Renewable Energy Trends
Schwartz Problem Set #9, Due Wednesday, June 5

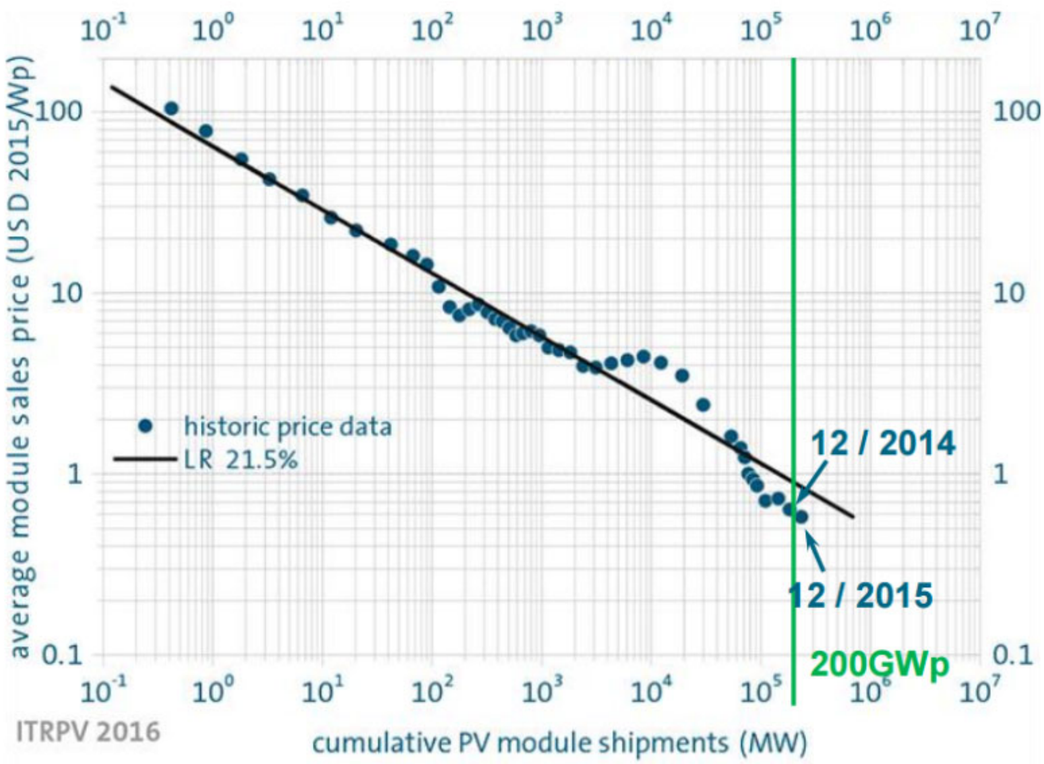
1. Calculate the surface area of standard PV panels (20% efficiency) necessary for you to live your life. Please include the following consideration:
   a) We live in SLO and can anticipate the corresponding solar incidence. I'm estimating about 4 hours of sunlight per day. I remember that we get the "June Gloom" in summer and it rains in winter (sometimes). That represents a duty cycle of 1/6, or about 17%.
   b) You continue to use electricity like always, and continue to drive like you always do, but in a (shared?) electric car. There's a bunch of ways you could calculate this. Our electricity bill is about $20 / month. If we spend $0.15 / kWh, this corresponds to about 130 kWh / month…. Or about 1,500 kWh/year I probably drive 10 miles per week in winter, but 50 miles per week in summer taking kids to the beach (Junior Guards in Avila). So about 1000 miles times 2 for Partner, so 2000 mi/year in our electric car. This corresponds to about 500 kWh / year for driving. Total use is about 2000 kWh/year. In a year, we have 8760 hours, but our duty cycle is 1/6, so we estimate the number of sunny hours to be 1500 h/yr. Thus, I need a system that is about 1.3 kW. But let's be careful and get a 2 kW system. I mean, the kids are going to start driving (OH shit!). At present one can buy solar panels at the factory door for $0.20/W, but we can't get that anywhere in the states. I'd estimate a 2 kW system will presently cost me $1000 for the panels. Sunlight is 1000 W/m^2, but with an efficiency of about 20%, we need 5 m^2, for a kW, or I will need 10 m^2 total… or about 100 ft^2, which is about the size of my office. Hardly greedy of me in terms of global surface area. We'll be good with panels on the roof.

