Renewable Energy

ECE 111 Introduction to ECE

Jake Glower - Week #5

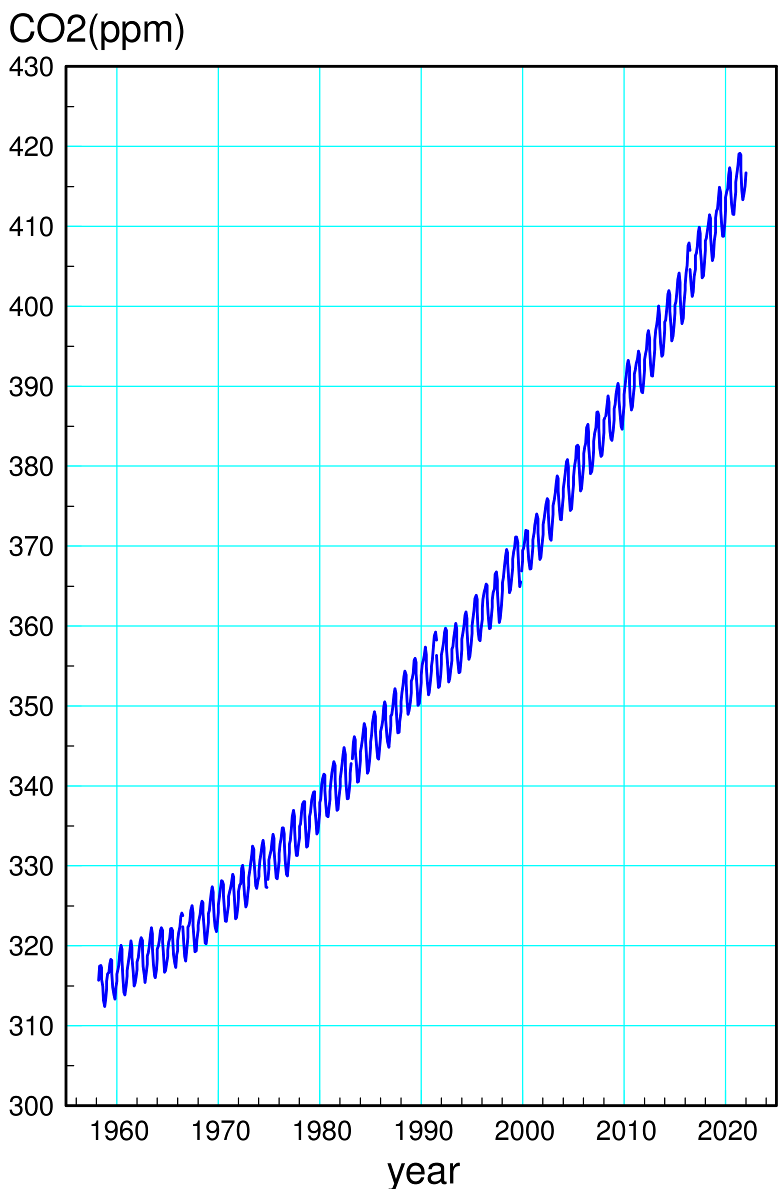
Please visit Bison Academy for corresponding lecture notes, homework sets, and solutions

Recap from Lecture #4:

- Global CO_2 levels are going up
- Global temperatures are going up
- The Arctic is melting

This has happened before

- The results were not good
- Permian Extinction:
  - Everything bigger than a mouse became extinct
  - Took 10 million years to recover
- Planet Venus:
  - Runaway global warming
  - Planet never recovered



Can anything be done?

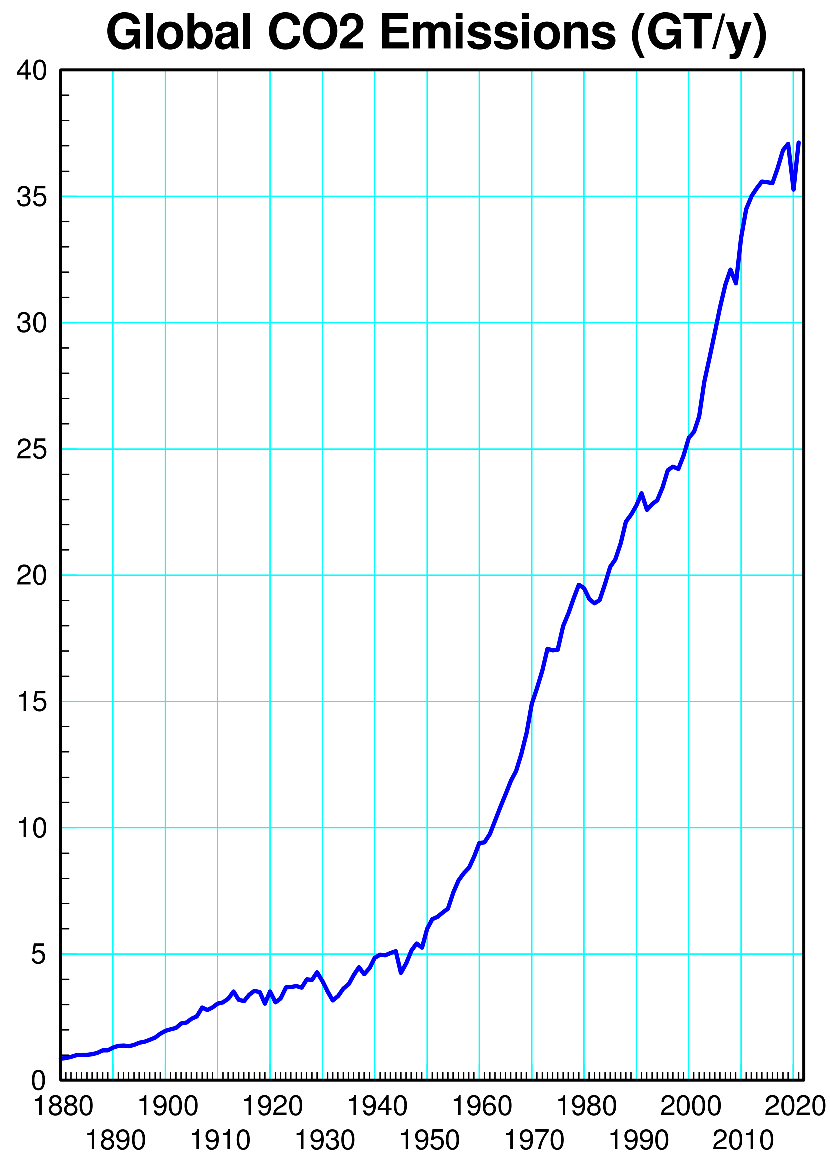
If the causes are not man-made

- We're hosed

If the causes are man-made

- We can do something about it

https://www.ourworldindata.org/co2-emissions
https://www.iea.org/data-and-statistics/charts/global-co2-emissions-from-energy-combustion-and-indistrial-processes-1900-2022

