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Reflections on Power Generation

From civilizations across history which have venerated the Sun's phenomenal power, to the filing of the first U.S. Patent for harnessing light for photovoltaic power in 1913 (W. Coblentz, US1077219A). These efforts underscore and indicate a strong desire, perhaps common to humans across time, to capture the Sun's power. Today, due to research innovations and government incentives, humanity has been the most successful (in terms of GW) in harnessing energy from the Sun. Future projections see the expansion of renewable energy sources, including wind and Solar, and to meet the goals set to counteract human caused climate effects, obstacles to deployment must be overcome at a rapid rate within the next decade.

In their initial development stages, PV systems were expensive, inefficient, and faced a dubious public. As the 2010's went along, solar cell technologies increased 10% in efficiency and thus dropped dramatically in price [1]. This growth culminated with 2020's rate of installation of 19 GW of PV, the highest rate of new PV installations ever recorded in the United States - providing a cumulative total of 97 GW, enough to power 17 million homes, according to SEIA [2]. This, however, has not been a uniform trend across all of the U.S. states, with a large proportion of new installations concentrated across California and Northeast states (MA, NH, VT), with the U.S. south and midwest distinctly lacking [Figure 1, Berkeley Lab]. There are a variety of reasons for this disparity in installation including unequal solar irradiation rates, existing alternative energy production methods, lack of incentive for adoption, existing incentives for conventional fossil fuel power generation,

Historically, and currently, most of America's power generation comes from natural gas processing, representing more than 40% of all power generated [3]. However, a goal commonly brought up in discussions on reaching net-zero carbon emissions is striving for a diversified power grid - made up of various sources of renewable electricity generation to produce a larger share of total power generated. Since 2010, the share of energy generation comprising PV has risen about to 5% [1]. However, as mentioned above, this has not been entirely uniform and faces unique challenges in expanding scale - much of which is the focus of utility scale installation. This disparity can be seen to different degrees in the domestic and international context of expanding adoption of photovoltaics for power generation.

Currently, due to favorable price points and government incentives [4], utility scale photovoltaics (>10MW) are where the greatest expansion and adoption has been seen. Utility scale has been broadly described as the short-term move toward reaching the long-term goal of net-zero carbon emissions - recommending an installation rate of 30 GW of renewables a year. The challenges rise with determining price points for government incentives, such that attracts investors that are both competitive and competent. A paper by development bankers studies and gives recommendations for sustainable energy financing, both in areas which are developing their energy infrastructures [5]. They advise a delicate balance must be achieved between taking on risks away from investors (thus attracting competitive investments) and between achieving low-cost outcomes for consumers in the short and long term. However, achieving a favorable price point for the technology shouldn't be the only consideration - but the actual deployment itself. Historically [6], the emphasis of energy development begins with identifying energy poverty, then building infrastructure as part of industrialization. Focus then goes to expanding access to all before tackling the environmental issues, such as pollution, that arises with expanded energy use and consumption. Indeed, special considerations and a consistent feedback loop of needs from society should be a necessary inclusion to expanding the deployment of PV.

National Renewable Energy Laboratory, NREL, lays out a few policy adoption scenarios ranging from conservative to advanced - detailing impacts for each scenario across various parameters (module cost, installation efficiencies, and energy yield) [7]. Table 1 in the Appendix lists future year projections derived from benchmarking of PV capital expenditures and engineering analysis of Operation & Management costs. These scenarios serve to highlight the complexity of the energy markets through the lens of policy and research investment.

While many of the new moves in the solar market are predominantly in the commercial / utility scale, the impacts of the wide adoption of rooftop photovoltaics among residential sites should not be understated. If adoption of rooftop PV in the US were more equitable, NREL estimates that the total of all building rooftops in the US hold a potential PV capacity of 1,118 GW, comprising nearly 40% of the total national electric-sector [7,8].

