The Economics of Distributed Solar PV: California in International Comparison

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INTRODUCTION

This article gives an overview of the current business case and regulation as well as relevant developments for distributed generation focusing on California as the biggest market for solar installations in the U.S. We then compare these developments with those ongoing in four other distinct legislations and energy systems: Australia, Germany, India, and South Africa. These five locations were chosen because of their diversity to cover a spectrum of geographic, infrastructural and political conditions for residential rooftop PV. We model households for each location in exemplary spots close to main population centers to, as close as possible, represent each location in installation cost and interest rate, insolation and climate profile; San José, Brisbane, Berlin, Kanpur and Melkbosstrand. The simulation then iterates through all possible scenarios to optimize the profitability for each combination of solar and battery capacities. As we aim to analyze the viability of prosumage for an individual investor, we do not consider system effects, i.e. the role of prosumage for total system costs (see Green, 2016; Schill et al., 2017), nor distributional implications.

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See footnotes at end of text.

FUNDAMENTALS

When analyzing the economics of distributed solar, the most influential factors for the economic performance of a rooftop PV system have to be identified first. Lang et al. (2015) clustered the driving factors into three categories: geographic, technological and economic. For geographical influencing factors irradiation is found to be the most significant one. The module type, capacity, orientation, and inclination directly affect the output of the system: Since solar power is the energy source for a PV system, the local irradiation is the key element for a good performance. But it also increases the temperature of the module and hence leads to efficiency losses. Among the technological factors are the design of the building and attributes of the installed module. The size and type of the roof constraints the installed capacity and the possible orientation of the PV system. When modeling the economic performance in times of prosumage, energy demand of the household is a driving technological effect on the achievable rates of self-consumption. If the installed system contains demand side management devices like a battery for storage, up to 24 % higher self-consumption rates and therefore higher returns can be reached (see Luthander et al., 2015). The economic factors cover the investment (module price, battery price, capital costs) and installation costs and the operation and maintenance costs. They also include retail prices that are avoided while self-consuming, and the remuneration when feeding in production surpluses; the higher both factors, the better the overall performance of the system.

SOLAR IN THE U.S. AND CALIFORNIA

Several U.S. states have seen rising installation rates of solar capacity for the past ten years. In general, this is due to favorable regulation, great solar potential because of high insulation and plummeting costs for modules and BOS (balance of system). Figure 2 shows the biggest U.S. solar markets by the absolute rate of installed capacity. While California is by far the biggest market with over three gigawatts of capacity installed in 2015 (this includes residential, commercial and utility scale), several smaller markets with a larger per capita installation also exist. The solar boom was started by regulatory incentives which first made investments in PV systems profitable: In California and many other states these incentives where implemented in the form of "net metering". In this scheme, investors can connect their PV systems to the grid and can either sell the generated electricity or consume it directly. By feeding it in, they roll back their meter and thereby reduce their electricity bill. Self consumption is exempted from taxes and fees. Prosumers can choose to pay their monthly or annual net electricity consumption, users with larger solar systems and small storage can benefit more from yearly net metering because of greater feed in during the summer months. Additionally they receive a tax credit of 30 % of their PV systems cost. This framework resulted in 580,000 solar projects in California since 2006 (see California Energy Commission & California Public Utilities Commission, 2016). Research has shown that a doubling in cumulative installed solar capacity drops the price of modules on average by 23 %. Through massive installation

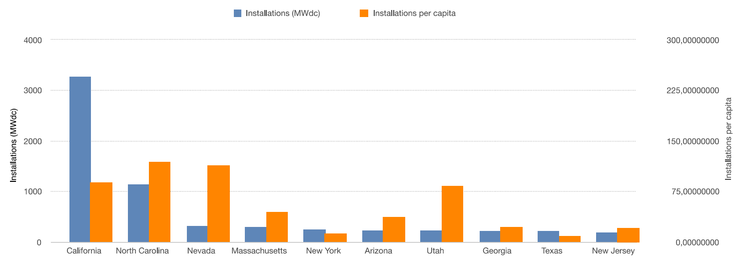

Figure 1: Solar Installations absolute and per Capita in Biggest US Markets 2015

Source: own illustration after SEIA (2016).

