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Supply and Demand Constraints on Future PV Power in the USA

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***Abstract* — An economic analysis with a defined uncertainty range is presented that considers whether the future deployment of utility-scale PV (UPV) systems in the USA will be limited by the supply of PV modules or by market demand for these systems. An analysis of global PV module manufacturing growth and the fraction of modules produced that will be available for installation in the USA gives a plausible range of cumulative capacity for the UPV segment of 50 – 170 GW in 2030 and 60 – 500 GW in 2040. A parallel analysis of the future demand for UPV systems in the USA indicates a plausible range for cumulative capacity of 80 – 230 GW in 2030 and 150 – 530 GW in 2040. The plausible ranges for supply and demand substantially overlap in both 2030 and 2040, suggesting that neither supply nor demand is more likely to limit PV deployment in the USA. Consequently, mechanisms for enabling growth in both supply *and* demand can benefit efforts intended to increase the deployment of PV in the USA.**

***Index Terms* — photovoltaics, strategy, USA, utility-scale**

I. Introduction

The adoption of photovoltaic (PV) solar power in the USA may be constrained either by the supply of appropriate products or by the market demand for those products. Supply and demand are both affected by price. Higher margins promote growth of the supply chain, while lower prices promote growth of market demand. Supply and demand are thus inextricably linked and must both be considered in strategic planning.

The analysis reported here compares the plausible range (based on our assumptions) for deployment of utility-scale photovoltaics (UPV) in the USA from a supply perspective and from a demand perspective. The PV module supply constraints are drawn from [1]. The PV system demand constraints are based on scenario analysis using the ReEDS model [2]. Further details on the models from [1] and [2] are provided in Section II and Section IV, respectively. The supply constraints arise from the high capital investment required to grow the PV module manufacturing supply chain. The demand constraints arise from competition with other sources for electricity supply. The manufacturing supply analysis was global in scope, whereas the market demand analysis was for the contiguous USA. To compare the supply and demand of UPV using the two models, it is necessary to estimate the fraction of global module shipments that will be deployed in the USA.

Fig. 1 illustrates the logic flow used to compare the supply and demand constraints. In each block shown, there is considerable uncertainty in one or more key parameters. We attempt to bound this uncertainty by defining low and high limits of "surprise" for these key parameters. In order to capture a fairly wide range, we assign these limits to the 10^{th} and 90^{th} percentiles of a normal probability distribution (i.e. the edges of the 80% confidence interval). The future evolution of PV deployment predicted by this model is also probabilistic, producing a range of outcomes that can be considered "plausible," and beyond which would be "surprising."

The following sections address each of the blocks in Fig. 1, from left to right.

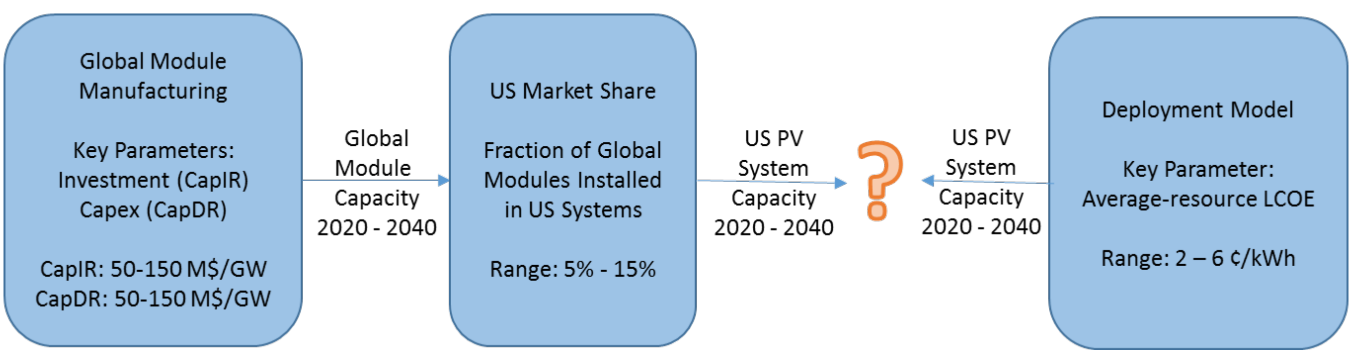

Fig. 1. Logic flow for applying the constraints of supply (left) and demand (right). The plausible ranges shown are the limits of surprise.

