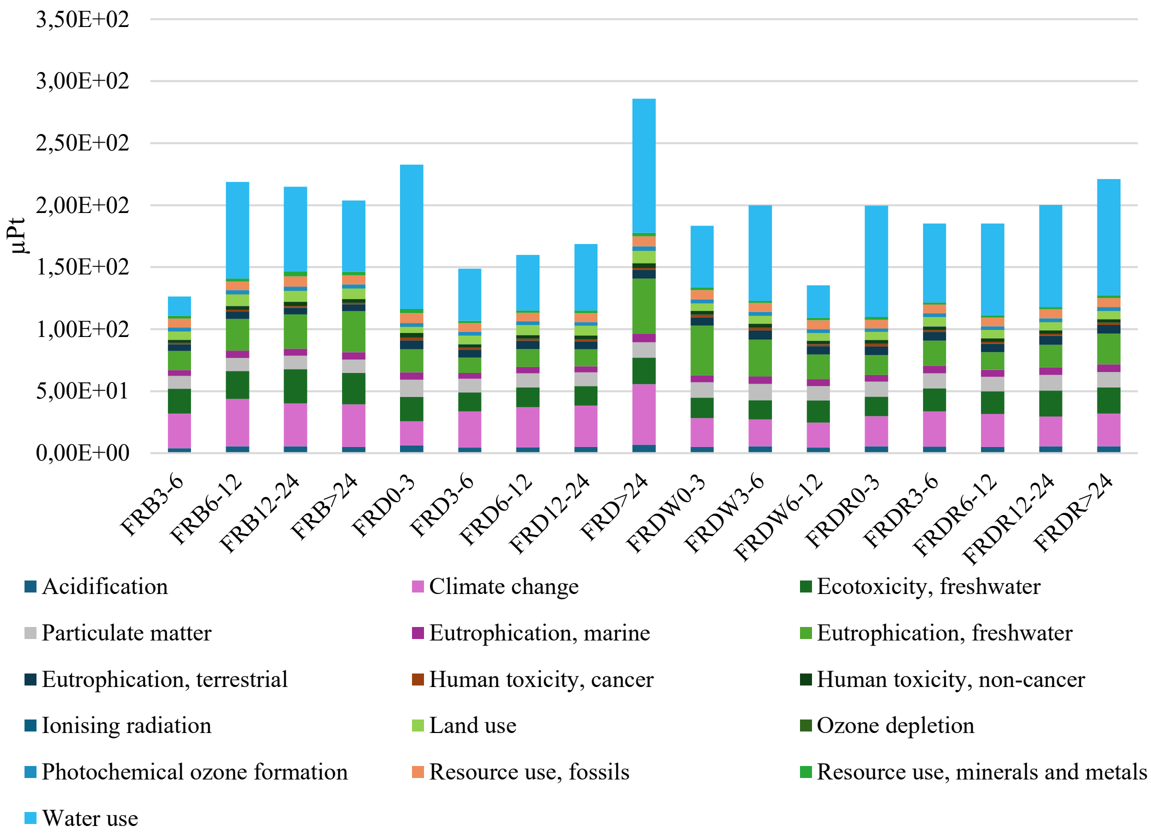

Figure 7: Impact assessment for each impact category of the different feed rations for the different categories of cattle expressed as a single score, expressed in eco-points and distinct for each impact category

Figure 7 shows the graphical contribution for each food ration analyzed. The most impactful *Food Ratio* is the $FRD_{>24}$ (289.9µPt – 55% corn silage, 5% forage mix, 40% concentrates), followed by the $FRD_{0\text{-}3}$ (232.7 µPt – 60% milk, 9.6% corn silage, 30.4% concentrates), the $FRDR_{>24}$ (221.1 µPt – 30% corn mash silage, 21.4% forage mix, 28.6% concentrates), the $FRB_{6\text{-}12}$ (218.8 µPt – 38% corn silage, 15.2% corn mash silage, 18 forage mix, 28.8% concentrates) and the $FRB_{12\text{-}24}$ (214.9 µPt – 27% corn silage, 30% corn mash silage, 17% forage mix, 26% concentrates).

The percentage contributions of the categories vary depending on the composition of the food ration, but generally the most relevant impact categories for all the Food Ratios are *Water use*, *Climate change*, *Eutrophication freshwater* and with less significant weight the *Particular matter* and the *Resource use fossils*.

1.2 LCIA: cattle breeding in Italy

This paragraph describes the impact assessment of the breeding phase, distinguishing the environmental contribution of meat breeds and dairy breeds. As previously defined, there are different variables between the two systems: the purpose of their breeding, for which only meat is obtained from the former and milk and meat (as a secondary product) from the latter; the feed rations; the management practices; the breeding system (extensive, semi-extensive, semi-intensive, intensive); the sex; the maximum age they reach before going to slaughter; the imports of some breeds; transport; the technologies used. The most significant meat breeds (*Piemontese* and *Limousine*), dairy breeds (*Frisona*) and dual-purpose breeds (*Pezzata Rossa*) are described below. These breeds were analyzed considering the environmental contribution, for male and female specimens, of the five age groups considered in the study (0-3 months, 3-6 months, 6-12 months, 12-24 months, >24 months).

1.2.1 Breeding meat breeds

In Italy, the most representative beef cattle breeds in terms of population are the *Piemontese* (13%) and the *Limousine* (12.5%), excluding crossbreds. It is, therefore, essential to analyze at least these breeds, which together constitute a quarter of the total Italian beef cattle population.

The datasets for this phase were developed using 1 kg of LW as the functional unit, as previously defined. However, the following results are presented based on the average weight of each category within the *Piemontese* breed. This approach allows for an assessment of the environmental contribution of individual animals, categorized by sex and age group. For the sake of completeness, the results relative to the functional unit of 1 kg of live weight are also included in the discussion.

1.2.1.1 *Piemontese* breed: Farming Inventory and Impact Results

Piemontese is an indigenous Italian cattle breed representing 13% of the national beef population. The production system typically adopted for this breed is semi-intensive. For female specimens, a replacement rate of 80% is considered; slaughter occurs on average at 16 months with a mean weight of approximately 500 kg. The remaining 20% (culling/replacement) reach up to 600 kg at 24 months of age. For male specimens, slaughter generally takes place around 18 months, reaching an average weight of approximately 675 kg.

The characterization factors are detailed in **Table 18.** Global Warming Potential is higher for adult specimens: $M_{>24}$ = 23,559 kg CO_2-eq (24.7 kg CO_2-eq /kg LW); $M_{12\text{-}24}$ = 13,021 kg CO_2-eq (19.3 kg CO_2-eq /kg LW); and $F_{12\text{-}24}$ = 12,004 kg CO_2-eq (23.1 kg CO_2-eq /kg LW). Conversely, for $F_{>24}$, the impact is lower (4,951 kg CO_2-eq; 8.3 kg CO_2-eq /kg LW), as a significant portion of their environmental burden is allocated to the suckling calves, which carry the impact of the dam during gestation and lactation. The dam's contribution was quantified using a factor based on the calf's weight at weaning (3 months). It should be noted that when normalized per kilogram of LW, the ranking of results changes due to the different average mass associated with each class.

Table 19 presents the results expressed via the eco-indicator for each impact category. Please note that, compared to previous sections, the scale in this chapter has shifted to milli-points (mPt) instead of micro-points (µPt). Errore. L'origine riferimento non è stata trovata. provides a graphical representation of these results. The bull ($M_{>24}$) is the most impactful individual specimen, with 3,969 mPt (4.2 mPt/kg LW), primarily due to its significantly higher body mass compared to other classes. For the bull, the most relevant impact categories are Water Use (826 mPt), Climate Change (657 mPt), Particulate Matter (548 mPt), and Acidification (525 mPt). Other categories follow in descending order of weight, with the exception of the adult cow ($F_{>24}$) for the reasons mentioned above.

When analyzed *per* kilogram of LW, the ranking is reversed. The young female (F_{0-3}) is the most impactful (5.5 mPt/kg LW), followed by M_{0-3} (5.1 mPt/kg LW), F_{6-12} (5.0 mPt/kg LW), and M_{6-12} (4.3 mPt/kg LW). The bull ($M_{>24}$) ranks only fifth (4.2 mPt/kg LW). The determining factor is the low body weight of young specimens, which additionally bear the allocated burden of the dam. Furthermore, as the animals age, the feed ration for beef breeds changes substantially, showing a marked decrease in concentrates. As established in previous sections, concentrates have a higher environmental impact per kg than forage or silage. Additionally, the contribution of milk from the dam is entirely phased out after the initial months

Table 18: Characterization for each impact category relating to the breeding of *Piemontese* breed specimen differentiated by sex and age group and associated with the relative average weight

Category	**Unit**	**$F_{0\text{-}3}$** (135 kg)	**$M_{0\text{-}3}$** (145 kg)	**$F_{3\text{-}6}$** (185 kg)	**$M_{3\text{-}6}$** (215 kg)	**$F_{6\text{-}12}$** (395 kg)	**$M_{6\text{-}12}$** (465 kg)	**$F_{12\text{-}24}$** (520 kg)	**$M_{12\text{-}24}$** (675 kg)	**$F_{>24}$** (600 kg)	**$M_{>24}$** (950 kg)
Acidification	mol H^+ eq	9,68E+01	9,72E+01	1,33E+02	1,33E+02	2,00E+02	2,08E+02	2,54E+02	2,71E+02	9,39E+01	4,70E+02
Climate change	kg CO_2 eq	5,13E+03	5,15E+03	6,40E+03	6,46E+03	9,42E+03	9,81E+03	1,20E+04	1,30E+04	4,95E+03	2,36E+04
Ecotoxicity, freshwater	CTUe	8,61E+04	8,64E+04	1,02E+05	1,05E+05	1,38E+05	1,55E+05	2,00E+05	2,47E+05	8,37E+04	5,80E+05
Particulate matter	disease inc.	7,00E-04	7,03E-04	9,65E-04	9,65E-04	1,45E-03	1,53E-03	1,91E-03	2,09E-03	6,80E-04	3,64E-03
Eutrophication, marine	kg N eq	1,32E+01	1,33E+01	1,57E+01	1,60E+01	2,29E+01	2,49E+01	3,16E+01	3,70E+01	1,27E+01	7,57E+01
Eutrophication, freshwater	kg P eq	2,13E+00	2,13E+00	2,38E+00	2,43E+00	3,11E+00	3,48E+00	4,25E+00	5,22E+00	2,06E+00	1,37E+01
Eutrophication, terrestrial	mol N eq	4,45E+02	4,47E+02	6,13E+02	6,12E+02	9,21E+02	9,66E+02	1,20E+03	1,30E+03	4,32E+02	2,26E+03
Human toxicity, cancer	CTUh	6,23E-06	6,25E-06	7,14E-06	7,33E-06	1,04E-05	1,03E-05	1,25E-05	1,27E-05	6,05E-06	2,21E-05
Human toxicity, non- cancer	CTUh	4,72E-05	4,75E-05	5,60E-05	5,75E-05	8,98E-05	1,04E-04	1,56E-04	2,04E-04	4,53E-05	3,83E-04
Ionizing radiation	kBq U-235 eq	5,88E+00	5,96E+00	7,56E+00	7,79E+00	9,66E+00	9,03E+00	1,53E+01	1,59E+01	4,85E+00	2,25E+01
Land use	Pt	5,59E+05	5,60E+05	6,36E+05	6,52E+05	9,09E+05	9,17E+05	1,08E+06	1,12E+06	5,42E+05	2,13E+06
Ozone depletion	kg CFC11 eq	4,28E-05	4,30E-05	4,84E-05	4,95E-05	7,17E-05	8,00E-05	1,16E-04	1,46E-04	4,07E-05	2,94E-04
Photochemical ozone formation	kg NMVOC eq	1,22E+01	1,23E+01	1,38E+01	1,41E+01	1,95E+01	2,14E+01	2,68E+01	3,18E+01	1,16E+01	6,90E+01
Resource use, fossils	MJ	2,96E+03	3,02E+03	3,49E+03	3,56E+03	4,55E+03	3,28E+03	6,23E+03	4,58E+03	2,31E+03	-2,79E+03
Resource use, minerals and metals	kg Sb eq	2,64E-03	2,64E-03	3,15E-03	3,26E-03	4,25E-03	4,82E-03	7,00E-03	9,01E-03	2,56E-03	2,00E-02
Water use	m^3 depriv.	1,54E+04	1,55E+04	1,65E+04	1,67E+04	2,48E+04	2,88E+04	3,73E+04	4,78E+04	1,49E+04	1,11E+05

