Building Pathways to Sustainability

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ALGIX™
Formulating the Potential of Algae

Full LCA Results:
Algix Algae Blended Plastics

December 17, 2014

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For the complete report, including additional analyses and data tables, please see *Algix Algae Blended Polymers_Full LCA.pdf.*

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The Steps of an LCA

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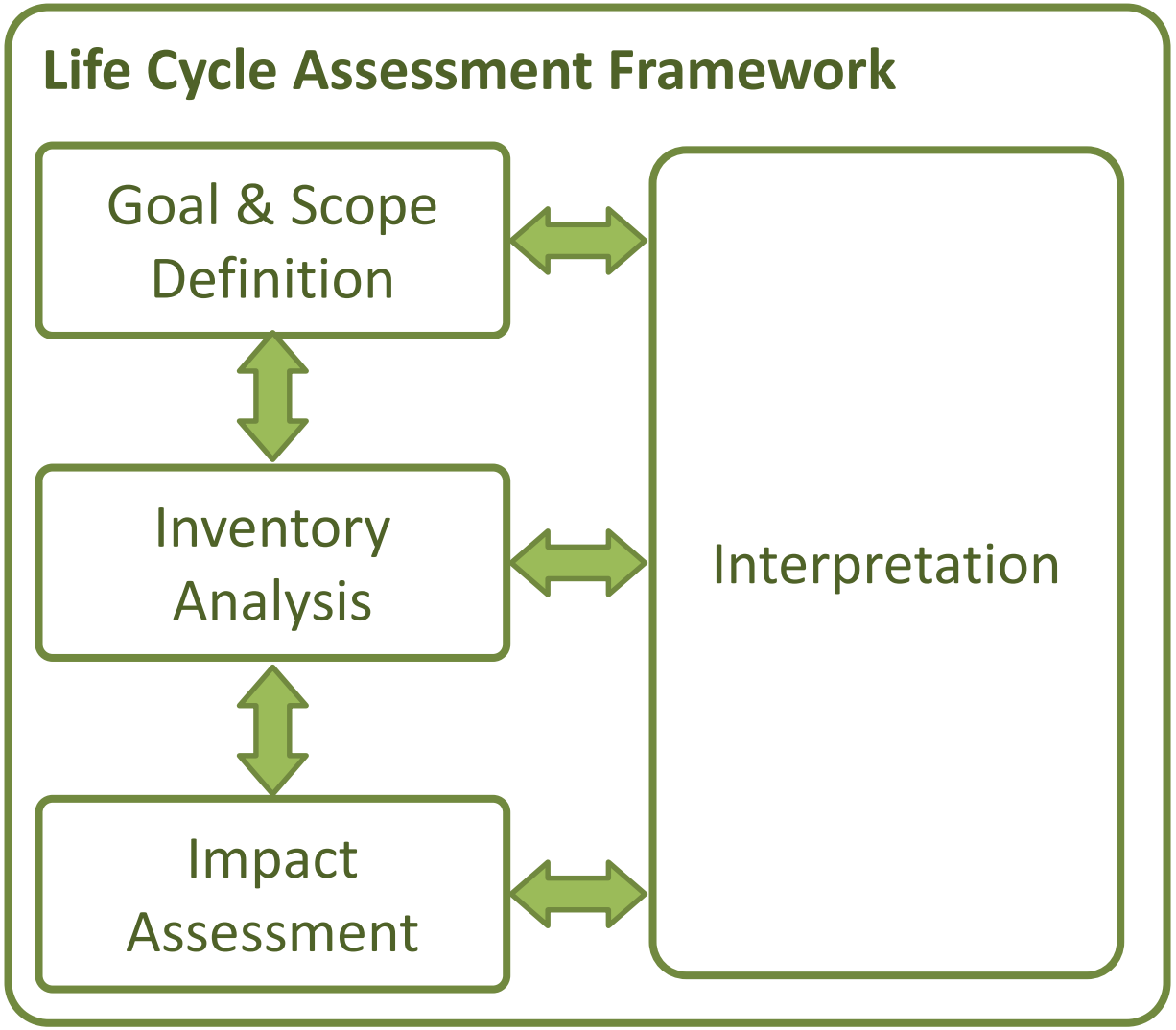

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What is the goal of the study? What does the study entail?

GOAL AND SCOPE

Goal & Scope

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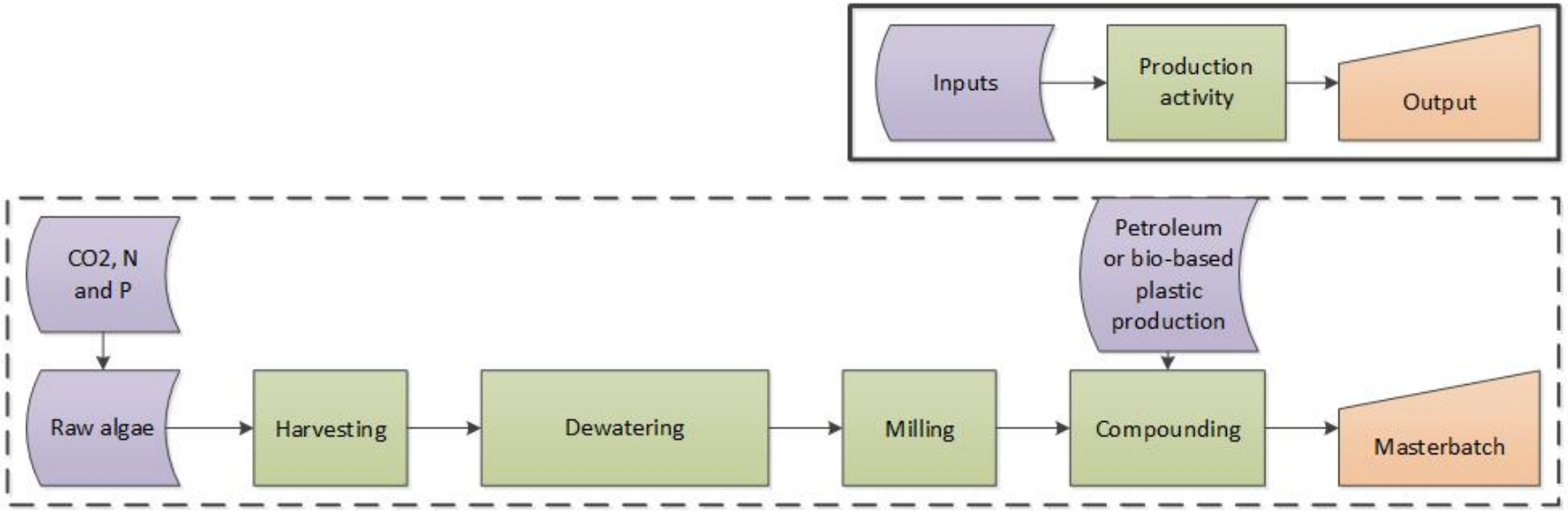
- **Intended applications**
  - Algix algae blended plastic: Dried and milled algae blended with petroleum and bio-based plastics.
  - Thermoformed plastic with or without algae blended plastic.
- **Reasons for carrying out the study**
  - To understand the environmental impacts of the milled algae and to inform process development.
  - To understand the environmental impacts of replacing petroleum or bio-based plastics with milled algae in plastic applications.
- **Target audience**
  - Algix intends to communicate the results of the full LCA study with its customers.
- **Functional units**
  - One pound of masterbatch plastic (cradle-to-gate).
  - One pound of thermoformed plastic (cradle-to-grave).

System Boundaries

Masterbatch with Aquaculture Pond Model (Cradle-to-Gate)



Excluded Processes:

- Infrastructure (e.g. buildings and plant equipment);
- Human activities (e.g. employee travel to and from work);
- R&D (i.e. the laboratory and inputs related to the development of the technologies);
- Services (e.g. the use of purchased marketing, consultancy services, business travelling).

System Boundaries

Thermoformed Polymer (Cradle-to-Grave)

