UCC501 Sustainable Energy

Homework (2)

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Question 1 (Energy Scales, CO2 Emissions and Renewables)

a) *What was the total Natural gas consumption in the UAE in 2011? Express in MTOE/year and GWh/year.*

Solution:

The total Natural Gas consumption in the UAE in 2011 was 2221 billion cubic feet.

$$1\ billion\ cubic\ feet = 0.026\ MTOE$$

Therefore, the total natural gas consumption in the UAE in 2011 was (www.eia.gov)

$$0.026 * 2221 = 57.746\ MTOE/year$$

And we know

$$1\ MTOE = 11{,}630\ GWh$$

Therefore the total natural gas consumption in the UAE in 2011 was

$$\mathbf{11,630 * 57.746 = 671,585.98\ GWh/year}$$

b) *What was the total annual CO2 emissions (in kg) from natural gas consumption in 2011? Base your answer on 1a. findings. Hint: Assume complete combustion.*

Solution:

From the www.eia.gov website, the total annual CO2 emissions from Natural gas consumption in the year 2011 for the UAE were 149.710 million metric tonnes.

$$\mathbf{CO2\ emissions_{2011} = 149.71 * 10^9 kg}$$

c) *How much CO2 do we save in total by installing a solar system that will generate (throughout its lifetime) energy equal to 15% of natural gas secondary (useful) consumption in 2011? What is the size (in mW) of such a plant?*
Assumptions:
Solar power obtains 1700 full load hours in the UAE
The fossil fuel conversion efficiency is 40%
Grid Transmission efficiency is 92%
Lifetime is 25 years
It is possible to convert any and all fossil fuel used to electricity instantaneously

Solution:

We can use the following equation to calculate the size of the solar power plant:

$$Solar\ Power * 0.92 * Lifetime * 1700 = 15\%\ of\ Natural\ gas\ consumption * 0.4$$

15% of the natural gas consumption in the year 2011=
$0.15 * 671585 * 0.4 = 40295.1\ GWh$

$$Solar\ Power = \frac{40295.1}{0.92 * 25 * 1700} = 1{,}030{,}565\ kW = 1030.565\ MW$$

$EROEI\ (Energy\ returned\ on\ energy\ invested) = \frac{Net\ Energy+1}{Energy\ Expended}$ (www.wikipedia.org)

Net Energy=15% of Natural gas consumption=100,737.75 GWh

Therefore, energy expended=5301.987 GWh

Primary Energy=energy expended/conversion efficiency

=13254.97 GWh=13254.97*10^6 KWh

CO2 emissions from natural gas per kWh=0.553kg
(http://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11)

Therefore the amount of CO2 emitted = 7,329.998*10^6 kg

CO2 from 15% of the natural gas consumption=55707.976*10^6 kg

$$\boldsymbol{CO_2\ Emissions\ saved = 48377.978 * 10^6\ kg}$$

Question 2 (Economic Analysis)

Solution:

In Attached Excel Workbook

Question 3 (Vehicle Kinetics, CO2 and Renewable Energy)

a) *Based on the principles of vehicle kinetics, estimate the propulsion power required (in Watt) for an average SEDAN (Toyota Camry VX50 type, gasoline). Use the following assumptions:*
   - *Average car speed: 100 km/h = 27.778 m/s.*
   - *80km trip.*
   - *Effective aerodynamic cross sectional area = 2.45 m^2.*

- *Air density =1.2 kg/m^3.*
- *Drag coefficient = 0.28.*
- *Rolling resistance coefficient = 0.01.*
- *Total vehicle mass: 1440 (vehicle) + 70 (passenger) + 40 (fuel) kg.*

Solution:

The mechanical propulsion power required can be obtained from the following equation:

$$P_v = mechanical\ power + aerodynamic\ drag + rolling\ resistance$$

$$P_v = \frac{m_v \cdot u^3}{2 \cdot d} + \frac{1}{2} \cdot \rho_{air} \cdot A \cdot c_d \cdot u^3 + m_v \cdot g \cdot c_{rr} \cdot u$$

$$P_v = \frac{1550 \cdot 27.778^3}{2 \cdot 80000} + \frac{1}{2} \cdot 1.2 \cdot 2.45 \cdot 0.28 \cdot 27.778^3 + 1550 \ \cdot 9.79 \cdot 0.01 \cdot 27.778$$

$$Pv = 207.64 + 8822.02 + 4215.14$$

$$\boldsymbol{P_v = 13244.8W}$$

b) *For the CV in a), calculate the amount of energy (in MWh) required for travelling an average total distance of 36000 km/year (considering all efficiencies).*

Solution:

If the internal combustion engine efficiency is assumed to be 25%:

Average travelling time = distance/average speed = 36000/100 = 360 hours

The total annual amount of energy required for a single CV operation = power/motor efficiency*average travelling time = 13.2448/0.25*360

$$\boldsymbol{E_T = \ 19.073\ MWh}$$

c) *Calculate annual energy required (in MWh) for 500,000 vehicles registered in Abu Dhabi and estimate the corresponding CO2 emissions (in kg) caused by the vehicle activity.*

Solution:

The total annual amount of thermal energy needed for all CV's operation = 19.073*500,000=9,536,500 MWh.

Using the gross heat of combustion of one cubic meter of gasoline to be 12.26kWh/kg (http://wogone.com/science/the_energy_and_fuel_data_sheet.pdf)

1kg of gasoline = 12.26kwh

777,854,812.4kg of gasoline = 9,536,500 MWh

The chemical equation of gasoline combustion is $CH_2 + \frac{3}{2}O_2 \rightarrow CO_2 + H_2O$ (Tester, Drake, Driscoll, Golay, Peters, Sustainable Energy: Choosing Among Options Chapter 7:pg.316).

(The molar mass of CH_2=12+2=14g/mol, the molar mass of CO_2=12+16+16=44 g/mol)

$$14g\ CH_2 \rightarrow 44g\ CO_2$$

$$\mathbf{777{,}854{,}812.4\ kg\ CH_2 \rightarrow 2{,}444{,}686{,}553\ kg\ CO_2}$$

d) *What is the rate of solar power installations that the UAE would have needed to install per year for the next 5 years so that the CO2 emissions from the CVs are kept constant – at the level of 50% less than now? Assume that the number of CVs grows at a rate of 3% per year. Use the assumptions in 1.c.*

Solution:

The target CO2 emissions, 50% of now, is $\frac{1}{2} \cdot 2{,}444{,}686{,}553 = 1{,}222{,}343{,}277\ kg/year$

In 5 years' time the CO2 emissions of cars in Abu Dhabi would have increased to

$$2{,}444{,}686{,}553 * 1.03^5 = 2{,}834{,}061{,}741\frac{kg}{year}$$

Making the amount of CO2 that needs to be reduced

$$2{,}834{,}061{,}741 - 1{,}222{,}343{,}277 = 1{,}611{,}718{,}464$$

This means that $1{,}611{,}718{,}464 * \frac{14}{44} = 512{,}819{,}511.3\ kg$ of gasoline needs to be reduced.

This amount of gasoline equates to
$512{,}819{,}511.3\ kg\ gasoline * \frac{12.26kWh}{kg} = 6{,}287{,}167.21\ MWh$ that needs to be installed over 5 years.

The average number of hours of full load sunlight in a year in the UAE is 1700.

That means that $6{,}287{,}167.21 \div 1700 = 3{,}698.34\ MW$ need to be installed over the next 5 years.

The yearly capacity that needs to be installed is $\mathbf{3,698.67 \div 5 = 739.67}\ \boldsymbol{MW}$