Life Cycle Impact of Nanosilver Polymers-Food Storage Containers as a Case Study

Supplemental Information

Table S1: LCA inventory data

	Inputs	Outputs	Sima Pro Reference	Database
Nanosilver synthesis	**1 kg of AgNP = 1.57 kg silver nitrate + 0.35 kg sodium borohydride**			
	1 kg silver nitrate		-	
	0.49 kg nitric acid		Nitric acid, in water (60% HNO3), at plant/RER	Agri
	0.64 kg silver		Silver {GLO} market for	EcoInvent 3
		0.07 kg water	Water - Airborne emission	
		0.06 kg Nitrogen monoxide	Nitrogen oxide - Airborne emission	
	1 kg sodium borohydride		-	
	2.74 kg trimethyl borate		Trimethyl borate {GLO} market for	EcoInvent 3
	2.54 kg sodium hydride		Not in SimaPro	
	0.958 kg Na + 0.042 kg H2 = 1 kg NaH		[Sodium {GLO} market for][Hydrogen (cracker) E]	EcoInvent 3, Industry Data 2.0
	13,915 kg Water		De-ionised water, reverse osmosis, production mix, at plant, from surface water RER System	Agri Footprint
	0.024 m ^{3} Water for cooling		Water, cooling, unspecified natural origin/m ^{3} - Raw material	
		0.009 kg hydrogen	Hydrogen - Airborne emission	
		0.13 kg diborane	Not in SimaPro - Created as Airborne emission	
		0.79 kg sodium nitrate	Sodium nitrite -Waterborne emission	
nAg containers production	64.35 g of plastic/container		Polyethylene, high density, granulate {RER} production	EcoInvent 3
	64.35 µg of Ag / Container A		Not in SimaPro	
	765.77 µg of Ag / Container B		Not in SimaPro	
Usage phase	820 cm ^{3} of food/container		-	
		1.27 µg of Ag / Container A	Silver -Waterborne emission	
		15.16 µg of Ag / Container B	Silver -Waterborne emission	
Washing of containers	0.2 gallons of water/cycle*container		Drinking water, water purification treatment, production mix, at plant, from surface water RER S	ELCD
	0.0625 kWh/cycle*container		Electricity, at grid, US, 2010/kWh/RNA	US LCI
	1.2 g of detergent/cycle*container		Soap {Row} production	EcoInvent 3
		0.2 gallons of water/cycle*container	Emission to water>water	
		0.47 µg of Ag / Container A	Waterborne emission	
		5.64 µg of Ag / Container B	Waterborne emission	
End of life		41.04 µg of Ag / Container A	Inert Waste, for final disposal {RoW} treatment of inert waste, inert material landfill	EcoInvent 3
		488.35 µg of Ag / Container B	Inert Waste, for final disposal {RoW} treatment of inert waste, inert material landfill	EcoInvent 3
		64.35 g of plastic/container	Waste polyethylene {RoW} treatment of waste polyethylene,	EcoInvent 3

Table S2: Environmental impact contributions for the three scenarios during raw materials and manufacturing phase.

Impact category	Unit	No-Ag	Low Ag	High Ag	% No-Ag	%Low Ag	%High Ag
Ozone depletion	kg CFC-11 eq	8.05E-11	8.62E-11	0.000	25.61%	27.40%	46.99%
Global warming	kg CO2 eq	0.124	0.124	0.125	33.29%	33.30%	33.40%
Smog	kg O3 eq	0.005	0.005	0.005	33.19%	33.23%	33.58%
Acidification	kg SO2 eq	4.14E-04	4.14E-04	0.000	33.23%	33.25%	33.52%
Eutrophication	kg N eq	2.96E-05	3.04E-05	0.0000	29.77%	30.60%	39.64%
Carcinogenics	CTUh	3.99E-09	4.00E-09	4.08E-09	33.08%	33.14%	33.78%
Non carcinogenics	CTUh	1.98E-09	2.16E-09	4.15E-09	23.89%	26.08%	50.03%
Respiratory effects	kg PM2.5 eq	3.26E-05	3.27E-05	3.33E-05	33.10%	33.15%	33.75%
Ecotoxicity	CTUe	0.228	2.33E-01	2.78E-01	30.89%	31.46%	37.65%
Fossil fuel depletion	MJ surplus	0.657	6.57E-01	6.57E-01	33.33%	33.33%	33.35%