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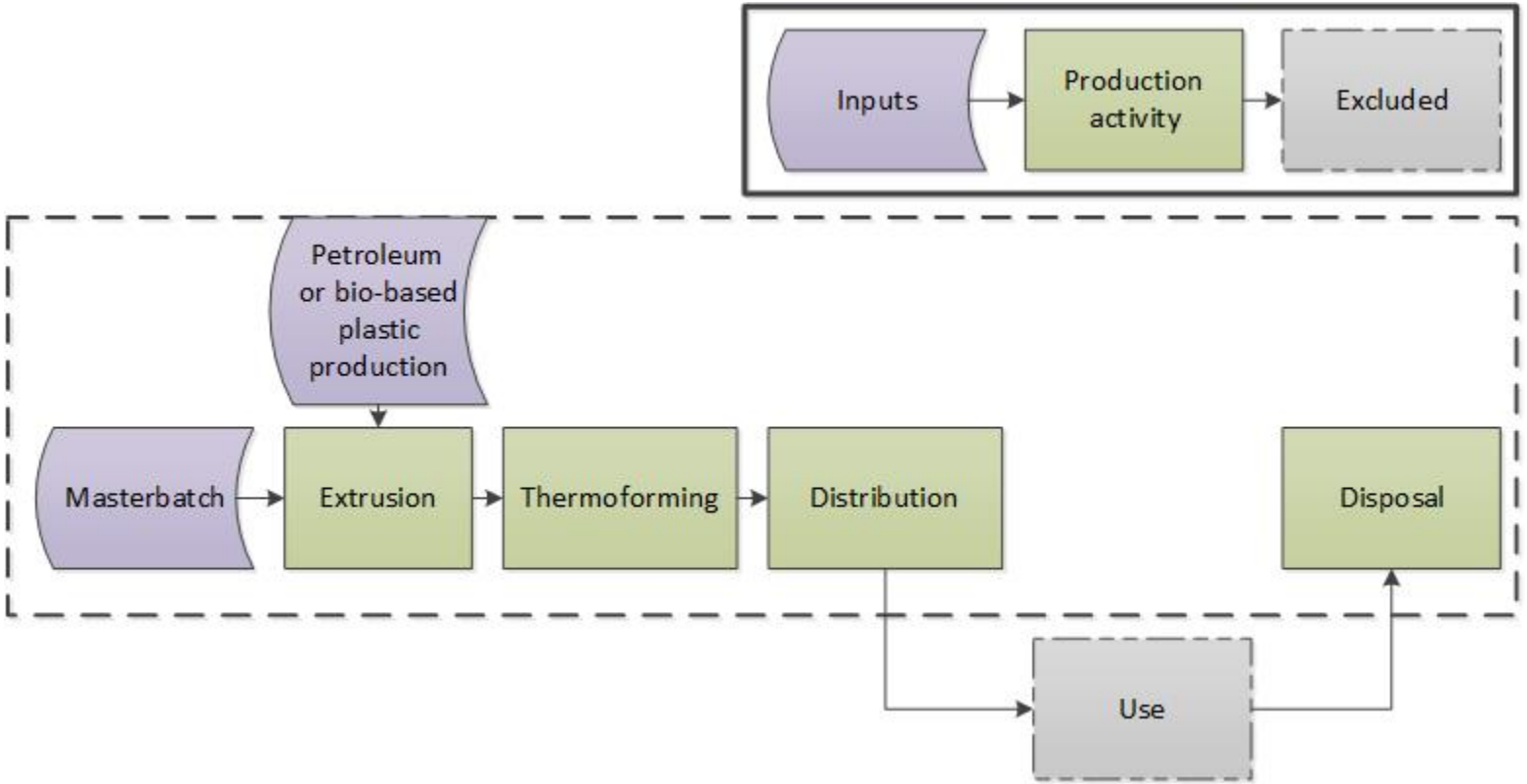

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What data was used? What assumptions were made?

LIFE CYCLE INVENTORY

Key Assumptions and Limitations

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Algae Harvest and Processing

- Algae is harvested from an aquaculture pond where it consumes CO_2, N and P.
- Potential benefits of reduced chemical use and aeration at the aquaculture pond are not included in study.
- Horizontal decanting is used for the dewatering scenario.

Milling and Compounding

- No air emissions (besides water vapor) occur from evaporation during membrane, milling and compounding steps.
- No losses occur during algae processing and compounding.

Masterbatch and Thermoforming

- Masterbatch consists of approximately 49% dry algae/49% petroleum-based plastic.
  - Other 2% is odor neutralizer.
- The plastics added to the algae blended masterbatch are transported 500 miles by rail.
- No increase in mass for thermoforming compared with petroleum-based plastics.
  - Does not account for performance differences.

Distribution and Disposal

- 2,000 miles by truck.
- 82.2% landfilled, 17.8% incinerated. → Supporting data required to include recycling.
- Recycling rate of 8.2% for petroleum-based plastics.

Life Cycle Inventory

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- **Primary data** (Provided by Algix)
  - Energy consumption for harvesting, dewatering, milling and compounding.
  - Moisture content after each dewatering process.
  - Water consumption for harvesting, dewatering, milling and compounding.
  - Transportation distances for transportation from aquaculture pond to dewatering facility and to compounding facility.

- **Secondary data** (Used literature, US-EI[1] and Ecoinvent 2.2[2])
  - LCI data for raw materials, electricity generation and transport.
  - CO_2, N and P consumption.

[1] See http://earthshift.com/software/USEI-database for more information about US-EI.

[2] See www.Ecoinvent.ch for more information about Ecoinvent 2.2.

Electricity Consumption

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Activity	Electricity (kWh/lb of dry algae)
Harvesting	0.33
Horizontal Decanting and Microwave Drying*	1.13
Milling	0.22
Compounding	0.23

*A sensitivity analysis is included comparing to the vacuum decanting, membrane dewatering and thermal dewatering scenario (best case scenario - 0.27 kWh/lb of dry algae)

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What are the environmental hotspots?

FULL LCA RESULTS

Contribution Analysis

Milled Algae

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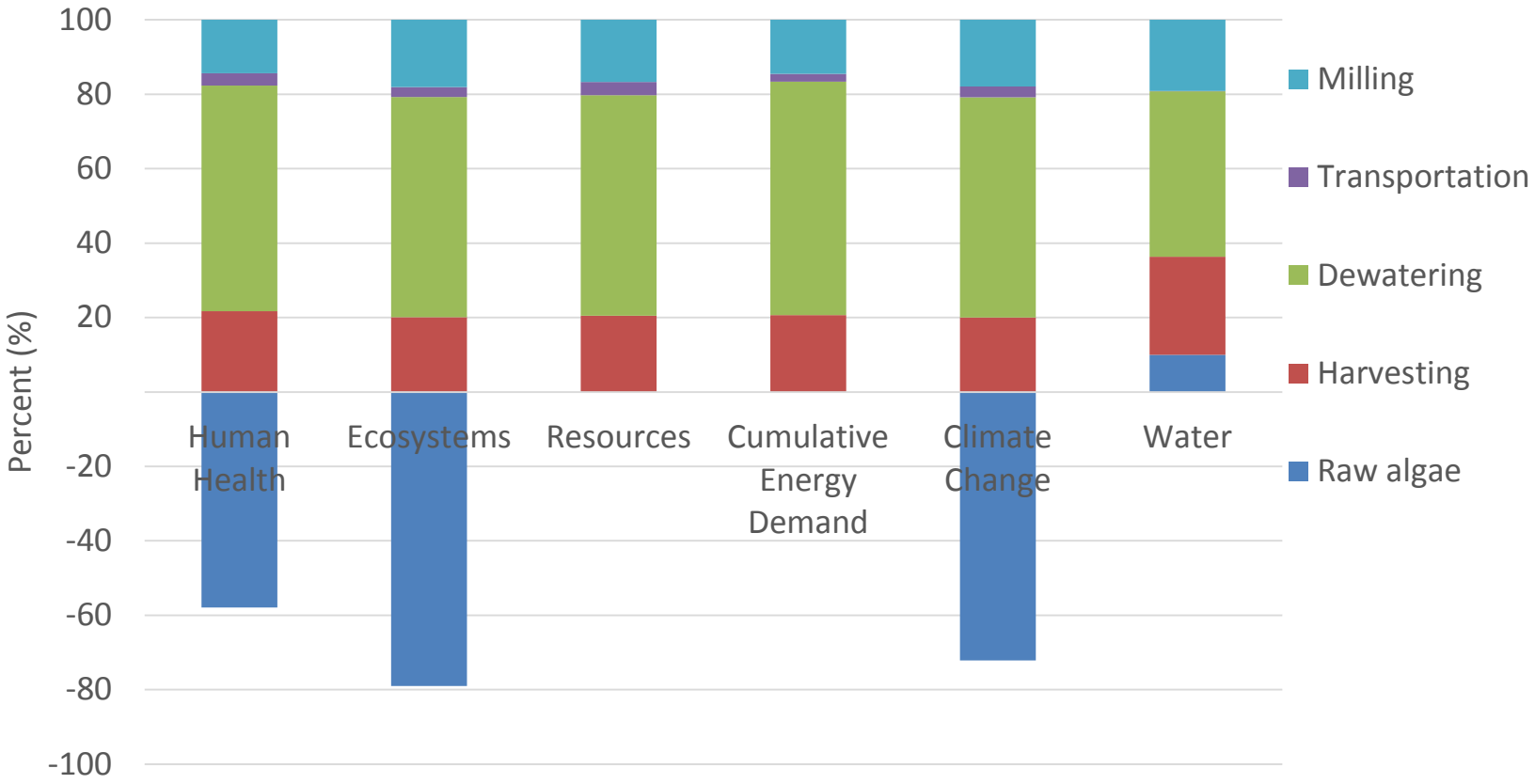

Dewatering contributes the majority of impacts in all categories except water depletion, primarily due to electricity consumption. The consumption of N, P and CO_2 offsets 60-80% of the human health, ecosystems and climate change impacts.

