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TASK 3. SOLUTION

Firstly, we need the inventory per functional unit, that is 1 kg of detergent. The calculations for electricity and raw materials consumption are shown in the next equations:

$$CO_2 emissions\ (electricity) = 0.5\ \frac{kg\ CO_2}{kWh} * \frac{1\ kWh}{3.6\ MJ} \frac{4.4\ MJ}{kg\ detergent} = 0.61\ \frac{kg\ CO_2}{kg\ detergent}$$

$$CO_2 emissions\ (raw\ materials) = 0.1\ \frac{kg\ CO_2}{g} * \frac{33\ g\ detergent}{kg\ detergent} = \ 3.3\ \frac{kg\ CO_2}{kg\ detergent}$$

Table 1a provides the LCI from cradle to gate and **Table 1b** from gate to gate for detergent 1 and 2, respectively.

Table 1a. *Cradle to gate emissions due to electricity and raw materials consumptions for detergent 1.*

	Detergent 1 (cradle to gate)		
	Energy emissions (4.4 MJ) (kg/kg detergent)	**Raw materials (33 g) (kg/kg detergent)**	**Total**
CO_2	6.11E-01	3.30	3.91
CO	2.04E-04	7.26E-04	9.30E-04
H_2SO_4	0	0	0
Fluoride	1.89E-08	9.17E-09	2.81E-08
COD	4.31E-04	3.23E-03	3.67E-03
Phenol	2.15E-07	2.46E-07	4.61E-07
Total N	0	0	0
Total P	0	0	0

Table 1b. *Cradle to gate emissions due to electricity and raw materials consumptions for detergent 2.*

	Detergent 1 (cradle to gate)		
	Energy emissions (3.3 MJ) (kg/kg detergent)	**Raw materials (44 g) (kg/kg detergent)**	**Total**
CO_2	4.58E-01	4.40	4.86
CO	1.53E-04	9.68E-04	1.12E-03
H_2SO_4	0	0	0
Fluoride	1.42E-08	1.22E-08	2.64E-08
COD	3.24E-04	4.31E-03	4.64E-03
Phenol	1.61E-07	3.27E-07	4.89E-07
N	0	0	0

Phosphorus	0.00E+00	0.00E+00	0.00E+00

For the gate to gate inventory the emissions are given per functional unit, so any calculation is required. **Table 1c** shows the LCI from gate to gate of detergent 1 and 2.

Table 1c. *Gate to gate emissions due to electricity and raw materials consumptions.*

Emissions	Detergent 1 (kg/kg detergent)	Detergent 2 (kg/kg detergent)
CO_2	1.5	1.4
CO	9.00E-04	1.00E-03
H_2SO_4	1.00E-04	2.00E-04
Fluoride	5.40E-08	5.60E-08
COD	4.10E-03	1.20E-03
Phenol	5.70E-03	7.60E-03
N	3.00E-04	2.00E-04
Phosphorus	1.00E-06	1.00E-06

To transform the LCI into impact indicators we need the characterisation factors published in "The Sustainability Metrics" (**Table 2**).

Table 2. *Characterisation factors IChemE.*

Category	CO_2	CO	H_2SO_4	Phenol	COD	Fluorides	Total N	Total P
GWP	1	3						
Aq.Ac			0.02			0.05		
AOD				2.38				
EU					0.22		0.4	3.06

To determine the environmental burden (EB) the results of the inventory are multiplied by the characterisation or potency factor (FP)

$$\mathrm{EB} = \mathrm{FP} * \mathrm{Emissions}$$

The results of both detergent from cradle to gate and from gate to gate are shown in **Table 3,** whereas **Table 4** gives the total environmental impact.

Table 3. *LCIA results for cradle to gate and gate to gate.*

	Gate to Gate		Cradle to Gate	
	Detergent 1	**Detergent 2**	**Detergent 1**	**Detergent 2**
GW (kg CO_2 eq./kg detergent)	1.50	1.40	3.91	4.86
AqA (kg SO_2 eq./kg detergent)	2.87E-04	3.84E-04	2.36E-08	2.50E-08
AOD (kg O_2 eq./kg detergent)	1.29E-07	1.33E-07	1.10E-06	1.16E-06

EU (kg Phosphate eq./kg detergent)	2.19E-04	1.13E-04	8.06E-05	1.02E-04

***Table 3. Total** LCIA results.*

	Total	
	Detergent 1	**Detergent 2**
GW (kg CO_2 eq./kg detergent)	5.42	6.26
AqA (kg SO_2 eq./kg detergent)	2.87E-04	3.84E-04
AOD (kg O_2 eq./kg detergent)	1.22E-06	1.30E-06
EU (kg Phosphate eq./kg detergent)	3.00E-04	2.15E-04

Table 4 and **Table 5** depict the normalized and weighted results, respectively.

***Table 4.** Normalized LCIA results.*

	Normalized results	
	Detergent 1	**Detergent 2**
GW (kg CO_2 eq./kg detergent)	8.65E-01	1.00
AqA (kg SO_2 eq./kg detergent)	7.47E-01	1.00
AOD (kg O_2 eq./kg detergent)	9.45E-01	1.00
EU (kg Phosphate eq./kg detergent)	1.39	1.00

***Table 5.** Weighted LCIA results.*

	Weighted results	
	Detergent 1	**Detergent 2**
Air index	8.65E-01	1.00
Water index	1.03	1.00