The Contemporary Precedence of Building-Applied Photovoltaic Systems: A Multileveled Review to Derive a Holistic Cost-Benefit Analysis

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ABSTRACT

The United States had contributed 6.457 GtCO$_2$eq in greenhouse gas emissions towards the approximated 49 GtCO$_2$eq global total. 27.3 percent of all the United States' greenhouse gas emissions was from the production of electricity under a carbon-intensive, fossil fuel energy paradigm. The growing concern over anthropogenic climate change as a global commons issue, stresses a need for a global transition to renewable energy to mitigate contributing greenhouse gas emissions. A multifaceted focus remains on solar technology, specifically that of building-applied photovoltaic (BAPV) systems, as a first step in transitioning to a renewable energy paradigm. BAPV systems are the cheapest solar energy variant and are integrable with existing infrastructure on a mass-scale, unlike that of other renewable energy technologies. As the employment of solar energy has been increasing over the past few decades, solar technology is still substantially expensive. This research project set out to perform a four-tiered review on the contemporary precedence of BAPV systems to derive a holistic answer as to what has been propagating the trend of increased solar energy employment, despite the technology still being substantially expensive. An ending analysis of the costs and benefits to solar energy use, concluded that the free-market and governments may both propagate the market attractiveness of solar energy through: university and corporate investment into solar energy within a capitalist supply and demand system, and through state and national policies and programs that favor the expansion of solar energy use. The contemporary precedence of BAPV systems, is based on the interaction of practical, economic, sociocultural, political, and environmental elements found and listed in the concluding cost-benefit analysis. As the global solar industrial complex continues to grow, solar technology will inevitably be employed on a larger scale in the near future. With future public and private sector cooperation, solar technology can be made more equitable; solar technology maintains a positive economic and environmental outlook with substantial political and sociocultural issues regarding the Global South's role in renewable energy within this contemporary era of globalization.

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INTRODUCTION

The Trend in Emissions: In 2010, total global anthropogenic greenhouse gas (GHG) emissions was approximated at 49 $GtCO_2eq$. A significant source of total global GHG emissions was from the production of electricity (Edenhofer et al. 2014; EIA 2018). In 2017, the United States (US) has contributed 6.457 $GtCO_2eq$ in GHG emissions towards the 49 $GtCO_2eq$ global total. In relation, the production of electricity within the US had contributed a total of 1.763 $GtCO_2eq$ in GHG emissions – 27.3 percent of all US GHG emissions (EIA 2019; EPA 2019).

The United States' Energy Paradigm: The US' electricity-sector emits a notable amount of GHGs because its current energy paradigm is heavily dependent on carbon-intensive fossil fuels. For example, in 2017 the US produced 30 percent of its electricity from coal – a very carbon-intensive fossil fuel. Even though the utility of coal within the production of electricity has decreased from 52 percent in 1990 to 30 percent in 2017, the utility of natural gas – a less carbon-intensive fossil fuel – within the production of electricity has increased from 12 percent in 1990 to 32 percent in 2017 (EIA 2018, 2019; EPA 2019). Since fossil fuels emit GHGs, a shift in the US' energy paradigm, away from carbon-intensive fossil fuels to low-emitting renewable energy (RE) sources, has been proposed as a legitimate avenue for mitigating GHG emissions and its associated concerns (Gielen et al. 2018; Kalogirou 2014; Kimmel 2019).

The Concern Over Emissions: Historical and recent anthropogenic GHG emissions have resulted in a looming global climate change crisis. Evidence of regional impacts from climate change has already been documented. There is a growing concern for the impacts that are predicted to be exacerbated from worsening climate change (Melillo et al. 2014). In consequence, anthropogenic climate change is a global commons issue that needs to be mitigated through a number of means, incorporating: transnational cooperation, national and local policy action, sociopolitical agency, technological adaptation, and a global energy paradigm shift. The United Nations (UN) Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (AR5) denoted that the avenues to reducing GHG emissions and mitigating climate change were obstructed by dynamic social, political, cultural, environmental, and economic contexts. And notably, a transition away from carbon-intensive fossil fuels to RE is not a process that can be done in isolation, as the implications and side-effects of transition are inevitably globalized (Edenhofer et al. 2014; Gielen et al. 2018; Kalogirou 2014).

Future Global Energy Demand: Despite ubiquitous concern over GHG emissions, future projections have indicated that GHG emissions will inevitably increase globally; carbon-intensive fossil fuels will be employed to satisfy a portion of future global energy demand. As global energy supply was recorded at approximately 500 EJ in 2015, the increasing demand for energy is unavoidable. An optimistic estimate regarding the total global energy demand anticipated for 2050, predicted it at 700 EJ – an estimated 40 percent increase from 2015 to 2050. In contrast, a pessimistic 2050 estimate predicted it above 700 EJ, at 4,000 EJ based on a "business as usual" model – an estimated 700 percent increase from 2015 to 2050. Irrespective of either scenario, global energy demand is predicted to increase under an exponentially growing global population and a growing Global South per capita affluence. Future Global South affluence is calculated to be three-times to eight-times more in 2100 than in contemporary terms (Edenhofer et al. 2014; Gielen et al. 2018; Trainer 2010).

The Renewable Energy Issue: To satisfy even the most optimistic future global energy demand estimate and mitigate the US' GHG emissions under a contemporary carbon-intensive energy paradigm, investing into RE is going to be pivotal for maintaining energy security in a future predisposed to a plethora of climate change impacts (Edenhofer et al. 2014; Field et al. 2014; Gielen et al. 2018; Melillo et al. 2014). Although, RE has paramount issues regarding its practicality. All RE sources are intermittent and require a significant allocation of land area, beyond what has been required for carbon-intensive energy sources. In consequence, an energy paradigm transition to RE will need to make a compromise with land use and address intermittent electrical production (Nonhebel 2005; Prasad & Snow 2005; Tsoutsos et al. 2005).

