UCC501 Homework 2 Solutions

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1 Energy Scales, CO2 Emissions and Renewables

1.1 Energy Scales

- Natural gas consumption year 2012: in Billion Cubic Feet: 2235.169.
- For natural gases btu we have

$$1cf \rightarrow 1027Btu \tag{1}$$

source: http://www.aga.org/KC/ABOUTNATURALGAS/ADDITIONAL/Pages/HowtoMeasureNaturalGas.aspx, use MATLAB to convert units, we have

$$2012\ Yearly\ btu\ =\ 2235.169 * 10^9 * 1027 \tag{2}$$

Evaluate the equation we get $2.2955 * 10^{15}\ Btu$, divided by millions we get $2.2955 * 10^9\ MBtu$.

- From this unit conversion site http://www.eia.gov/cfapps/ipdbproject/docs/units.cfm we have

$$MTOE\ =\ MBtu * 0.02520 * 10^{-6} \tag{3}$$

Evaluate the above equation we have $57.8471 MTOE$

- Similarly we have $1MBtu = 1.05506 * 10^9 Joules$ and $1KWh = 3.6 * 10^6 Joules$, thus

  $$2012\ Yearly\ GKWh = 2.2955*10^9*1.05506*10^9/(3.6*10^6*10^9) \quad (4)$$

  Evaluate the above equation we have $672.7527\ GKWh$

1.2 CO2 Emissions

- Assume complete combustion, we have $2235.169\ Bcf$ natural gas burned in UAE for year 2012. Assume under normal temperature and pressure the natural gas is measured, we google the bold texts **natural gas density** and get the following:

  ```
  Density
  0.656 g/L at 25 C, 1 atm; 0.716 g/L at 0 C, 1 atm;
  0.42262 g cm3; (at 111 K)
  ```

  Since we assume normal density, we use $\rho = 0.656g/L = 656kg/m^3$. Thus we have the total mass of CO2 burned in year 2012

  $$Mass\ of\ CH_4 = 4.1525 * 10^{13}kg \quad (5)$$

  Since the background is complete combustion, from chemistry we have

  $$CH_4 + 2O_2 = CO_2 + 2H_2O \quad (6)$$

  and introduce a concept from chemistry, **molecular weight** we have

  $$Mass\ of\ CO_2 = m_{CH_4} * \frac{M_{CO_2}}{M_{CH_4}} \quad (7)$$

  where m_{CH_4} is the mass, the M_{CH_4} is the molecular weight. This equation is deducted by **carbon equilibrium** under complete combustion. Evaluate equation (7) we have $m_{CO_2} = 1.1419 * 10^{14}kg$

1.3 Renewables

Since we mentioned **in total** in the question, my answer would follow the *total* CO2 generated by burning natural gas.

Thus $m1_{co_2} = 0.05*m_{CO_2}$, evaluating it we have $m1_{co_2} = 5.7097*10^{12}kg$.

- Set the size of such solar plant is $x\ MW$, then from **Energy Conservation Law** we have

$$Energy_{solar} \;=\; Energy_{gas\ useful} * 0.05 \tag{8}$$

- For energy generated by a solar plant's lifetime, we have

$$E_{solar} \;=\; x * 3.6 * 10^9 * 1700 * 25 \tag{9}$$

- For energy generated by burning natural gas, we have the secondary energy as follows:

$$E_{gas_useful} \;=\; E_{gas} * 0.40 * 0.92 \tag{10}$$

  The E_{gas} can be calculated and/or converted from the above. Because we get 2012 yearly gas btu $2.2955 * 10^{15}$, convert that to Joule unit

$$E_{gas} \;=\; 2.2955 * 10^9 * 1.05506 * 10^9 \tag{11}$$

  Put all these values into (8) we have $x \;=\; 291.2624$. Thus the size of such a plant is $291.2624 \simeq 300\ MW$. (I put 300MW here for *industrial term*.)

2 Economic Analysis

2.1 LCOE Calculation

From section 1 we have the scale of solar farm is close to 300MW. So to be practical we here use `Scale = 300MW`.

