

Review

Not peer-reviewed version

Attributing Farm-to-Slaughter Emissions to Hides: Evidence from Beef Supply Chains

[Mondina Francesca Lunesu](#) , [Fabio Correddu](#) , [Silvia Carta](#) , [Sara Sechi](#) , [Marco Farina](#) , [Giuseppe Pulina](#) *

Posted Date: 5 November 2025

doi: 10.20944/preprints202511.0292.v1

Keywords: leather; beef by-product; carbon footprint; life cycle assessment; allocation



Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This open access article is published under a Creative Commons CC BY 4.0 license, which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Review

Attributing Farm-to-Slaughter Emissions to Hides: Evidence from Beef Supply Chains

Mondina Francesca Lunesu, Fabio Correddu, Silvia Carta, Sara Sechi, Marco Farina and Giuseppe Pulina *

Dipartimento di Agraria, Sezione di Scienze Zootecniche, University of Sassari, viale Italia, 39, 07100 Sassari, Italy

* Correspondence: gpulina@uniss.it; Tel.: +39-079-229-308

Simple Summary

The debate on how to allocate greenhouse gas emissions from cattle between meat, milk and raw hides remains unresolved. This review explains why hides are co-products (not by-product or waste), summarizes allocation methods used in life-cycle assessment, and reports Italian evidence on the contribution of hides to the total carbon footprint. Economic allocation best reflects market reality and circular-economy practices.

Abstract

Climate change is driven by anthropogenic greenhouse gases (GHGs). In the cattle supply chain, correctly allocating emissions to meat, milk and hides is crucial for life-cycle assessment (LCA). This paper reviews LCA boundaries and allocation criteria, discusses new global warming potential metrics (GWP*) and presents original Italian data on raw hides. Both literature and audit practice agree that hides should be assigned an upstream burden as co-products. Under economic allocation, the upstream environmental impact of raw hides is significantly lower than under mass allocation. Neglecting co-products at slaughter leads to an overestimation of the climate burden of meat and an underestimation of leather's share. This study tested three specific hypotheses: that raw hides carry a non-zero upstream burden as marketable co-products (H1); that economic allocation assigns them a lower share of emissions than physical allocation (H2); and that price dynamics influence economic allocation shares over time (H3). Results from large-scale Italian data confirmed all three hypotheses. Although GWP* more accurately reflects methane dynamics, it could not be implemented due to a lack of detailed temporal data; therefore, GWP₁₀₀ values were used to ensure consistency with the available inventories and current LCA standards. Overall, economic allocation appears to be the most appropriate method for hide accounting in beef production chains, as it is consistent with market valuation and circular economy principles.

Keywords: leather; beef by-product; carbon footprint; life cycle assessment; allocation

1. Introduction

Livestock production is widely considered one of the main sources of non-CO₂ agricultural emissions; it accounts for two-thirds of these and thus represents 7.4% of global emissions, excluding land use, land-use change and forestry (LULUCF) [1].

The greenhouse gas (GHG) emissions are measured, in accordance with international standards (ISO 14060 series), using carbon-dioxide equivalents (CO₂e), which translates the climate impact of the various greenhouse gases into CO₂ terms. This equivalence is known as the Global Warming Potential (GWP) and evaluates how much a given GHG contributes to global warming compared with CO₂. According to this standard equivalence, over a 100-year period, the GWP₁₀₀ of CH₄ is 28 times that of CO₂ (1 kg CH₄ = 28 kg CO₂e), while for N₂O the GWP₁₀₀ is 273 times that of CO₂ (1 kg

N₂O = 273 kg CO₂e) [2]. However, the different behaviour of these GHGs in the atmosphere (CO₂ and N₂O persist for centuries, whereas CH₄ is removed within few decades) has led to the development of new metrics, the most widespread of which are the Global Temperature Potential (GTP) [2] and the Global Warming Potential star (GWP*, with values expressed as warming equivalent, *we*), the latter being the most used in recent literature as it better matches the dynamics of temperature change induced in the atmosphere by climate-altering gases [3].