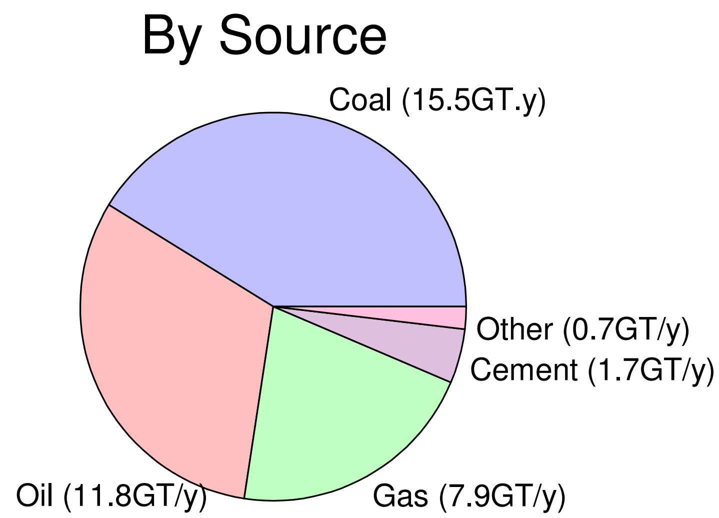


Sources of CO2 Emissions

2021: 37.12GT (world)

- Coal: 15.5GT (41.7% world total)
- Other: 0.7GT
- Cement: 1.7GT
- Gas: 7.9GT
- Oil: 11.8GT

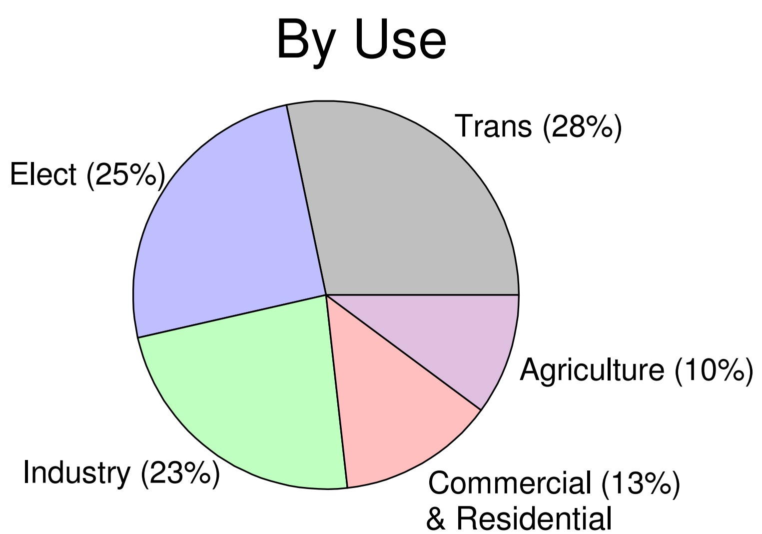
carbonbrief.org/analysis-global-co2-emissions-from-fossil-fuels-hit-record-high-in-2022/



2021: 6.340GT (USA)

- Agriculture: 10%
- Transportation: 28%
- Electric Power: 25%
- Industry: 23%
- Commercial & Residential: 13%

epa.gov/ghgemissions/sources-greenhouse-gas-emissions



How to Move Away from Fossile Fuels

Solar Energy

- Produce electricity using photovoltaic panels
- Also provides jobs for ECE majors

Wind Energy

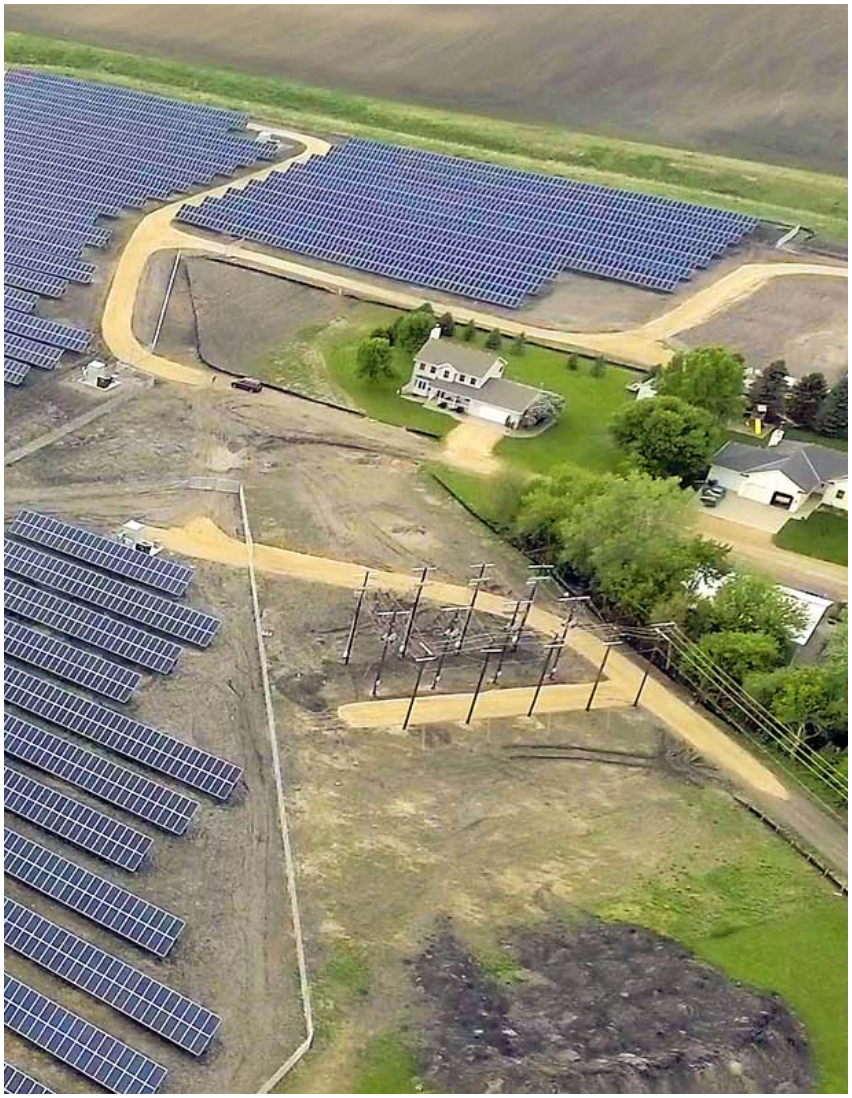
- Produce electricity using the wind
- Also provides jobs for ECE majors

Electric Vehicles

- Transportation without CO_2 emissions
- Also provides jobs for ECE majors

LED Light Bulbs

- Reduce electricity demand by 40%
- Also provides jobs for ECE majors



Why major in Electrical, Computer, or Software Engineering?

Make money

- Almost guaranteed entry into the middle class

Have a lot of fun building toys that

- Make people's lives better, and
- May save the planet

If you care about the planet and your kids and grandkids, ECE is a good major.

If you don't care about the planet, your kids, or your grandkids, ECE is still a good major.

In this lecture, we'll cover

- Determine the energy production of a solar panel
- Determine the energy production of a wind turbine
- Is solar energy good investment in Fargo from a purely financial standpoint?
  - Do residential solar panels pay for themselves in 7 years or less?
- Is wind energy good investment in Fargo from a purely financial standpoint?
  - Do industrial-size wind turbines pay for themselves in 7 years or less?

