

# 以生命週期評估與生命週期最佳化建立淨零排放與永續產品設計策略

## Rethinking Product Lifecycle Management: An Optimization-Based Approach to Sustainable Design

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### 摘要

本研究通過一套全面、用戶友善且實用性高的方法學來解決永續產品設計中的重要研究缺口，該方法學平衡產品生命週期中經濟目標與環境和社會永續性。儘管永續產品設計在實現長期永續目標和產業競爭力日益重要，但現有方法通常缺乏實用性、未能整合環境、社會、經濟三面向中的各永續目標，且忽視部分生命週期階段，以致於無法提供完整的永續產品設計方法學。本研究所提出的方法包括四個主要步驟：(1)識別潛在的產品設計路徑，(2)評估潛在設計路徑的永續衝擊，(3)制定永續產品設計最佳化模型，以及(4)解決最佳化模型。其採用決策樹方法來協助產品設計者釐清產品設計選項，且納入生命週期影響評估（LCIA）概念以量化環境與社會衝擊，並使用生命週期成本評估（LCCA）進行經濟衝擊評估。

該方法學的主要特點包括其可適應不同組織需求的靈活性，對整個產品生命週期的全方面考量，以及融入不同組織對各永續目標的優先層級，或產品所面臨到的社會和環境規範，如：歐盟碳邊境調整機制等，提供全面並可隨設計者、組織需求彈性調整的永續產品設計方法學。為展示該方法學的實際應用及成效，本研究將透過案例分析，實際運用所提出之方法學，進一步說明該方法學如何協助產品設計者權衡環境、社會、經濟目標，驗證其是否可有效協助產品設計者，設計出更具永續性的產品。

本研究通過提供一套實用、具高度自由性的工具來促進實務端，落實永續產品設計，從而為永續領域做出貢獻。此外，本研究所提出之永續產品設計方法學，亦有助於產品設計者、實務端達成淨零排放目標，透過分析產品生命週期各階段之潛在淨零路徑，並配置出一套最具成本效益減碳策略，使設計者在削減產品在整個生命週期中的碳足跡之餘，打造產品低碳與永續競爭力，從而加速我們邁向淨零排放的最終願景。

關鍵詞：永續產品設計、生命週期評估、生命週期最佳化、生態設計、產品淨零排放

## Abstract

The research addresses critical gaps in sustainable product design by developing a comprehensive, user-friendly methodology that balances economic objectives with environmental and social sustainability across the entire product lifecycle. Despite the growing importance of sustainable product design in achieving long-term ecological stability and corporate competitiveness, existing methodologies often lack practicality, fail to integrate all aspects of sustainability, and neglect certain lifecycle phases. The proposed methodology consists of four main steps: (1) Identifying potential product design pathways, (2) Assessing sustainability of potential design pathways, (3) Formulating a sustainable product design optimization model, and (4) Solving the optimization problem. It employs a decision tree approach to map out design options, incorporates life cycle impact assessment (LCIA) for environmental and social impacts, and uses life cycle cost assessment (LCCA) for economic evaluation.

Key features of the methodology include its flexibility in adapting to diverse organizational needs, comprehensive consideration of the entire product lifecycle, and a tiered system of sustainable objectives to reflect varied corporate priorities. The approach allows for the integration of computer-aided design tools and accommodates specific product design constraints. To demonstrate the practical application and effectiveness of the methodology, this research will conduct a case study implementing the proposed framework. This implementation will illustrate how the methodology assists product designers in balancing various sustainability objectives, providing real-world validation of its utility and impact.

This research contributes to the field by offering a practical, adaptable tool that enhances industry acceptance of sustainable product design practices. By addressing the challenge of balancing economic goals with sustainability objectives and demonstrating its application through a case study, this methodology aims to promote more sustainable industrial practices and contribute to a more sustainable future. Importantly, this research directly supports global net zero ambitions by enabling businesses to systematically reduce the carbon footprint of their products throughout the entire lifecycle, from raw material selection to end-of-life management. The methodology's holistic approach to sustainability optimization provides a tangible pathway for industries to align their product design processes with long-term climate goals, thus accelerating the transition towards a net zero economy.

Keywords: Sustainable product design, life cycle assessment, life cycle optimization, eco-design, net zero