

UCC501 Homework 2 Solutions

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October 15, 2014

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

$$1cf \rightarrow 1027Btu \quad (1)$$

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

$$2012 \text{ Yearly } btu = 2235.169 * 10^9 * 1027 \quad (2)$$

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

$$MTOE = MBtu * 0.02520 * 10^{-6} \quad (3)$$

Evaluate the above equation we have $57.8471MTOE$

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

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

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

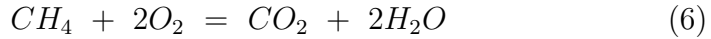
0.656 g/L at 25 C , 1 atm ; 0.716 g/L at 0 C , 1 atm ;

0.42262 g cm^3 ; (at 111 K)

Since we assume normal density, we use $\rho = 0.656 \text{ g/L} = 656 \text{ kg/m}^3$. Thus we have the total mass of CO_2 burned in year 2012

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

Since the background is complete combustion, from chemistry we have



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

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

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 $m_{CO_2} = 1.1419 * 10^{14} \text{ kg}$

1.3 Renewables

Since we mentioned **in total** in the question, my answer would follow the *total* CO_2 generated by burning natural gas.

Thus $m_{1_{CO_2}} = 0.05 * m_{CO_2}$, evaluating it we have $m_{1_{CO_2}} = 5.7097 * 10^{12} \text{ kg}$.

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

$$Energy_{solar} = Energy_{gas\ useful} * 0.05 \quad (8)$$

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

$$E_{solar} = x * 3.6 * 10^9 * 1700 * 25 \quad (9)$$

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

$$E_{gas\ useful} = E_{gas} * 0.40 * 0.92 \quad (10)$$

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

$$E_{gas} = 2.2955 * 10^9 * 1.05506 * 10^9 \quad (11)$$

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.
-

$$Total\ Capital\ Cost = Unit\ Capital\ Cost * Solar\ Farm\ Scale \quad (12)$$

- 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.

$$WACC = (debt\ return * debt\ ratio) + (equity\ return * equity\ ratio) \quad (13)$$

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

$$Levelized\ cost = 0.2145\ \$/KWh \quad (14)$$

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 1440 Kg we can infer that the type of engine is a 2.5 L one. From the manual and Wikipedia² we have the combined fuel

¹<http://www.mathworks.com/help/finance/irr.html>

²[http://en.wikipedia.org/wiki/Toyota_Camry_\(XV50\)](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 Wikipedia³. 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

```
1 % UCC501 HW2 Calc
2
3 %% BTU
4 NG_cf = 2235.169 * 1e9
5 NG_btu = NG_cf * 1027
6 NG_mbtu = NG_btu * 1e-6
7
```

³http://en.wikipedia.org/wiki/Heat_of_combustion

```

8 %% TOE
9 NG_toe = NG_mbtu * 0.02520
10 NG_mtoe = NG_toe * 1e-6
11
12 %% GKWh
13 NG_GKWh = NG_mbtu * 1.05506 * 1e9 / (3.6*1e6 * 1e9)
14 % GKWh = MBtu * 0.94782*1e9 / (3.6*1e6 * 1e9) wrong
15
16 % just run the above scripts in MATLAB
17
18 %% CH4 mass
19 NG_cm3 = NG_cf * 0.02832
20 rho = 656
21 NG_mass = NG_cm3 * rho
22 CO2_mass = NG_mass * 44 / 16
23
24 %% Renewables
25 ene_gas = NG_mbtu * 1.05506 * 1e9
26 ene_gas_useful = ene_gas * 0.40 * 0.92
27 ene_gas_useful_to_solar = ene_gas_useful * 0.05
28 ene_solar = ene_gas_useful_to_solar / (3.6 * 1e9 * 1700 * 25)

```

4.2 economic_analysis.m

```

1 %% Levelized cost of energy
2
3 % Housekeeping
4 solar_scale = 300 * 1e3 % in KW
5 cost_unit_capital = 2700 % in dollars/Kilowatt
6 debt_return = 0.03
7 debt_ratio = 0.7
8 equity_return = 0.15
9 equity_ratio = 0.3
10
11 const_year = 1
12 oper_year = 25
13 n = const_year + oper_year
14
15 annu_maintain_rate = 0.05
16 land_unit_scale = 7.9 % this is is per MW