16kW Solar Energy in Fargo

- Is this a good investment?
- How long does it take for the solar panels to pay for itself?

Specifications:

- 16kW Solar Panel System
- $18,999 as of July 3, 2023

1.6kW-32kWatt Solar Panels DIY Grid Tie Kit with Microinverter & Racking System

Condition: New

System Power: 16KW

Quantity: 1 Last One

Price: US $18,999.00

$124.77 for 24 months with PayPal Credit*

Buy It Now

Add to cart

Add to watchlist

Questions:

- How much energy will it produce on an hourly basis for April 2023?
- What is the total amount of energy these will produce in kWh?,
- How many pounds of coal would this offset, and
- How long will you have to wait for these panels to pay for themselves assuming
    - You live in Moorhead Minnesota (and have net metering), or
    - You live in Fargo, North Dakota (and do not)

NDAWN

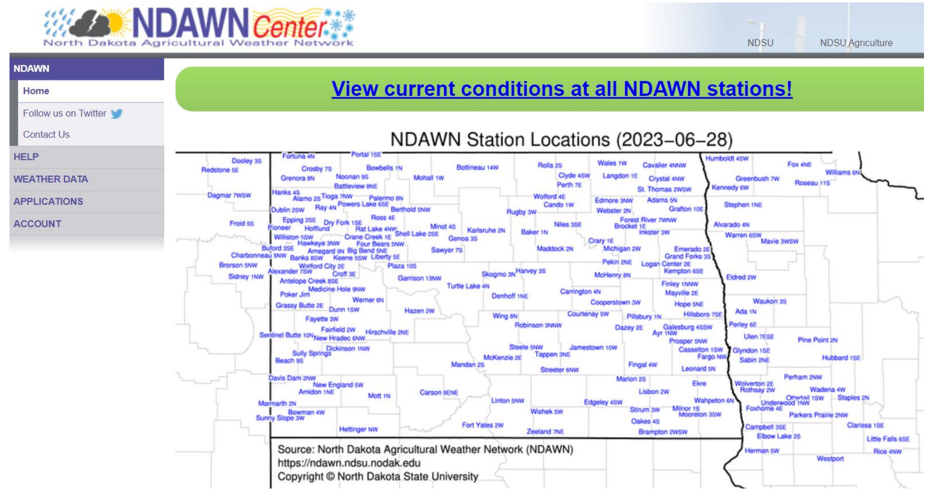
Go to the NDSU NDAWN web site:

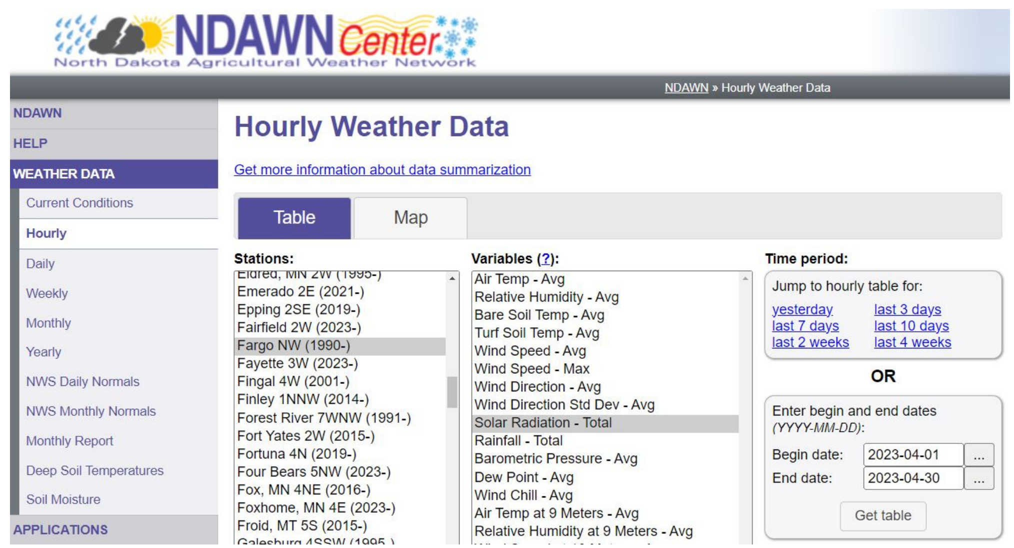
- https://ndawn.ndsu.nodak.edu/

Click on Weather Data, Hourly

Select Fargo North Dakota, Solar Radiation for April 2018

Select Metric





Open the CVS file

- Copy and paste into Matlab:

```
MJ = [          start of matrix
    paste your data here
       ];
end of matrix
```


NDAWN Center
North Dakota Agricultural Weather Network

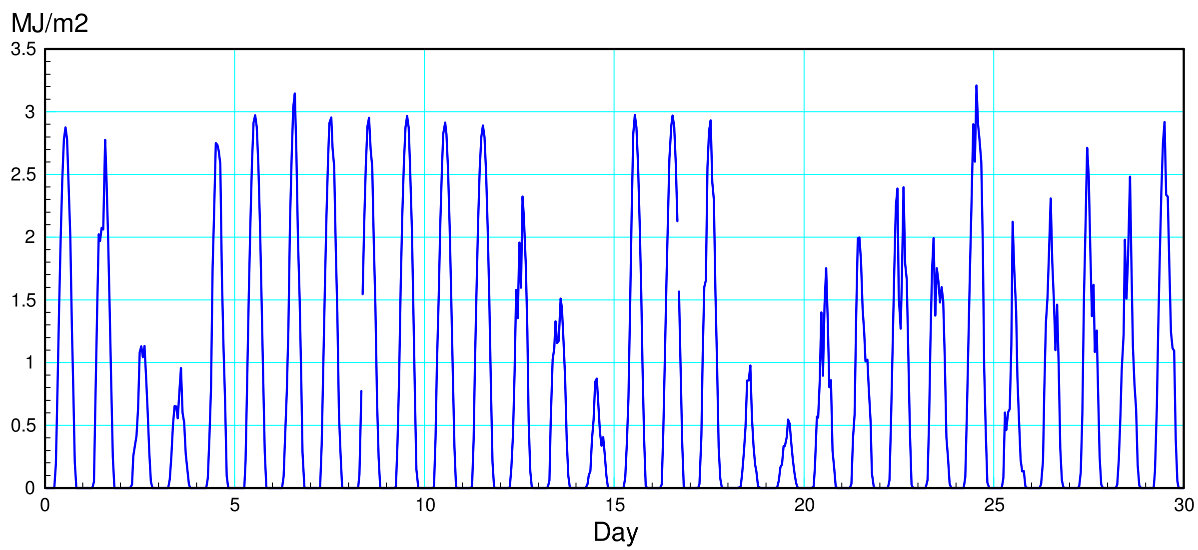
NDAWN » Hourly

NDAWN hourly data for April 1, 2023 to April 30, 2023

Key: E = Estimate; M = Missing; N/A = Not Available
Click on column headings for definition
Click on graph icon in column headings ( ) for graph

[English | Metric] Export CSV File
Print table
Switch station: Fargo NW (1990-)

Date	Hour (CST)	Fargo Total Solar Rad (MJ/m^2)
2023-04-01	100	0.0
2023-04-01	200	0.0
2023-04-01	300	0.0
2023-04-01	400	0.0