   Please give your answer in square meters…. Does this area seem reasonable to you? Do you feel you are taking too much of the planet's surface area with this?
   c) Indicate what kind of lifestyle changes you would need to make in order to live like this. Oops, I didn't consider any lifestyle changes. We already have an electric car. I suppose the next step is going to be cooking and heating water. Let's say I cook with two natural gas burners for about half an hour per day, constituting a kWh/day, so I have to add about 400 kWh to my electricity demand. Hot water? I shower outside with the solar thermal-heated water, but my teen doesn't and she takes long showers. Let's estimate 15 minute showers at 10 gal/minute, 150 gallon showers (600 kg!). We need to heat this water from about 20 C to about 45C to make a nice steaming shower for her. I get 15,000,000 calories, or about 60 MJ, or about 15 kWh. Per shower. She's with her mama most of the time, so she'll take 50 showers per year. For an additional 750 kWh. Oops, it's looking like I'm going to have to up my solar panel surface area.

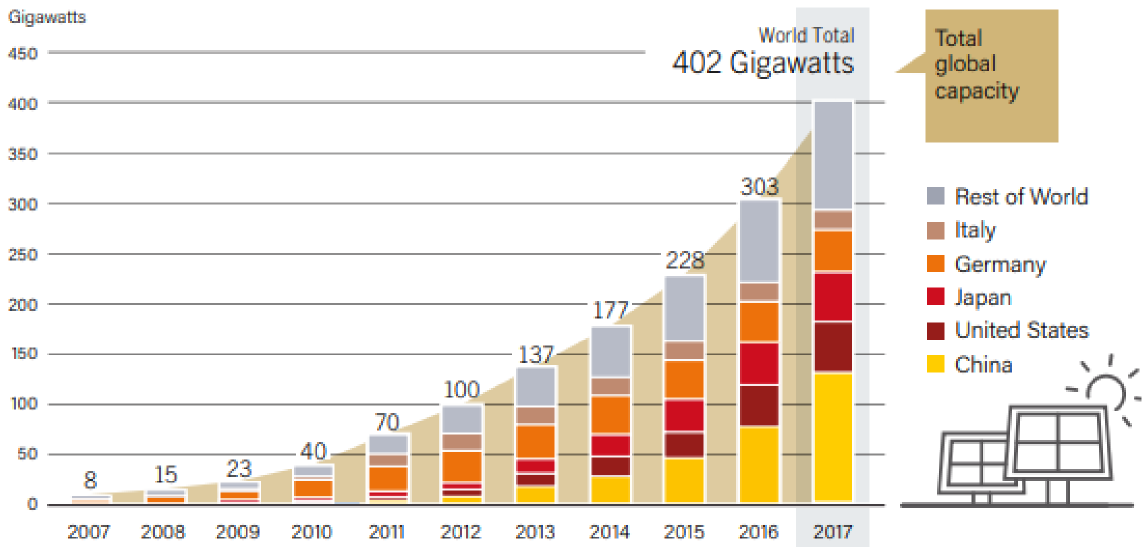
2. We have seen how solar deployment has been growing at a near exponential rate. We have also learned about the learning curve: That the cost of a technology decreases with the total deployment of that technology. For instance, look at a car: ~$10,000 for about 100 kW: *10 cents a Watt*… and that $10,000 covers way more than the engine. That's because we humans have considerable experience, having produced… maybe a few billion cars. Anyway, please look up some graphs of how global deployment of solar electricity has increased over the years, and how the cost to produce solar panels has decreased:

