Supporting Information for the article:

Uncertainties in a carbon footprint model for detergents; quantifying the confidence in a comparative result

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1. Sensitivity Analysis

Methods

In the sensitivity analysis the most influential parameters will be determined. Two methods have been used for the sensitivity analysis. A variance based method called Fourier Amplitude Sensitivity Test (FAST; Saltelli et al. 2000; 2004) and a screening method called the Morris method. Both methods are global sensitivity analysis tools, i.e. the input parameters are varied simultaneously over their full range. Monte Carlo analysis was only used for uncertainty analysis and not used to examine the contribution of the uncertainty in input parameters to the uncertainty in the response variable(s). Simlab is the software used in the sensitivity analysis. It includes the most recent variance-based methods and screening methods for sensitivity analysis besides the more generally known regression based methods (Simlab 2004).

The Morris method is a so-called screening method that uses minimal information to determine the most sensitive parameters. It needs a smaller number of model runs compared to Monte Carlo analysis and FAST. It cannot take into account correlation coefficients among input parameters and a distribution does not have to be specified. The Morris method takes the value ranges of the input parameters as specified by a minimum and maximum and 'jumps' through this parameter space in a number of predefined steps meanwhile measuring the response (elementary effects) of the model. On the basis of the elementary effects a measure of sensitivity is calculated. Two measures are provide μ^* and σ. The μ^* is a measure for overall importance of the parameter. If μ^* of a specific input parameter is higher compared to the μ^*'s of other parameters this specific input parameter has a larger contribution to the uncertainty in the response variable than the other input parameters. The σ value can be seen as a measure of non-linear influence of the parameter. The input parameters may be ranked on basis of μ^* and σ but little meaning should be attributed to the absolute value of the sensitivity indices. Also the values for the μ^* and σ cannot be compared between different sensitivity analysis. The method cannot be used for uncertainty analysis.

The FAST method is a variance based method (Saltelli et al. 2004). It needs a larger number of samples compared to Monte Carlo analysis. It can be used for sensitivity and uncertainty analysis. We have compared the results of the uncertainty analysis from the FAST method and the Monte Carlo analysis for a quality check. The FAST method can calculate sensitivity indices for individual parameters but also for groups of parameters. The FAST method was only used to calculate sensitivity indices for groups of parameters and is thus complementary to the Morris method. Using the FAST method for the calculation of sensitivity indices for individual parameters would have needed too much time. The sensitivity indices as calculated by the FAST method may be used quantitatively and used to express the contribution of the input parameter to total uncertainty. The FAST method uses distributions as input and takes into account correlation coefficients.

The results of the FAST analysis are shown in Figure 1 for the Compact Powder. The calculated FAST total indices are plotted as a pie chart illustrating the contribution of the uncertainty in each parameter group to the total uncertainty of the calculated carbon footprint.

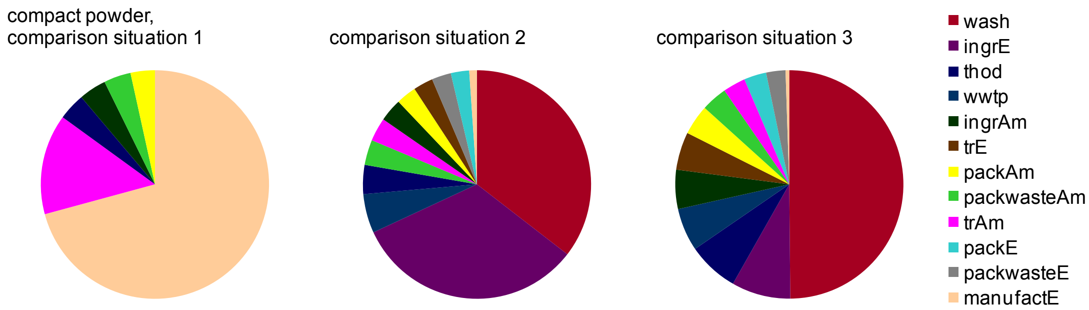

Figure 1: Contribution of the different parameter groups to the total uncertainty of the carbon footprint according to the FAST total indices for the Compact Powder product in comparison situation 1, 2 and 3.

In comparison situation 1, the uncertainty is dominated by uncertainty of the carbon footprint of the detergent manufacturing process and uncertainties of the amount of transport needed. In comparison situation 2 the uncertainty in calculated carbon footprint is dominated by uncertainties in the carbon footprint of chemicals production, the uncertainties in the use phase (efficiency washing machine) and uncertainties with regard to the greenhouse gases emanating from waste water treatment. In comparison situation 3, washing phase, chemicals production and waste water treatment are also dominating the total uncertainty of the calculated carbon footprint.

If we look at the differences between the three comparison situations, the detergent formulation process is dominant in comparison situation 1 and insignificant in comparison situation 2 and 3. The important parameter groups in comparison situation 2 and 3 are quite similar except that uncertainties in the wash phase become even more important.

