Name:

Midterm 2a

ISYE 4803F. Energy and Environmental Analysis. November 4 2013. V. Thomas

I have upheld the Academic Honor Code:

We have been studying two types of life cycle assessment (LCA). The first is regular, “process-based” LCA, which you saw in the SimaPro homework, and components of which (system energy use, system water use, system greenhouse gas emissions) we worked out in part 1 of the course. The second type is economic input-output LCA (EIO-LCA) which uses input-output analysis to evaluate the full environmental impact, throughout the economy, of activity in a specific economic sector. In this midterm you will explore the appropriate application of each type of LCA, and how they can complement each other. Since freight transport is a key topic in industrial engineering, this exam focuses on freight transport.

1. Consider an urban delivery truck – for example a UPS truck – that has an average diesel fuel consumption rate of 8 miles per gallon.
2. If the truck delivers an average of 1 package every five miles, how many gallons of gasoline can be attributed to each package? (5 points)

**(5 miles/package)/(8 miles/gallon)= 0.625 (or just 0.6) gallons/package**

1. Given that burning a gallon of diesel fuel results in the emission of about 20 lbs of CO2, what are emissions from delivery of one package? (5 points)

**0.625 gallons/package x 20 lbs CO2/gallon = 12.5 lbs/package or 5.67 kg/package**

1. To evaluate the lifecycle greenhouse gas emissions from the urban delivery truck, what additional processes, stages or activities would generally be included within the system boundary, in addition to driving the truck? Provide at least two, and draw a simple system boundary diagram showing these. (10 points)

**Truck production, truck end-of-life, number of packages per unit time, truck lifetime**

Truck

end-of-life

Truck

use

Truck production

1. If instead of evaluating the lifecycle greenhouse gas emissions of the urban delivery truck, the functional unit of analysis was the lifecycle greenhouse gas emissions per package, what additional processes, stages or activities would be included within the system boundary, in addition to transporting the package in the delivery truck? Provide at least two, and draw a simple system boundary diagram showing these. (10 points)

**Packaging materials production, packaging materials end-of-life**

Package material

end-of-life

Package delivery

Package materials production

1. The urban delivery truck carries an average payload of 3 tons. What is its energy use per ton-mile (in MJ/ton-mile)? (5 points)

**E=(1 gallon/8 mi)x 45 MJ/kg x 3.785 l/gal)/(0.8 l/kg x 3 tons) = 8.87 or 9 MJ/ton-mi**

1. When package delivery increases by, for example, $1 million dollars, there may be other economic activity that ensues throughout the economy as a result. In the EIO-LCA homework you worked with a 9 sector model of the US economy. Assume package delivery is in the transportation sector and that package delivery has average greenhouse gas emissions of the transportation sector. The direct requirements matrix A, and the Leontief inverse (I-A)-1, the sector names corresponding to the rows and columns, and the greenhouse gas emissions from $1 million of activity in each sector are given below.
   1. How much total greenhouse gas emissions are emitted from all economic sectors as a result of a $1 million increase in activity in the transportation sector? (10 points)

**R x (I-A)-1 x Y = 2,099 tons CO2**

**This is R, which is a row vector:**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| sector | agriculture | minerals | construction | manufactured products | transportation | trade | finance | services | other |
| GHG (t/$M) | 4260 | 1150 | 698 | 776 | 1400 | 192 | 100 | 183 | 20 |

