An Updated Review of the Solar PV Installation Workforce Literature

Sika Gadzanku, Alexandra Kramer, and Brittany L. Smith

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-7A40-83652
April 2023

An Updated Review of the Solar PV Installation Workforce Literature

Sika Gadzanku, Alexandra Kramer, and Brittany L. Smith

Suggested Citation

Gadzanku, Sika, Alexandra Kramer, and Brittany L. Smith. 2023. *An Updated Review of the Solar PV Installation Workforce Literature*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-83652. https://www.nrel.gov/docs/fy23osti/83652.pdf.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-7A40-83652
April 2023

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

U.S. Department of Energy (DOE) reports produced after 1991 and a growing number of pre-1991 documents are available free via www.OSTI.gov.

Cover Photo by Dennis Schroeder: NREL 53270

NREL prints on paper that contains recycled content.

Acknowledgments

The authors would like to thank Andrew Graves, Betony Jones, Shrayas Jatkar, and Sarah Wilder of the U.S. Department of Energy (DOE) for their support and review of this work. We would like to acknowledge the following individuals for their helpful comments, corrections, and feedback: Kevin Conner (University of Utah), Jeanine Cotter (Luminalt), Khalia Davis (SOLV Energy), Trevor Falk (North America's Building Trades Unions), Kate Griffith (independent), Jessie Hammerling (University of California, Berkeley), Brad Heavner (California Solar and Storage Association), Erin Hutson (Laborers' International Union of North America), Jason Kaasovic (TruNorth Solar), Alaa Kamel (BlueGreen Alliance), Taylor Waites (International Brotherhood of Electrical Workers), and Isa Ferrall, Eric Lockhart, and Adam Warren (NREL). Editing was provided by Susannah Shoemaker (NREL). Any omissions are the sole responsibility of the authors.

List of Acronyms

AAPI	Asian American and Pacific Islander
AHJ	authority having jurisdiction
ALJ	administrative law judge
ARB	administrative review board
ARRA	American Recovery and Reinvestment Act
BESS	battery energy storage systems
BLS	U.S. Bureau of Labor Statistics
CA	Copeland “Anti-Kickback” Act
CBA	collective bargaining agreement
CFR	Code of Federal Regulations
CGE	computable general equilibrium
CSP	concentrating solar power
CWA	community workforce agreement
CWHSSA	Contract Work Hours and Safety Standards Act
DBA	Davis-Bacon Act
DBRA	Davis-Bacon and Related Acts
DEIA	diversity, equity, inclusion, and accessibility
dGen	Distributed Generation Market Demand
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
EE	energy efficiency
EIA	U.S. Energy Information Administration
EO	executive order
ETP	energy training partnerships
FAR	Federal Acquisition Regulations (Title 48 of the C.F.R)
FERC	Federal Energy Regulatory Commission
FOH	Field Operation Handbook
FLSA	Fair Labor Standards Act
GDP	gross domestic product
GWD	Davis-Bacon General Wage Determinations
I-O	input-output
IBEW	International Brotherhood of Electrical Workers
ILO	International Labor Organization
IMPLAN	Impact M for Planning
IRA	Inflation Reduction Act
IREC	Interstate Renewable Energy Council
IRENA	International Renewable Energy Agency
ITC	Investment Tax Credit
JEDI	Jobs and Economic Development Impact
LBNL	Lawrence Berkeley National Laboratory
LIUNA	Laborers International Union of North America
LMI	low- and moderate-income
K-12	Kindergarten through 12th grade
kW	kilowatt
MW	megawatt

NABCEP	North American Board of Certified Energy Practitioners
NABTU	North America's Building Trades Unions
NAICS	North American Industry Classification System
NCEER	National Center for Construction Education and Research
NCSL	National Conference of State Legislatures
NECA	National Electrical Contractors Association
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
NLRA	National Labor Relations Act
NLRB	National Labor Relations Board
NREL	National Renewable Energy Laboratory
NFPA	National Fire Protection Association
O&M	operations and maintenance
OSHA	Occupational Safety and Health Administration
PCA	Walsh-Healey Public Contracts Act
PLA	project labor agreement
PPA	power purchase agreement
PV	photovoltaic
RE	renewable energy
ReEDS	Regional Energy Deployment System
RFI	request for information
RSP	renewable portfolio standard
SCA	McNamara-O'Hara Service Contract Act
SEI	Solar Energy International
SETO	Solar Energy Technologies Office
SOC	Standard Occupational Classification
TERO	Tribal Employment Rights Ordinance or Office
WAB	Wage Appeals Board
WDOL	Wage Determinations On-Line
WHD	Wage and Hour Division
WHI	Wage and Hour Investigator
UL	Underwriters Laboratory
USEER	U.S. Energy and Employment Report
UVR	ultraviolet radiation

Executive Summary

The recent Solar Futures Study from the U.S. Department of Energy (DOE) showed how high solar deployment levels can decarbonize the U.S. grid and the broader economy. This would require significant growth in the current solar workforce. In order to develop a well-trained, equitable, and inclusive workforce with high-quality jobs, DOE's Solar Energy Technologies Office (SETO) solicited input from a variety of stakeholders on employment-related needs, strategies, and challenges for the solar industry. The solicitation emphasized a need for analytical context around different PV project characteristics and labor aspects, and how they might impact workforce well-being and PV industry growth. To determine the most valuable novel analytical contributions, this work reviews the existing literature on solar workforce topics to identify which areas have been studied previously and where gaps remain.

Focus areas in the literature review include the following topics:

1. Metrics related to solar workforce, deployment, and costs (and associated studies) capturing aspects such as demographics and regional distribution
2. Solar workforce well-being, including employee contracting mechanisms, compensation, occupational safety and health, and community impacts
3. National and state policies most relevant to the U.S. solar workforce
4. Ongoing efforts to expand the solar workforce participation, including local staffing dynamics, challenges, and relevant strategies.

The first section discusses metrics related to solar workforce and deployment. A review of the available data for different metrics is important for understanding the limitations of the current literature and the potential for future work. This review includes the current size of the solar workforce, including recent changes due to the coronavirus pandemic; the workforce distribution across the stages of PV system installation and operation as well as the different solar market sectors, such as utility-scale and rooftop; the regional distribution of solar workers, deployment, and costs; the demographic composition of the solar workforce; the distribution of trades across various market segments; data on worker compensation; and the use and availability of organized labor for solar installations. We also present a review of related studies that assess interactions between some of these metrics, although few exist in the literature.

The second section discusses the definition of workforce well-being and the concept of "good jobs." Some of the major contributors to workforce well-being are reviewed in detail, namely, contracting mechanisms (including the use of organized labor), compensation (wages and benefits), occupational health and safety (including standards and certifications, as well as job-specific risks), and broader community impacts. This section also reviews solar employment and economic impact assessment analyses. These often rely on economic input-output (I-O) and computable general equilibrium (CGE) models (which tend to account for multisector or economywide employment impacts), or on simple analytical models (which do not account for the broader economic impacts of deployment).

The third section reviews policies at both the national and state level that are most relevant to U.S. solar workers. This includes prevailing wage policies at the state and federal level (including the potential for racial discrimination); collective bargaining policies; health and safety regulations; labor law enforcement and violations; executive actions; and other relevant policies; as well as international standards that progress the quality of solar jobs worldwide.

The fourth section provides a brief overview of solar workforce development, including skills needs and training pathways, encompass licensing, certification, accreditation, and the union apprenticeship model. This section also reviews the literature on broader barriers to accessing clean energy jobs, the literature on fossil fuel transition workers, and a few examples of efforts to reduce the identified barriers.