Methane is the principal GHG emitted by livestock and represents 32% of anthropogenic emissions of this gas. The European Union (EU-27) has demonstrated to be extremely efficient in decreasing GHG emissions, particularly for enteric methane, when compared with the rest of the planet [4].

Italy falls virtuously within the downward evolution of methane emissions from EU livestock. Global, European and Italian CH₄ emissions, and relative 30 years cumulative impact expressed with standard (GWP₁₀₀) and new metrics (GWP*), are reported in Table 1. Under the new metrics, for the EU and Italy emissions of this gas show a negative contribution to atmospheric warming, while the global figure—especially for cattle—is more than halved.

Table 1. Application of Global Warming Potential (GWP) and Global Warming Potential star (GWP*) to enteric methane emissions from 1990 to 2020 in Italy, EU and world.

	Emission (kt CH ₄) ¹				Cumulative impact (30 years) ²			
	1990		2020		All animals		Cattle	
	All animals	Cattle	All animals	Cattle	GWP (kt CO ₂ e)	GWP* (kt CO ₂ we)	GWP (kt CO ₂ e)	GWP* (kt CO ₂ we)
World	89,060	66,562	101,776	73,132	80,151,120	46,741,380	58,671,480	28,464,870
EU	8,652	7,436	6,376	5,519	6,311,760	-3,201,660	5,441,100	-2,665,425
Italy	793	674	580	477	576,660	-303,135	483,420	-292,845

¹ Emission values from FAOSTAT [4]. ² Cumulative impacts calculate for GWP₁₀₀ and GWP* [5].

This study aims to assess whether raw bovine hides should bear a share of upstream greenhouse gas emissions from farming and slaughter, and how such allocation depends on methodological choices. Specifically, we test three hypotheses: H1, raw hides, being marketable co-products rather than waste, bear a non-zero share of upstream emissions; assigning them a null footprint (United Nations Industrial Development Organisation, UNIDO option) introduces bias; H2, the burden assigned to hides under economic allocation is significantly lower than that under physical (mass-based) allocation, consistently with market valuation; H3, the hide share under economic allocation varies over time with the hide/meat price ratio; a multi-year average provides more stable estimates for Life Cycle Assessment (LCA) comparability.

Analyses were performed using Italian beef sector data provided by INALCA, the most important beef production hub in this Country, and national price series, as detailed in the next section.

2. Life Cycle Assessment and the Assessment of Climate-Altering Gas Emissions in Beef Supply Chains

The LCA represents the most used method to quantify emissions generated by livestock farms [6]. This method evaluates both GHG emissions and its impacts, on the environment, on humans and on natural resource use over the entire production cycle of a good, service or process. The methodology considers all production stages, from raw-material extraction and transport to processing, distribution, use, re-use, recycling and final disposal (“cradle-to-grave” approach, ISO 14040:2006 and ISO 14044:2006) [7,8]. In this contest the carbon footprint (CFP) can be defined as an LCA limited to a single impact category (climate change) and referred to a functional unit (kg of milk, body mass, protein, etc.). The CFP assesses the overall set of GHG emissions associated with a product, expressed in CO₂e (or CO₂we when using GWP*) [9]. A critical aspect for correct CFP

calculation is defining the system boundary to include in the model and the allocation method for the overall impact among the different products, co-products and by-/sub-products of a production cycle. Although the ISO standards [7,8] discourage allocation, the case of bovine production is so specific that the scientific literature and environmental-audit professionals agree that the practice is unavoidable in order to correctly apportion impacts between milk and meat and, within the latter, between the main product and co-/sub-products, bearing in mind, as accepted in both literature and practice, that scraps sent for disposal cannot bear environmental charges.