The Potential of Solar Energy: The land use compromise that is needed for RE employment will be difficult to reach. Most RE sources are not easily integrable into the built environment on a large-scale. The RE sources that are most commonly recognized by the lay public but are difficult to integrate with buildings on a large-scale, include: wind, geothermal, hydro, and biomass. In contrast, solar photovoltaic (PV) technology is a RE source that has the ability to be integrated into the built environment on a large-scale. With PV technology, buildings have the opportunity to produce a fraction of their own electricity that they consume. Building-applied PV (BAPV) systems and building-integrated PV (BIPV) systems are the two PV variants that attention is being allocated to for future RE prospects within the built environment. Both variants have the potential to reach the land use compromise via existing infrastructure, in addition to producing a contributory amount of electricity that supersedes general concern over intermittency issues with electrical production (Gielen et al. 2018; Nonhebel 2005; Prasad & Snow 2005).

BACKGROUND

The Cost of Photovoltaic Systems: Residential, commercial, and utility-scale PV systems are being installed within the US at exponential rates. This positive trend has been continuous since the 1990s. Although despite its increased employment, PV technology is still exceptionally expensive in comparison to fossil fuels and other RE sources (Fu et al. 2017; GTM 2010; Prasad & Snow 2005). The total cost of a PV system is determined by six broad variables:

1. *Raw Metals:* There is a cost involved in the extracting and smelting of the raw metals used in PV modules. Depending on the type of PV module, boron (B), cadmium (Cd), copper (Cu), gallium (Ga), indium (In), iodine (I), lead (Pb), phosphorous (P), selenium (Se), silicon (Si), tellurium (Te), and titanium (Ti) may be used. This variable is mostly concerning mine labor and the associated market prices of the mined metals (Fu et al. 2017; Lewis 2007; NREL 2012; Prasad & Snow 2005; Woodhouse et al. 2013; World Bank & IFC 2002).

2. *Manufacturing:* There is a cost involved in the manufacturing of PV modules, inverters, and hardware, and in turning raw materials into compounds to be used as semiconductors within PV cells. This variable is where a majority of a PV system's cost come from (Abu-Rumman et al. 2017; Fu et al. 2017; Lewis 2007). And despite Si being the most commonly used material employed as a semiconductor within PV cells, material compounds are more-efficient; these can include: cadmium telluride (CdTe), copper indium diselenide (CIS), copper indium gallium diselenide (CIGS), lead selenide (PbSe), and titanium dioxide (TiO_2) (Lewis 2007; NREL 2012; Prasad & Snow 2005).

3. *Transportation:* There is a cost involved in transportation throughout a PV system's supply chain. This is a net transportation cost accrued from a point source of raw material extraction, to a smelter, to a manufacturer, to a distributer, and finally to a consumer. This variable is in consideration of a global supply chain within a globalized world economy (Fu et al. 2017; Rodrigue 2007).

4. *Labor:* There is a cost involved in labor throughout a PV system's supply chain. This is a net labor cost accrued from the point of raw material extraction, to smelting, manufacturing, transportation, distribution, marketing, and to the installation of a PV system. This variable is in consideration of global supply chain labor that is stratified by wage inequalities between first-world and third-world nations (Abu-Rumman et al. 2017; Fu et al. 2017; Krugman 1994).

5. *Legalities:* There is a cost involved when companies, whether that be manufacturers or distributers etc., purchase the necessary legal permits to operate commercially. Additionally, this variable may include considerations for the careful manufacturing, recycling, and disposal of PV modules utilizing toxic compounds as semiconductors (Abu-Rumman et al. 2017; Fu et al. 2017; Prasad & Snow 2005); CdTe, CIS, CIGS, and PbSe are all environmentally toxic compounds, while TiO_2, as well as CdTe, are carcinogens (Fthenakis & Zweibel 2003; LTS 2019; Skocaj et al. 2011; Tanaka & Hirata 2013).

6. *Commercialization:* There is a cost associated with PV module type, production efficiency, marketization, and size. And notably in terms of capital, a company's affluence can also determine PV module prices (Fu et al. 2017; O'Shaughnessy & Margolis 2017, 2018).

Building-Applied Versus Building-Integrated Photovoltaic Systems: Despite PV technology's general low viability in terms of monetary expense, the installation of BAPV systems is still financially competitive in comparison to BIPV systems. The domain of BAPV includes bulky, rooftop PV modules that are mounted onto buildings to form arrays. In contrast, the domain of BIPV includes architecturally conscientious, PV-integrated building materials like: shingles, glass, siding, tiling, facades, etc. Despite BIPV's implied aesthetic superiority, this variant has yet to be adapted within the technological, infrastructural, commercial, and political intricacies of the contemporary electricity market. Since its initial marketization in the 1950s, PV has gradually been adapted into the contemporary electricity market and now BIPV, as BAPV's evolutionary successor, is projected to gain ground within the next few decades (Fu et al. 2017; GTM 2010; James et al. 2011; Prasad & Snow 2005).

The Focus on Building-Applied Photovoltaic Systems: *To review: PV technology is expensive, especially that of BIPV systems; the rate at which PV systems are being installed throughout the US, is increasing; PV technology is integrable with existing infrastructure; and PV technology is a promising RE source that can reduce electricity-sector GHG emissions, despite electrical production intermittency issues.* There is salience in implementing residential, commercial, and utility-scale BAPV systems to minimize the carbon footprint of the built environment. Given PV technology's current state of development, BAPV is the more cost-effective and viable RE solution (Fu et al. 2017; GTM 2010; James et al. 2011; Prasad & Snow 2005).

The Relevance of Roof Types: A building's roof slope and the materials used to construct it, affects the cost of BAPV system installation. For flat roofs, the recommended roof types for BAPV system installation are: a thermoplastic olefin/polyolefin

(TPO) membrane roof, an ethylene propylene diene monomer (EPDM) membrane roof, and a polyvinylchloride (PVC) roof. Buildings with river rock-ballasted membrane roofs are known to be too tedious and costly to integrate with BAPV systems, as such roofs would have to be removed to secure a system and its supplementary equipment. For sloped roofs, a standing-seam roof is preferable, as it can withstand the weight of BAPV systems and does not have to be penetrated for installation. Shingled roofs are also acceptable but require penetration at an additional cost. Lastly, tile roofs pose structural challenges for BAPV systems and are not recommended for installation (Lisell et al. 2009; Prasad & Snow 2005).

