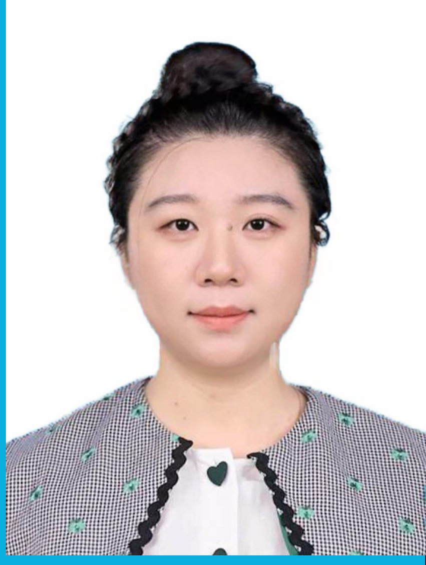
Life Cycle Assessment of Footwear Production under Sustainable Design Scenarios

S. Wang [1, 2] and T. Liu [1, 2] *

[1] State Key Laboratory of Materials Low-Carbon Recycling, Beijing, 100124, China
[2] College of Materials Science and Engineering, Beijing University of Technology, Beijing, 100124, China
Emails: tingting.liu@bjut.edu.cn; wsn6935@emails.bjut.edu.cn



Introduction

- **Industry Challenge:** The footwear industry, a resource-intensive sector, faces massive challenges in resource waste and environmental pollution[1].
- **Sustainable Imperative:** Since 80% of environmental impacts are locked in during the design stage[2], sustainable design is a critical necessity for industry-wide mitigation.
- **Research Gap:** Conventional LCA often treats manufacturing as a "process black box," lacking insights into the synergistic benefits of integrated technical strategies.
- **Research Objective:** This study deconstructs the manufacturing process of size 41 (EUR) basketball footwear. By collecting on-site measured data, we identify precise environmental hotspots and quantify the ecological benefits of 8 sustainable design scenarios.