Beef production emits GHGs along the entire chain (feed production, farming, processing and distribution). The LCA of beef evaluates the overall impact calculated as the system's main output, using a functional unit (FU) represented by 1 kg of live weight, 1 kg of weight gain, 1 kg of carcass weight, or 1 kg of edible beef. Per kg of live weight, the carbon footprint generally ranges from 9 to 20 kg CO_{2e}; lower values have been estimated for animals originating from dairy chains (in particular culled dairy cows), while higher impacts have been calculated for extensively managed herds or low-efficiency herds typically located in lower-income countries [10,11].

Although two-thirds of the CFP is attributed to the farming phase alone, a full-chain quantification process should also account for the contribution of individual co- and by-products to the total footprint [1,11,12]. This is especially true considering that edible parts of a bovine represent on average ~50% of live weight, while the remaining part consists of hides, bones and other non-edible material. Literature reports that reusing non-edible material as such could create carbon credits able to offset the impact associated solely with processing. For this reason, it would be advisable to include this process into the LCA assessment. However, most studies ignore the quantification of the impact of residual materials from processing, because they adopt a spatial boundary of the "from cradle to farm gate" type, focused on the main product only. This inevitably leads to an overestimation of emissions associated with meat alone.

One of the most important co-products of beef is the hide, which influences the value of overall by-/co-products by ~30–75% [13], and whose uses vary depending on animal category. The most valuable hides are those from calves and are used in the footwear and apparel industries. Hides from young bulls are used for automotive and furniture, while hides from adult animals are used to produce everyday items.

In the following paragraphs we delve into the partitioning of emissions generated in the farming and slaughter stages among the main bovine products (meat and milk) and the co-/by-products, including hides, which receive the main attention of this paper.

3. Carbon Footprint Allocation for Bovine Hides: From Slaughterhouse to Tannery

The question of whether hides should bear any environmental load prior to tanning would seem to have been settled by the UNIDO [14], which, in assessing leather CFP, excludes farming and slaughter stages according with the following considerations:

"(a) Raw hides must be considered co-products of renewable materials: a renewable resource is a natural resource with the capacity to reproduce itself through biological or natural processes and is replenished over time. Renewable resources are part of our natural environment and contribute to build the ecosystem. For cattle, sheep and goats, this definition perfectly applies to meat production (the determining product), which is a renewable material, with raw hides as co-products.

(b) Raw hides, the non-determining co-products, are not completely used, but at least partly substitute other products. As widely known in sector literature, a small part of the input raw materials (about 20–25%) is transformed into finished leather. The remainder consists of other by-products and animal wastes. At the same time, leather replaces other materials (mostly synthetics) in footwear, leather goods, clothing, automotive interiors and furniture.

Slaughtering is the intermediate process. Finished leather could also be credited for the avoided treatment of waste from raw hides entering the tanner. Therefore, system boundaries must be considered from the

slaughterhouse, where activities and treatments to prepare hides for tanning (e.g., preservation through cooling or salting) end at the tannery gate."

In summary, according to UNIDO, since hides are waste subject to disposal that the leather industry valorises and recycles, they should reach the tannery with zero environmental footprint and, consequently, the CFP of leather products should be calculated only for tanning and industrial transformation.

Opposed to this, the scientific literature and environmental-audit opinions agree in assigning raw hides an environmental footprint, albeit a minimal one, depending on the objectives of the estimates and the allocation methods detailed below [15]; this also in view of concerns that international trade in these materials directly affects deforestation, as in analyses of commodity flows between Brazil and Italy [16].