and (I-A)-1 Y is

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1.337 | 0.017 | 0.033 | 0.076 | 0.011 | 0.009 | 0.012 | 0.015 | 0.004 | 0 |
| 0.021 | 1.264 | 0.030 | 0.057 | 0.075 | 0.008 | 0.005 | 0.010 | 0.007 | 0 |
| 0.030 | 0.051 | 1.014 | 0.023 | 0.058 | 0.017 | 0.033 | 0.018 | 0.024 | 0 |
| 0.409 | 0.255 | 0.519 | 1.612 | 0.185 | 0.119 | 0.058 | 0.199 | 0.042 | 0 |
| 0.116 | 0.149 | 0.080 | 0.114 | 1.232 | 0.073 | 0.044 | 0.067 | 0.027 | 1 |
| 0.104 | 0.057 | 0.126 | 0.112 | 0.041 | 1.037 | 0.013 | 0.041 | 0.008 | 0 |
| 0.151 | 0.384 | 0.071 | 0.085 | 0.097 | 0.109 | 1.221 | 0.115 | 0.015 | 0 |
| 0.139 | 0.152 | 0.205 | 0.173 | 0.218 | 0.206 | 0.131 | 1.222 | 0.027 | 0 |
| 0.006 | 0.006 | 0.006 | 0.010 | 0.007 | 0.010 | 0.012 | 0.011 | 1.003 | 0 |

**=**

|  |
| --- |
| 0.01 |
| 0.08 |
| 0.06 |
| 0.18 |
| 1.23 |
| 0.04 |
| 0.10 |
| 0.22 |
| 0.01 |

**So R x (I-A)-1 x Y= 2099 tons CO2**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 4260 | 1150 | 698 | 776 | 1400 | 192 | 100 | 183 | 20 |

**X**

|  |
| --- |
| 0.01 |
| 0.08 |
| 0.06 |
| 0.18 |
| 1.23 |
| 0.04 |
| 0.10 |
| 0.22 |
| 0.01 |

**=**

1. What fraction of the total emissions are from the direct (zeroth level, just from transportation) are from the initial $1 million activity in transportation? (10 points)

**The greenhouse gas emissions from one million dollars of activity in the transportation sector is 1400 tons CO2.**

**1400/2099 = 0.67 or 67% or 70%**

**or R x I x y = R y**

1. What fraction of the total emissions is from the direct plus first level activity? (10 points)

**The total emissions from the first level activity is R x A x Y = 386 tons CO2**

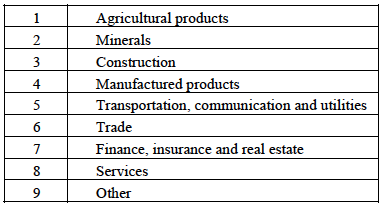
**So the sum to the first level is 1400+386 = 1786 and the fraction is 1786/2099=85%**

1. Which sector is the top contributor of greenhouse gas emissions to the first level emissions? What are the total first level emissions from that sector? Explain what this means. (15 points)

**To answer this question, look at the numbers that are summed to get Ray. Which is the biggest? Visually this is easy to see by writing R as a column vector, putting it next to Ay as a column vetor, and multiplying each entry, as shown below.**

|  |  |  |  |
| --- | --- | --- | --- |
| sector | GHG (tons/$M) | Ay | RiAyi |
| agriculture | 4260 | 0 | 0 |
| minerals | 1150 | 0.045 | 52 |
| construction | 698 | 0.041 | 29 |
| manufactured products | 776 | 0.058 | 45 |
| transportation | 1400 | 0.166 | 232 |
| trade | 192 | 0.014 | 3 |
| finance | 100 | 0.033 | 3 |
| services | 183 | 0.122 | 22 |
| other | 20 | 0.003 | 0 |

**Transportation has the largest contribution at 232 tons CO2. This means that other transportation is induced by the $1 million of activity in transportation.**



