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

$$Levelized\ cost = 0.0412\ \$/KWh \tag{14}$$

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 eco_ana.m

```
%% Levelized cost of energy

% Housekeeping
solar_scale = 300 * 1e3
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

% Life is fucking awesome in AE
total_capital_solar = solar_scale * cost_unit_capital
discount_wacc = debt_return*debt_ratio + equity_return*equity_ratio
alpha = 1 / (1 + discount_wacc)

% npv series (for the rate) = sum (a+a^2+a^3+...+a^26)
npv_rate_series = (alpha * (1-alpha^n))/(1-alpha) % This is the
                                                  % summing up, you
                                                  % ESM people!
npv_total_capital = total_capital_solar / npv_rate_series % This
                                                          % turned
                                                          % out to
                                                          % be annual
annu_maintain_cost = annu_maintain_rate * total_capital_solar
total_maintain_cost = annu_maintain_cost * 26  % this may be 25,
                                               % then we need to
                                               % re-cal npv series
                                               % for it.
npv_total_maintain = total_maintain_cost / npv_rate_series

solar_land_area = land_unit_scale * 300  % acres and MW
annu_land_compen = solar_land_area * 1800 * acre_to_hec
total_land_compen = annu_land_compen * 26
npv_total_land = total_land_compen / npv_rate_series

%% Time to pay
annu_all_cost = npv_total_capital + annu_maintain_cost + ...
    annu_land_compen
levelized_cost = annu_all_cost / (annu_hour * solar_scale)

% rate_discount = 1/1.066
% series_rate_dr =
(rate_discount * (1 - rate_discount^26)) / (1 - rate_discount)
```

4.3 internal_rr.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)]

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

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

4.4 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
```