because of investment incentives in many jurisdictions world market prices of PV modules have fallen from 3.3 $/kWp to around 0.6 $/kWp of capacity between 2007 and 2017 (see Fraunhofer, 2017). While residential installations in California have slightly dropped after 2015 because of the anticipated end of the net metering program in 2019, installations of commercial systems up to one megawatt under net metering are not affected by this trend and are rising (see Figure 2). This could indicate an increasing independence of the prosumage business case from net metering due to steadily sinking module costs, which should eventually cause further increase in residential installations. The Californian utilities already offer Time-of-Use (TOU) pricing schemes. A TOU pricing reflects the current price of electricity and reflects the balance between supply and demand. Hence, prosumers are incentivized under this scheme to feed in when supply is low and demand is high (high electricity prices). New incentive policies will likely aim in a similar direction (see PG&E, 2016a). PV systems with storage capabilities for load shifting could become the most profitable investment under these new policies.

THE CURRENT BUSINESS CASE IN CALIFORNIA

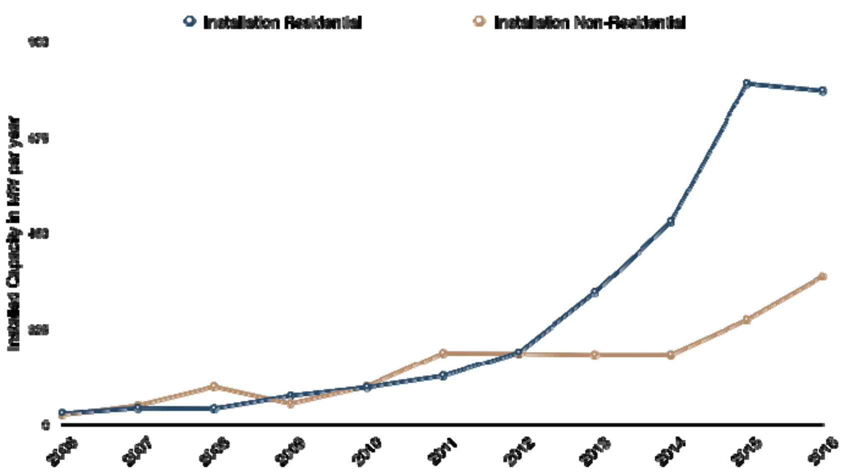

Figure 2: Yearly Residential and Non-Residential Solar Installations under Net Metering in California

Source: own illustration after Public Utilities Commission (2016).

When looking at a simplified investment decision example in rooftop PV the potential investor determines if the expected income per unit of electricity will exceed the levelised cost of electricity (LCOE)[1] of the PV system. The returns can be either selling the generated electricity or avoiding the electricity retail price when consuming it directly. Hence, an investor in California under the net metering policy would compare the LCOE of a PV system with the expected retail price which would be earned when feeding in or avoid by self consumption. If the retail price is expected to be higher until the costs are amortized, the investment is profitable.

The time of day or market demand currently does not affect the electricity retail price; additionally, most electricity retailers in California have multiple (PG&E has 3) pricing brackets for electricity to promote energy efficiency: Energy used above the baseline allowance is in tier 2 and billed at a higher price, even higher consumption is in tier 3 and billed accordingly. The tiers are not fixed but need to be calculated for each household based on their baseline territory (see California Energy Commission & California Public Utilities Commission, 2016). Especially smaller PV systems without storage are incentivized by this situation, because the avoided electricity price when self-consuming or feeding in is invariable over time, equal to the retail price and decreases when reaching lower pricing brackets. Ony the netto consumption is relevant. The highest rates of return can therefore be achieved by shaving the upper brackets with a small PV system without storage.