Materials & Methods

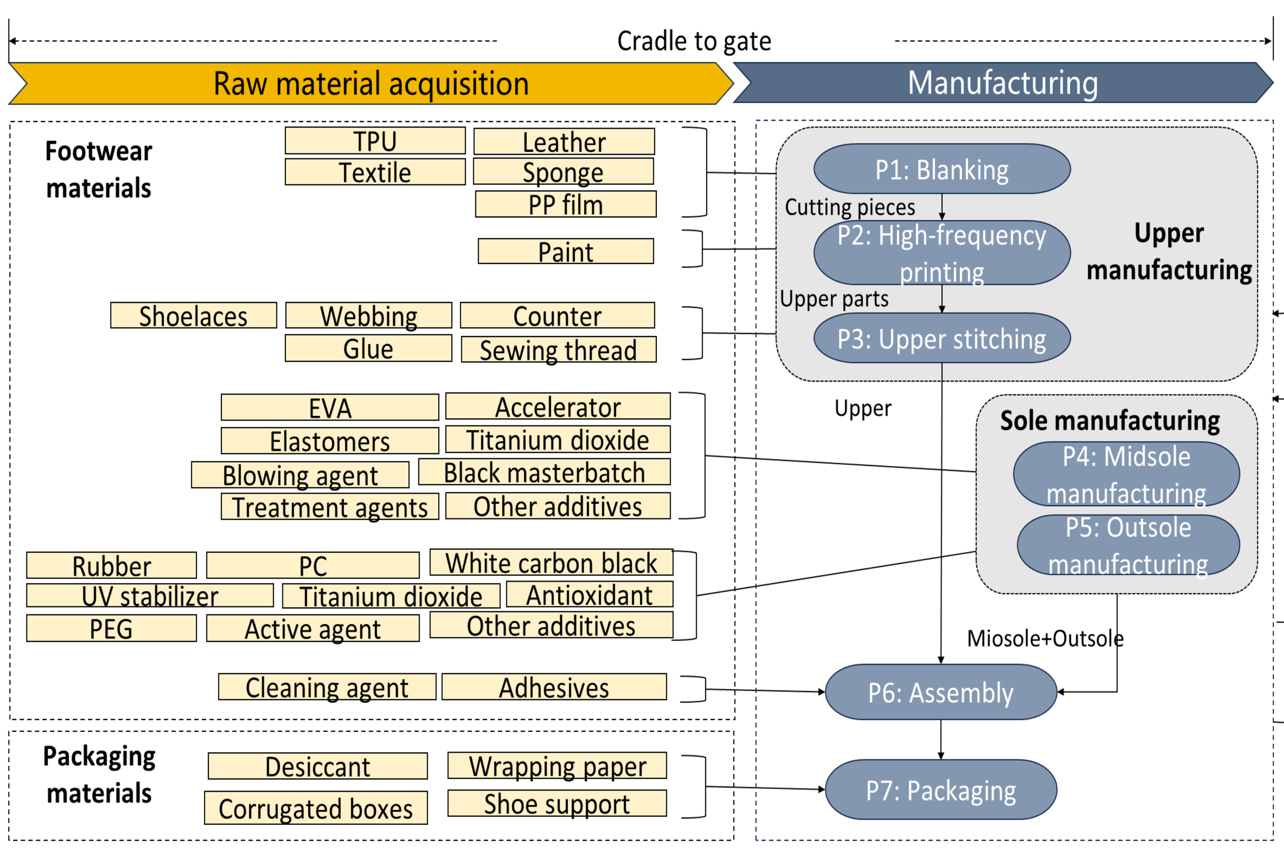


Fig. 1. System boundary

- **Functional Unit & Boundary:** One pair of size 41 (EUR) basketball footwear. System boundary covers a cradle-to-gate scope including P1–P7 manufacturing processes.
- **Life Cycle Inventory** Primary data was prioritized through on-site measurements and workshop records across 7 processes.
- **Method:** Calculated via CML 2001 method using the GaBi database, evaluating 11 categories.

Table 1. Scenario settings

Scenarios	Description	Baseline scenario indicators	Parameter settings
S1	Upper material substitution scenario	PET fiber fabric	PLA fiber fabric
S2	Upper reduction scenario	Synthetic leather, fabric upper	3D printing (TPU)
S3	Sole reduction scenario	Traditional adhesive assembly	Mortise and tenon jointing
S4	Packaging reduction scenario	Virgin pulp corrugated box	50% reduction in packaging
S5	Packaging material substitution scenario	Virgin pulp corrugated box	Recycled pulp corrugated box
S6	Renewable substitution scenario		S1 & S5
S7	Reduction scenario		S2 & S3 & S4
S8	Combined scenario		S1 & S2 & S3 & S4 & S5 (The consumable for 3D printed upper is PLA)

