23 Gennaio 2026

Applicazione del LCA alle filiere agro-alimentari

Food waste to reduce food waste

The circular story of bio-derived active packaging in the **AgriBioPack** *project*

Agata Costanzo[1], Francesca Albano[1], Serena Fabbri[1], Serena Carpentieri[2], Giovanna Ferrari[2], Francesco Donsì[2], Monia Niero[1]

[1]Scuola Superiore Sant'Anna, Centro Interdisciplinare per la Sostenibilità e il Clima, Pisa, Italia
[2]Università degli Studi di Salerno, Dipartimento di Ingegneria Industriale, Salerno, Italia

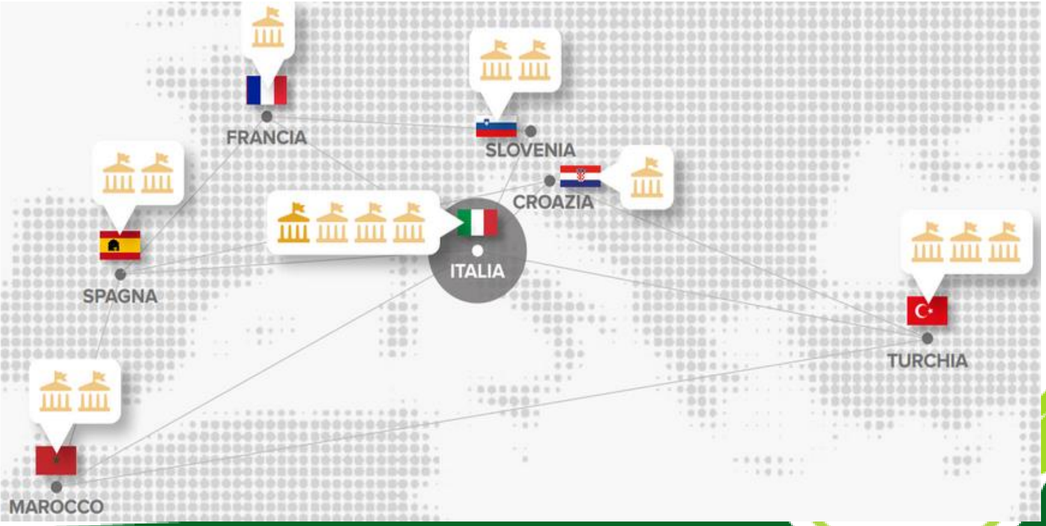
What is AgriBioPack?

Valorizing Agrifood Residues for Bio-based Packaging Solutions.
June 2024-June 2027 (1 year extension requested)

PRIMA is a funding programme linking research and innovation between EU countries and Mediterranean partners on sustainable water, agriculture, and food.

AgriBioPack has partners in:

- Italy (University of Salerno, University of Perugia, Sant'Anna School of Advanced Studies, X-Team)
- Turkey (Istanbul Technical University, Ege University, Yeditepe University)
- Morocco (National School of Agriculture, Université Mohammed V)
- Spain (Lleida University, University of Granada)
- Croatia (University of Split)
- France (University of Technology of Compiègne)



What is AgriBioPack?

AgriBioPack develops **bio-based active packaging** solutions that can modulate the microbiome in **Mediterranean food products**, contributing to improving their marketability by **extending their shelf life** and **reducing food waste**. The bio-based packaging solutions will be derived from **agrifood residues**, both for the **structural and functional components**.

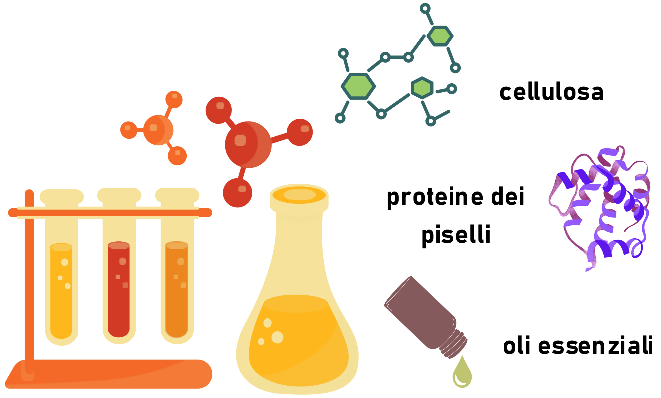
"Active packaging is defined as packaging that modifies the condition of the packed food, so as to extend its shelf life and improve its safety (Ahvenainen, 2003)."