Table 19: Impact assessment for each impact category relating to the breeding of a *Piemontese* breed specimen differentiated by sex and age group and associated with the relative average weight expressed as a single score (eco-indicator in mPt)

Category	Unit	$F_{0\text{-}3}$ (135 kg)	$M_{0\text{-}3}$ (145 kg)	$F_{3\text{-}6}$ (185 kg)	$M_{3\text{-}6}$ (215 kg)	$F_{6\text{-}12}$ (395 kg)	$M_{6\text{-}12}$ (465 kg)	$F_{12\text{-}24}$ (520 kg)	$M_{12\text{-}24}$ (675 kg)	$F_{>24}$ (600 kg)	$M_{>24}$ (950 kg)
Acidification	mPt	1.08E+02	1.08E+02	1.49E+02	1.49E+02	2.23E+02	2.32E+02	2.84E+02	3.03E+02	1.05E+02	5.25E+02
Climate change	mPt	1.43E+02	1.44E+02	1.78E+02	1.80E+02	2.63E+02	2.74E+02	3.35E+02	3.63E+02	1.38E+02	6.57E+02
Ecotoxicity, freshwater	mPt	2.92E+01	2.93E+01	3.47E+01	3.57E+01	4.68E+01	5.23E+01	6.76E+01	8.35E+01	2.83E+01	1.96E+02
Particulate matter	mPt	1.05E+02	1.06E+02	1.45E+02	1.45E+02	2.19E+02	2.30E+02	2.88E+02	3.14E+02	1.02E+02	5.48E+02
Eutrophication, marine	mPt	2.00E+01	2.01E+01	2.38E+01	2.42E+01	3.47E+01	3.76E+01	4.79E+01	5.61E+01	1.92E+01	1.15E+02
Eutrophication, freshwater	mPt	3.70E+01	3.72E+01	4.14E+01	4.23E+01	5.41E+01	6.07E+01	7.41E+01	9.10E+01	3.60E+01	2.39E+02
Eutrophication, terrestrial	mPt	9.35E+01	9.38E+01	1.29E+02	1.29E+02	1.93E+02	2.03E+02	2.52E+02	2.73E+02	9.07E+01	4.74E+02
Human toxicity, cancer	mPt	7.69E+00	7.72E+00	8.82E+00	9.05E+00	1.28E+01	1.27E+01	1.54E+01	1.57E+01	7.47E+00	2.72E+01
Human toxicity, non- cancer	mPt	6.75E+00	6.79E+00	8.01E+00	8.22E+00	1.28E+01	1.48E+01	2.23E+01	2.91E+01	6.48E+00	5.47E+01
Ionizing radiation	mPt	6.98E-02	7.07E-02	8.98E-02	9.25E-02	1.15E-01	1.07E-01	1.82E-01	1.89E-01	5.76E-02	2.67E-01
Land use	mPt	5.41E+01	5.43E+01	6.16E+01	6.32E+01	8.81E+01	8.88E+01	1.04E+02	1.08E+02	5.25E+01	2.07E+02
Ozone depletion	mPt	5.16E-02	5.18E-02	5.83E-02	5.97E-02	8.64E-02	9.65E-02	1.40E-01	1.76E-01	4.90E-02	3.55E-01
Photochemical ozone formation	mPt	1.42E+01	1.43E+01	1.62E+01	1.65E+01	2.28E+01	2.50E+01	3.13E+01	3.72E+01	1.36E+01	8.08E+01
Resource use, fossils	mPt	3.79E+00	3.87E+00	4.46E+00	4.55E+00	5.83E+00	4.20E+00	7.98E+00	5.86E+00	2.96E+00	-3.57E+00
Resource use, minerals and metals	mPt	3.13E+00	3.14E+00	3.74E+00	3.86E+00	5.04E+00	5.72E+00	8.31E+00	1.07E+01	3.04E+00	2.37E+01
Water use	mPt	1.15E+02	1.15E+02	1.22E+02	1.24E+02	1.84E+02	2.14E+02	2.77E+02	3.55E+02	1.11E+02	8.26E+02
Total	**mPt**	**7.41E+02**	**7.43E+02**	**9.26E+02**	**9.34E+02**	**1.36E+03**	**1.45E+03**	**1.81E+03**	**2.05E+03**	**7.16E+02**	**3.97E+03**

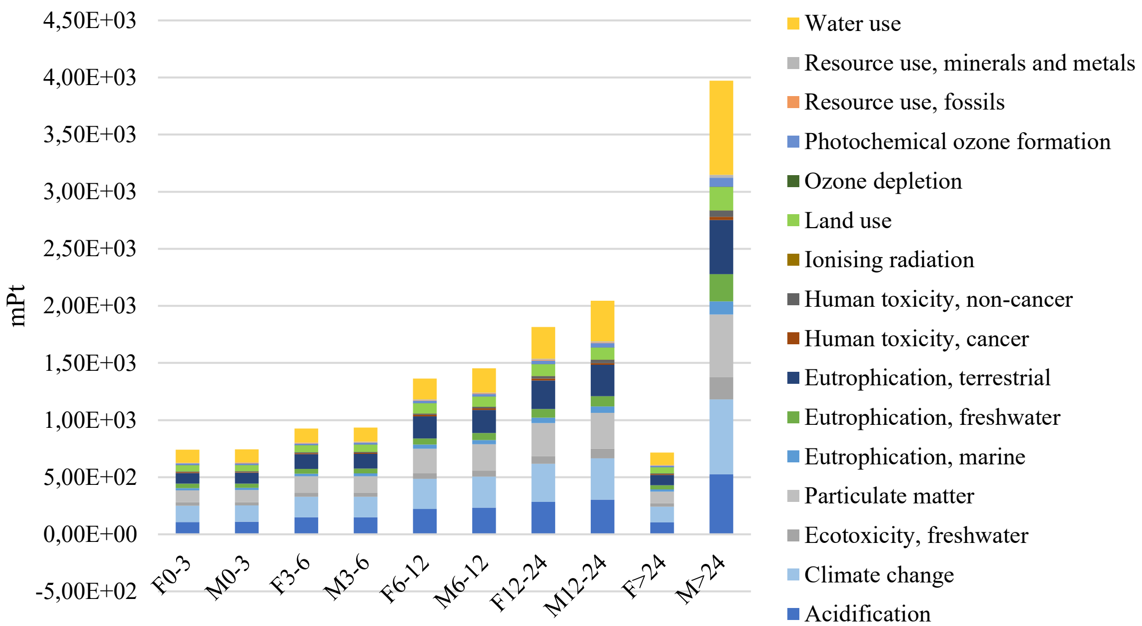

Figure 8: Impact assessment for each impact category relating to the breeding of a Piedmontese breed specimen differentiated by sex and age group and associated with the relative average weight, expressed in eco-points and distinct for each impact category

1.2.1.2 Limousine breed: Import Impacts and Comparative LCI

Among imported breeds, the *Limousine* is the most populous (12.5%) among the meat breeds nationwide. Typically, young animals between 3 and 6 months old are imported to add to the herd already present in Italy. Male animals have a higher import rate, equal to 70% compared to 30% for Italian animals, while imported females average only 55%, while 45% are already settled in Italy. Imported *Limousin cattle* generally come from France, for which a distance of approximately 1,200 km was considered.

Unlike the *Piemontese* analyzed in the previous chapter, the dataset relating to the 0-3 month age group was therefore developed considering the percentages indicated above. The imported *Limousine* was modeled using a dataset present in the Ecoinvent database called "*Calf, weaned, conventional, suckler cow system, less than 1.2 LU per ha, at farm gate {FR} U* ". Furthermore, the breeding system associated with the *Limousine* is semi-intensive.

Figure 9 shows the environmental results per 1 kg of live weight for the F_{0-3} and M_{0-3} Italian and imported classes, as well as the mix used for the final impact assessment (45-55% for females and 30-70% for males, respectively). The environmental contribution of imported animals is less impactful and more virtuous than that of Italian specimens, despite the increased transport costs due to imports. One of the main reasons for this difference is that grazing in France has a lower characterization factor than that in Italy according to the chosen calculation method (EF 3.1), as does the use of water from land in Italy, a country with a higher water risk than France. Furthermore, the practices used, energy consumption, and raw materials are more efficient.

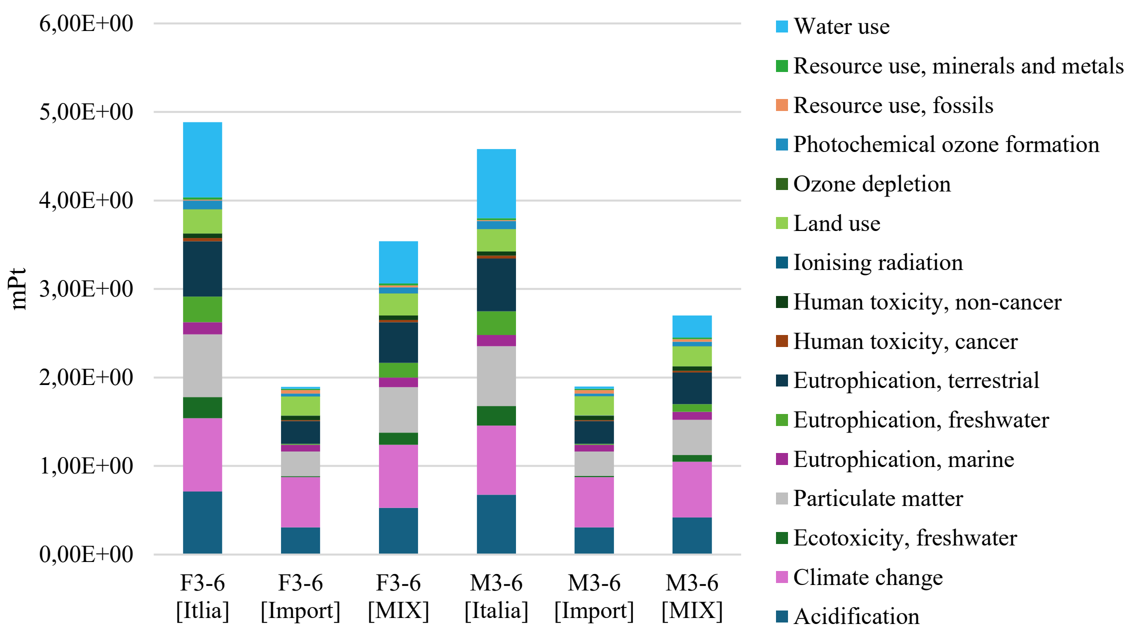

Figure 9: Comparison of the environmental performance of Italian Limousine cattle, imported (France) and the mix considered in Italy, aged between 0 and 3 months, both female and male

