

INVESTIGACIÓN EN MARCHA

TESIS DOCTORAL
CURSO 2023-24



PROGRAMA DE DOCTORADO EN
MEDIO AMBIENTE Y SOSTENIBILIDAD



**DOCTORADO EN
MEDIO AMBIENTE Y SOSTENIBILIDAD**

UNIVERSIDAD MIGUEL HERNÁNDEZ DE ELCHE

ECONOMÍA CIRCULAR EN CALZADO MEDIANTE EL ANÁLISIS DE CICLO DE VIDA



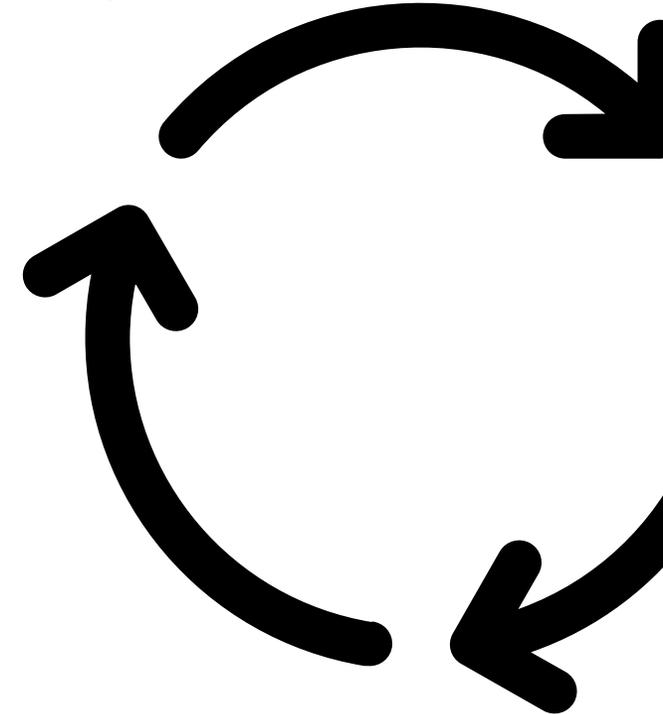
Doctorando: Borja Mateu Romero

Directores: Maria Belen Almendro Candel e Ignacio Meléndez Pastor

Director industrial: Francisca Arán Ais (INESCOP)

Tutor: Jose Navarro Pedreño

Departamento: Agroquímica y Medio Ambiente - UMH



ECONOMÍA CIRCULAR EN CALZADO MEDIANTE EL ANÁLISIS DE CICLO DE VIDA

Líneas de investigación:

1. Reciclado mecánico de calzado



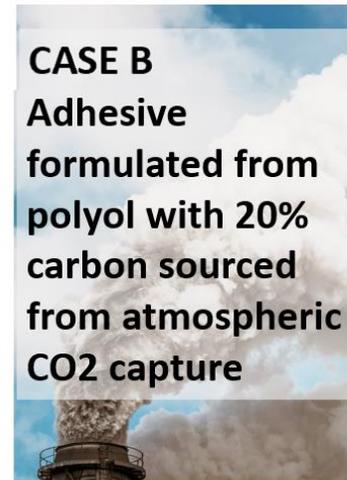
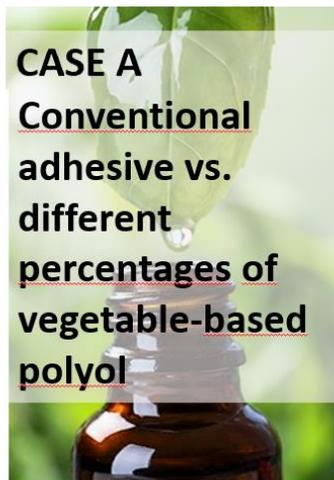
2. Análisis de ciclo de vida



ECONOMÍA CIRCULAR EN CALZADO MEDIANTE EL ANÁLISIS DE CICLO DE VIDA

Ponencia oral

→ The objective of this case study is to analyze whether a reduction in environmental impact is achieved by incorporating bio-based materials into the composition of adhesives and how this affects the rest of the value chain



XXII Congreso Internacional Adhesión y Adhesivos 2023
16 y 17 nov. MÁLAGA

CERTIFICADO DE PONENCIA

D. Borja Mateu Romero

De INESCOP, ha presentado la ponencia titulada: "Environmental assessment of commercial vs. Biobased adhesives: A technical comparative analysis" y co-autores: M. B. Almendro-Candel, I. Melendez-Pastor, J. Navarro-Pedreño, E. Orgilés-Calpena, F. Arán-Ais.