What is AgriBioPack?

AgriBioPack develops **bio-based active packaging** solutions that can modulate the microbiome in **Mediterranean food products**, contributing to improving their marketability by **extending their shelf life** and **reducing food waste**. The bio-based packaging solutions will be derived from **agrifood residues**, both for the **structural and functional components**.

Agrifood residues

Olive waste, grape pomace, apple pomace, onion peels, pomegranate juice residues, and pea waste



Mild extraction techniques

Hydrodynamic Cavitation, Ultrasounds, and Microwaves to extract biopolymers, functional compounds (antimicrobial and antioxidant). Microbiome from residues through fermentation processes

Active packaging

Formulation of bio-based and biodegradable packaging (starting from PLA and pea proteins), using recovered extracts with reinforcing or antimicrobial properties

What do we do? WP7 Leader

WP7: Sustainability Assessment

Assesses the **overall sustainability** of the proposed bio-packaging solutions and newly designed food products.

- Techno-Economic Analysis (TEA) (University of Salerno, IT)
- Life Cycle Assessments (LCA) (Sant'Anna School of Advanced Studies, IT)
- Life Cycle Costing (LCC) (Sant'Anna School of Advanced Studies, IT)
- Market Analysis (University of Salerno, IT)
- Stakeholder Engagement Plan (National School of Agriculture, MR)
- Business Model Development (University of Salerno, IT)

What about LCA?

From an LCA modeling perspective, the AgriBioPack project offers some interesting aspects..

Modelling extraction processes from food waste streams

Extraction pathways developed at lab scale

Allocation choices for agri-food residues (waste vs by-product vs co-product)

Bio-derived and biodegradable formulation

Lab-scale production of PLA-based solutions

Do additives influence biodegradability and end-of-life?

Quantification of shelf-life extension

How can shelf life be integrated into the LCA?

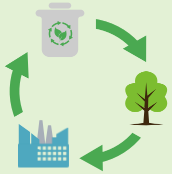
How to link prolonged shelf life to reduced losses at retail and consumer stages?

First things first: The literature

To understand the current status of research around LCA, active packaging, and shelf life extension, a **scoping literature review** was performed.

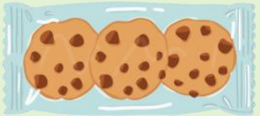
LCA

"life cycle assessment" or LCA or "environmental impact assessment" or "life cycle analysis"



Active packaging

“active packaging" or " functional packaging" or "smart packaging" or "intelligent packaging" or "responsive packaging"



Shelf life

"shelf life" OR "prolonged life" OR "extended life"

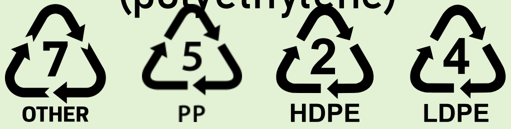
Entries from Scopus (n= 26) → Entries screening (n= 10)

Exclusion criteria: non-LCA studies and literature reviews only mentioning potential environmental benefits of smart packaging applications

The literature: overview

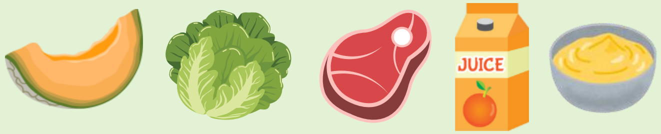
All studies perform **comparative** LCAs of active or functionalised versus conventional packaging

Most studied polymers: **PLA** (polylactic acid), PP (polypropylene), and PE (polyethylene)

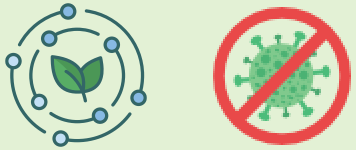


Functional properties from: chitin, nanoclays, ZnO, oregano essential oils, bacterial coating

Food products: Fresh foods (beef, melon, lettuce, strawberries), juice, and pastry cream



Active packaging improves antioxidant and antimicrobial properties, increasing shelf life



The literature: LCA

System boundaries

- cradle-to-grave (8, 2 excluding use),
- cradle-to-gate (2)

Modelling extraction processes from food waste streams

The majority of papers adopt a **burden-free** approach for agrifood residues used for extracting active compounds.