The weak point in UNIDO's guidelines is equating raw hides with waste, on the grounds that only 25% of input mass is effectively transformed into finished product and that, if not used by tanneries, hides would need disposal with associated costs. Against the first argument, it suffices to observe that all industrial processes produce offcuts, but their efficiency is tied to lower scrap per unit of finished product: buyers of raw materials are aware of disposal burdens and factor them into margin evaluations. Moreover, bovine raw hides are sold in Italy by slaughterers as food products precisely to enable trimming to be used by industries transforming them into gelatine or other products for human consumption [17]. Against the second argument, it suffices to note that when there is a positive market for raw hides (tanners pay slaughterers to acquire them, not vice versa for removal), hides must be considered co-products of bovine chains and therefore bear an environmental footprint. The question to address is thus the best allocation method to avoid unjustifiably inflating (or deflating) the footprint of raw hides. In the next paragraphs we detail allocation, provide a brief literature analysis for beef chains and report original examples from large-scale Italian experience. Although the GWP* metric provides a more accurate representation of the climate impact of short-lived climate pollutants such as methane, it was not applied here because the available emission data are expressed as annual CO₂e under GWP₁₀₀, and conversion to GWP* would require detailed temporal emission profiles (herd dynamics and methane flow data) that are unavailable at the required resolution. The discussion therefore refers to GWP₁₀₀ values, as in current LCA and policy frameworks.

4. The Problem of Environmental Impacts Allocation in Bovine Chains

Among the many procedures proposed for correct partition between milk and meat, the following represent the most important:

- a) bio-physical methods, preferred by researchers as they are based on partitioning physical and energy flows of the system among products.
- b) physical methods, preferred by production chains as they allow allocation of explicit and hidden values and costs on a weighted basis.
- c) economic methods, preferred by LCA professionals as they are simpler with respect to concrete values to be recognised [18].

In the case of dairy cattle carbon footprint, the International Dairy Federation (IDF) [19] suggests a standard bio-physical split of 85% to milk and 15% to meat (total sold liveweight), but Ineichen *et al.* [20] showed that bio-physical assignment is proportional to herd milk yield, varying from over 20% for <2 kL production to under 5% for >8 kL production. Kytä *et al.* [15] in their literature review and expert auditor survey found that bio-physical partition, assessed with different methods, is close to the IDF value, but farmers' perceived intrinsic value assigned to individual products and co-products diverges, placing 50–60% on animals and the remainder on milk.

Allocation becomes more complex when assessing the weight of the various parts of animals destined for slaughter, whether from dairy or beef systems. Cattle are part of an articulated circular system that can supply, besides meat, a whole series of co- and by-products generated during

slaughter [21]. Processing yields a large quantity of materials in three categories: *i)* co-products, parts with some market value; *ii)* by-products, parts whose valorisation generally offsets disposal costs; *iii)* waste, parts bearing only disposal costs. Some are not intended for human consumption, and are considered as secondary resources for the feed, textile, pharmaceutical and fertiliser industries; unrecoverable organic material can be sent to anaerobic digestion to produce biogas [22]. As mentioned above, raw hides are included into the co-product category, having value and thus an active market.

At present, there is no consensus among authors on the allocation method to quantify the environmental impact of by-/co-products remaining after beef production and generating economic value at stages following farming. However, literature analysis and auditor opinions suggest that economic allocation is the most popular method used in beef (and other species) supply chains [18]. The method chosen inevitably influences the impact of individual outputs; nonetheless, re-use of beef co-/by-products will be increasingly important in the transition to a circular economy and, therefore, it is appropriate to recognise them as values generated by primary production and to detail a specific methodology that includes them in LCAs of bovine-chain products and services.

In light of the above, we can suggest some practical indications: *i)* raw hides are a co-product of the beef industry; *ii)* carbon-impact evaluation via LCA must be extended to the slaughterhouse gate; *iii)* allocation of overall impacts to raw hides must be economic.