```

```

17 acre_to_hect = 0.404686
18 land_unit_compen = 1800 % this is in year
19
20 % Yet more housekeeping
21 % annu_hour = 365 * 24 % assume regular 365 days/year
22 annu_hour = 1700
23
24
25 %% The battle begins
26 total_capital_solar = solar_scale * cost_unit_capital % in dollars
27 discount_wacc = debt_return*debt_ratio + equity_return*equity_ratio
28 alpha = 1 / (1 + discount_wacc)
29
30 solar_land_area = land_unit_scale * 300 % acres and MW
31 annu_land_compen = solar_land_area * 1800 * acre_to_hect
32
33 %% Time to tariff
34 unit_tariff = 0.3
35 annu_tariff = unit_tariff * annu_hour * solar_scale
36
37 %% TOTO or Total
38 total_capital = [total_capital_solar, zeros(1, 25)]
39 total_maintain =
40 [0, annu_maintain_rate*total_capital_solar .* ones(1, ...
41                                     25)]
42 total_land = annu_land_compen .* ones(1, 26)
43 total_tariff = [0, annu_tariff .* ones(1, 25)]
44
45 %% Level, Angel or Demon
46 total_cost = total_capital + total_land + total_maintain
47 npv_cost = total_cost .* npv_series
48 annu_work = solar_scale * annu_hour % in KWh
49 total_work = [0, annu_work * ones(1, 25)]
50 npv_work = total_work .* npv_series
51
52 levelized_cost = sum(npv_cost) / sum(npv_work)
53
54 % Net return
55 total_net_return =
56 total_tariff - (total_capital + total_land + total_maintain)

```

```

57
58 irr(total_net_return) % this requires Finance toolbox

```

4.3 vehicle_power.m

```

1
2 %% Parameters
3 velocity = 20
4 d_trip = 180 * 10^3
5 rho_air = 1.2
6 aero_area = 2.45
7 co_drag = 0.28
8 mass_vehicle = 1550
9 gravity = 9.79
10 co_rolling = 0.01
11
12 % Yet more housekeeping
13
14
15 %% 180Km Propulsion power
16 power_trip = (mass_vehicle * velocity^3)/(2 * d_trip) + 0.5 * rho_air ...
17     * aero_area * co_drag * velocity^3 + mass_vehicle * gravity * ...
18     co_rolling * velocity
19
20
21 %% Annual Traveler
22 d_annual = 40 * 1e3 * 1e3 % in meters
23 time_annual = 40 * 1e3 / 72 % in hours
24 % This part is not valid
25 % $$$ power_annual = (mass_vehicle * velocity^3)/(2 * d_annual) + 0.5 * .
26 % $$$     rho_air * aero_area * co_drag * velocity^3 + mass_vehicle * ..
27 % $$$     gravity * co_rolling * velocity
28 unit_fuel_con = 0.08 % in L/Km
29 rho_petrol = 0.755 % Kg/L
30 cars_abud = 600000
31
32 fuel_volume_annu = d_annual * 1e-3 * unit_fuel_con % convert d_annu to
33 % Km, result in Litre
34 fuel_mass_annu = rho_petrol * fuel_volume_annu
35 heat_petrol_unit = 47.30 * 1e6 % MJ/Kg

```



```

36 heat_petrol_annu = fuel_mass_annu * heat_petrol_unit % in
37 % Joules per car
38 energy_petrol_annu = heat_petrol_annu / (3.6 * 1e6 * 1e3)
39 % in MWh
40
41 %% Year by year
42 mass_petrol_carbon = (12 / 14.1) * fuel_mass_annu
43 mass_carbon_dio = (44 / 12) * mass_petrol_carbon % Carbon
44 % Equilibrium
45 energy_vehicle_abud = energy_petrol_annu * cars_abud % in MWh
46 mass_carbon_dio_abud = mass_carbon_dio * cars_abud % in Kg
47 %% How much solar must a man consume?
48 % Yet more and more housekeeping
49 solar_flh_uae = 1700
50
51 energy_solar_five = 0.5 * energy_vehicle_abud
52 energy_solar_annu = energy_solar_five / 5
53 power_solar_annu = energy_solar_annu / solar_flh_uae % for power,
54 % we mean Watts

```