The potential of rooftop solar can be seen in a data science study estimating the full electricity-generation potential from a wide adoption of PV systems across all households in Beirut, Lebanon [9]. The study identified a potential PV capacity of 200 MW - 300 MW assuming full adoption across all viable rooftops in the city of Beirut - enough to power over 140,000 homes. However, with adoption rates below 1%, the researchers identified the barriers to wide deployment of Rooftop PV. The biggest impacts were seen in changes achieved through artificially lowering the electricity tariff subsidy, although this option remains constrained due to policy.

Additionally, an article studying barriers for PV adoption in Chile identified suitable promotion energy policies, regulatory changes, and financing options can drive PV deployment at a minimal impact on the government budget. [10] These options would give opportunities to the people to accelerate decarbonization with a decentralized energy transition. The researchers point out socio-economic and socio-environmental benefits, based on solar PV technology, would also aid in democratization of the energy sector.

Internationally, expansion of renewables can be a form of energy independence and autonomy. The lasting legacy of global colonialism has resulted in poverty, political corruption, conflict, lack of investment in critical infrastructure, and the depletion of natural resources across the African continent. In the case of South Africa- rising population has seen demand for electricity rise as well. As of 2017, South Africa's installed electricity capacity was about 53 gigawatts which was enough to electrify ~90% of households in 2016, leading the continent in electrification rates. [11]

However, failing electricity infrastructure and slim margins between power generation and peak demand have resulted in nearly a decade of continuous load-shedding - the intentional interruption to the power supply instituted by electricity regulators in order to prevent a total collapse of the national grid. Other than the effects on daily life (which impacts working, farming, cooking, studying, etc.), the World Bank estimates the GDP of sub-Saharan countries shrinks by 2 percent as a result of load-shedding alone.

Indeed, in 2020 South Africa spent more than 850 hours of load shedding - the equivalent to 10% of the year spent without electricity [12]. In order to produce more power, South African Energy Minister Gwede Mantashe last week announced the results of a new investment program. 50% of power would be distributed among new coal, renewable (PV and Wind), liquified natural gas, and geothermal facilities - and 50% would be imported from floating natural gas power plants known as Powerships, operated by Turkish company Karpowership [13]. While these are touted as a short term solution until the full implementation of the new long term power sources - they have proven in the past to be prohibitively expensive and massive sources of offshore pollution. In Sudan, a 150MW of power from the Turkish Karadeniz Powership was abruptly cut-off when the Sudanese government failed to pay the bill, leading to health problems, food insecurity, and economic losses [14]. These considerations underscore the significant challenges the developing world faces in the transition toward renewable power generation sources. A research paper discussing the viability of the idea of economy-wide energy leapfrogging [15], the concept of the ability for developing countries to bypass the conventional power generation methods utilized in the past by already developed countries to build their infrastructure. However, an analysis of energy diversification in Sub-saharan Africa [16], finds that it is more likely that African countries will utilize the multiple-use energy model, where conventional fossil fuel based systems still dominate (Figure 2).

While the world mobilizes and struggles to meet our sustainable climate goals, the expansion and adoption of PV technologies is a multifaceted problem with no one-size-fits-all solution - either domestically or internationally. However, rapid adoption trends leading up to this past year give hope that a sustainable future is possible.

Appendix

Table 1: Scenario Descriptions, Solar Adoption by Policy Scenario, NREL, 2020 [11]

Scenario	Module Efficiency[1]	Inverter and Power Electronics	Installation Efficiencies	Energy Yield Gain[1]
Conservative	**Technology Description:** Tariffs expire, as scheduled, though some form of friction still remains, keeping U.S. panel pricing halfway between current U.S. and global pricing. Efficiency gains for panels are consistent with one standard deviation below International Technology Roadmap for Photovoltaic (ITRPV—an annual document prepared by 55 leading international poly-Si producers, wafer suppliers, c-Si solar cell manufacturers, module manufacturers, PV equipment suppliers, and production material providers, as well as PV research institutes and consultants) to 2030for PERC n-type mono module; well below historical mono average gains and below leveling off point (21.5%) -$0.30/WDC **Justification:**Represents the low end of manufacture expectations and additional friction despite the scheduled removal of the tariffs.	**Technology Description:** Larger market size **Justification:** global PV industry expected to continue to expand	n/s	n/a
Moderate	Technology Description: Tariffs expire, as scheduled, and efficiency gains consistent with median ITRPV roadmap to 2030for PERC n-type mono module; well below historical mono average gains and below leveling off point (22.5%)	**Technology Description:** Design simplification and manufacturing automation	**Technology Description:** 30% labor cost improvements through automation, pre-assembly efficiencies, and	**Technology Description:** 6% energy gain (5% energy yield gain at module), lower system losses, and degradation rate