To convert to energy in kWh, you need to know

- The area of the solar panel,
- The efficiency of the solar cells, and
- The conversion from MJ to kWh

Assume 80 x 200W Ecoworthy solar panels to produce 16kW:

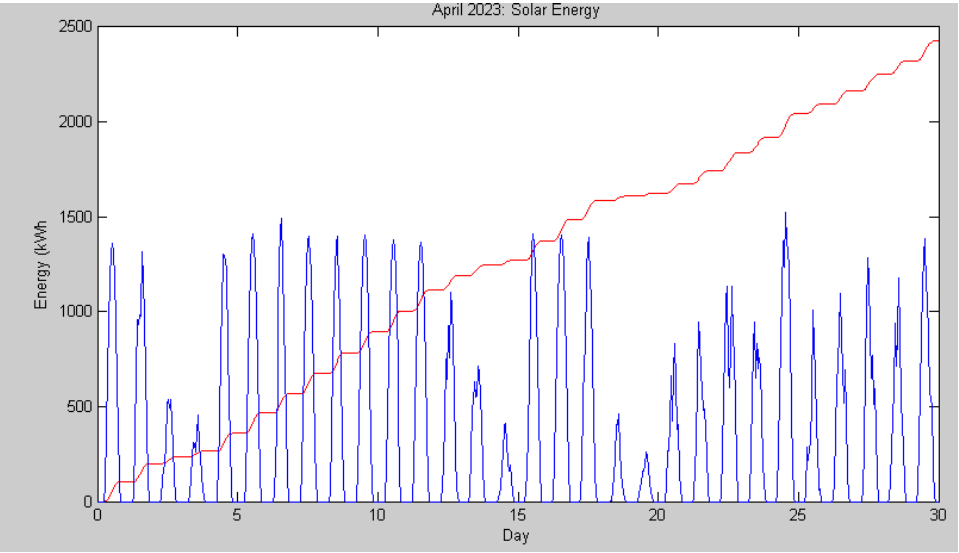
- Area = 80 x 1.480m x 0.670m = 79.328 m2
- Efficiency of solar cells = 21.5%
- 1MJ/m2 for one hour = 4.7376kWh

To convert from MJ per square meter for one hour to kWh, scale this data by

$$1\left(\frac{MJ}{m^2}\right)(79.328m^2)\left(\frac{kWh}{3.6MJ}\right)(0.215) = 4.7376kWh$$

Matlab Code

```
MJ = [          start of matrix
  paste the data here
          ];
 end of matrix

kWh = 3.167*MJ;

size(kW)

   720      1
there are 720 hours in April, 2018

hr = [1:720]';
kWh = Integrate(hr,kW);
plot(hr/24,kWh,'r',hr/24,kW*100,'b')
xlabel('Day');
ylabel('Energy (kWh');
title('April 2023: Solar Energy');

>> kWh = sum(kW)

    2428.1
```



Questions & Answers

What is the hourly energy production for these panels?

- See the blue line in the above figure.

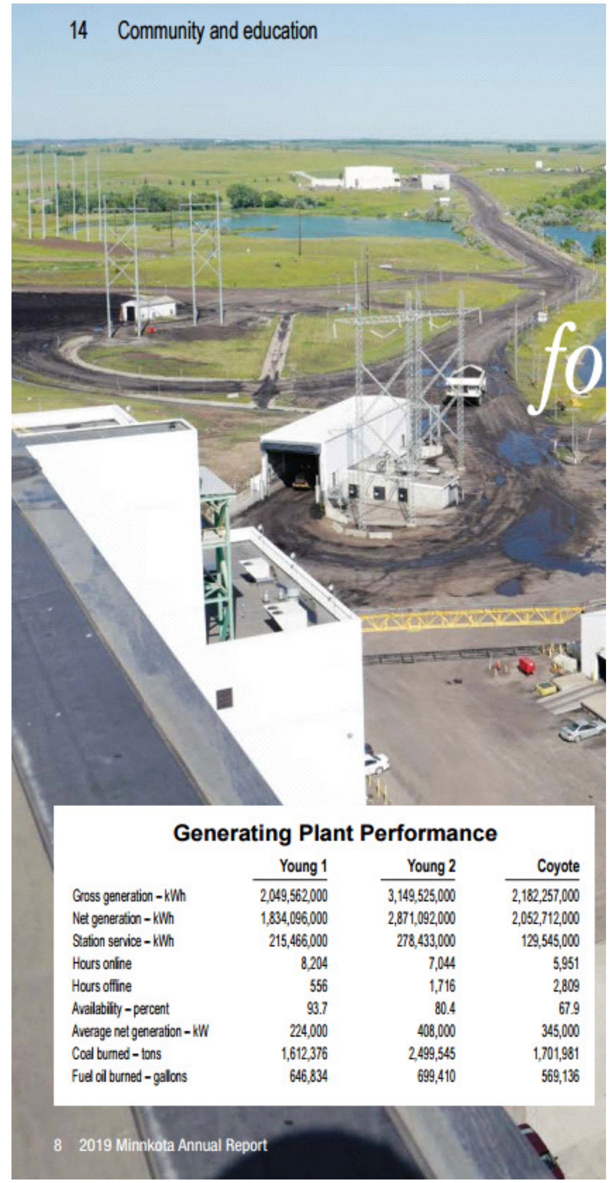
What is the total energy production over the month?

```
>> kWh = sum(kW)

    2428.1
```

How many pounds of coal would this offset?

- 1.78 Pounds of North Dakota lignite coal produces 1kWh (Minnkota 2019 annual report for Young1 440MW coal plant)

```
>> Pounds = kWh * 1.78

Pounds = 4322.0 pounds of coal per month
```



Generating Plant Performance

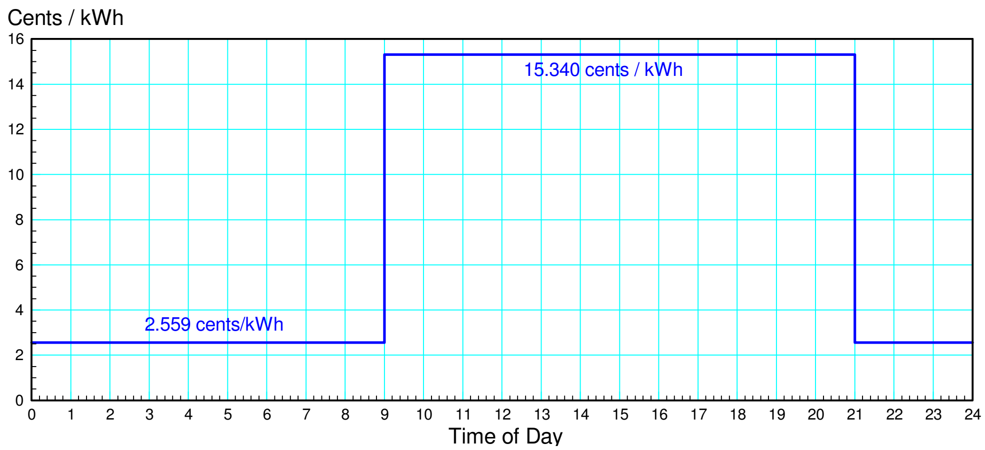
	Young 1	Young 2	Coyote
Gross generation – kWh	2,049,562,000	3,149,525,000	2,182,257,000
Net generation – kWh	1,834,096,000	2,871,092,000	2,052,712,000
Station service – kWh	215,466,000	278,433,000	129,545,000
Hours online	8,204	7,044	5,951
Hours offline	556	1,716	2,809
Availability – percent	93.7	80.4	67.9
Average net generation – kW	224,000	408,000	345,000
Coal burned – tons	1,612,376	2,499,545	1,701,981
Fuel oil burned – gallons	646,834	699,410	569,136

How long will you have to wait for these panels to pay for themselves?