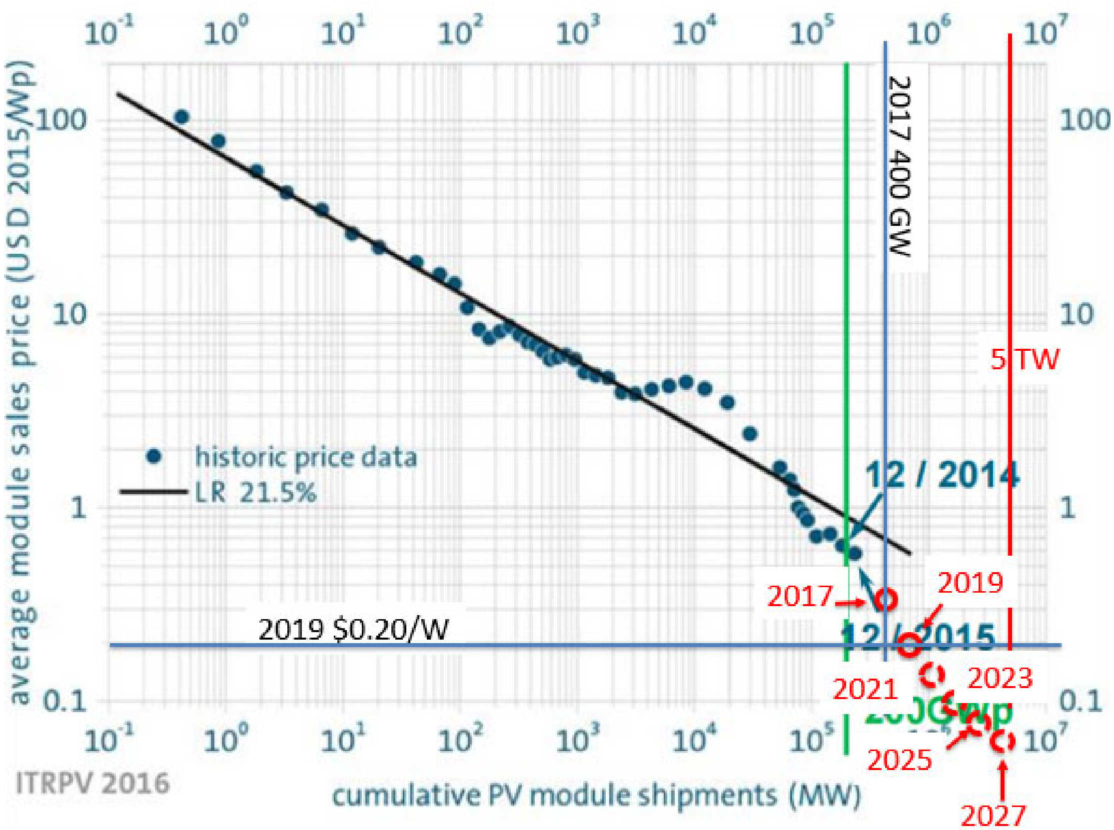
a) If these trends continue through 2025, please project the cost to produce solar and total global deployment in 2025. Please include the graphs or references you used. OK, if you see below, I found a learning curve for PV On the union of concerned scientists website, I can update global capacity to 2017 400 GW with the attached graph from REN 21, and you can see my research website (http://sharedcurriculum.peteschwartz.net/direct-dc-solar-research/) to update the cost of solar to $0.20 / W. If you see the last graph, I estimate that this will happen in about 2028 at a price of about $0.05 / W. I've extrapolated every 2 years. Why did I make the trajectory curve instead of a straight line? I think that the drastic decrease in price will cause deployment to increase (moving points more to the right), and that the price decrease will not continue at its present rate, but will revert to the slope of the historical line (shown in black). Anyway, at the point that solar panels cost $0.05/W, we can safely say that they are free. All costs will be putting up solar panels and managing the electricity. Because solar electricity isn't the only renewable electricity (wind will also play a role), we will likely reach this "100% renewable electricity" earlier than 2018… just 10 years away! How are we going to manage that electricity?

b) Of course, this trend will not continue indefinitely. Project when total global consumption of electricity can be met by solar… be careful to include consideration of duty cycle. We spoke in class, if you remember that we calculated total electricity consumption to be between 2 and 3 TW. As we project in the future, we hope that more people will have electricity, although efficiency measures will improve. Let's aim for 4 TW. However, we will also electrify transportation. Transportation has roughly the same energy draw as electricity, but when we switch from the ICE (~ 10%) efficiency, to electricity (~60% efficiency), we get a bipg boost! Thus 5 TW should cover us. But then we'll electrify heating with heat pumps… OK how about 6 TW. Good for me.



This graph shows a learning factor of 21.5% from 1976 through 2015. Short-term fluctuations are partly due to supply chain issues. Source: International Technology Roadmap for Photovoltaic.


Gigawatts
World Total
402 Gigawatts
Total global capacity
Rest of World
Italy
Germany
Japan
United States
China
8
15
23
40
70
100
137
177
228
303
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017


average module sales price (USD 2015/Wp)
cumulative PV module shipments (MW)
historic price data
LR 21.5%
2017 400 GW
5 TW
12 / 2014
12 / 2015
2019 $0.20/W
2017
2019
2021
2023
2025
2027
ITRPV 2016