Utility-scale Solar Construction Waste Stream Mitigation and Potential Repurposed Use of Photovoltaic Modules

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Abstract: This paper presents a quantitative analysis of the utility-scale solar construction waste stream and the identification of potential use items within that waste stream. The purpose of the analysis is to understand the total renewable energy loss due to current construction practices and invite consideration of potentially mitigating these modules from the waste stream as demand for solar energy continues to grow nationwide. This analysis conducted onsite evaluations of photovoltaic (PV) modules in the construction waste stream of 2 utility-scale solar projects totaling 90MW of renewable energy. The investigation concluded that 15 – 20% of the PV module waste stream could be categorized as still functional. Typical utility-scale construction breakage rates for commercial-grade PV modules is 0.3 – 0.6% of the total installed PV modules. When assessing the potential waste stream mitigation of these modules, just one utility-scale solar project is sending hundreds of functional PV modules to landfills that can still produce renewable energy. Going further, the data collected in this study, when applied to the entire US annual solar install capacity, solar construction companies are sending tens of thousands of functional PV solar modules into landfills across the US. These results invite solar EPCs, Owners, & Manufacturers to reassess the value of these modules and amend construction practices or warranty standards to focus on this valuable solar asset.

None of the material in this paper has been published or is under consideration elsewhere.

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1 Introduction

It is now broadly accepted that anthropogenic climate change will be one of the greatest challenges facing mankind in the 21st century, putting our health, economy, communities, and the ecosystem at risk ("5th IPCC Assessment Report" 2014) (Moss, 2010). The significance of anthropogenic climate change, its impact on the earth and our society will be determined by our ability to adapt to this change and how mankind responds to this challenge with regulations, policies, technology, and the development of a society that does not continue to exacerbate the effects of climate change. Utility-scale solar energy is poised to be a linchpin technology in this response to climate change by providing an inexpensive, low risk, renewable energy source. Recent "future road mapping" of the US energy infrastructure, in response to the need to reduce greenhouse gas (GHG) emissions, shows that a plan for 80% renewable energy by 2030 and 100% renewable energy by 2050 is indeed possible (Jacobson, et al., 2015). Utility-scale solar energy would make up approximately 31%+ of our renewable energy needs with another 14 – 19% coming in other forms of solar energy (Jacobson, et al., 2015). According to the US Energy Information Administration, in 2018, solar energy contributed approximately 1.6-2% of our energy budget at 67 billion kWh (EIA, 2019). Jacobson's plan would require developing hundreds of millions of MWs of utility-scale solar projects over the coming decades. However, this will need to be done in an environmentally conscious and sustainable manner. Components of solar energy production that have a substantial environmental impact are the construction process used to build these facilities, and the waste stream. Industry practice cites a 0.3-0.6% module breakage rate as part of module purchase estimates for construction; this includes everything from shipping to installation ("Vivo Power US, Rick Borry - Executive Director, Personal Communication"). When an individual solar project has hundreds of thousands of modules, the referenced breakage rate represents thousands of PV modules entering the waste stream. The waste stream from solar projects is not quantitatively different than that in other common commercial construction processes. As the solar industry continues to grow, refining construction processes will help to reduce environmental impacts, reduce cost, and increase efficiency during development and construction.

2 Current Construction Processes

Reviewing the construction of some of the most recent utility-scale PV projects, the process to build these arrays is becoming ever faster, focused, and regulated. There isn't much difference from other ground up construction projects whether it is a commercial structure or otherwise. During construction, anything that is identified as unacceptable for installation is either thrown away or in some cases sent to a recycling facility. This is typically done by having large "shipping container" size waste receptacles which are regularly picked up including those specified for only scrap metal or recycling. This system is primarily used because it effectively removes the large quantities of construction waste from the job site in a timely manner. Commercial PV modules are not excluded from this process and those which have been identified as unacceptable for installation are placed into these receptacles for removal.

An important application to commercial-grade PV modules is that a warranty is applied to them from their manufacturer. This can be the case for more complex equipment such as transformers and substations, but also simple equipment, i.e. the aluminum racking that the modules sit on as they produce power. Warranties are designed to ensure equipment from manufacturer defects and provide recourse for replacement of an item in the event of an issue (warranty reference). For all utility PV plants, the manufacturer warranties must be strictly followed, and they only apply to equipment in a narrow range of issue. The strict nature of these warranties is a result of the PV plant being evaluated during the financial closing due-diligence period and the requirement that all warranty's on equipment are current & valid. This requirement is important for closing as many utility-scale projects have multiple investment groups, partners, and are often sold after construction ("Vivo Power US, Rick Borry - Executive Director, Personal Communication"). As such, meticulous inspections and QA/QC take place during construction classifying even the smallest issues / warranty voidance.

