

Global livestock systems circa 2020: An integrated analysis of livestock production, feed use and GHG emissions

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Abstract

Livestock systems are central to global food security and livelihoods but are also major contributors to land use and greenhouse gas (GHG) emissions. Global assessments often rely on spatially aggregated data that overlook the biological and spatial heterogeneity of livestock systems, limiting the evaluation of mitigation and adaptation options. Here, we develop a biologically consistent, spatially explicit global dataset representing livestock production, feed consumption, and GHG emissions circa 2020, harmonized with national statistics while resolving variation across species, production systems, and agroecological regions. Results reveal strong regional specialization of livestock systems. Ruminant production is widely distributed, with South Asia dominating dairy production and Latin America and the Caribbean oriented towards beef production. In contrast, monogastric production is highly concentrated in East and Southeast Asia. These production patterns are closely mirrored in feed use, with ruminant systems relying predominantly on roughage-based diets, while monogastric systems are dominated by concentrate feeds, including grains and protein-rich inputs. These structural differences underpin global GHG emissions patterns. Together, these findings highlight the importance of accounting for spatial heterogeneity and system structure when assessing livestock impacts and mitigation opportunities. By explicitly linking production systems, feed composition, and GHG emissions, this framework provides a robust foundation for integrated analyses and for exploring future sustainability pathways under changing environmental and socio-economic conditions

1. Introduction

Livestock systems are foundational to global food systems and sustainability, supporting nutrition, cultural identity, and economic development while exerting substantial pressures on land, water, nutrients, and climate^{1, 2}. As one of the world's largest land-use systems, livestock occupies roughly 30% of the ice-free terrestrial surface, contributes about 40% of global agricultural output value, and underpins the livelihoods of more than 1.3 billion people—particularly in low- and middle-income countries where livestock function as productive assets, safety nets, and sources of resilience^{3, 4}. By converting low-opportunity-cost biomass, crop residues, and by-products into nutrient-dense foods^{5, 6}, livestock play a critical role in food security and land stewardship, yet they also contribute substantially to GHG emissions, especially methane (CH₄) from ruminant systems^{4, 7}. These benefits and trade-offs are highly heterogeneous across species, production systems, and regions, and are increasingly amplified by climate change and growing climatic, economic, and geopolitical shocks⁸⁻¹⁰.

Despite livestock's centrality to food security, livelihoods, and climate mitigation, global assessments have largely relied on spatially aggregated national statistics that mask herd dynamics, feed sources, and the biophysical and biochemical processes governing productivity, nutrient cycling, and emissions^{4, 11}. Such simplifications limit the assessment of adaptation and mitigation options, which are inherently place specific. Here, we address this gap by developing a biologically consistent, spatially explicit global dataset representing livestock biomass fluxes (feed availability, consumption, and production), animal productivity, and GHG emissions circa 2020, harmonized to FAO national totals while resolving variation by species, production system, and agroecology. By explicitly representing herd dynamics, spatial feed distributions, and manure-mediated nutrient flows, this framework provides a realistic baseline for integrating livestock into land-use, cropping systems, climate and economic modelling analyses.

2. Methods

2.1 Overall framework and system representation

Building on this framework, we quantify global livestock production, biomass consumption, and GHG emissions circa 2020 within a spatially explicit system at 5-arc-minute resolution ($\approx 10 \times 10$ km), designed to be regularly updated. The datasets cover six animal types—cattle, sheep, goats, buffalo, poultry, and pigs—and four livestock products: meat, milk, eggs, and wool. Multiple agroecological regions¹² and production systems are represented, including grazing, mixed, and urban ruminant systems¹³, as well as backyard, intermediate, and industrial systems for poultry and pigs, with industrial poultry further differentiated into broilers and layers¹⁴. Climate and management play a central role in shaping livestock distributions, feed availability, and animal performance, forming the basis for a bottom-up representation of livestock systems¹³.

National production totals are harmonized to FAO statistics, while spatial disaggregation is guided by animal numbers, feed availability, and related indicators to ensure internal biological consistency across species and systems¹⁵.