Following the initial distinction between domestic and imported specimens, the following analysis adopts the weighted mix representative of the Italian market to compare environmental performance across different classes (categorized by sex and age group).For female specimens, a replacement rate of 90% is assumed; slaughter occurs on average at 18 months with a mean weight of 525 kg, while the remaining 10% (culling) reach 615 kg at 24 months. For male specimens, slaughter typically occurs around 20 months at an average weight of approximately 700 kg. **Table 20** presents the impact assessment characterization factors for the ten analyzed classes based on average animal weight. A preliminary observation regarding the mass is necessary: the growth factor for this breed is higher than that of the *Piemontese.* While young Limousine specimens are lighter than their *Piemontese* counterparts of the same sex and age, adult specimens are significantly heavier. Interestingly, although one might expect the total Global Warming Potential of an adult *Limousine* to be higher due to its greater mass, it is actually lower than the breed analyzed in the previous section. This trend shifts when the analysis is performed per kilogram of LW. In this case, the *Limousine*'s contribution is lower for adults (>24, 12-24), growing cattle (6-12), and young males (3-6), while the trend reverses for pre-weaning calves (0-3) and young females (3-6). The allocation logic for the adult female (>24 months) remains consistent with previous sections: part of the environmental burden is allocated to suckling calves, which exhibit a higher impact per kg LW partly due to their lower average mass compared to *Piemontese* calves.

The GWP for the $M_{>24}$ class is 21,551 kg CO_2-eq (21.6 kg CO_2-eq/kg LW). This is followed by $M_{12\text{-}24}$ at 12,056 kg CO_2-eq (17.2 kg CO_2-eq /kg LW) and $F_{12\text{-}24}$ at 10,599 kg CO_2-eq (19.9 kg CO_2-eq /kg LW). For suckling calves, the total absolute contribution is lower, but the impact per functional unit (FU) is higher: $F_{0\text{-}3}$ = 4,662 kg CO_2-eq (42.4 kg CO_2-eq /kg LW) and $M_{0\text{-}3}$ = 4,674 kg CO_2-eq (40.6 kg CO_2-eq /kg LW). **Table 21** details the total eco-indicator contributions for each class and impact category, with the corresponding graphical representation in **Figure 10**. While the overall considerations for the *Limousine* breed align with the previous chapter, a distinct downward cusp is observed in the impact profile between the 0-3 and 3-6 month age groups. This is explained by the fact that suckling calves are typically born and raised in Italy (higher impact), followed by the introduction of imported specimens, which are environmentally more efficient, before the impact rises again in line with the animal's subsequent growth.

The $M_{>24}$ class remains the most impactful per specimen at 3,653 mPt (3.65 mPt/kg LW). Conversely, the M_{3-6} class is the least impactful (594 mPt; 2.7 mPt/kg LW) due to the 70% import share. The corresponding female class (F_{3-6}) shows a slightly higher impact (707 mPt; 3.5 mPt/kg LW) because of the lower share of imported animals (55%).

Table 20: Characterization for each impact category relating to the breeding of *Limousine* breed specimen differentiated by gender and age group and associated with the relative average weight

Category	Unit	F_{0-3} (110 kg)	M_{0-3} (115 kg)	F_{3-6} (200 kg)	M_{3-6} (220 kg)	F_{6-12} (400 kg)	M_{6-12} (420 kg)	F_{12-24} (534 kg)	M_{12-24} (700 kg)	$F_{>24}$ (625 kg)	$M_{>24}$ (1,000 kg)
Acidification	mol H^+ eq	8.68E+01	8.70E+01	9.49E+01	8.24E+01	1.49E+02	1.42E+02	2.14E+02	2.28E+02	8.47E+01	3.96E+02
Climate change	kg CO_2 eq	4.66E+03	4.67E+03	5.11E+03	4.99E+03	7.52E+03	7.64E+03	1.06E+04	1.21E+04	4.51E+03	2.16E+04
Ecotoxicity, freshwater	CTUe	1.15E+05	1.15E+05	7.98E+04	4.86E+04	1.27E+05	1.01E+05	2.01E+05	2.28E+05	1.12E+05	5.59E+05
Particulate matter	disease inc.	6.45E-04	6.46E-04	6.86E-04	5.81E-04	1.11E-03	1.04E-03	1.65E-03	1.81E-03	6.31E-04	3.14E-03
Eutrophication, marine	kg N eq	1.49E+01	1.49E+01	1.42E+01	1.30E+01	2.18E+01	2.13E+01	3.23E+01	3.81E+01	1.44E+01	7.63E+01
Eutrophication, freshwater	kg P eq	2.94E+00	2.94E+00	1.89E+00	1.12E+00	2.93E+00	2.27E+00	4.31E+00	4.68E+00	2.87E+00	1.32E+01
Eutrophication, terrestrial	mol N eq	4.06E+02	4.07E+02	4.37E+02	3.75E+02	7.01E+02	6.63E+02	1.03E+03	1.12E+03	3.97E+02	1.94E+03
Human toxicity, cancer	CTUh	5.21E-06	5.22E-06	3.96E-06	3.11E-06	5.74E-06	4.83E-06	8.33E-06	8.18E-06	5.09E-06	1.63E-05
Human toxicity, non- cancer	CTUh	5.88E-05	5.89E-05	7.09E-05	7.64E-05	1.15E-04	1.25E-04	1.95E-04	2.63E-04	5.67E-05	4.51E-04
Ionizing radiation	kBq U-235 eq	6.10E+00	6.16E+00	1.82E+01	2.58E+01	1.92E+01	2.65E+01	2.60E+01	3.62E+01	4.66E+00	4.62E+01
Land use	Pt	5.16E+05	5.17E+05	5.14E+05	5.17E+05	6.89E+05	6.90E+05	8.95E+05	9.58E+05	5.04E+05	1.93E+06
Ozone depletion	kg CFC11 eq	5.40E-05	5.42E-05	5.80E-05	6.01E-05	8.72E-05	9.20E-05	1.41E-04	1.83E-04	5.16E-05	3.38E-04
Photochemical ozone formation	kg NMVOC eq	1.47E+01	1.48E+01	1.16E+01	9.22E+00	1.82E+01	1.64E+01	2.69E+01	3.08E+01	1.41E+01	6.76E+01
Resource use, fossils	MJ	1.45E+03	1.49E+03	3.65E+03	5.22E+03	2.83E+03	3.98E+03	4.78E+03	5.86E+03	5.71E+02	-2.22E+03
Resource use, minerals and metals	kg Sb eq	3.61E-03	3.62E-03	3.56E-03	3.28E-03	5.09E-03	4.99E-03	8.42E-03	1.08E-02	3.53E-03	2.22E-02
Water use	m^3 depriv .	2.13E+04	2.13E+04	1.28E+04	7.39E+03	2.50E+04	2.09E+04	4.00E+04	4.71E+04	2.08E+04	1.11E+05

Table 21: Impact assessment for each impact category relating to the breeding of a *Limousine* breed specimen differentiated by gender and age group and associated with the relative average weight expressed as a single score (eco-indicator in mPt)

Category	Unit	F_{0-3} (110 kg)	M_{0-3} (115 kg)	F_{3-6} (200 kg)	M_{3-6} (220 kg)	F_{6-12} (400 kg)	M_{6-12} (420 kg)	F_{12-24} (534 kg)	M_{12-24} (700 kg)	$F_{>24}$ (625 kg)	$M_{>24}$ (1,000 kg)
Acidification	mPt	9.68E+01	9.70E+01	1.06E+02	9.20E+01	1.67E+02	1.58E+02	2.39E+02	2.55E+02	9.45E+01	4.41E+02
Climate change	mPt	1.30E+02	1.30E+02	1.42E+02	1.39E+02	2.10E+02	2.13E+02	2.96E+02	3.36E+02	1.26E+02	6.01E+02
Ecotoxicity, freshwater	mPt	3.88E+01	3.88E+01	2.70E+01	1.65E+01	4.30E+01	3.41E+01	6.81E+01	7.72E+01	3.80E+01	1.89E+02
Particulate matter	mPt	9.70E+01	9.72E+01	1.03E+02	8.74E+01	1.67E+02	1.57E+02	2.49E+02	2.72E+02	9.49E+01	4.73E+02
Eutrophication, marine	mPt	2.26E+01	2.26E+01	2.16E+01	1.97E+01	3.30E+01	3.22E+01	4.89E+01	5.76E+01	2.19E+01	1.15E+02
Eutrophication, freshwater	mPt	5.12E+01	5.13E+01	3.30E+01	1.95E+01	5.11E+01	3.96E+01	7.51E+01	8.15E+01	5.01E+01	2.30E+02
Eutrophication, terrestrial	mPt	8.53E+01	8.55E+01	9.18E+01	7.87E+01	1.47E+02	1.39E+02	2.16E+02	2.35E+02	8.33E+01	4.07E+02
Human toxicity, cancer	mPt	6.44E+00	6.45E+00	4.89E+00	3.84E+00	7.09E+00	5.96E+00	1.03E+01	1.01E+01	6.29E+00	2.01E+01
Human toxicity, non- cancer	mPt	8.40E+00	8.42E+00	1.01E+01	1.09E+01	1.64E+01	1.79E+01	2.79E+01	3.76E+01	8.11E+00	6.45E+01
Ionizing radiation	mPt	7.25E-02	7.31E-02	2.16E-01	3.07E-01	2.28E-01	3.15E-01	3.08E-01	4.30am-01am	5.54E-02	5.48E-01
Land use	mPt	5.00E+01	5.01E+01	4.98E+01	5.01E+01	6.68E+01	6.69E+01	8.68E+01	9.28E+01	4.89E+01	1.87E+02
Ozone depletion	mPt	6.51E-02	6.53E-02	6.99E-02	7.25E-02	1.05E-01	1.11E-01	1.70E-01	2.20E-01	6.22E-02	4.08E-01
Photochemical ozone formation	mPt	1.72E+01	1.73E+01	1.36E+01	1.08E+01	2.13E+01	1.92E+01	3.14E+01	3.61E+01	1.65E+01	7.90E+01
Resource use, fossils	mPt	1.85E+00	1.91E+00	4.68E+00	6.68E+00	3.62E+00	5.10E+00	6.12E+00	7.50E+00	7.30am-01am	-2.84E+00
Resource use, minerals and metals	mPt	4.28E+00	4.29E+00	4.22E+00	3.90E+00	6.05E+00	5.92E+00	9.99E+00	1.28E+01	4.19E+00	2.63E+01
Water use	mPt	1.58E+02	1.58E+02	9.52E+01	5.49E+01	1.85E+02	1.55E+02	2.97E+02	3.50E+02	1.54E+02	8.23E+02
Total	**mPt**	**7.68E+02**	**7.70E+02**	**7.08E+02**	**5.94E+02**	**1.12E+03**	**1.05E+03**	**1.66E+03**	**1.86E+03**	**7.47E+02**	**3.65E+03**

