HW4

Energy Conversion & Supply

Q1.

Data:

Nameplate capacity	1711 MW
Capacity factor	0.636
Efficiency	0.37
Energy density of coal	28 GJ/tonne
Carbon emission	88.5 kg CO2/GJ
Plant Life	55 years
Forest sequestration rate	2 kg CO2/m2/yr

a.

i. To find area of forestation:

All calculations are done on per year basis

Electricity generated, $E = 1711 * 0.636 * 24 * 365 = 9.53 * 10^6 MWh$

Coal required, $C = \frac{E}{0.37} = 25.76 * 10^6 MWh$

$1MWh = 3.6\ GJ$[1]

Thus, $C = 92.75 * 10^6 GJ$

It is said that 1 GJ of coal emits 88.5 kg CO2

$$CO_2 = C * 88.5\ kg\frac{CO_2}{yr} = 8.208 * 10^9 kg\frac{CO_2}{yr}$$

Using this, to find the Area:

$$A = \frac{CO_2 emitted\ per\ year}{Carbon\ sequestration\ rate} = \frac{8.208 * 10^9 kg\frac{CO_2}{yr}}{2\ kg\frac{CO_2}{m^2 * yr}}$$

$$\boldsymbol{A = 4.104 * 10^9\ m^2 = 4104\ km^2}$$

ii.

Forest sequestration cost=$ 20-30/tonne

From i: $CO_2 = 8.208 * 10^9 kg\frac{CO_2}{yr}$

Range of cost of sequestration:

[1] http://www.kylesconverter.com/energy,-work,-and-heat/megawatt-hours-to-gigajoules

$$C_{min} = 20\frac{\$}{tonne} * 8.208 * 10^9 kg * \frac{1}{1000} * \frac{tonne}{kg} = 164.16\frac{million}{yr}$$

$$C_{min} = 30\frac{\$}{tonne} * 8.208 * 10^9 kg * \frac{1}{1000} * \frac{tonne}{kg} = 246.24\frac{million}{yr}$$

Range of annualized cost of forestation: 164.16-246.24 million $ per year

iii.

The additional cost of sequestration would lead to increase in the total annual cost of operation of the coal fired power plant. Due to this, in order to recover this cost, there would be an increase in the cost of electricity charged to the customer due to an increase in the operating cost (this cost of sequestration can be embedded in the operating cost).

The increase in the cost of electricity can be calculated as:

$$\Delta Cost_{min} = \frac{164.16*10^6\$}{9.53*10^9 kWh} = 0.017\frac{\$}{kWh}$$

$$\Delta Cost_{max} = \frac{246.24*10^6\$}{9.53*10^9 kWh} = 0.026\frac{\$}{kWh}$$

iv.

Cost of electricity = 0.06 $/kWh

Total cost of electricity, $CE = E * 0.06 = 9.53 * 10^9 kWh * 0.06\frac{\$}{kWh} = 571.8\, million\, \$$

$$\%change\ in\ LCOE = \frac{LCOE_f - LCOE_i}{LCOE_i} * 100$$

Where $LCOE_i: initial, LCOE_f = final$

Assuming that the total cost of electricity is the total annual cost

$$Total\ annual\ cost = CE = 571.8\, million$$

And $Total\ annual\ cost\ new = Total\ annual\ cost + Cost\ of\ sequestration\, per\ year$

<u>Minimum case:</u>

$$Total\ annual\ cost\ new = 571.8 + 164.16 = 735.96\, million$$

$$\%change = \frac{164.16}{571.8} * 100 = 28.71\%$$

<u>Maximum case:</u>

$$Total\ annual\ cost\ new = 571.8 + 246.24 = 818.04\, million$$

$$\%change = \frac{246.24}{571.8} * 100 = 43.06\ \%$$

Range of relative change in LCOE: 28.71 to 43.06 %

b.

i.

Assuming all CO2 is sequestered and generates methane at San Juan in the USA:

For San Juan: Ratio $(\frac{m^3}{tonne\ CO_2}) = 263$

Using this: From a.i, $CO_2 = 8.208 * 10^6 tonne \frac{CO_2}{year}$

Amount of CH_4= $8.208 * 10^6 tonne \frac{CO_2}{year} * 263 \frac{m^3}{tonne\ CO_2} = 2.16 * \frac{10^9 m^3 CH_4}{year}$

Further, Energy content of methane=35 MJ/m^3 and Price of methane=3 $/GJ

Energy content, $E_{CH_4} = 2.16 * \frac{10^9 m^3}{year} * 35 \frac{MJ}{m^3} = \mathbf{7.56} * \frac{\mathbf{10^{10} MJ}}{\mathbf{year}}$

Cost of CH_4, $C_{CH_4} = 7.56 * \frac{10^{10} MJ}{year} * 3 \frac{\$}{GJ} = \mathbf{226.8\ million} \frac{\$}{\mathbf{year}}$

ii.

$\%\ Change\ in\ LCOE = \frac{\Delta Cost}{original\ cost}$

Original cost=571.8 million

$\%change = \frac{-226.8\ million}{571.8\ million} * 100 = -\mathbf{39.66}\%$

iii.

Let x be the $ per tonne of carbon capture and storage

Thus, if the LCOE remains the same,

Total cost of carbon capture=Total cost from methane

$x * (8.208 * 10^6) = 226.8 * 10^6 \$$

$\boldsymbol{x} = \mathbf{27.63} \frac{\$}{\mathbf{tonne\ CO_2}}$

iv.

Let x be the $ per tonne of carbon capture and storage

LCOE is now the original one with forestation (upper limit).

$LCOE_i = \frac{818.04*10^6}{9.53*10^9} = 0.086$

$\Delta LCOE * (Total\ output) = Costof\ carbon\ capture - Cost\ of\ methane$

$(0.086 - 0.06) * 9.53 * 10^9 = x * (8.208 * 10^6) - 226.8 * 10^6$

$$\boldsymbol{x = 57.82 \frac{\$}{tonne\ CO_2}}$$