CE 3890/5999 SCS

Homework 4: Process–based LCA and uncertainty

Due: Thursday 10/26/18

Professor D. Work *Fall 18*

1 Assignment overview

This is an individual assignment. The first objective is to perform a life cycle impact assessment. You will construct the technology matrix A and interventions matrix B based on a simplified process flow diagram for bus manufacturing. You will compute the life cycle inventory using the computational structure presented in class. After obtaining the life cycle inventory, you will perform a life cycle impact assessment by using the TRACI LCIA method.

The second objective of this assignment is to perform an uncertainty analysis on bus manufacturing using a Monte Carlo analysis.

You will need the following data files from Brightspace to complete this assignment.

- *environmental_intervention.xlsx*
- USEPA's *TRACI_2.0.xls*

You will need to submit files which contain your results.

- A PDF report, which contains typed solutions to each of the problems in this assignment, a description of any supporting code, and a description of how to run the supporting code.
- A zip file containing any supporting Python code (i.e., *.py and *.ipynb files).
- *If you would like to combine textual responses into a Jupyter Notebook, you may do so but be sure to format responses properly.*

Both files must be electronically submitted on the course website. Your solutions to the following questions should be typed in a suitable editor (e.g. Word or LaTex), with appropriate references (if you used them), figures, and text, as needed to explain your results. It is important that you properly cite any sources (of data or otherwise) used in your report. You may use the ASCE guidelines, or another consistent style of your choice. Submit an electronic copy on Brightspace, and bring a printed copy to class.

2 Introduction

In the first part of this assignment, you will perform a life cycle impact assessment for bus manufacturing, which considers upstream inputs in addition to direct inputs. A complete process flow diagram for a bus

