Life Cycle Assessment
of 1 kg of Packaged Potato Chips

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Contents

1. Executive Summary

This Life Cycle Assessment (LCA) study evaluates the environmental impacts associated with the production, packaging, distribution, and end-of-life treatment of 1 kg of packaged potato chips in India. Conducted in accordance with ISO 14040/44 guidelines, the assessment follows a Cradle-to-Grave system boundary and utilizes the ReCiPe 2016 Midpoint (H) methodology via the SimaPro 9.4 demo version for impact analysis.

Goal and Scope

The primary goal of this study is to quantify and interpret the environmental impacts of packaged potato chips across their life cycle stages: Agriculture, Processing, Packaging, Distribution, and End-of-Life. The defined functional unit is 1 kg of packaged potato chips ready for retail.

Key Findings

- Agriculture is the most significant contributor to environmental impacts, driven by the use of synthetic fertilizers, diesel fuel, and high irrigation demand.

- Processing contributes heavily to marine eutrophication and energy use, primarily due to soybean oil refining (used as a substitute for sunflower oil) and natural gas consumption.

- Packaging materials, particularly LDPE plastic and cardboard, contribute to land use and fossil resource depletion.

- Distribution, involving 150 km of truck transport, adds to ozone formation and fossil fuel use.

- End-of-life impacts are relatively modest, with partial recycling of packaging materials helping to reduce waste.
- End-of-life modeling assumes average municipal waste handling, which can vary by region.

Recommendations for Environmental Improvement

- Optimize Agricultural Inputs: Shift to organic or precision farming techniques and adopt diesel-alternative machinery to reduce emissions.

- Enhance Processing and Packaging Efficiency: Use renewable energy sources, reusable or biodegradable packaging, and promote green electricity adoption.

- This study identifies key environmental hotspots and presents viable interventions across the supply chain, offering actionable insights for reducing the environmental footprint of packaged snack products in developing economies like India.

2. Goal and Scope

2.1 Goal and Scope of the study

Life Cycle Assessment (LCA) is a method for estimating the environmental impacts of a product or service in the entire supply chain. The goal of the study focuses on to assess and interpret the environmental impacts associated with producing, packaging, distributing, and disposing of 1 kg of packaged potato chips, using quantified input data across the product life cycle. The ISO 14040/44 guidelines on LCA analysis for Products in accordance with the LCA methodology based on ReCiPe 2016 Midpoint (H) was used for the impact assessment.

Functional Unit

The functional unit serves as the reference point for evaluating the life cycle impacts of a product. It enables the quantification of environmental impacts across the entire Cradle-to-Grave life cycle. All material and energy inputs, as well as emissions, effluents, and waste outputs, are scaled in relation to this functional unit through the reference flow.

The functional unit for the study is 1 kg of packaged potato chips

Reference Flows and Key Environmental Parameters

The reference flow is the quantified amount of a product or service required to fulfil the functional unit in an LCA study