The Relevance of a Building's Age: BAPV system installation is not feasible on aged buildings beyond historical precedence – a defined building age based on the contemporary connotation of structural antiquity. Historical precedence, in regard to BAPV system installation, is defined as 1945 or older. The roofs of buildings of historical precedence sustain ubiquitous obstacles for PV technology due to their constructed natures. BAPV systems have been recorded to produce deficient levels of electricity because of these obstacles (Cabeza et al. 2018; Kooles et al. 2012).

The Links Between Roof Type, Age, and System Weight: Notably with roof type and age, roofs must be capable of supporting BAPV systems at an average weight of 3 lbs/ft^2. For flat-ballasted membrane roofs, the average weight of an BAPV system can reach up to 4 to 6 lbs/ft^2 due to the need for additional supplemental equipment (Lisell et al. 2009; Prasad & Snow 2005). The weight of a BAPV system can also be compounded by weather events, such as snow pack and water runoff, and must be anticipated for buildings in certain climate regions (Eicker 2003; Porteous & MacGregor 2005).

The Relevance of Climate Change Adaptation and Resilience: The terms adaptation and resilience are used within the UN IPCC AR5 to denote the options society has in facing anthropogenic climate change. Adaptation is defined as the adjustment of behaviors and practices to account for gradual and sudden changes caused from climate change. While, resilience is defined as the capacity of a system to return to its original state prior to a perturbation from climate change. Adaptation and resilience to climate change are based on assessing risk. The salience of policy regarding adaptation and resilience to climate change is based on mitigating risk, transferring risk, and accepting risk (C2ES 2019; Edenhofer et al. 2014; Levina & Tirpak 2006). In relation, global energy security is threatened by climate change as it will transform ecological and human systems (e.g. via hydrological variability, fossil fuel-related conflicts, etc.). RE is critical to adapting to climate change by reducing GHG emissions and in bouncing back from its associated impacts on energy security by providing infinite, clean energy (Edenhofer et al. 2011; Field et al. 2014; Gielen et al. 2018; Melillo et al. 2014).

Using Cost-Benefit Analyses: A salient tool within the social sciences, that is employed to weigh the anticipated consequences from a planned decision, action, or trend, is a cost-benefit analysis (CBA). A rudimentary CBA can be used to assess the dynamic factors behind a decision, action, or trend relating to PV technology. But notably in essence, a traditional CBA is based on transient value judgments and not on a set standard of morality. This leaves a broad interpretation of what selection of value judgments would constitute an inferential CBA on PV technology. However, as long as discretion is placed on the contributing factors and anticipated impacts of a planned decision, action, or ongoing trend, an inferential and holistic CBA can be performed (Boardman et al. 2018; Fu et al. 2017; Pearce 1983).

RATIONALE

Research Question and Purpose: What has been favoring the installation of BAPV systems, as to merit its increased rate of installation within the past few decades despite it being considerably expensive? The purpose of this research is to review the major variables that contribute to the installation attractiveness of BAPV systems.

Research Significance: BAPV systems are integrable with existing infrastructure as a promising source of RE but are significantly expensive in contemporary market terms. A holistic review into PV technology is necessary to address its contemporary precedence. A review of university, state, national, and international levels regarding what contributes to BAPV technology's attractiveness, will provide opportunity for an inferential and holistic CBA to be performed. A concluding CBA will synthesize the economic, political, and sociocultural variables behind the growing trend in BAPV system installation to constitute its contemporary precedence.

METHODS

A University Level Review: To define the contemporary precedence of BAPV systems on a university scale, four geographically distinct American university campuses were reviewed: The University of Idaho, Boise State University, Stanford University, and The University of California Los Angeles. The review synthesized the universities' sustainability goals, campus climate action plans (CAPs), and campus strategic action plans (SAPs) to determine whether these campuses had already invested into BAPV systems or not. In remedy, news articles were reviewed in the event that their sustainability goals, CAPs, and SAPs were not explicit enough in detailing so. The spatial selection of the four universities was based on geographical and American College and University Presidents' Climate Commitment (ACUPCC) relevance. The University of Idaho and Boise State University were selected as they are in the state of Idaho, while Stanford University and The University of California Los Angeles were selected as they are in the state of California. In contrast to their statehood, The University of Idaho, Boise State University, and The University of California Los Angeles are public institutions that are members of the ACUPCC, while Stanford University is a private institution that is not.

A State Level Review: As they are distinct, the state political markets of Idaho and California were reviewed to determine the contemporary precedence of BAPV systems on a state scale. Idaho has a captive electricity market and California has a competitive electricity market. The review compared the states' politics, associated policies addressing GHG emissions, and interests within RE.

A National Level Review: To define the contemporary precedence of BAPV systems on a national scale, a review of US protectionism and corporate environmental responsibility (CER) was performed. A review of the US International Trade Commission's (ITC) 2017 Solar Tariff was used to determine how it had impacted PV market prices.

An International Level Review: A review of the effects of globalization in the Global South was paramount in holistically defining the contemporary precedence of BAPV systems on an international scale. The Global South was reviewed based on its salience in exemplifying inequalities from a globalized economy, its associated environmental injustices from a growing global industrial complex, its current sociopolitical development (SPD), and how it all coalesces into a further question regarding the future precedence of PV technology use.

UNIVERSITY LEVEL REVIEW

Universities and Renewable Energy: Universities play an essential role in technological innovation, economic growth, and sustainable development through a variety of means (Vidican 2009). Although as of recently, universities have been more attentive towards addressing social trends and shifts. There is a growing trend where prospective students are being more conscientious of a university's overall commitment to environmental responsibility and RE. In association, the ACUPCC was founded in 2007 as a formal network of universities that are committed to reducing their campus' carbon footprints. Participating ACUPCC members lead by example through assessing climate-related risks and through innovating solutions that mitigate their contributions to climate change. Additionally, the ACUPCC provides its members a framework for campus sustainability programs (Bradford et al. 2019; Krier 2019; Second Nature 2019b).