5. Allocation of the Environmental Impacts in the Beef Chain and the Weight of Hides

According to Kyttä *et al.* [15], considering an economic allocation for the beef chains, it results that the 87% of the impact is associated with meat and the 13% with co-/by-products; of the later, the hide accounts for just under 5% of the total. The economic approach better represents demand-supply environmental consequences but makes temporal comparisons harder [13]. Compared to the economic allocation, the bio-physical allocation, based on partitioning metabolizable energy used by the animal for growth of different tissues separated at slaughter [23], allocates 80% of impact to meat and 20% to co-/by-products. Meat’s impact decreases further with a mass (physical) allocation (73%), while that of co-/by-products increases (27%); in this case, note that the hide’s share of total live weight varies by breed and sex [24]. Ethnologically, hide share of live weight tends to be greater in specialised beef breeds than in dairy breeds, and in tropical-origin breeds than in European ones [13]. Table 2 reports physical allocation for different animal categories, arising from a large sample within the INALCA system (Cremonini Group). Physical allocation of hide ranges from a minimum of 4.2% in cull dairy cows (27 kg hide on 647 kg live weight at slaughter) to a maximum of 6.9% in semi-heavy young bulls (37 kg hide on 538 kg liveweight), with a mean of 5.88% and an average slaughter liveweight of 555 kg.

Table 2. Physical allocation of raw hide in the INALCA system.

Category*	Liveweight (kg)	Hide weight (€/kg)	Hide allocation (% of live weight)
Young bulls	538	37	6.9%
Calves	346	23	6.6%
Young bulls & heifers	618	38	6.1%
Culled dairy cows	627	35	5.6%
Culled dairy cows	647	27	4.2%

* Data from different slaughterhouses (about 750,000 slaughtering/y).

Economic allocation of hide, for the same extensive sample (Table 3), shows markedly lower values for all animal categories, at less than half those calculated by physical allocation, averaging 2.68% for 2023.

Table 3. Economic allocation of raw hide in the INALCA system (average prices in 2023).

Item*	Young bulls		Calves		Young bulls & heifer		Culled dairy cows		Culled dairy cows	
Meat	1,260 €	95.6%	899 €	92.5%	1,997 €	96.9%	1,600 €	97.0%	992 €	96.0%
Fat	21 €	1.6%	41 €	4.2%	17 €	0.8%	6 €	0.4%	15 €	1.5%
Hide	37 €	2.8%	32 €	3.3%	46 €	2.2%	43 €	2.6%	26 €	2.5%
TOTAL	1,318 €	100%	972 €	100%	2,060 €	100%	1,649 €	100%	1,033 €	100%

*Data from different slaughterhouses (about 750,000 slaughtering/y).

However, these values, if recalculated over the historical series in Table 4, tend to fall due to the relative loss of hide value compared with meat: for dairy cows, for example, the ratio was 0.70 in 2015, falling to 0.19 in 2023. As extensively discussed in the literature, this suggests the need for annual recalculation of allocations and, where possible, a five-year average of LCA values for stable, comparable data.

Compared with literature, it should be noted that the INALCA survey separated only hides and fat from the remainder of carcass products and co-products. The “meat” category here includes edible fifth-quarter parts; as a result, values reported in Tables 2 and 3 for the main product are considerably higher than those drawn from the literature.

Table 4. Wholesale price trends (€/kg) in Italy for beef products and co-products (INALCA data).

Animal part	2023	2022	2021	2020	2019	2018	2017	2016	2015
Animal fat	1.16	1.55	1.11	0.82	0.71	0.68	0.80	0.72	0.67
Hides	1.24	1.29	1.23	1.14	1.47	1.95	2.33	2.25	2.04
Cow meat	6.39	6.16	4.28	3.98	4.21	3.82	3.52	4.13	3.41
Young-bull meat	6.40	6.34	5.07	4.86	4.90	4.90	4.84	4.86	4.77
Veal	6.69	6.75	6.90	6.12	6.21	6.41	6.27	5.68	5.59

6. Estimating the Climate Impacts of Raw Bovine Hide

The impact associated with hide production can be expressed per unit mass or surface. For raw hides, the kilogram represents the common FU, while for finished leather it is represented by the square metre [25]. The carbon footprint per kg of raw hides in the only reference found in the literature is 12.3 kg CO₂e with economic allocation, rising to 12.9 kg CO₂e with mass allocation [13].