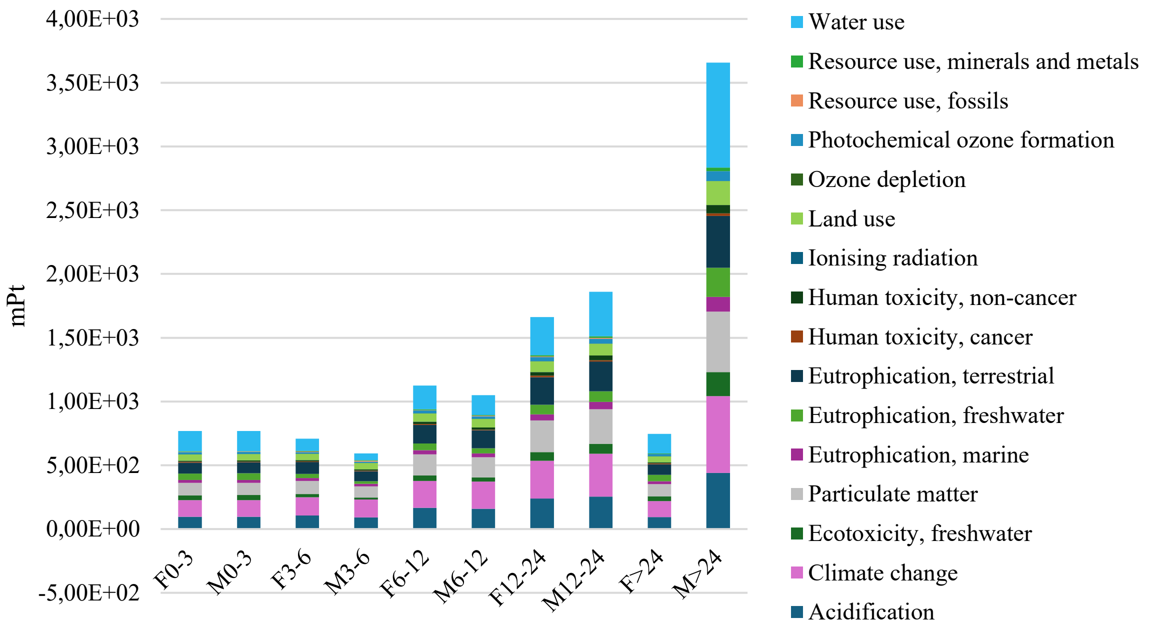

Figure 10: Impact assessment for each impact category relating to the breeding of a Limousine breed specimen differentiated by gender and age group and associated with the relative average weight, expressed in eco-points and distinct for each category

1.2.2 Dairy cattle breeding

In Italy, the dairy cattle population considered in this study (applying a cut-off > 20 kg of daily milk production) is predominantly composed of the *Frisona* breed, accounting for 78.6% of the total. The second most significant breed is the *Pezzata Rossa*, contributing approximately 7.5%, which is categorized as a dual-purpose breed.

The Methodological Report previously detailed the general parameters required to develop the LCI (Life Cycle Inventory) for the dairy farming phase, including dietary compositions, Italian husbandry systems, average weights, and allocation factors.

For these breeds, it is essential to consider that milk is the primary product, while beef production is a secondary output (co-product). Furthermore, within this supply chain, a clear distinction between specimens is required, as management systems and feed rations vary significantly based on the animal's role:

- ✓ *Females*: Utilized almost exclusively for milk production.
- ✓ *Males*: Of limited utility to the dairy supply chain except for breeding purposes; they are typically intended for slaughter at a young age for the production of either white veal or red meat.

1.2.2.1 Frisona breed: Productivity and Allocation

Frisona breed is characterized by high milk productivity, typically yielding 10,015 kg of FPCM (Fat and Protein Corrected Milk) *per* year, with a total lifetime production of 31,297 kg of FPCM over a productive life slightly exceeding three years. Beyond this peak, yields decline, and these specimens are sent to slaughter as culled cows, to be replaced by younger and more productive animals. The replacement rate is 32%, with an average weight of 600 kg at slaughter. The production system typically adopted for this breed is intensive.

In dairy breeds, male and female specimens follow distinct production pathways:

- ✓ *Females*: Primarily intended for milk production. However, only about 89% are retained for the milking herd; the remaining 11% of young females (12-24 months) are culled due to insufficient productivity.
- ✓ Males: Intended for fattening to produce white veal or red meat. Approximately 70% are slaughtered at 8 months of age for white veal production, following a diet based exclusively on concentrates (excluding forage). The remaining 30%, a minor share used for breeding, are intended for red meat production and are fed with forage, thereby reducing the relative concentrate share in their diet.

The following analysis considers the environmental contributions of females and males intended for white veal production, as the population of males for red meat is statistically negligible. For females, the inventory accounts for age-based classes as well as culled cows (sent to slaughter), replacement heifers, and discarded heifers. Furthermore, the environmental burden relative to the annual milk production (10,015 kg FPCM) is specified.

Table 22 provides the characterization factors for the various female *Frisona* classes based on average weight, while **Table 23** lists the factors for males intended for white veal. In dairy breeds, the GWP for females is aligned with beef breeds of the same age. The highest values are observed for replacement and culled F_{12-24}, at 12,002 kg CO_2-eq and 11,302 kg CO_2-eq, respectively (approx. 20 kg CO_2-eq /kg LW for both). For F_{6-12}, the value is 11,302 kg CO_2-eq (approx. 11.3 kg CO_2-eq /kg LW). Interestingly, for younger specimens, the GWP is significantly lower than in beef breeds, despite the allocated burden from the dam. For F_{3-6}, the GWP is 1,469 kg CO_2-eq (7.7 kg CO_2-eq /kg LW), and for F_{0-3}, it is 338.7 kg CO_2-eq (3.4 kg CO_2-eq/kg LW). These variations occur because milk is the primary product, thus attracting a substantial allocation factor, a parameter that is negligible for specialized beef breeds. For *Frisona* breed, the milk allocation factor (AF_{milk}) is approximately 0.86, while the meat allocation factor (AF_{meat}) is 0.14. Annual milk production generates a total GWP of 13,743 kg CO_2-eq, translating to approximately 3.4 kg CO_2-eq *per* kg of FPCM. Since dairy cow calves and produces milk annually, the milk output is associated with a specific share of the dam's environmental load, while another share is allocated to suckling calves (pre-weaning).

Table 24 details the eco-indicators for each impact category for female cattle, while **Table 25** lists the corresponding impacts in milli-points (mPt) for the three male cattle classes. Replacement F_{12-24} shows an eco-indicator of 1,840 mPt, while culled F_{12-24} is 1,733 mPt (approx. 3.1 mPt/kg LW for both). The lowest results are found for F_{0-3} (49.7 mPt), F_{3-6} (240.1 mPt), and culled $F_{>24}$ (338.6 mPt), with corresponding normalized values of 0.5 mPt, 1.2 mPt, and 0.49 mPt per kg LW.

For male cattle (white veal), the highest impact is for M_{12-24} (372 mPt; 1.2 mPt/kg LW), followed by M_{6-12} (271 mPt; 1.1 mPt/kg LW) and M_{0-3} (55 mPt; 0.46 mPt/kg LW). As shown in **Figure 11**, the most significant impact categories are Climate Change, Particulate Matter, Water Use (particularly for lactating cows), and, to a lesser extent, Terrestrial Eutrophication and Acidification.

Table 22: Characterization for each impact category relating to the breeding of a female *Frisona* breed specimen, differentiated by age group and associated with the relative average weight and average annual milk production

Category	**Unit**	**F_{0-3} (100 kg)**	**F_{3-6} (190 kg)**	**F_{6-12} (365 kg)**	**F_{12-24} culled (565 kg)**	**F_{12-24} lactation (600 kg)**	**$F_{>24}$ culled (690 kg)**	**Milk produced *per* year (10,015 kg)**
Acidification	mol H^+ eq	1.91E+00	2.85E+01	8.12E+01	1.90E+02	2.02E+02	2.76E+01	1.81E+02
Climate change	kg CO_2 eq	3.39E+02	1.47E+03	4.14E+03	1.13E+04	1.20E+04	2.09E+03	1.37E+04
Ecotoxicity, freshwater	CTUe	9.48E+03	3.43E+04	9.59E+04	2.72E+05	2.89E+05	5.03E+04	3.31E+05
Particulate matter	disease inc.	2.15E-05	2.29E-04	6.50E-04	1.55E-03	1.65E-03	2.20E-04	1.45E-03
Eutrophication, marine	kg N eq	1.01E+00	3.93E+00	1.16E+01	3.18E+01	3.38E+01	5.35E+00	3.52E+01
Eutrophication, freshwater	kg P eq	1.87E-01	6.15E-01	1.80E+00	4.88E+00	5.18E+00	2.17E+00	1.43E+01
Eutrophication, terrestrial	mol N eq	1.13E+01	1.39E+02	3.97E+02	9.31E+02	9.88E+02	1.32E+02	8.70E+02
Human toxicity, cancer	CTUh	2.28E-07	1.15E-06	3.34E-06	9.73E-06	1.03E-05	1.07E-06	7.05E-06
Human toxicity, non- cancer	CTUh	5.02E-06	1.94E-05	5.71E-05	1.62E-04	1.72E-04	2.61E-05	1.72E-04
Ionizing radiation	kBq U-235 eq	4.57E+00	7.48E+00	1.11E+01	4.10E+01	4.36E+01	5.09E+00	3.35E+01
Land use	Pt	1.41E+04	7.32E+04	2.48E+05	7.11E+05	7.55E+05	1.11E+05	7.32E+05
Ozone depletion	kg CFC11 eq	2.32E-05	3.24E-05	5.54E-05	1.49E-04	1.59E-04	1.80E-05	1.18E-04
Photochemical ozone formation	kg NMVOC eq	1.02E+00	3.68E+00	1.16E+01	3.51E+01	3.73E+01	5.83E+00	3.83E+01
Resource use, fossils	MJ	3.19E+03	3.83E+03	4.12E+03	1.89E+04	2.01E+04	7.15E+02	4.70E+03
Resource use, minerals and metals	kg Sb eq	5.80E-04	1.46E-03	3.34E-03	1.01E-02	1.07E-02	1.86E-03	1.22E-02
Water use	m^3 depriv .	2.18E+03	5.82E+03	1.61E+04	4.99E+04	5.30E-04	1.34E+04	8.83E+04

Table 23: Characterization for each impact category relating to the breeding of a male *Frisona* breed specimen intended for the production of white meat, differentiated by age group and associated with the relative average weight

Category	**Unit**	**M $_{0\text{-}3}$** (120 kg)	**M $_{3\text{-}6}$** (245 kg)	**M $_{6\text{-}12}$** (305 kg)
Acidification	mol H^+ eq	2.31E+00	2.54E+01	3.85E+01
Climate change	kg CO_2 eq	4.38E+02	1.61E+03	2.23E+03
Ecotoxicity, freshwater	CTUe	1.08E+04	4.20E+04	6.33E+04
Particulate matter	disease inc.	2.59E-05	2.22E-04	3.32E-04
Eutrophication, marine	kg N eq	1.18E+00	4.93E+00	7.04E+00
Eutrophication, freshwater	kg P eq	3.79E-01	1.43E+00	1.90E+00
Eutrophication, terrestrial	mol N eq	1.33E+01	1.28E+02	1.93E+02
Human toxicity, cancer	CTUh	2.94E-07	1.33E-06	1.85E-06
Human toxicity, non- cancer	CTUh	5.71E-06	2.30E-05	3.24E-05
Ionizing radiation	kBq U-235 eq	5.60E+00	1.30E+01	1.67E+01
Land use	Pt	1.70E+04	6.63E+04	9.65E+04
Ozone depletion	kg CFC11 eq	2.61E-05	7.27E-05	8.17E-05
Photochemical ozone formation	kg NMVOC eq	1.30E+00	4.87E+00	6.84E+00
Resource use, fossils	MJ	4.20E+03	9.82E+03	1.16E+04
Resource use, minerals and metals	kg Sb eq	5.77E-04	1.83E-03	2.50E-03
Water use	m^3 depriv .	1.52E+03	7.91E+03	9.37E+03

