UNIVERSITY OF JOHANNESBURG

FACULTY OF SCIENCE

DEPARTMENT OF GEOGRAPHY, ENVIRONMENTAL MANAGEMENT & ENERGY STUDIES

MODULE	**ENS8X05** ENERGY MODELLING
CAMPUS	**APK**
EXAM	**NOVEMBER 2020**

DATE	**9 NOVEMBER 2020**	**SESSION**	**08:30 – 16:30**
ASSESSOR(S)		**DR KRISTY LANGERMAN**	
EXTERNAL MODERATOR		**DR PHILIP GOYNS**	
DURATION	**8 HOURS**	**MARKS**	**200**
FORMAT: OPEN BOOK EXAM WRITTEN AT HOME		**NUMBER OF PAGES: 8 PAGES**	

Dr Kristy Langerman

Dr Philip Goyns

INSTRUCTIONS:

1. Please answer Question 1 (compulsory) and then answer any ONE of Questions 2-3. Two questions are to be answered in total.
2. The mark allocation is shown next to each question.
3. Answers are to be written on A4 white paper.

4. Write your student number and the course code/course name clearly at the top of the first page of your answers.
5. You may type your answers or write by hand. Hand drawn diagrams may be used to supplement answers.
6. If you type your answers, please use Arial 12 font and portrait mode A4 and save all your answers in one file.
7. Clearly number the answers to the questions.
8. Since the examination is open book, you are allowed to refer to course material.
9. The use of cell phones, email and/or the internet (except for Blackboard) during the examination period is NOT allowed.
10. Calculators are permitted.
11. There is to be no communication between students whatsoever between 08:00 and 17:30.
12. The only communication permitted between 08:00 and 17:30 is with the examiner.
13. No person may assist you in any way to answer the exam questions.
14. References are not required.
15. The following schedule must be adhered to:

Time	Action
08:00	Log on to Blackboard and find the exam question paper under Energy Modelling – Course Content – Exam: 9 November 2020. Read the question paper.
08:00-08:30	Email any questions for clarification to the examiner at klangerman@uj.ac.za. The examiner will respond to the questions in the order received.
08:30-16:30	Write or type your answers to the questions. (If typing, save your file every few minutes as you go along.)
16:30	Stop writing. Exam question paper will be removed from Blackboard.
16:30-17:30	If **typing**, ensure all your answers are saved in one file, in addition to the Excel spreadsheet. If answers are **hand-written**, scan your answers. The best

	way to do this is by downloading the (free) Adobe Scan app onto your cell phone. Scan your answers by taking a series of photographs of the pages with your phone (through the app) and saving as a pdf document. Upload your answers to Blackboard through the **Exam: 9 November 2020** link. If any technical problems with Blackboard are experienced, please email exam answers to klangerman@uj.ac.za.
17:30	Deadline for uploading exam answers to Blackboard.

16. Exam answers will be subject to a plagiarism test. **Answers that are plagiarised, even in part, will receive zero.** The disciplinary process will be followed for those found guilty.
17. If any technical problems are experienced during the exam, please send a screen shot and email/whatsapp to Kristy Langerman (klangerman@uj.ac.za; 083 704 2543).

QUESTION 1 (COMPULSORY) [150]

You are intending to purchase a new car, and would like to base your decision on which car to buy on the cost and CO_2 emissions of the car. The three options that you are considering are:

i) A conventional internal combustion engine (ICE) vehicle using petrol
ii) A battery electric vehicle (BEV) that you will charge using grid electricity in South Africa
iii) A hydrogen fuel cell vehicle (FCV), for which the hydrogen is produced by electrolysis with grid electricity in South Africa

Compare the costs and CO_2 emissions of the three vehicles over a 5-year period by following these steps:

a. Articulate the problem posed by identifying the focus question, key variables, time horizon, base year and scenarios. [14]

Answer:

Focus question: Which of the three cars (ICE, BEV, FCV) has the least cost over 5 years [2 marks] and the lowest CO2 emissions [2 marks]

Key variables: Distance travelled, fuel consumption rate, efficiencies, purchase price, CO2 emissions, cost [any 5, 1 mark each]

Time horizon: 5 years [1 mark]

Base year: 2020 (year 1) [1 mark]

Scenarios: ICE, BEV, FCV [3 marks]

b. Construct a causal loop diagram to show three factors that affect the greenhouse gas emissions from a motor vehicle. Then explain in words how the factors that you have identified influence greenhouse gas emissions, with reference to the causal loop diagram [40]

Mark allocation:

4 variables – 2 marks each [8 marks]

6 arrows – 1 mark each [6 marks]

6 arrow labels – 1 mark each [6 marks]