The INALCA group data (2024) [26] on overall climate impacts allow calculation of the CFP per kg of raw hide, also accounting for the slaughterhouse perimeter, equal to 3.55 kg CO₂e under physical allocation and 1.63 kg CO₂e under economic allocation for 2023.

Pignatelli and Marino [27] evaluated the impact of 1 kg of raw hide at the farm gate as 1.9 kg CO₂e for young bulls and 0.97 kg CO₂e for dairy cows, without specifying the allocation method used. Table 5 reports the data of Vicenza tanning district [28], calculated as m² of processed leather, on minimum, maximum and average yields, based on the INALCA’s CFP per kg raw hide.

Table 5. Carbon footprint per m² of leather processed in the Vicenza district (calculated on the INALCA value of carbon footprint).

Allocation	Minimum (m ² /kg)	Minimum (CO ₂ /m ²)	Maximum (m ² /kg)	Maximum (CO ₂ /m ²)	Average (m ² /kg)	Average (CO ₂ /m ²)
Physical	0.09	39.44	1.57	2.26	0.12	29.58
Economic	0.09	18.11	1.57	1.04	0.12	13.58

The values obtained are extremely variable as a function of raw-hide-to-surface yield, but an average upstream CFP (farming and slaughter) of ~13.5 kg CO₂ per m² is reasonable in relation to finished-product data reported below. A recent assessment for a tannery estimated upstream farming-and-slaughter impact at 6.78 kg CO₂e per m² of processed leather [29]. For finished leather,

literature CFP ranges between 64.8 and 151.9 kg CO_{2e}/m² [25,30]. Among finished leathers, aniline leather is particularly valuable as processing confers a “natural effect” [31]: the CFP of aniline leather increases with thickness, and 78% of the impact is attributed to extraction of raw materials needed for processing, with the remainder from internal manufacturing energy (21%) and distribution (<1%) [25].

Ultimately, the CFP of hides, analogously to meat, must also consider the tanning system’s effective capacity to generate co-products such as splits for collagen production, so as to reward operators who achieve such recoveries compared with those taking non-food hides and thus unable to generate co-products for the food or feed sectors.

7. Conclusions

Attributing climate-altering impacts to leather products deriving from raw hides from the farming and slaughter stages (so-called upstream) is debated and controversial across the supply chain. On the one hand, the tanning industry claims its role as valoriser of a product otherwise destined for disposal; on the other, farmers and slaughterers think correct to load a share, albeit minimal, of emissions also onto raw hides.

Scientific literature agrees on allocating an emission share to slaughter co-products, as these are secondary parts of the animal, subject to market exchange. However, there is debate on how to subdivide it: bio-physical methods, considered the most scientifically correct, are complex to adopt and impose excessive loads on co-products; physical methods share this drawback without the precision advantage; economic methods, although affected by temporal and local price variability, are nevertheless considered best as they aim to attribute to the main and co-products a climate burden proportional to market value and to avoid green-washing of the main product at the expense of secondary ones usually hidden from the consumer’s attention.

The results obtained in this study confirm H1, showing that raw hides, being co-products with a positive market value, bear a non-zero share of upstream emissions; attributing them a null footprint would introduce systematic bias. They also confirm H2, as economic allocation consistently assigns a lower burden to hides than physical (mass-based) allocation across animal categories, in line with price-based valuation and LCA practice. Evidence also supports H3, since the hide share under economic allocation varies over time with the hide/meat price ratio, and multi-year averaging provides more stable values for LCA comparability. None of the hypotheses is confuted by the results presented here.

Finally, the tanning and leather goods industry should calculate the incoming emission load of raw hides by requiring suppliers to provide transparent LCA for this raw material using economic allocation. However, the lower the final upstream burden per unit product (m² of processed leather), the greater the operator’s ability to add value to raw hides in physical (or economic) terms, and to conveniently redirect processing offcuts to the collagen and hydrolysed protein industries. The GWP* was considered, but not applied due to the lack of the temporal herd emission series necessary for its correct implementation. Nonetheless, the conclusions remain robust under the standard GWP₁₀₀ accounting framework and are aligned with current international LCA guidance.

