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Ambitious Solar Plans in France

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The following guest post was written by Tom Standing, a "semi-retired, part-time civil engineer for the City of San Francisco." In Arizona Solar Power Project Calculations, published a few days ago, Tom took a look at a 280 MW solar thermal plant in Arizona. In this post, Tom examines France's ambitious solar plans.

The December 1 issue of the Oil and Gas Journal carried a “Quick Take” article about France’s “national plan for renewable energies” that they unveiled on November 17. Their plan includes all the popular ideas for alternative energy: biomass, wind, hydro, waves and tides, with a major emphasis on solar. For now, France has 13 megawatts of installed capacity in solar, but the energy minister wants solar to be an ambitious 5,400 MW in 2020. He says that France will change its carbon-based energy model to a completely decarbonized model: each home, company, and community will produce its own energy.

Why is France doing this? They already have the least carbon-intensive energy system of any industrialized nation. They generate 75% of their electricity with nuclear, supported by the most extensive technology to reprocess spent nuclear fuel, compared to any other nation in the world. Practically 100% of their rail system is electrified, packed with people, whether on the Paris Metro or speedy intercity trains. France has already developed the working model of a low-carbon energy system for other nations to emulate.

Let’s do some calculations on France’s solar plan, similar to my last email. We can see what surface area of collectors would be needed, and how much electricity would be generated.

Collector Area

As I explained previously, solar panels are rated at their maximum output, when the sun is near its highest altitude for the year under cloudless skies. Under such ideal conditions, insolation is about 1,000 watts per square meter. The most cost-effective panels convert about 10% of insolation into useful electricity, a factor that has remained unchanged for 10 years. Some PVs might convert 15%, but they cost more and are not mass-produced. Thus a typical panel of one square meter is rated at 100 watts.

To estimate the area of PV panels that France wants to install, we simply divide 5,400 MW by 100 W/m^2 and we get an incomprehensible 54 million m^2! It means that one million homes and businesses would have to be covered with 54 m^2 of panels. A typical home can accommodate only 25-30 m^2, so more than a million buildings would have to install PV. I do not know the worldwide capacity for manufacturing PV panels, but I would guess that current capacity is a small fraction of 54 million m^2/year. Certainly, capacity will grow, but what about PV for Germany, Spain, UK, the Low Countries, and the US? California alone would suck up a major chunk of that capacity.

Solar Electricity Generated

Let's say that France actually installs 54 million m^2 of solar by 2020. (I doubt it is possible, but let's carry the scenario through.) How much electricity will the fully built-out system generate?

First, we need to estimate the insolation upon the collectors. While I have copious insolation data from NREL for the US, I have no site-specific data for Europe. But I can make a reasonable estimate. Having traveled throughout France at various times for a total of about 3 months (typically in the summer), I can say that France has mild sun conditions. I would compare the French summer sun to that of Cleveland or Minneapolis. However, France is located at somewhat higher latitudes, which tends to reduce midday sun strength and spreads it out over more daylight hours. The northern suburbs of Paris, say around de Gaulle International, is latitude 49o, the northern-most boundary between the US and Canada. The south-most reaches of France, are between latitude 43 and 44, equivalent to Buffalo, NY or Portland, Maine.

I will pick a number on the generous side for annual average insolation in France, equivalent to that of Boston, New York, Chicago, and Minneapolis:

4.6 kWh/ (m^2-day).

This level of insolation is for optimum panel orientation: facing due south with no shading, tilted at an angle equal to local latitude. Varying amounts of shading with less than ideal orientation will reduce the insolation on the collectors of most installations.

Now we are ready to calculate the annual energy generated from the fully-built French PV system. As I showed in Section 8 of my previous email, the annual energy generated by a solar installation is the product of four factors:

Insolation, average day during a year = 4.6 kWh/ (m^2-day)

10% conversion of insolation into electricity, the industry standard for PV

Area of solar collectors = 54 million m^2

365 days/year

Cancelling out units and carefully watching orders of magnitude, we come up with 9 billion kWh of useful electricity generated during the first year of complete build-out. But we need to give this number some perspective.

Energy Generation in Perspective

EIA statistics show that French consumption of electricity grew from 353 billion kWh in 1992 to 415 billion in 2002, or 62 billion kWh in 10 years for an average gain of 6.2 billion kWh/year.