2.2 Feed systems and spatial allocation

While livestock distributions are informed by existing spatial products (Gridded Livestock of the World v4, updated to circa 2020)¹⁴, predefined diets by animal type and production system^{4, 16} are dynamically adjusted

according to locally produced and imported feeds¹⁵. Biomass availability in grasslands¹⁷ is further constrained by tree cover¹⁸ and biomass losses from prescribed and escaped fires^{17,19}.

Feed systems and diet composition are represented using more than 180 feed items, with explicit spatial characterization of grassland extent²⁰ and vegetation type including productivity^{17,21} and legume content. Additional feed sources—including hay, silage, supplements, crop residues, and by-products—are spatially allocated by linking livestock systems to cropping systems and productivity datasets^{11,22-24}.

2.3 Animal performance and herd dynamics

Herd dynamics and animal performance account for age structure, physiological status, breed type, and management, with performance constrained by feed quality, climate, and topography. Ruminant performance and enteric fermentation are simulated using the Ruminant Nutrition System model^{25,26}, while monogastric performance and nitrogen excretion are estimated using established nutritional equations^{16, 27, 28}.

2.4 Greenhouse gas emissions accounting

The emissions include CH₄ from enteric fermentation and manure, direct nitrous oxide (N₂O) from manure deposition and management and indirect nitrogen emissions via nitrate leaching and ammonia volatilization. Manure management pathways by animal type, region and agroecological zone were informed by existing datasets^{4, 16, 29, 30}. The accounting framework also considers fertilizer application on improved pastures and wetland management on mineral and organic soils³⁰⁻³². Emissions from all these sources were aggregated and converted to CO₂eq using AR6 GWP100 values (27 for CH₄ and 273 for N₂O).

3. Results

3. 1. Livestock production

Livestock production is strongly concentrated in a limited number of regions, with clear differences across animal groups and production orientations (Figure 1). For cattle and buffalo meat, Latin America and the Caribbean (LAC) and North America (NAM) emerge as the dominant regions, each reaching on the order of ~15 Mt and exceeding production in other regions by a factor of two to three. In contrast, production in

Sub-Saharan Africa (SSA), Western Europe (WE), and East and Southeast Asia (ESEA) remains notably lower, generally below ~10 Mt.

