Verification of economic feasibility and environmental sustainability of incorporating unsold bakery products into compound feed

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Abstract

This paper presents an innovative business model for the production of compound animal feed using unsold bakery products, addressing the dual challenges of food waste reduction and sustainable livestock nutrition. The process involves the collection, de-packaging, drying, milling, and enrichment of surplus bread and pastries, transforming them into high-quality feed for cattle, pigs, and poultry. Applying the Triple Layer Business Model Canvas (TLBMC), we assess economic, environmental, and social impacts. Life cycle inventory and cost-benefit analyses indicate that replacing up to 30% of conventional feed ingredients with bakery-derived components can reduce greenhouse gas emissions by nearly 30% CO_2 annually and lower feed costs for farmers. The model supports local supply chains, reduces reliance on imported soy and corn, and creates new opportunities for collaboration between bakeries, feed mills, and farmers. Policy recommendations include the establishment of digital traceability systems and legal frameworks to facilitate surplus food valorization.

INTRODUCTION

Food waste is a significant global issue, with approximately 13% of produced food discarded at the retail and consumer levels, much of it still suitable for consumption (FAO, 2023). Bakery products, due to their short shelf life, constitute a major portion of this waste stream. Conventional disposal methods, such as landfilling or anaerobic digestion, fail to utilize the nutritional value of surplus bread and pastries, while livestock production (in particular hogs, poultry, and cattle) in Slovenia continues to depend heavily on imported feed ingredients like soy and corn. This dependence not only increases production costs but also contributes to harmful displacement effects (eg. stimulating further deforestation and monocultures in South America, emissions from long-distance transport).

To address these challenges, we propose a circular economy solution: the conversion of unsold bakery products into compound animal feed. This business model leverages local resources, reduces food waste, and enhances sustainability in the agricultural sector. The Triple Layer Business Model Canvas (TLBMC) framework, developed by Joyce and Paquin (2016), enables a holistic assessment of economic, environmental, and social dimensions. Our aim is to evaluate the feasibility, benefits, and limitations of integrating bakery waste into animal feed production, and to provide recommendations for stakeholders and policymakers.

METHODS

The process of producing animal feed from unsold bakery products is designed as a comprehensive, multi-stage system that maximizes resource efficiency and sustainability. The first stage involves the systematic collection and logistics of surplus bakery items such as bread, pastries, and dough, sourced from bakeries, food processors, and retailers. Establishing reliable partnerships and efficient logistics is essential to ensure that these products are collected promptly, thus preventing spoilage and maintaining the nutritional quality required for animal feed production (FAO, 2023). Direct collaboration with bakeries is preferred, as it enables consistent supply and easier coordination, but cooperation with retailers is also feasible, provided legal requirements for food surplus use are met. Current cost of collection surplus bakery items averages from 0-80€/t.

Upon arrival at the processing facility, bakery products are subjected to de-packaging and pre-treatment. Many items are delivered in plastic packaging, which is removed using a specialized de-packaging machine with a capacity of 500 kg per hour. For raw dough, thermal treatment (baking) is applied to ensure microbiological safety and product stability. This step is crucial, as it prevents contamination and extends the shelf life of the feed component. The next phase is drying, where products are processed in industrial drying chambers. This controlled drying prevents mold growth and ensures the long-term stability of the feed. The dried products are then milled to a particle size of 2–3 mm using industrial mills, which enhances digestibility for livestock and allows for homogeneous mixing with other feed components.

Mixing and enrichment follow, where the milled bakery fraction is blended with protein sources (such as soybean meal or sunflower meal), minerals, and vitamins. The target inclusion rate for bakery-derived material is 30% of the final feed mix, balancing energy content and digestibility while meeting the nutritional needs of cattle, pigs, or poultry. Industrial mixers ensure even distribution of all ingredients, resulting in a consistent and high-quality compound feed. After mixing, the feed is packaged in bags or stored in bulk, depending on the needs of farms and feed mills. Packaging involves weighing, filling, and sealing, which facilitates transport and storage. The entire process, from collection to packaging, is designed for efficiency and traceability, supporting both food safety and supply chain transparency.

A life cycle inventory (LCI) was established for a model facility processing 500 tons of bakery surplus annually. System boundaries included collection, processing, and distribution. Energy consumption was estimated at 155 kWh per ton of input, totalling 77.500 kWh per year. Environmental impacts were assessed using EcoInvent v3.8 emission factors, focusing on greenhouse gas emissions (CO_2 equivalents). Key environmental benefits include the reduction

of methane emissions from landfill avoidance and the substitution of imported soy and corn, which are associated with significant carbon footprints (EcoInvent Database, 2022).
Economic analysis encompassed capital and operational expenditures, including labour costs for two full-time employees, energy, maintenance, and raw material acquisition. Sensitivity analyses considered fluctuations in the price of bakery surplus and energy. The business model was evaluated using the Triple Layer Business Model Canvas (TLBMC), which structures the analysis across economic (value proposition, cost structure, revenue streams, partnerships), environmental (resource efficiency, emission savings, circularity), and social (stakeholder benefits, job creation, supply chain resilience) dimensions (Joyce & Paquin, 2016).
This integrated methodological approach ensures that the production of animal feed from unsold bakery products is assessed not only for technical and economic feasibility but also for its broader environmental and social impacts, supporting the transition to a circular bioeconomy (Osterwalder & Pigneur, 2010; Joyce & Paquin, 2016).