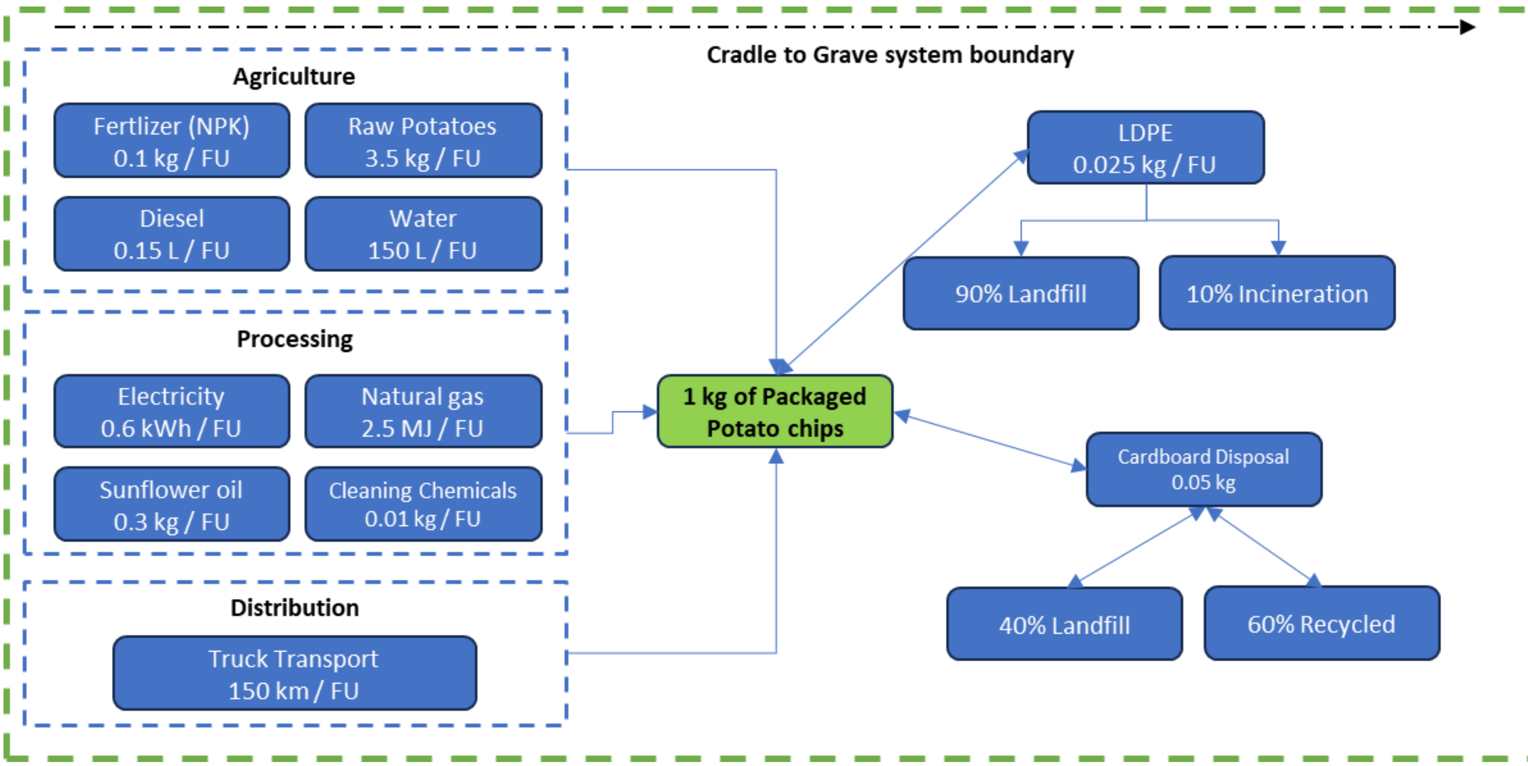
Table 1. Reference Flows and Key Environmental Parameters

PRODUCTS OR SYSTEM	FUNCTIONAL UNIT	REFERENCE FLOWS	KEY ENVIRONMENTAL PARAMETERS
Packaged Potato Chips	1 kg of packaged potato chips (ready for retail)	3.5 kg raw potatoes, 0.1 kg fertilizer, 0.15 L diesel, 150 L irrigation water, 0.6 kWh electricity, 2.5 MJ natural gas, 0.3 kg sunflower oil, 0.01 kg cleaning chemicals, 0.025 kg LDPE, 0.05 kg cardboard, 150 km truck transport	- High irrigation water demand (150 L/kg chips) Frying is energy- and oil-intensive (2.5 MJ gas, 0.3 kg oil) Packaging creates plastic waste (90% to landfill) 5% food loss at consumer stage Fertilizer and diesel add to upstream emissions

System Boundary

The system boundary is defined below, which is based on 1kg of Packaged Potato chips. The life cycle stage contains the stages of Agriculture, Processing, Packaging, Distribution, and End-of-Life. The detailed description of each phase is given below.

Figure 1. Generic system boundary for 1kg of Packaged potato chips



Geographical Coverage

The geographical system boundaries of the LCA cover the production of 1kg of packaged potatoes in India.

2.2 Assumptions

- **Potato Yield Conversion**: It is assumed that 3.5 kg of raw potatoes are required to produce 1 kg of potato chips, including peeling losses and moisture evaporation.
- **Energy Use in Processing**: The energy requirement (0.6 kWh electricity and 2.5 MJ natural gas) is assumed based on typical industrial frying and packaging operations.
- **Single-use Sunflower Oil**: In the frying process, sunflower oil is utilized once and then discarded. However, due to the limitations of the SimaPro demo version, refined soybean oil has been used as a substitute for sunflower oil in the evaluation.
- **Cleaning Chemicals:** Owing to database constraints in the SimaPro demo version, the global market dataset for soap has been used as a proxy for cleaning chemicals