Looking toward future research—based on the literature and input from reviewers, the primary aspects of solar installation projects that may impact workers and workforce requirements fall into three major categories: (1) project features (technical aspects and ownership/funding), (2) regional conditions (including policies, local market trends, population, and weather), and (3) workforce characteristics and contracts (including work arrangements, licensing requirements, injury rates, and unionization rates).

To capture the impacts of these three categories—and how they differ across projects and regions—empirical research, regional comparisons, and a limited set of case studies are needed. Scenarios corresponding to the case study regions can then be modeled using the NREL photovoltaic (PV) system cost model to capture impacts on system costs. In turn, the system costs can be interpreted in context with the price sensitivity provided by the NREL Regional Energy Deployment System (ReEDS) capacity planning model and the Distributed Generation Market Demand (dGen) model, enabling an evaluation of cost impacts on PV deployment and adoption.

The potential for installation labor to affect system quality (lower electricity output or premature repairs) should also be evaluated, since this could increase maintenance and electricity costs over the lifetime of the system. An empirical approach could evaluate the metadata available in data sets on existing PV systems for insight into any of the primary aspects listed previously, then analyze the data to determine whether a statistically significant difference exists in the electricity generation, technical performance, or quality of solar installation projects with differing features. If adequate empirical data is not available, levelized cost of electricity (LCOE) models can evaluate how much additional electricity generation would be required to offset higher labor training expenses. Similarly, LCOE models could also evaluate the reduction in maintenance costs required to offset an increase in labor training costs.

Table of Contents

List of Figures

List of Tables

Introduction

The recent Solar Futures Study from the U.S. Department of Energy (DOE) analyzed how solar photovoltaics (PV) could play a sizable role in decarbonizing the U.S. grid and the broader U.S. energy economy (Ardani et al 2021). For example, to achieve a decarbonized U.S. grid by 2035, the solar capacity installed annually would need to quadruple from the amount installed during 2020.

These deployment levels will require significant growth in the current solar workforce, with hundreds of thousands of jobs set to be created across the country (Truitt et al. 2022). Research and initiatives supported by DOE's Solar Energy Technologies Office (SETO) aim to enable this accelerated deployment of solar technologies by developing a well-trained, equitable, and inclusive workforce with high-quality jobs (U.S. Solar Energy Technologies Office 2022).

Through a request for information (RFI), SETO solicited input from a variety of stakeholders on employment-related needs, strategies, and challenges for the solar industry (U.S. Solar Energy Technologies Office 2021). This feedback they received emphasized a need for analytical context around different labor factors and how they might impact workforce well-being and PV industry growth.

To determine the most valuable novel analytical contributions, the National Renewable Energy Laboratory (NREL) proposed a thorough review of existing solar workforce research to identify which areas have been studied previously and where gaps remain. **The goal of this literature review is to confirm the originality, utility, and feasibility of future PV workforce analysis supported by NREL. This will be achieved by assessing the existing literature on labor in the U.S. solar industry and adjacent industries.**

Topics identified as priorities include:

1. Metrics and studies related to solar workforce, costs, and deployment that capture aspects such as demographics and regional distribution
2. Solar workforce well-being, including employee contracting mechanisms, compensation, occupational safety and health, community impacts, and job estimates
3. National and state policies relevant to the U.S. solar workforce
4. Ongoing efforts to expand the solar workforce, including local staffing dynamics, challenges, and relevant strategies.

Methodology

We identified the literature reviewed in this report primarily by using Google Scholar, Scopus, and NREL Library resources, in addition to collecting recommendations from reviewers. Initially, we focused on academic and peer reviewed literature on solar installation jobs, which identified a limited set of literature. Therefore, we expanded the search to include adjacent industries and broader literature, such as general technical reports and media reports, to gather more context on how labor is used, valued, and considered in solar deployment in the United States.

The following assumptions were made in this review:

- Policies are categorized as either national or state. National policies include federal policies that apply to the entire United States. In contrast, state policies are not national and are only

applicable to a portion of the United States. Local or regional trends may be included in the discussion on state policies.
- The system sizes used to define PV sectors are reported in Table 1, in units of kilowatts (kW) to megawatts (MW).

Table 1. PV Sector Definitions (Fu, Feldman, and Margolis 2018)

PV Sector	Description	Size Range
Residential	Residential rooftop systems	3–10 kW
Commercial	Commercial roof	10 kW–2 MW
Utility-Scale	Ground-mounted systems, fixed-tilt and one-axis tracker	>2 MW

1 Metrics for Solar Workforce, Deployment, Costs, and Related Studies

This section discusses metrics related to the solar workforce, PV project costs, and deployment, as well as related studies. A review of the available data for different metrics is important for understanding the limitations of current solar workforce databases and literature and the potential for future work. Metrics discussed in this section include:

- The size of the solar workforce, including insight into different market sectors (such as utility-scale systems, rooftop systems, and systems paired with storage)
- The regional distribution of the current solar industry (current local rate of solar installs)
- The maturity of local solar industry (cumulative number of historical solar installs)
- Databases of PV project costs
- Data on solar workforce demographics, trades, and compensation, and availability of organized labor.

1.1 Current State of the U.S. Energy Workforce

In 2019, the energy sector accounted for about 5% of the entire U.S. workforce and was adding jobs three times as fast as the rest of the economy (Truitt et al. 2022). Of the 7.5 million 2020 U.S. energy sector workers, 40% were in power and fuels, 28% were in energy efficiency (largely construction jobs), and 32% were in motor vehicle and component part sectors. The clean energy sector accounted for 3 million workers, nearly three times the size of the fossil fuel extraction and generation sector (E2 et al. 2021; Williams et al. 2021; U.S. DOE 2021; Truitt et al. 2022).

The 2019 coronavirus pandemic led to ~10% job loss across the entire U.S. energy sector, with higher job losses in fuels, extraction, and power generation. The greatest number of losses occurred in Texas, California, Michigan, Ohio, and New York (U.S. DOE 2021; IREC 2022b; Kirk 2022; Truitt et al 2022). The solar industry was especially impacted during the pandemic because much of solar labor involves construction work, which stalled due to necessary public health measures. Once lockdown measures were eased, there was continued growth in the solar labor market and other clean energy sectors (Chen et al 2022).

Overall, however, the U.S. energy sector has now largely recovered from the earlier job loss. Unemployment trends in 2021 revealed higher unemployment for racial and ethnic minorities, women, young workers, and those with less advanced degrees (Philip Jordan 2020a, 2020b, 2020b). In the energy sector, this translated to Black and Latino workers facing higher unemployment rates, especially in automobile manufacturing and fossil fuel extraction, respectively (Philip Jordan 2020a, 2020b, 2020b).

In the clean energy workforce, the data reveals a sizable share of workers of color in the clean energy workforce. However, most of these are in lower wage jobs with fewer in senior positions. Though Latinx workers are well represented in the clean energy workforce overall, deeper analysis reveals most of these jobs are in low-wage positions, which are most vulnerable to economic and societal shocks like the coronavirus pandemic. Black workers remain underrepresented (at 8% compared to 13% in the broader economy), which is ~40% disparity in employment levels (E2 et al. 2021). Black worker participation in sub industries is only comparable to broader economic trends in industries with big employers and/or union shares (such as utilities, automakers, and oil and gas companies). This disparity is also due to the slower growth in clean energy deployment in the southeast, which is home to a big share of Black communities (E2 et al. 2021). Asian workers in the clean energy workforce are comparable to the broader energy industry and economy. The share of Pacific Islanders and Native Americans is slightly higher (2.5%) compared to the broader economy (1%). Considering female workers, renewable electricity generation has the highest percentage of female workers (at 30%) and the clean vehicles industry has the lowest (at 23%) (E2 et al. 2021).

