Comparative Life Cycle Assessment of a Reusable Water Bottle vs. Single-use Plastic Bottles

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Step 1: Goal and Scope Definition

This study aims to compare the environmental impact of using a reusable stainless steel water bottle versus using single-use plastic (PET) bottles over one year. The goal is to provide a clear, evidence-based comparison to help consumers make more sustainable choices in daily life. While designed for general public awareness, the study also follows basic Life Cycle Assessment (LCA) methodology, which is suitable for academic review.

The functional unit for this comparison is the delivery of 365 liters of drinking water to a single user over one year, equivalent to consuming 1 liter per day. This enables a fair comparison between using one reusable bottle (used and washed daily) and using 365 single-use bottles.

The system boundaries cover the full life cycle — cradle-to-grave — including:

- Raw material extraction
- Manufacturing
- Transportation
- Usage (including daily washing for reusable bottle)
- End-of-life (landfilling, recycling, or incineration)

The following impact categories are assessed:

- Global Warming Potential (GWP) – kg CO_2-equivalent
- Energy use – MJ (megajoules)
- Water use – liters

Step 2: Life Cycle Inventory (LCI)

Category	Reusable Bottle	Single-Use PET Bottle
Units	1 bottle reused 365 times	365 bottles
Materials (kg)	0.5 kg stainless steel	7.3 kg PET (365*0.02 kg)
Bottle Manufacturing Energy (MJ)	50 MJ	15.3 MJ (365*0.042 MJ)

Transportation Energy	3 MJ	36.5 MJ (0.1 MJ/bottle)
Washing (water, soap)	0.3 L+ 0.1 MJ/day = 109.5 L, 36.5MJ/year	0
End-of-life	70% recycled	30% recycled
CO2 from Manufacturing (kg CO2)	7kg	182.5kg
CO2 from transport (kg CO2)	6.3kg	0.091kg
CO2 from Washing (kg CO2)	1.07kg	0

Life Cycle Inventory- Data Sources and Calculation:

The life cycle inventory for this study uses region-specific and literature-based values:

Electricity: We use the average German emissions intensity of 0.321 kg CO_2/kWh, adjusted to 0.105 kg CO_2/kWh to reflect the Bavarian electricity mix.

Road Freight: An emission factor of 0.126 kg CO_2 per tonne-km is applied, based on German data for heavy goods transport.

Manufacturing impacts use standard LCI values from **Ecoinvent** and **PlasticsEurope**:

Stainless steel bottle production: ~14 kg CO_2/kg → 0.5 kg = 7 kg CO_2

PET bottles: ~0.5 kg CO_2 per 0.02 kg bottle → 365 × 0.5 = 182 kg CO_2

Washing impacts (water, soap, heating): 0.3 L + 0.1 MJ per wash, multiplied by 365 uses, based on typical dishwashing LCA data.

End-of-life assumptions: 70% recycling for stainless steel (EU average), 30% for PET (current German average).

CO_2 Emissions Calculations:

1. Electricity-related CO_2 (cleaning & manufacturing):
   Energy (kWh)×0.321 kgCO2/kWh
2. Transport CO_2:
   - Reusable:
     100 km × 0.5 tonnes × 0.126 kg = ~6.3 kg CO_2

- Single-use:
  (7.3 kg total weight) × (100 km × 0.126) / 1000 = ~0.092 kg CO_2 per total shipments
  (Alternatively, use 0.1 MJ energy * avg electricity CO_2)

3. Production Emissions:
   - Stainless steel: ~14 kg CO_2 per kg → 0.5 kg ≈ 7 kg CO_2
   - PET: ~0.5 kg CO_2 per bottle → 365 × 0.5 = ~182 kg CO_2
     (**Values from Ecoinvent/PlasticsEurope**)

System Boundary Diagram:

Reusable bottle System (Cradle to Grave)

Single-Use PET Bottle System

Step 3: Life Cycle Impact Assessment (LCIA)

3.1 Define Impact Categories and Methods:

1. Global Warming Potential (GWP) – measured in kg CO2-equivalent
2. Energy Use – total energy input in MJ
3. Water Use – total liters consumed

3.2 Apply Impact Factors to your Inventory:

We'll now calculate the impact for each item from your LCI using conversion factors (also known as characterization factors).

Inventory Item	Unit	Conversion Factor	Impact Category
Electricity (Germany avg)	1 kWh = 3.6 MJ	0.321 kg CO_2/kWh → **0.0892 kg CO_2/MJ**	GWP
Manufacturing – PET	1 bottle (0.02 kg)	0.5 kg CO_2	GWP
Manufacturing – Stainless Steel	1 kg steel	14 kg CO_2	GWP
Water (hot) use	1 L	0.002–0.01 kg CO_2	GWP & Water
Road transport (Germany)	1 tonne-km	0.126 kg CO_2	GWP

3.3 Calculate Total Impacts:

Reusable bottle (Steel):

1. GWP Total =
   - Manufacturing: 0.5 kg steel * 14 kg CO_2/kg = 7 kg CO_2
   - Washing = 36.5 MJ * 0.0892 kg CO_2/MJ = 3.26 kg CO_2
   - Transport = 100 km * 0.5 tonnes * 0.126 = 6.3 kg CO_2
   - Total = 16.56 kg CO_2
2. Energy Use = 50 MJ + 3 MJ + 36.5 MJ = 89.5 MJ
3. Water Use (Lit) = 0.3 L/day * 365 days = 109.5 L/year

Single-Use PET Bottles:

1. GWP Total =
   - Manufacturing: 365 bottles * 0.5 kg CO_2/bottle = 182.5 kg CO_2
   - Transport = 7.3 kg * 100 km * 0.126 CO_2/ton-km / 1000 = 0.091 kg CO_2
   - Washing = 0 (No washing needed)
2. Energy Use = 15.3 MJ + 36.5 MJ = 51.8 MJ

3. Water Use = 0 (bottles are discarded after use)

Step 4 Interpretation:

This study compared the environmental impacts of using a reusable stainless steel water bottle versus 365 single-use PET plastic bottles over one year (365 liters of drinking water). Impacts were assessed using Global Warming Potential (kg CO_2-eq), energy use (MJ), and water use (L).

Impact Summary Table:

Impact Category	Reusable Bottle	Single-Use PET Bottle
GWP (kg CO_2-eq)	16.56	182.6
Energy Use (MJ)	89.5	51.8
Water Use (L)	109.5	0

Over the course of one year, the reusable bottle had ~91% lower carbon emissions than the single-use plastic bottles. While it required more energy and water (mainly for cleaning), its emissions savings far outweighed these impacts. For example, if the stainless-steel bottle is only reused 50 times and then discarded, its GWP per liter would increase significantly and may not outperform PET. However, at 365 uses or more, the break-even point is quickly surpassed.

Conclusion:

The results of this study show that a reusable stainless-steel bottle has a significantly lower environmental impact than using 365 single-use PET plastic bottles over one year, especially in terms of carbon emissions. While the reusable bottle requires more energy and water during use, its long-term benefits make it a more sustainable choice when used consistently and cleaned efficiently.