Results & Discussion

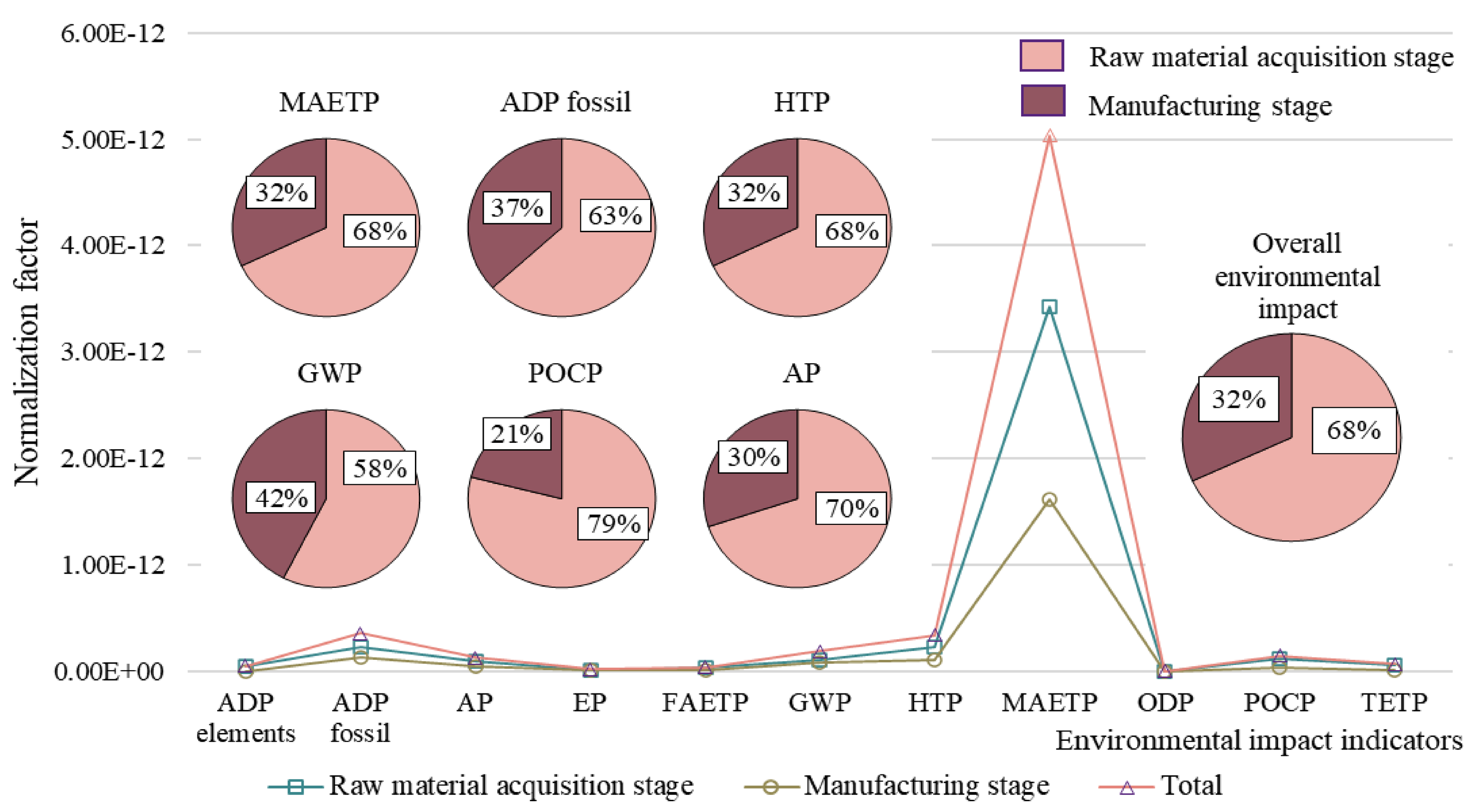


Fig. 2. Environmental impacts of different production stages

- The footwear production exerts a significant impact on MAETP, followed by ADP fossil, HTP, GWP, POCP, and AP.
- In terms of production stages, the environmental impacts generated during the raw material acquisition stage are consistently higher than those in the manufacturing stage.
- The raw material acquisition stage accounts for 68% of the total environmental impact, while the manufacturing stage contributes 32%.
- Blanking (P1) makes the largest contribution to the environmental impact (accounting for 55%), followed by high-frequency printing (P2) (accounting for 16%).

