Examination Renewable Energy Sources (4P510)

Date: **January 30, 2014**
Time: **14.00 – 17.00 hours**

Note: Different lecturers will correct the answers to the various problems for this examination.

Write down every answer on a different sheet of paper.

Please write on every sheet of paper you use the following:

1. the problem number;
2. your last name and initials;
3. your identity (student) number;
4. your email;
5. your department;

Should you write down answers to more than one problem on one piece of paper, then the first answer will be corrected and the other answers will be void.

The exam consists of 5 questions. For each question 20 points are available, the maximum score is 100 points.

The use of course books and notes is <u>not</u> allowed.
The use of simple calculators is allowed.

Good luck!

Problem 1 General introduction

For this problem, don't worry if you don't know the exact numbers. It's more about the order of magnitude which counts.

a) Given the world-wide primary energy use of around 560 EJ per year in 2010, tabulate the distribution of the primary energy consumption by "fuel type" and indicate for each fuel type its contribution as a percentage. All renewables can be viewed as one fuel type "new renewables". The most important fuel type is oil.

Fuel	Primary energy contribution (%)
Oil	40%
… Coal	21%
Nat gas	19%
New renewables	6%
…	14%
Total	100%

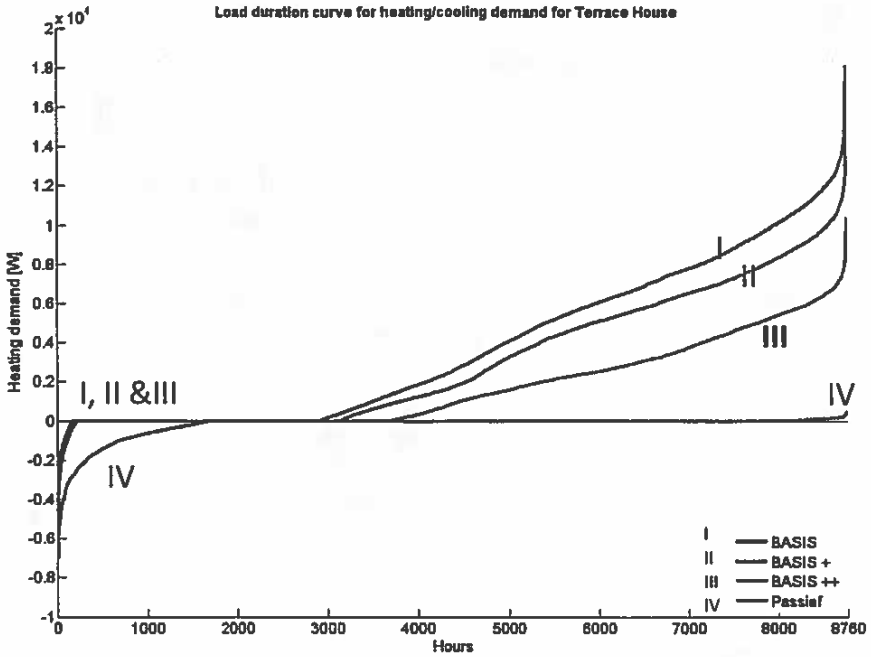
b) Name at least 5 most important groups of renewable energy sources for electricity production and put them in order of production capacity. Give an estimation of their production capacity in EJ/year or TWh/year.

c) List different methods to reduce CO2 emissions in order of importance.

d) What are the 3 main key factors in an energy scenario determining the development of future global energy demand? Explain your answer.

Problem 2 Renewables in the built environment

In the figure the load duration curves of the required annual heating & cooling power for typical Dutch terrace houses are given. With from I to IV different refurbish programs over the years.



a) Explain the curve for the 'passive' renovation (IV) and give the measures used in the 'passive renovation'.
b) Taken the six values of integral design, what are the consequences of the 'passive' renovation for the **Basic** and the **Economic** values?
c) What other alternative strategies/measures could lead to a comparable energy efficiency for heating with the same environmental impact, when not considering a single dwelling but for a district with 1000 dwellings renovated to category III 'BASIS ++' with additional measures not directly related to the dwellings itself.
d) The 'Trias Energetica' is a 3-step approach towards a self-supporting built environment. Name the 3 steps and when considering a small city, give for each step suitable measures towards a self-supported built environment.

