

Mapping macro-environmental drivers and barriers to biowaste valorisation from dairy processing wastewater treatment facilities in Europe

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Background

- Dairy processing wastewater treatment facilities generate nutrient-rich biowaste streams, including wastewater, sludge, biosolids, dairy cattle slurry, and processing by-products.
- These streams can be valorized into energy, nutrients, water, and bio-based materials, supporting circular economy goals in European agri-food systems.
- Circular use depends on more than technology. Implementation is shaped by wider political, economic, social, technological, environmental, and legal conditions.
- Existing studies often focus on technical or environmental performance, while the macro-environmental factors that enable or constrain scale-up remain less systematically understood.
- A PESTEL-based review can identify the key levers, bottlenecks, and governance gaps affecting dairy biowaste valorisation in Europe.

Information

- Review type:** Scoping review
- Databases:** Scopus & Web of Science
- Search date:** August 2025
- Records identified:** 1,356
- Studies included:** 66
- Geographic scope:** Europe
- PESTEL factors coded:** 235
- Themes identified:** 35

Objectives

- Examine how PESTEL factors affect dairy-related biowaste valorisation in Europe.
- Map the evidence base across feedstocks, countries, study types, and valorisation routes.
- Identify recurring macro-environmental themes across the literature.
- Classify each factor as supporting, conditionally supporting, limiting, or constraining.

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Methodology

Search & screening flow

Scopus + Web of Science (n = 1,629)

Duplicates removed (n = 273)

Records screened (n = 1,356)

Full texts assessed (n = 83)

Studies included (n = 66)

Extraction & coding flow

Study characteristics extracted:

Country · Feedstock · Study type · Valorisation route · PESTEL statements

PESTEL coding:

Statements coded into 35 themes

Influence classification:

Supporting · Conditionally supporting · Limiting · Constraining

Results

Political; n = 50



Mixed influence

Economic; n = 55



Mixed influence

Social; n = 15



Under-researched

Technological; n = 57



Largely supportive

Environmental; n = 66



Largely supportive

Legal; n = 47



Strongest bottleneck



Figure 1. Heatmap of included countries

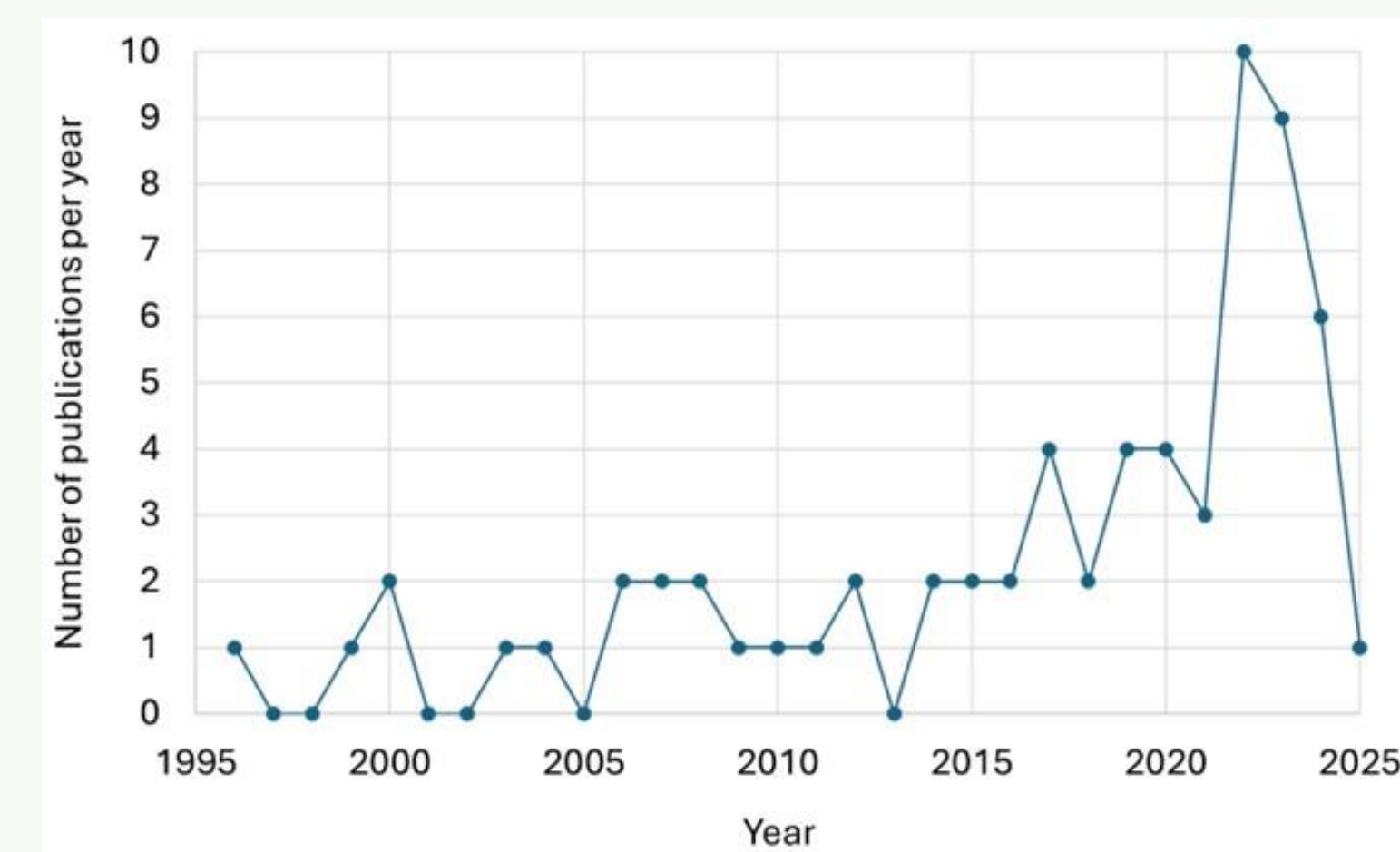


Figure 2. Number of included publications per year (n = 66) from 1996 to 2025

Table 1. PESTEL-influence matrix

Dimension	Supporting	Conditionally supporting	Limiting	Constraining
Political	CE/bioeconomy targets	nutrient-loop policies	policy ambiguity	land-spreading restrictions
Economic	fertiliser savings	emerging markets	capital/logistics costs	—
Social	rural benefits	stakeholder engagement	low adoption/knowledge gaps	health/risk concerns
Technological	mature technologies	scale-up potential	infrastructure fit	performance risk
Environmental	soil/emission benefits	nutrient recovery	site-specific trade-offs	nutrient losses
Legal	product quality standards	regulatory alignment	permitting burden	waste/product status

Findings

- Europe's macro-environment is broadly aligned with circular economy and sustainable agri-food transition goals.
- Dairy biowaste valorisation is technically feasible and environmentally promising, but implementation remains constrained by regulation, cost, uncertainty, and social acceptance.
- Legal and economic barriers can delay or prevent scale-up, even when environmental and technological evidence is favourable.
- Social and governance dimensions require more attention, especially farmer adoption, public trust, stakeholder engagement, and business models.
- Future work should integrate PESTEL, LCA, techno-economic assessment, and social research to support route-specific implementation strategies.

