Exam

Answers of quantitative questions:

2.4) -8.20E-04 kg CO2e/UF
2.5) 4.42E-02 kg CO2e/UF
3.2) Good decision. The total footprint is: = 3.72E-02 kg CO2e/UF for the complete life cycle representing a reduction of -7.02E-03 kg CO2e/UF.
4.1) Arsenic
4.2) Use phase of the scoopter
Production phase
4.3) Ecosystem quality, ressources and climate change
4.5) Electric scooter: 3.93E-06 person*an/UF
Gas scooter: 1.03E-05 person*an/UF

Questions

1. Functional unit, reference flow calculations (2.5 points)

Imagine you are working for a Quebec environmental organization whose mission is to educate the public on the environmental impacts of products and to propose environmentally preferable alternatives. Your current task is to carry out a life cycle assessment (LCA) comparing different types of "chicken broth", used in soups and other recipes:

- Chicken broth cubes, which are dehydrated and to which boiling water must be added to be used in a recipe;
- Chicken broth in liquid form, sold in a "Tetra Pak" packaging.

1.1 Name three aspects that are different between both products that will have an impact on their respective environmental performance. **(0.5 point)**

1.2 Suggest an appropriate functional unit for this LCA. **(0.5 point)**

1.3 Identify three (3) reference flows for each of the compared products. **(1 point)**

1.4 For one of the reference flows, and considering the chosen functional unit (question 1.2), write the equation used to scale the reference flow to the functional unit. You do not have to specify any values, but the nature and the units of the different parameters should be clear. **(0.5 point)**

Figure 1 – Dehydrated chicken broth cubes (left) and ready-to-use chicken broth (right)

2. Simple carbon footprint calculation – case of the toy top **(4 points)**

You want to calculate the « cradle-to-gate » carbon footprint of a toy top (Figure 2). As a reminder, a carbon footprint is a life cycle assessment that only considers the impacts on the climate change impact category.

Figure 2 : Toy top

You have the following information:

- The top is made of unvarnished wood.
- The factory that produces the trucks receives, that it must then cut and machine to produce the toy top.
- The annual quantity of wood purchased by the factory is given in Table 2.1.
- Table 2.1 also provides information on annual losses of wood.
- The factory produces 500 000 toy tops annually.
- The electrical energy necessary to work the wood (cut, machine) is 0.005 kWh/toy top.
- All wastes from the factory are landfilled.
- The greenhouse gas (GHG) emissions associated with the production and use of the toy top are presented in Table 2.2. They are either "cradle-to-gate" or "gate-to-grave" emissions.
- The average transport distances and means of transport are presented in Table 2.3.
- The use of the toy top does not generate any GHG emissions.
- The toy top is landfilled at the end of its life.
- The characterization factor for methane is 28 kg CO_2e/kg CH_4.

2.1 What does the unit « kg CO_2e » mean? **(0.25 point)**

2.2 What do the terms « cradle-to-gate emissions » and « gate-to-grave » emissions mean? **(0.25 point)**

2.3 Represent the product system using a flow diagram. Identify the unit processes that are modelled using agregated datasets. **(0.5 point)**

2.4 Calculate the carbon footprint of the toy truck using the following functional unit: "Use of a toy top over its useful life". Use the same characterization factors for biogenic and fossil CO_2. **(2 points)**

2.5 Redo the calculation of the toy top carbon footprint using the same functional unit as in question 2.4, but this time using the simplifying assumption that assuming that biogenic carbon flowing into the system and flowing out of the system cancel out (characterisation factor for biogenic CO_2 = 0). Explain why you do not obtain the same results. **(1 points)**

Bonus question 2.6 For an **additional** 1.5 points, present the technology matrix (**A**), the elementary flow matrix (**B**) and the final demand vector (**f**) associated with this system. You do not have to answer this question: it is a bonus question. (**1.5 bonus points**)

Table 2.1 : Yearly quantities of materials purchased and lost

	Purchase	Loss	Unit
Wood	50 000	10 000	kg/year

Table 2.2: GHG emissions (cradle-to-gate or gate-to-grave)

	Biogenic CO_2 - Input	Biogenic CO_2 - Emissions	Fossil CO_2	CH_4
	[kg]	[kg]	[kg]	[kg]
Per kg of wood	-2*	0.35**	0.15	3.00E-04
Per kWh of electricity	-	-	1	0.001
Per tkm of heavy truck	-	-	0.1	-
Per tkm of light truck	-	-	0.5	-
Per kg landfilled wood	-	1.2***	0.001	-

* Carbon dioxide taken up by trees during growth (photosynthesis)