Universities and Building-Applied Photovoltaic Systems: Most ACUPCC members abide by campus CAPs that provision goals for increasing the campus RE use (Second Nature 2019b). While acknowledging the limitations of producing electricity from other RE sources, many universities are investing into BAPV systems as a means to producing clean energy on their campuses. As a cheaper means to reaching campus RE goals, other universities have decided to purchase electricity from local utility companies that generate electricity from PV technology. But generally, despite BAPV systems being so expensive to install, universities are still investing into PV technology through limited subsidization options. Thus, it is distinguishable that the environmental benefits of BAPV in mitigating a university's carbon footprint, far surpasses the technology's high economic costs (Bradford et al. 2019; Kabir et al. 2018).

The University of Idaho: A preliminary assessment was conducted at The University of Idaho in 2017, to determine if campus-based PV energy production was feasible. *The University of Idaho Solar Site Assessment*, conducted by The University of Idaho Sustainability Center (UISC) and The University of Idaho Facilities – Utilities and Engineering Services (UES), evaluated 15 campus locations in their potential for hosting a variety of PV systems. Four out of the 15 locations selected for the preliminary, were concluded to maintain favorable conditions for PV system installation. Even though the preliminary was very limited in its scale, it employed metrics that measured a location's favorability in PV system installation based on: public visibility, payback interval, aesthetic impact, location and service accessibility, percent energy supply, and rooftop integrity. None of the variables initially thought after in the preliminary were concerned over the *initial cost* of PV system installation (Caisley et al. 2017).

The University of Idaho Solar Site Assessment concluded in an official proposal solicitation to install a BAPV system on the campus' Integrated Innovation and Research Center (IRIC). The assessment detailed that the IRIC was the most favorable out of the 15 locations for a BAPV system, given that the building was recently completed in 2016 (Caisley et al. 2017; McIlroy 2019). The IRIC, illustrated in **Figure 1**, is also a Leadership in Energy and Environmental Design (LEED) Gold-level certified building, denoting that it was already constructed under an environmentally contentious and sustainable design. The subsequent IRIC BAPV Project that was launched in 2017, concluded in 2019 with the university's administration and a fundraising campaign securing approximately 61 percent of the ^{US}\$365,000 needed for the full installation of a 145 kW BAPV system. Once the remaining 39 percent of the funds is raised, the IRIC's new BAPV system will have a total of 393 BAPV panels, 273 on its

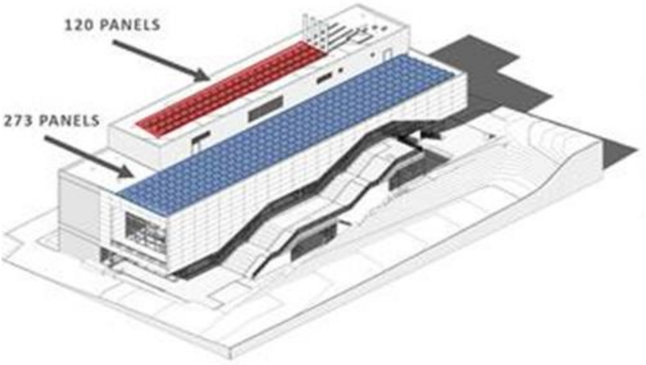


Figure 1. The 145 kW, US$365,000 University of Idaho IRIC BAPV Project. 273 panels are being installed on the lower roof (blue) and 120 on the upper roof (red), for a total of 393. The finished BAPV project will produce 196,000 kWh/yr and will satisfy 15 percent of the IRIC's total annual energy needs (Mathieson 2019a, b).

lower roof and 120 on its upper roof, while producing 196,000 kWh/yr of electricity. The new BAPV system will only satisfy 15 percent of the IRIC's total annual energy needs, as it is an energy-intensive research facility (Mathieson 2019a; Samarasekera 2017).

The University of Idaho's latest CAP was written in 2010 by the UISC. It detailed a promise of reaching climate neutrality by 2030 through reducing GHG emissions from campus operations. In relevance, The University of Idaho joined the ACUPCC in 2007 to develop a comprehensive plan to reaching climate neutrality via a commitment to a green building policy and a campus waste minimization policy. The green building policy establishes the LEED Silver-level certification as the minimum standard for future building prospects and the campus waste minimization policy correlates to the university's SAP. There is no explicit language within the university's 2010 CAP and its most recent 2018 SAP, alluding to the investment into the IRIC BAPV system (Mathieson 2019a; Staben 2018; UISC 2010).

Boise State University: As an ACUPCC member, Boise State University currently has a 25 kW BAPV system on its Skaggs Hall of Learning (known as the Micron Business and Economics Building). It was installed in 2015 to supplement the building's limited use of geothermal energy and considerations for future expansion of the BAPV system to 65 kW has been proposed. Despite Boise State University lacking a CAP, its commitment to ACUPCC GHG emission reduction goals and general campus sustainability is detailed. But the university's rudimentary SAP, does not allude to the intention of expanding RE use (Bertel 2015; BSU 2017; Second Nature 2019a).

Stanford University: As a prestigious private university, Stanford University had a better predisposition in reducing GHG emissions from their campus operations. The university's CAP extensively details how it has already employed energy conservation and efficiency measures within its facilities, as well as implemented strict building standards and expanded its investment within campus RE. Additionally, despite the university not being a member within the ACUPCC and not having a university-specific SAP (as the university has department SAPs), the university is adamant in its commitment in reducing its GHG contributions and expanding its use of PV energy (DSEM 2015).

As of 2015, Stanford University had already committed a total of 78.5 MW of electricity from variant campus PV systems. Regarding where some of these variant PV systems were located, a 22 kW BAPV system was on the Leslie Shao-Ming Sun Field Station, a 14 kW hybrid PV system was on the Yang and Yamazaki Environment and Energy Building, a 30 kW BAPV system was on the Jen-Hsun Huang Engineering Center, a 30 kW BAPV system was on the Spilker Engineering and Applied Science Building, a 355 kW BAPV system was on the Knight Management Center, and a 125 kW BAPV system was on the Shriram Center for Bioengineering and Chemical Engineering. Notably, the campus' CAP lacked vigilant language denoting a concern over the cost of expanding PV use on campus. As anticipated, in 2017, Stanford University had expanded PV use onto 32 other campus structures in a devout determination to meet California's 100 percent RE dependency goal prior to its set 2045 target (Domonoske 2018; DSEM 2015; Sullivan 2017).