3 loop labels – 2 marks each [6 marks]

6 explanations (1 for each arrow) (2 marks each) – [12 marks]

Overall construction [2marks]

c. Construct a spreadsheet model in which you calculate:

   a. Annual CO_2 emissions for each of the three vehicle technologies. For each of the technologies, tabulate the fuel/electricity input, equivalent energy input, energy output and annual CO_2 emissions. (HINT: Start by calculating the energy output for the ICE vehicle, and then assume that all three vehicles require the same energy output per km). [40]

Answer:

ICE vehicle:

Petrol used in a year = 2000 km/year * 0.1 litres/km = 2000 litres [4 marks]

Input energy GJ/year = 2000 litres * 0.033152 GJ/litre = 66.3 GJ [4 marks]

CO2/year = 66.304 GJ/year * 69.3 kg/GJ = 4594.867 kg [4 marks]

Useful energy output/year = 66.304 GJ * 0.3 = 19.89 GJ [4 marks]

BEV

Energy input/year = 19.89 GJ / 0.75 = 26.5216 GJ [4 marks]

Electricity input/year = 26.5216 GJ/3.6 = 7.367 MWh [4 marks]

CO2 emissions/year = 7.367111 MWh * 1000 * 1.06 kg/kWh = 7809.14 kg [4 marks]

FCV

Energy input/year = 19.89 GJ / 0.245 = 81.18857 GJ [4 marks]

Electricity input/year = 81.18857 GJ/3.6 = 22.552378 MWh [4 marks]

CO2 emissions/year = 22.552378 MWh * 1000 * 1.06 kg/kWh = 23905.52 kg [4 marks]

b. Total cost of ownership of each vehicle over the 5-year period. Only consider fuel and net capital costs. [24]

Answer:

Input fuel/electricity		[3 marks each, 9 marks total]
ICE	R29,000.00	
BEV	R15,470.93	
FCV	R47,360.00	

Depreciated Capital cost		[2 marks each, 6 marks total]
ICE	R235,000.00	
BEV	R350,000.00	
FCV	R500,000.00	

Total cost over 5 years		[3 marks each, 9 marks total]
ICE	R380,000.00	
BEV	R427,354.67	
FCV	R736,800.00	

d. Create two graphs comparing CO_2 emissions and cost of ownership of the three vehicle technologies. [12]

Mark allocation:

For each of the two graphs, allocate marks as follows:

Categories (ICE, BEV, FCV) [1 mark]

Y axis label [1 mark]

Y axis scale [1 mark]

Type of graph [1 mark]

Correct appearance (data in graph) [2 marks]

e. On the basis of your calculations, discuss which vehicle you would buy and motivate your choice. Is your decision based on a trade-off, and if so, motivate the trade-off? [8]

Mark allocation:

Choice of vehicle and reason [6 marks]

Understanding of trade-off [2 marks]

f. Classify the model you constructed as deterministic/stochastic, and empirical/mechanistic, and motivate your answer. [6]

Answers:

Deterministic [2 marks]

Mechanistic [2 marks]

Motivation [2 marks]

g. Identify two externalities that are not included in the model, and explain briefly how they could be included. [6]

Mark allocation:

2 externalities – 2 marks each – 4 marks total

How include – 1 mark each – 2 marks total

Externalities include health impact of air pollution, climate change impacts of greenhouse emissions, cost of safely housing car etc

The input parameters and assumptions that you are to use in your calculations are as follows:

Input and assumptions:

1. You are intending to keep the car for 5 years and then sell it.
2. The car will drive for 20 000 km/year.
3. The ICE vehicle consumes 10 litres of petrol per 100 km.

4. The energy content of petrol is 0.033152 GJ/litre
5. CO_2 emission factors are:
    a. Petrol: 69.3 kg/GJ
    b. Grid electricity: 1.06 kg/kWh
6. The efficiencies of the vehicles are:
    a. ICE vehicle: 30%
    b. BEV: 75% (includes charging and electric motor efficiency)
    c. FCV: 35% (includes hydrogen-to-electricity conversion and electric motor efficiency)
7. The efficiency of the production of hydrogen through hydrolysis (using grid electricity) is 70%. Do not consider any other inefficiencies in the transport of petrol or electricity.
8. All costs should be in 2020 Rand (do not consider inflation).
9. Input energy costs are:
    a. Petrol: R14.50/litre
    b. Electricity: R2.1/kWh
10. Cars lose 50% of their value over 5 years
11. The purchase prices of the new vehicles in 2020 South African Rand are:
    a. ICE vehicle: R470 000
    b. BEV: R700 000
    c. FCV: R1 000 000
12. Conversion factors:
    a. 1 MWh = 3.6 GJ

Answer any **ONE** of the following TWO questions:

QUESTION 2 **[50]**

In an essay, describe the modelling approach that is used for the Integrated Resource Plan, considering the inputs, output, scenarios and exclusions.