The importance of the different parameter groups is also reflected in the results of the Morris method, see Table 1. The parameters that belong to groups indicated as important by the FAST method are indicated by grey rows. The most important parameters according the FAST method are always ranked high in every comparison situation according the Morris method. Having two completely different sensitivity analysis method pointing towards the same parameters as being the parameters that contribute mostly to the uncertainty in the carbon footprint increases the reliability of the results of the sensitivity analysis.

An indication of the shape and width of the distribution of the uncertainty of the carbon footprint for the Compact Powder, using the preliminary assessment of the uncertainty in the input parameters, is given in Figure 2. The resulting uncertainty increases going from comparison situation 1 to 3. The shape of the distribution is slightly skewed.

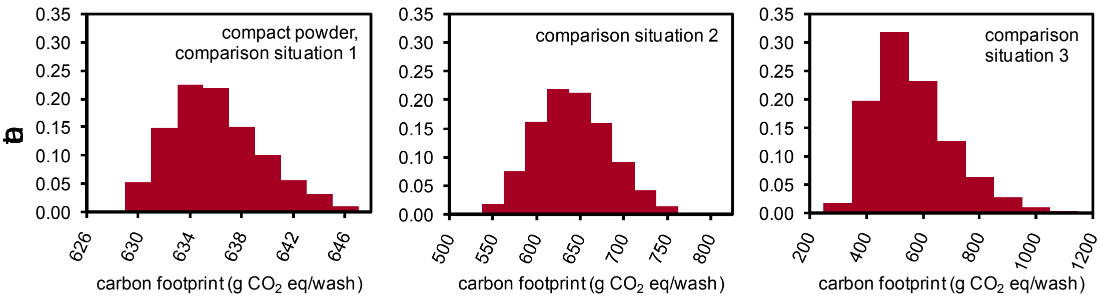

Figure 2: Shape and width of the uncertainty distribution of the carbon footprint for the Compact Powder product calculated with Monte Carlo analysis.

Table 1: Results of the sensitivity analysis using the Morris method for the Compact Powder product for comparison situation 1, 2 and 3. The Morris Index, μ*, is shown which is a measure of the total importance of a parameter. Grey rows indicate parameters that belong to a group which is important according the FAST analysis, see Figure 1. Only the top twenty most important input parameters are shown.

Comparison situation 1			Comparison situation 2			Comparison situation 3	
parameter	μ*		parameter	μ*		parameter	μ*
manufactE	9.8462		washElek	97.9106		tempToggle	360.42
trrawrtopoAm	4.0848		zeoliteE	66.3323		ElekE	325.9625
trrawrtoplAm	0.8173		carbonateE	27.4692		wwtpToggle	121.8669
trfinrAm	0.793		einorgwwtp	19.0672		zeoliteE	64.2605
zeoliteAm	0.5285		nalasE	18.8316		washElek	40.3287
corruAm	0.5196		percarbonateE	18.5065		carbonateE	23.7292
carbonateAm	0.4756		taedE	18.0145		nalasE	19.434
nalasAm	0.3492		co2wwtp	16.3023		taedE	18.5853
percarbonateAm	0.3491		manufactE	9.8462		percarbonateE	17.9592
trrawstoplAm	0.3401		eorgwwtp	8.1342		manufactE	9.2611
corrulandfAm	0.3289		truckE	6.1656		einorgwwtp	8.1087
thnalas	0.3187		ae7E	5.708		co2wwtp	6.8747
waterAm	0.12		ch4wwtp	4.4112		ae7E	5.8935
taedAm	0.1161		trrawrtopoAm	3.7168		truckE	3.965
ae7Am	0.0927		corruE	2.9299		eorgwwtp	3.4629
thtaed	0.0923		citricE	2.5017		ch4wwtp	3.0299
ldpeAm	0.0867		cmcE	1.6062		trrawrtopoAm	2.8359
thae7	0.0846		acrylicE	1.4261		citricE	2.8074
corrureAm	0.0789		k1clE	1.0406		corruE	2.6258
sulfateAm	0.0622		hedpE	0.967		wasteToggle	2.5601

The results of the sensitivity analysis for the Ultra Liquid product using the FAST method is given in Figure 3. In comparison situation 1 the uncertainty in the carbon footprint is mainly caused by uncertainties in the transport amounts used in the model and emissions during formulation of the detergent. Compared to the Compact Powder product, emissions during formulation of the detergent have become much less important. This is likely the result of the large difference in emissions during the formulation of the Compact Powder (129 g CO2 eq/kg) and Ultra Liquid (44 g CO2 eq/kg).

In comparison situation 2 and 3 the parameter groups that contribute most to the uncertainty of the carbon footprint are the wash phase, emissions in the waste water treatment and emissions during the production of chemicals for the detergent. However, compared to the Compact Powder product the importance of waste water treatment and chemicals production is not so clear cut. Differences between second third, fourth and fifth in rank are small. There is another difference between the Ultra Liquid product and the Compact Powder product. While in the Compact Powder product the importance of the wash phase increased relatively going from comparison situation 2 to 3, for the Ultra Liquid product it decreases.

