MEMORANDUM

FROM: AMOS HAN
TO: PROF. NICODEMUS
DATE: DUE APRIL 15, 2014
RE: BIBLIOGRAPHY AND METHODOLOGY

Annotated Bibliography

Arif, Mashail S. Residential Solar Panels and Their Impact on the Reduction of Carbon Emissions. Rep. 2013. Berkeley University of California. p. 3-5 <http://nature.berkeley.edu/classes/es196/projects/2013final/ArifM_2013.pdf>.

This is a report on how solar panels contribute to the reduction of carbon emissions. Specifically, the author of the report has studied the residential and solar systems in California. Greenhouse gas emissions have resulted in several consequences, including rising sea levels, and during the past 200 years, CO2 have only been increasing. This is often due to the increasing energy demand. Solar energy is renewable, so therefore can be responsible for reducing CO2 emissions while still meeting the energy demand. The use of rooftop solar panels can create a huge difference.

"Modeling distributed generation in the buildings sectors." U.S. Energy Information Administration (EIA). Aug. 2013. <http://www.eia.gov/forecasts/aeo/nems/2013/buildings/pdf/distribgen.pdf>.

In this EIA report, generation technologies are distributed and dispersed to generate electricity near the residential and commercial buildings that is intended to be served. Therefore, there are forecasts for the capacity for the DG sectors in the gigawatts; a graph shows that the solar PV is projected to have a significantly higher DG capacity in AEO2013 reference case. What is also put into account when forecasting is the historical capacity estimates, in addition to the costs and incentives of an installed system.

"Most states have Renewable Portfolio Standards." Most states have Renewable Portfolio Standards. 3 Feb. 2012. <http://www.eia.gov/todayinenergy/detail.cfm?id=4850>.

While this article is mainly focused on all renewables rather than focusing purely on solar, this is an important part of pushing the renewables forward, including solar PV. Renewable Portfolio Standards (RPS), also known as Renewable Electricity Standards (RES), are energy policies whereas the intent was to increase the electric generation of renewable sources. A large amount of energy policies are part of RPS and oftentimes, RPS sets minimums to increase the use of renewables.

"NW Wind & Solar." How do solar systems produce energy? 2014. NW Wind & Solar. 15 Apr. 2014 <http://www.nwwindandsolar.com/solar-power-in-seattle-and-the-northwest/how-do-solar-systems-produce-energy/>.

In this article, there are descriptions of how sunlight turns into electricity. Solar panels are made of special materials that can turn sunlight into energy. Specifically, the solar panels are made of silicon. This can be done when sun's rays cause the excitation of electrons in silicon cells using photons from the sunlight. Moreover, are descriptions of how the inverter and net meter works. Furthermore, other benefits of solar, including reducing air pollution, is mentioned.

" Growth in electricity use slows but still increases by 28 percent from 2011 to 2040." U.S. Energy Information Administration (EIA). Apr. 2014. <http://www.eia.gov/forecasts/aeo/MT_electric.cfm#solar_photo>.

This EIA article shows the market trends that forecasts certain energy use between 2011 and 2040. Specific to the solar PV and wind, the solar PV and wind are projected to be the majority of the capacity growth. Renewable generating capacity is therefore projected to account for nearly 20% of all generating capacity in 2040. As the capacity growth is minimal, however, renewables become cost competitive and the capacity could rebound.

"Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants." U.S. Energy Information Administration (EIA). Table 2. 12 Apr. 2013. <http://www.eia.gov/forecasts/capitalcost>.

As this EIA article said, it is important to know the projected cost and performance characteristics of a new electric generating capacity. Moreover, the information was gathered on the overnight construction costs, operating costs and performance characteristics for large amount of generating technologies. The overnight costs have been broken into multiple parts, including owners costs, project indirect costs, installation and mechanical equipment supply. There were findings on spreadsheet that summarized updated cost estimates for generic utility-scale generating plants and the 2013 comparison of overnight cost estimates to the 2010 report, whereas the currency was in 2012 USD. It was determined that the EIA electric market projections are not the sole driver of these statistics.

"Utility-scale installations lead solar photovoltaic growth." U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. 31 Oct. 2012. 15 Apr. 2014 <http://www.eia.gov/todayinenergy/detail.cfm?id=8570>.

Solar PV has been rapidly growing during the recent years. There is a graph that divides solar PV capacity by sector. The grid-connected PV capacity is rapidly increasing to the point that it has quadrupled between 2008 and 2011. In addition, there are several federal, state and local programs and policies that would encourage solar power development. Solar projects built in the United States through 2016 are eligible for a 30% investment tax credit at the federal level. Moreover, the cost of PV has been decreasing.

"World energy demand and economic outlook." U.S. Energy Information Administration (EIA). Figure 13. 25 July 2013. <http://www.eia.gov/forecasts/ieo/world.cfm>.