** Associated with the combustion of wood residues by the wood mill

*** CO_2 emissions associated with wood degradation.

Tableau 2.3 : Transport associated with the product

Transport	Distance		Type
Transport wood to toy factory	100	km	Truck - Heavy
Transport waste from factory to landfill	50	km	Truck - Heavy
Toy distribution	500	km	Truck – Light
Transport toy to landfill at end-of-life	50	km	Truck – Light

3 Multifunctional system **(1.5 points)**

The factory that produces the toy top (Question 2) is considering selling its wood scrap to a neighbouring factory that could use it as fuel and thereby reduce its heavy fuel consumption. You are tasked with determining if this decision makes sense from a GHG emission point of view. Use "system expansion" as the preferred approach to answer this question.

3.1 Redraw the flow diagram to account for the use of wood scrap by the neighbouring plant **(0.5 point)**

3.2 Knowing that the combustion of 1 kg of wood produces 20 MJ of heat and emits 1.65 kg of CO_2, and knowing that producing 1 MJ of heat from heavy fuel emits 0.1 kg CO_2e/MJ, determine whether this decision would actually reduce GHG emissions attributable to the production and use of the toy top. (**1 point**)

4 Impact assessment **(6 points)**

Figure 3 presents a comparison between an electric scooter and a traditional gasoline scooter for the Human Health endpoint indicator, as calculated using the IMPACT 2002+ LCIA methodology.

4.1 Determine, on the basis of information provided in Table 4, the elementary flow that most contributes to the Human Health impacts for the electric scooter. **(2 points)**

4.2 Identify the life cycle stage that contributes most to the Human Health impacts for both scooters. **(0.5 point)**

4.3 To obtain a complete LCIA environmental profile, what other endpoint indicators should be included in this study? **(0.5 point)**

4.4 Name the LCIA elements (according to ISO 14044) that were used to generate the results in Figure 3. **(1 point)**

4.5 Determine the normalized impact score for both scooters knowing that the normalization factor for human health equals 0.007 (DALY/ (personne * an)) **(1 point).**

4.6 How to interpret the normalized impact score? What is a normalized impact score used for? (**1 point**)

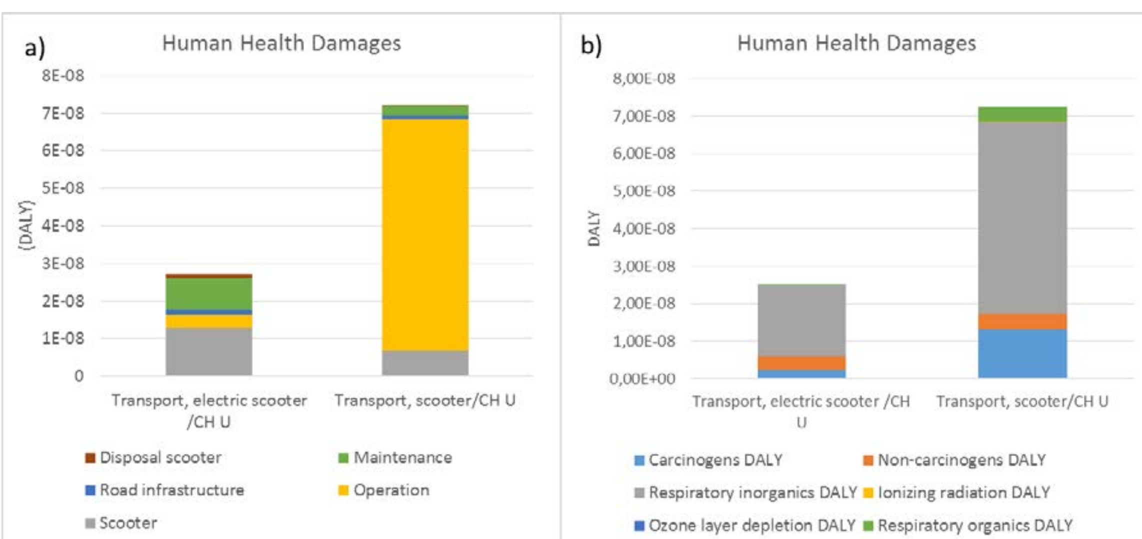

Figure 3 - Comparison of an electric scooter and a traditional gasoline scooter for the endpoint indicator "Human Health"; (a) contribution analysis by life cycle stage; (b) contribution analysis by problem (midpoint).

Tableau 4.1 - Inventory of emissions for the five elementary flows contributing most to the human health impacts for both scooters (electric and traditional gasoline); Midpoint characterization factors and midpoint-to-endpoint conversion factors (midpoint to damage).