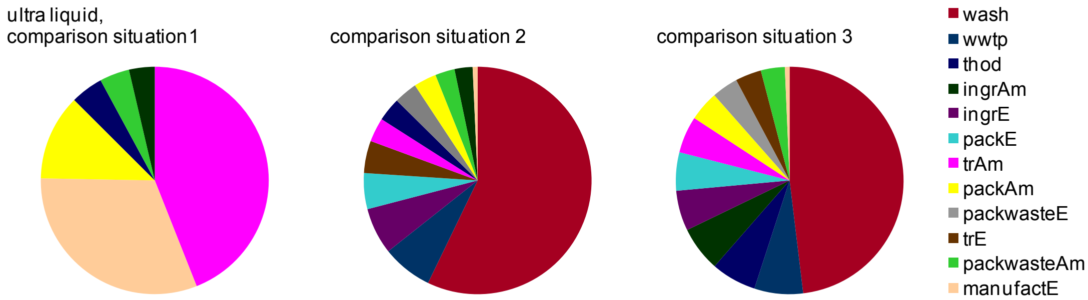

Figure 3: Contribution of the different parameter groups to the total uncertainty of the carbon footprint according to FAST total indices for Ultra Liquid in comparison situation 1, 2 and 3.

The distribution of uncertainties calculated for the Ultra Liquid product, using the preliminary assignment of uncertainties is shown in Figure 4. Just like the Compact Powder case, uncertainties increase going from comparison situation 1 to 3. The shape of the distribution is slightly skewed.

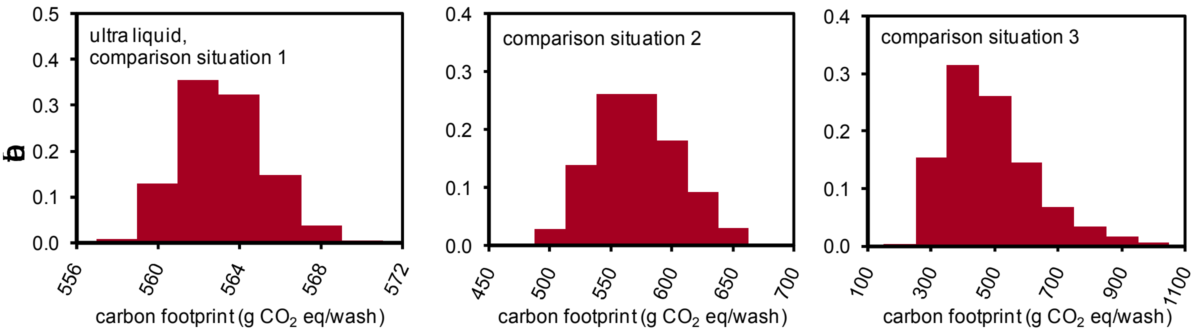

Figure 4: Shape and width of the uncertainty distribution of the carbon footprint for Ultra Liquid calculated with Monte Carlo analysis.

The results of the Morris method corroborate the findings of the FAST method except that the differences between the Morris sensitivity indexes for the parameters are not so big, see Table 2. For instance, in comparison situation 1 the amount of HDPE (packaging material) that goes into Ultra Liquid packaging (hdpeAm) scores quite high while the FAST index for the group of parameters describing the amount of package material (packAm) is ranked third. Grey rows indicate input parameters that belong to a parameter group indicated as most important according to the FAST analysis.

Table 2: Results of the sensitivity analysis using the Morris method for the Ultra Liquid product for comparison situation 1, 2 and 3. The Morris Index, μ*, is shown which is a measure of the total importance of a parameter. Grey rows indicate parameters that belong to a group which is important according to the FAST analysis, see Figure 3. Only the top twenty of most important parameters is shown.