1.2 Solar Market Sectors and Employment

The 2021 U.S. solar workforce was estimated to consist of approximately 250,000 full-time workers (IRENA and ILO 2021; U.S. DOE 2021; IREC 2022b).[1] The total exceeds 330,000 if part-time workers—those who spend less than half of their time on solar—are included (IREC 2022b). Installation and project development jobs account for the majority of solar jobs (66%), followed by manufacturing (13%), wholesale trade and distribution (11%), operations and maintenance (5%), and other jobs (5%) (IREC 2022b). Considering the installation and project development sub-sector, a further breakdown shows that only 37% (i.e., 62,160) of workers in this sub-sector are directly involved in installation or repair occupations. Other workers in this sub-sector focus on production (or manufacturing), administrative, management, sales, or other occupations.

In recent years, utility-scale solar has accounted for 60%–70% of installed capacity, with its market share projected to grow (Bolinger, Seel, et al 2022; Feldman et al 2022). However, the majority (51%) of solar jobs are in the residential sector, followed by the utility-scale and commercial sectors (20% each), then community solar (9%) (IREC 2022b). This indicates that solar installer job productivity is higher for utility-scale solar projects than distributed solar projects.

Additionally, there has been significant growth in battery energy storage system (BESS) deployment, especially for BESS paired with solar, and particularly for distributed (behind-the-meter) systems (Bolinger, Gorman, et al 2022). This growth in deployment has led to an estimated 22,000 additional jobs focused on storage that include some solar paired with storage (IREC 2022b). Solar plus storage as a sector is expected to grow; distributed solar plus storage was 11% of all 2021 distributed solar

[1] A solar worker is defined as anyone who spends 50% or more of their time working on solar-related activities (IREC 2022b).

installations, and this share is projected to grow to 29% by 2025 (Wood Mackenzie Power & Renewables & SEIA 2021).

1.3 Regional Distribution of Projects and Costs

There has been nationwide growth in the solar workforce, with growth concentrated in states leading in solar deployment: California, Florida, Massachusetts, New York, and Texas, and to a lesser extent, Arizona, Colorado, Ohio, and Nevada (Bolinger, Seel, et al 2022; IREC 2022b). For more insight into where (and what kind of) deployment is occurring, we will review available data sets here, because these trends have implications for the broader solar workforce.

The U.S. Energy Information Administration (EIA) publishes monthly (EIA 2022b) and annual (EIA 2022a) reports on completed PV projects in the United States. Form EIA-860 annually reports the county, capacity, utility name, sector/ownership type, and month of first operation for PV systems larger than 1 MW_{AC} in the United States, along with some other system characteristics, such as racking type, existence of net metering agreements, and PV material (EIA 2022c). Forms EIA-861 and EIA-861M collect data sets annually and monthly (respectively), which both include estimates of smaller distributed PV systems (EIA 2022a, 2022d).

Lawrence Berkeley National Laboratory (LBNL) publishes an annual report on utility-scale solar (defined as projects larger than 5 MW_{AC}) that synthesizes information from EIA-860 and many other sources (Bolinger, Seel, et al 2022). The full set of individual project data includes information on capacity, geographic coordinates, commercial operation date, pricing (where available), as well as characteristics such as racking type, tile, inverter loading ratio, and storage technology. Power purchase agreement (PPA) price data are gathered from Federal Energy Regulatory Commission (FERC) electric quarterly reports, FERC Form 1, Form EIA-923, state regulatory filings, company financial filings, and trade press articles. The report provides annual statistics for installed system costs, which are based on large but non-exhaustive sets of systems. Data on installed system costs are estimated from sources such as Section 1603 grant data from the U.S. Treasury, FERC Form 1, state incentive programs and regulatory filings, company financial filings, trade press articles, and interviews with developers and owners, among others.

LBNL also publishes an annual report, “Tracking the Sun,” that considers distributed systems (with sizes smaller than 5 MW_{AC}) only (Barbose et al 2022). The data set of distributed systems behind this report is not exhaustive, but it captures some information about more than 75% of existing systems in the United States, and typically captures installed price information for around a third of systems installed annually. The data is collected on PV systems participating in incentive programs, renewable energy (RE) credit registration systems, and interconnection processes, typically from state agencies, utilities, and other organizations. The data set reports system size, zip code, utility service territory, sector, ownership type, installer name, and total installed price (and rebates or grants) when available. Other system characteristics, such as the inverter loading ratio, panel tilt, and module manufacturer, are also reported.

Additional regional metrics were determined to be significant in Gillingham et al. (2016), as well as other metrics discussed later in Section 1.5. A higher number of installer firms in a given region was shown to be correlated with lower prices. Greater installer experience (defined as installs per firm) in a given region was correlated with lower prices as well. However, greater installer competition (measured by Herfindahl-Hirschman index) was observed to be correlated with higher prices, which the study suggests might be explained by concentrated markets achieving economies of scale. The study also shows that areas with higher interconnection scores (indicating greater ease of interconnection) have higher prices, as do areas with greater total installations (measured in thousands of installs). The study speculates that these higher prices may be occurring in regions with high demand that outpaces supply. However, evaluating cumulative installation metrics by state may introduce bias toward larger states; other metrics, such as installs (or total PV capacity) per capita, should also be considered.

1.4 Worker Demographics, Trades, Compensation, and Organized Labor

In terms of the demographic makeup of the solar workforce, the industry is generally young, with women and Black employees underrepresented in general, and women and people of color underrepresented in leadership and management roles. Women and Black employees (30% and 8%, respectively) remain underrepresented in the solar industry compared to the broader workforce (47% and 12%, respectively). Hispanic and Asian American workers are well represented in the general solar workforce (20% and 9%, respectively) compared to the broader workforce (18% and 7%, respectively) (IREC 2022b). However, all these groups are underrepresented in management positions across all solar sectors.

The occupations (sometimes referred to as trades, or crafts) used in solar installation can vary slightly between different regions, market segments, and studies. Occupations are typically defined using the Standard Occupational Classification (SOC) system created by the U.S. Department of Labor (DOL). For example, utility-scale solar installations in California are developed under a five-trade agreement between electricians, laborers, carpenters, iron workers, and operating engineers (Ferris 2021). The annual NREL PV system benchmark models the use of laborers, electricians, and operating engineers (Ramasamy et al 2021). Earlier studies emphasized participation from other occupations, such as roofers (Friedman et al 2011).

The U.S. Bureau of Labor Statistics (BLS) publishes annual data on the total number and geographic distribution of workers in the aforementioned occupations (whether they are engaged in solar-specific projects or not). BLS also reports annual data on “Solar Photovoltaic Installers” as its own occupation (established in 2010). However the total number of workers under this occupation category was 16,420 in 2021 (BLS 2022). This is less than 10% of the estimated 2021 solar installation workforce size (IREC 2022b) and includes operations and maintenance workers, so it is likely that most installation workers are accounted for under other occupation categories. BLS also reports the distribution of industries for workers in each occupation, defined by North American Industry Classification System (NAICS) codes.

Statistics on wages and total annual income by location and industry are available for each occupation from BLS. BLS also publishes annual statistics for various nonfatal occupational risks, injuries, and illnesses, available for SOC codes as well as NAICS codes (U.S. Bureau of Labor Statistics 2021). The DOL collects Form 5500 from all employers, which reports which workers have access to retirement plans and what fraction utilize the plans (U.S. DOL 2022). Some studies rely on the RSMeans Handbook for estimates of nonwage compensation for occupations in the construction industry and wage differentials for unionized workers in a given occupation and region (Fu et al 2018; Ramasamy et al 2021).

About 10% of the current solar workforce is unionized (higher than the national private sector average), largely driven by higher unionization rates for utility-scale projects in California and northeast United States (U.S. Department of Energy 2022b). There are several unions associated with the various trades involved in solar installation, which represent union electricians, iron workers, laborers, carpenters, and operating engineers. More detail is provided in Section 2.1.