It depends upon where you live, who your utility provider is, and what plan you're on.

Option #1: Assume

- You live in Moorhear, MN (across the river from Fargo, ND) and get your energy from Xcel Energy.
- You have net metering. This means you buy and sell electricity at the same price.
- You sign up for time-of-day metering. This means the price of electricity is:
    - $0.15340/kWh 9am to 9pm
    - $0.02559/kWh other times



Comments:

In April, 2023, you would produce $355.25 in revenue

It would take 4.45 years for the panels to pay for themselves

This is a good investment from a purely economic standpoint

Less time if you include 20% tax credit to install
More time if you include installation costs

In Matlab

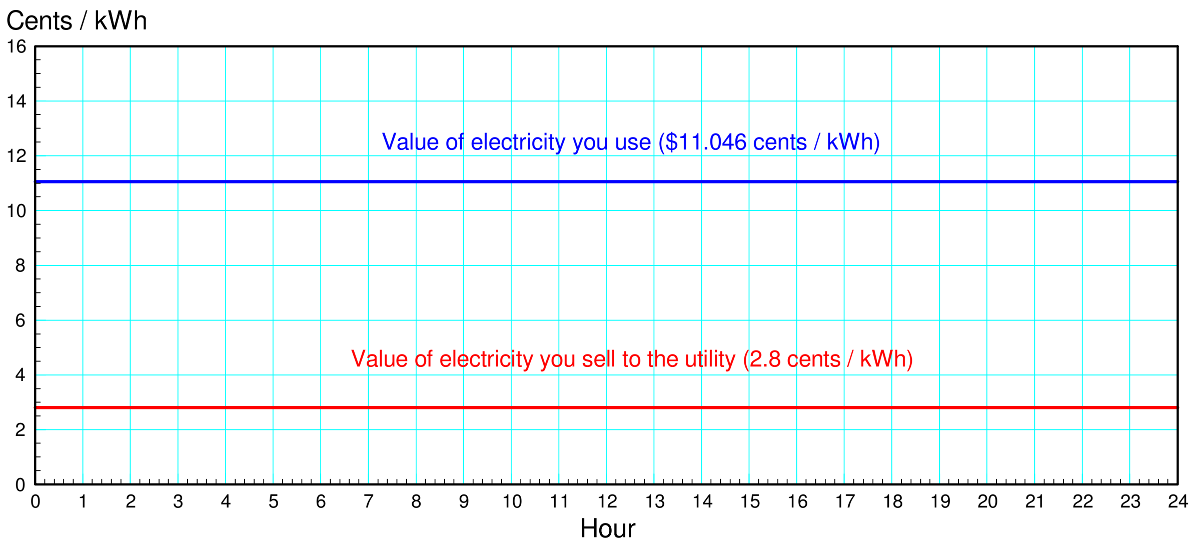
```
>> kW = 4.7376 * MJ;

>> Time = [1:720]';
>> hr = mod(Time, 24);
>> peak = (hr >= 9) .* (hr < 21);
>> offpeak = 1 - peak;

>> Price = peak*0.15340 + offpeak*0.02559;
>> Price(9:20) = 0.15340;
>> Price(21:24) = 0.02559;

>> Dollars = sum(Price .* kW)
Dollars = 355.2553

>> Months = 18999 / Dollars
Months =   53.4799

>> Years = Months / 12
Years =    4.4567
```

Option #2: You live in Fargo, ND

- Utility provide is Cass County Electric where you
  - pay $0.11046 / kWh for electricity you use, and
  - get $0.02146 / kWh for electricity you put back on the grid.

Assume

- You use half of the electricity you produce at the time you produce it
- The net value of electricity is $0.06923 / kWh.



Comments:

In North Dakota, the electricity you produce is worth $168.10

It takes 9.41 years for the panels to pay for themselves

- Less time if you include 20% tax credit to install
- More time if you include installation costs

This is *not* a good investment from a purely economic standpoint.

In Matlab

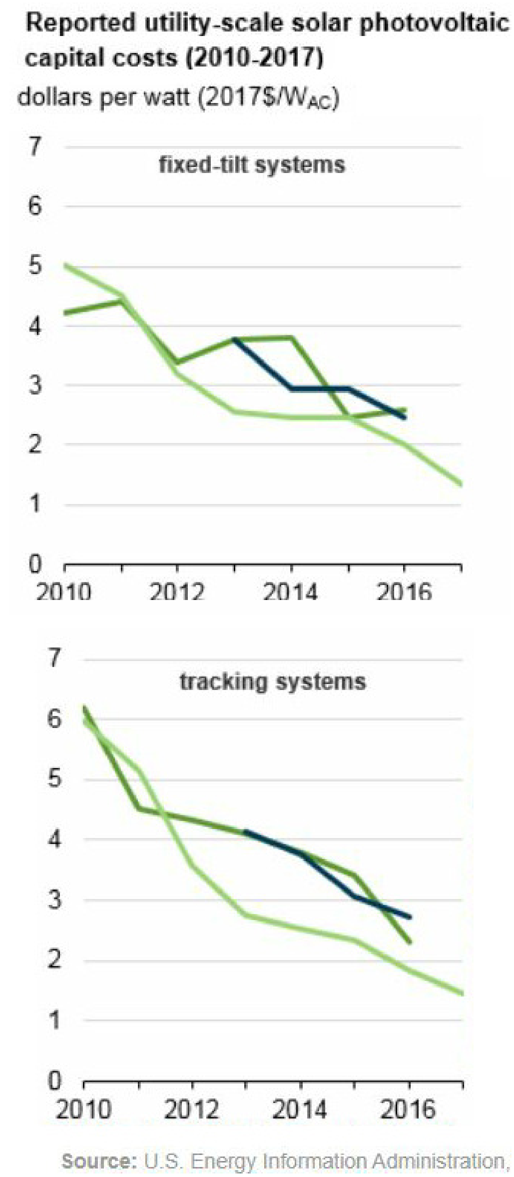
```
>> kWh = sum(kW)

kWh = 2428.1

>> Dollars = kWh * 0.06923

Dollars =  168.0974

>> Months = 18999 / Dollars

Months =  113.0238

>> Years = Months / 12

Years =   9.4186
```

But.....

9.42 years is really close to 7 years.

- If the price of solar panels drop by 26% (through tax breaks or price reduction), this will be a good investment from a purely economic standpoint.
- If the efficiency of solar panels can be increased from 21.5% to 28,9%, this will be a good investment
- If you take in to account environmental issues, you might still want to invest in solar panels.
- If you lived somewhere that gets more sun than Fargo, ND, the payback time will drop as well.