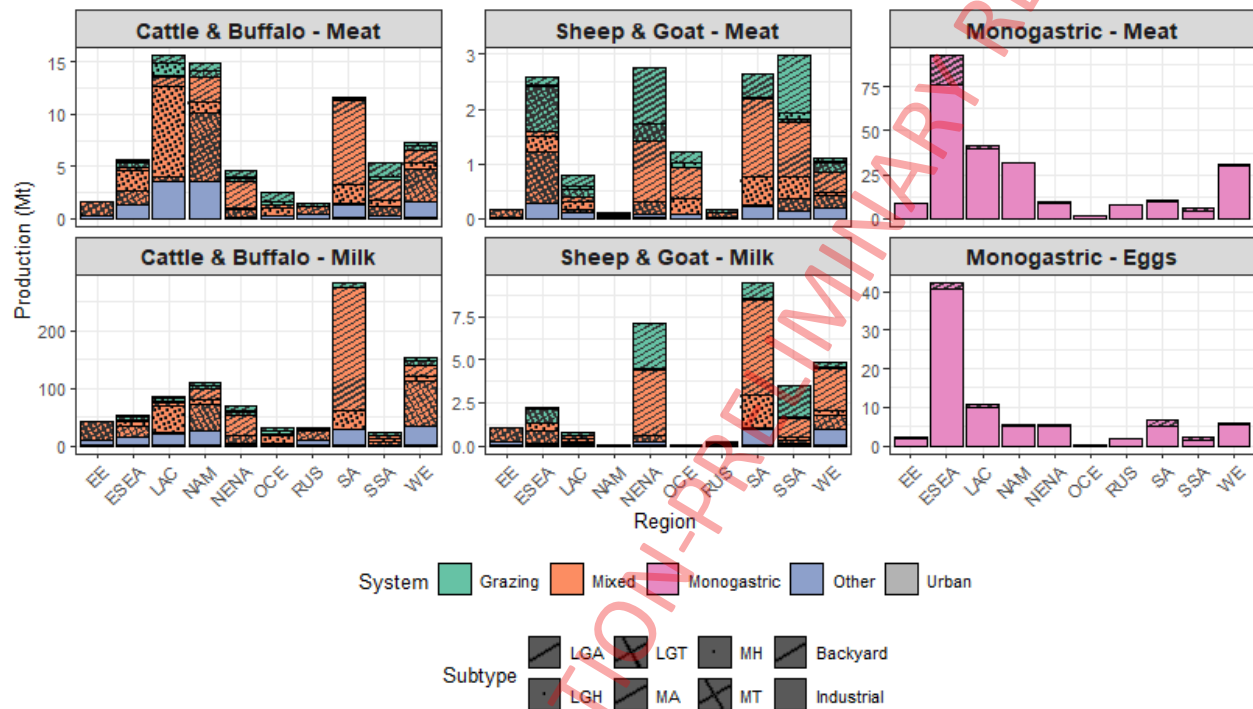


Figure 1. Regional distribution of livestock production by animal group, production system, and climatic zone. For clarity and space, livestock production is aggregated into three groups: cattle and buffalo; sheep and goats; and monogastric. Monogastric meat includes both pig and poultry meat, while monogastric eggs represent production from backyard and layer chicken systems. Regions are defined as follows: EE (Eastern Europe), ESEA (East and Southeast Asia), LAC (Latin America and the Caribbean), NAM (North America), NENA (Near East and North Africa), OCE (Oceania), RUS (Russian Federation), SA (South Asia), SSA (Sub-Saharan Africa), and WE (Western Europe). Livestock production systems are classified as: LGA (livestock grazing, arid), LGH (livestock grazing, humid), LGT (livestock grazing, temperate), MA (mixed, arid), MH (mixed, humid), and MT (mixed, temperate). Backyard systems include production from backyard poultry and/or pig systems. Industrial systems include production from intermediate and industrial pig systems, as well as layer and broiler poultry systems.

A different pattern is observed for milk production. South Asia (SA) clearly dominates cattle and buffalo milk production, with values approaching ~250–300 Mt. The WE, NAM and LAC form a second tier (~150 Mt and ~100 Mt), while other regions contribute substantially smaller volumes. This contrast highlights strong regional specialization, with SA acting as the global center of dairy production, whereas LAC and NAM are more oriented toward beef production.

In contrast to cattle and buffalo, which are predominantly associated with mixed systems, small ruminants are more evenly distributed between mixed and grazing systems. Sheep and goat production follows similar but lower-magnitude patterns. Meat production is concentrated in SSA, Near East and North Africa (NENA), ESEA, and SA, generally exceeding ~2 Mt, while milk production is more localized, with SA

again standing out (~9 Mt), followed by NENA and WE. Overall, small-ruminant production is both smaller in scale and more evenly distributed across regions.

Monogastric production is more spatially concentrated and dominated by fewer regions. Pig and poultry meat production is heavily concentrated in ESEA, reaching ~80–90 Mt, more than double the levels observed in LAC and NAM (~40 Mt), and far exceeding all other regions. Poultry egg production follows a similar pattern, with ESEA dominating (~40 Mt), followed by LAC and NAM (~10–15 Mt). These patterns indicate a strong regional concentration of monogastric production in Asia, associated with more industrialized production systems.

3. 2. Feed consumption

Feed consumption patterns closely reflect the regional structure of livestock production and underlying production systems (Figure 2). Ruminant systems are dominated by roughages across all regions, with particularly large contributions in LAC, SA, and SSA. For cattle and buffalo, roughage use exceeds ~700 Mt in LAC for beef-oriented systems and remains above ~600–700 Mt in dairy systems in SA, highlighting the central role of fibrous biomass in sustaining large ruminant populations.



Figure 2. Regional distribution of livestock feed consumption by animal group and production system. For clarity and space, feed consumption is aggregated into four animal groups: cattle and buffalo; sheep and goats; pigs; and poultry. For cattle and buffalo, and sheep and goats, consumption is further disaggregated into dairy and beef systems. Poultry feed consumption includes feed required for both meat and egg production. Regions are defined as follows: EE (Eastern Europe), ESEA (East and Southeast Asia), LAC (Latin America and the Caribbean), NAM (North America), NENA (Near East and North Africa), OCE (Oceania), RUS (Russian Federation), SA (South Asia), SSA (Sub-Saharan Africa), and WE (Western Europe). Feed categories are defined as follows: Roughages include browses (leaves from shrubs), natural grasslands, improved and cultivated pastures, silage, fodder crops, stover, and traded forages (e.g., hay). Grains, oilseeds, and pulses include all major crops used as feed (e.g., maize, sorghum, millet, soybean,