Comparison situation 1			Comparison situation 2			Comparison situation 3	
parameter	μ*		parameter	μ*		parameter	μ*
trrawtopoAm	4.6794		washElek	94.5887		ElekE	317.577
manufactE	3.5223		co2wwtp	23.7134		tempToggle	269.2361
hdpeAm	1.7064		einorgwwtp	18.7587		wwtpToggle	157.6786
trrawrtoplAm	0.8838		nalasE	15.3045		washElek	46.972
corrulandfAm	0.7658		hdpeE	12.9363		nalasE	16.2663
corruAm	0.586		c14ae7E	11.952		hdpeE	16.116
nalasAm	0.4846		eorgwwtp	11.5858		einorgwwtp	11.615
trrawstoplAm	0.3897		truckE	8.5799		c14ae7E	11.5864
c14ae7Am	0.3258		soapE	7.6782		soapE	8.0906
ppAm	0.2976		metaborateE	7.6756		truckE	7.8073
thnalas	0.2663		ch4wwtp	6.31		metaborateE	7.7146
waterAm	0.2434		citrateE	5.8275		citrateE	6.0159
soapAm	0.2232		c12aesE	4.8761		eorgwwtp	5.7845
corrureAm	0.1936		propglycolE	4.2059		wasteToggle	5.7513
thc14ae7	0.166		manufactE	3.8459		c12aesE	5.3565
c12aesAm	0.1515		trrawtopoAm	3.394		co2wwtp	4.738
thsoap	0.1264		ehdqE	2.4598		propglycolE	4.4656
meaborateAm	0.123		corrulandfE	2.4169		manufactE	3.8459
citrateAm	0.1063		ppE	2.2953		trrawtopoAm	3.8313
hdpeinceAm	0.1025		corruE	1.7884		ch4wwtp	3.8218

Concluding given our preliminary assessment of the uncertainty of the input parameters, the parameters that have the largest contribution to uncertainty in the response variable are quite similar for the Compact Powder and Ultra Liquid product. In comparison situation 1, the parameters with the largest contribution are the carbon footprint of detergent formulation and transport distances. In comparison situation 2, efficiency of the washing machine, carbon footprint of chemicals production and waste water treatment are the largest contributors to the uncertainty of the carbon footprint. These are also the input parameters with the largest contribution to the uncertainty in comparison situation 3, but with a different magnitude.

2. Uncertainty specification input parameters Compact Powder

Compact Powder: Comparison situation 1						
				mathematical description		
Stage	parameter	mean value	unit	distribution	μ	σ
product ingredient production	amount ingredients	Nondisclosed Information		Nondisclosed Information		
packaging production	amount LDPE in package and bulk pack	5.93	g/wash	log normal	1.779	0.04766
	amount Corrugate in package and bulk pack	98.71	g/wash	log normal	4.591	0.04766
transport	distance transport raw material, road to port, by truck	500	km	log normal	6.137	0.3931
	distance transport raw material, sea to plant, by ship	100	km	log normal	4.528	0.3931
	distance transport raw material, road to plant, by truck	100	km	log normal	4.528	0.3931
	distance transport finished product, road in UK (to oxford), by truck	100	km	log normal	4.528	0.3931
formula manufacturing	emissions during formulation compact powder	129	g CO2 eq/kg	log normal	4.783	0.3931
packaging waste treatment	fraction recycling of LDPE in package and bulk pack	0.1	-	log normal	-2.311	0.1312
	fraction recycling of Corrugate in package and bulk pack	0.37	-	log normal	-1.003	0.1312
	fraction packaging landfilling of LDPE in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of LDPE in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of LDPE in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	fraction packaging landfilling of Corrugate in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of Corrugate in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of Corrugate in package and bulk pack	0.001	-	log normal	-6.916	0.1312

waste water treatment	Theoretical oxygen of ingredients	Non disclosed information	Non disclosed information

Compact Powder: Comparison situation 2						
				mathematical description		
Stage	parameter	mean value	unit	distribution	μ	σ
use	energy use washing machine (a measure of efficiency)	0.0168	kWh/ºC.wash	normal	0.01680	0.005450
product ingredient production	amount ingredients	Non-disclosed information		Non-disclosed information		
packaging production	amount LDPE in package and bulk pack	5.93	g/wash	log normal	1.779	0.04766
	amount Corrugate in package and bulk pack	98.71	g/wash	log normal	4.591	0.04766
	emission during production LDPE for package and bulk pack	2086.3	g CO2 eq/package	log normal	7.566	0.3931
	emission during production Corrugate for package and bulk pack	550.98	g CO2 eq/package	log normal	6.234	0.3931
transport	distance transport raw material, road to port, by truck	500	km	log normal	6.137	0.3931
	distance transport raw material, sea to plant, by ship	100	km	log normal	4.528	0.3931
	distance transport raw material, road to plant, by truck	100	km	log normal	4.528	0.3931
	distance transport finished product, road in UK (to oxford), by truck	100	km	log normal	4.528	0.3931
	emissions during transport by truck	107.118	g CO2 eq/ton.km	log normal	4.597	0.3931
	emissions during transport by ship	44.5794	g CO2 eq/ton.km	log normal	3.720	0.3931
formula manufacturing	emissions during formulation compact powder	129	g CO2 eq/kg	log normal	4.783	0.3931
packaging waste treatment	fraction recycling of LDPE in package and bulk pack	0.1	-	log normal	-2.311	0.1312
	fraction recycling of Corrugate in package and bulk pack	0.37	-	log normal	-1.003	0.1312