Impact Assessment Method: ES Method

Contribution Analysis

Masterbatch (Algae/Polystyrene)

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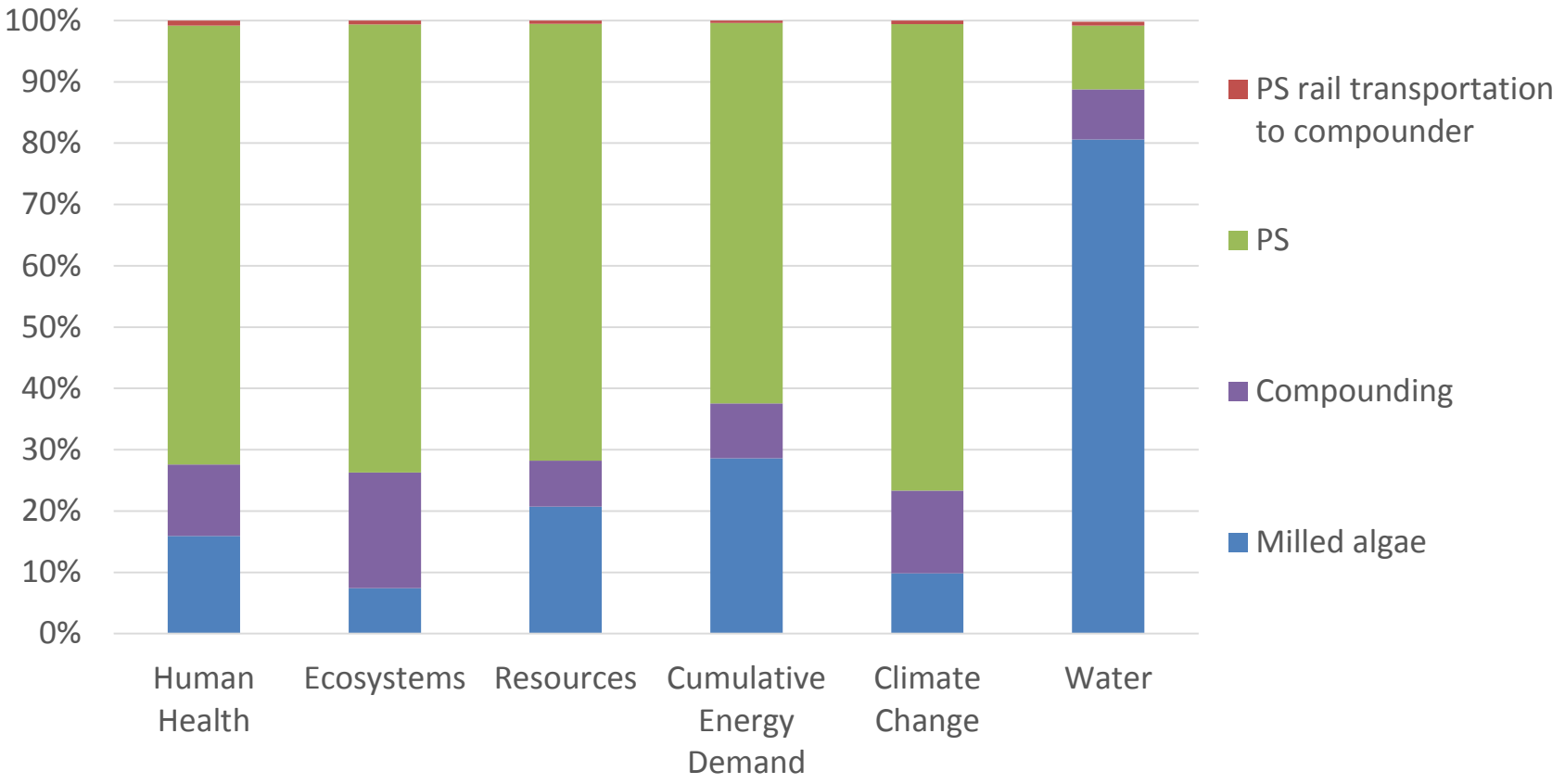

The polystyrene (PS) contributes between 60% - 80% in all impact categories, except water depletion, and results in two to ten times the impacts in those categories than the milled algae when compared on an equivalent weight basis.

Impact Assessment Method: ES Method

Contribution Analysis

Thermoformed Algae / PS (Cradle-to-Grave)

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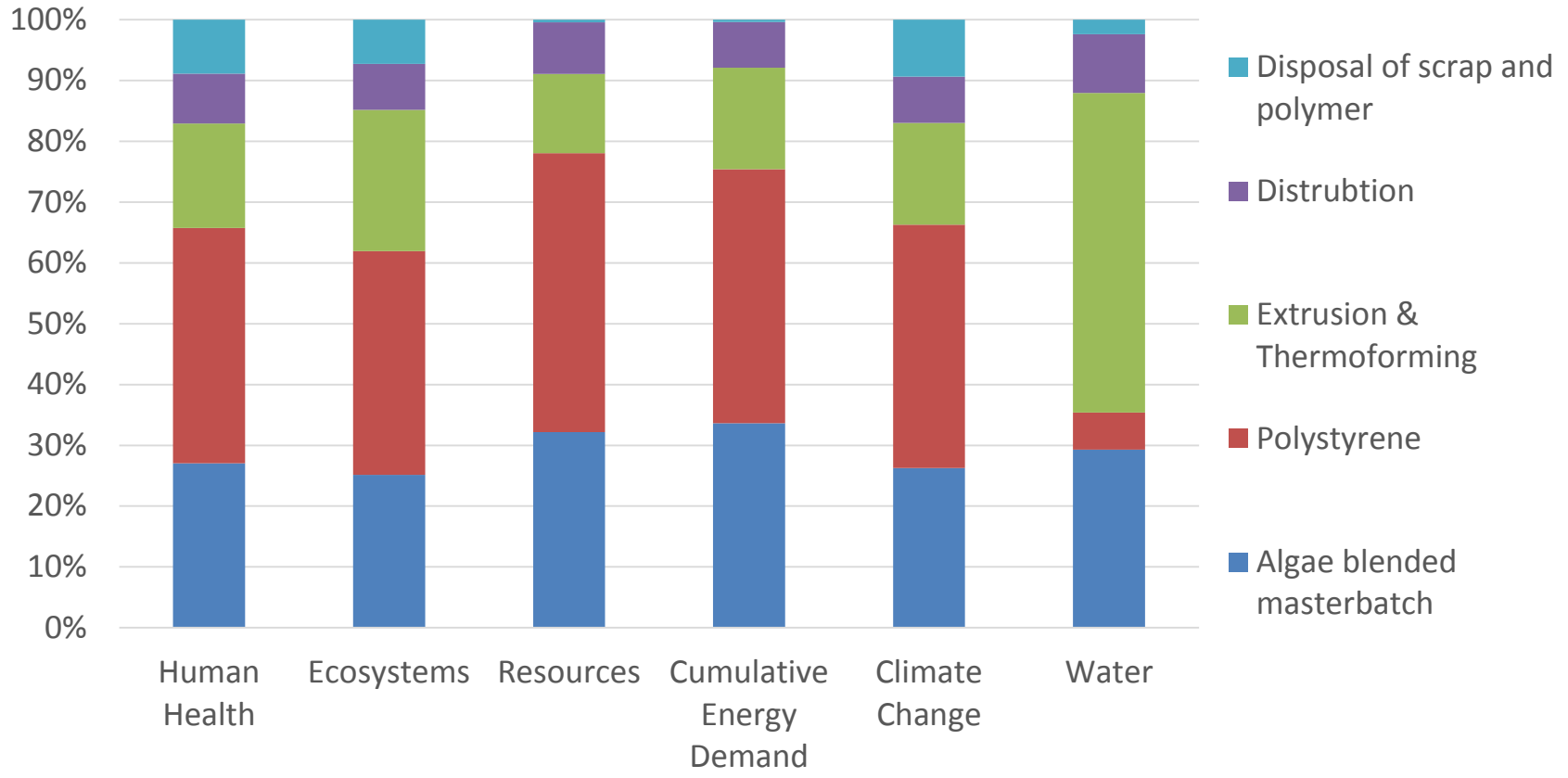

Extrusion and thermoforming, driven by electricity, contributes between 10% - 50% of the impacts in all categories. The algae blended masterbatch contributes less than 34% of the impacts in all categories.