For the 9 sector model of the US economy, the direct requirements matrix A is

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0.24 | 0.001 | 0.006 | 0.035 | 0 | 0.001 | 0.005 | 0.003 | 0.001 |
| 0.001 | 0.198 | 0.007 | 0.025 | 0.045 | 0 | 0 | 0 | 0.003 |
| 0.012 | 0.025 | 0.001 | 0.007 | 0.041 | 0.008 | 0.024 | 0.008 | 0.022 |
| 0.173 | 0.095 | 0.297 | 0.346 | 0.058 | 0.044 | 0.008 | 0.094 | 0.014 |
| 0.047 | 0.075 | 0.025 | 0.046 | 0.166 | 0.043 | 0.022 | 0.033 | 0.018 |
| 0.052 | 0.023 | 0.083 | 0.06 | 0.014 | 0.022 | 0.002 | 0.02 | 0.002 |
| 0.069 | 0.232 | 0.015 | 0.018 | 0.033 | 0.067 | 0.169 | 0.068 | 0.006 |
| 0.035 | 0.04 | 0.104 | 0.064 | 0.122 | 0.142 | 0.079 | 0.15 | 0.012 |
| 0.001 | 0 | 0.001 | 0.004 | 0.003 | 0.007 | 0.009 | 0.007 | 0.002 |

and the Leontief Inverse, (I-A)-1 is

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1.337 | 0.017 | 0.033 | 0.076 | 0.011 | 0.009 | 0.012 | 0.015 | 0.004 |
| 0.021 | 1.264 | 0.030 | 0.057 | 0.075 | 0.008 | 0.005 | 0.010 | 0.007 |
| 0.030 | 0.051 | 1.014 | 0.023 | 0.058 | 0.017 | 0.033 | 0.018 | 0.024 |
| 0.409 | 0.255 | 0.519 | 1.612 | 0.185 | 0.119 | 0.058 | 0.199 | 0.042 |
| 0.116 | 0.149 | 0.080 | 0.114 | 1.232 | 0.073 | 0.044 | 0.067 | 0.027 |
| 0.104 | 0.057 | 0.126 | 0.112 | 0.041 | 1.037 | 0.013 | 0.041 | 0.008 |
| 0.151 | 0.384 | 0.071 | 0.085 | 0.097 | 0.109 | 1.221 | 0.115 | 0.015 |
| 0.139 | 0.152 | 0.205 | 0.173 | 0.218 | 0.206 | 0.131 | 1.222 | 0.027 |
| 0.006 | 0.006 | 0.006 | 0.010 | 0.007 | 0.010 | 0.012 | 0.011 | 1.003 |

The carbon dioxide emissions from each of the sectors, R, is approximately

|  |  |
| --- | --- |
| sector | GHG (tons/$M) |
| agriculture | 4260 |
| minerals | 1150 |
| construction | 698 |
| manufactured products | 776 |
| transportation | 1400 |
| trade | 192 |
| finance | 100 |
| services | 183 |
| other | 20 |

1. In developing an LCA, it is possible to choose between regular process-based LCA and EIO-LCA, and it is also possible to develop a “hybrid” LCA in which regular process-based LCA is used for the best-measured part of the system and EIO-LCA is used for parts of the system that can’t be well characterized. For each of the two projects described below, describe what type of LCA would be most appropriate (regular, EIO-LCA, or hybrid) for characterizing the energy and environmental benefits, and describe in one sentence whether EIO-LCA is appropriate for all or part of the analysis, and if only for part, describe which part.
   1. A senior design project that reduces Coca-Cola’s use of urban delivery truck services through better planning of supply routes. (10 points)

**This could use a basic analysis of the energy savings, plus also a full analysis using EIO-LCA of the total greenhouse gas emissions savings. EIO-LCA is appropriate because the entire use of the transportation sector is being reduced.**

* 1. A senior design project that reduces the greenhouse gas emissions of UPS delivery trucks by 10% through use of more efficient trucks. (10 points)

**For this project I would use a regular, process-based LCA, not EIO-LCA because the same economic interactions will occur throughout the economy, while only the fuel use of the trucks is reduced.**

Potentially useful information

1 metric ton (tons) = 2205 pounds (lbs)

1 kg of diesel fuel has 80% the mass density of water.

Energy density of diesel fuel: ~ 45 MJ/kg

1 gallon = 3.785 liters