For a representative Californian household in San Jose, the consumption allowance for tier one pricing would be 9.3 kWh per day in summer and 16.7 kWh in winter (see PG&E, 2016b). These allowances are determined by region and multiplied by the amount of days in the current monthly billing period. San Jose is located in region "X" (the 12 grid regions in California are historical legacy and are labeled alphabetically) which covers the area of PG&E's operational territory (see PG&E, 1990). The tier prices for this household would be 18.35 $ct/kWh, 24.28 $ct/kWh and 40.31 $ct/kWh for tier 1, 2 and 3 respectively (see PG&E, 2016b) and the therefrom calculated PV LCOE is at around 22,85 $ct/kWh (for the values used, please see appendix). Given the household consumes enough electricity to reach the higher tiers of this rate structure the real return could be maximized by only shaving of the highest tier consumption with net metering. In practice, the LCOE drops for bigger installations due to static costs for installation and electronics, which makes it more profitable to shave both of the top tiers. The average plant size in California between 2014 and 2016 of 5,48 kWp reflects that calculation (see Public Utilities Commission, 2016). Currently, home owners in California are deterred by the uncertain future of the net metering program after 2019 (see California Energy Commission & California Public Utilities Commission, 2016), which means that the retail prices are only known for a fraction of the lifetime of the PV system, which are usually assumed to be twenty years for the LCOE calculation. This uncertainty decreases the potential profitability for small plants and is most likely the reason for the stagnating installation count. For commercial and utility scale plants with far lower LCOE this apparently does not apply, since installations continously increase for this segment (see appendix for details).

INTERNATIONAL COMPARISON

Method

We now compare the LCOE of residential PV in California with four other locations, using production data generated by the website "www.renewables.njna" by Pfenninger and Staffell (see Pfenninger, Staffell, 2016; Staffell, Pfenninger, 2016) for each location. To generate comparable data that can be scaled to each of the observed system sizes we generate the data for a system of 1 kWp, without any tracking capabilities, and oriented optimally i.e. to the south on the northern hemisphere, and to the north in the southern hemisphere, as well as optimal tilt. An internal system loss of 10 % is assumed. The calculation takes into account PV-inverters as well as installation costs for each examined location. PV panels are assumed to cost 46 €ct/kWp after tariffs for each country which is the price of European panels in Europe as well as Chinese panels after import and penal tariffs (see pvxchange, 2017). The prices are then multiplied by the sales tax rate at each location.

To have a representative grasp on inverter costs for different sizes of PV and storage systems the products examine of world market leader for inverters and similar equipment "SMA Technologies" (see Munsell, 2016) are examined. The PV inverter required was determined for PV capacities from 1.5 kWp to 10 kWp in steps of 0.5 kWp. It is assumed that the maximum capacity of the PV inverter needs to be greater or equal to the capacity of the solar installation.

Installation costs in Germany, California and Australia were sourced from the Rocky Mountain Institute Paper (see Calhoun et al., 2014). Installation Costs for India and South Africa were approximated by sourcing hourly labor costs for all five countries (see Labour Organization, 2017).[2] Then the factor between mean hourly labor costs in Germany, Australia and California and the mean hourly installation costs in these three countries was calculated to account for differences in pay for this kind of specialized labor. This factor was then applied to Indian and South African hourly labor costs. They were then multiplied by the median installation time per kWp of the other three countries, which is Australia's 6.1 h/kWp to arrive at installation costs per kWp, same as for the other three countries. To take taxes for labor into account, the costs were multiplied with the sales tax rate. Also, costs for cable and other installation material have to be considered. We assumed 10 % of the total costs to reflect those.

The interest rates in each location except Germany were derived by calculating the mean interest rates on home loans of the four largest banks in each country. For Germany the interest rate of the government owned KfW bank, which offers low interest rates specifically for solar installations, are taken as input.

RESULTS

Figure 3 shows the results of the LCOE calculation of residential PV (exchange rate euro to usd 1:1.1). The LCOE might not differ much on first sight, but the conditions for investments into own generation differ significantly between the countries, and thus can't be generalized. The cost of capital can outweigh efficiency gains and per unit cost reductions (such as in India), whereas a stable institutional environment is worth a lot (case of Germany so far).

