Renewables Homework 3

```python
import numpy as np
import units as u
import numpy as np
from IPython.display import display, Markdown, Latex
```

Chapter 6

6.2.

Under which, if either, condition is the lift-to-drag ratio of a wind turbine airfoil higher? At 10 m height where the air density is 1.23 kg/m3 and the wind speed is 5 m/s, or at 100 m height, where the air density is 1.21 kg/m3 and the wind speed is 9 m/s?

Also, under which condition is the lift greater? Assume the blade length is 60 m, the blade width is an average of 1 m, the drag coefficient is 0.01, and the lift coefficient is 1.0.

```python
def calc_lift_or_drag(C, rho, v, Af,):
    return C*rho*Af*v


C_lift = 1
C_drag = 0.01

rho_a = 1.23 * u.kg / u.m**3
v_a = 5 * u.m/ u.s

rho_b = 1.21 * u.kg / u.m**3
v_b = 8 * u.m/ u.s
```

```
blade_area = 60 * u.m * 1 * u.m


lift_a = calc_lift_or_drag(C=C_lift, rho=rho_a, v=v_a, Af=blade_area)
lift_b = calc_lift_or_drag(C=C_lift, rho=rho_b, v=v_b, Af=blade_area)

drag_a = calc_lift_or_drag(C=C_drag, rho=rho_a, v=v_a, Af=blade_area)
drag_b = calc_lift_or_drag(C=C_drag, rho=rho_a, v=v_a, Af=blade_area)

display(Markdown(f"""
For case A, the lift-to-drag ratio is {lift_a/drag_a:P~}, while for case B it is {np.round

In case A, the lift is {lift_a:P~}, but in case B it is {lift_b:P~}. Case B has the greate
"""))
```

For case A, the lift-to-drag ratio is 100.0, while for case B it is 157.0. Case B has the higher ratio.

In case A, the lift is 369.0 kg/s, but in case B it is 580.8 kg/s. Case B has the greater lift.

6.4.

If a wind turbine's blade diameter is 100 m, calculate the kinetic energy passing through the blade's swept area over 1 hour if the wind speed is 10 m/s. Assume the air density is 1.21 kg/m3. Also determine the power in the wind.

```
Dt = 100 * u.m
t = 1 * u.hour
v = 10 * u.m / u.s
rho = 1.21 * u.kg / u.m**3

x = v * t
At = np.pi * (0.5*Dt)**2 # A = pi * r^2
Ma = rho * At * x

KE = 0.5 * Ma * v**2

P = 0.5 * rho * At * v**3


display(Markdown(f"""
```

```
The kinetic energy is {KE.to("megajoules"):.2E~P}, and the power in the wind is {P.to("kil
"""))
```

The kinetic energy is 1.71E+04 MJ, and the power in the wind is 4.75E+03 kW.

6.5.

If the wind speed at 100 m height above the ground is 8 m/s and that at 10 m height is 5 m/s, calculate the power law coefficient for this profile. Using the coefficient, estimate the wind speed at 200 m above the ground.

```
# hello whats up
v100 = 8 * u.m / u.s
h100 = 100 * u.m

v10 = 5 * u.m / u.s
h10 = 10 * u.m

# v100 = v10 * (h100/h10)^alpha
# log10(v100/v10) = log10((h100/h10)^alpha) -->  h100/h10 = 10
# log10(v100/v10) = log10((10)^alpha)
# log10(v100/v10) = alpha

alpha = np.log10(v100/v10)

h200 = 200 * u.m
v200 = v10 * (h200/h10)**alpha

display(Markdown(f"""
Alpha is  {alpha:.2f~P}, and the wind speed at {h200:.0f~P} is {v200:.2f~P}.
"""))
```

Alpha is 0.20, and the wind speed at 200 m is 9.22 m/s.

6.9.

Using the empirical capacity factor equation, estimate the capacity factors of a 5-MW turbine with a 126-m blade diameter and of a 1.5-MW turbine with a 77-m blade diameter when the mean wind speed (assuming a Rayleigh distribution) is 8 m/s in both cases. What is the annual energy output in both cases (assuming a non-leap year)?

```
# no units, equation is not empirical

Vm = 8 # * u.m / u.s
st_year_hours = 8760 # * u.hour, standard year hours

# turbineA = {"Pr": 5000 * u.kilowatt, "D": 126 * u.m}
# turbineB = {"Pr": 1500 * u.kilowatt, "D": 77 * u.m}
turbineA = {"Pr": 5000 , "D": 126 }
turbineB = {"Pr": 1500, "D": 77 }

def calc_CF_and_energy(t, Vm=Vm, hours=st_year_hours):
    CF = 0.087 * Vm - (t["Pr"]/ t["D"]**2)
    Et = t["Pr"] * CF * hours * u.j
    return CF, Et.to("megajoule")

A = calc_CF_and_energy(turbineA)
B = calc_CF_and_energy(turbineB)


display(Markdown(f"""
For the 5-MW turbine, the capacity factor is   {A[0]:.2f}, and the annual energy output is

For the 1.5-MW turbine, the capacity factor is   {B[0]:.2f}, and the annual energy output
"""))
```

For the 5-MW turbine, the capacity factor is 0.38, and the annual energy output is 17 MJ.