The University of California Los Angeles: As an ACUPCC member, The University of California Los Angeles currently has a BAPV system on its Ackerman Union Building. As per the campus' CAP and SAP, The University of California Los Angeles is devout in expanding its general use of RE and specific use of PV energy. The university has a goal of installing five BAPV systems on its campus within the 2019 to 2020 academic year. It also plans on continuing its commercial partnerships with the *Los Angeles Department of Water and Power* (*LADWP*) and the *Southern California Edison Company* (*SCE*). Noting the potential high-costs associated with expanding campus PV energy use, the university is instead focusing on the *LADWP*'s and *SCE*'s ability and commitment to reducing their GHG contributions from their electrical production operations (Dudman et al. 2008; REA 2017; UCLA 2017).

STATE LEVEL REVIEW

The Political Markets of Idaho and California: Idaho is a politically conservative state with a captive electricity market, while California is a politically liberal state with a competitive electricity market. A captive market is where electrical utility providers are heavily regulated by the government, to where free market competition is disallowed. In such a market, consumers are only allowed to purchase electricity from a regional monopoly. In contrast, a competitive market is where electrical utility providers are not heavily regulated by the government, to where free market competition is encouraged. In such a market, consumers are allowed to purchase electricity from any provider within a region. This differentiation is mapped in **Figure 2** (EPA 2017a, b; Hyink & Provost 2016; Weatherby & Stapilus 2005).

Why Political Markets Matter: The salience of political markets is based on how states can dictate policies that favor PV technology, extend its market attractiveness, promote its commercial growth, or do nothing to its benefit. Notably, the rate of PV system installation is higher within liberal states versus in conservative ones, and higher in competitive electricity markets versus in captive ones. And as per the economic law of supply and demand, the greater the demand for a product, the cheaper the product gets. Thus, state policies are integral to building the cost attractiveness of PV systems (Augustyn et al. 2013; Yi & Feiock 2014).

Idaho: In addition to being a politically conservative state with a heavily regulated electricity market, Idaho does not have a Net Metering Program and lacks official state Renewable Portfolio Standards. Although in contrast, Idaho grants a small Tax Credit in favor of PV technology. This is ironic as

Figure 2. A map of the United States' electricity markets. Regulated, captive electricity markets are in grey and deregulated, competitive electricity markets are in blue. The state of Idaho is outlined in red and the state of California is outlined in blue (EPA 2017a, b).

the state is deterred from anything that is other than hydropower; the lush state boasts an abundance of potential hydropower sites (EPA 2017b; SolarNation 2015; Weatherby & Stapilus 2005).

California: As a politically liberal state with a deregulated electricity market since the 1990s, California had instituted RE-related and GHG reducing policies. For example, in 2005, California had implemented Executive Order S-3-05 that provided official GHG reduction standards. In 2006, California passed the Global Warming Solutions Act that required the state to reduce its GHG contributions, back down to 1990 levels by 2020. In 2013, California instituted a Cap-and-Trade Program that set a firm limit on industry-related GHG contributions. From 2002 through 2011, California maintained amendments to its Renewable Portfolio Standards that required electrical utility providers to match new demand in electricity via energy efficiency measures and increased RE use, prior to generating more electricity from carbon-intensive sources. And lastly, California has a Feed-In Tariff that spurs investment into RE sources and a Net Metering Program that incentivizes residential BAPV system installation (DSEM 2015; EPA 2017b; GTM 2010; Hyink & Provost 2016).