A meticulously regulated construction process, as it relates to these warranties, maintains that every module installed holds their warranty and have zero identifiable issues with them. A voided warranty issue would include damaged glass, bent frames, any damage to the wiring box / connectors, and even any scratches or scuffs to the back of the module. If even the smallest issue is identified, that module is removed and replaced. If a module is selected to be replaced, but a pre-existing issue is discovered, the manufacturer would not pay the cost to replace that module. The removed modules are placed into the onsite waste receptacles and sent to landfills. Many of these warranty issues do not affect the functionality or power production of the solar cells. This raises the question of, if a voided warranty PV module is still functional, does it need to be thrown away or is there another approach?

3 A New Approach: Value Added of the Current Waste Stream

A new approach proposed in this report is to reconsider the utility-scale solar waste stream and the value of the equipment that is being sent to landfills. Could value be based on functionality and not only if the warranty holds on a PV module? The report also invites manufactures and construction companies to reassess the standards applied to warranty-voided modules and consider further use of these commercial-grade solar modules, instead of discarding them into landfills. Further use of these modules can include non-profit community solar programs, donation to facilities such as schools, recycling onsite for use when modules are functionally damaged, and even redeployment of modules into the solar industry after potential repair & reissuance of a warranty (Ludt 2019). This would be executed by identifying and categorizing the equipment as it enters the waste stream, prioritizing equipment condition and what a suitable reuse may be. The goal and outcome of this is to reduce the waste stream of large-scale utility solar projects, reduce CO_2 emissions, and prevent any value loss of commercial PV modules, including their materials and power production, due to current construction processes and warranty requirements.

Objective

The objective of this paper was to conduct a quantitative analysis of the waste stream on two utility-scale solar construction projects, focusing on the commercial-grade solar modules themselves. The determination of this was to detect potential waste stream mitigation and evaluate the level at which PV modules could be repurposed. An on-site inventory was conducted to determine how many modules were damaged, what categories of damage occurred, and how many modules retained functionality.

4 Analysis & Methods

Two currently operating utility-scale solar projects in North Carolina were selected as case studies, Site A & Site B. Site A is a 43 MW AC (Alternating Current) utility-scale solar project located in Bladen County, NC. The site was built on a cow pasture, sections of cleared forest, and an old corn field. Site B is a sister site to Site A, in that both sites had the same financial owners and investment groups. Site B is located adjacent to Site A in Robeson County, NC producing 50 MW AC of energy. This site was built on a previous corn field in a geographical feature called a Carolina Bay, which had previously been drained for agricultural use. In many cases, multiple types of commercial-grade modules are used on each array. On these sites, there was a mix of 320, 325, 335, and 340-watt modules. These sites were developed around the same time, however, while they have the same owners, they were constructed by different Engineering, Procurement, and Construction (EPC) companies.

Over the periods of construction from Fall 2016 to Fall 2017, the installation groups collected every damaged and/or removed PV module from the array and organized them in stacks on the equipment receiving yards. This provided an opportunity for assessment and did not drastically divert the construction crews from standard operations as the construction waste receptacles are located adjacent to the equipment receiving / logistics yards.

The data within this assessment on the PV modules was collected between June 1st 2018 thru August 1st 2018. First a detailed visual inspection of each rejected, commercial-grade PV module was conducted, consisting of every angle and element of the module. This visual inspection is critical for determination and categorization of the condition of the modules and to identify those modules that clearly would not have functionality. Modules were found with punctures, severely damaged glass faces, and demolished wire connections and connectors. As it is likely that these types of severe damage would be more costly and energy intensive to repair than to replace, we considered placement of these damaged modules into the construction waste stream as appropriate and they were not included in the counts of re-useable PV modules. During the visual inspections, less severe damage was also identified, including bent frames, cracked glass faces, missing MC4 wire connectors, minor manufacturer defects, such as incorrect bolt hold placement on frames, and PV cell hotspots. Lastly, the visual inspection also found those modules which appeared “undamaged.” What was found seemed to be scuff marks to the back of the panels and generic “wear and tear,” but nothing of a functional concern was observed.