Figure 3: LCOE of PV in Selected Places
Source: Own calculation (see appendix).

Just like California, Germany represents a large-scale, highly interconnected energy system, with high penetration of solar PV and increasing privately owned storage. Both have set similar renewables standards (~ 50 % share by 2030), but California has a significantly higher solar intensity (see EEI, 2016; Fraunhofer, 2016). Australia is probably the most interesting developed country for prosumage due to its low population density and favorable insolation profiles across the country. India's government has set 100 GW and 40 GW of grid-connected and rooftop solar PV respectively as a goal for 2022 (see IEA, 2015) as it needs both grid-connected and off-grid electricity. Thus, India might see the fastest increase of prosumage. South Africa too, has ambitious plans for PV development and excellent natural conditions, although the economic case for prosumage is not yet evident, given highly subsidized retail prices and ongoing investments into coal and nuclear power. The sharp decline in prices for PV components and the simultaneous rise of retail prices lead to grid parity in an increasing number of places (see IEA, 2014).

OUTLOOK

Besides a rapid price drop of PV module prices, smarter generation and storage will shape the future of prosumage. Ongoing innovation of solar modules is reforming solar generation, exemplary the company SolarCity introduced solar cells integrated into roof shingles. The so called Solar Roof is marketed with costing equally or even less than a conventional roof (see Elon Musk Solar City, 2016).

Storage has great potential to expand. Battery storage might surpass hydro in the coming years. In the past, battery innovation was largely focused on making batteries lighter and smaller for electric vehicles (EV), less on making them cheaper and more powerful. The rise of EV and the advent of so called “gigafactories”, very large factory-plants which are designed to minimize the production cost of cells via economies of scale, yield improvements in battery production.

Net Metering has impacted the energy landscape in California and other parts of the world. Although the immense growth of solar in these places in the past five years can mostly be attributed to support schemes and residential installation currently stagnating as the end of the program approaches, the trend will most likely continue with different or without such regulation, as technological advances and economies of scale further decrease prices for PV and storage. The growing affordability of EV and the market entry of new products such as the Solar Roof and similar products will enable prosumers to leverage synergistic effects between electric transportation, heating, cooling, home improvement or renovation, and prosumage. This will result in a further increase in rates of return and a higher degree of independence from the grid and therefore regulation. As a result of these developments we believe that prosumage will grow in California, other U.S. states, and the considered jurisdictions to become an increasingly important factor in the energy systems of those countries.

Footnotes

[1] The LCOE is a method to measure the total production costs of one unit of electricity a certain power generating asset provides. This implies that the investment will exactly break-even at the end of its lifetime if the generated electricity is always sold for the LCOE (including the risk-adjusted interest rates of an investor).

[2] Indian data had to be substituted with values from Sri Lanka, due to data being not up to date.

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APPENDIX

Location	Germany Berlin	California San Jose	India Kanpur	South Africa Cape Town/ Melkbosstrand	Australia Brisbane
Capacity Ftr.	0.13	0.185	0.176	0.23	0.21
Discount Rate	1.5 %	5.22 %	9.15%	15%	3.32%
Labor Cost per Hour in €	38.4	47.8	0.37	9.85	54.13
Hours per KWp	4.3	9.4	6.1	6.1	6.1
Panel Price in € per Wp	0.60	0.548	0.579	0.576	0.556
Inverter Price per KwP (5 kWp Inastallation) in €	279.8	279.8	279.8	279.8	279.8
Wiring, Mounting Etc.	10% of Total Costs	10% of Total Costs	10% of Total Costs	10% of Total Costs	10% of Total Costs
Conversion Rate Eur/Usd	1.1	1.1	1.1	1.1	1.1
Total Initial Costs per kWP in USD	$1.304,90	$1.589,86	$1.042,72	$1.119,40	$1.451,53

LCOE Calculation