Problem 3 Photovoltaic conversion

a) Describe which phenomena take place when sunlight strikes on a crystalline silicon solar cell. In detail, answer the following questions and motivate your answers.

1. Which photons are responsible for carrier generation?
2. How is it possible to estimate the penetration depth of the sunlight in silicon?
3. Where are the carriers generated within the c-Si solar cell?
4. Where does carrier separation occur? Explain this concept by making use of the band diagram of the p-n junction.
5. Write the current-voltage equation for a solar cell under illumination and derive the equation defining the open-circuit voltage V_{OC}.

b) 1. Draw the diagram of the current-voltage (IV) characteristics of a solar cell and indicate where the maximum power point (Pmp) is located.

2. Calculate the P_{mp} for a solar cell characterized by a fill factor (FF) of 0.75, a short circuit current (I_{SC}) of 40 mA/cm^2 and an open circuit voltage (V_{OC}) of 640 mV.

3. Define the standard test conditions and calculate the electrical efficiency of this solar cell.

c) Make an accurate sketch of a grid-connected PV system and describe the function of its several components.

Problem 4 Wind energy

Suppose a new offshore wind farm is going to be built off the coast of The Netherlands with an provided area of 5 x 5 km. The project developer has two choices for different sizes and numbers of wind turbines to "fill" the area:

- 42 wind turbines with 3 MW capacity and 100 m diameter
- 20 wind turbines with 6 MW capacity and 150 m diameter

The cost of a 6 MW 150 m diameter wind turbine is <u>three</u> times the cost of a 3 MW 100 m diameter wind turbine.

a) What would be your choice with respect to selection of the wind turbines for this wind farm (explain why)?

b) Calculate the yearly production of both wind turbines in a wind regime with an average wind speed of 8.5 m/s at hub height. Assume a factor 1.1 for taking in to account the variations around the average wind speed and take an (average electrical) power coefficient of 0.40, see formula below. (density of air ρ =1.225; T=8760 hrs)

$$E_{windturbine} = 1.1 \cdot (\frac{1}{2} \rho \bar{C}_P \bar{V}^3 A) T$$

c) What does this mean for the capacity factor of both wind turbines?

d) Does the difference in capacity factor give rise to wind turbine design modification?
And if so what would you suggest?

e) Calculate the total energy yield of the wind farm with both type of wind turbines. Does this change your mind on the choice of the turbine?

f) What is the most logical arrangement of the wind turbines on the project area?

g) If you think about the additional costs in an offshore wind farm (support structures, cables etc), would you then stick with your first choice? Explain your answer.

h) Can you give at least 2 recommendations for further optimisation to the project developer? (think about number of wind turbines, capacity factors, rated power/wind speed, etc etc).

Problem 5 Biomass

a) Woody biomass consists of three CHO components.
   1. Give their names.
   2. Give their average mass fractions in woody biomass.
   3. What is the average elemental composition CH_xO_y of woody biomass? Give x and y.

b) Biomass can be converted by means of thermo-chemical processes.
   1. What are the three main thermo-chemical conversion processes?
   2. What is the difference between these processes in terms of fuel air ratio?
   3. What are the main products of each process?
   4. Are these processes endothermic or exothermic?

c) Biomass derived fuels, such as bio-alcohols, are burnt in engines to produce heat and power. Ethanol (C_2H_5OH) has a heating value of 26.8 MJ/kg and a density of 789 kg/m^3.
   1. Write down the reaction equation for the combustion of ethanol.
   2. How much oxygen [kg] is needed to burn 1 liter of ethanol?
   3. How much CO_2 is emitted per unit of heat released [kg CO_2/MJ]?
   4. This is more than for natural gas. Explain why it is beneficial for CO_2 emissions to use bio-alcohols.

Molar masses: C = 12 gr/mol, H = 1 gr/mol, O = 16 gr/mol, N = 14 gr/mol.