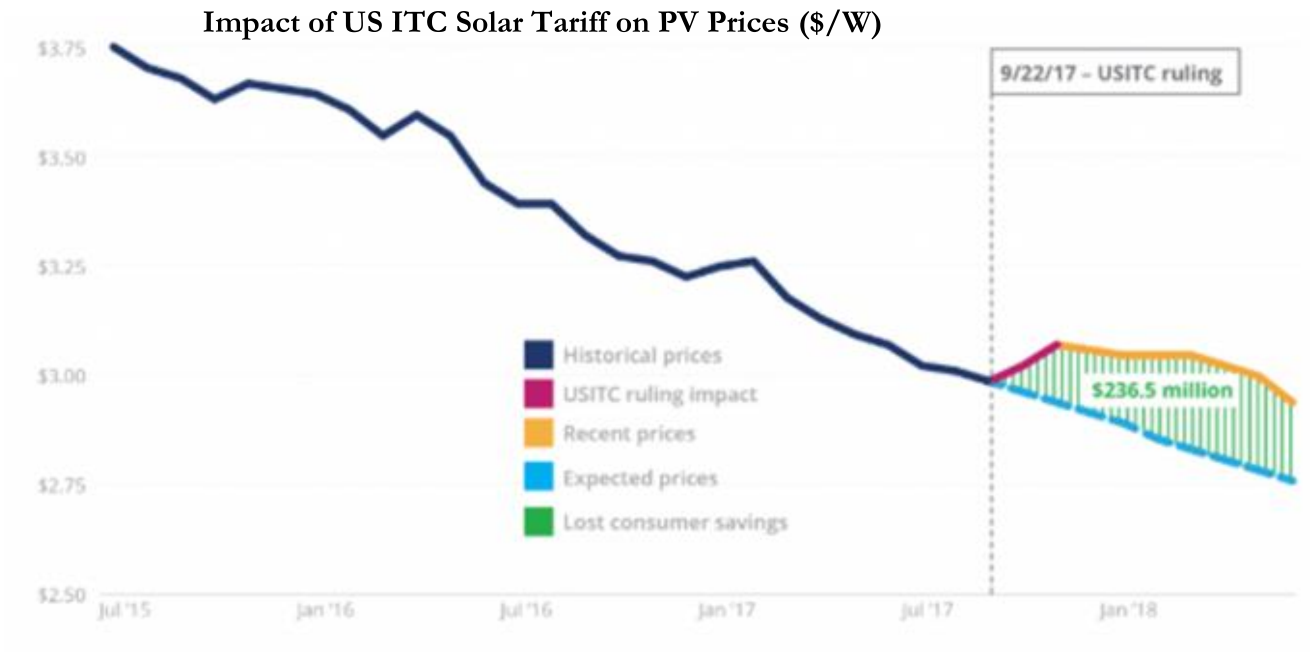
NATIONAL LEVEL REVIEW

Right-Wing Populism in the United States: A populist is an individual who appeals to groups that feel dismissed by society's elites. In November 2016, US President Donald J. Trump was elected on a platform of "economic nationalism" – a term used as a euphemism for protectionism – that pandered to the rising plight of the economic have-nots – the sector of the US population that has found itself in opposition to global free-trade policies and low-income immigration. Despite the President originating from wealth himself, his antagonism of the elite paradigm within the US had awarded him popularity among these economic have-nots (Kazin 2016; Rodrik 2017).

The Effects of United States Protectionism: The economic practice of sheltering domestic companies against international competition is the pinnacle of protectionism. The Trump administration addressed the negative impacts of economic globalization through bilateral trade tariffs. In September 2017, the Trump administration instituted an ITC Solar Tariff that had negatively impacted the cost of PV systems. As depicted in **Figure 3**, an estimated US$236.5 million in taxes had since been payed forward by US consumers in light of the 2017 ITC Solar Tariff. Although despite the institution of the 2017 ITC Solar Tariff, PV market prices in US$/W have still been deflating at a near paralleled rate as originally predicted prior to the institution of the 2017 ITC Solar Tariff (Irwin 2017; Walker 2018a, b).

Corporate Environmental Responsibility in the United States: CER is a corporation's active compliance to law, ethical conduct, and international expectations regarding environmental issues. A corporation's CER would thus be attentive to climate change and its impacts, an issue that concerns electric utility providers and Fortune 500 companies beyond the mandates of government policies and regulations (Dummett 2006; Pop et al. 2011). Examples of Fortune 500 and electric utility companies that are committing to CER pacts that transcend the mandates of state political markets and US policies, include:

1. *Amazon*: Following heavy criticism in early 2019, this Fortune 500 online retailer announced its intention to minimizing its GHG emissions. It will achieve this by reaching 80 percent company-wide RE use by 2024. To start, the company bought 100,000 all-electric delivery vans that will go into operation between 2021



Impact of US ITC Solar Tariff on PV Prices ($/W)

Figure 3. A graph showing the July 2015 to January 2018 trend in PV prices in USD per Watt, in consideration of the September 2017 US ITC Solar Tariff. Historical BAPV prices (navy), the impact from the Solar Tariff (red), prior projected prices (blue), recent prices in consequence of the Solar Tariff (orange), and lost consumer savings (green), are all quantified. Consumers had lost approximately ^{US}\$236 million from the 2017 US ITC Solar Tariff (Walker 2018a, b).

and 2024. Additionally, the company will construct two solar facilities with a total capacity of 215 MW, to help power their operations in North Carolina and Virginia. The company is expecting these solar facilities to produce approximately 500,997 MWh/yr (Frangoul 2019a; Howard 2019).

2. *Apple*: Regarding climate change, this Fortune 500 technology company takes responsibility for the GHG emissions that stem from their global operations. As of 2019, the company claimed to be 100 percent dependent on RE sources, but it currently continues to transition all its operations and machinery to low-carbon alternatives and further invest into RE. The company currently has 25 RE projects in operation around the world, amounting to 626 MW in total. It also has 15 more projects currently under construction that will produce over 1.4 GW of RE across 11 nations (Jackson 2019; Moseman 2018).

3. *Avista*: In April 2019, this electric utility monopoly in Northern Idaho indicated its intention to becoming carbon-neutral by 2027 and 100 percent RE dependent by 2045. This announcement was paramount, as the Idaho state government has been dismissive in setting renewable portfolio standards and has disregarded addressing climate change adequately (Fielder & Tyrie 2019; Kimmel 2019).

4. *General Motors*: This Fortune 500 vehicle manufacturer has 22 solar facilities around the globe and plans to expand its RE use to satisfy its 350 operations across 59 countries. The company's overall goal is to be 100 percent RE dependent by 2050, via investing into RE, all-electric vehicles, and efficient machinery. But to power their 350 operations and all-electric vehicular ambitions, the company will need to construct 9 TW of RE infrastructure. In prominence, the company has saved ^{US}\$5 million annually from using RE (GM 2016).

5. *Google*: Following heavy criticism from its own employees, this Fortune 500 technology company will spend more than ^{US}\$2 billion in 1,600 MW of wind and solar projects across the globe. 720 MW of electrical infrastructure will be constructed within North Carolina, South Carolina, and Texas, while 125 MW will be constructed in Chile. The company has expressed intentions in investing into RE infrastructure within other South American nations and Europe (Khalid 2019; Koksal 2019). But aside from the company's endeavors within wind and solar infrastructure, it has also achieved a technological breakthrough in concentrated solar energy (CSE) in cooperation with the company *Heliogen*. The two companies were able to integrate artificial intelligence with a field of mirrors that was able to concentrate sunlight to an extreme heat above 1,000°C. The implications of this breakthrough being that CSE can now be employed as a heating method to make cement, steel, glass, and other industrial goods that have always been dominated by other carbon-intensive heating methods (Egan 2019).

6. *Idaho Power*: In March 2019, this electric utility monopoly in Southern Idaho indicated its intention to becoming 100 percent RE dependent by 2045. As the company had already reduced its GHG emissions by approximately 50 percent since 2005, it has recently ended its participation with two coal plants in the region and will be constructing 120 MW of solar infrastructure within Southern Idaho. And just like *Avista*, its RE ambitions go in contrast to the state's lack of addressing RE and climate change adequately (Berg 2019).

