Seaweed: The Solution to Pollution? A Comparative Life Cycle Assessment of LDPE and Algal Flexible Film Packaging

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Background

In this report, we perform life cycle assessments (LCA) to compare the environmental tradeoffs from cradle to grave for fossil-and seaweed-based flexible polymer films to inform packaging material choices that minimize environmental impacts. We also consider additional factors, through a literature review and consumer survey, to address PANGAIA's environmental priorities that are not quantified in LCA.

Plastic production has grown dramatically since the 1950s due to its wide applicability across consumer products, industrial goods, and packaging. An estimated 40% of all plastic produced is used for packaging, and low-density polyethylene (LDPE) is the industry-standard for the apparel sector. Plastic is derived from fossil fuels and, because most is not recycled, accumulates in landfills and the environment. Plastics break down into microplastics, which are harmful to human and ecosystem health. Thus, environmentally-conscious brands are looking for alternative packaging materials to reduce their reliance on an extractive industry with a significant waste footprint. Seaweed-derived compounds can form films that serve the same function as plastic. Seaweed cultivation requires few inputs and provides ecosystem services. Further, seaweed-based materials decompose under certain conditions, resulting in little to no waste.

Methods

We used the GaBi database and software from Sphera to model cradle-to-gate impacts for LDPE and six algal flexible film production scenarios. We developed the LDPE model using industry data included in the database. We built the algal flexible film models with primary data from film producers and secondary data from literature. The environmental impact indicators we selected to compare these production processes include the potential for: acidification (AP), ecotoxicity (ETP), eutrophication (EP), global warming (GWP, both excluding and including biogenic carbon), human toxicity (HT, cancer and non-cancer), and smog (SFP). The six scenarios are as follows: (1) a baseline scenario that uses the more intensive production processing options for all steps; (2-5) four scenarios where an improvement was made to one process compared to the baseline; and (6) a 'best-case' scenario that was fully optimized to reduce environmental impacts. We also modeled how changing the algal flexible film production location affects cradle-to-gate impacts. Finally, we modeled LDPE and algal flexible film gate-to-grave impacts using literature data.

Additionally, we conducted a survey that assesses access to waste services and common waste sorting behaviors to understand how these factors would affect packaging material disposal. The survey was promoted on PANGAIA's LinkedIn account. The research questions that guided our survey questions were, "How do recycling and composting rates compare to each other?" and, "How strong is the correlation between access to a waste service and engagement with that waste service?"

Seaweed Collection
Seaweed can be harvested from wild stocks or cultivated.

Seaweed Drying
Wet seaweed biomass is dried for transport and processing.

Seaweed Processing
Useful materials are extracted from seaweed biomass.

Film Formulation
Processed seaweed products are transformed into a flexible film.

Figure 1. *System diagram for seaweed sourcing to film conversion.*

Results

Table 1. *Algal flexible film scenarios and LDPE environmental performance comparison, using TRACI 2.1 impact categories. LDPE impacts normalized to 1.*

Impact category	Seaweed baseline	Seaweed best case	LDPE
AP	9.64	0.54	1.00
ETP	3.89	-13.56	1.00
GWP	6.10	0.30	1.00
GWP w/ biogenic C	5.69	0.21	1.00
HT (cancer)	14.79	4.52	1.00
HT (non-cancer)	12.46	1.86	1.00
SFP	5.30	1.07	1.00
EP	-676.22	-687.68	1.00

Cradle-to-gate scenario analysis:
The baseline algal flexible film scenario resulted in higher environmental impacts than the LDPE model, but the best-case scenario matched or exceeded LDPE's performance (see Table 1). In general, the production process changes that most significantly impact algal flexible film environmental performance were: (1) drying seaweed without electricity (passive drying); (2) obtaining seaweed from wild stocks; and (3) generating co-products while extracting phycocolloid from the seaweed. Implementing changes (1) and (2) likely would decrease in feasibility as algal flexible film manufacturing is scaled, but change (3) remains viable and may become more common at scale.

Geographical cradle-to-gate analysis:
Producing algal biofilm in less carbon-intensive grids results in a lower-impact material.

Gate-to-grave analysis: For both LDPE and the algal flexible film, cradle-to-gate impacts far outweigh gate-to-grave impacts. The differences in impact between the end-of-life for the two materials depend predominantly on the carbon content of the materials and the proportion entering each waste stream. Our end-of-life model for the algal flexible film has significant uncertainty due to a lack of robust data.

Survey: While many survey respondents had access to recycling (85%) and composting services (48%), survey findings on disposal behavior may be a better indication for disposal pathways. When asked about how they would dispose of a cardboard box and compostable flexible film packaging after opening their package, 65% of respondents stated that they recycled the box, while only 28% composted their flexible film packaging. These results highlight that recyclable materials may be a more viable packaging solution for PANGAIA.

Recommendations

Our research highlights several opportunities and risks for transitioning from LDPE to algal flexible film:

Opportunities

- May outperform LDPE with optimization
- May be fully compostable, leaving no waste and contributing nutrients to the environment
- Cultivation provides ecosystem services without requiring significant inputs nor any land area

Risks

- Optimizations may not be viable at scale
- May be difficult to source sufficient seaweed to meet demand
- Composting may not be widely available and behavior in landfill is unknown

Based on our findings, algal flexible film production can be optimized to have impacts comparable to, or lower than, those of LDPE. Future research should focus on achieving this theoretical performance in practice while mitigating potential risks uncovered by our research.