UNIVERSITY OF JOHANNESBURG

FACULTY OF SCIENCE

DEPARTMENT OF GEOGRAPHY, ENVIRONMENTAL MANAGEMENT & ENERGY STUDIES

MODULE	**ENS8X05** ENERGY MODELLING
CAMPUS	**APK**
EXAM	**NOVEMBER 2019**

DATE **18 NOVEMBER 2019** **SESSION** **08:30 – 11:30**

ASSESSOR(S) **DR KRISTY LANGERMAN**

EXTERNAL MODERATOR **DR PHILIP GOYNS**

DURATION **3 HOURS** **MARKS** **300**

NUMBER OF PAGES: 3 PAGES

INSTRUCTIONS:

1. **Please answer any THREE of the five questions below.**
2. **Each answer should be in the form of a comprehensive essay, with sketches, diagrams and calculations where these may be appropriate to enhance your answer.**
3. **Each question is worth the same number of marks (100).**
4. **Calculators are permitted.**

Dr Kristy Langerman

Dr Philip Goyns

QUESTION 1

Describe the stages of setting up a mathematical model. Then construct a model to determine:

1. The cost of heating water for a house using a newly installed solar water heater compared to the cost with the existing electric geyser, over a 5-year period
2. The CO_2 emissions avoided per year by using a solar water heater rather than an electric geyser
3. The minimum additional CO_2 tax required to make a solar water heater the cheaper option.

Assume the following:

a. The power rating of the electric geyser is 3 kW
b. The electric geyser typically needs to operate for 3 hours a day to heat sufficient water
c. Electricity costs R1.00/kWh
d. The cost of a solar water heater installation is R25 000
e. The solar water heater and the electric geyser will both not need to be replaced in the 5-year period
f. The CO_2 emission factor for the South Africa electricity grid is 1.05 tons per MWh
g. Inflation and interest rates are zero

[100]

Mark allocation

Stages of setting up mathematical model:

1. Build: define objectives, choose equations
2. Study: including sensitivity analysis
3. Test: replicate known results
4. Use: scenarios, output

(or workable equivalent) [20 marks in total, with 5 for each step]

OR:

1. Define the state of nature (energy balance, add dynamics)
2. Define the understanding (test the hypotheses)
3. Make strategic choices (stress testing)

Model construction:

1. Cost of heating water with solar heater = R25 000 (capital cost only) [10 marks]

Cost of heating water with electric geyser = 9 kWh/day x 365 days/year x 5 years x R1/kWh = R16 425 [30 marks]

2. CO_2 emissions from electric geyser = 3.285 MWh/year x 1.05 tons/MWh = 3.45 tons/year [20 marks]

3. Minimum additional CO_2 tax:
   Electricity in 5 years = 16.425 MWh
   CO_2 emissions in 5 years = 17.25 tons
   Cost difference between solar and electric geysers: R8575
   Additional CO_2 tax = R8575 / 17.25 tons = R497/ton [20 marks]

QUESTION 2

Compare and contrast top-down energy models with bottom-up energy models, and suggest applications that both types of model could be used for.

[100]

Mark allocation

This answer should be written in the form of an essay, with an introduction, body and conclusion. Marks are allocated mainly for content, but also for coherence and structure. Answers should demonstrate understanding of how the two types of models work, what their strengths and weaknesses are, and what types of applications that are used for.

Extract from Herbst et al., 2012 (p.111) on the top-down vs bottom-up models: "Detailed techno-economic (or process-oriented) models can simulate the market penetration and related cost changes of a new energy technology or policy with a certain degree of technical detail (which is why they are called "bottom-up" models). However, they cannot project the corresponding economic, structural, or employment net impacts or net cost for society. The results of these models are often cited by environmentally-concerned scientists, NGOs and politicians to elucidate the feasibility of major changes to the energy system, particularly in the context of urgent and extensive change of the mainly fossil fuelled energy systems in almost all countries.

On the other hand, macroeconomic models (also called top-down models) can simulate sector-specific future energy demand and supply including the impacts on economic growth, employment or foreign trade. However, they rely very much on energy price changes and financial policies and are not well suited to describe the development of specific technologies or sectoral policies and related changes in energy demand, related emissions, and investments at a sufficiently detailed level. They may also reflect rather constant trends in structural changes of the economy and, to an unsatisfactory extent, saturation processes and innovations. The results of these models are often cited by representatives of trade associations, large energy-intensive or energy supply companies, and conservative politicians”.

Marks are to be allocated as follows:
Excellent: 80, 85, 90 or 95%
Very good: 72, 74%
Good: 62, 65, 68%
Average: 52, 55, 58%
Poor: 31, 37, 45%
Unacceptable: 20, 25, 30%
An answer that does not answer the question must score less than 50%.