Five most contributing elementary flows to Human health Damages				
Substance	Compartment	Unit	Transport, electric scooter/CH U	Transport, scooter/CH U
Nitrogen oxides	Air	g	0.059	0.294
Particulates, < 2.5 um	Air	mg	11.6	23.5
Hydrocarbons, aromatic	Air	mg	0.136	1.25
Sulfur dioxide	Air	mg	98.9	150
Arsenic	Air	mg	52	5.37

Midpoint characterization factors		
Nitrogen oxides	0.13	kgPM2.5eq/kg
Particulates, < 2.5 um	1	kgPM2.5eq/kg
Hydrocarbons, aromatic	3537	kgC2H3Cleq/kg
Sulfur dioxide	0	kgPM2.5eq/kg
Arsenic	13731	kgC2H3Cleq/kg

Midpoint to Damage conversion factors		
Damage category	Human health	
Carcinogens	2.8E-06	DALY / kg C2H3Cl eq
Non-carcinogens	2.8E-06	DALY / kg C2H3Cl eq
Respiratory inorganics	0.0007	DALY / kg PM2.5 eq
Ionizing radiation	2.1E-10	DALY / Bq C-14 eq
Ozone layer depletion	0.00105	DALY / kg CFC-11 eq

5. Interpretation **(3 points)**

Figure 4a show comparative LCA results of two transformation processes from milk into Greek Yogurt. The functional unit is "to produce 1 kg of Greek Yogurt". Results focus on the transformation stage from milk into yogurt. Milk production and transportation stages are excluded from Figure 4a, but included in Figure 4b.

5.1 Knowing that process UF-LAIT uses 10% more milk than process UF YOG for the same functional unit, please confirm or infirm the conclusion drawn by the author of the study " From the comparative LCA of the two transformation processes one concludes that the process UF LAIT allow to reduce the environmental impacts compared to the process UF YOG". Justify your answer (**1 point**)

5.2 If one would apply the ReCiPe methodology instead IMPACT 2002+, would conclusion be modified or not? Justify your answer (**1 point**)

5.3. What is the advantage of using a midpoint-damage methodology when the sponsor of the LCA study doesn't has the intention to communicate the results in units of DALY or PDF·m2·yr? (**1 point**)

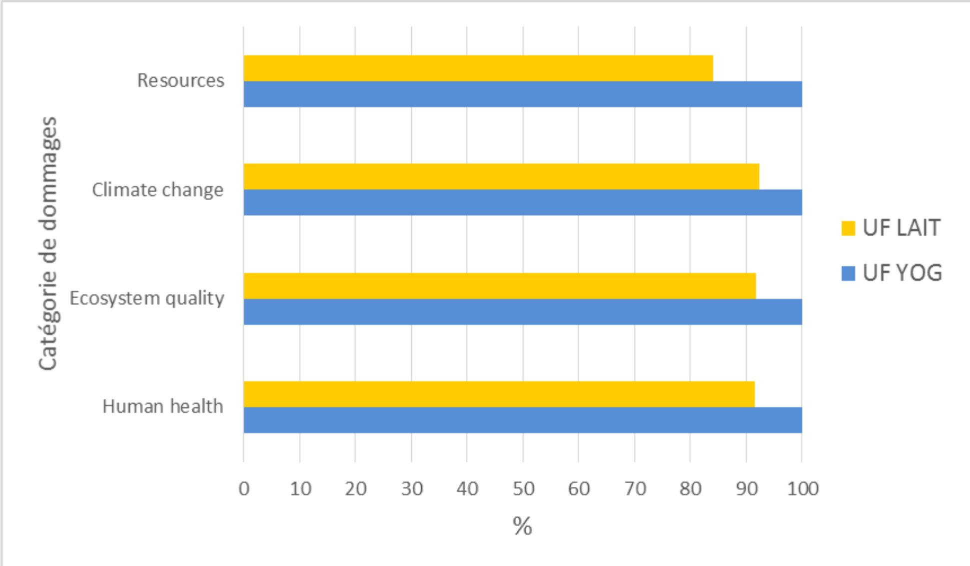

Figure 4a : ACV comparative de deux procédés de transformation du lait par ultrafiltration du lait avant fermentation (UF LAIT) et par ultrafiltration après fermentation (UF YOG) : uniquement l'étape de transformation est considérée (production et transport du lait exclus)