For the 1.5-MW turbine, the capacity factor is 0.44, and the annual energy output is 6 MJ.

6.11.

Calculate the reduction in electricity generation that is possible in Haiti, without reducing end-use electricity availability, if the transmission and distribution loss is reduced by 5 percentage points from its 2014 value.

```
del_Ltd = 5 # percentage
Ltd = 60.1
del_Gelec = (100 * del_Ltd )/(100 - Ltd + del_Ltd)

display(Markdown(f"""
Haiti can reduce electricity generation by {del_Gelec:.2f}%  by reducing its transmission
"""))
```

Haiti can reduce electricity generation by 11.14% by reducing its transmission and distribution losses.

6.14.

Explain the difference between footprint and spacing of an energy technology. What are some of the uses of the spacing?

The footprint is the physical area on the topsoil or water that is touched by an energy technology. Spacing is the area that is essentially "in between" the energy technologies. For instance, wind turbines require a certain spacing for optimal energy production and to prevent harm to the surrounding locations and each other. Spacing can be used for agriculture, other energy technologies like solar arrays, or can exist as forests/open space.

6.16.

How many 5-MW onshore wind turbines with a rotor diameter of 126 m operating in a mean annual wind speed of 7.5 m/s are needed to power the U.S. on-road vehicle fleet consisting of battery-electric (BE) vehicles if the end-use energy required to run such a fleet is Ev = 1.15 × 1012 kWh/y (2017) and the plug-to-wheel efficiency of an electric vehicle is e = 0.85? Assume the system efficiency of each wind turbine is t = 0.9. Hint: First determine the total electrical energy required to run the fleet by dividing the end-use energy required to run vehicles by the plug-to-wheel efficiency.

```
# --- electric vehicle fleet
Ev = 1.15e12 * u.kwh / u.year # end use energy of battery electric vehicle fleet
eta_e = 0.85 # plug-to-wheel efficiency of an electric vehicle

Ev_total = (Ev/eta_e).to("megawatt * hour / year") * u.year
Ev_total_joules = (Ev_total).to("megajoule")

# -- wind turbines
# See function definition in problem 6.9. The turbine described here has the same characte
Vm2 = 7.5 # u.m / u.s
CF, Et = calc_CF_and_energy(turbineA, Vm=Vm2)

eta_t = 0.9 # turbine efficiency
Et_available = Et * eta_t

n_turbines = Ev_total_joules / Et_available
```

```
display(Markdown(f"""
Accounting for the plug-to-wheel efficiency of an electric vehicle, the total energy neede
"""))

display(Markdown(f"""
After accounting for the system efficiency of each turbine, the energy that will be availa
"""))
```

Accounting for the plug-to-wheel efficiency of an electric vehicle, the total energy needed to run the fleet will be 1.35E+09 MW · h per year, or 4.87E+12 MJ.

After accounting for the system efficiency of each turbine, the energy that will be availabe from each will be 1.33E+01 MJ per year. Dividing the total annual energy need of the electric vehicle fleet by the energy available from each turbine yields the number of turbines that will be needed: 3.66E+11.

Chapter 7

7.1.

Explain the difference between primary energy and end-use energy.

Primary energy is the energy released by breaking chemical bonds in raw fuels, or the solar/wind/geothermal that is naturally available as renewable energy. End-use energy is the energy consumed by various applications after primary energy has been converted, transmitted, and distribution losses have been accounted for.

7.4.

Identify four ways that electrifying all energy and providing the electricity with 100 percent wind, water, and solar reduces end-use power demand.

1. Electric vehicles are more efficient than combustion vehicles, so they need less energy to run.
2. In producing high temperature heat in industiral settings, electric appliances are also far more efficient than current combustion-based techniques, which decreases the end use demand.
3. End use demand is also decreased by using heat-pumps, which rely on heat transfer to create comforable infoor temperatures, rather than generating heat from fuel.
4. Using renewable sources eliminates the need for energy to mine, transport and process fossil fuels, which decreases end-use demand

7.10.

If a wind farm produces $50,000/y in annual revenue for 30 years, what is the present value of that income, assuming a private discount rate of 4 percent?

```
# present_val = future_val * (1/(1+r)^n)
future_val = 50_000
n = 30 # number of periods
r = 0.04 # discount rate
present_val = future_val * (1/(1+r)**n)
display(Markdown(f"""
The present value of the income is  ${present_val:.0f}.
"""))
```

The present value of the income is $15416.

7.11.