These modules had fallen out of warranty, because of scuff marks, scratches, or low power output after voltage testing.

As visual inspection took place, the modules were divided into their respective categories of power output and condition. The categories are as follows:

-*Installed* - is the total in-field deployed equipment that is currently operating. This has been recorded separately according to the wattage of the PV modules.

-*Storage* - is the requirement by the owners that any left-over modules and over-purchase be left on site for use in repairs over the lifetime of the project. Storage does not include the damaged modules and this number is only used as reference for percentages of modules onsite and in use.

-*Total Damaged* - were all modules that were removed from the site and sent to the waste stream. This includes the following categories.

-*Damaged Unusable (Non-Repairable)* – are the modules in total disrepair. Those would include, but are not limited to, modules with holes through them, mangled electrical wiring, and separated frames.

-*Damaged Usable (Minor Repair)* - was defined as those modules requiring minor frame repair, sealant to front or back, and wire lead repair including the replacement of MC4 connectors. These repairs may or may not be done onsite, but would require labor to bring back to a deployable condition.

-*Not Damaged (No Repair)* - are those modules which fall out of warranty due to minor scuffs or other qa/qc reasons preventing their installation in the field. These modules may not require repair and could be installed at another site with the understanding that the initial manufacturer warranty is not valid.

For this case study, a conservative approach was applied to define the damaged useable from damaged un-useable. The power output was tested using a Fluke 115 Compact Voltmeter to compare the nameplate value (meaning the manufacturers specification of module output) to its actual production. Through the visual inspection and voltage testing the damaged useable were easily identified from the total damaged.

5 Results

The totals of each category of PV module condition are referenced in Table 1.

Table 1 - PV module count inventory data and subsequent categorization of the modules from two utility-scale solar projects located in North Carolina. Data collected between June 1st – August 1st, 2018.

PV MODULE COUNT INVENTORY	Site A		
	335W	**340W**	**TOTAL**
INSTALLED	48360	79200	127560
STORAGE (NEW)	257	649	906
TOTAL DAMAGED	369	515	884
DAMAGED UN-USEABLE (NON-REPAIRABLE)	314	425	739
DAMAGED USEABLE (MINOR REPAIR)	24	43	67
NOT DAMAGED (NO REPAIR)	31	47	78

PV MODULE COUNT INVENTORY	Site B		
	320W	**325W**	**TOTAL**
INSTALLED	104690	43396	148086
STORAGE (NEW)	239	572	811
TOTAL DAMAGED	278	173	451
DAMAGED UN-USEABLE (NON-REPAIRABLE)	232	130	362
DAMAGED USEABLE (MINOR REPAIR)	25	16	41
NOT DAMAGED (NO REPAIR)	21	27	48

Site A installed a total of 127,560 commercial-grade PV modules on the site. This was a mixture of 335- and 340-watt modules with their respective totals detailed in Table 1. 906 PV modules were kept in their original boxes and stored onsite to be used in the event of repair. The difference between their wattage totals was due to the availability of modules for purchase. The number of modules that were set aside adjacent to the construction waste receptacles due to an identifiable issue (*total damaged*) was 884, including 369 335W modules and 515 340W modules. Of the 884 damaged PV modules on Site A, 145 were either *damaged usable* (67) or *not damaged* (78). Thus, 16.4% of the total damaged modules on Site A were suitable to be repurposed and could be diverted from the module waste stream.

Site B installed a total of 148,086 commercial-grade PV modules in the array. This was a mixture of 320- and 325-watt modules with their respective totals referenced in Table 1. 811 PV modules were kept in their original boxes and stored onsite to be used in the event of repair. Of the 451 *total damaged* PV modules on Site B, 89 were either *damaged useable* (41) or *not damaged (48)*. Thus, 19.7% of the total damaged modules on Site B were suitable to be repurposed and diverted to the PV module waste stream.

Overall, the two solar sites would have sent 234 functional modules to the landfill that could have been diverted from the construction waste stream. That reflects a 17.5% average waste stream diversion of valuable PV modules with 100% functionality across these sites. The wasted modules could produce 79.56 kw or enough power to supply 20 local homes with renewable energy.

