

E X A M**Course code: BYG404****Course name: Life-cycle assessment of constructions**

Date: December 14, 2016

Duration: 3 hours

Number of pages incl. front page: **4**

Resources allowed: Simple calculator, English dictionary, one 2-sided piece of paper (A4 size) with notes

Notes: The exam translates to **165** points with all points being weighted equally.

You may choose to answer in English or Norwegian

1. Functional units (15 points)Define *functional units* for the following (15 points)

- a. Production of potatoes and carrots
- b. Production of paints
- c. A mobile telephone
- d. A roof on a building
- e. Comparative analysis between coal power production and wind power production

2. Goal and scope (20 points)

- a. A construction project taking place in Norway requires a large amount of steel in order to be completed. The purchasing manager of the construction project has to decide whether to purchase steel from China, Poland or Norway. While the material characteristics of the steel from each country will be identical, the purchasing manager has been told to find the steel that has the least environmental impact per ton. What should the purchasing manager include in their study to do a fair comparison when determining the impacts of each? What factors do you think will influence their decision? (10 points)
- b. Briefly explain the four main components of an LCA study. (10 points)

3. Allocation (40 points)



A Norwegian shipping company has been tasked with transporting goods along a route from Norway to South Africa with their ship, the 1 000 000 ton capacity MS Brunost Ekspress. The MS Brunost Ekspress will take the following itinerary:

Kristiansand → Rotterdam → Porto → Lagos → Capetown

- The ship will begin in Kristiansand with a 600 000 ton load of brown cheese and a 300 000 ton load of gravel. The ship will travel 800 km to Rotterdam.
- In Rotterdam, the ship will drop off 100 000 tons of brown cheese and all of the gravel. The ship will pick up 300 000 tons of tulips before travelling 1600 km to Porto.
- In Porto, the ship will drop off 100 000 tons of tulips and 100 000 tons of brown cheese before picking up 400 000 tons of wine. The ship will then travel 3500 km to Lagos.
- In Lagos, the ship will drop off 200 000 tons of tulips, 200 000 tons of brown cheese, and 100 000 tons of wine. The ship will also pick up 500 000 tons of furniture before travelling 2700 km to Cape Town, South Africa.
- In Cape Town, the ship will drop off all remaining cargo

The MS Brunost Ekspress releases 6 000 tons of SO₂-equivalent emissions of the ship for the total 8 600 km journey from Kristiansand to Cape Town.

- a. Calculate the emissions for delivering goods to each destination based on itinerary given. (38 points)
- b. What method of allocation is used in this example? (2 p)

4. Inventory analysis (60 points)

The Stjernehus housing block in Kristiansand was previously declared Norway's coldest apartment building. The owners of the building decided to do a renovation to bring the building up to current TEK10 building standards in order to reduce the amount of energy use in the building. The company who did the construction work, Kruse-Smith, decided that they wanted this project to be a test case for sustainable building renovation and decided to do an LCA study to determine the pay-back period for both CO₂-emissions and energy demand by looking at the materials used in the renovation. The renovation involved upgrading the exterior wall with better insulation and a better material barrier, adding new doors and windows, fixing the roof and adding a new ventilation system. The new ventilation system also allowed for a connection to the Kristiansand Incineration plant, meaning that heat requirements for the building now come from the incineration plant.

The Stjernehus apartment building has a heating area of 3717 m² with an average apartment size of 63 m².

Exterior walls

The exterior walls are made up of insulation, concrete, wood and a moisture barrier. The exterior walls require 15 tons of insulation, 47 tons of concrete, 102 m³ of wood and 1,5 tons of moisture barrier. The wood, insulation and concrete is transported 25 km to the work site, while the moisture barrier comes from a factory 200 km away.

Windows and doors

There are 760 m² of new double pane glass windows, with a combined glass thickness of 3cm. Each m² of window has 65 kg polyvinylchloride (PVC) and 20 kg of steel on the frame. There are an additional 139 m² of wooden doors with a thickness of 3 cm. The steel parts on the doors are not included in the scope of the study. The windows and doors come from the same factory and are transported 75 km from factory site to Stjernehus.

Roof

The new sections of the roof included an additional 2,3 tons of moisture seal 3,0 tons of insulation and 2,0 tons of concrete. The transport of materials in the roof are the same for the exterior walls.

Ventilation

In order to be able to connect to the district heating system, a new ventilation system consisting of 2,1 tons of steel ducts and 1,7 tons of insulation was required. The steel ducts are transported 1000 km while the insulation comes from a factory 25 km away from Stjernehus.

Energy on construction site

Diesel machinery used in the renovation operated for 1200 hours while using 0,923 liters of fuel per hour of operation, mostly in cranes, earthworks machinery and diesel generators. The electricity used in the renovation was 45277 kWh, mainly for temporary lighting, heating and ventilation

Additional information

- Density of wood: 480 kg per m³
 - Density of glass: 2600 kg per m³
 - Calorific value of diesel fuel: 44 MJ/liter diesel
 - 1 kWh = 3,6 MJ
 - Transportation is assumed to be done by a 16-to-32 ton truck that consumes 0,02 liters diesel per ton-km transported
- a. Draw a basic flow chart for this system. Please note any assumptions you have made with respect to system boundaries. (10 p)
 - b. What are the material requirements for one average apartment? (25 p)
 - c. What is the total transport (in tkm) of all materials required for an average apartment? (15 p)
 - d. How much direct energy is required (in MJ) for the renovation (including transport) for one average apartment? (5 p)
 - e. Is this study a consequential(change-oriented) or attributional(accounting) study? Please explain. (5 p)

5. Life cycle impact assessment (25 points)

A Norwegian energy company has taken an emissions inventory to produce 1 GJ of ethanol fuel from wood products. The main impact categories that they have collected data for are *terrestrial acidification* and *photochemical oxidant formation*. Using the tables below, calculate the total terrestrial acidification (in SO₂-equivalents) and photochemical oxidant formation (in NMVOC-equivalents) emissions for producing 50 GJ of ethanol fuel.

	Raw emission per GJ fuel
Emission	g Emission
Sulfur dioxide	236,20
Nitrogen oxides	173,77
Ammonia	33,82
Non-methane volatile organic compounds	56,99
Carbon monoxide, fossil	202,42

	Terrestrial acidification	Photochemical oxidant formation
Emission	Characterization factor (kg SO ₂ equivalent/kg raw emission)	Characterization factor (kg NMVOC equivalent/kg raw emission)
Sulfur dioxide	1,000	0,655
Nitrogen oxides	0,560	1,375
Ammonia	2,450	-
Non-methane volatile organic compounds	-	1,000
Carbon monoxide, fossil	-	0,095

6. SimaPro (5 points)

Below is an example of two processes for high voltage electricity in Norway. Please explain the difference between these two processes.

Electricity, high voltage {NO}| electricity production, hydro, pumped storage | Alloc Rec, U
Electricity, high voltage {NO}| market for | Alloc Rec, U

7. Bonus section (extra points!)

- The original Stjernehus building had an annual energy demand of 337 kWh per m² per year while the renovated Stjernehus building has annual energy demand of 102 kWh per m² per year. Including all of the indirect energy from producing materials, direct energy used in construction energy and fuel used in transport, the Stjernehus renovation used 9 430 000 MJ. Using this total, calculate how many years (approximately) it will take for renovated building to “pay-back” the energy used in the renovation process. Please show your work. (4 p)
- Who received the most votes in the 2016 United States Presidential Election? (1 p)