QUESTION 3

Energy models are frequently used for planning purposes. Evaluate the benefit that can be derived from the use of such models, and the limitations of a modelling approach. What trade-offs need to be considered in energy system models? How are externalities handled by models?

[100]

Mark allocation

Marks are to be allocated as follows:

a. Benefit of using energy system models [25 marks]
b. Limitations of modelling [25 marks]
c. Trade-offs [15 marks]
d. Externalities [15 marks]
e. Overall structure and coherence [20 marks]

Some points to be included for each aspect (the list is not exhaustive; points are to be allocated based on the level of knowledge and understanding shown by the student):

a. Benefit of using energy system models
    - Understanding
    - Forecasting
    - Decision evaluation
    - Integrated: consider all parts of the system

b. Limitations
    - Our current level of understanding
    - The input provided
    - The scope of the model
    - The way in which the input is handled (the equations)

- Outputs need to be contextualized for decision-makers

c. Trade-offs
   - Trade-offs between environmental, economic and social sustainability
   - Influenced by value judgements

d. Externalities
   - An externality is a cost that is external to the system
   - For example damage to the environment
   - Can be ignored or built in

QUESTION 4

Answer all three parts of this question:

i) Using your knowledge of Systems Thinking and Systems Dynamics, draw a causal loop diagram which shows two factors that influence the electricity consumption of a typical household in Johannesburg.

ii) Explain how the factors that you have identified influence the electricity consumption of the household, with reference to the causal loop diagram.

iii) Identify the system archetype depicted in the causal loop diagram drawn for part i) of this question, and justify your answer.

[100]

Mark allocation

i) Causal loop diagram [50 marks]

Any two factors can be identified, as long as they make sense.

Marks are allocated as follows:

- State variables (two factors + energy of household): 3 state variables x 4 marks each = 12 marks
- Arrows showing direction of influence = 4 arrows x 1 mark each = 4 marks
- Labelling of arrows as S (or +) or O (or -) indicating polarity of change: 4 labels x 4 marks each = 16 marks
- Time delay (if applicable) || : 3 marks
- Indicate balancing loops B (odd number of "O" polarities) or reinforcing loops R (even number of "O" polarities): 2 labels x 4 marks each = 8 marks
- Overall construction: 7 marks

ii) Explanation of how factors influence electricity consumption [30 marks]

iii) Identification of system archetype and justification [20 marks]

System archetypes are:

- Shifting the burden
- Limits to growth (at least one reinforcing loop driving growth and at least one balancing loop constraining or limiting growth)
- Eroding goals
- Escalation (a reinforcing loop set up by competing actors trying to get ahead of each other)
- Success to the successful (A reinforcing loop which divides a system into winners who keep on winning and losers who keep on losing)
- Fixes that fail
- Tragedy of the commons (growth or escalation in the usage of a commonly shared, erodible environment or resource)
- Growth and underinvestment (elaborated limits to growth
- archetype where the capacity to act becomes a growth inhibitor or limit)

Assess whether the explanations make sense and show understanding of how causal loop diagrams work.

QUESTION 5

Critically assess the energy modelling approach that is used for South Africa's Integrated Resource Plan. Consider the inputs, output, scenarios and exclusions for the modelling, and the role that the modelling plays in the compilation of the final plan.

[100]

Mark allocation

Critical assessment of modelling approach and role that modelling plays in compilation of final plan [30 marks]

- Discuss process of developing the IRP: input – modelling (least cost optimisation with PLEXOS) – outputs (scenarios) – public hearings – policy adjusted IRP (more modelling) - gazetted

Inputs [20 marks]

- demand forecast
- existing supply forecast (plants under construction, preferred bidders, decommissioning, plant performance)
- new supply options (technology costs, technology technical characteristics)

- Constraints (CO_2 limits, security/adequacy of supply)

Output [20 marks]
Per scenario:
- Total system costs
- Capacity expansion (GW)
- Energy share (TWh)
- CO_2 emissions
- Water usage
- Jobs in electricity sector

Key questions: what to build (MW)? When to build it?

Scenarios (seven and policy adjusted plan) [20 marks]
- Demand forecast (high, median, lower)
- CO_2 mitigation (PPD/carbon budget)
- Annual new-build limit (yes/no)
- Fuel prices (constant / market-related)

Exclusions for modelling [10 marks]
- Grid-related costs
- Costs for additional system services (e.g. inertia requirements, black start, reactive power)
- Metering, billing, customer services

TOTAL [300]