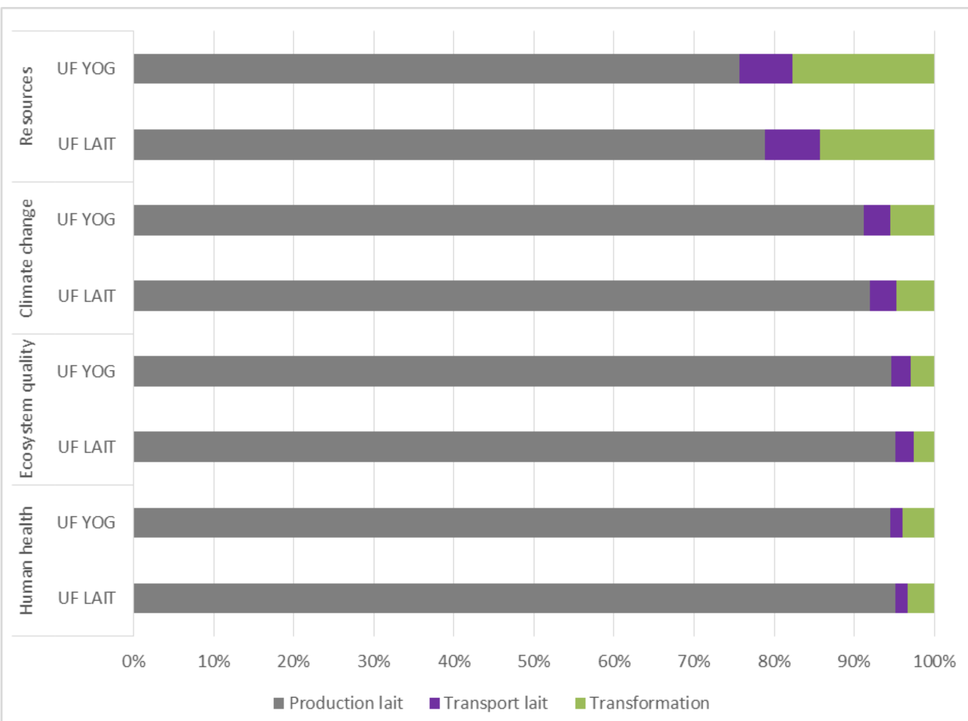

Figure 4b : ACV comparative de deux procédés de transformation du lait par ultrafiltration du lait avant fermentation (UF LAIT) et par ultrafiltration après fermentation (UF YOG) : toutes les étapes du cycle de vie sont incluses.

6. Interpretation of your project **(2 points)**

The question on interpretation deals with the group project you did this semester as part of the course (comparative LCA).

6.1 Qualification of sensitivity and uncertainty. **(1.5 points)**
You used many different types and sources of data in the course of your project.

- Indicate (very briefly) one data type/data point that you would place in quadrants 1, 2 and 3, respectively, and two that you would place in quadrant 4.
- Briefly name the data source you used for these data.

Sensitivity→	Quadrant 2	Quadrant 4
	Quadrant 1	Quadrant 3
	Uncertainty→	

6.2 Improvement of your study **(0.5 point)**

Suppose we were to offer you a few additional weeks and a budget of 25,000$ to improve your study. What would you do in priority?

7. Interpretation **(2 points)**

7.1 Describe in your own words what a Monte-Carlo analysis is and how it can be used in LCA. **(1 points)**

7.2 Describe in a sentence or two three types of sensitivity analyses that it is possible to carry out in the context of a comparative LCA. **(1 points)**

Bonus questions

The following questions are short bonus questions. <u>You are not obliged to answer them</u>. Each good answer is worth **+0,25 point (bonus)**.

Bonus.1 Consider elementary flows form Figure B1. How much wood (“bois rond”) is allocated to planks (“planches”), in kg of wood per kg of plank, using an economic allocation?

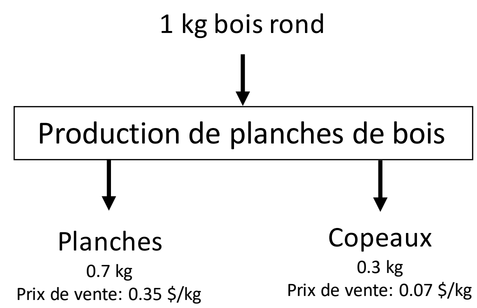

Figure B1 : Processus multifonctionnel

Bonus.2 Name two things that one can do with a disaggregated inventory data that one cannot do with an aggregated inventory data.

Bonus.3 What is the meaning of the following damage units DALY, PDF*m2*yr.

Bonus.4 Name two elementary flows classified in the impact category photochemical ozone formation.