IEO2013 reference case determines that the world energy consumption was at 524 quadrillion BTU in 2010 and expected to have a 56% increase to 820 quadrillion BTU in 2040. Several economic and

political issues make it complicated for the long-term assessment of world energy markets, therefore causing several different paths within the forecast. As the GDP is forecasted to rise by 3.6%/year between 2010 and 2040, future energy consumption is driven by non-OECD demand. As of 2013, fossil fuels continue to be the majority of the world's energy source. There are several sectors, including residential, industrial and commercial, whereas the energy consumption statistics are divided into. Figure 13 determines that while China recently surpassed the United States as the world's largest energy consumer, it is projected to consume at least twice as many energy as the US in 2040.

Methodology

Solar photovoltaic system uses sunlight as the power source using solar panels to convert sunlight into energy. This is done when the sun's rays are converted into electricity by exciting electrons into silicon cells using photons of sunlight. Not only that it is a renewable source of energy, but also that it does not spew any carbon emissions. While there are several advantages, such as a lack of noise and supplied by a free and abundant source, there are a few setbacks, such as the lack of sunlight at night and heavy cloud cover. Therefore, it would be necessary to research further into facts and statistics about solar photovoltaic use in the United States.

Capacity: It is important to factor in the amount of renewable generating capacity to determine how much energy can be supplied. Solar generation capacity is the leader in capacity growth as there is projected to be a 1,000% increase (46 Gigawatts) from 2011 to 2040. Renewable generation increases from 524 Terawatthours (TWh) in 2011 to 858 TWh in 2040. This is a 63.74% increase as determined by the equation (858-524)/524.

Cost: Monetary information is crucial to determining how much it would cost to run solar plants. This would determine whether it is cost effective and how much money would be budgeted. In addition, the capacity increase would lead to the decrease of cost; therefore, solar power would be cheaper. According to EIA, there are two options for solar power plants; 20MW rating and a 150 MW rating. The cost of PV plant's capital costs is given per kW, and the capital cost for the 20MW plant is $4,183/kW and the O&M is $27.75/kW-year. For the 150MW plant, the capital cost is $3,873/kW and O&M is $24.69/kW-year. Assuming that there was a 6% interest rate and both plants had a lifetime of 20 years and a salvage value of $1,000, engineering economics were used to determine the annualized cost of each plant. The equations include:

- P = F/((1+i)^n) whereas P is present worth, F is future worth, i is interest rate and n is the number of years.
    - In this case, this is how the salvage value was converted to present worth:

      P = 1000/((1+0.06)^20)

      P = $311.80
- U = P(i/(1-(1+i)^-n)) whereas U is the uniform series. This time, P is the capital cost subtracted by the salvage value converted to present worth
    - For the 20MW plant:

      U = (4,183-311.80)*(0.06/(1-(1+0.06)^-20))

      U = $337.51

      Added O&M cost to U to get the annualized cost: 337.51+27.75 = **$385.26/year for each kW**
    - For the 150MW plant:

U = (3,873-311.80)*(0.06/(1-(1+0.06)^-20))

U = $310.48

Added O&M cost to U to get the annualized cost: 310.48+24.69 = **$335.17/year for each kW**

Prediction: We are not 100% certain about the future but the forecast is a basic idea of what may go on in the future. This can be helpful in how to be prepared for the future based on the forecasted information we have. Although it is unlikely, calculation was done to determine how many 150MW solar power plants would need to be installed in order to supply *all* the power in the United States in 2040. First, we must determine the amount of energy reached to consumers by a single 150MW plants by solving this equation, assuming that capacity factor is 30%

- $E_{elec,cons}$ = (Power rating)(8,760 hours/year)(η_{trans})(Capacity factor)
- Power rating = 150MW
- η_{trans} = 0.93
- Capacity factor = 0.3
- $E_{elec,cons}$ = (150MW)(8,760 hours/year)(0.93)(0.3) = **366,606 MWh/year**

In 2040, 107.2 quadrillion BTU is expected to be used in the US. In order to convert BTU to MWh, since 1 MWh = 3,412,141.63 BTU, 107.2 quadrillion was divided by 3,412,141.63 to become 3.14E10 MWh. Then, 3.14E10 was divided by 366,606 to determine that 85,676 of 150 MW PV plants would be needed in 2040 to completely eliminate other power sources in the US.

Of course, we must not forget monetary costs. It was already determined that the cost per kWh would be $335.17/kW. Therefore, 335.17 are multiplied by 150,000 since there are 150,000 kW in a 150 MW plant; this is followed by multiplying by 85,676 plants.

Therefore, 335.17*150,000*85,676 = **$4.307E12, which is the cost of running United States' grid purely on solar PV in 2012 dollars.**

CO2 emissions: Solar PV would be very crucial to significantly reducing CO2 emissions. For each kWh of electricity, 6.9 x 10^-4 metric tons of CO2 are spewed. To determine how much CO2 emissions would be reduced by purely running the US on solar, the following equation does so: 31,409,305,785*1000*6.9 x 10^-4 =21,672,420,991.7 metric tons of CO2 would be cut annually.

Renewable energy policy: In order to encourage the use of renewable energy, including solar PV, policies were implemented to push it forward. Specifically, Renewable Electricity Standards are series of policies with an intention of increasing generation from renewable resources. This would encourage electric producers produce minimum share of renewable resources within certain jurisdictions.