6 Discussion

The percentages of damaged module of the total installed for the two case studies fell within the 0.3 – 0.6% breakage rate, confirming its use as the industry standard. The industry-standard breakage rate is relied upon when a developer purchases the installation and storage modules from the manufacturer. This helps to prevent the site from having to purchase additional modules without the benefit of bulk pricing. The percentages of total damaged PV modules were similar across construction companies and sites. Site A had a 0.06% breakage rate while Site B had a 0.03% breakage rate, yet both sites had roughly 15-20% functional modules within their waste streams. This suggests that the functional modules which could be diverted from the waste stream could be a typical result on other large commercial PV plants across the US, even having the potential to be used as an industry standard. Furthermore, the process of waste stream analysis used here is also reproducible, as it was designed to limit impact on the field teams by fitting into their typical installation and construction processes.

An important note for the total damaged module categorical group, is that there remains potential for diverting additional damaged modules from the waste stream if new repair processes are developed. For example, if the cost of a repair currently deemed too expensive is brought down, the damage modules category may provide more reusable PV modules. Recently, some companies are working towards a recycling process that could take these more severely damaged modules and re-glass them or essentially bring them back to a functional and redeployable condition (Ludt 2019).

Potential of PV Module Reuse Applied to National Installation Rates

These case study solar projects completed their construction in 2017. In that year, 10.6 GW of solar energy capacity was installed nationally (SEIA & GTM 2018) or 106 times the total of these case studies. When we apply the results in this report to the total installed solar capacity of 2017, the industry is discarding 24,000 to 25,000 functional solar modules into the construction waste stream. That capacity could conservatively produce around 8 - 9 MW of solar energy. Depending upon location and demand, typically 1MW of power can supply 750-1000 homes in the US with electricity (Richardson 2012). In essence, the industry has the potential to power 6,000 – 8,000 additional homes in the US, if waste stream mitigation of this equipment becomes widespread in the industry.

Repurposed Potential

Considering the thousands of discarded, commercial-grade solar modules that have been potentially identified as having functional value, the question becomes what to do with them. Applications for reuse could include donation to non-profit programs, overseas sites, or to local schools, or even warrantied through a third party after repair and inspection and redeployed into the market for installation or as on-site stored modules (Ludt 2019). This redistribution or donation might have particular application for low-income housing. The US supports not-for-profit organizations that maintain hundreds of thousands of low-income housing units that would greatly benefit from low-cost, solar energy, as their electric bills are some of the costliest operating expenses. This study has identified power potential for 6,000+ homes per year, at current install rates, from this waste stream diversion and applicable mitigation programs.

Furthermore, in addition to modules diverted from the waste stream, all modules at the end of their warranty lifetimes could be applied to a repurposing program (Ludt 2019). End of life warranties are not the end of functionality, thus, during the solar array decommissioning process, the modules could be fed into this new market, after similar inspections to those in this study. The typical commercial-grade solar module warranty can range from 10 years for workmanship and 25 years for performance of maintaining 80% of nameplate ("Vivo Power US, Rick Borry - Executive Director, Personal Communication"). Solar module degradation rates are conventionally around 0.7% per year with an initial light induced degradation (LID) of roughly 2% (Jordan & Kurtz 2011). Thus, at decommissioning many modules will be operating at 80% and if they are not repurposed, they too will enter the waste stream.

7 Conclusion

This investigation has identified a current value loss and potential waste stream diversion from large-scale utility solar projects. Waste stream inspections of the commercial grade PV modules, conducted on-site, found that roughly 15-20% of the total damaged modules could be considered as functional. Nationally, tens of thousands of PV modules are being unduly discarded each year based on the results. Two large-scale utility solar arrays were used as case studies, which confirmed the 0.3 – 0.6% breakage rate of modules currently used as the industry standard, and suggests a new industry standard related to waste stream diversion. Site A diverted 16.4% of the damaged / uninstalled modules. Site B diverted 19.7% of the damaged / uninstalled modules. By diverting these PV modules, we can reduce CO_2 emissions, reduce construction waste, and minimize the environmental impact of the solar industry. The reused modules from the diversion can be redeployed, repaired on-site, donated to non-profits or schools, or sent to overseas, low-cost solar projects.

These results invite solar EPCs, Owners, & Manufacturers to reassess the value of these modules and amend construction practices or warranty standards to focus on this valuable solar asset.

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