Mark allocation:

Approach [5]
Inputs [10 marks]
Outputs [10 marks]
Scenarios [10]
Exclusions [5]
Overall [10]

QUESTION 3 **[50]**

Answer all components of this question. Answer section 2.3 with reference to China's energy balance table (Table 1)

2.1 Explain what the energy balance is, and why it underpins energy system models. [10]

Energy balance is energy supply = energy demand [4 marks]

Underpins energy system models [6 marks]

2.2 Discuss the use of optimization in energy system modelling, and give two examples. [10]

Optimise is to maximise or minimize [4 marks]

Least cost [3 marks]

Lowest CO2 emissions [3 marks] or any other example

2.3 Answer the following questions with reference to China's energy balance table for 2018 (Table 1):

a) Is China a net importer or net exporter of energy? *Importer* [2]

b) What proportion of China's primary energy supply is derived from coal? *62%*

[4]

c) What energy source accounts for over 50% of China's energy imports? *Crude oil*

[2]

d) What energy source generates the second most electricity in China? *Hydro*

[2]

e) What is the difference between total energy supply and total final consumption? Account for the difference in terms of the law(s) of

thermodynamics. *1 143 925 ktoe. Energy lost when converted from one form to another (second law of thermodynamics)* [6]

f) Which energy source/carrier has the highest losses, and why? *Electricity, inefficient coal-fired power stations* [4]

g) What sector of the economy uses the most energy? *Industry* [2]

h) Comment on the main energy sources used by the residential sector, and whether you consider this to be typical of a developed or developing country. *Most electricity but lots of biofuels and coal – developing country* [4]

i) What energy source is used most by the agriculture/forestry sector, and what do you think that energy source is used for? *Oil products for vehicles* [4]

TOTAL [200]

Table 1: Energy balance table for China for 2018 (source, IEA data and statistics, https://www.iea.org/data-and-statistics/data-tables?country=CHINAREG&energy=Balances&year=2018)

	Coal	Crude oil	Oil products	Natural gas	Nuclear	Hydro	Wind, solar, etc.	Biofuels and waste	Electricity	Heat	Total
	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe	ktoe
Production	1 859 684	189 351		135 314	76 865	103 113	81 120	116 799			2 562 246
Imports	156 091	461 885	90 998	100 508				3	1 680		811 167
Exports	-6 574	-2 627	-64 546	-2 834					-1 856		-78 437
International marine bunkers			-21 462								-21 462
International aviation bunkers			-17 052								-17 052
Stock changes	-23 376	-18 849	-3 676								-45 901
TES	**1 985 825**	**629 760**	**-15 737**	**232 988**	**76 865**	**103 113**	**81 120**	**116 802**	**-176**		**3 210 561**
Transfers	-1 156	-4 513	6 276								606
Statistical differences	-7 497	-3 626	-15 170	2 262				-7	-2 804	3 995	-22 847
Electricity plants	-638 388	-155	-2 564	-25 114	-76 865	-103 113	-46 851	-35 771	448 305		-480 515
CHP plants	-508 303			-24 950				-94	169 533	101 547	-262 266
Heat plants	-8 513		-4 428					-1 322		12 393	-1 870
Gas works	-5 837		-273	1 488				-7			-4 630
Oil refineries		-623 188	607 085								-16 103
Coal transformation	-127 400										-127 400

	Coal	Crude oil	Oil products	Natural gas	Nuclear	Hydro	Wind, solar, etc.	Biofuels and waste	Electricity	Heat	Total
Liquefication plants	-10 573	5 815									-4 758
Other transformation											
Energy industry own use	-42 256	-3 082	-36 718	-30 113					-65 303	-13 390	-190 861
Losses		-476	-12	-2 668					-28 913	-1 212	-33 282
Total final consumption	**635 903**	**536**	**538 459**	**153 894**			**34 269**	**79 602**	**520 642**	**103 332**	**2 066 636**
Industry	495 570	536	45 681	65 460			482		320 591	69 351	997 672
Transport	2		290 492	22 269				2 311	12 162		327 235
Residential	45 329		43 877	41 301			26 626	77 286	85 253	27 042	346 713
Commercial and public services	17 122		16 387	14 599			5 606	3	38 439	2 806	94 962
Agriculture / forestry	13 790		18 884	111			1 472		10 914	34	45 204
Fishing											
Non-specified	18 776						82	3	53 283	4 100	76 243
Non-energy use	45 314		123 138	10 154							178 606