chickpea). Residues refer to feed from scavenging systems, including domestic and commercial food waste, primarily used in backyard monogastric systems. Roots and tubers include feeds such as cassava and potatoes. Protein meals include oilseed cakes and fish meals. Agro-industrial by-products include residues from crop processing (e.g., oilseeds, cereals, sugarcane, fruit), such as cottonseed cake, rapeseed cake, molasses, and bran.

In contrast, ruminant feed use in NAM and WE is lower in total magnitude (~100–250 Mt) but shows a relatively greater contribution from grains, protein meals, and agro-industrial by-products. This is particularly evident in dairy systems, where concentrate feeds represent a larger share of total intake compared to the more roughage-dominated systems in SSA and SA. These patterns reflect a transition toward more input-intensive feeding strategies in regions with highly specialized dairy production.

Sheep and goat systems follow similar trends at smaller scales. Roughage use remains dominant across all regions, with the largest value observed in SSA, ESEA, and NENA, consistent with their production distribution. As in cattle systems, concentrate feeds play a more visible role in higher-input regions but remain secondary overall.

Monogastric systems exhibit a fundamentally different feed structure. Pig feed consumption is highly concentrated in ESEA (~250 Mt), more than double that of WE (~90 Mt) and substantially higher than in other regions. Poultry feed shows a similar pattern, with ESEA again dominating (~250 Mt), followed by NAM and LAC (~100–120 Mt). Unlike ruminants, monogastric diets are dominated by grains, oilseeds, and pulses, with substantial contributions from protein meals and agro-industrial by-products, while roughages play a negligible role.

Overall, these patterns highlight a clear structural divide between livestock systems: ruminant production relies on large volumes of fibrous biomass, whereas monogastric production depends on more concentrated and processed feed inputs. This contrast underpins differences in production intensity and GHG emissions profiles.

3. 3. Greenhouse gas emissions

The GHG emissions are dominated by ruminant systems and are highly concentrated in a small number of regions (Tables 1–2). For cattle and buffalo, LAC and SA are the largest contributors, together accounting for roughly half of total emissions. South Asia alone contributes a particularly large share, driven by mixed systems (MA and MH; ~555,000 kt CO₂eq combined), while in LAC emissions are dominated by mixed humid systems (MH; ~375,000 kt CO₂eq).

The SSA region represents a third major contributor (~12% of total cattle and buffalo emissions), but with a distinct structure. GHG emissions are more evenly distributed across systems, with large contributions from both grazing (e.g., LGA ~78,800 kt CO₂eq) and mixed systems (MA ~106,500 kt CO₂eq), reflecting the coexistence of extensive and semi-intensive production. In contrast, NAM and WE contribute smaller shares and are dominated by temperate mixed systems (MT), indicative of more intensive production.

Sheep and goat emissions are lower in magnitude but similarly concentrated. SSA and NENA together contribute nearly half of total GHG emissions, with grazing systems dominating, particularly LGA systems (~46,500 kt CO₂eq in SSA and ~28,900 kt CO₂eq in NENA). Mixed arid systems also contribute substantially, especially in SSA.

Monogastric emissions are more spatially concentrated and strongly associated with industrial systems. For pigs, ESEA alone accounts for nearly half of global GHG emissions (~46%), with additional contributions

from WE (~17%) and NAM (~14%). Industrial systems dominate in these regions, although backyard systems remain important in SSA and parts of Asia.

Poultry emissions are even more concentrated, with ESEA contributing approximately 60% of the global total. This is driven primarily by layer systems (~99,000 kt CO₂eq), which are an order of magnitude larger than broiler emissions in the same region (~7,500 kt CO₂eq). Outside ESEA, emissions are substantially smaller, with LAC and NENA as secondary contributors.