- **LDPE Packaging**: LDPE is used for primary packaging (0.025 kg per kg chips) and cardboard (0.05 kg) for bulk transport. Due to database limitations in the SimaPro demo version, the waste recycled version of LDPE has been used for modeling. For municipal landfill, it is assumed that 60% of the waste is sorted and treated as recycled LDPE. Similarly, for municipal incineration, the sorted recycled LDPE dataset has been considered.
- **Transport Distance**: A fixed average transport distance of 150 km by a medium-duty diesel truck is considered from factory to retailer.
- **Water Source**: Irrigation water is assumed to be extracted from groundwater sources.
- **End-of-Life Scenarios**: Disposal assumptions are based on average municipal solid waste management in a developing country:
  1. Plastic: 90% landfill, 10% incineration
  2. Cardboard: 60% recycled, 40% landfill
  3. Food waste: 5% of chips discarded by consumer

2.3 Exclusions

- **Consumer Phase Activities**: Cooking, refrigeration, or energy used by consumers after purchase is excluded from the system boundary.
- **Seasonings and Additives**: Minor ingredients like salt, spices, preservatives are excluded due to negligible mass (<1%) and assumed low impact.
- **Packaging Ink and Labels**: These are not included in the inventory due to lack of reliable data and their small contribution to total impact.
- **Machinery Production**: The manufacture of factory machinery and farm equipment is excluded (capital goods not considered).
- **Office & Administrative Functions**: Emissions from offices or support services are excluded as they are not directly attributable to product output.

2.4 Cut-off Criteria

- All material or energy flows contributing less than 1% of the total mass or energy are excluded, provided their cumulative contribution does not exceed 5%.
- Any process for which data is unavailable and deemed to have an insignificant environmental impact is omitted, with justification.

3. Life Cycle Inventory (LCI)

3.1 Detailed Description

The Life Cycle Inventory (LCI) stage is based on a functional unit of 1 kg of packaged potato chips delivered to the end consumer. The system boundary is defined as Cradle-to-Grave, covering stages from agriculture to disposal. This includes agricultural inputs (A1), processing and manufacturing (A2), packaging (A3), distribution (A4), and end-of-life treatment.

In the agriculture stage, the inputs consist of 3.5 kg of raw potatoes, 0.1 kg of synthetic NPK fertilizer, 0.15 liters of diesel for field operations using tractors, and 150 liters of groundwater for irrigation.

The processing stage includes the use of 0.6 kWh of electricity (for cutting, drying, and packaging lines), 2.5 MJ of natural gas (for frying), 0.3 kg of sunflower oil (used once for frying), and 0.01 kg of cleaning chemicals for equipment sanitation.

In the packaging stage, 0.025 kg of LDPE plastic is used for primary packaging and 0.05 kg of cardboard for bulk transport cartons.

The distribution stage involves transporting the packaged chips over an estimated 150 km using a medium-duty diesel truck.

At the end-of-life stage, it is assumed that 5% of the product (chips and packaging) is discarded without consumption. Regarding packaging disposal, 90% of the LDPE plastic is landfilled and 10% is incinerated, while 60% of the cardboard is recycled and 40% goes to landfill. These figures are based on average municipal waste data.

3.2 Data sources

The data for this LCI was sourced from SimaPro demo datasets, supported by values from published literature and reasonable approximations where exact data was not available.

3.3 LCA Software info.

CA S/W name – Simapro demo version

LCA S/W version - 9.4.0.2

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For end of life process, the waste generated for plastic packaging and cardboard disposal is considered under waste paperboard and waste recycling as proxy enteries, due to limitations of sima pro demo version.