- The whole calculation is done through MATLAB programming, therefore, to save pages, we do not repeat the values. We list relevant equations here.

-

$$Total\ Capital\ Cost \;=\; Unit\ Capital\ Cost * Solar\ Farm\ Scale \tag{12}$$

- From the values we have, we can use WACC as a **pretty rough** estimation of **project annual discount rate**. It is also listed in the UAE bureau of statistics the expected CPI of next 5 years, we would like to do another estimate adding this value, if possible.

$$WACC \; = \; (debt\ return * debt\ ratio) + (equity\ return * equity\ ratio) \tag{13}$$

- The remaining part of question is self-evident in the codes as can be seen in the reference link. Following the program, we have

$$Levelized\ cost \; = \; 0.2145\ \$/KWh \tag{14}$$

2.2 IRR Calculation

- IRR means the discount rate which balances income and outcome. In **Financial Toolbox**[1] of MATLAB, there is the irr function provided.

- Following the codes implemented in MATLAB in `internal_rr.m` we have $IRR \; = \; 0.13$.

3 Vehicle Kinetics

3.1 Propulsion Power

- From the question we have all the values needed, so just evaluate the equation we have $P_v \; = \; 6.2321 * 10^3\ W$. The whole calculation code is shown in reference as well as the link.

3.2 Annual Vehicle Energy Consumption

- For this question I tried to replace the d (distance between stops) with $40,000\ Km$ but it did not work out as expected. Therefore we need to consider this problem in a *macro* scale.

- Since the given mass is $1440Kg$ we can infer that the type of engine is a $2.5L$ one. From the manual and Wikipedia[2] we have the combined fuel

[1] `http://www.mathworks.com/help/finance/irr.html`
[2] `http://en.wikipedia.org/wiki/Toyota_Camry_(XV50)`

consumption of around $8L/100Km$. Moreover, we can get the standard reference density of marketable gasoline $0.755Kg/L$.

- The rest part is and only is calculation, and that is reflected in the source code.

3.3 Abu Dhabi Car Annual

- The data used in this question can be referred from heat of combustion Wikipedia[3]. We use $47.30MJ/Kg$ for gasoline heating value.
- The process of calculation is a bit tedious but self-evident in codes, we can get $1.9046 * 10^7 MWh$ energy requirement for an estimated 600,000 registered cars in Abu Dhabi. The figure is also calculated under full conversion efficiency.
- For CO_2 emissions, we get $4.5236 * 10^9 Kg$.

3.4 Panel Installment

- According to all the assumptions and calculations above, we get the annual installment of solar power, in MWh is $1.1204 * 10^3 MWh$

4 Reference

All codes are in the **public domain**, which means they can be found at `https://github.com/ProfessorX/UCC501/tree/master/Labs/Homework2`

4.1 calc.m

```
% UCC501 HW2 Calc

%% BTU
NG_cf = 2235.169 * 1e9
NG_btu = NG_cf * 1027
NG_mbtu = NG_btu * 1e-6

```

[3] `http://en.wikipedia.org/wiki/Heat_of_combustion`

```
%% TOE
NG_toe = NG_mbtu * 0.02520
NG_mtoe = NG_toe * 1e-6

%% GKWh
NG_GKwh = NG_mbtu * 1.05506 *1e9 / (3.6*1e6 * 1e9)
% GKwh = MBtu * 0.94782*1e9 / (3.6*1e6 * 1e9) wrong

% just run the above scripts in MATLAB

%% CH4 mass
NG_cm3 = NG_cf * 0.02832
rho = 656
NG_mass = NG_cm3 * rho
CO2_mass = NG_mass * 44 / 16

%% Renewables
ene_gas = NG_mbtu * 1.05506 * 1e9
ene_gas_useful = ene_gas * 0.40 * 0.92
ene_gas_useful_to_solar = ene_gas_useful * 0.05
ene_solar = ene_gas_useful_to_solar / (3.6 * 1e9 * 1700 * 25)
```