1.5 Analyses of PV Labor and Project Costs

This section reviews prior studies that contain any analysis of labor and solar PV system costs, deployment, or performance. Given the limited number of studies directly about the solar industry, we also considered adjacent industries, such as construction and energy efficiency. Because a comparatively large amount of literature exists on the broader construction industry (which shares many common features with PV installation), some of this literature is also reviewed briefly here.

1.5.1 Solar PV Industry

Some studies capture **how to reduce labor hours (and the corresponding total cost**) during solar PV installation by improving and standardizing specific hardware or optimizing certain procedures (Ardani et al 2013; Goodman et al 2014; Ardani et al 2018). However, mechanisms to reduce other costs were also presented in these studies, because labor does not represent the largest expense category for PV systems. Early studies often compared the United States and Germany, which had a larger solar market at the time (Seel et al 2013, 2014; Morris et al 2014).

The **annual NREL PV system cost benchmark report** captures some differences in project labor costs for different project types, sizes, and select locations (Feldman et al 2021; Ramasamy et al 2021). Some proprietary cost models exist that capture these aspects as well, such as Wood Mackenzie & SEIA (2022), but they are not reviewed here because they are not publicly available. Some NREL benchmarks from earlier years also included a comparison of union labor costs for utility-scale systems (Fu et al 2016, 2017, —although these were critiqued in Jones (2020b). This study observed that some states with prevailing wage laws have **higher labor costs but lower total solar project costs** than other states without prevailing wage laws.[2] However, there may be multiple contributing factors involved such as demand for solar and economies of scale in regions with higher labor costs. More detail on prevailing wage laws and the associated literature is presented in Section 3 of this report.

In another study, a regression analysis of existing systems determined that **higher local labor costs were associated with lower PV system prices** (Gillingham et al 2016). The authors suggest that this might be partially explained by the higher labor costs in areas with lower PV system demand, which may cause lower PV system prices. A different regression analysis found that labor costs have an inverse relationship with soft costs (Nemet et al 2020). Soft costs are the non-hardware costs associated with solar installation. This may include labor, permitting, and supply chain costs (Nemet et al. 2020). A review of solar installation wages in Illinois found that the prevailing wage increased system costs between 1% and 9%, with the largest increases seen for smaller residential systems (Jones 2020a), before accounting for potential increased productivity, improved workforce well-being, and other cost savings for projects under prevailing wage laws.

Relatedly, regression analysis has offered some insight into how **knowledge spillovers and learning by doing** can reduce soft costs for PV, including labor costs (Nemet et al 2020). This relies on some assumptions regarding the rate of learning given employee turnover (Grubler & Nemet 2014), which

---

[2] The U.S. Department of Labor (DOL) defines the prevailing wage rate as the average wage paid to similarly employed workers in a specific occupation in the area of intended employment (U.S. Department of Labor (DOL) n.d.).

may be influenced by various labor factors. Another study that considers learning by doing also provides some discussion about the role of labor costs (Bollinger & Gillingham 2019).

The cost effects of **competition and installer experience** have also been examined to some extent. One study found that greater PV installer density leads to lower prices due to increased competition at the local or county level, and greater firm experience (history of prior installs) is likely to reduce prices (Gillingham et al 2016). In another study, lack of competitive bidding led to higher prices, from higher customer acquisition costs recovered through higher bid prices (Slick 2018).

Some discussion exists around the impact of **ownership or power purchase agreements** (PPAs) on labor costs—because developer revenue is dependent on returns, this can act as an incentive to keep costs low. In contrast, for utilities that own their own plants, there may be less incentive to lower costs, because their rate of return is set by regulators (Scheiber 2021). However, some states also regulate developers as electric utilities when using a PPA model (SEIA 2022).

Studies on how **labor factors affect system performance** are limited. For example, an analysis of installed systems observed a negative correlation between first-year hardware issues and the number of systems built by the installation company (D. C. Jordan et al. 2020). NREL published a cost model to estimate costs associated with the operations and maintenance (O&M) of installed PV systems, which includes an assessment of O&M labor and associated costs (H. Walker et al 2020). This model was based on an O&M best practices document that describes labor characteristics most relevant to O&M (H. A. Walker 2018).

1.5.2 Construction, an Adjacent Industry

There are multiple existing literature reviews that evaluate the impact of prevailing wages on construction costs (Mahalia 2008; Manzo IV et al 2016; Duncan 2021). These publications have noted that for construction projects built under prevailing wage requirements, the requirements generally do not have a statistically significant impact on construction costs but exceptions may exist based on market conditions and regional policies (Duncan & Ormiston 2014).

One study showed that prevailing wage regulations did not affect bidding behavior on construction projects or reduce the participation or chances of nonunion contractors winning bids (Kim et al 2012). A review of prevailing wage laws in New York highlighted how these regulations prevent shifting the cost of worker benefits to the taxpayer (Kotler 2018).

By contrast, projects without prevailing wage laws have been found to have more work completed by contractors and workers from outside of the local area or state (Duncan 2021). A case study of the West Virginia repeal of its prevailing wage law showed subsequently lower wages and higher worker injury rates, with no statistical impact on construction costs (Kelsay & Manzo IV 2019).

2 Solar Workforce Well-Being

Given the dual goals of decarbonizing the U.S. energy economy and creating high-quality, family-supporting jobs, this section examines the literature on the well-being of solar workers, spanning different solar project sizes (residential, commercial, and utility scale), geographies (rural, peri-urban, urban), and labor classifications and experiences (employees, union workers, non-union workers, independent contractors, subcontractors, temporary workers, etc.).

The definition of **workforce well-being** used in this report is based on framings presented in the job quality literature. Adamson and Roper's review of the job quality literature shows that rising income inequality has led to an increase in literature exploring the qualities of and differences between "good jobs" and "bad jobs" (Adamson & Roper 2019). For example, bad jobs are discussed in the literature as undercutting the well-being of the individual worker, workforce, and broader society because the negative externalities of poor working conditions are borne by both the individual (in terms of impacts on health and well-being) and society (in terms of the increased costs of providing social welfare). Good or decent jobs as described in the literature are those that provide high-quality employment that improves the health and well-being of the individual and the broader community, and they have become a growing area of labor research (Adamson & Roper 2019; Green et al 2013; Kalleberg 2011). Bazaj analyzed California's solar job market and defined a good solar job as consisting of five elements: adequate wages (based on the local cost of living), nonwage compensation, opportunities for advancement, workplace safety, and accessibility (Bazaj 2020).

At the federal level, the U.S. DOL recently launched its Good Jobs Initiative (U.S. Department of Labor 2022a), which outlined eight principles of good jobs:

1. Active and equitable recruitment and hiring
2. Family-sustaining benefits
3. Intentional and effective diversity, equity, inclusion, and accessibility (DEIA) policies
4. Worker empowerment and representation
5. Job security and safe and healthy working conditions
6. Healthy organizational culture
7. Stable and predictable living wage
8. Equitable skills and career advancement.

Based on this, the working definition for good jobs in this literature review is as follows: jobs that provide adequate wages and benefits, consistently safe working conditions, transparent growth opportunities, and a sense of belonging to all workers. Similarly, **solar workforce well-being is defined as the conditions and experiences of workers, from temporary workers to full-time employees, that allow for financial, physical, and mental fitness for workers, their families, and the broader community.**

The rest of this chapter presents the literature on solar workforce well-being, discussing—solar contracting mechanisms and the use of organized labor, solar worker compensation (wages and benefits), and solar workplace health and safety. The first two subsections—contracting mechanisms and worker compensation—are based on emerging evidence from the solar literature and the extensive literature from the construction industry (given its similarities and overlap with solar installation work). The third subsection is framed by the research and best practices developed by the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH).[3]

2.1 Contracting Mechanisms

Workforce and worker well-being are significantly impacted by the terms of workers' employment, which can vary substantially based on the contracting mechanisms in place. Because solar installation

[3] NIOSH is a federal research agency tasked with developing workplace safety and health recommendations.

labor involves an appreciable amount of construction work, aspects of the solar installation workforce, such as contracting and subcontracting mechanisms, career mobility opportunities, and occupational risks, may mirror those of the construction industry. Some examples of different **work arrangements** (not necessarily mutually exclusive) among solar installation workers include:

- Standard workers (or part-time or full-time employees)
- Nonstandard workers (which include subcontractors, independent contractors, temporary workers, and contingent, on-call, direct hire, agency, and gig workers)
- Unionized employees.