Results

The results of the assessment indicate that substituting up to 30% of conventional feed ingredients with bakery-derived material leads to substantial environmental and economic benefits. For an annual processing volume of 500 tons of bakery products, the total avoided greenhouse gas emissions were estimated at 269.6 tons of CO_2 equivalents per year We estimate that we have reduced the protein requirement from soy by 30%. According to EcoInvent data, the production of 100 tons of soy results in 301 tons of CO_2 emissions. This means our reduction translates to a savings of 270 tons of CO_2, or approximately 29.9%. These savings were achieved through several mechanisms: the diversion of bakery waste from landfill, which reduced methane emissions; the replacement of imported soy and corn, particularly from South America, where 77% of soy-related emissions are attributed to deforestation and logistics; and a reduction in water and land use compared to traditional feed crops (EcoInvent Database, 2022).
The life cycle inventory confirms that the energy requirement for processing is 77.500 kWh per year, or 155 kWh per ton of input. The bakery-based feed successfully replaced 30% of the soy and corn components in compound feed, resulting in a 30% reduction in water use compared to conventional feed production.
From an economic perspective, the total production cost for bakery-based feed ranged from €0.15 to €0.23 per kilogram, depending on the price of raw bakery inputs (assumed between €0 and €80 per ton). This cost is competitive with the average market price of corn (€0.28/kg) from 2018 to 2025 (Agricultural Institute of Slovenia, 2025). The net present value (NPV) of the investment over a 10-year period for the production of 500 tons yearly was calculated at €221.520 and with an internal rate of return (IRR) of 52%. The project supported two full-time jobs and generated annual revenues of €150.000, assuming full capacity utilization.
The business model also fostered collaboration between bakeries, retailers, feed mills, and farmers. Bakeries benefited from reduced disposal costs and enhanced corporate responsibility, while farmers accessed affordable, high-quality feed. The local economy was strengthened through job creation in logistics and processing, and the model contributed to greater food system resilience by reducing reliance on global supply chains and imported feed ingredients. Overall, the results demonstrate that the valorization of bakery surpluses into animal feed is both environmentally and economically sustainable, with significant social benefits for local communities.

Discussion

The findings of this study demonstrate that integrating unsold bakery products into compound animal feed production offers significant environmental, economic, and social advantages. Environmentally, the valorization of 500 tons of bakery surplus per year resulted in a reduction of approximately 270 tons of CO_2 emissions annually, primarily due to the avoidance of landfill methane and the substitution of imported soy and corn, which are associated with high carbon footprints and deforestation, especially in South America (EcoInvent Database, 2022). The process also led to a 30% reduction in water use compared to conventional feed production, further supporting sustainable resource management.
Economically, the production cost for bakery-based feed, ranging from €0.15 to €0.23 per kilogram, proved competitive with the market price of corn, and the calculated net present value and internal rate of return affirm the financial viability of the business model (Agricultural Institute of Slovenia, 2025). This is particularly relevant in the context of rising feed prices and increasing pressure on farmers to reduce input costs. The model also supports job creation, as two full-time positions are required to operate the production line, and it fosters local economic resilience by strengthening supply chains and reducing dependence on global commodity markets.
Socially, the business model encourages collaboration among bakeries, retailers, feed mills, and farmers, leading to reduced food waste, enhanced corporate responsibility, and improved food system resilience. By transforming a waste stream into a valuable resource, the model not only addresses sustainability goals but also contributes to the circular economy and local food security (Joyce & Paquin, 2016). However, the success of such initiatives depends on establishing reliable supply chains, maintaining high standards of food safety and traceability, and ensuring supportive policy frameworks. The implementation of digital platforms for surplus tracking and transparent legal guidelines would further facilitate the scaling of this model.
Compared to traditional animal feed production, the use of bakery surpluses as feed ingredients provides a clear pathway to reducing the environmental footprint of livestock farming, supporting EU Farm-to-Fork and circular economy strategies. Nevertheless, challenges remain, particularly in ensuring consistent supply quality and

overcoming logistical barriers. Further research should focus on optimizing nutrient formulations, assessing long-term animal health impacts, and evaluating the scalability of the model in different regional contexts.

Conclusion

This study confirms that the production of compound animal feed from unsold bakery products is a viable and sustainable strategy for reducing food waste and supporting circular agriculture. The approach delivers measurable environmental benefits, including substantial reductions in greenhouse gas emissions and resource use, while also offering economic gains for feed producers and farmers. Socially, the model strengthens local supply chains and creates employment opportunities, contributing to greater food system resilience. For successful implementation, it is essential to establish efficient collection systems, robust quality control, and supportive policy measures, such as digital traceability platforms and clear regulatory frameworks. Overall, the valorization of bakery surpluses into animal feed represents a replicable and scalable solution for advancing sustainability in the agri-food sector.

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