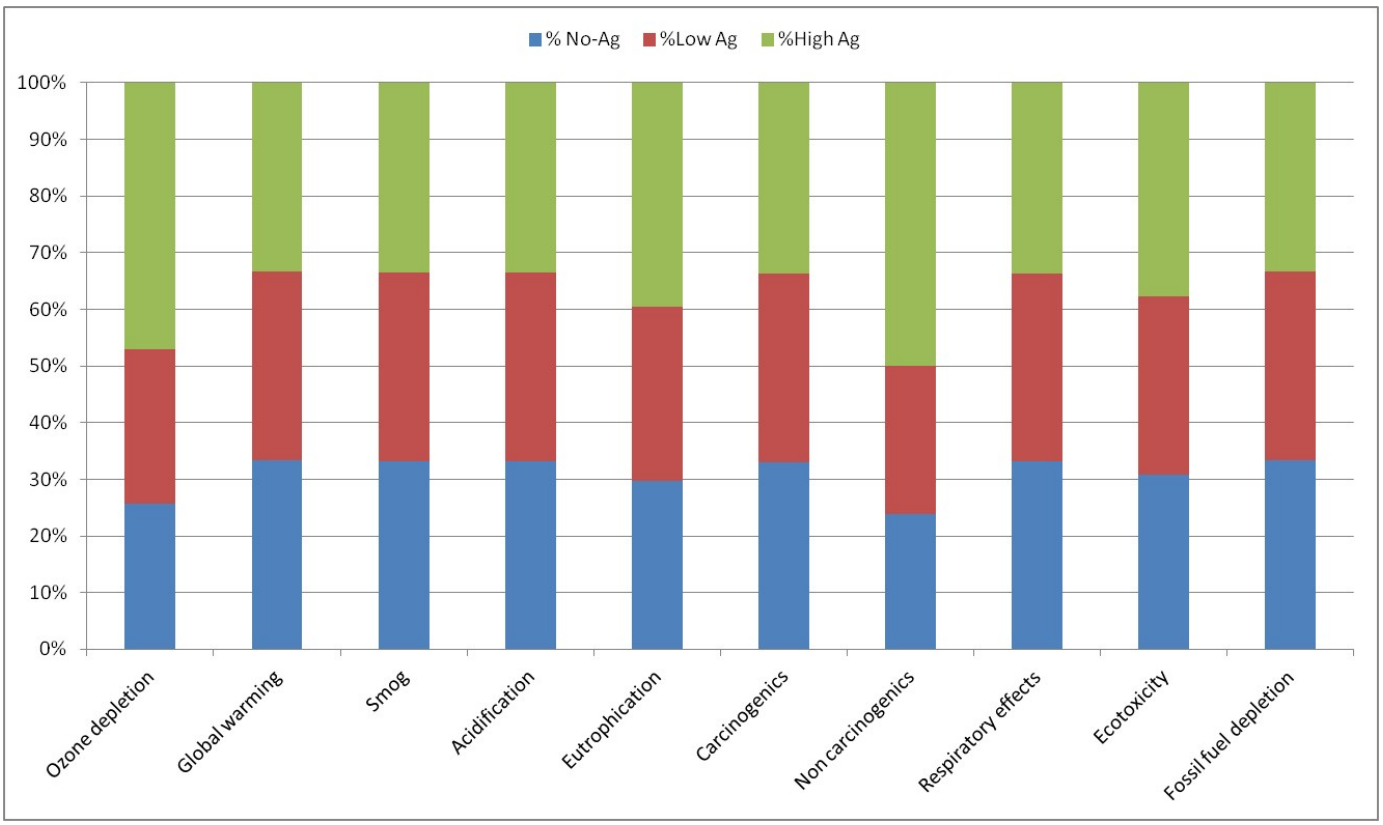

Figure S1: Environmental impact contributions for the three scenarios during raw materials and manufacturing phase.

Table S3: Non-carcinogenic environmental impact contributions of nanosilver and polymer for three scenarios during raw materials and manufacturing phase.

	No-Ag	**Low Ag**	**High Ag**
Plastic	1.98E-09	1.98E-09	1.98E-09
Nanosilver	0.00E+00	1.82E-10	2.17E-09

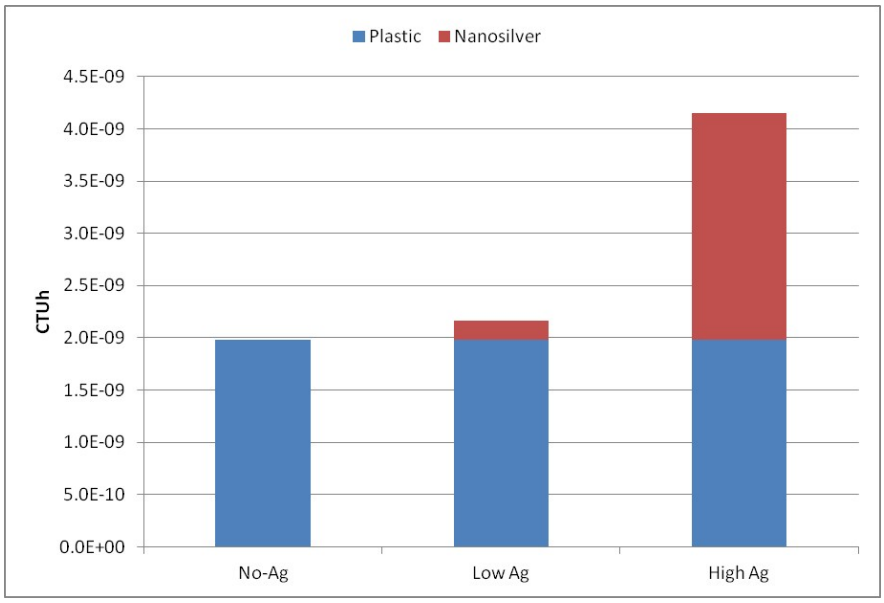

Figure S2: Non-carcinogenic environmental impact contributions of nanosilver and polymer for three scenarios during raw materials and manufacturing phase.

Table S4: Environmental impact contributions during washing phase of no-Ag container.