Even in Fargo, ND, a place not known for being sunny, solar energy is almost viable today.



What is the cost of solar energy on a $ / kWh basis?

Assume comperable production every month for 20 years

$$\left(2428.1\ \frac{kWh}{mo}\right)\left(12\ \frac{mo}{y}\right)(20y) = 582,744\ kWh$$

An initial cost of $15,640 results in

$$\left(\frac{\$18,999}{582,744kWh}\right) = \$0.0326\ /kWh$$

In comparison, other forms of energy cost:

• Wind	1.59	cents / kWh	
• Nuclear[1]	2.438	cents / kWh	
• Coal / Steam[1]	3.088	cents / kWh	*no carbon capture*
• Solar	3.26	cents / kWh	
• Gas[1]	6.44	cents / kWh	
• Hydro[1]	9.32	cents / kWh	
• Coal w/ CC	25 - 32	cents / kWh	*with carbon capture*

(1) U.S. Energy and Information Adminsitration 2019 estimates

Comments

Without any government subsidies, in 2023 the price of solar is almost the same as coal without carbon capture (meaning all waste is dumped into the atmosphere). It's about 90% cheaper than coal with carbon capture - assuming carbon capture works as advertised (which is a big question).

That is one of the reasons you're seeing so many solar farms going up across the country (Mapleton, MN solar farm below)

Wind Energy in Fargo:

https://www.vestas.com/en/products/offshore/V164-9-5-MW

Assume a Vestas V172-7.2MW Wind Turbine

- 7.2MW peak production
- 172m diameter blades
- The hub is 1114m toi 199m above the ground
- The cost is approximately $9.36 million, including installation cost, tower, generators, etc.

Specifically, let's investigate

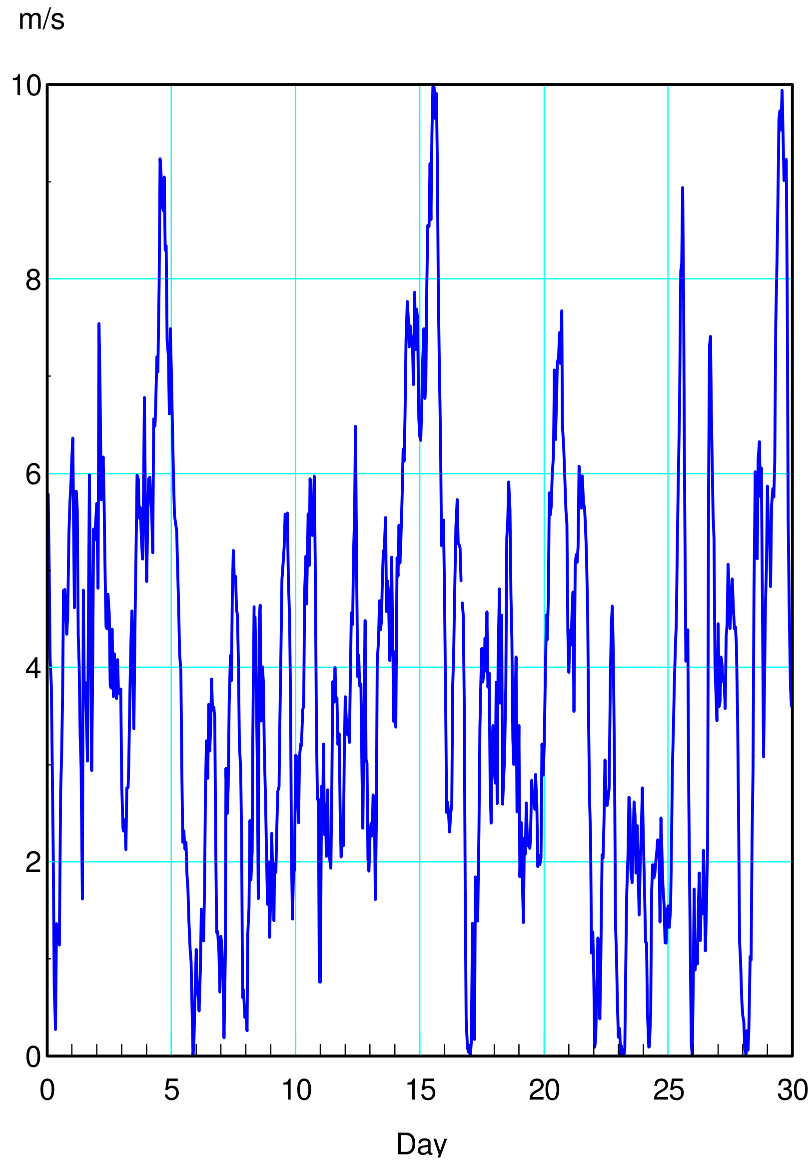
- How much energy would this wind turbine produce on an hour-by-hour basis if installed in Fargo, ND
- How many pounds of coal would this offset?
- How long you would have to wait until the wind turbine pays for itself (i.e. is it a good investment from a purely economic standpoint)

Step 1: Get Wind Data (NDAWN)

- Going to the NDAWN site (https://ndawn.ndsu.nodak.edu/)
- Select Fargo, ND, Average Wind Speed on an hourly basis
- Select metric units and download to a CVS file.
- Open the CVS file in Xcel and copy the last column

Paste into MATLAB as

```
Wind = [
< paste control V >
];
hr = [1:length(Wind)]';
plot(hr/24,Wind);
xlabel('Time (days)');
ylabel('Wind Speed (m/s)');
```



Convert wind speed @ 180m

Wind at 180m is more than on the ground

- Think of flying a kite

A rough approximation (wikipedia) is

$$v_w(h) = v_{10}\left(\frac{h}{h_{10}}\right)^{\alpha}$$

or, in other words, the wind speed at 180m would be approximately 2.2x the wind velocity recorded

```
Wind @ 180m = 2.2 * Wind @ 2m;
```