II. GLOBAL MODULE MANUFACTURING

The evolution of global module manufacturing capacity depends on how much capital is invested each year in supply-chain capacity and how much that new capacity costs (capex). If a given level of manufacturing capacity is to be sustained, annual investment in supply-chain capacity must be sufficient to replace existing capacity as it reaches end-of-life. Recently, the capital investment rate (CapIR) of $75M/yr for each GW/yr of production capacity ($75M/GW) is only about half of what is required to maintain manufacturing capacity, which we call the capital demand rate (CapDR, currently $150M/yr per GW/yr of production capacity) [1]. If CapIR is greater than CapDR (level of investment is greater than the cost of maintaining the current level of manufacturing capacity), manufacturing capacity will increase, while the opposite happens if CapIR is less than CapDR.

It would be surprising if the future investment rate dropped below $50M/GW, as that would lead to a rapid collapse of the industry. It would also be surprising if the investment rate more than doubled. It would be surprising for capital demand rate to increase, but equally surprising for it to fall below one-third of its current value. The nominal expectation is that the industry will achieve marginal sustainability, with investment rate and capital demand rate converging in the vicinity of $100M/GW.

The spreadsheet referenced in [1] uses annual PV module manufacturing capacity calculations to determine the cumulative amount of PV modules deployed in service versus time, assuming that all PV modules produced are deployed and accounting for the decommissioning of deployed PV systems at their end-of-life. Fig. 2 illustrates this calculated future global in-service PV module generation capacity (GW_{dc}) for four cases, from top to bottom:

(a) CapIR doubles ($150M/GW), CapDR drops ($50M/GW)

(b) CapIR doubles ($150M/GW), CapDR same ($150M/GW)

(c) CapIR drops ($50M/GW), CapDR drops ($50M/GW)

(d) CapIR drops ($50M/GW), CapDR same ($150M/GW)

In all cases, the investment and capital demand rates are assumed to ramp linearly to their new value over the period 2015 – 2030 and then remain stable through 2040. The average service life of deployed modules is assumed to ramp from 25 years in 2015 to 40 years in 2030 and then remain stable through 2040. The only one of these four scenarios that yields rapid growth (top curve) combines increased investment with reduced capex. In this high-growth scenario, we constrain supply-chain capacity expansion in later years in order to maintain 80% plant utilization.

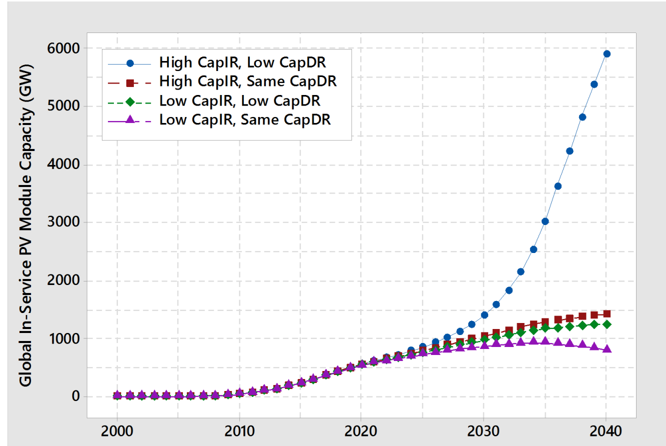

Fig. 2. Evolution of global PV module generation capacity for four combinations of investment rate and capital demand rate.