Impact category	Unit	Soap	Water	Electricity	% Soap	%Water	% Electricity
Ozone depletion	kg CFC-11 eq	9.05E-09	5.43E-10	3.47E-11	94.00%	5.64%	0.36%
Global warming	kg CO2 eq	1.93E-01	2.47E-02	2.15E+00	8.14%	1.04%	90.82%
Smog	kg O3 eq	5.12E-03	8.13E-04	1.23E-01	3.96%	0.63%	95.41%
Acidification	kg SO2 eq	5.13E-04	6.61E-05	1.85E-02	2.69%	0.35%	96.97%
Eutrophication	kg N eq	6.33E-04	2.85E-05	2.50E-04	69.41%	3.13%	27.47%
Carcinogenics	CTUh	4.36E-09	1.22E-10	4.36E-09	49.28%	1.38%	49.34%
Non carcinogenics	CTUh	2.72E-08	1.83E-10	7.31E-08	27.06%	0.18%	72.76%
Respiratory effects	kg PM2.5 eq	1.64E-04	2.23E-05	9.30E-04	14.68%	2.00%	83.32%
Ecotoxicity	CTUe	8.33E-01	2.98E-03	1.06E+00	43.91%	0.16%	55.93%
Fossil fuel depletion	MJ surplus	5.24E-02	1.16E-02	1.87E+00	2.72%	0.60%	96.68%

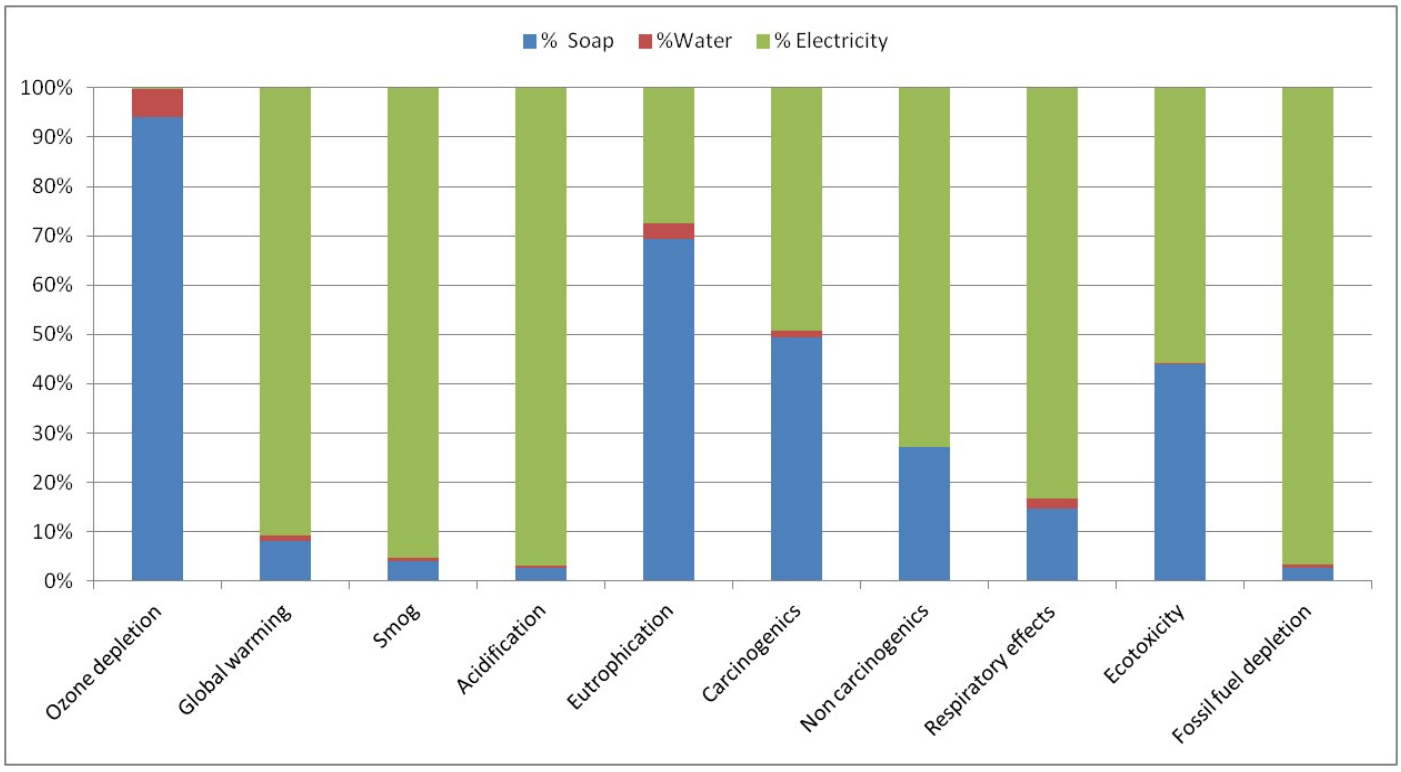

Figure S3: Environmental impact contributions during washing phase of no-Ag container.

Table S5: Non-carcinogenic environmental impact contributions of the three scenarios during all phases.

Phase	No-Ag	Low Ag	High Ag
Raw Materials and Manufacturing	1.98E-09	2.16E-09	4.15E-09
Usage	0.00E+00	4.52E-13	5.38E-12
Washing	1.01E-07	1.01E-07	1.01E-07
End of Life	3.73E-08	3.73E-08	3.73E-08