Always a good idea?

Functional Unit

Three main approaches for FU definition:

Type of packaging (4)

“a bag of 200 ml capacity (empty packages)”

Food delivered (6)

“delivering 1 kg fresh beef to the retail gate until its end of shelf life.”

Food consumed (2)

“a serving (130 g) of fresh cut lettuce ingested by the final customer”

Shift from **mass-based** to **service-based** FU

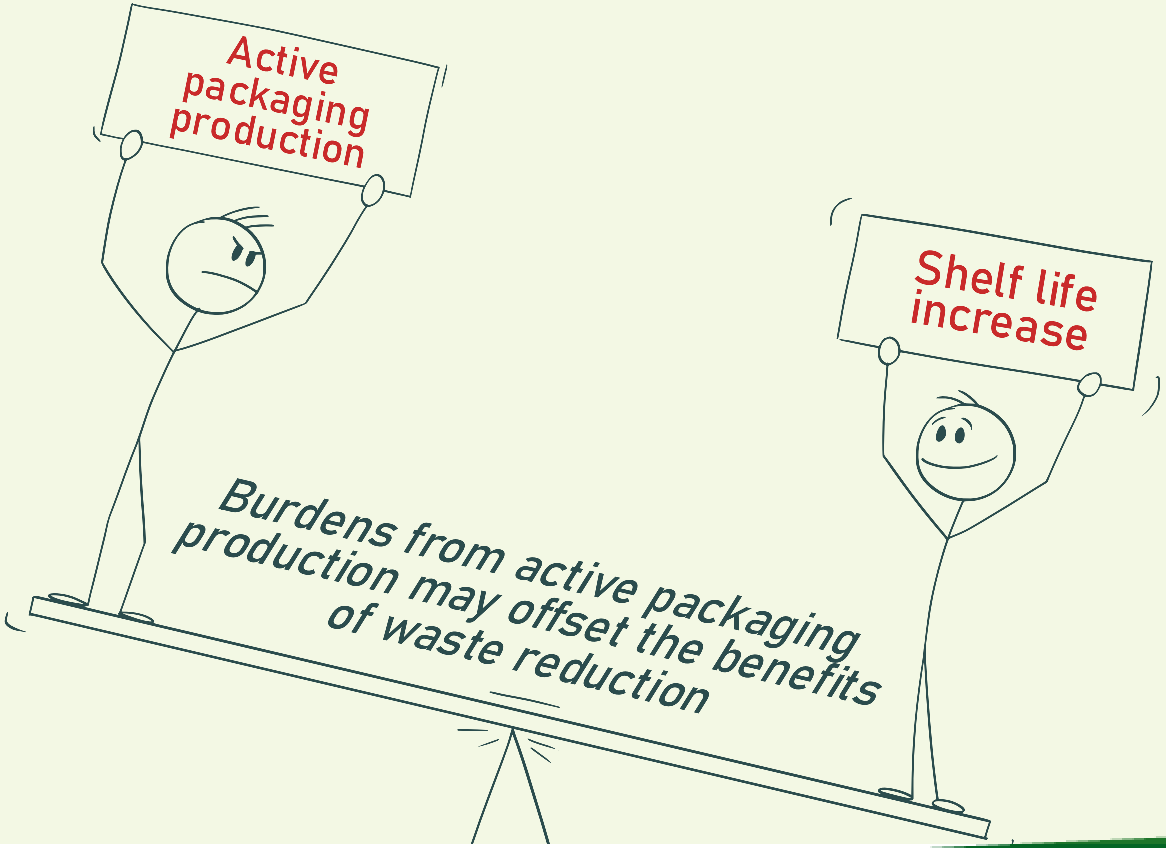
Shelf life

Shelf life extension (in terms of number of days), either derived from laboratory tests (6) or literature data (3).
Scenario analysis is often used.