	fraction packaging landfilling of LDPE in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of LDPE in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of LDPE in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	fraction packaging landfilling of Corrugate in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of Corrugate in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of Corrugate in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	emissions during recycling of LDPE in package and bulk pack	56	g CO2 eq/package	log normal	3.948	0.3931
	emissions during recycling of Corrugate in package and bulk pack	576.79	g CO2 eq/package	log normal	6.280	0.3931
	emissions during incineration with energy recovery of LDPE	1874.001	g CO2 eq/package	log normal	7.459	0.3931
	emissions during incineration w/o energy recovery of LDPE	2904.84	g CO2 eq/package	log normal	7.897	0.3931
	emissions during landfilling of LDPE	6.15	g CO2 eq/package	log normal	1.739	0.3931
	emissions during incineration with energy recovery of Corrugate	-377.02	g CO2 eq/package	log normal	5.855	0.3931
	emissions during incineration w/o energy recovery of Corrugate	41.1744	g CO2 eq/package	log normal	3.641	0.3931
	emissions during landfilling of Corrugate	1198.47	g CO2 eq/package	log normal	7.012	0.3931
waste water treatment	Theoretical oxygen demand of ingredients	Non-disclosed information		Non-disclosed information		
	electricity use per kg inorganic material in WWTP	0.65	kWh/kg	log normal	-0.5080	0.3931
	natural gas use per kg inorganic material in WWTP	0.0211	m3/kg	log normal	-3.936	0.3931
	diesel oil use per kg inorganic material in WWTP	0.011	g/kg	log normal	-4.587	0.3931
	electricity use per kg COD organic material in WWTP	0.29	kWh/kg COD	log normal	-1.315	0.3931
	natural gas use per kg COD organic material in WWTP	0.0093	cum/kg COD	log normal	-4.755	0.3931
	diesel oil use per kg COD organic material in WWTP	0.005	g/kg COD	log normal	-5.376	0.3931
	emission of CO2 in WWTP	577.2	g CO2/kg COD	log normal	6.332	0.2272
	emission of CH4 in WWTP	6.56	g CO2/kg COD	log normal	1.855	0.2272

Compact Powder: Comparison situation 3						
				mathematical description		
Stage	parameter	value	unit	distribution	μ	σ
use	washing temperature	30/40	ºC	discrete uniform	n.a.	n.a.
	energy use washing machine (a measure of efficiency)	0.0168	kWh/ºC.wash	normal	0.01680	0.005450
	emissions during electricity generation for washing machine	570	g CO2 eq/kWh	log normal	6.326	0.1982
product ingredient production	amount ingredients	Non-disclosed information		Non-disclosed information		
packaging production	amount LDPE in package and bulk pack	5.93	g/wash	log normal	1.779	0.04766
	amount Corrugate in package and bulk pack	98.71	g/wash	log normal	4.591	0.04766
	emission during production LDPE for package and bulk pack	2086.3	g CO2 eq/package	log normal	7.566	0.3931
	emission during production Corrugate for package and bulk pack	550.98	g CO2 eq/package	log normal	6.234	0.3931
transport	distance transport raw material, road to port, by truck	500	km	log normal	6.137	0.3931
	distance transport raw material, sea to plant, by ship	100	km	log normal	4.528	0.3931
	distance transport raw material, road to plant, by truck	100	km	log normal	4.528	0.3931
	distance transport finished product, road in UK (to oxford), by truck	100	km	log normal	4.528	0.3931
	emissions during transport by truck	107.118	g CO2 eq/ton.km	log normal	4.597	0.3931
	emissions during transport by ship	44.5794	g CO2 eq/ton.km	log normal	3.720	0.3931
formula manufacturing	emissions during formulation compact powder	129	g CO2 eq/kg	log normal	4.783	0.3931
packaging waste treatment	waste treatment package material	yes/no	-	discrete uniform	n.a.	n.a.
	fraction recycling of LDPE in package and bulk pack	0.1	-	log normal	-2.311	0.1312
	fraction recycling of Corrugate in package and bulk pack	0.37	-	log normal	-1.003	0.1312