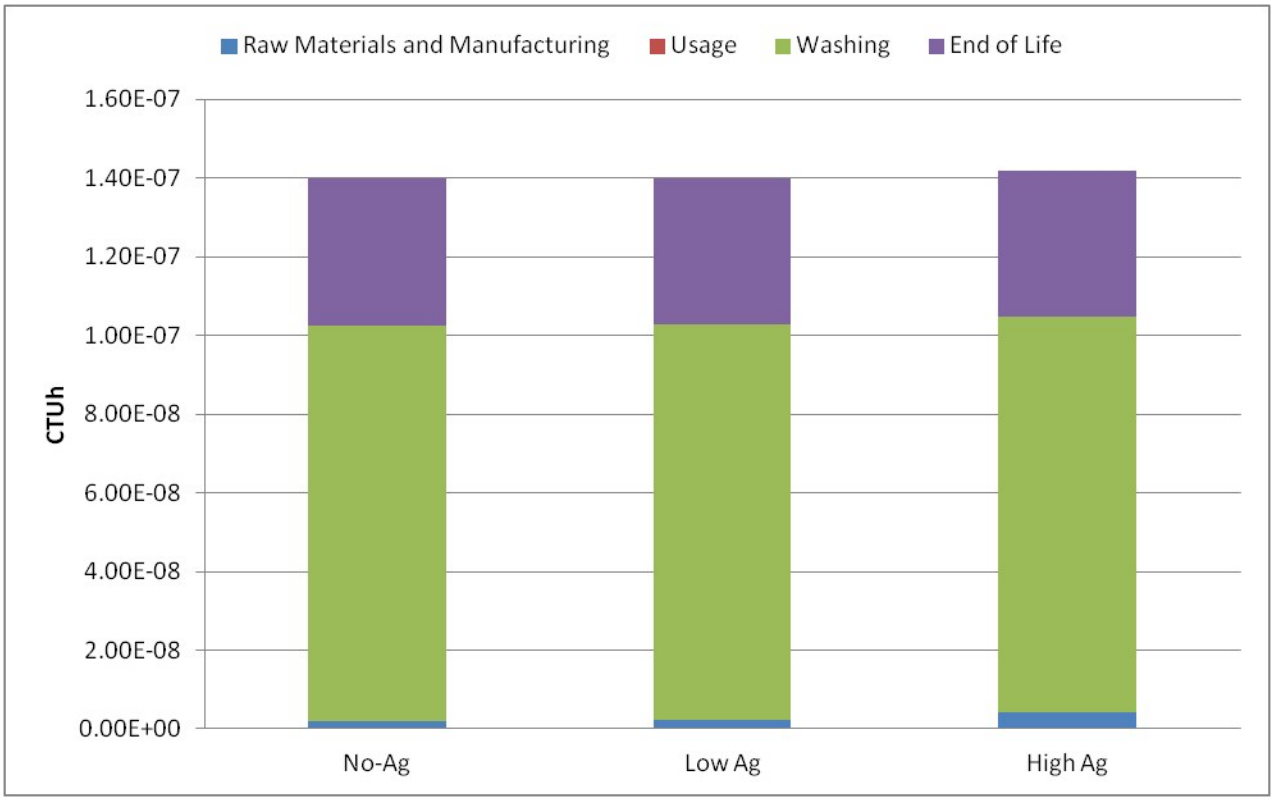

Figure S4: Non-carcinogenic environmental impact contributions of the three scenarios during all phases.

Table S6: Eutrophication environmental impact contributions of the three scenarios during all phases.

Phase	No-Ag	Low Ag	High Ag
Raw Materials and Manufacturing	2.96E-05	3.04E-05	3.94E-05
Usage	0.00E+00	0.00E+00	0.00E+00
Washing	9.12E-04	9.12E-04	9.12E-04
End of Life	9.38E-04	9.38E-04	9.38E-04