DRAFT: NOT FOR PUBLICATION-PRELIMINARY RESULTS

Table 1. Total GHG emissions by animal group, region, and livestock production system. Values in thousand tonnes CO₂eq. Regions are defined as follows: EE (Eastern Europe), ESEA (East and Southeast Asia), LAC (Latin America and the Caribbean), NAM (North America), NENA (Near East and North Africa), OCE (Oceania), RUS (Russian Federation), SA (South Asia), SSA (Sub-Saharan Africa), and WE (Western Europe). Livestock production systems are classified as: LGA (livestock grazing, arid), LGH (livestock grazing, humid), LGT (livestock grazing, temperate), MA (mixed, arid), MH (mixed, humid), and MT (mixed, temperate).

Animal_group	Region	LGA	LGH	LGT	MA	MH	MT	Other	Urban
Cattle & Buffalo	EE	2.5	0.0	101.6	115.0	0.0	29,349.9	7,880.6	192.1
	ESEA	7,298.9	11,424.6	16,286.1	11,166.3	93,567.5	52,341.1	56,822.2	120.8
	LAC	26,461.1	51,238.8	7,476.3	39,238.7	374,750.5	17,539.3	151,997.8	155.8
	NAM	16,734.5	1,429.2	12,646.4	40,776.4	17,630.2	101,802.4	57,212.9	808.7
	NENA	27,763.1	2,320.1	12,585.3	93,397.3	1,703.1	25,515.1	5,390.4	591.3
	OCE	16,830.6	5,616.5	620.0	7,077.1	15,067.4	382.2	6,242.3	150.0
	RUS	41.8	0.0	4,830.1	95.4	0.0	19,313.6	8,779.0	179.7
	SA	13,037.8	2,180.4	712.0	463,427.9	92,186.2	5,668.3	64,087.7	2,721.7
	SSA	78,816.8	16,346.3	8,747.7	106,489.0	36,930.1	58,282.6	14,967.4	462.6
	WE	1,105.8	6,799.4	13,673.4	28,495.2	14,696.0	85,859.3	40,606.9	1,532.2
Sheep & Goat	EE	1.7	0.0	11.3	49.0	0.0	3,468.8	1,028.1	37.1
	ESEA	3,647.7	452.0	21,546.4	1,710.7	7,478.6	22,337.3	5,824.4	46.5
	LAC	5,337.3	1,200.3	2,831.5	2,478.8	4,140.2	1,280.2	3,130.3	9.6
	NAM	308.6	15.0	224.0	241.6	87.0	481.8	555.1	14.9
	NENA	28,867.8	616.6	6,583.3	29,725.3	228.0	5,775.1	1,504.1	312.6
	OCE	2,646.0	1,240.4	357.1	8,451.9	4,371.9	159.6	1,080.7	21.6
	RUS	16.7	0.0	1,719.3	24.5	0.0	2,057.5	505.9	15.5
	SA	11,160.7	222.8	297.2	36,921.2	12,056.0	911.3	5,295.1	235.1
	SSA	46,484.9	3,121.6	1,653.0	36,472.1	11,609.5	7,729.7	3,940.5	160.0
	WE	1,314.6	676.9	3,431.1	7,418.1	1,118.1	5,107.2	3,652.9	108.3

Table 2. Total GHG emissions for pig and poultry systems by region and production system. Values in thousand tonnes CO₂eq. Regions are defined as follows: EE (Eastern Europe), ESEA (East and Southeast Asia), LAC (Latin America and the Caribbean), NAM (North America), NENA (Near East and North Africa), OCE (Oceania), RUS (Russian Federation), SA (South Asia), SSA (Sub-Saharan Africa), and WE (Western Europe).

Animal	Region	Backyard	Industrial	Intermediate	Broilers	Layers
Pig	EE	1,087.3	4,904.9	756.1	0.0	0.0
	ESEA	33,651.7	86,180.2	24,167.9	0.0	0.0
	LAC	7,330.3	24,512.7	4,504.9	0.0	0.0
	NAM	294.4	42,659.8	33.5	0.0	0.0
	NENA	93.1	330.7	31.3	0.0	0.0
	OCE	2,165.9	2,292.8	876.9	0.0	0.0
	RUS	306.8	2,957.9	2.1	0.0	0.0
	SA	2,664.3	365.6	2,217.5	0.0	0.0
	SSA	10,338.5	1,342.4	3,397.0	0.0	0.0
	WE	391.9	51,924.8	503.3	0.0	0.0
Poultry	EE	76.8	0.0	0.0	743.3	1,428.8
	ESEA	1,946.3	0.0	0.0	7,483.1	99,274.5
	LAC	403.9	0.0	0.0	5,388.3	15,662.2
	NAM	77.1	0.0	0.0	4,732.1	3,130.6
	NENA	281.9	0.0	0.0	1,778.8	12,484.7
	OCE	18.2	0.0	0.0	280.0	447.0
	RUS	20.6	0.0	0.0	626.8	2,522.1
	SA	934.8	0.0	0.0	2,544.8	4,321.5
	SSA	597.6	0.0	0.0	548.0	5,284.4
	WE	34.0	0.0	0.0	1,898.8	4,213.2

