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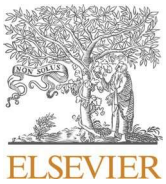

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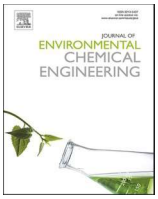

# Sustainability assessment of collagen extraction from fish skins: A comparative life cycle assessment of conventional and NADES-enhanced processes

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ABSTRACT

Collagen from blue shark skins offers a promising solution to utilize fishery by-products, reducing waste and improving resource efficiency. This study develops green chemistry-based extraction processes to minimize reliance on traditional chemical methods and lower environmental impacts, prioritizing sustainability and circularity. Two methods for collagen extraction are compared: a conventional alkaline-acid process and an innovative approach using natural deep eutectic solvents (NADES). Process simulations were conducted using SuperPro Designer software for the annual production of 500 kg of pure extracted collagen, followed by life cycle assessment (LCA) using SimaPro software and the Ecoinvent database, applying the Environmental Footprint (EF) method. For 1 kg of pure marine collagen from fish skin residues, defined as the Functional Unit, the conventional approach yielded a single-score impact of 48.1 mPt, while the NADES method achieved 41.5 mPt. Subsystem analysis reveals that, in the conventional method, the extraction and purification stages account for most of the environmental impact (43 % and 45 %, respectively). In contrast, the NADES method attributed 94 % of its total environmental impact to extraction stage, primarily due to NADES component production (citric acid, xylitol). Uncertainty analysis suggests that conclusions regarding impact reduction should be drawn with caution due to the environmental impact variability of considered inputs. Nevertheless, the mathematical model underscores the potential of the NADES method to reduce the environmental impact and promote more sustainable bioprocessing. This work offers valuable insights into the life cycle assessment of large-scale bioprocesses using green chemistry, providing a tool for optimization and environmental impact screening.

## 1. Introduction

Collagen, a primary structural protein found in the extracellular matrix of various connective tissues, has garnered significant attention due to its extensive applications in biomedical, pharmaceutical, cosmetic, and food industries [1,2]. Traditionally sourced from bovine and porcine skins, collagen extraction from these sources raises concerns over disease transmission and religious restrictions. Consequently, fish skins have emerged as a sustainable and safer alternative, offering a promising solution for collagen extraction [3]. Fish skin, a byproduct of the fishing industry, constitutes a considerable portion of marine waste, with millions of tons discarded annually, contributing to environmental pollution and resource loss [4,5]. Valorizing this waste by extracting collagen and other high-value compounds mitigates its environmental impact while increasing the economic resilience and diversification of the fishing industry.

The conventional process of extracting acid-soluble collagen from marine sources, such as fish skins, scales, and bones, involves several key steps to isolate and purify collagen, but it comes with a high ecological footprint [6]. The process includes washing the raw materials, cutting

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