Table 24: Impact assessment for each impact category relating to the breeding of a female *Frisona* breed specimen, differentiated by age group and associated with the relative average weight and average annual milk production expressed as a single score (eco-indicator in mPt)

Category	Unit	F_{0-3} (100 kg)	F_{3-6} (190 kg)	F_{6-12} (365 kg)	F_{12-24} culled (565 kg)	F_{12-24} lactation (600 kg)	$F_{>24}$ culled (690 kg)	Milk produced per year (10,015 kg)
Acidification	mPt	2.13E+00	3.18E+01	9.06E+01	2.12E+02	2.25E+02	3.08E+01	2.02E+02
Climate change	mPt	9.44E+00	4.10E+01	1.15E+02	3.15E+02	3.35E+02	5.83E+01	3.83E+02
Ecotoxicity, freshwater	mPt	3.21E+00	1.16E+01	3.25E+01	9.20E+01	9.77E+01	1.70E+01	1.12E+02
Particulate matter	mPt	3.23E+00	3.44E+01	9.78E+01	2.33E+02	2.48E+02	3.32E+01	2.18E+02
Eutrophication, marine	mPt	1.53E+00	5.96E+00	1.76E+01	4.82E+01	5.12E+01	8.10E+00	5.33E+01
Eutrophication, freshwater	mPt	3.26E+00	1.07E+01	3.14E+01	8.51E+01	9.03E+01	3.78E+01	2.49E+02
Eutrophication, terrestrial	mPt	2.38E+00	2.91E+01	8.33E+01	1.95E+02	2.07E+02	2.78E+01	1.83E+02
Human toxicity, cancer	mPt	2.82E-01	1.42E+00	4.13E+00	1.20E+01	1.28E+01	1.33E+00	8.71E+00
Human toxicity, non- cancer	mPt	7.17E-01	2.77E+00	8.15E+00	2.31E+01	2.45E+01	3.73E+00	2.45E+01
Ionizing radiation	mPt	5.43E-02	8.88E-02	1.31E-01	4.87E-01	5.17E-01	6.05E-02	3.97E-01
Land use	mPt	1.37E+00	7.10E+00	2.41E+01	6.89E+01	7.32E+01	1.08E+01	7.09E+01
Ozone depletion	mPt	2.79E-02	3.91E-02	6.68E-02	1.80E-01	1.91E-01	2.17E-02	1.43E-01
Photochemical ozone formation	mPt	1.20E+00	4.30E+00	1.35E+01	4.11E+01	4.36E+01	6.82E+00	4.48E+01
Resource use, fossils	mPt	4.09E+00	4.90E+00	5.28E+00	2.42E+01	2.57E+01	9.15E-01	6.02E+00
Resource use, minerals and metals	mPt	6.88E-01	1.73E+00	3.96E+00	1.20E+01	1.27E+01	2.21E+00	1.45E+01
Water use	mPt	1.61E+01	4.32E+01	1.19E+02	3.70E+02	3.93E+02	9.98E+01	6.56E+02
Total	**mPt**	**4.97E+01**	**2.30E+02**	**6.47E+02**	**1.73E+03**	**1.84E+03**	**3.39E+02**	**2.23E+03**

Table 25: Impact assessment for each impact category relating to the breeding of a male *Frisona* breed specimen intended for the production of white meat, differentiated by age group and associated with the relative average weight (eco-indicator in mPt)

Category	**Unit**	**M $_{0-3}$ (120 kg)**	**M $_{3-6}$ (245 kg)**	**M $_{6-12}$ (305 kg)**
Acidification	mPt	2.57E+00	2.84E+01	4.29E+01
Climate change	mPt	1.22E+01	4.50E+01	6.23E+01
Ecotoxicity, freshwater	mPt	3.66E+00	1.42E+01	2.14E+01
Particulate matter	mPt	3.90E+00	3.35E+01	4.99E+01
Eutrophication, marine	mPt	1.79E+00	7.46E+00	1.07E+01
Eutrophication, freshwater	mPt	6.61E+00	2.49E+01	3.32E+01
Eutrophication, terrestrial	mPt	2.80E+00	2.70E+01	4.05E+01
Human toxicity, cancer	mPt	3.63E-01	1.64E+00	2.29E+00
Human toxicity, non- cancer	mPt	8.16E-01	3.29E+00	4.64E+00
Ionizing radiation	mPt	6.65E-02	1.55E-01	1.98E-01
Land use	mPt	1.65E+00	6.42E+00	9.35E+00
Ozone depletion	mPt	3.15E-02	8.76E-02	9.85E-02
Photochemical ozone formation	mPt	1.52E+00	5.70E+00	8.00E+00
Resource use, fossils	mPt	5.38E+00	1.26E+01	1.49E+01
Resource use, minerals and metals	mPt	6.85E-01	2.17E+00	2.96E+00
Water use	mPt	1.13E+01	5.87E+01	6.95E+01
Total	**mPt**	**5.54E+01**	**2.71E+02**	**3.73E+02**

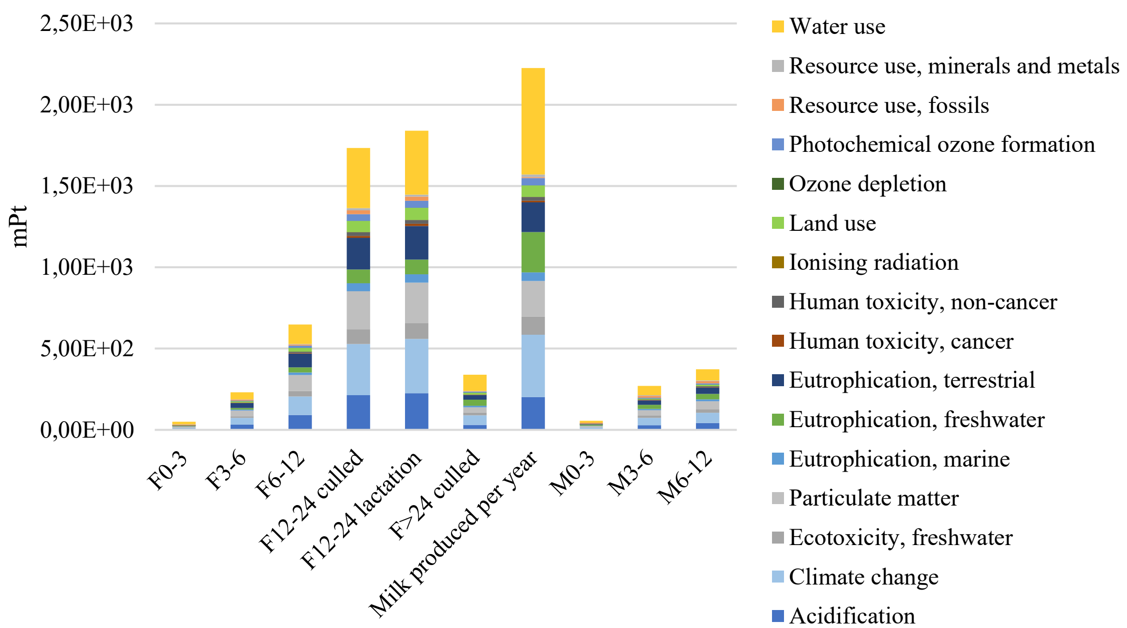

Figure 11: Impact assessment for each impact category relating to the breeding of a *Frisona* breed specimen differentiated by sex and age group and associated with the relative average weight and annual milk production, expressed in eco-points and distinct for each category

1.2.2.2 Pezzata Rossa Breed: Dual-Purpose system results

Pezzata Rossa is a dual-purpose breed with an annual milk productivity of approximately 7,187 kg of FPCM, which is lower than that *Frisona*. The replacement rate is 27%, while the percentage of discarded heifers is approximately 15%, higher than typical dairy breeds, owing to the higher market value and quality of its meat. Female specimens are slaughtered at 21 months with an average weight of 600 kg, while males are slaughtered at 19 months at approximately 700 kg. This breed is typically raised in semi-extensive farming systems.

Table 26 presents the characterization factors for female specimens across each impact category. Similar to *Frisona*, GWP is highest for replacement F_{12-24} (11,004 kg CO_2-eq) and discarded F_{12-24} (10,316 kg CO_2-eq), both corresponding to approximately 17.2 kg CO_2-eq /kg LW. Annual milk production generates a GWP of 10,505 kg CO_2-eq, which, when normalized to the FU, equals 1.46 kg CO_2-eq /kg FPCM.

Table 27 details the characterization results for male specimens. As a dual-purpose breed, males are managed similarly to specialized beef breeds to produce high-quality red meat. The GWP decreases in younger age groups. These animals are raised for fattening, with a diet consisting of a significant share of concentrates (approx. 50%), supplemented by forage and maize silage, components less prevalent in white veal production.

Table 28 reports the eco-indicator contributions for females. The most impactful processes are the farming of replacement $F_{12\text{-}24}$ (1,787 mPt) and culled $F_{12\text{-}24}$ (1,676 mPt), both resulting in approximately 2.8 mPt/kg LW. Notably, these impacts are lower than those of equivalent *Frisona* specimens, despite the higher average mass of *Pezzata Rossa*. The same trend applies to the functional unit. Annual milk production results in an impact of 1,581 mPt. While the absolute impact and total yield are lower than the *Frisona*, the environmental performance per FU (1 kg of FPCM) is identical at 0.2 mPt.

Regarding male specimens, the impact assessment in

Table 29 shows the highest result for $M_{>24}$, with a value of 3,113 mPt (3.1 mPt/kg LW). Compared to *Frisona* males raised for white veal, the meat-oriented *Pezzata Rossa* males are significantly more impactful at older ages (12-24 months or more). The primary variable is the upstream agricultural phase and the associated processing of distinct diets: white veal relies heavily on concentrates, whereas red meat incorporates a substantial quota of forage and silage. Conversely, for the youngest specimens (0-3 months), the impacts are comparatively lower.

As illustrated in **Figure 12**, and in contrast to *Frisona*, *Pezzata Rossa* is bred for high-quality meat, allowing males to reach more advanced ages. For both sexes, the most relevant impact categories remain Climate Change and Water Use, followed to a lesser extent by Particulate Matter and Acidification.