7. *Microsoft*: Throughout the past decade, this Fortune 500 technology company has been gradually building its RE portfolio to total more than 1.3 GW today. The company currently powers one of its San Antonio, Texas data centers from a 110 MW wind farm, purchases electricity from a 74 MW solar facility in North Carolina, has invested into two solar facilities in Virginia totaling 520 MW, and has entered into many commercial power agreements with the company *Invenergy*, which owns 1,600 of RE infrastructure that provides clean electricity to commercial contracts only. The company has indicated that it will continue to expand its RE use as a result of its 2012 commitment to reach carbon neutrality and then achieve 100 percent RE dependency company-wide (Esteves 2019; Frangoul 2019b; Microsoft 2019; Wang 2013).

8. *Walmart*: Following the rhythm of other Fortune 500 companies, this superstore retailer has reached 28 percent RE dependency on track to its 50 percent goal by 2025. And in collaboration with their 400 plus suppliers, the company has made a goal of reducing its associated GHG emissions by 1 $GtCO_2eq$ by 2030. As of recently, half of the company's suppliers have reported a net reduction of 0.02 $GtCO_2eq$ in GHG emissions. Regarding expanding RE use, the company has announced plans for adding hundreds of electric vehicle charging stations across its operations in 34 states and has partnered with 46 RE generation facilities to provide energy to their operations in five states (Domonoske 2019; Holbrook 2018, 2019).

INTERNATIONAL LEVEL REVIEW

An Era of Globalization: Globalization is the ongoing trend in integrating different technological, social, political, cultural, and economic paradigms of distinct nations and communities across the globe. The trend is shrouded in controversy, as its contemporary progression has resulted in historical achievements in addition to unquantifiable inequalities. Globalization is responsible for the expansion of supranationalism (e.g. The European Union, The African Union, etc.) and the growth in the Global South's per capita affluence. But in contrast, globalization is also responsible for global free-trade inequalities, widespread immigration issues, the rise in protectionist individualism from right-wing populist politics, and environmental injustices within the Global South. *As noted earlier regarding RE, a transition away from carbon-intensive fossil fuels is not a process that can be done in isolation, as its implications and side-effects are inevitably globalized.* The current progression of globalization is a salient issue that needs to be addressed to achieve any measurable action that will mitigate climate change (Edenhofer et al. 2014; Gielen et al. 2018; Irwin 2017; Kazin 2016; Rodrik 2017; Steger 2017; Watts et al. 2003).

The Converging Salience of Global South Sociopolitical Development and Environmental Injustices: Many of the raw materials used to manufacture PV modules are mined and refined in Global South nations that lack adequate human rights, social stability, and rudimentary labor protections. But in association, sociopolitical development (SPD) theory denotes: as a nation's per capita affluence increases, the general population's attention towards institutional and commercial social responsibility becomes more conspicuous. As the Global South's per capita affluence is expected to be three times to eight times more in 2100 than in contemporary terms and as the Global South's population is projected to increase exponentially, a consideration must be placed on the potential effects of Global South SPD on the globalized PV industry. The net supply chain labor costs involved within PV manufacturing are currently advantageous to Global North nations, due to the stratification of wages for labor between first-world and third-world nations. As Global South nations advance their social and political institutions to acquire basic labor protections, the previously favorable labor costs of PV manufacturing due to a stratified global economy, may be at risk from egalitarian developments (Fu et al. 2017; Klinsky et al. 2016; Martinez-Alier et al. 2016; Vidal 2015; Watts et al. 2003; World Bank & IFC 2002).

An Example of African Mine Labor Inequalities with Associated Sociopolitical Developments: Growth in global industrial development has been exponentially increasing demand in mined metals for key economic sectors, such as agriculture and high-tech industry, like that of PV manufacturing. In association, The Democratic Republic of the Congo (DRC), identified within **Figure 4**, has been under international scrutiny for their draconian low-wage child labor practices within the country's many mines of high-quality metals. Children in the DRC have been forced into mining Cu and other metals. As of mid-2019, 44,306 tons of Cu had been imported to Europe from the DRC, which amounted to nearly eight percent of all European Cu imports. In addition, 50 percent of all DRC exports to the US is Cu. *To review, Cu is one of the few materials commonly employed within PV modules* (Argus 2019; BAA 2019; BILA 2018b; Fu et al. 2017; ITA 2017; Prasad & Snow 2005; World Bank & IFC 2002).

Figure 4. A map of the African continent with the DRC emphasized in the green (BILA 2018a).

Within the DRC's government, there is no measurable effort to curb child mine labor. As the DRC is plagued by constant unrest and corruption, there is a growing prevalence of pro-democracy demonstrations demanding for the government to transition to democracy with improved transparency. This growth in public concern over government conduct exemplifies the premise of SPD theory. With US and UN assistance, the DRC may one day achieve this transition that will eventually lead to greater egalitarian efforts regarding mine labor practices (BDHRL 2018; Watts et al. 2003; World Bank & IFC 2002).

DISCUSSION

The Role of the Free-Market: The free-market, denoting the contributions of universities, companies, and the general consumers of utility-scale solar electricity, plays a vital role in PV technology's commercial feasibility (Baumol 2002; Chappelow 2019). The high-cost of a BAPV system is based on the associated costs of raw metal extraction and smelting, manufacturing, net transportation, net labor, legalities, and commercialization, but is made more economical by university and corporate investment and innovation, how a state's electricity market is structured, state and national programs and policies, and international economic stratification (EPA 2017b; Fu et al. 2017; Pop et al. 2011; Rodrik 2017; Solangi et al. 2011; Steger 2017; Vidican 2009; Yi & Feiock 2014). The expansion of the global PV industrial complex within the past few decades is associated with the law of supply and demand. The law of supply and demand states that the greater the demand for a product, the cheaper the product gets over time. In consideration of this economic law, PV modules will inevitably get cheaper over time as the social desire for a RE transition grows (Augustyn et al. 2013; Baumol 2002; Chappelow 2019).