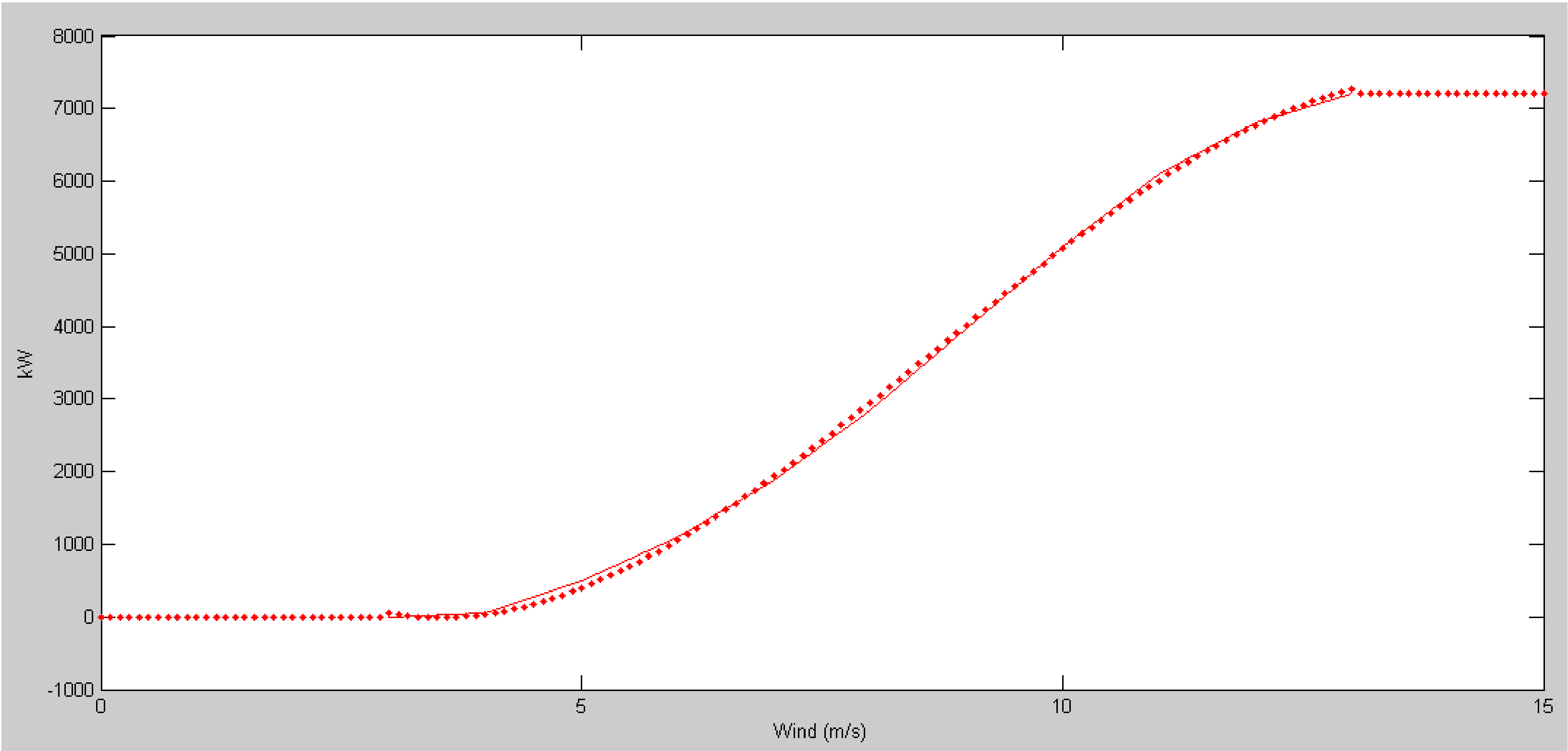
Convert Wind to kW (Power Curve)

Wind (m/s)	0..3	4	5	6	7	8	9	10	11	12	13+
kW	0	53	496	1,096	1,882	2,857	3,968	5,102	6,100	6,803	7,200

```
function [kW] = PowerCurve( Wind )

x = [3,4,5,6,7,8,9,10,11,12,13]';
y = [0,53,496,1096,1882,2857,3968,5102,6100,6803,7200]';
B = [x.^3, x.^2, x, x.^0];
A = inv(B'*B)*B'*y;

kW = 0*Wind;
for i=1:length(Wind)
    if(Wind(i) < 3)
        kW(i) = 0;
    elseif(Wind(i) > 13)
        kW(i) = 7200;
    else
        kW(i) = [Wind(i)^3, Wind(i)^2, Wind(i), 1]*A;
    end
end
```

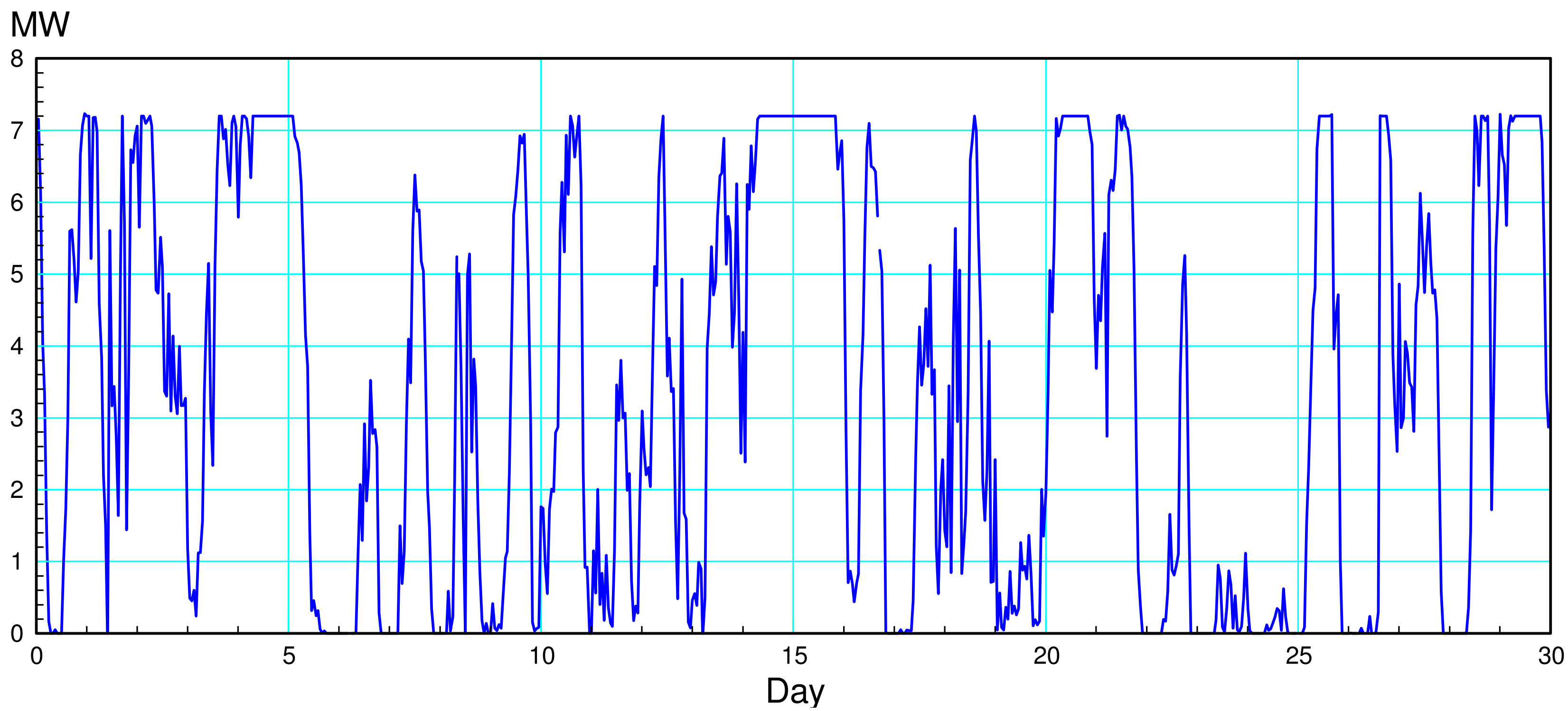
If you plot wind speed at the turbine vs. kW, you get the wind / power relation

```
>> X = [0:0.1:15]';
>> PowerCurve(X)
```



If you plot time vs. kW, you get the energy produced on an hour-by-hour basis

```
>> kW = PowerCurve(Wind * 2.2);
>> hr = [1:length(kW)]';
>> plot(hr/24,kW);
>> xlabel('Day');
>> ylabel('Power (kW)');
```



Wind Results

The average output of this wind turbine over this time frame is less than 7.2MW

- The wind isn't always blowing

```
>> mean(kW)

ans =   3392.9
```

The total energy produced in one month is

$$kWh = \int kW \cdot dh$$

$$kWh = \sum kW \cdot hr$$

```
>> kWh = sum(kW)

kWh =  2.4429e+006
```

Questions & Answers:

How much energy would this wind turbine produce if installed in Fargo, ND?