Estimate the cost per unit energy of a Pr = 5 MW nameplate capacity wind turbine with a capital cost of $1,200/kW, a capacity factor of CF = 34 percent, an O&M cost of $30/kW-y, and a lifetime of 30 years. Assume the discount rate is 3.5 percent, the construction time is 2 years, and the decommissioning cost is $13/kW. Also assume transmission, distribution, downtime, and array losses are 10 percent. Hint: Construct a table like Table 7.9.

```
Pr = 5000 # kw -> nameplate capacity
P_capital = 1200 # $/kw -> capital cost
CF = 30/100 # percent -> capacity factor
OandM = 10 # $/kW/year -> O+M cost
i = 3/100 # percent ->  private discount rate
T_construct = 1 # year -> construction time
F = 10 # $/kW -> decomissioning cost
losses = 10/100 # percent -> transmission, dist, and downtime losses
T_life = 30 # project lifetime

T_life_arr = np.arange(1, T_life+1)
i_factor = (1 + i )**(T_life_arr)
CRF =( i * i_factor ) / (i_factor  - 1 )

# print(CRF, T_life_arr, len(CRF))
```

```python
# energy available per year
Et = Pr * CF * st_year_hours * (1 - losses)

# presnet value of energy
Et_present = Et/i_factor

# costs
A_capital = P_capital * CRF
A_decom = (F/i_factor)* CRF
OM_cost = [0] + [OandM * Pr]*(T_life - 1)

costs = A_capital + A_decom + OM_cost

LCOE = (np.sum(costs/i_factor))/(np.sum(Et_present/i_factor))

display(Markdown(f"""
The levelized cost of energy is ${LCOE:.3f}.
"""))

# print(CRF, Et, LCOE)
```

The levelized cost of energy is \$0.006.

Chapter 8

8.4.

List four methods of changing the electric power system when instantaneous electric power generation plus storage cannot meet instantaneous demand during some times of the year.

1. Over-generation of energy
2. Energy storage
3. A highly interconnected grid enabling long-distance transmission
4. Demand-response

8.6.

Why should bundling of wind, solar, geothermal, and hydroelectric power significantly help to match power demand on the grid with power supply?

These renewable sources of energy often produce output at complementary times. For instance, the high pressure systems that occur when the sun is shining are often absent when the wind is blowing. Having a system where all sources are interconnected can smooth the supply curve, and ensure that when exess power is produced it can be stored.

8.7.

Calculate the number of heating degree days and cooling degree days over a four-day period relative to a reference temperature of 18 oC if the outdoor air temperatures on each day are −5ºC, 0ºC, 30ºC, and 35ºC, respectively.

```
temp1 = -5
temp2 = 0
temp3 = 30
temp4 = 35

ref = 18
hdds = (ref - temp1) + (ref - temp2)

cdds = (temp3 - ref) + (temp4 - ref)

display(Markdown(f"""
The number of heating degree days is {hdds:.0f}ºC and the number of cooling degree days is
"""))
```

The number of heating degree days is 41ºC and the number of cooling degree days is 29ºC.

8.10.

What WWS technologies can be used to perform regulation services?

Hydropwer, batteries, and storage from pumped hydropower, flywheel, compressed air, and gravitational storage with solid masses.

Chapter 9

9.1.

List four policy measures that could be implemented to encourage the expansion of WWS energy systems.

1. Renewable portfolio standards requiring certain fraction of ppwer generation to come from clean energy sources
2. Financial uncentives and laws for increasing energy efficiency and reducing energy use
3. Laws requiring demand response
4. Feed-in tariffs that cover the difference between electricity gemeration cost and wholesale electricity prices

9.2.

List four barriers that could slow the large-scale implementation of clean, renewable energy.

1. Long term vested interests from current energy infrastructure
2. Zoning issues
3. Countries engaged in conflict
4. Countireis with substantial poverty

9.3.

What fossil-fuel-based technologies will likely take the longest to transition to electricity or electrolytic-hydrogen alternatives?

Long haul airfraft will take the longest, estimated between between 2030 and 2040, to transition as fuel cell sizes and efficiencis will need to improve

9.4.

If the cumulative anthropogenic carbon emissions at the end of 2018 were 2,155 Gt-CO2, and the limit to avoid 1.5 oC global warming is 2,400 Gt-CO2, by what year will global warming reach 1.5 oC if the anthropogenic emission rate from fossil-fuel combustion, cement manufacturing, and land use change is 40 Gt-CO2/y?

```
co2_2018 = 2_155 # Gt-CO2
co2_lim = 2_400 # Gt-CO2 1.5ºC limit
em_rate = 40 # Gt-CO2 emitted / year

co2_remaining = co2_lim - co2_2018
years_remaining = co2_remaining/ em_rate
year_reached = years_remaining + 2018

display(Markdown(f"""
```

```
The world will reach the 1.5º global warming limit about {years_remaining:.3f} years from
""")
```

The world will reach the 1.5º global warming limit about 6.125 years from now, so in 2024.