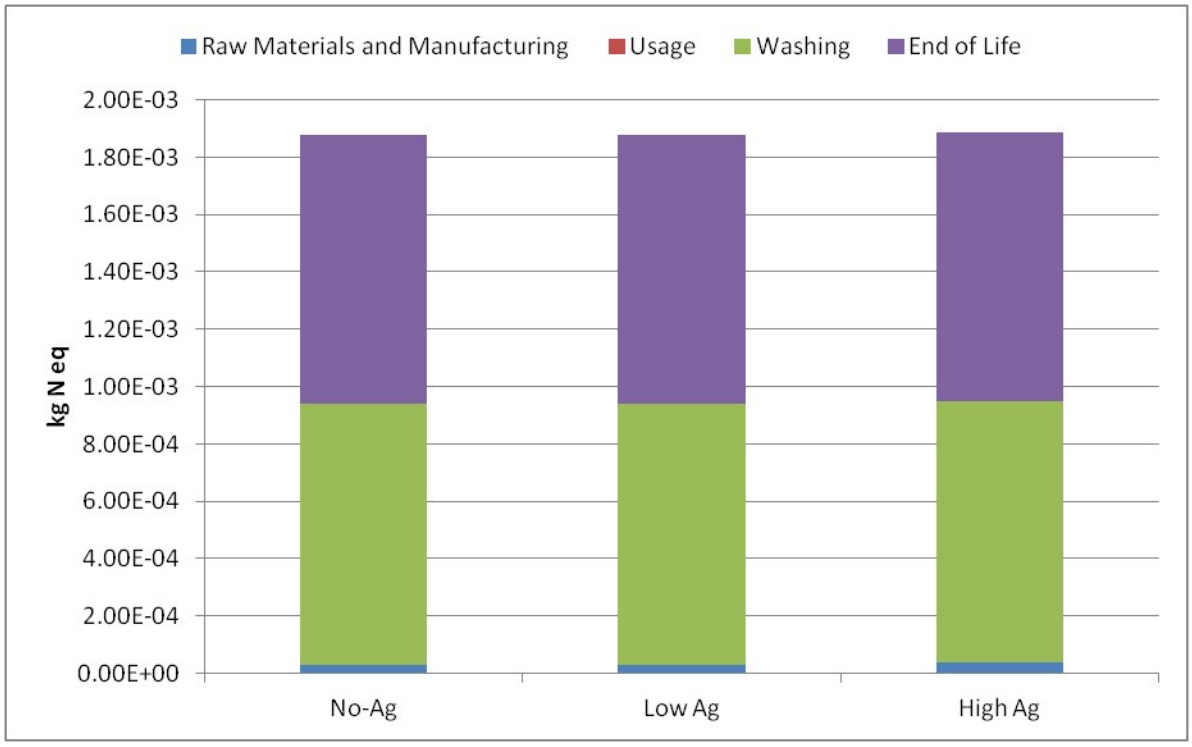

Figure S5: Eutrophication environmental impact contributions of the three scenarios during all phases.

Table S7: Smog environmental impact contributions of the three scenarios during all phases.

Phase	No-Ag	Low Ag	High Ag
Raw Materials and Manufacturing	5.18E-03	5.19E-03	5.24E-03
Usage	0.00E+00	0.00E+00	0.00E+00
Washing	1.29E-01	1.29E-01	1.29E-01
End of Life	1.24E-04	1.24E-04	1.24E-04

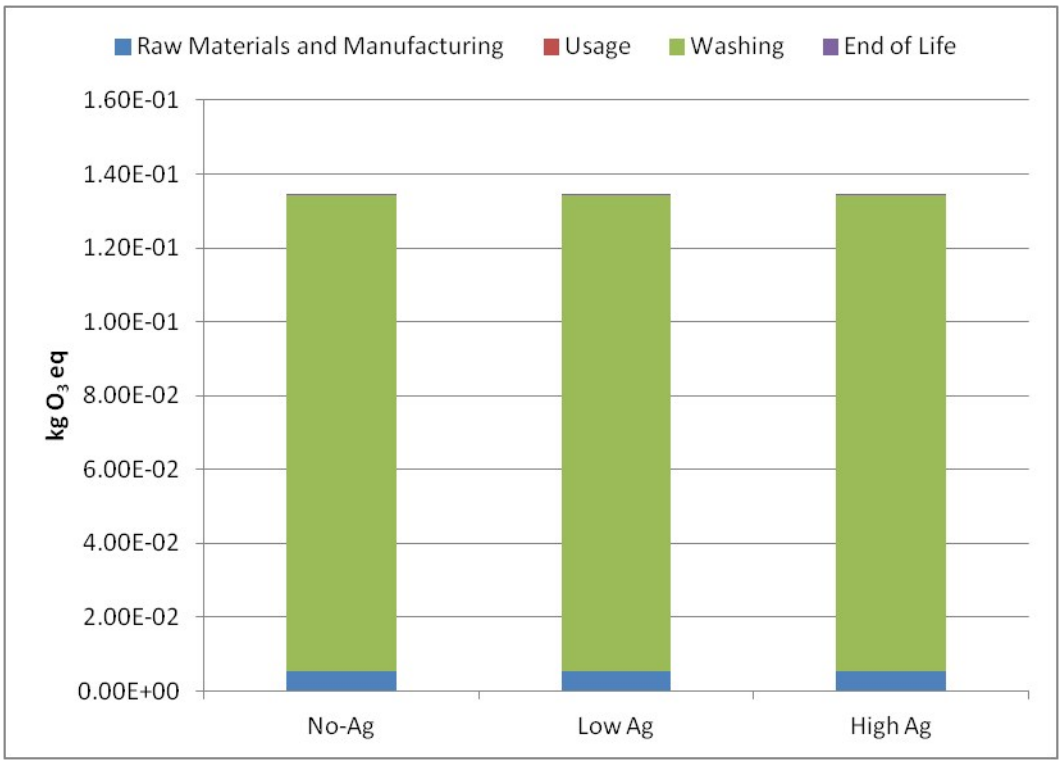

Figure S6: Smog environmental impact contributions of the three scenarios during all phases.

Table S8: Acidification environmental impact contributions of the three scenarios during all phases.

Phase	No-Ag	Low Ag	High Ag
Raw Materials and Manufacturing	4.14E-04	4.14E-04	4.18E-04
Usage	0.00E+00	0.00E+00	0.00E+00
Washing	1.91E-02	1.91E-02	1.91E-02
End of Life	5.50E-06	5.50E-06	5.50E-06