Author Contributions: Conceptualization, G. Pulina, M.F. Lunesu; methodology, G. Pulina, M.F. Lunesu, S. Sechi; validation, G. Pulina, F. Correddu; investigation, G. Pulina, M.F. Lunesu; writing—original draft preparation, G. Pulina, M.F. Lunesu; writing—review and editing, G. Pulina, M.F. Lunesu, S. Carta, F. Correddu; visualization, S. Carta, M. Farina, F. Correddu; supervision, G. Pulina.; funding acquisition, G. Pulina. All authors have read and agreed to the published version of the manuscript.

Funding: Not applicable.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data will be made available on request.

Acknowledgments: A preliminary version of this study was published as a chapter in the commemorative volume *Antichi per sempre. 80° anniversario della Sezione Concia di Confindustria Vicenza (1945–2025)*, edited by Dr. Mirko Balsemin (President, Confindustria Pelli Vicenza). The present paper is an updated and extended version, published with the kind permission of the editor of that volume.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

CFP	Carbon Footprint
GHG	Green House Gas
GTP	Global Temperature Potential
GWP	Global Warming Potential
GWP*	Global Warming Potential star
FU	Functional unit
IDF	International Dairy Federation
LCA	Life Cycle Assessment
LULUCF	Land Use, Land Use Change and Forestry

References

1. FAO. Emissions due to agriculture Global, regional and country trends 2000–2018, 2020. (<https://www.fao.org/3/cb3808en/cb3808en.pdf>).
2. IPCC. AR6 Synthesis Report: Climate Change 2023. (<https://www.ipcc.ch/report/sixth-assessment-report-cycle/>).
3. Allen, M.R., Fuglestvedt, J.S., Shine, K.P., Reisinger, A., Pierrehumbert, R.T., Forster, P.M. New use of global warming potentials to compare cumulative and short-lived climate pollutants. *Nat. Clim. Change* **2016** *6*, 773-776.
4. FAOSTAT. Food and Agriculture Data, 2024. (<https://www.fao.org/faostat/en/#home>).
5. Pulina G. *Sintesi analitica della sostenibilità delle filiere zootecniche italiane*. Annali Accademia Nazionale di Agricoltura, **2024**, *143*, 300-331.
6. McClelland, S.C., Arndt, C., Gordon, D.R., Thoma, G. Type and number of environmental impact categories used in livestock life cycle assessment: A systematic review. *Livest. Sci.* **2018**, *209*, 39-45.
7. ISO 14040. *Environmental Management-Life Cycle Assessment-Principles and Framework*. ISO **2006**, *578*, 235-248.
8. ISO 14044. *Environmental management—Life cycle assessment—Requirements and guidelines*. ISO **2006**, 1-46.
9. Dong, Q., Zhong, C., Geng, Y., Dong, F., Chen, W., Zhang, Y. A bibliometric review of carbon footprint research. *Carbon Footprints* **2024**, *3*, N-A.
10. De Vries, M.D., Van Middelaar, C.E., De Boer, I.J.M. Comparing environmental impacts of beef production systems: A review of life cycle assessments. *Livest. Sci.* **2015**, *178*, 279-288.
11. Pulina, G., Lunesu, M.F., Pirlo, G., Ellies-Oury, M.P., Chriki, S., Hocquette, J-F. Sustainable production and consumption of animal products. *Cur. Opin. Env. Sci. Health* **2022**, *30*, 100404.
12. Lunesu, M.F., Caratzu, M.F., Correddu, F., Sechi, S., Battacone, G., Nudda, A., Pulina, G. Applying an indirect method to assess the net carbon footprint of dairy sheep farms with a special focus on suckling lamb. *Ital. J. Anim. Sci.* **2025**, *24*, 689-710.
13. Desjardins, R.L., Worth, D.E., Vergé, X.P., Maxime, D., Dyer, J., Cerkowniak, D. Carbon footprint of beef cattle. *Sustainability* **2012**, *4*, 3279-3301.
14. UNIDO, United Nations Industrial Development Organisation. Eighteenth Session of the “Leather and leather products industry panel”, Shanghai, China, 01 – 05 September 2012.
15. Kytä, V., Roitto, M., Astaptsev, A., Saarinen, M., Tuomisto, H.L. Review and expert survey of allocation methods used in life cycle assessment of milk and beef. *Int J Life Cycle Assess* **2022**, *27*, 191-204.