	fraction packaging landfilling of LDPE in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of LDPE in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of LDPE in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	fraction packaging landfilling of Corrugate in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of Corrugate in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of Corrugate in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	emissions during recycling of LDPE in package and bulk pack	56	g CO2 eq/package	log normal	3.948	0.3931
	emissions during recycling of Corrugate in package and bulk pack	576.79	g CO2 eq/package	log normal	6.280	0.3931
	emissions during incineration with energy recovery of LDPE	1874.001	g CO2 eq/package	log normal	7.459	0.3931
	emissions during incineration w/o energy recovery of LDPE	2904.84	g CO2 eq/package	log normal	7.897	0.3931
	emissions during landfilling of LDPE	6.15	g CO2 eq/package	log normal	1.739	0.3931
	emissions during incineration with energy recovery of Corrugate	-377.02	g CO2 eq/package	log normal	5.855	0.3931
	emissions during incineration w/o energy recovery of Corrugate	41.1744	g CO2 eq/package	log normal	3.641	0.3931
	emissions during landfilling of Corrugate	1198.47	g CO2 eq/package	log normal	7.012	0.3931
waste water treatment	waste water treatment plant	yes/no	-	discrete uniform	n.a.	n.a.
	Theoretical oxygen demand of ingredients	Non-disclosed information		Non-disclosed information		
	electricity use per kg inorganic material in WWTP	0.65	kWh/kg	log normal	-0.5080	0.3931
	natural gas use per kg inorganic material in WWTP	0.0211	m3/kg	log normal	-3.936	0.3931
	diesel oil use per kg inorganic material in WWTP	0.011	g/kg	log normal	-4.587	0.3931
	electricity use per kg COD organic material in WWTP	0.29	kWh/kg COD	log normal	-1.315	0.3931
	natural gas use per kg COD organic material in WWTP	0.0093	cum/kg COD	log normal	-4.755	0.3931
	diesel oil use per kg COD organic material in WWTP	0.005	g/kg COD	log normal	-5.376	0.3931
	emission of CO2 in WWTP	577.2	g CO2/kg COD	log normal	6.332	0.2272
	emission of CH4 in WWTP	6.56	g CO2/kg COD	log normal	1.855	0.2272

3. Uncertainty specification input parameters Ultra Liquid

Ultra Liquid: Comparison situation 1						
				mathematical description		
Stage	parameter	mean value	unit	distribution	μ	σ
product ingredient production	amount ingredients	Non-disclosed information		Non-disclosed information		
packaging production	amount HDPE in package and bulk pack	68.5	g/wash	log normal	4.226	0.04766
	amount PP in package and bulk pack	10	g/wash	log normal	2.301	0.04766
	amount LDPE in package and bulk pack	0.688888889	g/wash	log normal	-0.3738	0.04766
	amount Corrugate in package and bulk pack	62.85555556	g/wash	log normal	4.140	0.04766
transport	distance transport raw material, road to port, by truck	500	km	log normal	6.137	0.3931
	distance transport raw material, sea to plant, by ship	100	km	log normal	4.528	0.3931
	distance transport raw material, road to plant, by truck	100	km	log normal	4.528	0.3931
formula manufacturing	emissions during formulation compact powder	44	g CO_2 eq/kg	log normal	3.707	0.3931
packaging waste treatment	fraction recycling of HDPE in package and bulk pack	0.5	-	log normal	-0.7018	0.1312
	fraction recycling of LDPE in package and bulk pack	0.1	-	log normal	-2.311	0.1312
	fraction recycling of Corrugate in package and bulk pack	0.37	-	log normal	-1.003	0.1312
	fraction packaging landfilling of HDPE in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of HDPE in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of HDPE in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	fraction packaging landfilling of PP in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of PP in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of PP in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	fraction packaging landfilling of LDPE in package and bulk pack	0.911	-	log normal	-0.1018	0.1312

	fraction packaging incineration with energy recovery of LDPE in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of LDPE in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	fraction packaging landfilling of Corrugate in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of Corrugate in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of Corrugate in package and bulk pack	0.001	-	log normal	-6.916	0.1312
waste water treatment	Theoretical oxygen demand ingredients	Non-disclosed information		Non-disclosed information		

Ultra Liquid: Comparison situation 2						
				mathematical description		
Stage	parameter	mean value	unit	distribution	μ	σ
use	energy use washing machine (a measure of efficiency)	0.0168	kWh/ºC.wash	normal	0.01680	0.005450
product ingredient production	amount ingredients	Non-disclosed information		Non-disclosed information		
packaging production	amount HDPE in package and bulk pack	68.5	g/wash	log normal	4.226	0.04766
	amount PP in package and bulk pack	10	g/wash	log normal	2.301	0.04766
	amount LDPE in package and bulk pack	0.688888889	g/wash	log normal	-0.3738	0.04766
	amount Corrugate in package and bulk pack	62.85555556	g/wash	log normal	4.140	0.04766
	emission during production HDPE for package and bulk pack	3700	g CO2 eq/package	log normal	8.139	0.3931
	emission during production PP for package and bulk pack	4400	g CO2 eq/package	log normal	8.312	0.3931
	emission during production LDPE for package and bulk pack	2086.3	g CO2 eq/package	log normal	7.566	0.3931
	emission during production Corrugate for package and bulk pack	550.98	g CO2 eq/package	log normal	6.234	0.3931
transport	distance transport raw material, road to port, by truck	500	km	log normal	6.137	0.3931