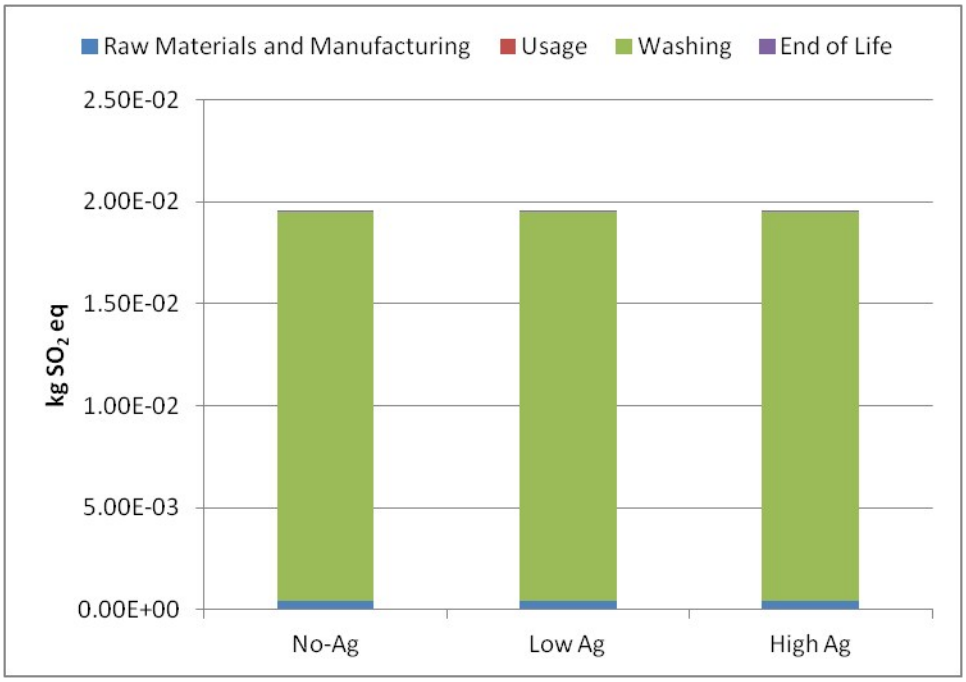

Figure S7: Acidification environmental impact contributions of the three scenarios during all phases.

Table S9: Carcinogenics environmental impact contributions of the three scenarios during all phases.

Phase	No-Ag	Low Ag	High Ag
Raw Materials and Manufacturing	3.99E-09	4.00E-09	4.08E-09
Usage	0.00E+00	0.00E+00	0.00E+00
Washing	8.84E-09	8.84E-09	8.84E-09
End of Life	1.25E-10	1.25E-10	1.25E-10

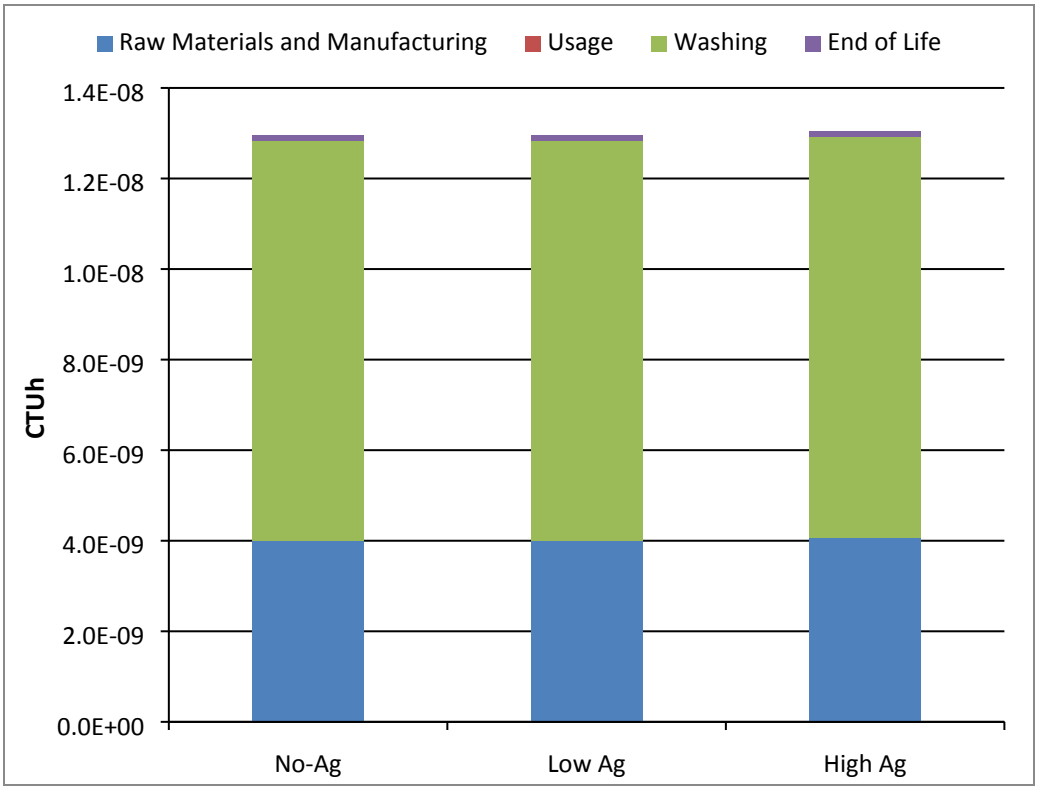

Figure S8: Carcinogenics environmental impact contributions of the three scenarios during all phases.

Table S10: Respiratory effects environmental impact contributions of the three scenarios during all phases

Phase	No-Ag	Low Ag	High Ag
Raw Materials and Manufacturing	3.26E-05	3.27E-05	3.33E-05
Usage	0.00E+00	0.00E+00	0.00E+00
Washing	1.12E-03	1.12E-03	1.12E-03
End of Life	9.37E-07	9.37E-07	9.37E-07