The Role of Governments: The UN IPCC AR5 describes RE options that global society can invest into, to mitigate anthropogenic climate change. Most prominently, global society must adjust its behaviors and practices, and be prepared to assess the risks to energy security that is anticipated to be impacted from climate change. As anthropogenic climate change will inevitably transform ecological and human systems, it is imperative that governments enact policies and make way for RE to reduce GHG emissions. Additionally, there is no doubt that globalization and Global South SPD will have lurking and confounding impacts that are yet to be assessed. As the current progression of globalization uncovers new issues and institutes the conditions for supranational cooperation, world governments must address the dynamic intricacies regarding domestic politics, growing global interconnectedness, low-income inequalities, and industrial labor inequalities (Edenhofer et al. 2011, 2014; Field et al. 2014; Gielen et al. 2018; Melillo et al. 2014; Rodrik 2017; Solangi et al. 2011; Steger 2017; Watts et al. 2003).

CONCLUDING COSTS TO BENEFITS

The Costs of Solar Energy: As detailed in this review, the costs of solar energy include:

1. *Practical Cons*:
   - PV technology's intermittent electrical production.
   - A need for a large allocation of land to produce an equitable amount of electricity from utility-scale solar facilities, as compared to carbon-intensive, fossil fuel-based electrical generation facilities.
   - BIPV systems are not technologically, infrastructurally, commercially, or politically adapted into the modern energy market.
   - A BAPV system's bulky and unaesthetic appeal.

- BAPV systems are only viable on buildings with favorable ages and roof types.
- BAPV systems may be too heavy for viable installation on certain buildings.
- PV systems only produce a contributary amount of electricity that do not always satisfy a building's full energy needs.

2. *Economic Cons*:
    - A high-cost of PV system installation.
    - Installing PV systems may not be as cost-effective as purchasing electricity from utility-scale RE facilities.
    - BIPV systems are not economically advantageous to BAPV systems.
    - PV market prices increase under trade tariffs, like that of the 2017 ITC Solar Tariff, that have resulted from protectionism.

3. *Sociocultural Cons*:
    - PV technology's contribution to the stratification of free-trade, wage, and supply chain labor inequalities between first-world and third-world nations.
    - The predicted expansion of the global PV industrial complex will inevitably increase demand for mined metals. Many of the metals used to manufacture PV modules are mined and refined in Global South nations that lack adequate human rights, social stability, and rudimentary labor protections.
    - Global South SPD could uproot the foundations of the global PV industrial complex, in the event of further egalitarian developments.

4. *Political Cons*:
    - The rate of PV technology use is lower within conservative states and in captive electricity markets, due to lower market attractiveness.
    - Governments can dictate policies that dismiss PV technology, decrease its market attractiveness, and repress its commercial growth.

5. *Environmental Cons*:
    - A traditional PV module's use of environmentally toxic and carcinogenic material compounds as semiconductors.

The Benefits of Solar Energy: As detailed in this review, the benefits of solar energy include:

1. *Practical Pros*:
    - PV systems are integrable with existing infrastructure on a mass-scale.
    - BAPV systems are technologically, infrastructurally, commercially, and politically adapted into the modern energy market.
    - A BIPV system's conscientious and aesthetic appeal.
    - PV systems can be integrated with other RE production methods to satisfy the energy needs of certain buildings.
    - PV technology can provide energy security in a future that is predisposed to climate change impacts.

2. *Economic Pros*:
    - BAPV systems are economically advantageous to BIPV systems.
    - Wealthier entities, such as private universities and Fortune 500 corporations, have the ability to invest into PV technology on a mass-scale, transcending concern over the high-cost of the technology.
    - The greater the demand for a product, the cheaper the product gets. PV technology has the potential to decrease in price as its deployment continues to increase globally.

- PV market prices have been deflating at a near paralleled rate as originally predicted prior to the 2017 ITC Solar Tariff.
- Direct invest by universities and corporations can spur innovation within PV technology.

3. *Sociocultural Pros*:
    - PV systems are favored by the ACUPCC, with direct investment coming from universities.
    - The social desire for a RE transition, predisposes PV technology's employment to increase globally.
    - The CER pacts of some Fortune 500 companies and electrical utility companies focus on reducing GHG emissions and investing into RE, such as PV technology, beyond the official mandates of government policies and regulations.

4. *Political Pros*:
    - The rate of PV technology use is higher within liberal states and in competitive electricity markets, due to higher market attractiveness.
    - Governments can dictate policies that favor PV technology's market attractiveness and commercial growth.
    - Net Metering Programs, Renewable Portfolio Standards, GHG reduction standards, Cap-and-Trade Programs, Feed-In Tariffs, and PV Tax Credits, all play in favor to the PV industrial complex.

5. *Environmental Pros*:
    - PV technology's potential as a RE source that can reduce electricity-sector GHG emissions.

The Contemporary Precedence of Building-Applied Photovoltaic Systems: As anthropogenic climate change is a global commons issue that can only be mitigated through international attention, transitioning to RE, specifically that of installing BAPV systems as a first step, is critical. BAPV systems can help society to adapt to climate change by reducing electricity-sector GHG emissions and in bouncing back from its anticipated impacts on energy security by providing infinite, clean, RE. The free-market contributes to the commercial growth and market attractiveness of BAPV systems through playing into the capitalist system of supply and demand economics. In association, governments, denoting state, national, and international authorities, can all contribute to the commercial growth and market attractiveness of BAPV systems through instituting competitive electricity markets and investing into programs and policies that play in favor to the expansion of the PV industrial complex.

The contemporary precedence of BAPV systems, is based on the interaction of the aforementioned practical, economic, sociocultural, political, and environmental elements regarding PV technology use. The expansion of the PV industrial complex and the continuously decreasing cost of PV technology have both been trends for a couple decades now. Despite the high-cost of PV technology and its plethora of issues, PV technology will inevitably be employed on a larger scale in the near future to help mitigate electricity-sector GHG emissions. With public and private sector cooperation, PV technology can be made more economically equitable. In conclusion, the future precedence of PV technology maintains a positive economic and environmental outlook with substantial political and sociocultural issues regarding the Global South's role in this era of globalization.

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