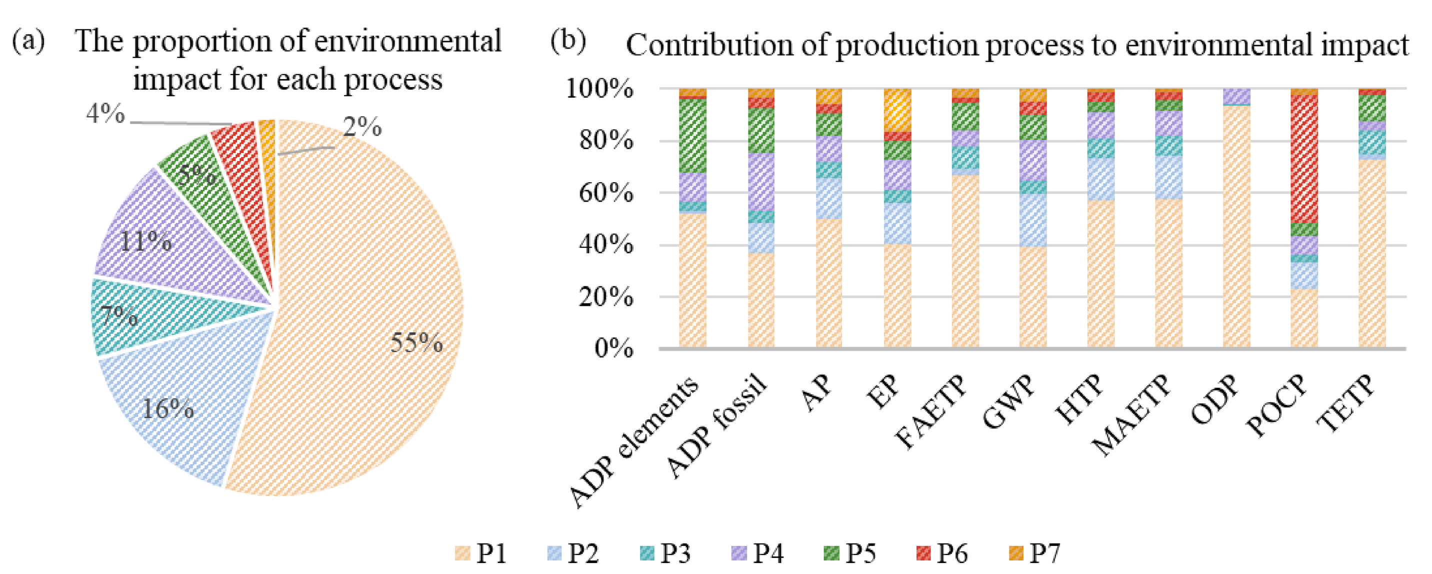


Fig. 3. Environmental impact results categorized by production processes

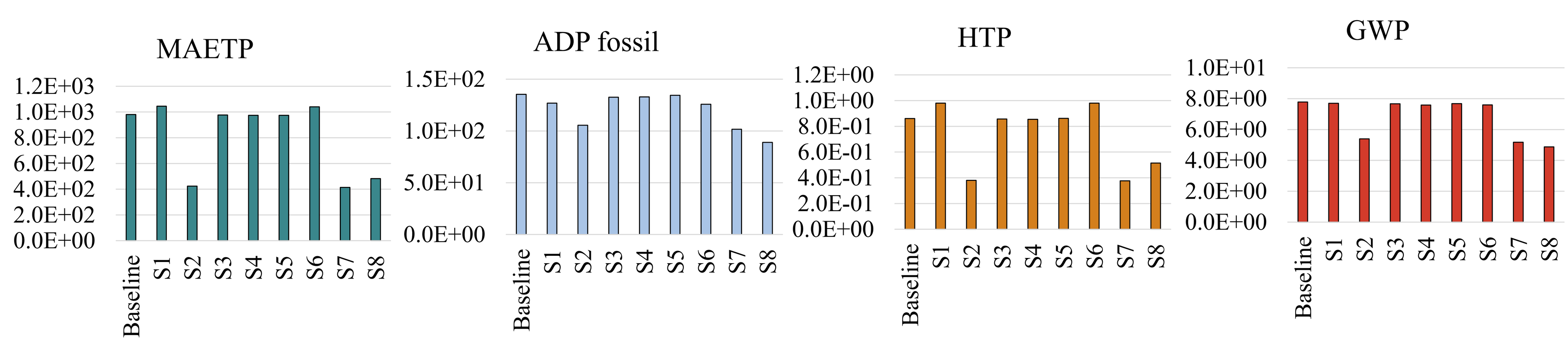


Fig. 4. Characterization results of environmental impacts under different scenarios

- Both S1 and S5 reduce resource dependence through material substitution. S1 is inferior to S5 because the ecological cost of PLA during the agricultural stage is a major drawback.
- Among the three reduction strategies (S2, S3, and S4), S2 shows the best performance. Multiple indicators under S2 improve significantly. S3 only has a significant impact on POCP. S4 reduces raw material waste, but its overall performance remains stable.
- The comprehensive performance of S6, S7, and S8 is ranked as S7 > S8 > S6.