Orgilés Calpena, en el XXII Congreso Internacional de Adhesión y Adhesivos celebrado los días 16 y 17 de noviembre de 2023, en Málaga, España.

Y para que conste, a los efectos oportunos, se expide el presente certificado.

En Málaga, a 17 de noviembre de 2023.

 20
Dra. Francisca Arán Ais
Secretaría GEAA. ASEFCA


D. Carlos Ruzafa Silvestre
Secretaría ASEFCA



PATROCINADO POR



COLABORADORES



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PROGRAMA DE DOCTORADO EN
MEDIO AMBIENTE Y SOSTENIBILIDAD

UNIVERSITAT
Miguel Hernández

Ponencia oral



Jornada Técnica: Introducción al Análisis de Ciclo de Vida

4 diciembre 2023



Introducción al Análisis de Ciclo de Vida

Jornada técnica gratuita.

El Análisis de Ciclo de Vida (ACV) emerge como una opción laboral crucial en la actualidad debido a su papel fundamental en la toma de decisiones empresariales responsables.

El objetivo de esta jornada es el de conocer las posibilidades de los cálculos de Análisis de Ciclo de Vida, las metodologías disponibles y las principales aplicaciones actuales.

Ponente: Borja Mateu Romero, licenciado en Ciencias Ambientales con Máster en Ingeniería Ambiental y doctorando en Medio Ambiente y Sostenibilidad, experto en Análisis de Ciclo de Vida y Ecodiseño

ECONOMÍA CIRCULAR EN CALZADO MEDIANTE EL ANÁLISIS DE CICLO DE VIDA

Asistencia a congreso



ECONOMÍA CIRCULAR EN CALZADO MEDIANTE EL ANÁLISIS DE CICLO DE VIDA

Presentación de poster



LIFE CYCLE ANALYSIS OF DIFFERENT END-OF-LIFE SCENARIOS FOR FOOTWEAR



B. Mateu-Romero^{1,2*}, M. B. Almendro-Candel¹, I. Melendez-Pastor², A. Amat-Bernabeu¹, J. Navarro-Pedreño¹, AB. Muñoz-Milán¹, E. Orjales-Calleja¹, F. Arán-Ris-
¹ INESCOP, Footwear Technological Centre, 03600 Elda (Alicante), Spain. bmateu@inescop.es
² Department of Agrochemistry and Environment, Miguel Hernández University of Elche, 03202 Elche (Alicante), Spain.



1. INTRODUCTION AND OBJETIVE
 In the footwear sector, with an estimated world production of 25.5 billion pairs by 2025, the current linear economic model generates considerable resource loss and high environmental impacts. In this sense, the deployment of circular economy model aims at optimizing the use of resources and minimize waste generation through a closed cycle of production and consumption. In response to this, different innovative solutions based on mechanical, chemical, and biological recycling of footwear and its components have been considered because they represent key processes for implementing circular economy models, in line with the requirements of the future Ecodesign for Sustainable Products Regulation (ESPR). Therefore, the objective of this work is to determine the environmental impacts at the different stages of the footwear life cycle, as well as analyze alternatives end-of-life (EoL) scenarios and how advanced recycling processes allow for the acquisition of raw materials with low environmental impact. Evaluate current and future recycling strategies, as well as the role of eco-design in adapting footwear to circular economy models.