	distance transport raw material, sea to plant, by ship	100	km	log normal	4.528	0.3931
	distance transport raw material, road to plant, by truck	100	km	log normal	4.528	0.3931
	emissions during transport by truck	107.118	g CO2 eq/ton.km	log normal	4.597	0.3931
	emissions during transport by ship	44.5794	g CO2 eq/ton.km	log normal	3.720	0.3931
formula manufacturing	emissions during formulation compact powder	44	g CO2 eq/kg	log normal	3.707	0.3931
packaging waste treatment	fraction recycling of HDPE in package and bulk pack	0.5	-	log normal	-0.7018	0.1312
	fraction recycling of LDPE in package and bulk pack	0.1	-	log normal	-2.311	0.1312
	fraction recycling of Corrugate in package and bulk pack	0.37	-	log normal	-1.003	0.1312
	fraction packaging landfilling of HDPE in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of HDPE in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of HDPE in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	fraction packaging landfilling of PP in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of PP in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of PP in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	fraction packaging landfilling of LDPE in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of LDPE in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of LDPE in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	fraction packaging landfilling of Corrugate in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of Corrugate in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of Corrugate in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	emissions during recycling of HDPE in package and bulk pack	56	g CO2 eq/package	log normal	3.948	0.3931
	emissions during recycling of LDPE in package and bulk pack	56	g CO2 eq/package	log normal	3.948	0.3931
	emissions during recycling of Corrugate in package and bulk pack	576.79	g CO2 eq/package	log normal	6.280	0.3931
	emissions during incineration with energy recovery of HDPE	1874.001	g CO2 eq/package	log normal	7.459	0.3931
	emissions during incineration w/o energy recovery of HDPE	2904.84	g CO2 eq/package	log normal	7.897	0.3931

	emissions during landfilling of HDPE	6.15	g CO2 eq/package	log normal	1.739	0.3931
	emissions during incineration with energy recovery of PP	1675.48	g CO2 eq/package	log normal	7.347	0.3931
	emissions during incineration w/o energy recovery of PP	2904.84	g CO2 eq/package	log normal	7.897	0.3931
	emissions during landfilling of PP	6.15	g CO2 eq/package	log normal	1.739	0.3931
	emissions during incineration with energy recovery of LDPE	1874.001	g CO2 eq/package	log normal	7.459	0.3931
	emissions during incineration w/o energy recovery of LDPE	2904.84	g CO2 eq/package	log normal	7.897	0.3931
	emissions during landfilling of LDPE	6.15	g CO2 eq/package	log normal	1.739	0.3931
	emissions during incineration with energy recovery of Corrugate	-377.02	g CO2 eq/package	log normal	5.855	0.3931
	emissions during incineration w/o energy recovery of Corrugate	41.1744	g CO2 eq/package	log normal	3.641	0.3931
	emissions during landfilling of Corrugate	1198.47	g CO2 eq/package	log normal	7.012	0.3931
waste water treatment	Theoretical oxygen demand of ingredients	Non-disclosed information		Non-disclosed information		
	electricity use per kg inorganic material in WWTP	0.65	kWh/kg	log normal	-0.5080	0.3931
	natural gas use per kg inorganic material in WWTP	0.0211	m3/kg	log normal	-3.936	0.3931
	diesel oil use per kg inorganic material in WWTP	0.011	g/kg	log normal	-4.587	0.3931
	electricity use per kg COD organic material in WWTP	0.29	kWh/kg COD	log normal	-1.315	0.3931
	natural gas use per kg COD organic material in WWTP	0.0093	cum/kg COD	log normal	-4.755	0.3931
	diesel oil use per kg COD organic material in WWTP	0.005	g/kg COD	log normal	-5.376	0.3931
	emission of CO2 in WWTP	577.2	g CO2/kg COD	log normal	6.332	0.2272
	emission of CH4 in WWTP	6.56	g CO2/kg COD	log normal	1.855	0.2272

Ultra Liquid: Comparison situation 3						
				mathematical description		
Stage	parameter	mean value	unit	distribution	μ	σ

use	washing temperature	30/40	ºC	discrete uniform	n.a.	n.a.
	energy use washing machine (a measure of efficiency)	0.0168	kWh/ºC.wash	normal	0.01680	0.005450
	emissions during electricity generation for washing machine	570	g CO2 eq/kWh	log normal	6.326	0.1982
product ingredient production	amount ingredients	Non-disclosed information		Non-disclosed information		
packaging production	amount HDPE in package and bulk pack	68.5	g/wash	log normal	4.226	0.04766
	amount PP in package and bulk pack	10	g/wash	log normal	2.301	0.04766
	amount LDPE in package and bulk pack	0.688888889	g/wash	log normal	-0.3738	0.04766
	amount Corrugate in package and bulk pack	62.85555556	g/wash	log normal	4.140	0.04766
	emission during production HDPE for package and bulk pack	3700	g CO2 eq/package	log normal	8.139	0.3931
	emission during production PP for package and bulk pack	4400	g CO2 eq/package	log normal	8.312	0.3931
	emission during production LDPE for package and bulk pack	2086.3	g CO2 eq/package	log normal	7.566	0.3931
	emission during production Corrugate for package and bulk pack	550.98	g CO2 eq/package	log normal	6.234	0.3931
transport	distance transport raw material, road to port, by truck	500	km	log normal	6.137	0.3931
	distance transport raw material, sea to plant, by ship	100	km	log normal	4.528	0.3931
	distance transport raw material, road to plant, by truck	100	km	log normal	4.528	0.3931
	emissions during transport by truck	107.118	g CO2 eq/ton.km	log normal	4.597	0.3931
	emissions during transport by ship	44.5794	g CO2 eq/ton.km	log normal	3.720	0.3931
formula manufacturing	emissions during formulation compact powder	44	g CO2 eq/kg	log normal	3.707	0.3931
packaging waste treatment	include packaging waste treatment	yes/no	-	discrete uniform	n.a.	n.a.
	fraction recycling of HDPE in package and bulk pack	0.5	-	log normal	-0.7018	0.1312
	fraction recycling of LDPE in package and bulk pack	0.1	-	log normal	-2.311	0.1312
	fraction recycling of Corrugate in package and bulk pack	0.37	-	log normal	-1.003	0.1312