Fig. 2 can be used to estimate the plausible limits on future global in-service PV module capacity. Assuming that CapIR and CapDR are statistically independent quantities, then the plausible range (80% confidence interval) for global in-service capacity is as shown in Table I. The upper plausible limit is less than the top curve in Fig. 2 because that curve requires both CapIR and CapDR to achieve their limits of surprise. Such an outcome is possible, but would be "doubly surprising" and thus falls outside the surprise limit.

TABLE I

PLAUSIBLE RANGE FOR SUPPLY-LIMITED GLOBAL IN-SERVICE PV MODULE GENERATION CAPACITY FOR THE YEAR INDICATED

2030	2040
890 – 1270 GW_{dc}	730 – 4400 GW_{dc}

III. U.S. MARKET SHARE

According to the International Energy Agency [3], global cumulative PV module shipments through 2015 were 228 GW. Of this, 6.1% was installed in U.S. UPV systems. In 2015 alone, 8.2% of the global module shipment of 50.7 GW_{dc} was installed in U.S. UPV systems. In the next two decades, we specify the low and high limits of surprise for U.S. market share by assuming that the fraction of cumulative global module capacity installed in U.S. UPV systems will not drop below 5%, or exceed 15%, thus defining a plausible future range for cumulative U.S. UPV market share of 5 – 15%.

U.S. generation capacity is equal to global in-service module capacity times the U.S. market share. The U.S. market share is not expected to be strongly correlated to global capacity, so these two factors can be treated as statistically independent. Table II lists the plausible range (80% confidence interval) for the product of global capacity times U.S. UPV market share.

TABLE II

PLAUSIBLE RANGE FOR SUPPLY-LIMITED UPV GENERATION CAPACITY IN THE USA FOR THE YEAR INDICATED, WITHOUT CONSIDERING DEMAND CONSTRAINTS

2030	2040
50 – 170 GW_{dc}	60 – 500 GW_{dc}

IV. DEPLOYMENT MODEL

The National Renewable Energy Laboratory (NREL) has developed the Regional Energy Deployment System (ReEDS) [4] to model the influence of policies, technology, and economic developments on the evolution of the electricity generation portfolio in the contiguous USA. The model deploys new electric generating capacity, transmission capacity, and energy storage capacity as they are required to meet growth in demand, to replace power plants scheduled for retirement, and to fulfill policy requirements. The model selects new capacity from all available renewable and non-renewable options to minimize the total system cost for the nation as a whole. Regulatory constraints and incentives as they are currently enacted into law are incorporated, but no additional future constraints or incentives are assumed.

The ReEDS was run for numerous scenarios associated with what we deem to be plausible future cost reductions for PV systems. The scenarios incorporated policies that were current as of summer 2016. The output, shown in Table III, provides an indication of the market demand for UPV systems in the USA as a function of the system cost, summarized here by the levelized cost of electricity (LCOE) for a typical UPV system in a location with average U.S. solar resource (LCOE is used here as a summary metric. It not used by the model to project adoption [4].). The PV system cost was assumed to gradually decline to the value indicated in 2030 and remain at that level thereafter (in 2016 U.S. dollars). All non-solar generation technologies and energy storage technologies assumed cost trajectories from NREL's Annual Technology Baseline (ATB) [5]. The column in Table III labeled ATB is the ATB Mid-Case Scenario, which has UPV average-resource LCOE at 6¢/kWh in 2030 and 5½¢/kWh in 2040.

TABLE III
REEDS DEPLOYMENT CALCULATION FOR UPV IN THE USA FOR PLAUSIBLE VALUES OF AVERAGE-RESOURCE LCOE ACHIEVED IN 2030

Avg-Resource LCOE (/kWh)	2¢	3¢	4¢	ATB
2030 Deployment (GW_{dc})	230	209	167	81
2030 U.S. Electricity Portion	10%	9%	7%	4%
2040 Deployment (GW_{dc})	531	435	313	148
2040 U.S. Electricity Portion	19%	16%	12%	6%

V. COMPARING SUPPLY AND DEMAND

The plausible deployment range based on supply (Table II) and the plausible range based on demand (Table III) can be seen to substantially overlap in both 2030 and 2040. The overlap indicates deployment levels that are plausible from both the supply perspective presented here and the demand perspective presented here. The joint probability for a given level of deployment, considering both supply and demand constraints, is the product of the supply and demand probability values at that level of deployment. This is illustrated in Fig. 3 for 2030 and in Fig. 4 for 2040. For comparison, UPV capacity in the USA at mid-2017 is approximately 25 GW_{dc}.