2. METHODOLOGY
Product: EU-manufactured pair of leather shoes with cardboard packaging.
Data: Provided by the manufacturer.
End-of-Life: Modeled on Inescop's footwear recycling pilot plants.
Standards: Aligned with Product Environmental Footprint Category Rules (PEFCR) draft for apparel and footwear methodology.
Functional Unit: 1 pair of size 42 EU shoes with primary packaging, total weight of 2036 g with data referring to February 2024.
Subcategory 13: boots, CPW/NICE code 15.20.13. Footwear with uppers of leather, other than sports footwear; footwear incorporating a protective metal toe-cap and miscellaneous special footwear. These mountain boots are designed to last 100 uses according to the PEFCR.
System Boundaries from cradle to grave: LCS1: Extraction and preprocessing of raw materials, LCS2: Manufacturing of components and shoe cementing, LCS3: Distribution and sale of the product, LCS4: End of life, with different alternative scenarios. *Note: The use phase (LCS4) is excluded from the study due to undefined models for calculating product durability.
Software and Database: Software: SimaPro 9.6 Database: Ecoinvent 3.10
Considered Impact Categories: The study focuses on the carbon footprint category to maximize understanding: Climate change Indicator: Global Warming Potential (GWP100) Unit: kg CO₂e Impact Assessment Method: Baseline model of 100 years of IPCC (based on IPCC 2013)
Considerations: (1) The current end-of-life scenario considered for footwear assumes 10% reuse, 48% landfill, and 42% incineration with energy recovery. Additionally in this work, alternative scenarios have been evaluated based on mechanical recycling processes using shredders, magnetic separators, and density separation for a capacity of 500 kg/h, developed by Inescop. (2) Furthermore, the current scenario of virgin raw materials such as vulcanized rubber and polyurethane (PUR) was compared to footwear materials ending in the conventional route (1) versus chemical recycling processes through rubber devulcanization and polyurethane glycolysis. What is more, biological recycling of leather through accelerated composting was also considered. A prior mechanical recycling process is necessary before chemical and biological recycling. Primary data from Inescop pilot plants were used for this purpose.

3. RESULTS AND DISCUSSION
 The greatest environmental impacts occur during the extraction and processing of raw materials (LCS1), which is typical of the linear economy model that entails considerable environmental effects (LCS5) and a loss of highly recyclable materials. The current end-of-life scenario for footwear by default represents 3.2% of the total analyzed footwear's environmental impact. Nevertheless, when mechanical recycling is considered as end-of-life scenario a decrease of 50% is achieved, which could represent approximately a reduction of 12,000 t of CO₂ per year by 2025 considering global production. It is due to the separation of polymer fractions, leather, metals, textiles and foams, materials that composed of the shoe, for further use as secondary raw materials that can be reintegrated into new footwear products or other industries such as composites for playgrounds or as construction insulation materials, among others, thereby creating industrial symbiosis.
 Moreover, chemical and biological recycling of the recovered materials after a mechanical recycling, despite of increasing the environmental impact, maximizes applications and value of the recovered materials. Advanced chemical and biological recycling processes can yield materials that enable upcycling or closed-loop material cycles. Therefore, these materials have been compared with conventional materials in the current scenario. Chemical recycling has a moderate impact, with potential focused on specific materials. In this case, only the sole part made of rubber and polyurethane (34% and 6% of the shoe's weight, respectively) has been considered. Biological recycling allows for materials to be reintegrated into the value chain, leather components account for 21% of leather in the analyzed model.

LCA of a pair of boots

LCS5	3%
LCS3	1.5%
LCS2	27.5%
LCS1	68%

Different EoL scenarios

Current end-of-life scenario	2.91 kg CO ₂ e
Mechanical recycling of footwear	1.20 kg CO ₂ e
Chemical recycling of footwear	2.24 kg CO ₂ e
Biological recycling of footwear	0.87 kg CO ₂ e
Biological recycling of footwear	0.50 kg CO ₂ e
Biological recycling of footwear	3.50 kg CO ₂ e