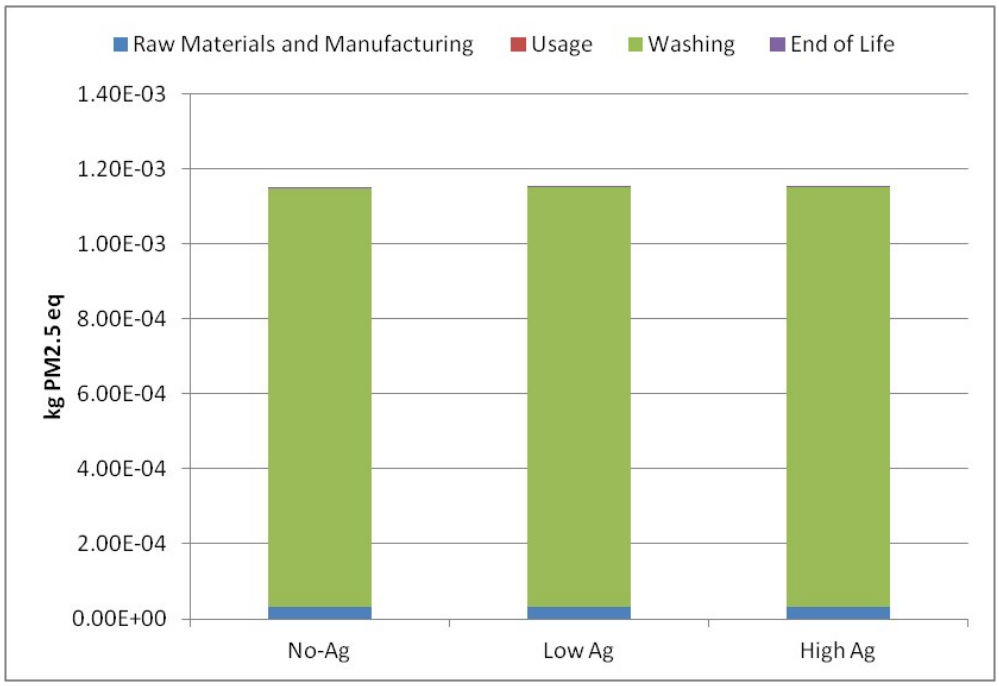

Figure S9: Respiratory effects environmental impact contributions of the three scenarios during all phases

Table S11: Fossil fuel depletion environmental impact contributions of the three scenarios during all phases

Phase	No-Ag	Low Ag	High Ag
Raw Materials and Manufacturing	6.57E-01	6.57E-01	6.57E-01
Usage	0.00E+00	0.00E+00	0.00E+00
Washing	1.93E+00	1.93E+00	1.93E+00
End of Life	2.28E-03	2.28E-03	2.28E-03

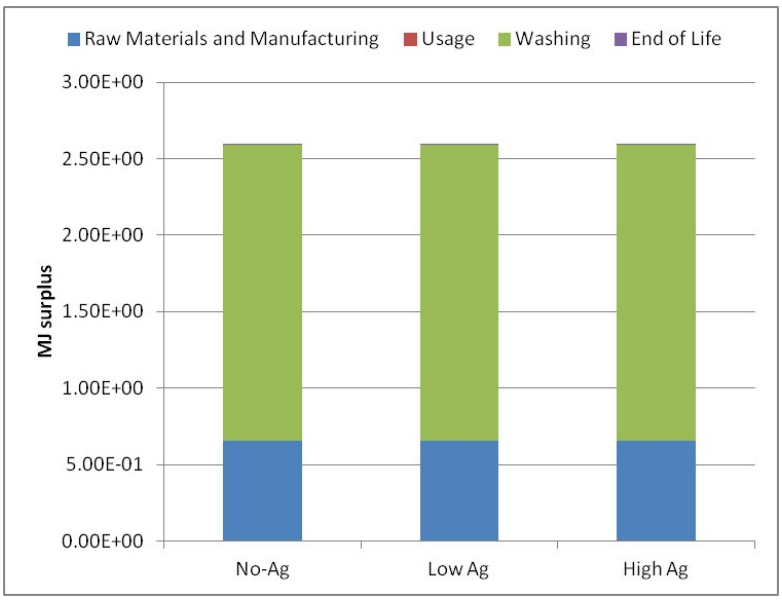

Figure S10: Fossil fuel depletion environmental impact contributions of the three scenarios during all phases

Table S12: Environmental impact contributions during washing phase of low-Ag container.

Impact category	Unit	Nanosilver	Soap	Water	Electricity	% Nanosilver	% Soap	%Water	% Electricity
Ozone depletion	kg CFC-11 eq	0.0E+00	9.0E-09	5.4E-10	3.5E-11	0.00%	94.00%	5.64%	0.36%
Global warming	kg CO2 eq	0.0E+00	1.9E-01	2.5E-02	2.2E+00	0.00%	8.14%	1.04%	90.82%
Smog	kg O3 eq	0.0E+00	5.1E-03	8.1E-04	1.2E-01	0.00%	3.96%	0.63%	95.41%
Acidification	kg SO2 eq	0.0E+00	5.1E-04	6.6E-05	1.9E-02	0.00%	2.69%	0.35%	96.97%
Eutrophication	kg N eq	0.0E+00	6.3E-04	2.9E-05	2.5E-04	0.00%	69.41%	3.13%	27.47%
Carcinogenics	CTUh	0.0E+00	4.4E-09	1.2E-10	4.4E-09	0.00%	49.28%	1.38%	49.34%
Non carcinogenics	CTUh	1.7E-13	2.7E-08	1.8E-10	7.3E-08	0.00%	27.06%	0.18%	72.76%
Respiratory effects	kg PM2.5 eq	0.0E+00	1.6E-04	2.2E-05	9.3E-04	0.00%	14.68%	2.00%	83.32%
Ecotoxicity	CTUe	9.1E-05	8.3E-01	3.0E-03	1.1E+00	0.00%	43.91%	0.16%	55.93%
Fossil fuel depletion	MJ surplus	0.0E+00	5.2E-02	1.2E-02	1.9E+00	0.00%	2.72%	0.60%	96.68%

Table S13: Environmental impact contributions during washing phase of high-Ag container.