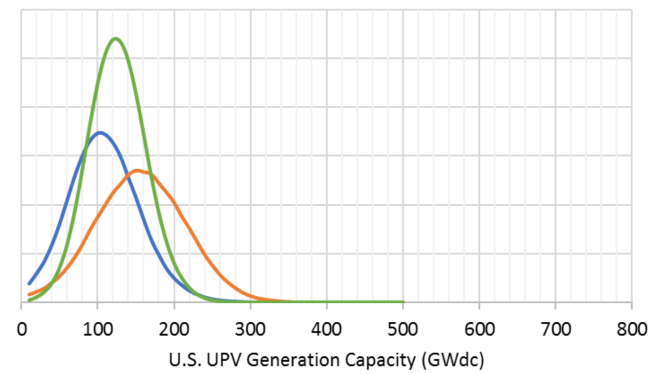

Fig. 3. Probability distributions for supply (blue) and demand (orange) constraints on U.S. UPV deployment in 2030. The product (green) is the joint probability considering both supply and demand constraints.

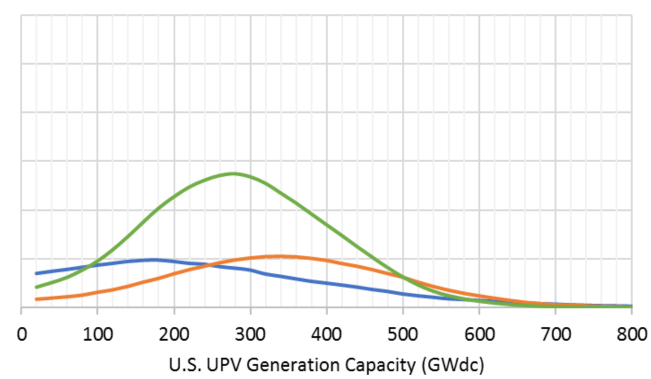

Fig. 4. Probability distributions for supply (blue) and demand (orange) constraints on U.S. UPV deployment in 2040. The product (green) is the joint probability considering both supply and demand constraints.

The resulting plausible range for U.S. UPV deployment in 2030 and 2040, considering both supply and demand constraints, is given in Table IV. Based on the ReEDS calculation shown in Table III, this level of deployment corresponds to UPV supplying roughly 5% of U.S. electricity in 2030 and 10% in 2040.

TABLE IV

PLAUSIBLE RANGE OF FUTURE U.S. UPV GENERATION CAPACITY CONSIDERING BOTH SUPPLY AND DEMAND CONSTRAINTS

	2030	2040
Deployment (GW_{dc})	70 – 170	120 – 440
U.S. Electricity Portion	3% – 7%	5% – 16%

The figures in Table IV do not include electricity generated by distributed photovoltaic systems (residential or commercial). The deployment of distributed PV (DPV) in the USA is currently similar to UPV. If that ratio is maintained in the future, then UPV and DPV together could supply roughly 10% of U.S. electricity in 2030 and 20% in 2040.

If greater PV deployment is desired, but is limited by supply of modules, a strategy for increasing PV deployment should focus on helping the module supply chain become more attractive for investment, for example by reducing capex and other manufacturing costs. On the other hand, if PV installations become limited by demand, a strategy for increasing PV deployment should focus on helping PV project developers deploy more systems, for example by reducing project costs and other barriers to deployment. Our results indicate that UPV generation capacity in the USA could plausibly be constrained by either supply or demand. Consequently, mechanisms for enabling growth in both supply *and* demand can benefit efforts intended to increase the deployment of PV in the USA.

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