Impact Assessment Method: ES Method

Comparative Analysis

Algae Blends vs. Unfilled Plastics

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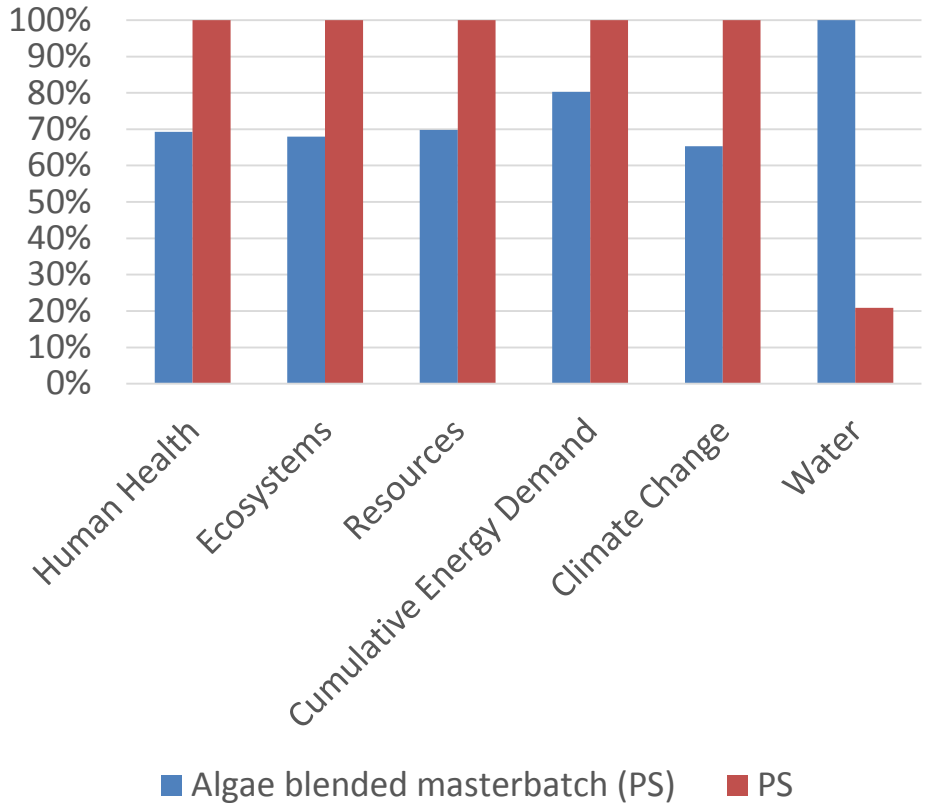
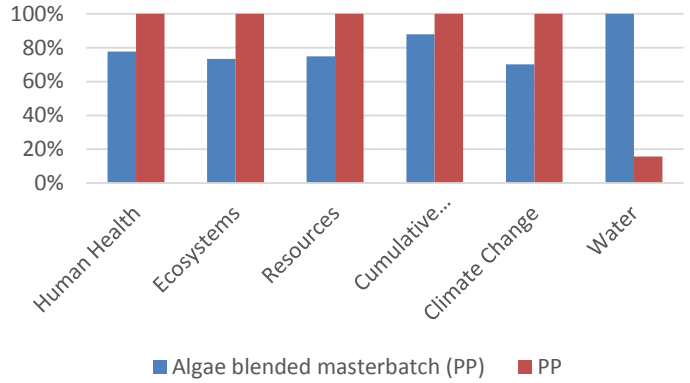
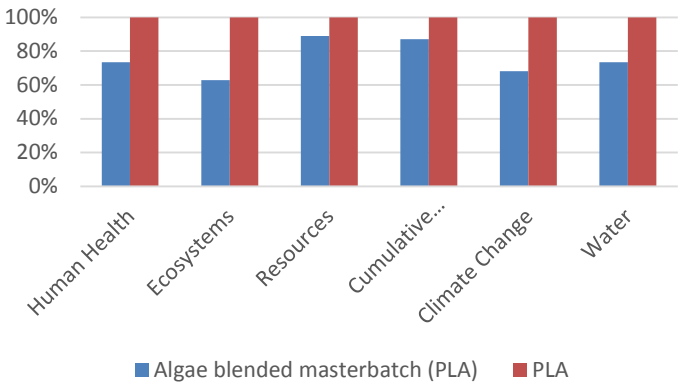




NOTE: Results above are representative to the HDPE comparison



In all categories except water depletion, the algae blended masterbatch has between 10% - 40% fewer impacts than the plastic resin it is blended with.

Impact Assessment Method: ES Method

Comparative Analysis

Thermoformed PS vs. Algae/PS (Cradle-to-Grave)

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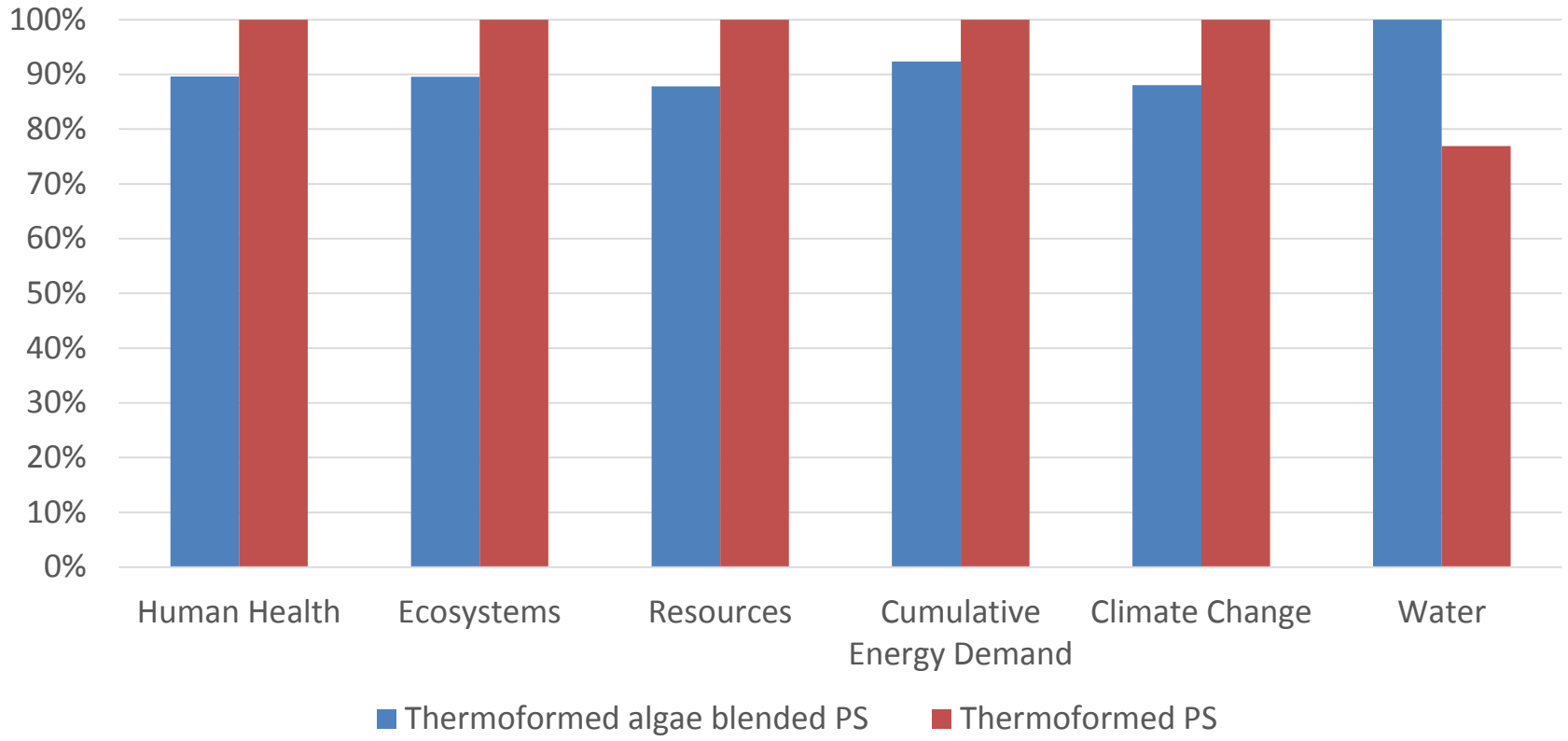

The thermoformed algae blended plastic has between 4% - 12% fewer impacts in all categories except water when compared to thermoformed PS.
Water scarcity is generally low in Alabama.

Impact Assessment Method: ES Method

Uncertainty Analysis

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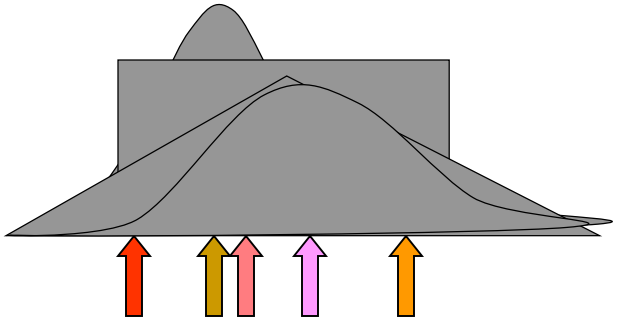
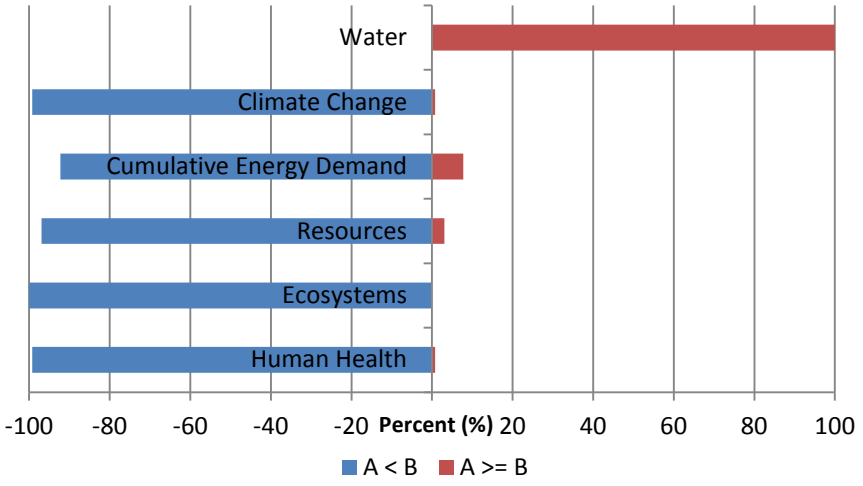
- Define a distribution and standard deviation based on reliability, completeness, temporal, geographic, and technological correlation on (every) input parameter.



- Randomly select a series of values according to the distribution.



- Recalculate the LCA for every parameter.

- Determine the level of confidence of one product having more or less impacts than another.

