

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

Daniel T. Burke ¹, Gaurav Rajauria ^{2,3}, Anushree Priyadarshini* ¹

¹ School of Business, Maynooth University, Maynooth, Ireland

² School of Microbiology, School of Food and Nutritional Sciences, University College Cork, Cork, Ireland

³ SUSFERM Centre for Sustainable Fermentation and Bioprocessing Systems for Food and the Bioeconomy, University College Cork, Cork, Ireland

Corresponding Author: anu.priyadarshini@mu.ie

Abstract

Introduction

While dairy wastewater treatment yields vast quantities of nutrient-dense biowaste, the macro-environmental drivers and barriers affecting its integration into Europe's circular economy remain inadequately understood. This study examines the political, economic, social, technological, environmental, and legal (PESTEL) factors influences the viability of biowaste from dairy-related processing and wastewater treatment facilities as a feedstock in Europe.

Material and Methods

A total of 1,356 studies were identified from online bibliographic database Scopus and Web of Science and 66 of these studies from European countries met the predefined eligibility criteria. Statements related to the macro-environmental factors (using PESTEL framework) were extracted and coded into 35 themes. Using a dimension-theme-influence triad these were classified as supporting, conditionally supporting, limiting, or constraining influences.

Results and Discussion

Findings highlight varying influence across the six PESTEL dimensions. Environmental (n=66) and technological (n=57) factors were the most prominent and largely supportive, driven by a mature suite of treatment technologies, significant soil-health benefits, and favourable emission profiles. Political and economic factors presented a mixed landscape, while bioeconomy targets and fertilizer-security concerns generally support valorisation, high capital requirements and logistical costs continue to hinder widespread adoption. Legal factors emerged as the most significant bottleneck, with rigid land use, water quality, and product-standard regulations acting as primary constraints. Finally, social factors (n=15) were notably under researched, appearing infrequently and with limited depth compared to the more technical and environmental drivers.

Conclusions

Overall, while Europe's macro-environment is aligned with circular economy objectives, practical implementation is hindered by regulatory complexity, inconsistent economic drivers, and a lack of focus on social and governance dimensions. The resulting PESTEL-influence matrix offers a

decision-support map to identify critical levers and bottlenecks across all six dimensions, providing a framework for policymakers and investors to align regulations, prioritize capital, and address the often overlooked social gaps in the bioeconomy.

Keywords: Circular bioeconomy; sludge; digestate; nutrient recycling; nutrient recovery

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