As examined by several researchers, there has been a **rise in nonstandard work arrangements and contracting mechanisms in the broader economy** (the share of the overall workforce widely varies by state and industry), and this has some implications for workforce well-being (National Employment Law Project 2016; Siqueira 2016; Howard 2017; Bernhardt 2017). Typically, standard workers (i.e., employees) are covered by existing legal protections (specifically employment and labor laws) and qualify for benefits (such as health insurance, disability insurance, and pensions), but some nonstandard work arrangements make workers ineligible for job protections and benefits.

Subcontracts are common throughout the construction industry and the solar installation industry (Howard 2017). In the construction industry, this typically takes the form of general contractors hiring several subcontracting companies who employ their workers as employees or independent contractors. Subcontracting companies may have employees that are eligible to unionize with access to similar compensation, benefits, and job protections as standard workers.

Hiring locally for solar projects promotes greater economic benefits for the local community; however, large installation projects sometimes require many temporary workers, which can be difficult to find locally (Solar Energy Technologies Office 2021). Out-of-state workers may be recruited for solar installation jobs due to difficulty with local hiring, and they may be recruited through temporary work agencies (also referred to as temp agencies). An investigative report that interviewed solar workers hired by temp agencies found that workers often start locally, but then end up traveling for future work, but receive insufficient or no travel compensation and delayed pay (Gurley 2022). Another report described some out-of-state workers not working under the proper safety or certification requirements set by the state (Scheiber 2021).

Adequate employment services are important for matching qualified applicants with jobs that ensure well-being, training, and safety for workers. Employment services may also provide relocation grants to promote labor mobility for workers who need to work in a different place than where they live or were trained (IRENA and ILO 2021).

2.2 Use of Organized Labor

About 10% of the current solar workforce is unionized (higher than the national private sector average), largely driven by higher unionization rates for utility-scale projects in California and northeast United States (U.S. Department of Energy 2022b). Unionization rates vary by state and industry; however, recent research that builds on the extensive literature on wage differences across various work arrangements has found that states with right-to-work laws (where workers covered under union collective bargaining agreements cannot be forced to pay union dues, creating a “free-rider” problem) have lower unionization and wages (N. Fortin et al 2022). The main unions involved in solar deployment represent the various trades involved in solar installation:

- International Brotherhood of Electrical Workers (IBEW)
- International Association of Bridge, Structural, Ornamental and Reinforcing Iron Workers (IW)
- Laborers' International Union of North America (LIUNA)
- United Brotherhood of Carpenters
- International Union of Operating Engineers (IUOE)

These unions represent union electricians, iron workers, laborers, carpenters, and operating engineers, respectively, with IBEW, IUOE, and LIUNA as the three main unions involved in commercial and utility-scale PV projects (Bazaj 2020; Sicotte et al 2022). California uses a five-trade agreement for larger solar projects with tasks allocated across the five unions listed (Jones 2020b). Another representative of organized labor is North America's Building Trades Unions (NABTU), which encompasses several building trades including IBEW, IUOE, IW, and LIUNA.

A high-level analysis of solar labor in California suggests that the use and availability of organized labor, project labor agreements (PLAs), and prevailing wage laws positively impact workforce well-being, especially for utility-scale PV projects (Bazaj 2020). However, most of the solar installation workforce (almost all commercial- and residential-scale installers) operate in a different project and organized labor context. In these sectors, most workers are not unionized, and residential installers (for instance) face the added craft and safety complexity of installing solar on a rooftop. Hands-on training, licensing, and certification play a larger role in ensuring high-quality jobs and high-quality installs in these sectors (Bazaj 2020).

2.3 Compensation

The literature reviewed in this report identified worker compensation as another important aspect of workforce well-being and a key determinant of job quality. Compensation typically includes wage compensation (i.e., per diem, and wages paid on an hourly or salaried basis) and nonwage compensation (typically a combination of healthcare, pension, and education benefits; others include protection from injury, career mobility opportunities, housing for transitory workers, etc.).

Besides the varying levels of training, qualification, and experience that workers bring to a job, the structure of an industry's value chain and its occupational requirements matter greatly. Relatively low-paid construction, wholesale trade, and maintenance jobs account for larger shares of solar employment in the United States than natural gas and coal, which have larger shares of mining and utility jobs (IRENA and ILO 2021). As such, worker compensation varies widely across the solar installer market due to differences in job type, market segment, use of organized labor, and local labor policies (such as prevailing wage laws).

There has been some data collection and analysis of **wage compensation** differences within the solar workforce. As noted, subcontracting plays a big role in the construction and solar installation industries especially for larger projects. When workers are hired as contractors instead of direct employees, it often makes them ineligible for legal job protections, union membership, and its associated benefits (National Employment Law Project 2016; Howard 2017). In 2020, less than a quarter of wind and solar projects used unionized workers, with high-level analysis indicating that non-union solar construction workers earned an hourly rate of $16–$19 compared to $28 for unionized workers (a similar trend was observed for wind, although there was a smaller difference between unionized and non-unionized wages) (IRENA and ILO 2021). In areas where union labor is available, research indicates that this can provide positive spillover effects (including increased wage and nonwage compensation) to non-unionized workers in nearby localities (N. M. Fortin et al 2021).

Beyond direct wages, **nonwage compensation** is another key determinant of worker experience and well-being. Nonwage compensation consists of monetary and non-monetary items in the form of benefits (healthcare, pension, education), career mobility opportunities, collective bargaining opportunities, and other benefits that are used to attract, retain, and motivate workers in a workplace (Budd 2004). Our review revealed limited literature on nonwage compensation as it relates to solar installers (with the exception of some studies on union workers). Jones et al. examined the impact of California's Renewables Portfolio Standard (RPS) on the quality of RE construction jobs from 2002 – 2015 (Jones, Philips, and Zabin 2016). The authors estimated the total number of jobs created in addition to the wage and non-wage compensation (apprenticeship training, pension, and health benefits) during that period across a range of crafts including solar relevant construction crafts such as carpenters, electricians, ironworkers, laborers, and operating engineers. Their work largely focused on large commercial and/or utility-scale solar projects, that typically used union labor and/or were governed by prevailing wage requirements. Their analysis concluded that the solar installation labor landscape (among other RE technologies) provided significant lifetime income and benefits for workers, especially in high unemployment California counties with high RE resource potential.

There is also broader research that may be applicable to the solar installation workforce. For example, Marinescu et al. (2021) use **labor right violations** such as being forced to work off the clock, failure to pay overtime rates, and worker misclassification as a proxy to explore nonwage compensation and job quality across many industries. Using multiyear data from multiple enforcement agencies, including OSHA and the National Labor Relations Board (NLRB), their work shows that higher wages and shorter commuting zones were associated with lower rates of employee labor rights violations, and that the presence of unions decreased the number of labor rights violations (Marinescu et al 2021).