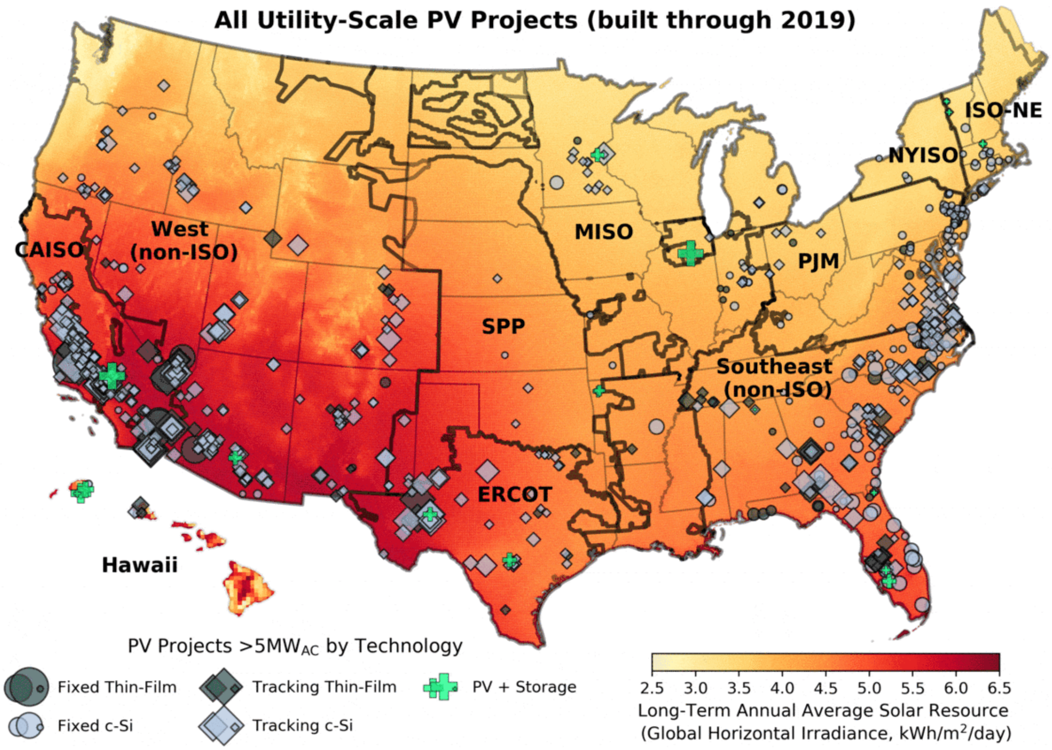
	-$0.19/W Justification:Represents manufacture expectations for 2030.	**Justification:** industry currently switching to this practice.	improvements in wind load design **Justification:** represents lower levels of improvement than historical average (Feldman et al. Forthcoming). With increased global deployment and more efficient supply chain, pre-assembly is possible. Development of best practices for permitting interconnection and PV installation, such as subdivision regulations, new construction guidelines, and design requirements.	reduction from 0.7%/yr to 0.5%/yr **Justification:** Significant R&D is currently spent on improved cell temperatures, and lower degradation rates. Companies will likely continue to focus on improved uptime to maximize profitability, and bifacial modules are already becoming a significant part of the global and U.S. supply chain. ITRPV estimates bifacial module's world market share will grow from 10% in 2018 to over 60% by 2030.. Industry participants have already demonstrated bifacial energy gain of 5%-33%, depending on module m
Advanced	**Technology Description:** Modules maintain historical average of 0.5% improvement per year (25%) -$0.17/W **Justification:** Manufactures reported that mass produced cell efficiencies will increase from 20%-23% in 2018 to 21%-24% by 2021. Mass production-monocrystalline and silicon heterojunctionhave already achieved cell efficiency records in a laboratory of 26.1% and 26.7% respectively.	**Technology Description:**Design simplification and manufacturing automation **Justification:** power electronics industry already has roadmaps to do simply and automate for current products and there is more potential with increased industry size.	**Technology Description:**40% labor cost improvements through automation and pre-assembly efficiencies; the use of low-cost carbon fiber cuts mounting costs **Justification:** represents lower levels of improvement than historical average (Feldman et al. Forthcoming). With increased global deployment and more efficient supply chain, pre-assembly is possible. Reduction of supply chain margins (e.g., profit and overhead charged by suppliers, manufacturers, distributors, and	**Technology Description:** 13% energy gain (10% energy yield gain at module), lower system losses, and degradation rate reduction from 0.7%/yr to 0.2%/yr **Justification:** In addition to the justification above, industry participants have already demonstrated bifacial energy gain of 5%-33%, depending on modu