Table 26: Characterization for each impact category relating to the breeding of female *Pezzata Rossa* breed specimen, differentiated by age group and associated with the relative average weight and average annual milk production

Category	**Unit**	**F 0-3 (90 kg)**	**F 3-6 (220 kg)**	**F 6-12 (350 kg)**	**F 12-24 culled (600 kg)**	**F 12-24 lactation (640 kg)**	**F >24 culled (700 kg)**	**Milk produced per year (7,187 kg)**
Acidification	mol H^+ eq	2.55E+00	3.96E+01	1.00E+02	2.27E+02	2.42E+02	2.86E+01	1.59E+02
Climate change	kg CO_2 eq	3.65E+02	1.69E+03	4.26E+03	1.03E+04	1.10E+04	1.89E+03	1.05E+04
Ecotoxicity, freshwater	CTUe	9.14E+03	3.78E+04	9.10E+04	2.07E+05	2.21E+05	3.33E+04	1.85E+05
Particulate matter	disease inc.	2.53E-05	3.09E-04	7.75E-04	1.75E-03	1.86E-03	2.15E-04	1.19E-03
Eutrophication, marine	kg N eq	1.03E+00	4.59E+00	1.20E+01	3.01E+01	3.21E+01	4.75E+00	2.64E+01
Eutrophication, freshwater	kg P eq	1.81E-01	6.72E-01	1.67E+00	3.78E+00	4.03E+00	1.33E+00	7.41E+00
Eutrophication, terrestrial	mol N eq	1.40E+01	1.90E+02	4.78E+02	1.08E+03	1.15E+03	1.33E+02	7.37E+02
Human toxicity, cancer	CTUh	3.35E-07	1.42E-06	4.03E-06	1.33E-05	1.42E-05	2.69E-06	1.49E-05
Human toxicity, non- cancer	CTUh	4.92E-06	2.14E-05	5.40E-05	1.31E-04	1.40E-04	1.83E-05	1.01E-04
Ionizing radiation	kBq U-235 eq	4.60E+00	7.71E+00	1.12E+01	1.93E+01	2.06E+01	4.75E+00	2.63E+01
Land use	Pt	2.19E+04	9.19E+04	2.98E+05	1.03E+06	1.09E+06	2.23E+05	1.24E+06
Ozone depletion	kg CFC11 eq	2.21E-05	3.25E-05	5.31E-05	1.04E-04	1.11E-04	1.45E-05	8.02E-05
Photochemical ozone formation	kg NMVOC eq	1.05E+00	4.07E+00	1.11E+01	2.87E+01	3.06E+01	4.52E+00	2.51E+01
Resource use, fossils	MJ	3.21E+03	3.80E+03	4.64E+03	6.13E+03	6.54E+03	2.13E+03	1.18E+04
Resource use, minerals and metals	kg Sb eq	5.50E-04	1.56E-03	3.15E-03	7.47E-03	7.96E-03	1.17E-03	6.51E-03
Water use	m^3 depriv .	2.03E+03	6.21E+03	1.48E+04	3.75E+04	4.00E+04	8.26E+03	4.58E+04

Table 27: Characterization for each impact category relating to the breeding of *Pezzata Rossa* male breed specimen intended for the production of white meat, differentiated by age group and associated with the relative average weight

Category	Unit	$M_{0\text{-}3}$ (110 kg)	$M_{3\text{-}6}$ (250 kg)	$M_{6\text{-}12}$ (450 kg)	$M_{12\text{-}24}$ (700 kg)	$M_{>24}$ (1000 kg)
Acidification	mol H^+ eq	2.96E+00	3.77E+01	1.04E+02	1.79E+02	3.80E+02
Climate change	kg CO_2 eq	4.53E+02	1.70E+03	4.33E+03	7.75E+03	1.71E+04
Ecotoxicity, freshwater	Technical consultancy	1.01E+04	4.39E+04	1.07E+05	2.02E+05	4.11E+05
Particulate matter	disease inc.	2.93E-05	2.99E-04	8.06E-04	1.39E-03	2.91E-03
Eutrophication, marine	kg N eq	1.21E+00	5.18E+00	1.36E+01	2.59E+01	5.71E+01
Eutrophication, freshwater	kg P eq	3.49E-01	1.11E+00	2.15E+00	3.84E+00	8.66E+00
Eutrophication, terrestrial	mol N eq	1.60E+01	1.82E+02	4.99E+02	8.60E+02	1.82E+03
Human toxicity, cancer	CTUh	4.02E-07	1.38E-06	4.23E-06	9.45E-06	2.58E-05
Human toxicity, non- cancer	CTUh	5.53E-06	2.21E-05	5.52E-05	1.02E-04	2.15E-04
Ionizing radiation	kBq U-235 eq	5.40E+00	8.21E+00	1.15E+01	1.71E+01	2.36E+01
Land use	Pt	2.64E+04	1.02E+05	3.13E+05	7.15E+05	1.93E+06
Ozone depletion	kg CFC11 eq	2.46E-05	4.45E-05	6.50E-05	9.76E-05	1.74E-04
Photochemical ozone formation	kg NMVOC eq	1.31E+00	4.45E+00	1.20E+01	2.39E+01	5.14E+01
Resource use, fossils	MJ	4.05E+03	4.93E+03	5.21E+03	7.57E+03	7.87E+03
Resource use, minerals and metals	kg Sb eq	5.37E-04	1.50E-03	3.17E-03	5.51E-03	1.16E-02
Water use	m^3 depriv .	1.46E+03	7.25E+03	2.14E+04	4.17E+04	9.23E+04

Table 28: Impact assessment for each impact category relating to the breeding of female specimen of the *Pezzata Rossa* breed, differentiated by age group and associated with the relative average weight and average annual milk production expressed as a single score (eco-indicator in mPt)

Category	Unit	F_{0-3} (90 kg)	F_{3-6} (220 kg)	F_{6-12} (350 kg)	F_{12-24} culled (600 kg)	F_{12-24} lactation (640 kg)	$F_{>24}$ culled (700 kg)	Milk produced per year (7,187 kg)
Acidification	mPt	2.84E+00	4.42E+01	1.12E+02	2.53E+02	2.70E+02	3.19E+01	1.77E+02
Climate change	mPt	1.02E+01	4.72E+01	1.19E+02	2.88E+02	3.07E+02	5.28E+01	2.93E+02
Ecotoxicity, freshwater	mPt	3.09E+00	1.28E+01	3.08E+01	7.02E+01	7.49E+01	1.13E+01	6.26E+01
Particulate matter	mPt	3.80E+00	4.65E+01	1.17E+02	2.63E+02	2.80E+02	3.23E+01	1.79E+02
Eutrophication, marine	mPt	1.56E+00	6.95E+00	1.81E+01	4.56E+01	4.86E+01	7.20E+00	3.99E+01
Eutrophication, freshwater	mPt	3.16E+00	1.17E+01	2.91E+01	6.59E+01	7.03E+01	2.33E+01	1.29E+02
Eutrophication, terrestrial	mPt	2.93E+00	3.98E+01	1.00E+02	2.27E+02	2.42E+02	2.79E+01	1.55E+02
Human toxicity, cancer	mPt	4.13E-01	1.76E+00	4.98E+00	1.64E+01	1.75E+01	3.33E+00	1.84E+01
Human toxicity, non- cancer	mPt	7.03E-01	3.05E+00	7.72E+00	1.87E+01	2.00E+01	2.61E+00	1.45E+01
Ionizing radiation	mPt	5.46E-02	9.16E-02	1.33E-01	2.29E-01	2.44E-01	5.64E-02	3.13E-01
Land use	mPt	2.13E+00	8.91E+00	2.89E+01	9.94E+01	1.06E+02	2.16E+01	1.20E+02
Ozone depletion	mPt	2.66E-02	3.92E-02	6.40E-02	1.26E-01	1.34E-01	1.74E-02	9.66E-02
Photochemical ozone formation	mPt	1.23E+00	4.77E+00	1.30E+01	3.35E+01	3.58E+01	5.29E+00	2.94E+01
Resource use, fossils	mPt	4.11E+00	4.87E+00	5.94E+00	7.85E+00	8.38E+00	2.73E+00	1.51E+01
Resource use, minerals and metals	mPt	6.52E-01	1.85E+00	3.73E+00	8.86E+00	9.45E+00	1.39E+00	7.72E+00
Water use	mPt	1.51E+01	4.60E+01	1.10E+02	2.78E+02	2.97E+02	6.13E+01	3.40E+02
Total	**mPt**	**5.20E+01**	**2.81E+02**	**7.00E+02**	**1.68E+03**	**1.79E+03**	**2.85E+02**	**1.58E+03**

Table 29: Impact assessment for each impact category relating to the breeding of a male *Pezzata Rossa* breed specimen intended for the production of white meat, differentiated by age group and associated with the relative average weight (eco-indicator in mPt)

Category	**Unit**	**M 0-3 (110 kg)**	**M 3-6 (250 kg)**	**M 6-12 (450 kg)**	**M 12-24 (700 kg)**	**M >24 (1,000 kg)**
Acidification	mPt	3.31E+00	4.20E+01	1.16E+02	1.99E+02	4.23E+02
Climate change	mPt	1.26E+01	4.74E+01	1.21E+02	2.16E+02	4.76E+02
Ecotoxicity, freshwater	mPt	3.43E+00	1.49E+01	3.63E+01	6.85E+01	1.39E+02
Particulate matter	mPt	4.42E+00	4.50E+01	1.21E+02	2.09E+02	4.38E+02
Eutrophication, marine	mPt	1.84E+00	7.84E+00	2.05E+01	3.93E+01	8.65E+01
Eutrophication, freshwater	mPt	6.08E+00	1.93E+01	3.75E+01	6.69E+01	1.51E+02
Eutrophication, terrestrial	mPt	3.36E+00	3.82E+01	1.05E+02	1.80E+02	3.81E+02
Human toxicity, cancer	mPt	4.96E-01	1.70E+00	5.22E+00	1.17E+01	3.18E+01
Human toxicity, non- cancer	mPt	7.90E-01	3.15E+00	7.89E+00	1.46E+01	3.08E+01
Ionizing radiation	mPt	6.41E-02	9.75E-02	1.37E-01	2.03E-01	2.80E-01
Land use	mPt	2.56E+00	9.84E+00	3.03E+01	6.92E+01	1.87E+02
Ozone depletion	mPt	2.97E-02	5.37E-02	7.83E-02	1.18E-01	2.10E-01
Photochemical ozone formation	mPt	1.53E+00	5.20E+00	1.40E+01	2.80E+01	6.01E+01
Resource use, fossils	mPt	5.18E+00	6.31E+00	6.67E+00	9.69E+00	1.01E+01
Resource use, minerals and metals	mPt	6.38E-01	1.78E+00	3.76E+00	6.54E+00	1.38E+01
Water use	mPt	1.09E+01	5.38E+01	1.59E+02	3.10E+02	6.85E+02
Total	**mPt**	**5.72E+01**	**2.97E+02**	**7.84E+02**	**1.43E+03**	**3.11E+03**