Discussions about labor shortages in the solar industry often overlap with discussions about worker compensation. The labor shortage has been challenged by labor organizations, who argue that the shortage refers to low-skilled, low-wage work with poor job continuity and high turnover. Unions emphasize that a more sustainable workforce is achieved with better worker well-being and lifelong careers, and that their members also provide higher productivity and quality on the job, which has longer-term payoffs. On the other hand, some developers have concerns about the increased costs of hiring union labor (Solar Energy Technologies Office 2021). However, some of the empirical studies reviewed in Section 1.5 report an inverse correlation between labor costs and total project costs. More insight into potential cost trade-offs would be valuable.

Overall, our review of the literature revealed sparse publicly available research on wage and nonwage compensation in the solar installer workforce. This highlights a need for more nationwide data and research on solar worker wage and nonwage compensation, with a breakdown by geography, work arrangement, unionization rate, and market segment (residential, commercial, or utility scale).

2.4 Health and Safety (Physical, Environmental)

Several elements of workplace design and operation can shape solar workforce safety and associated well-being. This section focuses on (1) a review of the standards that govern safety during solar installation, highlighting the current licensing and training requirements for solar installers, and (2) examining the range of occupational risks faced during solar installation and in adjacent industries.

2.4.1 Safety Standards and Certifications

Under federal regulations, workplace safety standards are under the purview of OSHA, but states can develop and implement their own safety standards if they are at least as effective as OSHA's (Gammon & Vigstol 2022). Solar installations are generally regulated under OSHA standard 1910.269, which covers electric power generation, transmission, and distribution activities.[4] This means that solar installer employers must train and equip workers to follow appropriate safety practices to mitigate against falls, lockouts, crane and hoist hazards, electrical hazards, and heat and cold stress (Oregon Solar Energy Industries Association 2006; OSHA n.d.). The construction industry, on the other hand, is regulated under OSHA standard 1926. Construction is a high-hazard industry, accounting for 25% of job-related deaths despite employing only 5% of workers (Duncan 2021; Memarian, Brooks, & Le 2022). Construction hazards that are prevalent in solar installation include those related to work at height, excavations, noise, dust, confined spaces, power tools, and equipment. Finally, the National Fire Protection Association (NFPA) also has standards for electrical safety in the workplace: NFPA 70 is the National Electrical Code, and NFPA 70E is the Standard for Electrical Safety in the Workplace (National Fire Protection Association 2021). NFPA, a nonprofit codes and standards organization, developed these standards based on a request from OSHA. Twenty-six states and two territories have OSHA-approved plans, and 21 states and one territory have protections for private sector workers; however, there is significant variation in how well funded and effective these plans are (Gammon & Vigstol 2022). This variation results in large differences in the number of workplace inspections, average fines, and fatal accident inspections per jurisdiction compared to the federal OSHA (Gammon & Vigstol 2022).

Licensing and workers' credentials are the main tools policymakers use to ensure that solar installers have the required qualifications, competence, and expertise to safely perform their solar installation duties to the appropriate standards (White Sarah, Dresser Laura, and Joel Rogers 2010). Licensing is typically a regulatory instrument, that may vary on a state-by-state basis. In the case of solar installation, a valid license gives the holder permission to carry out solar installation duties. On the other hand, a credential is a formal acknowledgement of training or knowledge in a particular field, indicates worker competency and provides some assurance of quality solar work (White Sarah, Dresser Laura, and Joel Rogers 2010). In the solar industry, credentials often take the form of certifications (which are typically comprehensive assessment of skills and knowledge) and certificates (which denote completion of specific courses and learnings) (White Sarah, Dresser Laura, and Joel Rogers 2010). Credentials can also be used as a basis for clean energy incentives.

There is no national requirement or standard for credentialing or certifying solar installers; however, there are several at the state level. A review of licensing and certification requirements in select jurisdictions (see Table 2) suggests that the North American Board of Certified Energy Practitioners (NABCEP) PV Installation Professional Certification is a common PV installation

[4] Employers' safety codes and standards must adhere to the regulations and standards set by the Occupational Safety and Health Administration (OSHA), which develops and regulates codes and standards to ensure the health and safety of all workers (Occupational Safety and Health Administration n.d.).

certification requirement. These types of certifications and other relevant training are discussed in more detail in Section 4.1.

For **electrical workers**, there is wide variation in state requirements—11 states have formal education or apprenticeship requirements, 16 states have no formal licensing requirements, and other states may not have state requirements but do have strict local licensing requirements (Gammon & Vigstol 2022). Most states also mandate some form of apprenticeship or electrical education (Gammon & Vigstol 2022). Unions typically offer pathways to solar certification, such as the National Electrical Contractors Association (NECA)/IBEW Electrical Journeyman and Apprenticeship Training; union apprenticeships are discussed in Section 4.1.3 in greater detail.

Table 2. Example Licensing, Certification, and Certificate Requirements

Locality	Licensing Requirement	Certification
Illinois	Electrical license, third-party certifications, or Associate degree	Distributed Generation Solar Installer Certification is required. Pathways include: • Electrical Journeyman and Apprentice Training through a registered DOL apprenticeship program • NABCEP distributed generation technology certification • Underwriters Laboratory (UL) distributed generation technology certification • Electronics Technicians Association distributed generation technology certification • Associate degree in Applied Science degree from an Illinois Community College Board approved community college program
New York State	No state-wide requirement, but some municipalities require licenses	Third-party certification is tied to incentive eligibility. Qualifying certifications include: • NABCEP PV Installation Professional Certification • NECA/IBEW Electrical Journeyman and Apprentice Training • ULPV System Installer.
Rhode Island	Electrical license	Installers need to have an electrical license or one of the prescribed certifications to advertise and operate as a general contractor for solar installation. Those without an electrical license can obtain a "Renewable Energy Professional" license. Some certificates that meet this requirement include: • Solar Energy International (SEI) Solar Professionals Certificate for Residential and Commercial Photovoltaic Systems • NABCEP PV Installation Professional or Solar Heating Installer (for solar hot water) certificate • UL PV Installer Certificate • Associate degree or higher in RE technology or solar PV installation from an accredited school • Certificate of training from a manufacturer of a specific technology for the installation of that specific technology.

An investigative report from the New York Times reported that some out-of-state workers were not working under the proper safety or certification requirements and were sent out on the job without these state requirements (Scheiber 2021). Developers denied these claims; however, this does illustrate a challenge of using non-local workers when different states have different safety and certification requirements. Stakeholders have cited a need for greater national coordination of training and certification programs so that skills and certifications are more transferable and streamlined between states (Solar Energy Technologies Office 2021).

Regarding the quality of installations, state requirements for installation of rooftop solar PV systems may include state-specific building, fire, and electrical codes, but these requirements vary by state. Some issues that impact rooftop solar are restrictive or ambiguous language in the codes, lag between updated best practices and adoption time, variation in codes and amendments, and inconsistent or inefficient enforcement of codes (Argetsinger 2017). Authorities having jurisdiction (AHJs) are generally different for each site and therefore may have different authority, not only by state but also by county or municipality (Argetsinger 2017).

2.4.2 Occupational Risks and Impacts on Workforce Well-Being

This section will review the literature on the occupational risks listed in the preceding section. The literature on the occupational risks of solar installation is quite limited; as such, this section also includes broader literature on occupational risks faced by construction workers, electricians, and outdoor workers.

Duroha and Macht conducted a literature review of the occupational risks associated with PV installations, the associated health and safety effects of these risks, research into potential mitigation opportunities, and areas for future research (Duroha & Macht 2021). Using OSHA standards, risks were loosely categorized into (1) falls, skips, and trip accidents, (2) electrical shock, electrocution, and fire accidents, and (3) heat-related risks. The most studied risks were the electrical and fire hazards, including research on both rooftop and utility-scale PV systems and proposed technological solutions to mitigate the hazards, such as emergency shutdown devices, the use of fire-resistant material, fire-resistant design, and changing the PV tilt angle (Duroha & Macht 2021). The report notes that this research area is relatively new, and further research into the risk areas highlighted above is needed. There is also a need to interview actual PV installers on their perspectives and exposure to solar installation occupational hazards.