			retailers), will likely occur naturally as the U.S. PV industry grows and matures. Additionally, streamlining of installation practices through improved workforce development and training and developing standardized PV hardware	
Impact	Lower module cost, per watt Reductions in PV system labor and BOS material, shipping, and warehousing	Reduced costs Higher efficiency power conversion	Lower costs Fewer building errors	Higher capacity factors
References	(ITRPV Forthcoming) (Fuscher and Bruno 2016; 2016) NREL, "Best Research-Cell Efficiencies (Rev. 04-06-20)" (Barbose and Darghouth 2019) (Feldman et al. Forthcoming)	(Feldman et al. Forthcoming)	(Feldman et al. Forthcoming) (Satpathy, n.d.)	(Satpathy, n.d.)

Future year projections are derived from bottom-up benchmarking of PV CAPEX and bottom-up engineering analysis of O&M costs. Three projections are developed for scenario modeling as bounding levels:

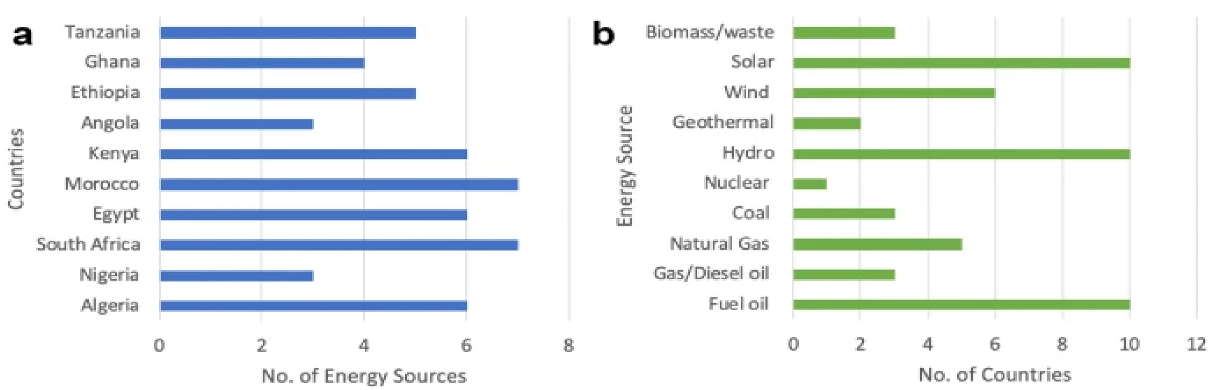
- **Conservative Scenario:** lower levels of R&D investment with minimal technology advancement and current global module pricing
- **Moderate Scenario:** assume R&D investment continuing at similar levels as today, with no substantial innovations or new technologies introduced to the market
- **Advanced Scenario:** an increase in R&D spending that generates substantial innovation, allowing historical rates of development to continue.

Figure 1: Utility-Scale PV Projects (thru 2019, Berkeley Lab)



Source: Berkeley Lab.

Figure 2: Energy Source per country in Africa



New forms of REs (non-hydro in particular) are increasingly gaining traction in the energy mix though conventional energy sources have not been replaced.

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