New models of circular economy

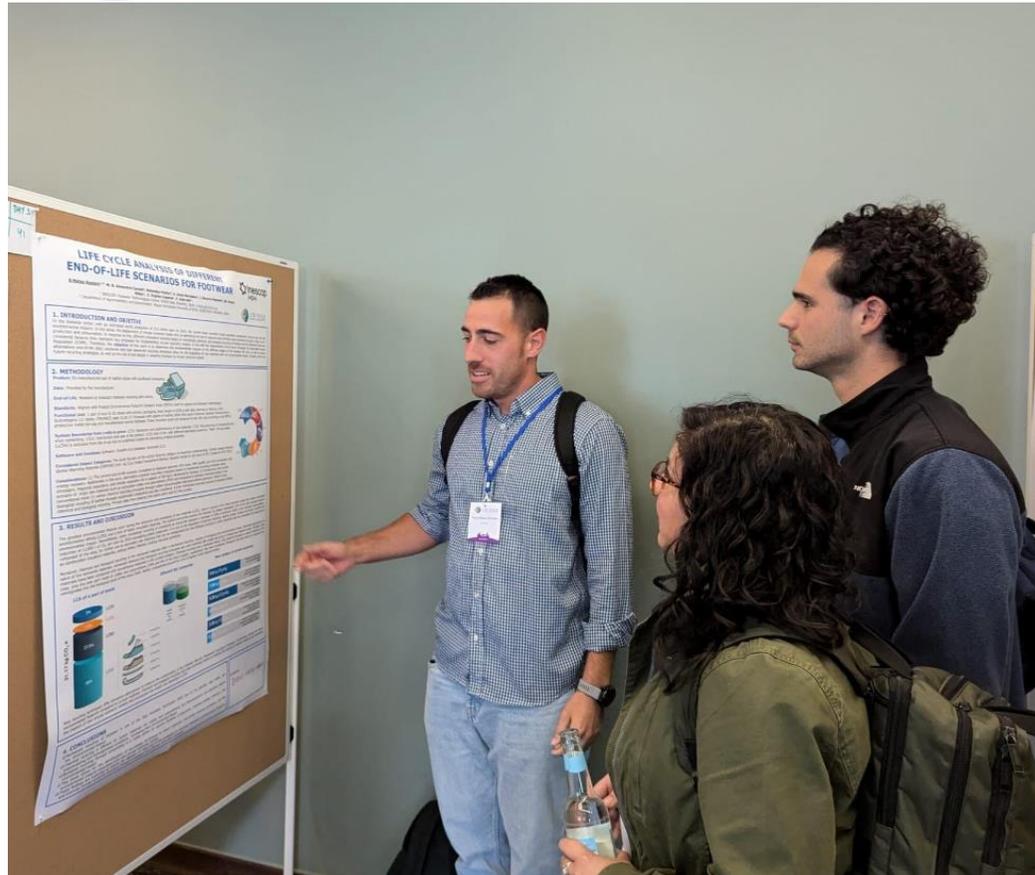
Production of virgin rubber + EoL, conventional footwear + rubber	6.65 kg CO ₂ e/kg
Production of devulcanized rubber through mechanical + chemical recycling	1.99 kg CO ₂ e/kg
Production of virgin polyurethane + EoL, conventional footwear + polyurethane	5.39 kg CO ₂ e/kg
Production of devulcanized polyurethane through mechanical + chemical recycling	0.40 kg CO ₂ e/kg
Production of compost from organic waste + EoL, conventional footwear + leather	2.39 kg CO ₂ e/kg
Production of compost through mechanical recycling of footwear + biological recycling of leather	0.41 kg CO ₂ e/kg

New recycling techniques offer attractive alternatives to enhance the sustainability of the footwear lifecycle. Mechanical recycling of footwear, in particular, exhibits the lowest environmental footprint compared to current methods. Chemical and biological recycling also showing promising results by enabling the recovery of specific materials and facilitating the creation of new circular economy models that incorporate low-impact raw materials in LCS1.

4. CONCLUSIONS

- Mechanical recycling of footwear is one of the Best Available Techniques (BAT) due to its capacity, high yields, and low environmental impact.
- Chemical recycling is efficient for certain materials like rubber and polyurethane, but devulcanization and glycolysis require preprocessing and homogeneous conditions, increasing their environmental impact.
- Biological recycling through composting is a viable option for specific footwear components, including leather, offering a low environmental impact.
- This study allows for the identification of eco-design techniques to select materials, end-of-life recycling pathways, and the environmental impacts associated with new circular economy models.
- These findings are expected to inform the industry on best end-of-life strategies to minimize footwear's environmental footprint and promote circular economy solutions through eco-design and efficient recycling strategies.