Another team conducted one of the **few epidemiological studies** on the relationship between clinical coccidioidomycosis (valley fever) prevention and outdoor construction work, with a focus on solar workers on two solar farms in California. Coccidioidomycosis is an infectious fungal disease that is endemic to the southwestern United States, especially Arizona and California. Their research showed that working in a dust cloud or storm was strongly associated with positive coccidioidomycosis cases and that at the sites considered, existing health and safety monitoring practices missed some positive cases (Sondermeyer Cooksey et al 2017). Depending on the severity of the disease, workers may have to miss work, leading to lost wages, which can negatively impact worker well-being (Sondermeyer Cooksey et al 2017). The authors recommended that in areas with heavy solar deployment and endemic valley fever like California, employers pause activities during dust storms and other soil-disturbing activities (because all workers are at risk of contracting the disease in endemic areas), increase the use of respiratory protection equipment, and encourage wetting of soil prior to any construction work. Other outdoor workforce risks identified in the literature include overexposure to ultraviolet radiation (UVR) compared to indoor workers, which increases the risk of non-melanoma skin cancer and other heat-related illnesses (Keurentjes et al 2022; Wittlich 2022).

In the broader literature, there are numerous studies on construction- and electrical-related occupational risks—including the costs of unsafe workplaces. The electrical literature considers the broad safety risks facing electricians, specifically in terms of injury rates across different types of electrical tasks and the associated equipment and working surfaces involved. Memarian et al. examine the electrical tasks and factors that contribute to on-the-job hazards, concluding that lockout/tagout is key to managing electrical risks in the workplace (Memarian, Brooks, Le, et al 2022). Others have analyzed publicly available statistics on electrical-related injuries using OSHA, BLS, and workers' compensation claim data (Gholizadeh et al 2021; Lombardi et al 2009). Some studies also consider the importance of electrical job hazard analysis in identifying hazards and developing preventative or hazard mitigation processes (Neitzel 2018; Memarian, Brooks, & Le 2022).

A state-by-state comparison of all occupational electrical fatalities and incidence rates, conducted using BLS and OSHA data, showed a correlation between workplace fatalities and state-level standards for safety interventions, training, and retraining (Gammon & Vigstol 2020). For example, a majority (10) of the 12 states with the highest fatality rates did not have OSHA-approved state-level safety standards. The analysis also showed that in some states (such as California and Texas), the number of deaths was disproportionately high in the Hispanic population, reinforcing the importance of multilingual electrical safety training, as well as providing general safety equipment (Gammon & Vigstol 2020). The analysis also found that the states with lower than average fatal injury rates required formal education or apprenticeship for electricians and did not have right-to-work laws (Gammon & Vigstol 2020). Another analysis on unionized and non-unionized construction firms in Canada suggested that unionized firms may encourage workers to report workplace injuries, and that these firms may reduce occupational risks through training and job hazard analysis (Amick et al 2015). Research shows that there is a difference in injury rates between employees (i.e., full-time workers) and nonstandard workers (i.e., temporary workers or independent contractors), as measured by differences in worker compensation claims and lower access to safety training (Benavides et al 2006; C. K. Smith et al 2010; Foley 2017; Howard 2017; Al-Tarawneh et al 2020). Regarding costs, Gammon et al. assessed the costs of electrical injuries in four states; their analysis showed that the costs of workplace electrical injuries are largely borne by the injured worker, their family and community, and other public and private funds (Gammon et al 2019). The authors also estimated that the financial cost of workplace injuries alone makes a case for investing in safer workplaces (Gammon et al 2019).

Another growing area of research that is applicable to solar workers is heat-related hazards. The literature here typically focuses on labor conducted outdoors, such as solar installation. There are several documented physiological effects of high-temperature exposure, such as dehydration, heat exhaustion, heat stroke, and death, all of which may be exacerbated by climate change (Geoffrey Heal & Jisung Park 2016; Ho et al 2018; OSHA n.d.; Samaniego-Rascón et al 2019). Heal and Park review the growing literature on the impacts of climate change and heat stress, and discuss how temperature stress impacts labor by affecting worker health, labor productivity, hours worked, and labor effort (Geoffrey Heal & Jisung Park 2016). Other studies have also shown that low-income households are more likely to be exposed and vulnerable to extreme heat (and cold) and more likely to have difficulty responding to and recovering from various extreme weather events, such as heatwaves (Russo et al 2019; Behrer et al 2021).[5] Part of this is because poorer workers are more exposed to warming; they are more likely to live

[5] Poor or low-income, as used in this multi-country analysis, refers to the "10% of countries with the highest fraction of the population below 200% of the federal poverty line." Rich refers to the countries with the smallest fraction, "calculated based on the average of 1990, 2000, and 2010 poverty rates" (Behrer et al 2021).

in areas with less green space and worse housing quality and health facilities, and importantly, they are more likely to work in jobs that involve more time spent outdoors (Behrer et al 2021). The report concludes that it is important to consider both climate exposure and vulnerability when considering potential labor impacts.

Similarly, another study assessed how temperature impacts workplace health and safety in California and its implications for labor market inequality (Park et al 2021). Using injury data from the California Worker's Compensation System, the authors considered the spatial and temporal aspects of workplace injuries. Their three main findings were that hotter temperatures significantly increase the probability of an on-the-job injury for both indoor and outdoor occupations; that temperature exposure worsens labor inequality (specifically compensation), with lower-wage workers typically experiencing more injuries (and lost income); and that policies and/or technologies could play a key role in helping the workforce adapt to hotter temperatures (Park et al 2021). Although this work did not exclusively consider solar installers, these observations are relevant to solar installation workers, given how much of their work occurs outdoors.

Broader local labor policies also play an important role in workforce well-being, especially occupational safety and health; this topic area has been extensively studied as it relates to the construction industry (Duncan & Ormiston 2014; Manzo IV et al 2016). Publicly available research on the solar industry remains limited. For example, prevailing wage laws, which are discussed in more detail in subsequent sections, are used to ensure that local workers are paid wages that are comparable to their local context. Even though these laws do not have safety requirements and provisions, workers hired under these laws typically undergo apprenticeship and general safety training, which has been shown to have an indirect effect on injury rates (Duncan 2021).

Overall, occupational health and safety is a core part of solar installer workforce well-being. Our literature review revealed some helpful insights and also highlighted key gaps in the literature. There is limited standardized, nationwide, publicly available data and research on (1) the occupational health aspects (mental and physical) of solar installation, especially across different socioeconomic populations, (2) solar workplace hazards in extreme cold, (3) potential mitigation and adaptation technologies to reduce temperature stress for solar installers, (4) the impacts of local labor policies, and (5) enforcement of various solar workplace safety requirements.

2.5 Community Impacts and Job Estimates

This section considers the literature on how solar workforce well-being (shaped by contracting mechanisms, work arrangements, use and availability of organized labor, compensation policies, and workplace safety and health conditions) **impacts the individual worker as well as their home, community, and society**.

Higher wages increase how much disposable income a worker and their household have to spend on their immediate needs and other spending needs that have broader economic impacts on their immediate community. Safe working conditions reduce the likelihood of injury and the potential for loss of income and livelihoods (Howard 2017; Gammon et al 2019). Similarly, research on California's workforce indicated that union workers on average earned more, had increased access to employment-based health coverage and retirement benefits, and had a decreased reliance on public safety net programs due to higher family income including a range of gains for women, immigrants, and people of color (K. Jacobs 2018; Thomason 2018).