This is the sum of the kWh produced over the month.

```
>> kWh = sum(kW)

kWh =  2,442,900
```

How many pounds of coal would this offset?

It takes 1.78 pounds of North Dakota lignite coal to produce 1kWh:

```
Pounds = kWh * 1.78

ans = 4,348,400
```

Each month, this wind turbine offsets 4,284,400 pounds of coal

How long would you have to wait for this wind turbine to pay for itself?

Option #1: Moorhead, Minnesota

Price of Electricity

- 15.340 cents / kWh during peak demand
- 2.559 cents / kWh off-peak

In the month of April, 2023

- $253,530 is produced

At this rate, it would take 3.07 years for the wind turbine to pay for itself

Wind energy is a very good investment from a purely economic standpoint.

Matlab Code

```
>> kW = PowerCurve(Wind * 2.2);
>> Time = [1:length(kW)]';
>> hr = mod(Time, 24);
>> Peak = (hr >= 9) .* (hr < 21);
>> OffPeak = 1 - Peak;
>> Price = 0.15340*Peak +
           0.02559*OffPeak;

>> Dollars = sum(kW .* Price)
Dollars =   2.5353e+005

>> Months = 9.36e6 / Dollars
Months =   36.9192

>> Years = Months / 12
Years =     3.0766
```

Option #2: Fargo, North Dakota

Assume

- 6.923 cents / kWh (all times of day)

$169,120 is produced during the month

It takes 4.61 years for the wind turbine to pay for itself

Less time if you get 15 cents / kWh

- The national average price of electricity

Matlab Code

```
>> Price = 0.06923;
>> Dollars = sum(kW * Price)

Dollars =  1.6912e+005

>> Months = 9.36e6 / Dollars

Months =   55.3446

>> Years = Months / 12

Years =    4.6121
```

What is the cost / kWh to produce energy with wind?

- A 20-year life (typical for generators)
- The wind each month is similar to April, 2023

The cost per kWh is then

$$\left(2,442,900\ \frac{kWh}{mo}\right)(12mo)(20y) = 586,300,000\ kWh$$

$$\left(\frac{\$9,300,000}{586,300,000\ kWh}\right) = \$0.0159\ /kWh$$

- Wind 1.59 cents / kWh *with no government subsidies*
- Nuclear[1] 2.438 cents / kWh
- Coal / Steam[1] 3.088 cents / kWh *no carbon capture*
- Solar 3.26 cents / kWh
- Gas[1] 6.44 cents / kWh
- Hydro[1] 9.32 cents / kWh
- Coal w/ CCS 25 - 32 cents / kWh *with carbon capture & sequestration*
- (1) U.S. Energy and Information Adminsitration

How much energy could we produce with wind energy in North Dakota?

1.182TWh of electricity each year

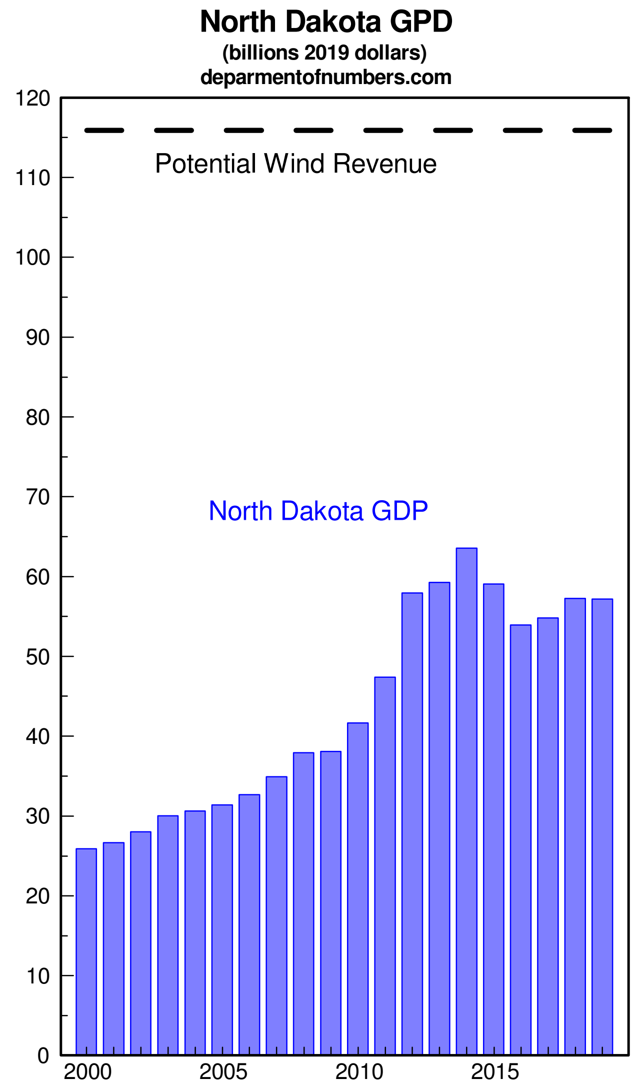
- Enough to supply 25% of the nation's electricity needs
- National Renewable Energy Administration
- https://www.nrel.gov/docs/fy00osti/28054.pdf

At $0.1 / kWh, that would generate $118 billion each year

- Equals $157,000 per person in North Dakota,
- More than double the entire GDP for North Dakota

http://www.deptofnumbers.com/gdp/north-dakota/

- More if you consider that the average cost of electricity in the United States is $0.15 / kWh



What about Bird Deaths

U.S. Fish and Wildlife Services

- Wind turbines kill about 234,000 birds per year
- This accounts for 0.01% of all bird deaths

Cause	Bird Deaths per year	% Total
Cats	2,400,000,000	73.08%
Building Glass	559,000,000	17.02%
Vehicles	214,500,000	6.53%
Poison	72,000,000	2.19%
Electrical Lines	25,500,000	0.78%
Communication Towers	6,600,000	0.20%
Electrocutions	5,600,000	0.17%
Oil Pits	750,000	0.02%
Wind Turbines	234,000	0.01%

Summary

With Matlab and the internet, you can analyze data yourself.

- You don't have to rely upon experts

Matlab is a really useful tool. With it, you can

- Evaluate how much energy a solar array should produce
- Evaluate how much energy a wind turbine should produce

At present

- Solar energy is one of the least expensive ways to generate electricity.
- Wind energy is *the* least expensive way to produce electricity.

This is good news for ECE majors

- We have jobs.

It's also good news for the planet

- Carbon-free electricity is possible and it's economic