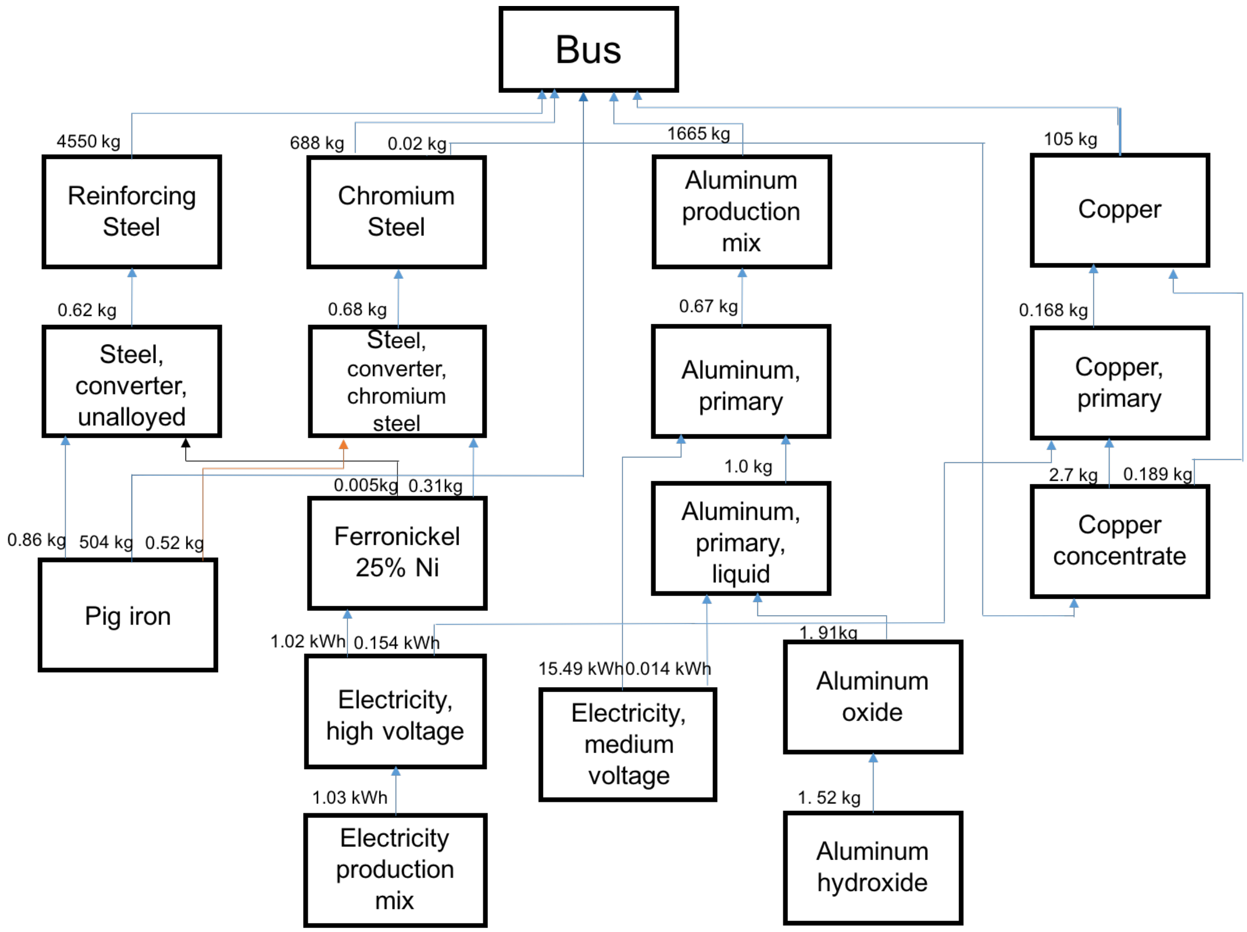

Figure 1: Simplified process flow chart for the manufacture of a bus. Data based on the manufacture of a Volvo 8500 bus in 2002 from SimaPro 7.3.

manufacturing contains several thousand processes. In this assignment, we have reduced the number of processes to 18 (Figure 2). The 18 processes consider direct inputs to the bus, such as reinforcing steel; chromium steel, and also indirect inputs such as aluminum, primary, copper concentrate. The 18 processes used in this assignment are chosen by selecting the 18 most significant processes (direct and indirect) for overall environmental impact from a complete LCA on bus manufacturing. The simplified flow chart with processes included in this assignment is shown in Figure 2.

In Figure 2, the number associated with each arrow indicates the amount of upstream material needed to produce 1 unit of downstream product. For example, to produce one bus, we need: 4550 kg of reinforcing steel; 688 kg of chromium steel; 1665 kg of aluminum production mix; and 105 kg of copper. Similarly, to produce 1 kg of reinforcing steel, 0.62 kg of steel converter, unalloyed is needed. Note again that Figure 2 is a simplification of a flow chart with more than 2000 processes, and as a result, not every process is shown. However, this flow chart has all of the processes necessary to understand the computational components of life cycle impact assessment, while still limiting the total amount of data you need to consider for the assignment.

Process	Process number
bus	1
Reinforcing steel, at plant	2
Chromium steel 18/8, at plant	3
Aluminum, production mix, at plant	4
Copper, at regional storage	5
Steel, converter, unalloyed, at plant	6
Pig iron	7
Steel, converter, chromium steel 18/8, at plant	8
Ferronickel, 25% Ni, at plant	9
Electricity, high voltage, production UCTE, at grid	10
Electricity, production mix UCTE	11
Aluminum, primary, at plant	12
Aluminum, primary, liquid, at plant	13
Electricity, medium voltage, aluminium industry	14
Aluminum oxide, at plant	15
Aluminum hydroxide, at plant	16
Copper, primary, at refinery	17
Copper concentrate, at beneficiation	18

Table 1: Coordinates for the bus manufacturing system

2.1 Mathematical modeling of process based LCA

In lecture, we have discussed how to mathematically model a life cycle inventory problem using a technology matrix A, a final demand vector f, an environmental interventions matrix B, and an inventory vector g. Now you will mathematically model this bus manufacturing problem by answering the following questions. It is imperative you use the coordinates defined in Table 1, so that the coordinates are consistent with supplemental datasets provided later in the assignment.

Question 2.1 Define the final demand vector associated with production of one bus.

Question 2.2 Construct the matrix A by using information from Figure 2. Save the data from Numpy as *matrixA.npy* using the command `np.save(filename, my_array)`. *Note: the inverse command is* `my_array = np.load(filename)`.

Question 2.3 Compute the scaling vector s.

The environmental outputs for each process have been provided to you in the Excel file *environmental_intervention.xlsx*. By examining *environmental_intervention.xlsx*, we see that some of the processes do not have any direct environmental outputs, yet they are still included, because they have downstream processes which have a significant contribution to environmental emissions. For example, the process reinforcing steel does not have any emissions to air, but it has an input process, steel, converter, unalloyed, which has significant air emissions.

