Measuring PV technical potential and financial feasibility for educational buildings in the United States

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Overview

In 2016, approximately 64% of total electricity generated in the United States came from fossil fuel sources, while less than 2% came from rooftop solar photovoltaic (PV) electricity generation[1]. Due to this mostly fossil fuel dependent electricity portfolio, electricity generation accounts for approximately 35% of total U.S. carbon dioxide (CO_2) emissions each year[2]. To assess how society may benefit from an increased penetration of renewables into the grid, we use educational institutions as our baseline for performing a cost-benefit analysis (CBA) from the perspective of the schools and the public. We target schools because they account for 11% of total U.S. building electricity consumption and approximately 4% of all U.S. carbon emissions – energy cost savings could expand strained education budgets[3]. In this paper, we address the following research questions:

1. What is the total potential electricity generation from solar PV on all U.S. educational buildings for which we have LIDAR data?
2. What are the total lifetime cost and benefits – both private and public – of installing today rooftop solar PV systems on all U.S. educational buildings for which we have LIDAR data?

Methods

To measure technical potential of PV on all U.S. educational institutions, we use the address and faculty and students counts from three National Center for Education Statistics (NCES) datasets[4]: Integrated Postsecondary Education Data System (for higher education institutions), Common Core of Data (for K12 public institutions), and the Private School Universe Survey (for K12 private institutions) within the U.S. territory, resulting in 134,137 educational institutions. We then produce estimates of available roof space for each institution using NREL LIDAR data. Since NREL estimates rooftop space for only rougly 28% of all of the schools listed in the NCES data (n = 38,022), future analyses will estimate rooftop space for the remaining institutions separately using linear regression.

We use the method outlined in Lorenzo[5] which is also used in Vaishnav et al.[6] to estimate hourly electricity generation at each of the 936 locations for which we have solar irradiance data made available from NREL's TMY3 data. Each school is assigned to the geographically closest TMY3 site and we calculate the power output for the systems installed on each roof for each hour of a typical year. We use the hourly load profiles for "secondary schools" compiled by the U.S. DOE for each of the TMY3 locations. We assume that all electricity generated offsets consumption and that excess generation is sold back to the grid.

The LBNL Tracking the Sun dataset provides information on historical system installation prices representing 85% of all residential and non-residential solar PV systems installed cumulatively through 2015 [7]. We use the data for 2015 projects and focus on school, government, and non-profit installations. Our mean project cost in our reduced dataset is $4,080/kW or $750,600 overall. We use this mean value to estimate project costs for all systems in our combined school building dataset. To determine available rebates, we reference the Database of State Incentives for Renewables and Energy Efficiency (DSIRE). We perform CBAs assuming net-metering is and is not available for each school. Offset electricity consumption is summed for each building for each year and then multiplied by the state-average 2015 commercial retail rate. Electricity sold back to the gird is valued at the hourly state-average LMP for 2015. In a future analysis, we will consider excess generation sold back at the retail rate.

We estimate marginal public benefits as avoided damages from reducing emissions of CO_2, SO_2, NO_x, and $PM_{2.5}$ first by calculating avoided emissions in each eGRID region using techniques outlined in Siler-Evans et al.[8] with 2016 emissions values for each U.S. fossil fuel power plant greater than 25 kW. Next, we translate emissions reductions to damage reductions using two integrated air quality models: AP2 and the EASIUR model [9,10]. We use these models to calculate offset air quality and greenhouse gas damages from a 1 kW system for each TMY3 location for each hour of a year, summed for an annual estimate. This annual estimate is then multiplied by the system capacity for all schools in that particular TMY3 location. Since we assume a 20-year system life, 2017-2035 damages are approximated by 2016 estimates. The CBAs will be completed at the educational institution level and are aggregated at the state-level. We are primarily interested in two CBAs: one with the school as the decision-maker and one with a public policy decision-maker. Costs to the school include the system price minus any available rebates; benefits include the present value of the electricity generated each year that the system is in operation (assuming a 20-yr lifetime). Social costs include any rebates made available to the schools; social benefits include the present value of monetized annual benefits associated with the reduction in CO_2, SO2, NO_x, and $PM_{2.5}$.

Preliminary Results

From the schools for which we have LIDAR data, we estimate a total installed power electricity generation potential of 1,700 GW or 2,500 TWh of annual energy generation. However, NREL found the total national technical potential of rooftop PV to be approximately 1,100 GW of installed capacity or 1,400 TWh of annual energy generation[11]. Therefore, we plan to compare the PV-generation modeling of Gagnon et al.[11] with Vaishnav et al.[6] to see which differences may cause our estimate to be larger. Only considering the schools for which we have LIDAR data and assuming a 7% discount rate for schools and society, we find school net-benefits to be -3,571,000 million USD and we find social net-benefits to be 730,000 million USD. Regional variation in technical potential and societal beneits is depicted in Figure 1.

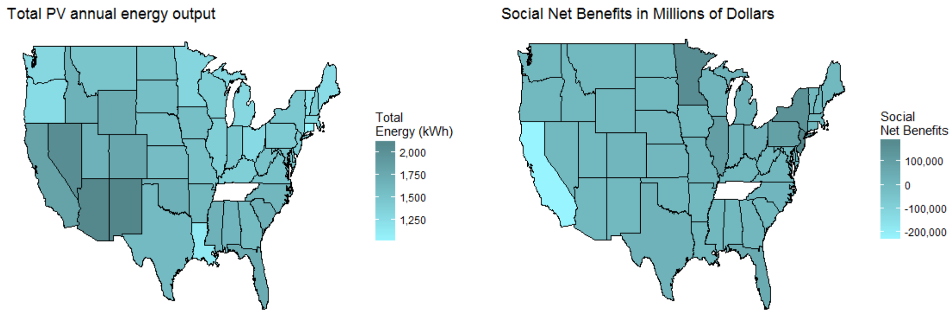

Figure 1. Maps of total PV electricity generation in kWh and total social net benefits in million USD aggregated at the state-level. These maps represent results from the roughly 38,000 schools for which we have LIDAR data.

Conclusions

Preliminary results from roughly 38,000 schools suggest that energy output will be the highest in the Southwest and lowest in New England. Furthermore, solar PV seems to have the highest health and environmental benefits in regions where it's offsetting high-polluting technologies such as coal-fired power plants in the Midwest. These findings follow those from a previous study by Siler-Evans et al.[8]. In the future, we plan to estimate roof space for the remaining school dataset that falls outside of the LIDAR measurements and replicate this analysis for the full dataset of 134,000 schools. We also plan to estimate the annualized per-kilowatt costs and benefits of solar PV systems installed on all educational buildings in the U.S. and perform a sensitivity analysis on the CBAs to determine how results vary in relation to key assumptions (e.g. available rebates).

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