Comparative Analysis – Uncertainty

Thermoformed PS vs. Algae/PS (Cradle-to-Grave)

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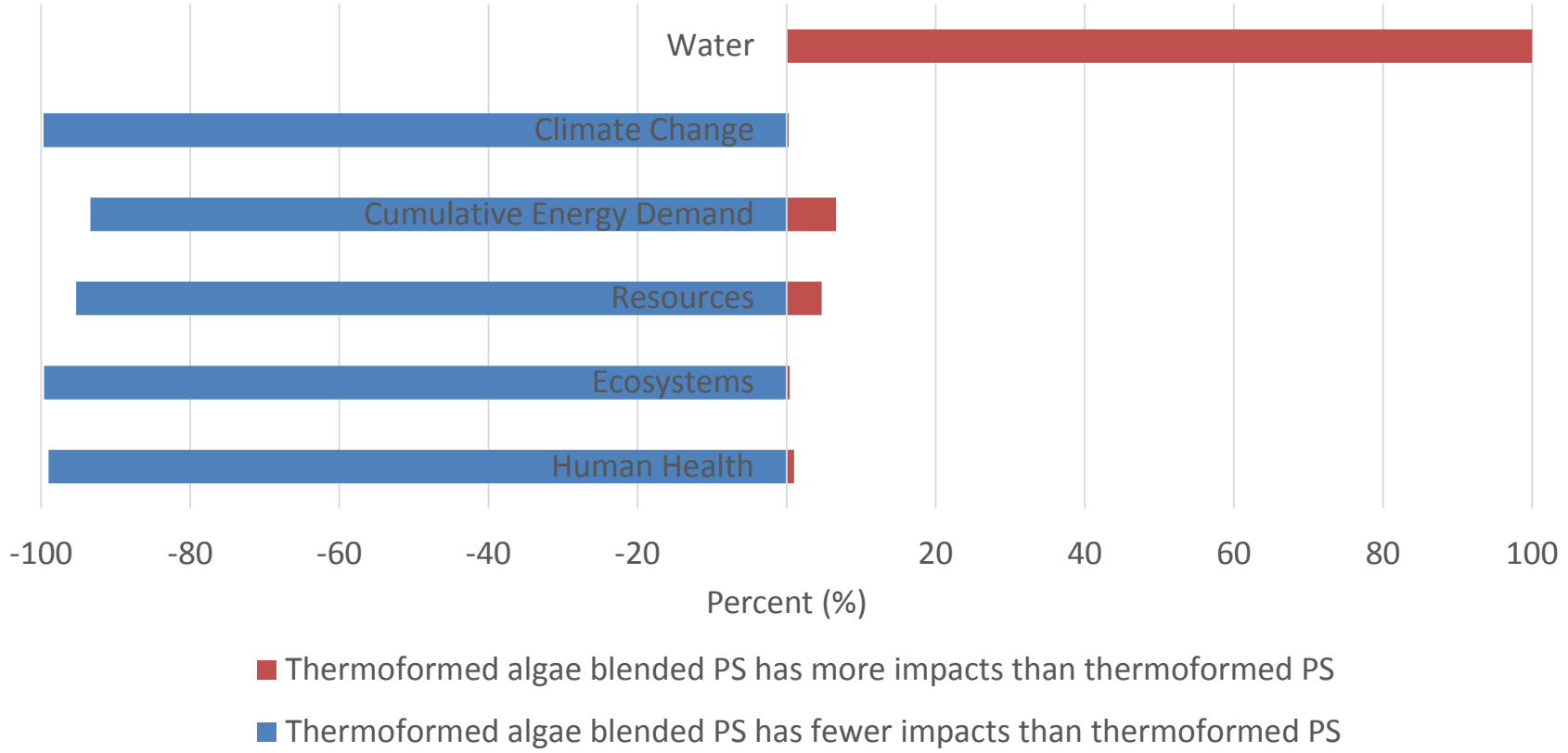

The algae / PS blend is significantly lower (within 95% confidence interval) in climate change, resources, ecosystems and human health impacts.
The PS is significantly lower in water depletion.

Impact Assessment Method: ES Method

Comparative Analysis – Uncertainty

Masterbatch (Cradle-to-Gate)

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	PS	PP	HDPE	PLA
Human Health				
Ecosystems				
Resources				
Climate Change				
Cumulative Energy Demand				
Water				

Legend
AI < P, 95% CI
AI < P, 90% CI
P < AI, 95% CI
Uncertain

The algae blended masterbatch generally has significantly lower climate change impacts and significantly higher water depletion. The results are less certain for PP.

Impact Assessment Method: ES Method

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Are the results sensitivity to certain parameters and assumptions?

SENSITIVITY ANALYSES

Sensitivity Analyses

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- What if the thermoformed algae blended plastic **weighs 5% or 10% more** than the petroleum-based plastic?
- How does **horizontal decanting and dewatering compare** to vacuum decanting, membrane dewatering and dewatering scenario cradle-to-grave?
- What impact would replacing **grid electricity with solar electricity** during one of the phases (e.g. harvesting) have on the overall impacts?
- What if the harvesting **transportation distance** between the pond and the dewatering facility is half? What if it is 3 times the distance?
- How do the thermoformed results compare if the raw algae **did <u>not</u> consume CO_2, N and P**?
- What happens if we use an alternative impact assessment method?

Sensitivity Analysis of Cradle-to-Grave

Cross-over points of thermoformed PS blend

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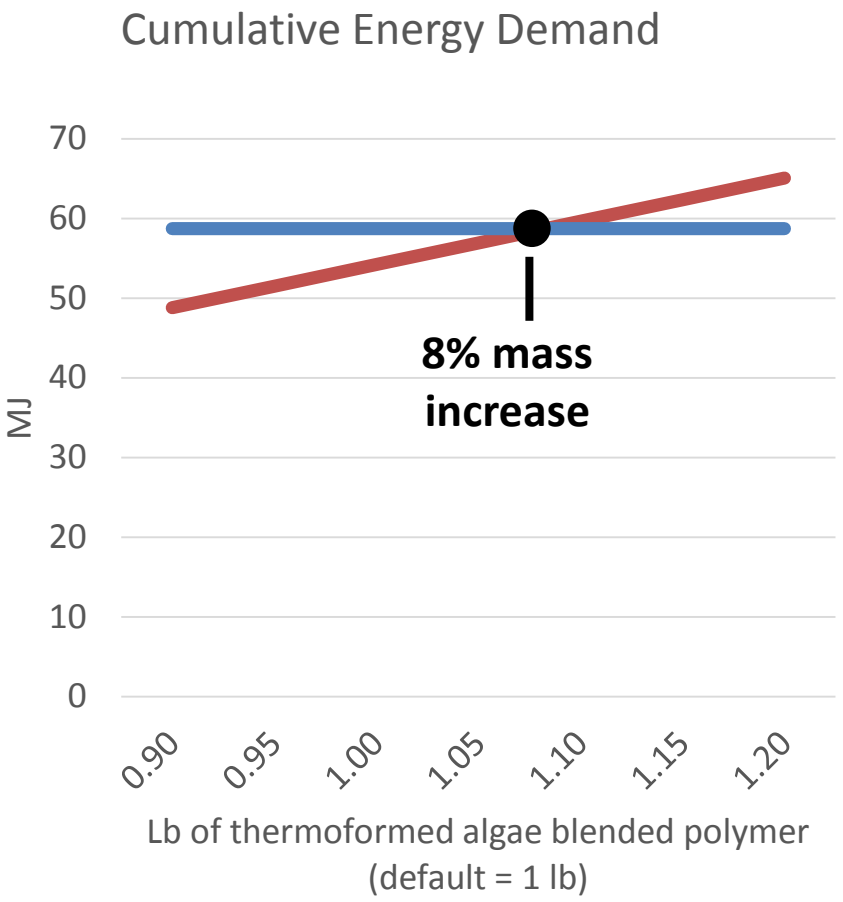