Table 2: Data Collection from Ecoinvent database

Input Data	SimaPro Category / Process Name	Amount	Unit	Source
Potatoes	Potatoes, at farm {IN} Economic, U	3.5	kg	Ecoinvent (India)
NPK Fertilizer	NPK (26-15-15) fertiliser {RoW} market for NPK (26-15-15) fertiliser | Cut-off, U	0.1	kg	Ecoinvent (RoW)
Diesel	Diesel, burned in agricultural machinery {RoW} | market for diesel	5.37	MJ	Ecoinvent (RoW)
Irrigation Water	Water, decarbonised {IN} | market for water, decarbonised | Cut-off, U	150	kg	Ecoinvent (India)
Natural Gas	Heat, central or small-scale, natural gas {GLO} | market group for heat	2.5	MJ	Ecoinvent (GLO)
Sunflower Oil (Soybean alt.)	Soybean oil, refined {GLO} | market for soybean oil, refined | Cut-off, U	0.3	kg	Ecoinvent (GLO) – Used as substitute
Cleaning Chemicals	Soap {GLO} | market for soap | Cut-off, S	0.01	kg	Ecoinvent (GLO)
LDPE (Plastic Bag)	Polyethylene, low density, granulate {GLO} | market for polyethylene	0.025	kg	Ecoinvent (GLO)
Cardboard (Bulk Transport)	Corrugated board box {RoW} | market for corrugated board box | Cut-off, U	0.05	kg	Ecoinvent (RoW)
Transport	Transport, freight, lorry with refrigeration, 7.5–16 ton, diesel, EU mix	150	kgkm	Ecoinvent (EU Mix)
Landfill Residue	Process-specific burdens, residual material landfill {RoW}	0.05	kg	Ecoinvent (RoW)
LDPE Waste (Unsorted)	Waste polyethylene, for recycling, unsorted {RoW} | market for waste polyethylene	0.0225	kg	Ecoinvent (RoW)
LDPE Waste (Sorted)	Waste polyethylene, for recycling, sorted {RoW} | market for waste polyethylene	0.0025	kg	Ecoinvent (RoW)
Cardboard Waste (Unsorted)	Waste paperboard, unsorted {RoW} | market for waste paperboard	0.02	kg	Ecoinvent (RoW)
Cardboard Waste (Sorted)	Waste paperboard, sorted {RoW} | market for waste paperboard	0.03	kg	Ecoinvent (RoW)

4. Life Cycle Impact Assessment (LCIA)

4.1 Detail description of Results

To reduce the environmental impacts associated with the life cycle of packaged potato chips, several interventions can be made across each stage of production and distribution.

In the **agricultural stage (A1)**, the use of sustainably or organically grown potatoes is encouraged to reduce dependence on synthetic fertilizers and promote soil health. Fertilizer application should be optimized or replaced with bio-fertilizers to minimize eutrophication and greenhouse gas emissions, the adoption of water-efficient irrigation systems like drip or sprinkler irrigation can significantly cut down the use of groundwater.

In the **processing stage (A2)**, switching from natural gas fryers to energy-efficient electric fryers powered by renewable sources can reduce fossil fuel dependence and associated emissions. While sunflower oil is typically used for frying, reusing filtered oil or selecting oils with a lower environmental impact can decrease the frequency and quantity of oil consumption. For electricity needs in cutting, drying, and packaging, sourcing green electricity or installing solar panels on-site is a practical solution to reduce indirect emissions. The use of biodegradable or eco-labelled cleaning chemicals can also help reduce the release of toxic substances into the environment.

In the **packaging stage (A3)**, shifting from conventional LDPE plastic bags to biodegradable or compostable alternatives can reduce plastic waste and potential pollution. Packaging designs should be optimized to minimize material use, and recycled cardboard should be used for outer cartons to lessen the impact on forests and decrease overall packaging material demand.

During the **distribution stage (A4)**, logistics efficiency plays a crucial role. Switching to electric delivery vehicles or optimizing transportation routes can reduce fossil fuel consumption and greenhouse gas emissions.

Finally, at the **end-of-life stage**, consumer education is vital to reducing food waste, as about 5% of chips are typically discarded uneaten. Take-back or recycling schemes for plastic packaging can improve circularity and reduce landfill and incineration burdens. Clear labeling and recycling programs for cardboard packaging can further increase recycling rates and reduce landfill waste.

These recommendations, when collectively applied, can significantly lower the environmental footprint of potato chips from farm to fork.