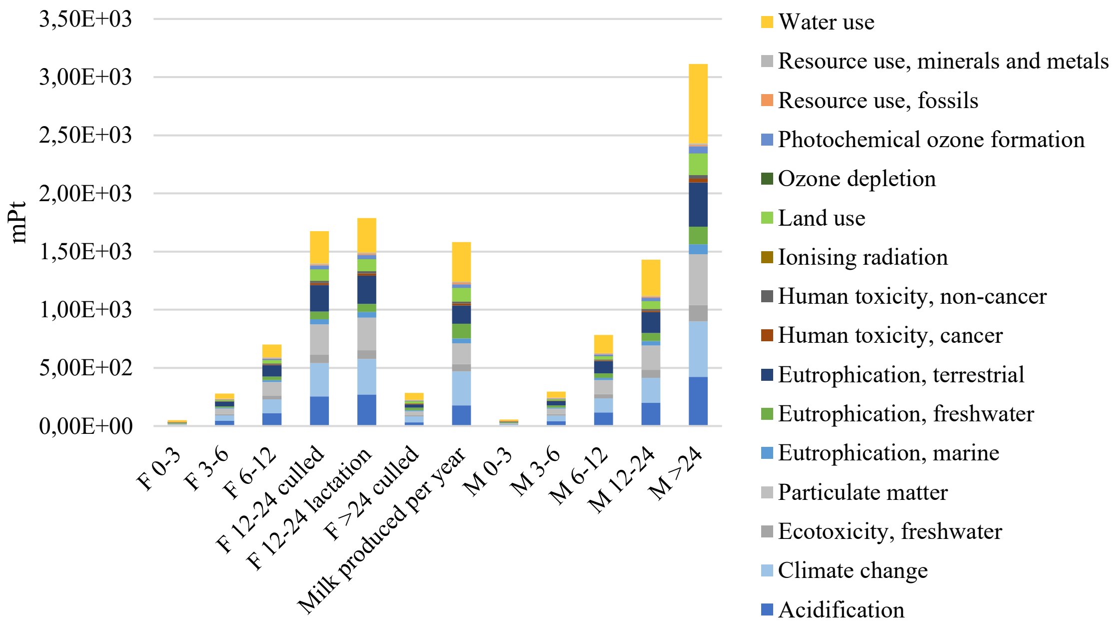

Figure 12: Impact assessment for each impact category relating to the breeding of *Pezzata Rossa* breed specimen differentiated by gender and age group and associated with the relative average weight and annual milk production, expressed in eco-points and distinct for each category

1.3 LCIA: Cattle Slaughtering in Italy

Slaughtering represents the final stage of the production cycle analyzed in this study. While the carcass is the primary output, cattle processing generates several other co-products and waste streams that are significant in terms of both mass and economic value. Therefore, it is essential to partition the environmental impact among the various outputs by applying appropriate allocation factors.

1.3.1 Slaughtering Phase: Beef Breeds

Consistent with the beef breeds selected for the farming phase, the following section reports the LCIA results for the *Piemontese* and *Limousine* breeds, expressed per kilogram of carcass. The primary categories sent to slaughter for these breeds include heifers ($F_{12\text{-}24}$), young bulls (vitellone, $M_{12\text{-}24}$), culled cows ($F_{>24}$), and bulls ($M_{>24}$).

Table 30 details the characterization factors for the impact assessment. The highest GWP is observed for bulls, reaching 37.4 kg CO_2-eq for the *Piemontese* and 34.4 kg CO_2-eq for the *Limousine*. Conversely, the lowest impact values are associated with cull cows (13.2 kg CO_2-eq and 12.2 kg CO_2-eq, respectively).

Table 30: Characterization for each impact category of the most represented meat breeds (per 1 kg of carcass)

Category	Unit	*Piemontese* Heifer	*Piemontese* young bulls	*Piemontese* Cow	*Piemontese* Bull	*Limousine* Heifer	*Limousine* young bulls	*Limousine* Cow	*Limousine* Bull
Acidification	mol H^+ eq	7.16E-01	5.63E-01	2.46E-01	7.44E-01	6.20E-01	4.81E-01	2.26E-01	6.29E-01
Climate change	kg CO_2 eq	3.39E+01	2.72E+01	1.32E+01	3.74E+01	3.08E+01	2.56E+01	1.22E+01	3.44E+01
Ecotoxicity, freshwater	CTUe	5.64E+02	5.14E+02	2.23E+02	9.19E+02	5.85E+02	4.83E+02	3.02E+02	8.91E+02
Particulate matter	disease inc.	5.38E-06	4.33E-06	1.79E-06	5.76E-06	4.78E-06	3.81E-06	1.69E-06	4.99E-06
Eutrophication, marine	kg N eq	8.89E-02	7.69E-02	3.34E-02	1.20E-01	9.34E-02	8.03E-02	3.86E-02	1.21E-01
Eutrophication, freshwater	kg P eq	1.19E-02	1.08E-02	5.41E-03	2.17E-02	1.25E-02	9.86E-03	7.66E-03	2.10E-02
Eutrophication, terrestrial	mol N eq	3.37E+00	2.70E+00	1.13E+00	3.57E+00	2.98E+00	2.36E+00	1.06E+00	3.08E+00
Human toxicity, cancer	CTUh	3.53E-08	2.66E-08	1.61E-08	3.51E-08	2.43E-08	1.74E-08	1.38E-08	2.61E-08
Human toxicity, non- cancer	CTUh	4.40E-07	4.23E-07	1.20E-07	6.06E-07	5.65E-07	5.55E-07	1.52E-07	7.17E-07
Ionizing radiation	kBq U-235 eq	4.44E-02	3.43E-02	1.43E-02	3.71E-02	7.65E-02	7.76E-02	1.41E-02	7.50E-02
Land use	Pt	3.03E+03	2.32E+03	1.42E+03	3.37E+03	2.59E+03	2.02E+03	1.35E+03	3.06E+03
Ozone depletion	kg CFC11 eq	3.29E-07	3.04E-07	1.09E-07	4.68E-07	4.09E-07	3.88E-07	1.40E-07	5.40E-07
Photochemical ozone formation	kg NMVOC eq	7.55E-02	6.61E-02	3.08E-02	1.09E-01	7.80E-02	6.53E-02	3.79E-02	1.08E-01
Resource use, fossils	MJ	1.85E+01	1.05E+01	7.26E+00	-3.28E+00	1.49E+01	1.34E+01	2.78E+00	-2.31E+00
Resource use, minerals and metals	kg Sb eq	1.97E-05	1.87E-05	6.75E-06	3.16E-05	2.44E-05	2.28E-05	9.46E-06	3.53E-05
Water use	m^3 depriv.	1.05E+02	9.92E+01	3.91E+01	1.76E+02	1.16E+02	9.93E+01	5.54E+01	1.76E+02

Table 31 specifies the environmental impact values expressed via the final eco-indicator, while **Figure 13** provides the corresponding graphical representation.

The data highlight that the slaughter of *Piemontese* bulls is the most impactful process at 6.28 mPt, compared to 5.81 mPt for *Limousine* bulls. This discrepancy is attributed to the fact that the *Piemontese* farming phase, up to the finishing stage, carries a higher environmental burden, which is not fully offset by its superior carcass yield relative to the *Limousine* (63% vs. 59%).

For both breeds, the heifer (*scottona*) exhibits a higher environmental contribution per kilogram than the young bull (*vitellone*). This is due to a more unfavorable dressing percentage, 65% and 61% for *Piemontese* and *Limousine* heifers, respectively, compared to their male counterparts (60% and 56%).

The LCI for the slaughtering stage remains largely consistent across beef breeds. The primary drivers of variation in the final results are the cumulative impacts from upstream supply chain stages and the specific process yields. Consequently, the percentage contribution of each impact category remains relatively stable across all analyzed slaughter processes, with minor shifts due to different allocation factors.

The most significant impact categories are:

- ✓ Water Use: Ranging from 15.23% to 22.48%.
- ✓ Climate Change: Ranging from 16.51% to 19.45%.
- ✓ Acidification: Ranging from 12.06% to 15.63%.
- ✓ Terrestrial Eutrophication: Ranging from 11.10% to 13.85%.

Table 31: Impact assessment for each impact category of the most represented meat breeds (per 1 kg of carcass), expressed in mPt

Category	Unit	*Piemontese* Heifer	*Piemontese* Young bull	*Piemontese* Cow	*Piemontese* Bull	*Limousine* Heifer	*Limousine* Young bull	*Limousine* Cow	*Limousine* Bull
Acidification	mPt	7.98E-01	6.28E-01	2.75E-01	8.30E-01	6.92E-01	5.37E-01	2.52E-01	7.01E-01
Climate change	mPt	9.45E-01	7.57E-01	3.67E-01	1.04E+00	8.59E-01	7.13E-01	3.41E-01	9.60E-01
Ecotoxicity, freshwater	mPt	1.91E-01	1.74E-01	7.53E-02	3.11E-01	1.98E-01	1.64E-01	1.02E-01	3.02E-01
Particulate matter	mPt	8.09E-01	6.52E-01	2.69E-01	8.66E-01	7.20E-01	5.73E-01	2.54E-01	7.51E-01
Eutrophication, marine	mPt	1.35E-01	1.16E-01	5.05E-02	1.81E-01	1.41E-01	1.22E-01	5.85E-02	1.84E-01
Eutrophication, freshwater	mPt	2.08E-01	1.89E-01	9.43E-02	3.78E-01	2.17E-01	1.72E-01	1.34E-01	3.65E-01
Eutrophication, terrestrial	mPt	7.07E-01	5.66E-01	2.38E-01	7.50E-01	6.25E-01	4.94E-01	2.22E-01	6.46E-01
Human toxicity, cancer	mPt	4.35E-02	3.29E-02	1.99E-02	4.33E-02	3.00E-02	2.15E-02	1.71E-02	3.22E-02
Human toxicity, non- cancer	mPt	6.29E-02	6.05E-02	1.71E-02	8.66E-02	8.07E-02	7.94E-02	2.17E-02	1.03E-01
Ionizing radiation	mPt	5.27E-04	4.07E-04	1.70E-04	4.40E-04	9.09E-04	9.21E-04	1.67E-04	8.90E-04
Land use	mPt	2.93E-01	2.25E-01	1.38E-01	3.27E-01	2.51E-01	1.96E-01	1.30E-01	2.97E-01
Ozone depletion	mPt	3.96E-04	3.67E-04	1.31E-04	5.64E-04	4.93E-04	4.67E-04	1.69E-04	6.51E-04
Photochemical ozone formation	mPt	8.83E-02	7.74E-02	3.60E-02	1.28E-01	9.12E-02	7.64E-02	4.43E-02	1.26E-01
Resource use, fossils	mPt	2.37E-02	1.34E-02	9.29E-03	-4.19E-03	1.91E-02	1.71E-02	3.55E-03	-2.95E-03
Resource use, minerals and metals	mPt	2.34E-02	2.22E-02	8.01E-03	3.75E-02	2.89E-02	2.70E-02	1.12E-02	4.19E-02
Water use	mPt	7.78E-01	7.36E-01	2.90E-01	1.31E+00	8.58E-01	7.37E-01	4.11E-01	1.31E+00
Total	**mPt**	**5.11E+00**	**4.25E+00**	**1.89E+00**	**6.28E+00**	**4.81E+00**	**3.93E+00**	**2.00E+00**	**5.81E+00**