	fraction packaging landfilling of HDPE in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of HDPE in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of HDPE in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	fraction packaging landfilling of PP in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of PP in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of PP in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	fraction packaging landfilling of LDPE in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of LDPE in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of LDPE in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	fraction packaging landfilling of Corrugate in package and bulk pack	0.911	-	log normal	-0.1018	0.1312
	fraction packaging incineration with energy recovery of Corrugate in package and bulk pack	0.088	-	log normal	-2.439	0.1312
	fraction packaging incineration w/o energy recovery of Corrugate in package and bulk pack	0.001	-	log normal	-6.916	0.1312
	emissions during recycling of HDPE in package and bulk pack	56	g CO2 eq/package	log normal	3.948	0.3931
	emissions during recycling of LDPE in package and bulk pack	56	g CO2 eq/package	log normal	3.948	0.3931
	emissions during recycling of Corrugate in package and bulk pack	576.79	g CO2 eq/package	log normal	6.280	0.3931
	emissions during incineration with energy recovery of HDPE	1874.001	g CO2 eq/package	log normal	7.459	0.3931
	emissions during incineration w/o energy recovery of HDPE	2904.84	g CO2 eq/package	log normal	7.897	0.3931
	emissions during landfilling of HDPE	6.15	g CO2 eq/package	log normal	1.739	0.3931
	emissions during incineration with energy recovery of PP	1675.48	g CO2 eq/package	log normal	7.347	0.3931
	emissions during incineration w/o energy recovery of PP	2904.84	g CO2 eq/package	log normal	7.897	0.3931
	emissions during landfilling of PP	6.15	g CO2 eq/package	log normal	1.739	0.3931
	emissions during incineration with energy recovery of LDPE	1874.001	g CO2 eq/package	log normal	7.459	0.3931
	emissions during incineration w/o energy recovery of LDPE	2904.84	g CO2 eq/package	log normal	7.897	0.3931
	emissions during landfilling of LDPE	6.15	g CO2 eq/package	log normal	1.739	0.3931
	emissions during incineration with energy recovery of Corrugate	-377.02	g CO2 eq/package	log normal	5.855	0.3931
	emissions during incineration w/o energy recovery of Corrugate	41.1744	g CO2 eq/package	log normal	3.641	0.3931
	emissions during landfilling of Corrugate	1198.47	g CO2 eq/package	log normal	7.012	0.3931
waste water treatment	include waste water treatment	yes/no	-	discrete uniform	n.a.	n.a.

	Theoretical oxygen demand of ingredients	Non-disclosed information		Non-disclosed information		
	electricity use per kg inorganic material in WWTP	0.65	kWh/kg	log normal	-0.5080	0.3931
	natural gas use per kg inorganic material in WWTP	0.0211	m3/kg	log normal	-3.936	0.3931
	diesel oil use per kg inorganic material in WWTP	0.011	g/kg	log normal	-4.587	0.3931
	electricity use per kg COD organic material in WWTP	0.29	kWh/kg COD	log normal	-1.315	0.3931
	natural gas use per kg COD organic material in WWTP	0.0093	cum/kg COD	log normal	-4.755	0.3931
	diesel oil use per kg COD organic material in WWTP	0.005	g/kg COD	log normal	-5.376	0.3931
	emission of CO_2 in WWTP	577.2	g CO_2/kg COD	log normal	6.332	0.2272
	emission of CH_4 in WWTP	6.56	g CO_2/kg COD	log normal	1.855	0.2272

References

Saltelli A., Chan K., Scott M. (2000) *Sensitivity analysis*. John Wiley & Sons, Ltd, New York.

Saltelli A., Tarantola S., Campolongo F., Ratto M. (2004) *Sensitivity analysis in practice; a guide to assessing scientific models*. John Wiley & Sons, Ltd, New York. Isbn 978-0470-87093-8.

Simlab (2004) *Simulation environment for uncertainty and sensitivity analysis*, Version 2.2, developed by the Joint Research Centre of the European Commission.