The EU's Livestock Impact on the Environment: A Cluster Analysis

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1. Introduction: The Livestock-Environment Paradox

Livestock management stands as a pillar of the European rural economy, providing livelihoods for millions and ensuring food security across the 27 EU Member States. However, this sector is currently at the center of a complex "sustainability paradox." While it is a primary supporter of rural vitality, it is also a significant contributor to environmental degradation, specifically through greenhouse gas (GHG) emissions, ammonia, volatilization, and nutrient leaching.

As the European Union moves toward the goals of the Farm to Fork Strategy and the Circular Bioeconomy, the pressure on livestock producers to mitigate their environmental footprint has never been higher. This research is conducted under the auspices of the ManuRefinery project (Grant Agreement ID: 101157679), which seeks to address these challenges by developing a biorefinery model capable of converting livestock manure into high-value bio-based fertilizers. By doing so, the project aims to close nutrient loops and drastically reduce ammonia emissions, aligning animal production with the EU's climate neutrality targets.

2. Research Objective and Scope

The primary objective of this study is to classify the EU-27 Member States based on their livestock structural characteristics and environmental impact profiles. By identifying patterns of intensity and sustainability, the research aims to provide a diagnostic tool for policy tailoring. While the analysis encompasses the entire EU-27 to provide a macro-scale benchmark, a specialized focus is placed on the nine countries forming the ManuRefinery consortium. These countries represent a diverse cross-section of European livestock systems, ranging from intensive pig farming in the North-West to extensive bovine systems in the South and East.

3. Methodology: Cluster Analysis on Panel Data

The research employs a quantitative approach based on Multivariate Cluster Analysis applied to panel data. Clustering is particularly effective in this context as it allows for the grouping of

countries with similar "livestock signatures," moving beyond simple geographical proximity to reveal functional economic-environmental similarities.

3.1. Data Sources and Temporal Scope

The study utilizes the Eurostat Database, specifically drawing from:

Air Emissions Accounts

Agri-environmental Indicators: For ammonia and enteric fermentation data.

Farm Structure Surveys (FSS): To determine the weight of different livestock types and farm holdings.

A significant methodological challenge identified was the asynchronous reporting of data. Eurostat reports structural indicators (like farm counts) and environmental indicators (like emissions) at different intervals. To ensure a robust panel, the study focuses on the three most recent comprehensive data windows: 2016, 2020, and 2023.

3.2. Indicator Selection

The analysis is built upon eight core indicators that bridge the gap between production and environmental impact:

%CO_2 animal production from agriculture*	*%*	***Air emissions accounts*
%bovine from total livestock	%	Animal production-Livestock
%poultry from total livestock	%	Animal production-Livestock
%bovine farms from total agricultural holdings with livestock	%	Farm structural indicators
%pig farms from total agricultural holdings with livestock	%	Farm structural indicators
%AMMONIA	%	Agri-environmental indicators
%Organic animal farming - BOVINE	%	Farm structure
%GHG Enteric fermentation of cattle	%	Agriculture and environment-Special sector topics

4. The ManuRefinery Context: A Technological Solution

The heart of this research is linked to the ManuRefinery technological intervention. Traditional manure management is a linear process often resulting in high ammonia emissions and nitrate runoff. The ManuRefinery biorefinery concept proposes a circular shift:

Emission Reduction: Capturing nitrogen before it volatilizes as ammonia.

Import Substitution: Replacing synthetic, fossil-fuel-based fertilizers with bio-based alternatives derived from manure.

Economic Resilience: Turning a "waste disposal cost" for farmers into a "product revenue stream."

By analyzing the clusters, this study identifies which regions would benefit most from the deployment of such biorefineries based on their manure density and current emission levels.

5. Preliminary Findings and Discussion

The cluster analysis reveals three distinct "Livestock Profiles" across the EU:

Cluster A: The Intensive Specialists

Characterized by high poultry and pig density, often seen in regions of the ManuRefinery consortium. These countries show high ammonia levels but also higher technological readiness for manure processing. In these nations, the environmental impact is concentrated, making the "biorefinery" model highly viable due to the high volume of feedstock (manure) available in small geographic radii.

Cluster B: The Bovine-Extensive Tradition

Countries with a high percentage of bovine farms and significant GHG emissions from enteric fermentation. In these regions, organic farming is more prevalent, but the carbon footprint per head remains a challenge. Here, the ManuRefinery project offers a way to manage nitrogen in pasture-based systems more efficiently.

Cluster C: The Transitioning Periphery

Member states where livestock contributes a smaller portion to the total agricultural
, often due to a decline in traditional farming. These countries face the "Knowledge Gap" mentioned in previous bioeconomy studies, where the lack of infrastructure prevents the modernization of manure management.

6. Environmental and Policy Implications

The study demonstrates that a "one-size-fits-all" environmental policy for EU livestock is inefficient. For example:

Ammonia mitigation should be the priority in Cluster A (intensive pig/poultry).

Methane reduction through feed additives and manure capture should be the focus for Cluster B (bovine).

Furthermore, the research underscores the importance of the Circular Bio-based Europe Joint Undertaking (CBE JU) in de-risking the transition. The ManuRefinery project serves as a pilot for how localized innovation can solve a continental environmental problem.

7. Structural Barriers: The Data Reporting Gap

A critical conclusion of the methodological phase is the urgent need for harmonized agri-environmental data. The fact that data for 2023 is still fragmented compared to 2016 structural data creates a "policy lag." Real-time monitoring of livestock impacts is essential if the EU is to meet its 2030 targets.

8. Policy Recommendation: Tailoring Regional Bioeconomy Roadmaps

Based on the cluster analysis of the EU-27, this study proposes a "Differentiated Regional Investment Framework" for livestock waste management. Regional planners and EU policymakers should move away from "one-size-fits-all" subsidies and instead adopt place-based strategies:

For High-Intensity Clusters (e.g., North-West EU): Policy should prioritize Industrial Scale-up of biorefineries like ManuRefinery. Financial support should be directed toward high-TRL (Technology Readiness Level) projects that can immediately integrate into existing intensive value chains to meet National Emission Ceiling Directive targets for ammonia.

For Bovine-Dominant Clusters (e.g., Romania/Ireland): Recommendations focus on Cooperative Circularity. Regional development funds should incentivize the formation of "Biomass Collection Hubs," enabling smaller farms to reach the critical feedstock mass required for biorefining, thereby turning methane-intensive manure into high-value bio-based fertilizers.

Cross-Sectoral Integration: We recommend that Member States include specific "Circular Manure Management" eco-schemes in their CAP Strategic Plans (2023-2027). This would provide farmers with stable income streams for "nutrient-safe" practices, reducing the reliance on synthetic fertilizers and supporting regional soil biodiversity.

9. Conclusion

Livestock management remains the heartbeat of the European countryside, but its future depends on its ability to decarbonize. This paper provides a clear mapping of where each EU member state stands in this journey. Through the lens of the ManuRefinery project, we see that technology—specifically the conversion of manure into bio-fertilizer—is not just a technical fix, but a structural necessity.

By understanding the clusters of livestock production, we can ensure that biorefinery technologies are deployed where they can have the maximum impact on reducing ammonia and emissions. Ultimately, the sustainability of the EU rural economy depends on transforming the livestock sector from an environmental liability into a cornerstone of the circular bioeconomy.

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