You have a few options to move this Excel data into Python. First, you could try installing and using a Python package to directly read the file. See this tutorial for some comprehensive instructions; note that you will need to use the command prompt/terminal to install the package. Alternatively, you can extract and save sections of the Excel file to a CSV file, which Python can read natively.

Question 2.4 Construct the environmental interventions matrix B by using information from *environmental_intervention.xlsx*. Save it from Numpy as *MatrixB.npy*.

Question 2.5 Using the scaling factor s you computed above, compute the inventory vector g. This completes the life cycle inventory of the simplified model of the bus.

Question 2.6 After completing the life cycle inventory and determining the total environmental interventions, you will now complete a life cycle impact assessment. You now need to perform the classification and characterization steps based on the TRACI LCIA methodology. The data you need is contained in the file *TRACI_2.0.xlsx*, which contains characterization factors of each environmental output (substance) for each impact category. This file was obtained directly from the US EPA.

Use the Global Warming Potential, Eutrophication, and Smog impact categories to complete the following.

Question 2.7 Classify the environmental interventions to each category by using information from *TRACI_2.0.xlsx*. Notes:

- If the characterization factor is 0 for all categories, it means this environmental intervention does not contribute to any of the categories. It does not need to be classified.
- Some of the Simapro LCI interventions are not considered in TRACI. You may ignore them or make other necessary assumptions.

Question 2.8 Apply the characterization factor and calculate the impact assessment result for each impact category. Summarize your results.

Question 2.9 What are the most significant two contributing processes to the Global Warming Potential impact category? You need to show your calculations for this problem.

3 Uncertainty modeling in LCA

In the questions above, you performed a simplified life cycle assessment for bus manufacturing that did not consider uncertainty. In reality, the material and/or energy flows between processes in the economy and environment are not exact. For example, the direct input reinforcing steel for bus manufacturing is 4550kg. However, the amount of steel could vary (i.e. if you are interested in a set of buses, not just the Volvo model stored in SimaPro), or you might not know precisely the amount of steel used (i.e., if you don't have access to the bus to measure the amount of steel). In the following questions, you will quantify how the uncertainty in the data introduces variability on the life cycle inventory.

In Figure 2 we assume the number associated with each arrow indicates the average amount of upstream material needed to produce one unit of downstream product. Moreover, we now assume all of the flows have uncertainty which is normally distributed, and described by a mean and a variance. The standard deviation for each material or energy flow input is assumed to be 12% of the mean, and the mean is assumed to be the values from Figure 2. To simplify the assignment, we will assume the environmental interventions matrix B is deterministic (use the matrix you constructed in the first part of the assignment).

Question 3.10 Write a Python program which performs a Monte Carlo analysis for bus manufacturing. Hints and requirements:

- Some helpful Numpy commands include:*std, median, mean.*
- The code should run for a specified number of samples, n.
- For each sample, make sure you save the environmental interventions vector g.

Question 3.11 Using your script, run a Monte Carlo simulation with $n = 100$ samples, plot the distribution of carbon dioxide emissions, and the distribution of nitrogen oxide emissions associated with bus manufacturing. The two plots should be histogram plots with appropriate labels and titles.

Question 3.12 Calculate the mean, standard deviation, and median value for the distribution of carbon dioxide and nitrogen oxide.

Question 3.13 Repeat the previous two steps, this time using $n = 10,000$ samples. Do the mean, standard deviation, and median values change? How?

Question 3.14 Repeat the steps again (you may skip the histogram plots), this time using

$$n = \{10, 50, 100, 300, 500, 1000, 2000, 3000, 5000, 10000\}.$$

Generate a plot with the number of samples n on the x axis, and the mean value of carbon dioxide emissions on the y axis. Describe what you observe.

Question 3.15 Briefly analyze the results for $n = 10,000$ samples and summarize your findings on the uncertainty in the emissions. What errors could you make if you only look at a deterministic LCI instead of considering the full distribution? Do you think the deterministic LCI gives a good estimate of the mean values obtained with the Monte Carlo analysis? Explain why or why not.

Question 3.16 Please read the paper, "Using Monte Carlo Simulation in Life Cycle Assessment for Electric and Internal Combustion Vehicles" posted on Brightspace.

- According to the authors, is the use of electric vehicles expected to reduce or increase carbon dioxide equivalent emissions compared to internal combustion vehicles? Please explain how the authors arrived at their result.
- OPTIONAL – You may produce box-whisker plots (similar to the plots in this paper) for your simulations for bus manufacturing in the Python package matplotlib using the boxplot command.