4.2 economic_analysis.m

```
%% Levelized cost of energy

% Housekeeping
solar_scale = 300 * 1e3  % in KW
cost_unit_capital = 2700  % in dollars/Kilowatt
debt_return = 0.03
debt_ratio = 0.7
equity_return = 0.15
equity_ratio = 0.3

const_year = 1
oper_year = 25
n = const_year + oper_year

annu_maintain_rate = 0.05
land_unit_scale = 7.9  % this is is per MW
```

```
acre_to_hec = 0.404686
land_unit_compen = 1800  % this is in year

% Yet more housekeeping
% annu_hour = 365 * 24  % assume regular 365 days/year
annu_hour = 1700


%% The battle begins
total_capital_solar = solar_scale * cost_unit_capital  % in dollars
discount_wacc = debt_return*debt_ratio + equity_return*equity_ratio
alpha = 1 / (1 + discount_wacc)

solar_land_area = land_unit_scale * 300  % acres and MW
annu_land_compen = solar_land_area * 1800 * acre_to_hec

%% Time to tariff
unit_tariff = 0.3
annu_tariff = unit_tariff * annu_hour * solar_scale

%% TOTO or Total
total_capital = [total_capital_solar, zeros(1, 25)]
total_maintain =
[0, annu_maintain_rate*total_capital_solar .* ones(1, ...
                                                  25)]
total_land = annu_land_compen .* ones(1, 26)
total_tariff = [0, annu_tariff .* ones(1, 25)]

%% Level, Angel or Demon
total_cost = total_capital +total_land + total_maintain
npv_cost = total_cost .* npv_series
annu_work = solar_scale * annu_hour  % in KWh
total_work = [0, annu_work * ones(1, 25)]
npv_work = total_work .* npv_series

levelized_cost = sum(npv_cost) / sum(npv_work)

% Net return
total_net_return =
total_tariff - (total_capital + total_land + total_maintain)
```

```

irr(total_net_return)  % this requires Finance toolbox
```

4.3 vehicle_power.m

```

%% Parameters
velocity = 20
d_trip  = 180 * 10^3
rho_air = 1.2
aero_area = 2.45
co_drag = 0.28
mass_vehicle = 1550
gravity = 9.79
co_rolling = 0.01

% Yet more housekeeping


%% 180Km Propulsion power
power_trip = (mass_vehicle * velocity^3)/(2 * d_trip) + 0.5 * rho_air ...
    * aero_area * co_drag * velocity^3 + mass_vehicle * gravity * ...
    co_rolling * velocity


%% Annual Traveler
d_annual = 40 * 1e3 * 1e3  % in meters
time_annual = 40 * 1e3 / 72 % in hours
% This part is not valid
% $$$ power_annual = (mass_vehicle * velocity^3)/(2 * d_annual) + 0.5 * ...
% $$$     rho_air * aero_area * co_drag * velocity^3 + mass_vehicle * ...
% $$$     gravity * co_rolling * velocity
unit_fuel_con = 0.08  % in L/Km
rho_petrol = 0.755  % Kg/L
cars_abud = 600000

fuel_volume_annu = d_annual * 1e-3 * unit_fuel_con   % convert d_annu to
                                             % Km, result in Litre
fuel_mass_annu = rho_petrol * fuel_volume_annu
heat_petrol_unit = 47.30 * 1e6  % MJ/Kg
```

```
heat_petrol_annu = fuel_mass_annu * heat_petrol_unit  % in
                                                      % Joules per car
energy_petrol_annu = heat_petrol_annu / (3.6 * 1e6 * 1e3) % in MWh


%% Year by year
mass_petrol_carbon = (12 / 14.1) * fuel_mass_annu
mass_carbon_dio = (44 / 12) * mass_petrol_carbon  % Carbon
                                                  % Equilibrium
energy_vehicle_abud = energy_petrol_annu * cars_abud  % in MWh
mass_carbon_dio_abud = mass_carbon_dio * cars_abud  % in Kg
%% How much solar must a man consume?
% Yet more and more housekeeping
solar_flh_uae = 1700

energy_solar_five = 0.5 * energy_vehicle_abud
energy_solar_annu = energy_solar_five / 5
power_solar_annu = energy_solar_annu / solar_flh_uae  % for power,
                                                      % we mean Watts
```