The literature: LCA

Food waste reduction

Shelf-life extension does not automatically translate into a net environmental benefit or waste reduction.



The literature: LCA

Food waste reduction

Shelf-life extension does not automatically translate into a net environmental benefit or waste reduction.

Scenario analysis based on assumptions (food loss (wi, %) (Zhang et al. 2015, Stramarkou 2022, 2025)

$w1 = 30\%$ $w2 = 10\%$ $w3 = 5\%$

50% probability that a product with 2 days left is purchased. Higher n (shelf life), lower loss (w). (Lorite et al. 2017)

$w = (2/n)*0.5.$

Mathematical relationship between shelf life (n) and probability of not being sold (p) and becoming waste (w) (Settier-Ramirez 2022).

$$p = 1 - \sqrt[n]{1-(1-w)}$$

Food loss probability (w) is modeled as linear and kinetic functions of shelf life (n) (Vigil et al. 2020)

$w \propto \text{-}n$ $ln(w) \propto \text{-}n$

AGRI BIO PACK

What to do in AgribioPack?

*A bit of **LCA design***

System boundaries and allocation rules

Understand the **TRL** of packaging production processes, from extraction of active compounds to production of functional films. Explore different **allocation rules**, depending on the agrifood residues under study.

Functional unit

"*a certain amount of food, ingested by the final user*"

- Account for food losses as influenced by packaging-induced shelf-life extension
- Compare different types of packaging

Food loss reduction

Investigate the relationship between **shelf life** increase and food **loss reduction**, exploring different approaches, and including **consumer-related information**.

References

- Stramarkou, M. et al. (2025). *Evaluating the sustainability of Tetra Pak smart packaging through life cycle and economic analysis.* **Sustainability**, 17(11), 4810. https://doi.org/10.3390/su17114810
- Wang, J.-D. et al. (2024). *A degradable multifunctional packaging based on chitosan/silk fibroin incorporating cellulose nanocrystal-stabilized cinnamon essential oil Pickering emulsion*. **Food Hydrocolloids**. https://doi.org/10.1016/j.foodhyd.2024.109978
- Srivastava, V., Singh, S. and Das, D. (2024). *Environmental impact assessment of active biocomposite packaging and comparison with conventional packaging for food application*. **NordDesign 2024 Conference Proceedings**. https://doi.org/10.35199/norddesign2024.43
- Villanova-Estors, R. et al. (2023). *Environmental consequences of shelf-life extension: Conventional versus active packaging for fresh-cut salads*. **Agronomy**, 13(11), 2749. https://doi.org/10.3390/agronomy13112749
- Stramarkou, M. et al. (2022). *Life cycle assessment and preliminary cost evaluation of a smart packaging system*. **Sustainability**, 14(12), 7080. https://doi.org/10.3390/su14127080
- Settier-Ramírez, L. et al. (2022). *Assessing the environmental consequences of shelf-life extension: Conventional versus active packaging for pastry cream*. **Journal of Cleaner Production**, 330, 130159. https://doi.org/10.1016/j.jclepro.2021.130159
- Vigil, M. et al. (2020). *Sustainability analysis of active packaging for the fresh-cut vegetable industry by means of attributional and consequential LCA*. **Sustainability**, 12(17), 7207. https://doi.org/10.3390/su12177207
- Lorite, G.S. et al. (2017). *Evaluation of physicochemical and microbial properties and life cycle assessment of PLA-based nanocomposite active packaging*. **LWT – Food Science and Technology**, 78, 23–31. https://doi.org/10.1016/j.lwt.2016.09.004
- Cinelli, P. et al. (20217). *Degradability and sustainability of nanocomposites based on polylactic acid and chitin nano fibrils. Chemical* **Engineering Transactions.** 10.3303/CET1760020
- Zhang, H. et al. (2015). *The effect of active packaging on minimizing food losses: Life cycle assessment of essential oil component-enabled packaging for fresh beef*. **Packaging Technology and Science**, 28, 761–774. https://doi.org/10.1002/pts.2135

Thanks for your attention!

Agata Costanzo, Francesca Albano, Serena Fabbri, Serena Carpentieri, Giovanna Ferrari, Francesco Donsì, Monia Niero

agata.costanzo@santannapisa.it