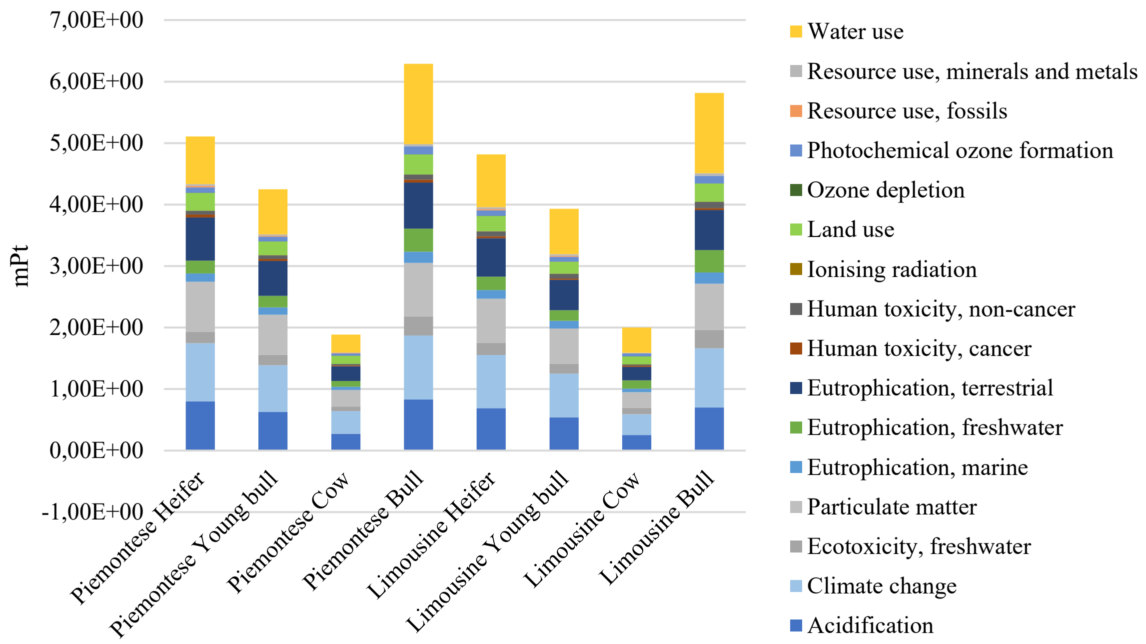

Figure 13: Impact assessment by category for the most representative beef breeds (per 1 kg of carcass) expressed in eco-points and categorized by impact type

1.3.2 Slaughtering Phase: Dairy and Dual-Purpose Breeds

For these breeds, slaughter is not the primary production objective. In specialized dairy breeds, the animals sent to slaughter include heifers culled due to low milk productivity, cull cows at the end of their productive life, and male calves raised for white veal. Conversely, in dual-purpose breeds, male calves are raised until they reach maturity as bulls to produce red meat. All results are expressed per kilogram of carcass.

Table 32 details the characterization factors for all specimens intended for slaughter, including both *Frisona* and *Pezzata Rossa* breeds. The GWP is highest for culled *Frisona* cows (35.0 kg CO_2-eq), followed by *Pezzata Rossa* bulls (29.8 kg CO_2-eq) and culled *Pezzata Rossa* cows (28.5 kg CO_2-eq).

Table 33 lists the environmental impact results expressed via the eco-indicator, with the same data represented graphically in **Figure 14**. As anticipated, *Pezzata Rossa* bull has the highest impact at 5.43 mPt, followed by the culled *Frisona* cow (5.36 mPt) and the culled *Pezzata Rossa* cow (4.61 mPt). The dressing percentage (carcass yield) is slightly higher for *Pezzata Rossa*, while it is lower than *Frisona*.

Table 32: Characterization for each impact category of the most represented dairy and dual purpose breeds (per 1 kg of carcass)

Category	**Unit**	**Culled *Frisona* cow**	**Adult *Frisona* cow**	**White meat veal *Frisona* cattle**	**Culled *Pezzata Rossa* Cow**	**Adult *Pezzata Rossa* Cow**	***Pezzata Rossa* Young bull**	***Pezzata Rossa* Bulls**
Acidification	mol H^+ eq	5.88E-01	7.27E-02	1.96E-01	6.25E-01	7.03E-02	4.08E-01	6.61E-01
Climate change	kg CO_2 eq	3.50E+01	5.58E+00	1.14E+01	2.85E+01	4.74E+00	1.78E+01	2.98E+01
Ecotoxicity, freshwater	CTUe	8.40E+02	1.34E+02	3.23E+02	5.72E+02	8.32E+01	4.63E+02	7.18E+02
Particulate matter	disease inc.	4.79E-06	5.82E-07	1.69E-06	4.80E-06	5.29E-07	3.17E-06	5.07E-06
Eutrophication, marine	kg N eq	9.83E-02	1.41E-02	3.59E-02	8.29E-02	1.17E-02	5.93E-02	9.95E-02
Eutrophication, freshwater	kg P eq	1.51E-02	5.69E-03	9.68E-03	1.04E-02	3.27E-03	8.76E-03	1.51E-02
Eutrophication, terrestrial	mol N eq	2.87E+00	3.49E-01	9.83E-01	2.98E+00	3.26E-01	1.96E+00	3.16E+00
Human toxicity, cancer	CTUh	3.02E-08	2.97E-09	9.57E-09	3.67E-08	6.73E-09	2.17E-08	4.50E-08
Human toxicity, non- cancer	CTUh	4.99E-07	6.91E-08	1.66E-07	3.61E-07	4.54E-08	2.34E-07	3.75E-07
Ionizing radiation	kBq U-235 eq	1.27E-01	1.43E-02	8.57E-02	5.38E-02	1.26E-02	3.99E-02	4.20E-02
Land use	Pt	2.20E+03	2.93E+02	4.91E+02	2.82E+03	5.47E+02	1.63E+03	3.36E+03
Ozone depletion	kg CFC11 eq	4.63E-07	4.90E-08	4.17E-07	2.89E-07	3.71E-08	2.24E-07	3.05E-07
Photochemical ozone formation	kg NMVOC eq	1.09E-01	1.55E-02	3.50E-02	7.91E-02	1.13E-02	5.48E-02	8.96E-02
Resource use, fossils	MJ	5.92E+01	2.70E+00	5.99E+01	1.76E+01	6.05E+00	1.80E+01	1.45E+01
Resource use, minerals and metals	kg Sb eq	3.12E-05	4.92E-06	1.27E-05	2.06E-05	2.91E-06	1.26E-05	2.02E-05
Water use	m^3 depriv.	1.54E+02	3.52E+01	4.76E+01	1.03E+02	2.02E+01	9.53E+01	1.61E+02

Table 33: Impact assessment for each impact category of the most represented dairy and dual-purpose breeds (per 1 kg of carcass), expressed in mPt

Category	Unit	Culled *Frisona* cow	Adult *Frisona* cow	White meat veal *Frisona* cattle	Culled *Pezzata Rossa* Cow	Adult *Pezzata Rossa* Cow	*Pezzata Rossa* Young bull	Pezzata Rossa Bulls
Acidification	mPt	6.56E-01	8.11E-02	2.19E-01	6.97E-01	7.85E-02	4.55E-01	7.37E-01
Climate change	mPt	9.76E-01	1.56E-01	3.19E-01	7.94E-01	1.32E-01	4.96E-01	8.31E-01
Ecotoxicity, freshwater	mPt	2.85E-01	4.53E-02	1.09E-01	1.94E-01	2.82E-02	1.57E-01	2.43E-01
Particulate matter	mPt	7.21E-01	8.76E-02	2.54E-01	7.23E-01	7.97E-02	4.77E-01	7.63E-01
Eutrophication, marine	mPt	1.49E-01	2.14E-02	5.43E-02	1.26E-01	1.77E-02	8.98E-02	1.51E-01
Eutrophication, freshwater	mPt	2.63E-01	9.91E-02	1.69E-01	1.81E-01	5.70E-02	1.53E-01	2.63E-01
Eutrophication, terrestrial	mPt	6.03E-01	7.32E-02	2.06E-01	6.25E-01	6.85E-02	4.12E-01	6.64E-01
Human toxicity, cancer	mPt	3.73E-02	3.66E-03	1.18E-02	4.52E-02	8.31E-03	2.68E-02	5.56E-02
Human toxicity, non-cancer	mPt	7.14E-02	9.88E-03	2.37E-02	5.15E-02	6.48E-03	3.34E-02	5.36E-02
Ionizing radiation	mPt	1.51E-03	1.70E-04	1.02E-03	6.39E-04	1.49E-04	4.74E-04	4.99E-04
Land use	mPt	2.13E-01	2.84E-02	4.76E-02	2.73E-01	5.30am-02am	1.58E-01	3.26E-01
Ozone depletion	mPt	5.58E-04	5.90E-05	5.02E-04	3.48E-04	4.48E-05	2.70E-04	3.67E-04
Photochemical ozone formation	mPt	1.27E-01	1.82E-02	4.10E-02	9.25E-02	1.32E-02	6.41E-02	1.05E-01
Resource use, fossils	mPt	7.58E-02	3.45E-03	7.67E-02	2.25E-02	7.74E-03	2.30E-02	1.86E-02
Resource use, minerals and metals	mPt	3.70E-02	5.84E-03	1.51E-02	2.44E-02	3.45E-03	1.50E-02	2.40E-02
Water use	mPt	1.14E+00	2.61E-01	3.53E-01	7.65E-01	1.50E-01	7.07E-01	1.19E+00
Total	**mPt**	**5.36E+00**	**8.94E-01**	**1.90E+00**	**4.61E+00**	**7.04E-01**	**3.27E+00**	**5.43E+00**

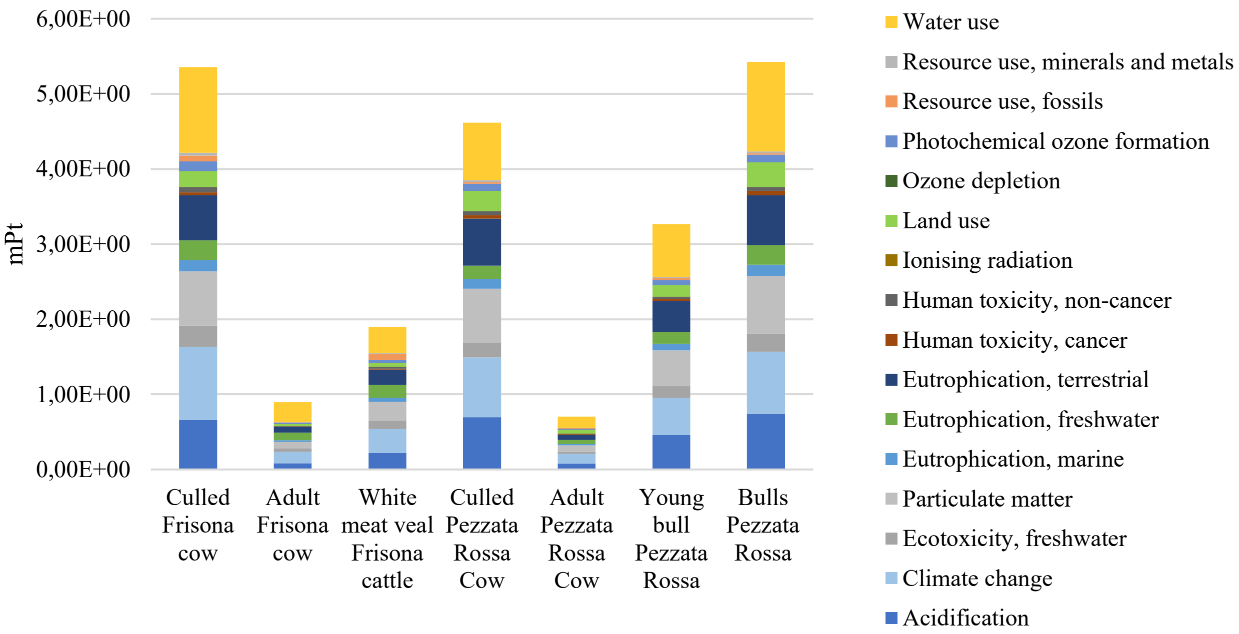

Figure 14: Impact assessment for each impact category of the most represented dairy and dual-purpose breeds (per 1 kg of carcass), expressed in eco-points and distinguished for each category.