4. Discussion

The harmonization of spatially explicit livestock production with official national statistics preserves biological realism while substantially reducing regional biases that can lead to systematic over- or underestimation of livestock production, feed use, and GHG emissions. Anchoring high-resolution spatial patterns to nationally reported figures ensures consistency between animal numbers, productivity, and feed use, which is critical for interpreting the regional patterns identified in this study.

The results highlight a strong regional specialization of livestock systems. Ruminant production is widely distributed but shows clear functional differentiation, with SA emerging as a global center of dairy production and LAC strongly oriented toward beef production. In contrast, monogastric production is highly concentrated in ESEA, reflecting the dominance of industrialized production systems. These structural differences are closely mirrored in feed consumption patterns, with ruminant systems relying predominantly on roughage-based diets, while monogastric systems depend on concentrate feeds, including grains and protein-rich inputs.

These differences in production orientation and feed composition are directly reflected in GHG emissions patterns. Ruminant systems dominate global GHG emissions, particularly in regions where mixed systems are prevalent, such as SA and LAC. In these regions, the combination of large animal populations and feed systems based on both roughages and concentrates contributes to high emissions levels. In contrast, monogastric emissions are more spatially concentrated and primarily associated with industrial systems, particularly in ESEA.

Beyond these structural insights, the dataset enables a wide range of analyses related to livestock productivity, diets, and mitigation strategies. For example, it allows assessment of how changes in diet composition, feed additives, herd dynamics, and genetic potential influence animal performance, feed-use efficiency, and GHG emissions. The explicit tracing of feed origin also enables the integration of upstream emissions and provides a basis for linking land-use change to regional shifts in diet composition driven by trade and feed sourcing dynamics.

The framework further supports analyses of climate change impacts on feed availability, productivity, GHG emissions, and soil organic carbon dynamics, as well as investigations of circularity pathways through the use of alternative and residual feed resources. Designed to be interoperable, transparent, and extensible, with a standardized structure implemented in R and comprehensive metadata, the dataset can be readily integrated with existing livestock, feed, land-use, environmental, and economic modelling frameworks.

This interoperability is particularly relevant for GTAP-based analyses, where improved livestock-system coefficients can help represent regional differences in productivity, feed requirements, manure nutrient flows, and emission intensities. These updated coefficients can support more region-specific estimates of the economic and environmental implications of producing livestock commodities, including meat and milk. More broadly, linking biophysical livestock accounting with economic modelling can improve the assessment of trade, land-use change, feed sourcing, and mitigation scenarios.

By integrating feed availability, herd dynamics, animal performance, and GHG emissions within a single biologically consistent framework, this approach provides a flexible foundation for analyzing livestock systems across scales and for exploring future sustainability pathways under changing environmental and socio-economic conditions.

5. Conclusion

This study presents a biologically consistent, spatially explicit global livestock dataset circa 2020 that integrates feed systems, herd dynamics, animal performance, and GHG emissions within a unified framework. The harmonization of high-resolution spatial data with national statistics ensures biological realism while reducing regional biases, enabling consistent analysis of livestock production, feed use, and GHG emissions.

The results reveal strong regional specialization of livestock systems, with ruminant production widely distributed and largely supported by roughage-based diets, and monogastric production highly concentrated and reliant on concentrate feeds. These structural differences underpin the observed spatial patterns of GHG emissions

By linking production systems, feed composition, and GHG emissions within a unified framework, this approach provides a robust and flexible foundation for analyzing livestock systems in the context of food security, land use, and climate change, and for exploring future sustainability pathways.

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