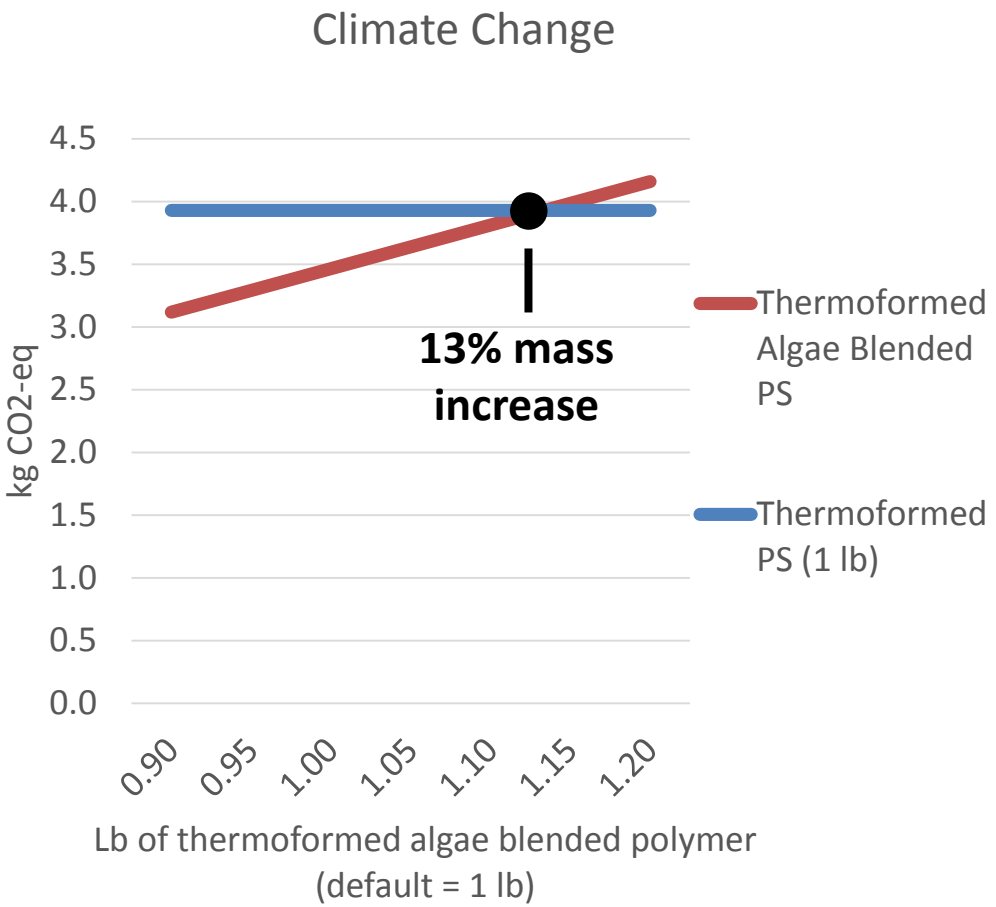

At current 25% loading level, algae blended PS will have greater cumulative energy demand impacts if application mass increases by 8% and will have greater climate change impacts if application mass increases by 13% or greater.

Impact Assessment Method: ES Method

Sensitivity Analysis of Masterbatch
Dewatering Scenarios

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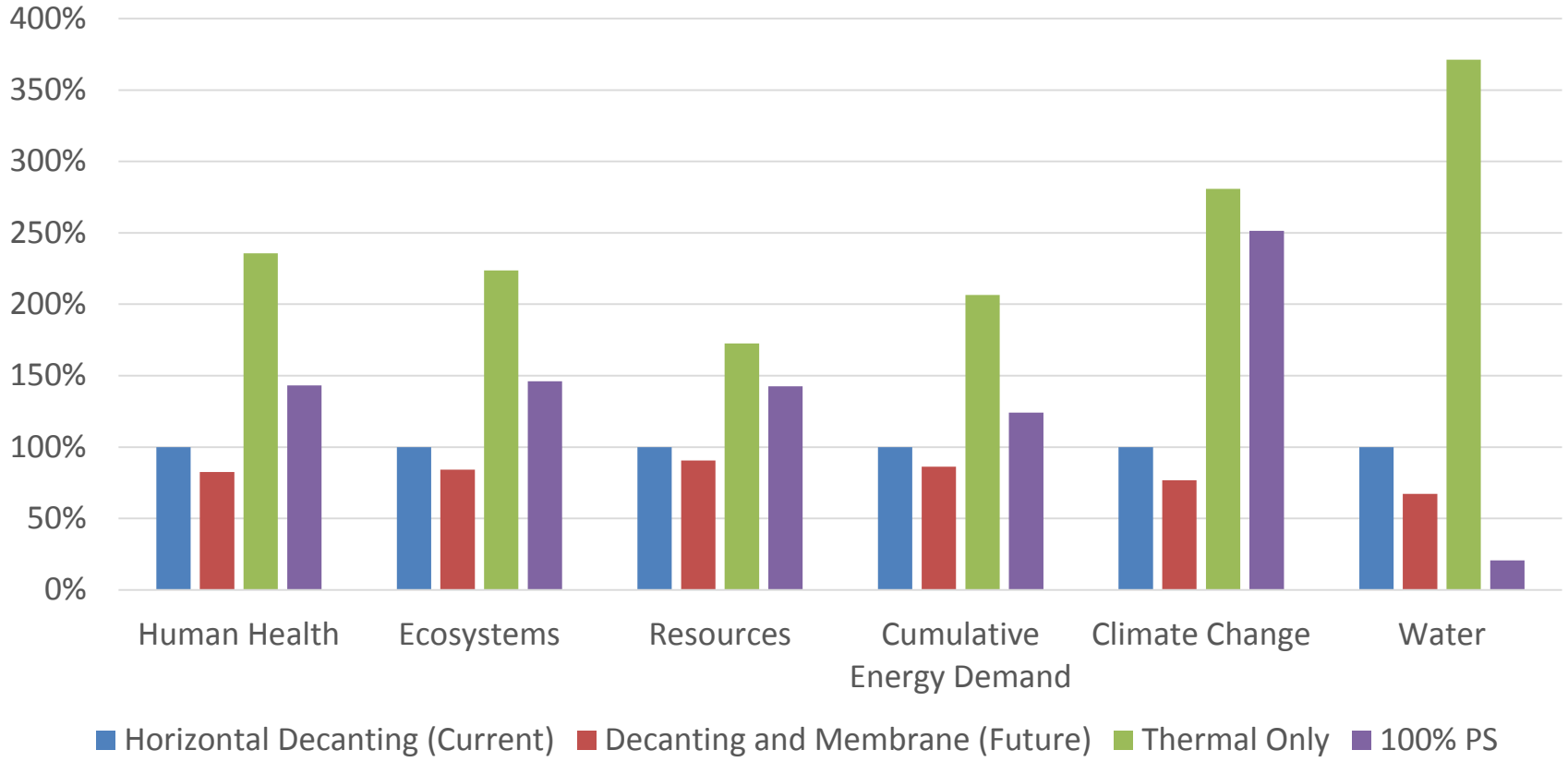

The dewatering process has a significant impact on the results. Full thermal dewatering would result in greater impacts than the unfilled polystyrene.