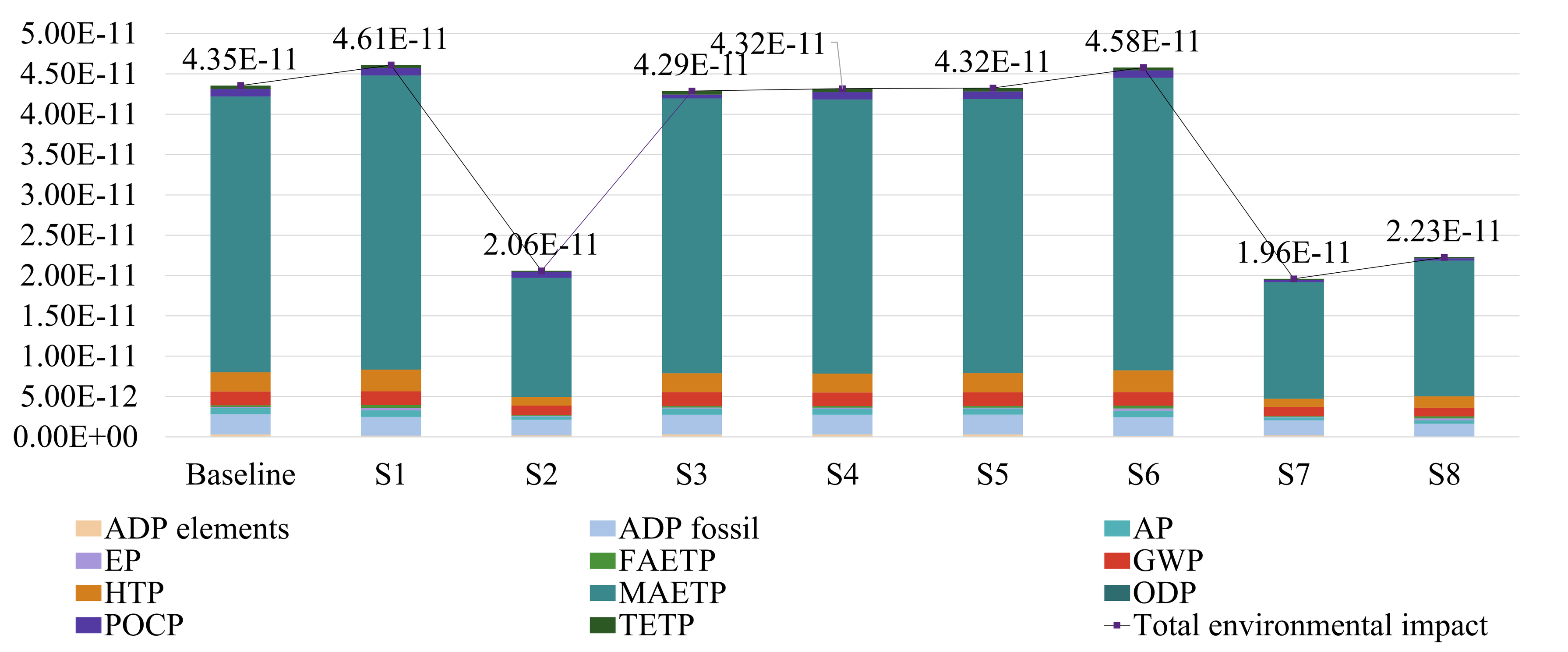


Fig. 5. Comparison of environmental impacts across different sustainable design scenarios

The research results highlight the short-term hidden costs of PLA due to agricultural production, as well as the long-term social risks of process innovation arising from the displacement of traditional labor. Therefore, sustainable design should integrate technical innovation with Life Cycle Assessment (LCA) rather than simply stacking technologies, thereby avoiding the scenario where short-term advantages in a single indicator mask long-term systemic risks, or where temporary risks in a single indicator obscure systemic advantages.

Conclusions

- Raw material acquisition is the core environmental burden, contributing 68% of the total environmental impact.
- S7 shows the best short term benefits. It can reduce the total environmental load to 45% of the baseline.
- Bio-based materials such as PLA have heavy agricultural production burdens. Their advantages depend heavily on degradation management at the end of the life cycle.
- Simple stacking of technologies does not lead to a linear increase in environmental benefits. Strategy combinations require synergistic optimization of technologies.

References

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