It means then, that this huge solar development would, at best, produce the equivalent of only 1.5 years of gain in France's electricity consumption. And it would take a 12-year crash program to install that much solar!

Another comparison is with the annual power output of one of France's 1,000 MW nuclear power reactors. If the reactor operates for a year at 90% capacity (typical for the industry), the three factors to multiply are: 90%, one million kW, and 8,760 hours/year. Multiplying out these factors, we find that a single reactor would produce about 8 billion kWh/year, roughly the equivalent electricity as all the solar panels covering nearly 2 million homes and businesses.

Costs for PV

In the US, homes and businesses that install PV typically receive “rebates,” (another word for “subsidies”) from state or local governments, or the utility, to be paid for by all ratepayers. Rebates usually amount to about half of the total installed cost. The unit cost for solar installations has changed little since 2000, in the range of $600 - $700 per square meter, or in the terms of the industry, $6,000 - $7,000 per rated kW. Thus a homeowner usually qualifies for a rebate of 6 or 7 thousand $ after installing a 2 kW PV system.

I don’t know if French taxpayers and ratepayers will subsidize solar installations, but the unsubsidized cost remains the same and must be paid by somebody. Total installed cost of the solar plan for France, then, would run in the neighborhood of $35 billion. What is the cost of building a single reactor in a nuclear power plant? Considerably less I would say.

Solar Capacity Factors

We can calculate capacity factors for any solar project directly from insolation data. This provides a shortcut to calculating electrical output on an annual or monthly basis when we are given the nameplate capacity. The capacity factor depends only on insolation during the time period in question, and is independent of the conversion factor between insolation and electricity.

The capacity factor is defined as the ratio of actual energy generated, to the energy generated at maximum insolation, i.e. nameplate capacity. Therefore, our ratio is:

actual average isolation/maximum insolation

Maximum insolation, we have seen, is 1,000 W/m^2.

Actual insolation is given in kWh/ (m^2-day). We have to convert this quantity into units of W/m^2. We cancel out hours and days by dividing actual insolation by 24 h/d. For example, if insolation is 5.0 kWh/ (m^2-day), the average power output during one day is 5,000/24 = 208 watts. Average power output divided by maximum insolation (1,000 W/m^2) gives a capacity factor of 20.8%.

Solar Capacity Factors

Because the ratings that are given to solar installations are only during the most ideal solar conditions (which, for many locales are achieved only during 40 or 50 hours per year) we must include the solar capacity factor for the locale under consideration. Multiplying the capacity factor by the local insolation enables us to determine actual power output and energy generated for a given time span.

From the NREL insolation database, we can calculate solar capacity factors for a wide expanse of locations across the U.S.

http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/sum2/

Select the link “In alphabetical order by state and city.” Then choose any city to bring up the data as a spreadsheet.

The striking fact gleaned from the database is that the range of solar potential across the entire U.S. is quite narrow. In the Lower 48, capacity factors range from the highest, 27.5% in California's Mojave Desert, to about 15.4% for the Pacific Northwest. Vast reaches of the Desert Southwest: most of Arizona, at least half of Nevada, southern Utah, the southern half of New Mexico, and the western tip of Texas exhibit capacity factors of 26 to 27%.

Other Regions

- Southern California basins: Los Angeles and San Diego – 23.3 to 24.2%
- San Francisco Bay region – 21.7 to 23.0%
- Denver/Boulder region – 23.0%
- Mississippi Valley (Minnesota through Louisiana) – 19.2 to 20.8%
- Great Lakes region – 17.1 to 18.3%
- Eastern Seaboard (Maine through Virginia) – 19.0 to 21.0%
- Florida – same as Southern California – 23.3 to 24.2%

From these capacity factors we can calculate that a large rooftop system of 30 square meters of PV (a 3-kilowatt system) costing about $20,000, oriented optimally toward the sun, located in the U.S. Heartland (in or around Kansas City or St. Louis), would actually generate about 600 watts, averaged over night and day for a year. The average daily generation works out to 14.4 kWh. This is roughly the usage of a typical household with modest lighting and moderate use of electrical appliances. For the same location, the capacity factor in July would be 24.6%; in December, 13.3%. The 3-kW system, then, would yield a power output averaging 738 watts in July and 400 watts in December. Average daily electrical generation would be 17.7 kWh in July and 9.6 kWh in December.

I welcome those interested in solar applications to calculate average power output and average daily energy generated, from the capacity factors shown above, for typical household-sized solar arrays.

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