Impact category	Unit	Nanosilver	Soap	Water	Electricity	% Nanosilver	% Soap	%Water	% Electricity
Ozone depletion	kg CFC-11 eq	0.0E+00	9.0E-09	5.4E-10	3.5E-11	0.00%	94.00%	5.64%	0.36%
Global warming	kg CO2 eq	0.0E+00	1.9E-01	2.5E-02	2.2E+00	0.00%	8.14%	1.04%	90.82%
Smog	kg O3 eq	0.0E+00	5.1E-03	8.1E-04	1.2E-01	0.00%	3.96%	0.63%	95.41%
Acidification	kg SO2 eq	0.0E+00	5.1E-04	6.6E-05	1.9E-02	0.00%	2.69%	0.35%	96.97%
Eutrophication	kg N eq	0.0E+00	6.3E-04	2.9E-05	2.5E-04	0.00%	69.41%	3.13%	27.47%
Carcinogenics	CTUh	0.0E+00	4.4E-09	1.2E-10	4.4E-09	0.00%	49.28%	1.38%	49.34%
Non carcinogenics	CTUh	2.0E-12	2.7E-08	1.8E-10	7.3E-08	0.00%	27.05%	0.18%	72.76%
Respiratory effects	kg PM2.5 eq	0.0E+00	1.6E-04	2.2E-05	9.3E-04	0.00%	14.68%	2.00%	83.32%
Ecotoxicity	CTUe	1.1E-03	8.3E-01	3.0E-03	1.1E+00	0.06%	43.88%	0.16%	55.90%
Fossil fuel depletion	MJ surplus	0.0E+00	5.2E-02	1.2E-02	1.9E+00	0.00%	2.72%	0.60%	96.68%

Table S14: Sensitivity analysis for the conventional container scenario. Reduction of 25% of the parameters.

-25%					
Impact category	**nAg**	**Plastic**	**Water**	**Electricity**	**Detergent**
Ozone depletion	-	-0.2%	-1.4%	-0.1%	-22.8%
Global warming	-	-1.2%	-0.2%	-21.5%	-1.9%
Smog	-	-1.0%	-0.2%	-22.9%	-1.0%
Acidification	-	-0.5%	-0.1%	-23.7%	-0.7%
Eutrophication	-	-0.4%	-0.4%	-3.3%	-8.4%
Carcinogenics	-	-7.7%	-0.2%	-8.41%	-8.40%
Non carcinogenics	-	-0.4%	0.0%	-13.1%	-4.9%
Respiratory effects	-	-0.7%	-0.5%	-20.2%	-3.6%
Ecotoxicity	-	-0.7%	0.0%	-3.4%	-2.7%
Fossil fuel depletion	-	-6.3%	-0.1%	-18.0%	-0.5%

Table S15: Sensitivity analysis for the low-nAg content container scenario. Reduction of 25% of the parameters.

Impact category	**nAg**	**Plastic**	**Water**	**Electricity**	**Detergent**
Ozone depletion	-0.0142%	-0.2%	-1.4%	-0.1%	-22.7%
Global warming	-0.0003%	-1.2%	-0.2%	-21.5%	-1.9%
Smog	-0.0009%	-1.0%	-0.2%	-22.9%	-1.0%
Acidification	-0.0004%	-0.5%	-0.1%	-23.7%	-0.7%
Eutrophication	-0.0110%	-0.4%	-0.4%	-3.3%	-8.4%
Carcinogenics	-0.0137%	-7.7%	-0.2%	-8.4%	-8.4%
Non carcinogenics	-0.0325%	-0.4%	0.0%	-13.1%	-4.9%
Respiratory effects	-0.0012%	-0.7%	-0.5%	-20.2%	-3.6%
Ecotoxicity	-0.0136%	-0.7%	0.0%	-3.4%	-2.7%
Fossil fuel depletion	-0.0003%	-6.3%	-0.1%	-18.0%	-0.5%

Table S16: Sensitivity analysis for the high-nAg content container scenario. Reduction of 25% of the parameters.

Impact category	nAg	Plastic	Water	Electricity	Detergent
Ozone depletion	-0.168%	-0.2%	-1.4%	-0.1%	-22.6%
Global warming	-0.004%	-1.2%	-0.2%	-21.5%	-1.9%
Smog	-0.011%	-1.0%	-0.2%	-22.9%	-1.0%
Acidification	-0.005%	-0.5%	-0.1%	-23.7%	-0.7%
Eutrophication	-0.130%	-0.4%	-0.4%	-3.3%	-8.4%
Carcinogenics	-0.162%	-7.7%	-0.2%	-8.4%	-8.3%
Non carcinogenics	-0.382%	-0.3%	0.0%	-12.9%	-4.8%
Respiratory effects	-0.014%	-0.7%	-0.5%	-20.2%	-3.6%
Ecotoxicity	-0.161%	-0.7%	0.0%	-3.4%	-2.7%
Fossil fuel depletion	-0.004%	-6.3%	-0.1%	-18.0%	-0.5%

The Ag losses were calculated utilizing data from experimental studies, as detailed in the article. Equations 1 and 2 were utilized independently to calculate the Ag losses from the initial Ag concentration as a function of losses due to washing and food storage. The remaining Ag in the container at the end of its life, was calculated by subtracting the Ag losses from the initial Ag content of the container.