4.2 Results and conclusion:

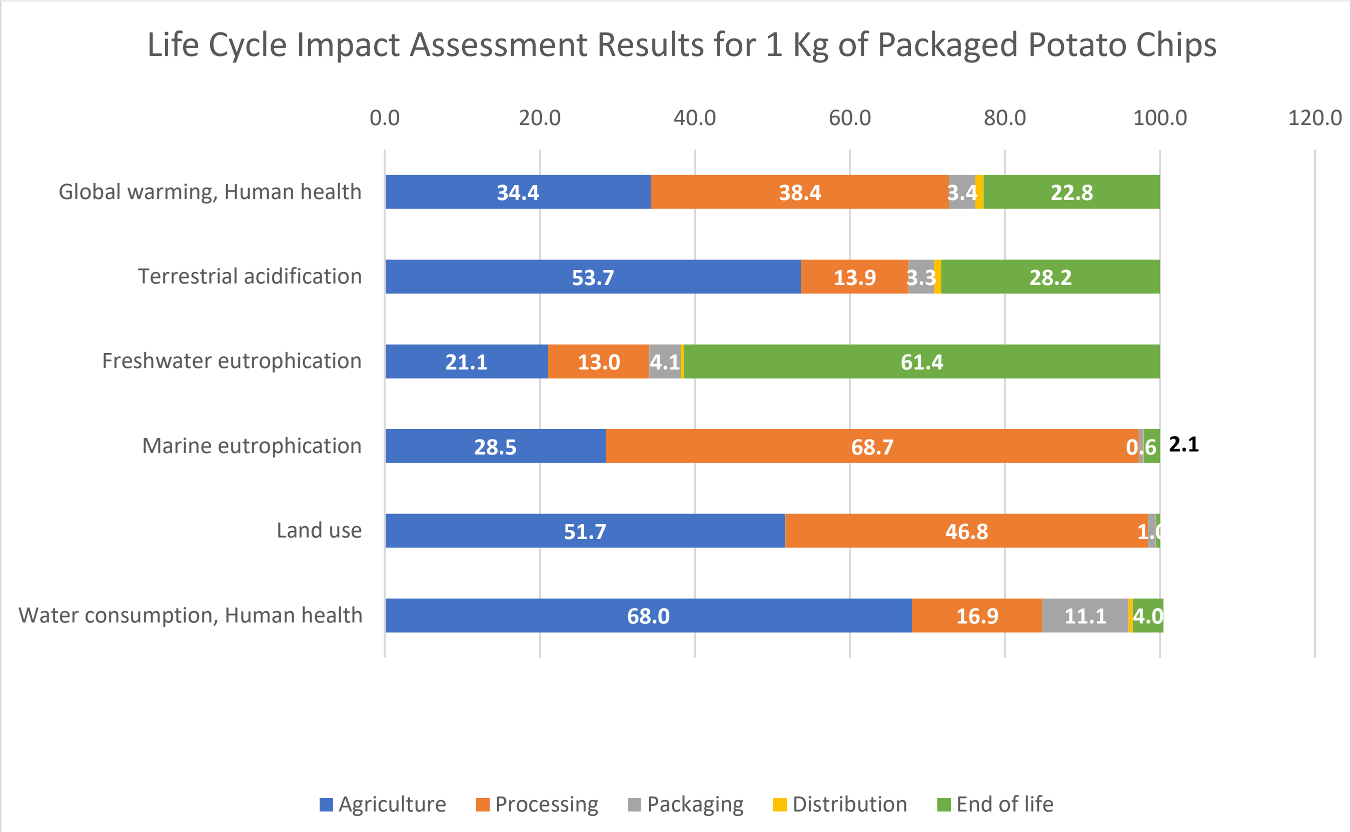

Figure 2 : Results of LCIA of 1 kg Packaged Potato Chips

The life cycle assessment of 1 kg of packaged potato chips reveals that the agriculture and processing stages are the most environmentally intensive. Major contributors include NPK fertilizer, diesel, and soybean oil, affecting categories such as global warming, eutrophication, and human toxicity. Packaging and distribution, though moderate, still contribute significantly to land use, fossil fuel use, and ozone formation due to plastic and board materials and refrigerated transport.

1.Agriculture contributes heavily to:

- Global warming potential (over 40% of total GWP)
- Freshwater eutrophication due to runoff from fertilizers (NPK 26-15-15)
- Ozone depletion and terrestrial ecotoxicity from diesel combustion and fertilizer production

2.Processing, especially from soybean oil refining and heat generation via natural gas, significantly contributes to:

- Marine eutrophication (66.3)

3.Packaging adds to:

- Land use and resource depletion, driven by LDPE and corrugated board materials

4. Interpretation

Trade-offs:

- Improving crop yield through fertilizers helps reduce land use but increases eutrophication and toxicity impacts.
- Using refined vegetable oils like soybean oil enhances shelf life but drastically increases marine eutrophication.

Uncertainties:

- Due to limitations of Simapro demo version, data from global datasets (GLO, RoW) might not reflect regional variations in farming and energy systems.
- Allocation of emissions in co-product systems (e.g., oil refining, soap) can affect accuracy.
- End-of-life scenarios such as actual recycling rates vary by geography and infrastructure.

Recommendations to Reduce Environmental Impacts

1. Optimize Agricultural Inputs

- Shift to organic or precision agriculture to reduce fertilizer overuse.
- Introduce diesel-alternative machinery (e.g., electric or biofuel-based) to cut emissions.

2. Improve Energy and Material Efficiency in Processing & Packaging

- Use renewable energy sources (e.g., solar/biogas) for heat and electricity in processing units.
- Explore biodegradable or recycled packaging materials to reduce fossil and land use impacts.

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