16. Mammadova, A., Masiero, M., Pettenella, D. Embedded deforestation: the case study of the Brazilian–Italian bovine leather trade. *Forests* **2020**, *11*, 472.
17. Regulation (EC) No 853/2004 lays down specific hygiene rules for food of animal origin; Annex III, Sections XIV and XV respectively allow production of gelatin and collagen for human consumption.
18. Wilfart, A., Gac, A., Salaün, Y., Aubin, J., & Espagnol, S. Allocation in the LCA of meat products: is agreement possible? *Clean. Environ. Syst.* **2021**, *2*, 100028.
19. IDF, A common carbon footprint approach for the dairy sector. The IDF guide to standard life cycle assessment methodology. *International Dairy Federation*, 2015.
20. Ineichen, S., Schenker, U., Nemecek, T., Reidy, B. Allocation of environmental burdens in dairy systems: Expanding a biophysical approach for application to larger meat-to-milk ratios. *Livest. Sci.* **2022**, *261*, 104955.
21. Bernardi, E., Capri, E., Pulina, G. *Meats and Cured Meats: The New Frontiers of Sustainability: Environment, Health, Safety, Culture, Economy and Ethics in Meat Supply Chain*. Franco Angeli: Italy, 2023.
22. Mogensen, L., Nguyen, T.L.T., Madsen, N.T., Pontoppidan, O., Preda, T., Hermansen, J.E. Environmental impact of beef sourced from different production systems-focus on the slaughtering stage: input and output. *J. Clean. Prod.* **2016**, *133*, 284–293.
23. Chen, X., Wilfart, A., Puillet, L., Aubin, J. A new method of biophysical allocation in LCA of livestock co-products: modeling metabolic energy requirements of body-tissue growth. *Int J Life Cycle Assess* **2017**, *22*, 883–895.
24. Terry, C.A., Knapp, R.H., Edwards, J.W., Mies, W.L., Savell, J.W., Cross, H.R. Yields of by-products from different cattle types. *J. Anim. Sci.* **1990**, *68*, 4200–4205.
25. Chen, K.W., Lin, L.C., Lee, W.S. Analyzing the carbon footprint of the finished bovine leather: a case study of aniline leather. *Energy Procedia* **2014**, *61*, 1063–1066.
26. INALCA, 2024. <https://www.inalca.it/it/bilancio-di-sostenibilita/>.
27. Pignatelli S., Marino M. *Impatti ambientali della carne bovina in Italia: sistemi di allevamento e trasformazione*. Università di Bologna—CRPA. We thank COOP for data availability, 2013.
28. UNIC, 2023. Concerie Italiane (<http://www.unic.it/>).
29. Mastrotto, R. (Group SpA). *LCA CO₂ journey – WW Brusarosco leather*. Personal communication, 2022.
30. Joseph, K., Nithya, N. Material flows in the life cycle of leather. *J. Clean. Prod.* **2009**, *17*, 676–682.
31. Rivela, B., Moreira, M.T., Bornhardt, C., Méndez, R., Feijoo, G. Life cycle assessment as a tool for the environmental improvement of the tannery industry in developing countries. *Environ. Sci. Technol.* **2004**, *38*, 1901–1909.

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.