Impact Assessment Method: ES Method

Sensitivity Analysis of Masterbatch

Harvest Electricity Source

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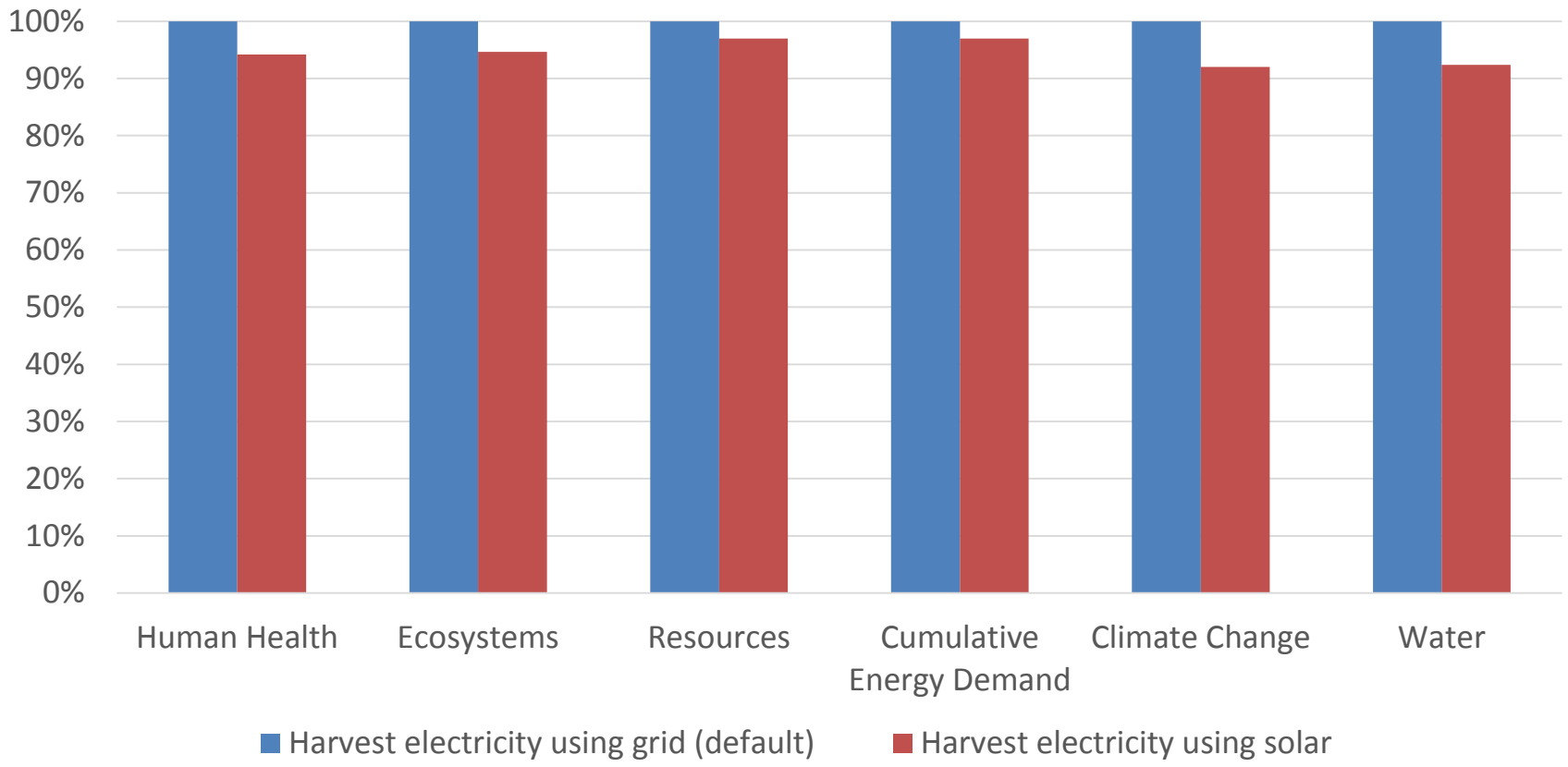
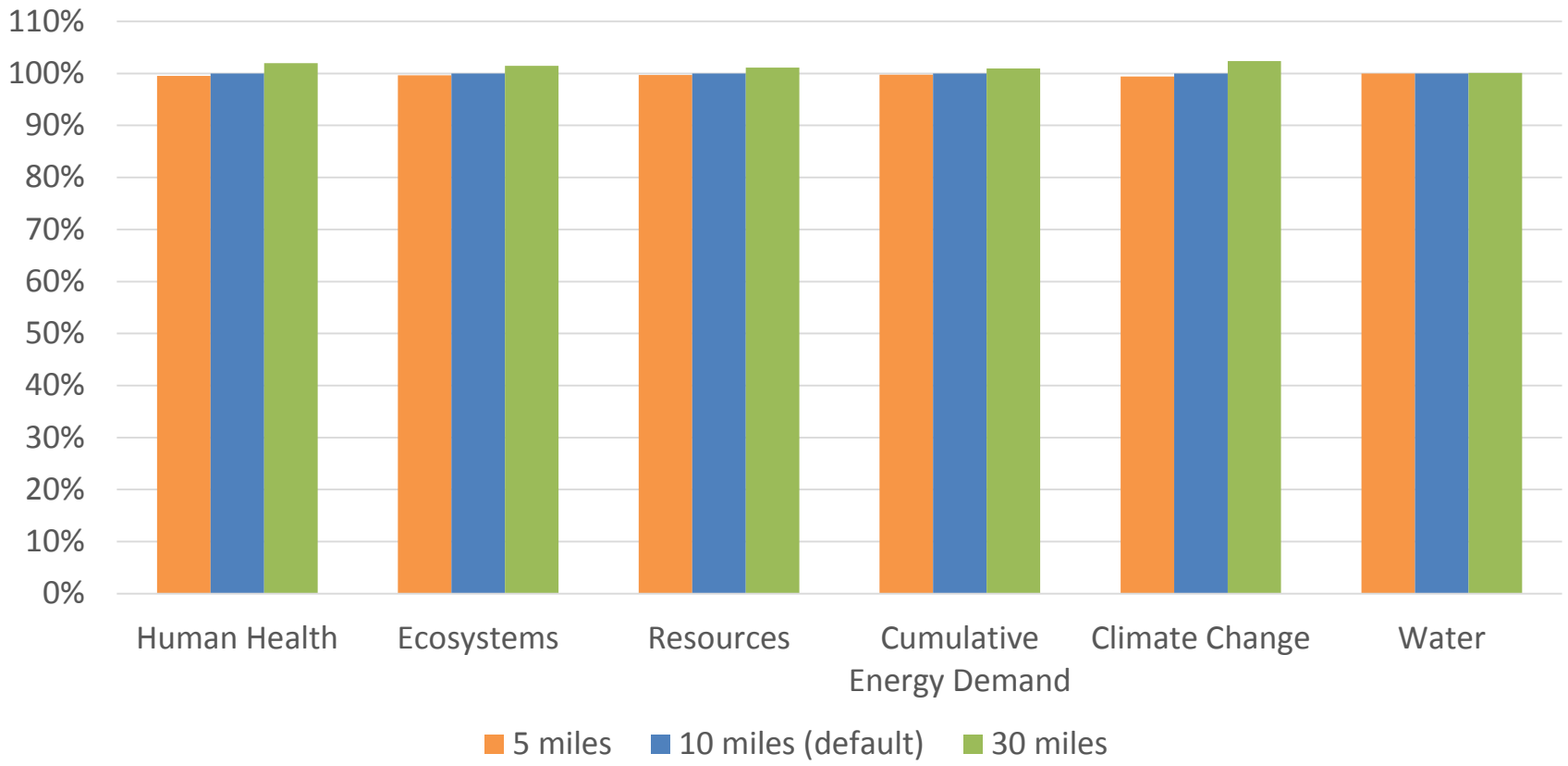


The use of solar electricity for harvesting has a 3 – 8% decrease in impacts compared with Alabama electricity, which is mainly comprised of coal (41%) and natural gas (24%).

Impact Assessment Method: ES Method

Sensitivity Analysis of Masterbatch

Harvest Distance



The results increase up to 2% if the transportation distance between pond and dewatering increases to 30 miles.

Impact Assessment Method: ES Method

Sensitivity Analysis of Cradle-to-Grave
Impact Assessment Method – IMPACT 2002+

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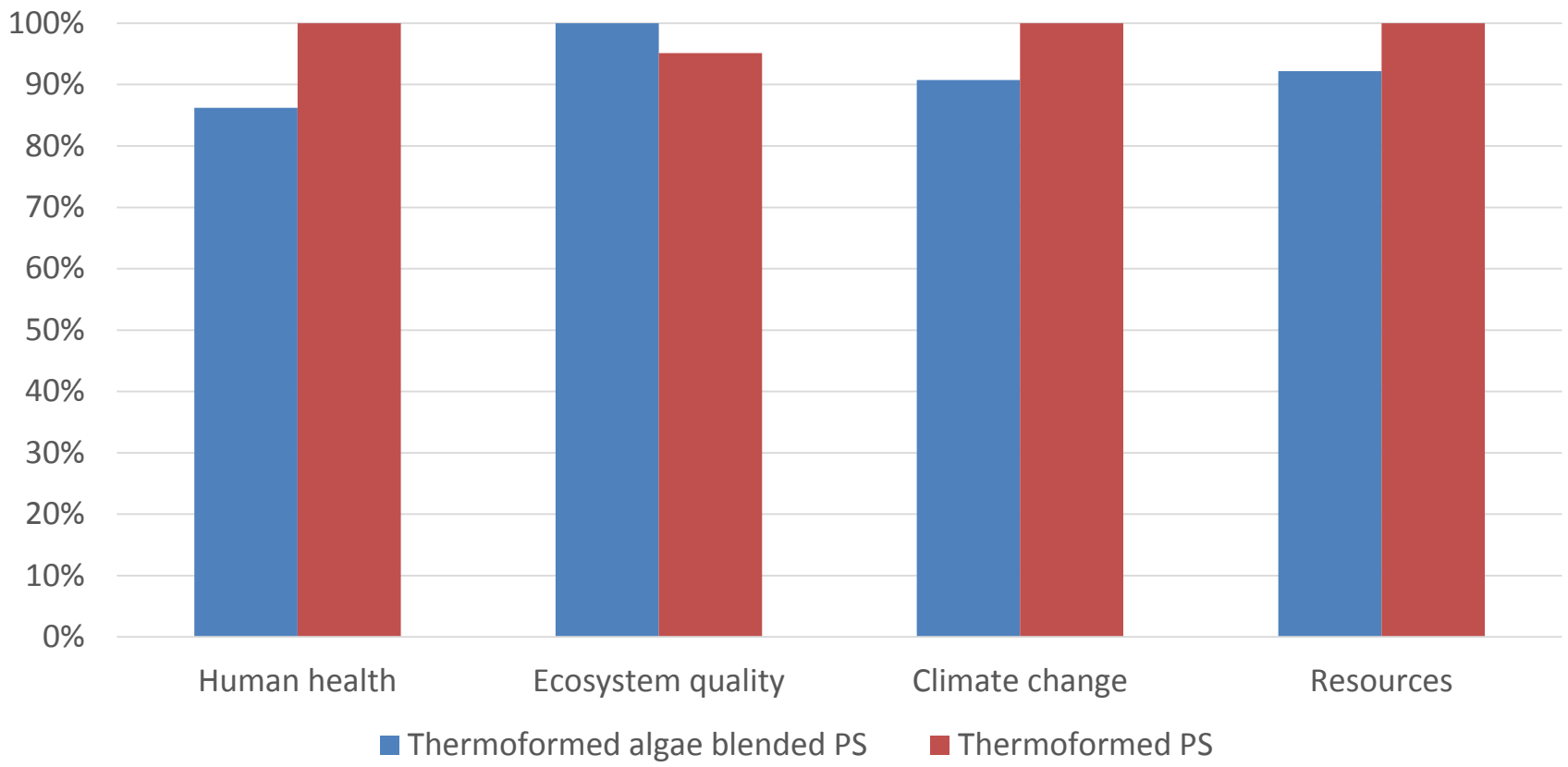

The algae / PS blend results in lower human health, climate change and resources impacts using the IMPACT 2002+ impact assessment method. The ecosystem quality impacts are higher due to how transportation impacts are accounted for.