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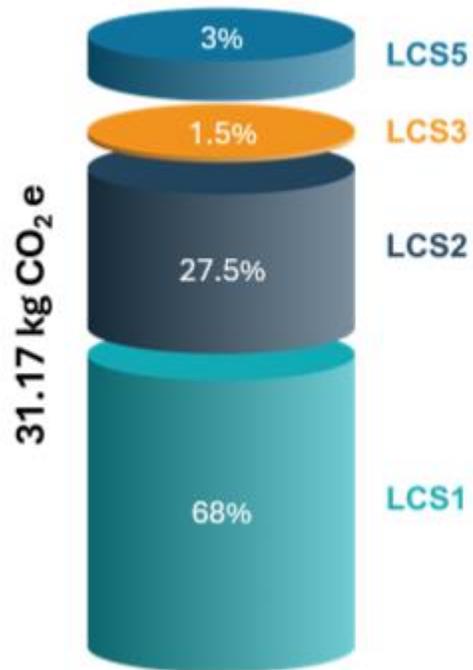
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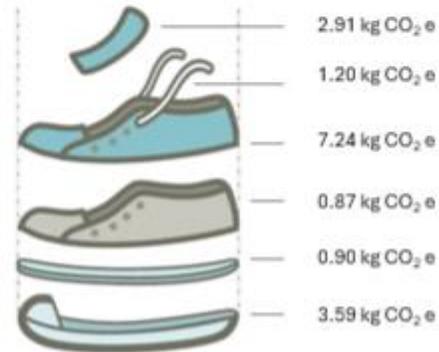
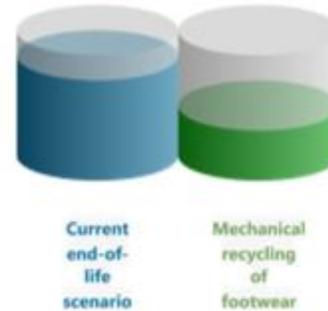
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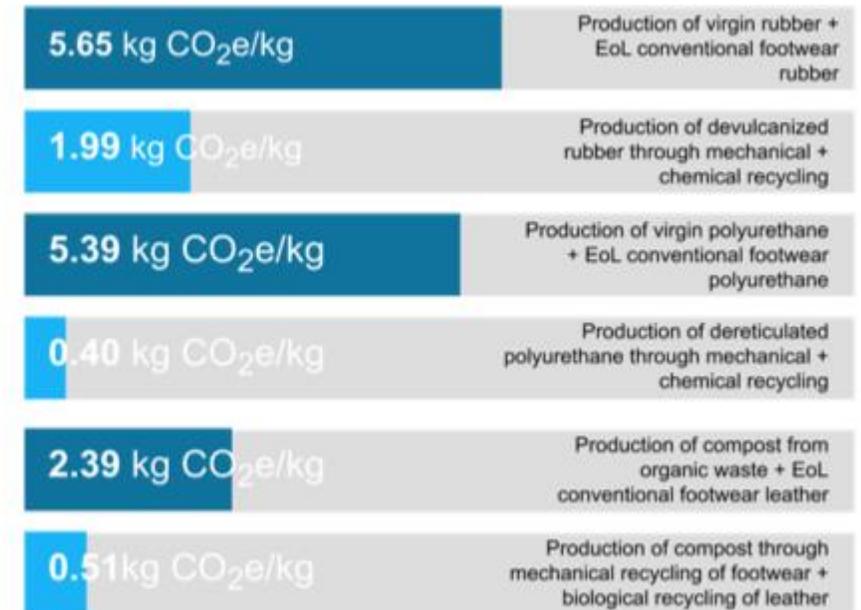
LCA of a pair of boots



Diferent EoL scenarios



New models of circular economy



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Próximos pasos

- Publicación revision bibliográfica
- Publicación Life Cycle Assessment of different end-of-life scenarios for footwear
- Ponencia oral Global Summit on Recycling and Waste Management (marzo 2025) – aceptada
- Ponencia en Textiles Recycling Expo (June 2025) Abstract enviado

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Gracias por vuestro tiempo