Impact Assessment Method: ES Method

Sensitivity Analysis of Milled Algae

Consumption Comparison

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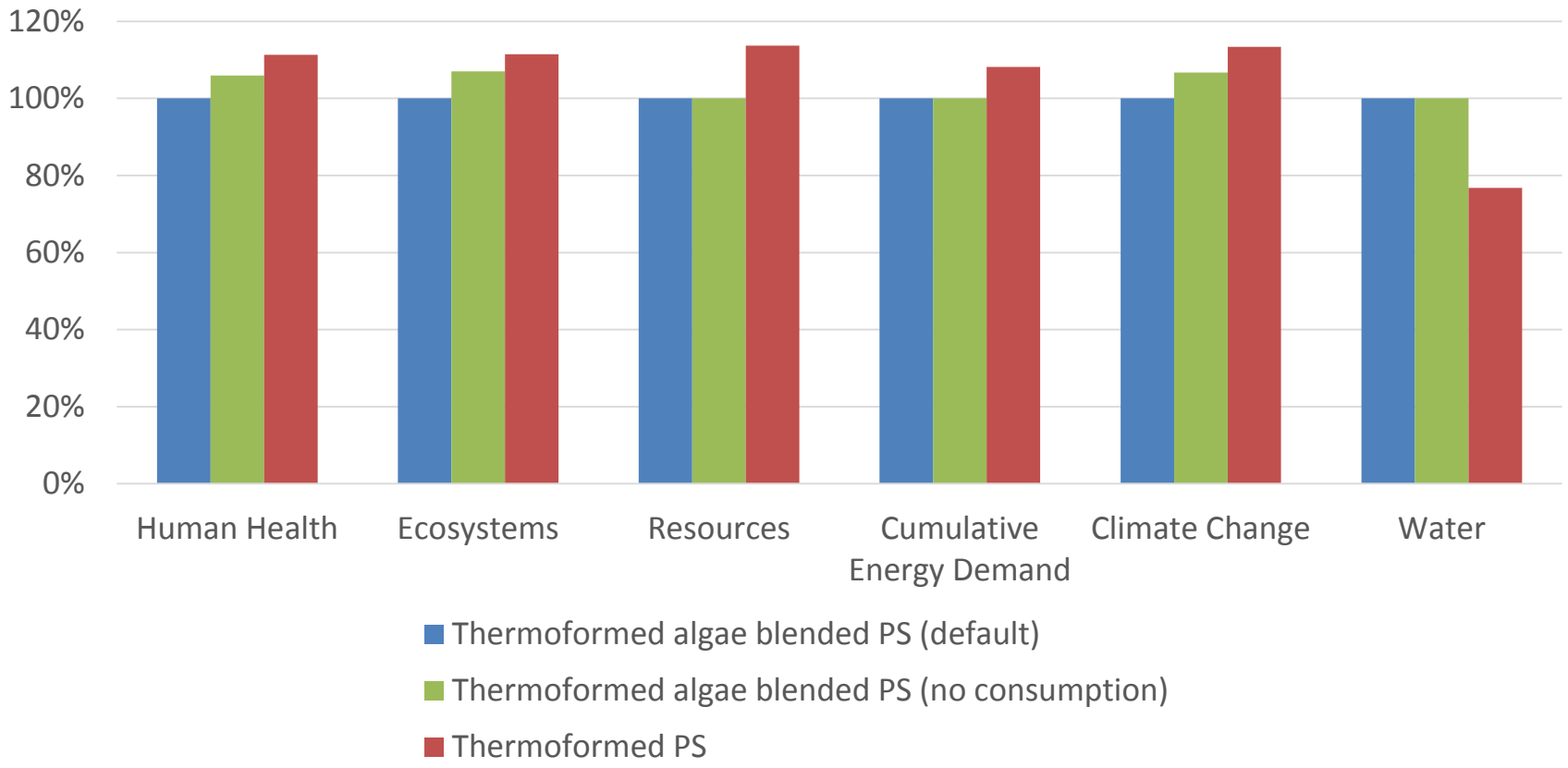

The thermoformed algae blended plastic, even without consumption of carbon dioxide, phosphorous and nitrogen during algae growth included, has fewer impacts cradle-to-grave in all categories except water when compared to thermoformed PS.

Impact Assessment Method: ES Method

Key Findings

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1) At 25% loading, mass equivalence and algae sourced from aquaculture site, the algae blended plastic results in lower environmental impacts in all categories except water, cradle-to-gate and cradle-to-grave.
   - → Focus on applications where mass equivalence or reduction can be achieved.
   - → Understand potential mass increase with algae and determine cross-over points.
   - → Increase algae loading while meeting performance requirements.
2) Harvesting, milling and dewatering contribute the majority of impacts in all impact categories, primarily driven by electricity consumption.
   - → Explore opportunities to increase energy efficiency. Prioritize harvesting and dewatering.
   - → Explore feasibility of on-site renewable energy.
3) The source of the algae and dewatering method can significantly change the environmental impacts.
   - → Focus efforts on achieving dewatering system with membrane.
   - → Compare based on similar geographies and electricity grid.

Key Findings

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4) Transportation of harvested algae and water is less than 4% of environmental impacts, however there are still opportunities to reduce impacts and cost.
   - → Continue siting algae milling facility within 20 mile radius.
   - → Determine feasibility of increased dewatering on-site at aquaculture pond to eliminate water return trip.
5) Additional data required or recommended to better quantify the environmental impacts of the algae blended plastic.
   - → Provide membrane flushing and chemical use data.
   - → Recycling performance study of algae blended plastic to document whether it can be recycled similar to base plastic.
   - → Explore chemical and aeration decrease in aquaculture ponds due to algae harvesting.

Next Steps

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- Algix report review
- Critical review by panel (2-4 weeks)
- Final report to Algix (January)

Once report has been critical reviewed, EarthShift can work with Algix to develop calculator or use EarthSmart to enable Algix to communicate the results.

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APPENDIX

Iterative Nature of LCA

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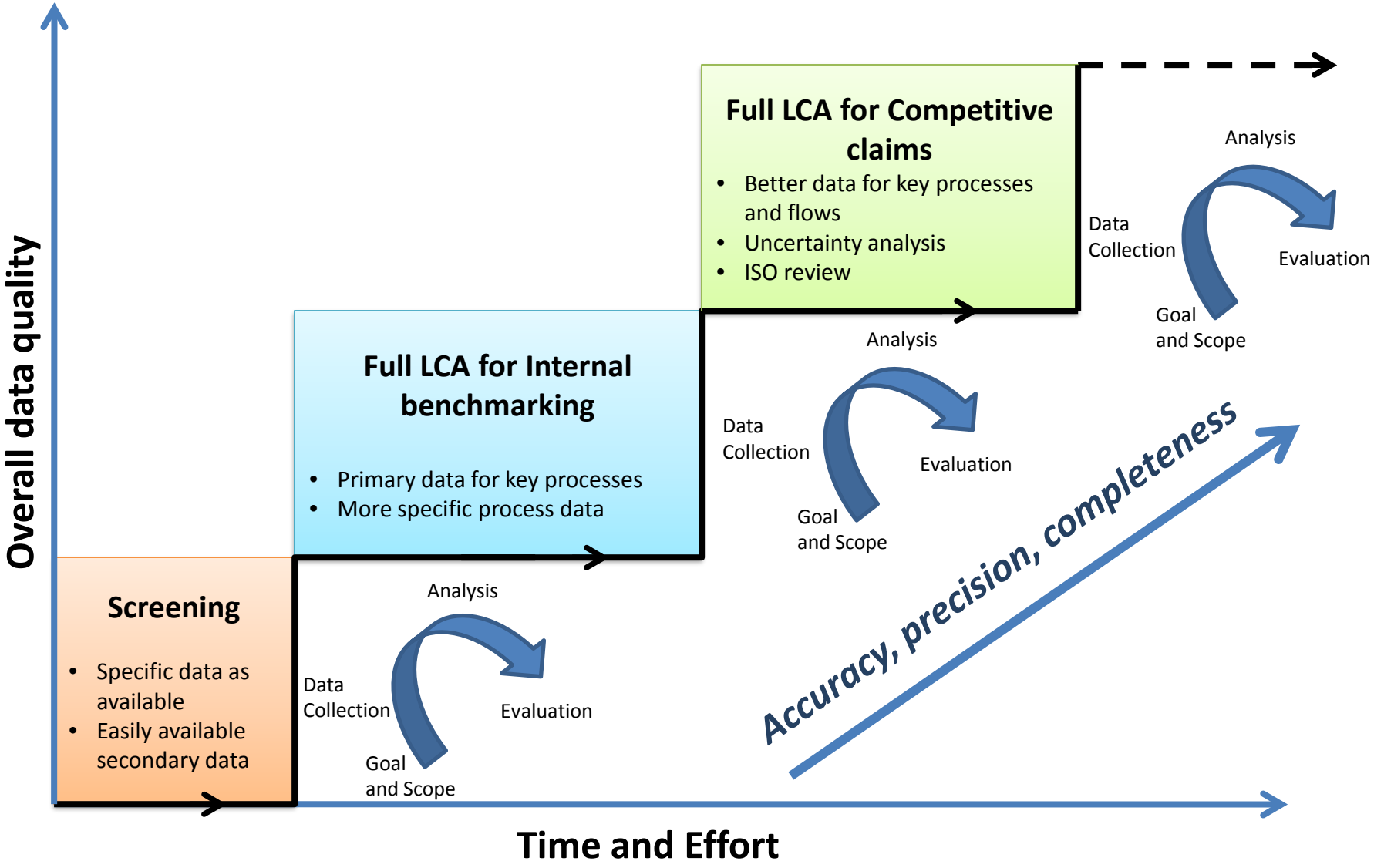

Taken from: ILCD-Handbook-General-guide-for-LCA-DETAIL