Currently, the main way research questions of this nature are studied is through **economic impact assessments**, with most focusing on estimating the direct, indirect, and induced (i.e., broader community) impacts of potential changes in overall jobs created or lost. These analyses often use economic input-output (I-O) and computable general equilibrium (CGE) models to examine multisector or economywide employment impacts. Sometimes, simple analytical models are used, although these generally do not account for the broader economic impacts of RE deployment. Overall, this type of green jobs literature generally tends to focus on:

1. Developing or adapting analytical approaches and models, such as I-O models, to estimate aggregated job creation potential for a given level of RE deployment
2. Estimating employment factors or labor intensity and productivity, such as the number of job years per MW installed and/or the number of jobs per MW installed.

As an example, NREL maintains a suite of **Jobs and Economic Development Impact (JEDI) models** for multiple energy technologies, which rely on technology-specific parameters and IMPLAN economic data (NREL 2022). NREL developed and used to maintain a solar PV JEDI model, but it has not been available in recent years. Prior publications based on the PV JEDI model include:

- Overview and validation from NREL (Friedman 2012; Billman & Keyser 2013)
- A comparison between IMPLAN results and PV JEDI results (Bae & Dall'erba 2016)
- An analysis of §1603 Treasury Grant Program impacts (Steinberg et al. 2012)
- Case studies in Illinois, Virginia, California, and Ohio (Loomis et al. 2016; James et al. 2017; (Jones, Philips, and Zabin 2016); Michaud et al. 2020)

Multiple U.S. **decarbonization studies include job estimates** (Phadke et al 2020b; Larson et al 2020). These studies began with employment data reported in Barrett and Yudken (2020) and then developed estimates using Impact M for Planning (IMPLAN) (Phadke et al 2020a) or developed their own labor productivity models, such as the model in Mayfield et al (2020, 2021), based on gross domestic product (GDP). Researchers have also published simplified job projections that rely on projections of metrics like technology costs or extrapolation of labor productivity (U.S. Department of Energy 2012; B. L. Smith et al. 2021). NREL has conducted comprehensive state-level employment projections through 2030 for the energy efficiency (EE), solar, battery, and land-based wind sectors (Truitt et al. 2022). Previous research demonstrates that investments in EE and RE can produce more jobs per dollar invested than investments in fossil fuels (Wei et al. 2010).

A comprehensive literature review conducted on employment factors for wind and solar technologies (Cameron & van der Zwaan 2015) discusses the strengths of these methods as well as some gaps in how the existing literature estimates job creation potential. For example, there have been several studies estimating the employment factors for wind, solar PV, and concentrating solar power (CSP); however, there are only a handful of comprehensive studies that compare employment factors for RE to coal, gas, and oil-fired plants. Part of this may be due to data availability, but overall, this points to a need for more robust job modeling and analysis. Additionally, studies often model solar installation employment by aggregating manufacturing and install jobs, although a handful attempt to disaggregate these job profiles given that the nature of labor across manufacturing and installation differs, and manufacturing jobs, especially for solar, may occur overseas (Cameron & van der Zwaan 2015). One of these reviews also found that 75% of the reviewed literature on Canada's RE sector was not in peer-reviewed publications (Cameron & van der Zwaan 2015). These findings support our observation during this literature review process that the green jobs literature is often not published using traditional academic platforms, emphasizing the need to look beyond academic literature in this area of research.

Workplace well-being and its intersection with the home, community, and society also involves considering how workers and the workforce are supported by their employers and others to prepare for and respond to climate change. This form of community resilience is especially important for workers from frontline communities who are disproportionately exposed and vulnerable to climate disasters (BlueGreen Alliance 2019).

Sharma and Banerjee (2021) proposed a framework for evaluating the spatial distribution of clean energy labor impacts and noted that aggregating labor estimates can mask the regional inequalities that occur with RE jobs. Their paper notes the gap in the literature and points to the need for more economic impact analysis on how the costs and benefits of solar jobs are distributed across various work segments, workers, and their communities.

3 National and State Policies Relevant to the U.S. Solar Workforce

This section reviews policies at both the national and state level that are most relevant to U.S. solar workers. This includes prevailing wage policies, including evidence around racial discrimination in prevailing wage law; collective bargaining policies; health and safety policies; labor law enforcements and violations; executive actions; and other relevant policies. This section does not cover all state policies in detail but aims to provide a broad overview of the variation in state policies most relevant to the solar workforce and worker well-being. Finally, this section explores international standards that provide context on international efforts to improve the quality of solar jobs worldwide. This section is intended to provide an overview of relevant policy, but it is not a comprehensive analysis of each policy, especially recent legislation like the Inflation Reduction Act (IRA). Additionally, this section only explores policy information available at the time of publication.

3.1 Federal Policies

3.1.1 Prevailing Wage Policies

Prevailing wage policies are a type of labor policy used to incentivize the provision of good-paying jobs that account for local living costs and economies. These policies can impact how workers are compensated on public construction projects, impacting the cost of public construction and the level of bid competition (Duncan 2021). The U.S. DOL defines the prevailing wage rate as the average wage paid to similarly employed workers in a specific occupation in the area of intended employment (U.S. Department of Labor (DOL n.d.). In 2015, the DOL published the Prevailing Wage Resource Book, which reviews relevant federal policies related to prevailing wages in the section titled "Introduction to the Labor Standards Statues Coverage" (U.S. Department of Labor 2015). These policies are federal labor standards that apply to U.S. solar labor on projects under federal jurisdiction and are summarized in the following paragraphs.

The **Davis-Bacon Act (DBA)**, enacted in 1931, requires all contractors and subcontractors to pay various classes of laborers and mechanics employed under a federal contract a level of wages and fringe benefits comparable to corresponding classes of employees engaged on similar projects in the locality. This federal requirement applies to each federal government or District of Columbia contract over

$2,000 for construction of public works and requires that the contract awardee meet certain labor standards (U.S. Department of Labor 2015). The stated purpose of this act is to protect communities and workers from the economic disruption caused by non-local contractors coming into an area and obtaining federal construction contracts by underbidding local wage levels. It also lays out requirements for contractors and subcontractors regarding pay frequency and wage rates (U.S. Department of Labor 2015).

The Davis-Bacon Act has been extended to **Davis-Bacon and Related Acts (DBRA)**. In the DBRA, the DBA prevailing wage requirements are extended to related acts that provide federal assistance for construction, such as grants, loans, loan guarantees, and insurance. This extension therefore applies the prevailing wage to agencies of the federal government as well as non-federal agencies and grant recipients (U.S. Department of Labor 2015). Some of the most common issues with the DBA and DBRA are misclassifying laborers; failing to pay the full prevailing wage, including benefits; inadequate recordkeeping; incorrect administration for apprenticeship programs; and incorrect information dissemination to laborers (U.S. Department of Labor 2022c).

Several other acts are important to prevailing wage standards. The **Fair Labor Standards Act (FLSA)** establishes minimum wage, overtime pay, recordkeeping, and child labor standards (U.S. Department of Labor 2015). The **Contract Work Hours and Safety Standards Act (CWHSSA)** is the standard for the 8-hour workday, requiring overtime pay after 8 hours per day on federal construction contracts and providing overtime pay after 40 hours per week. It has been amended to add safety and health provisions (U.S. Department of Labor 2015). The **Copeland "Anti-Kickback" Act (CA)** provides safeguards regarding "kickbacks" of wages and back wages, contractor and subcontractor pay compliance requirements, payroll regulations, and payment method regulations (U.S. Department of Labor 2015). The Walsh-Healey Public Contracts Act (PCA), McNamara-O'Hara Service Contract Act (SCA), and Miller Act also provide protection for laborers regarding the prevailing wage act but are not immediately relevant to this research.

The prevailing wage is determined by the Wage and Hour Division (WHD), which organizes, surveys, collects data, and then informs federal wage standards. Surveys generally capture information on a county basis, but when there is insufficient data in a county, more regional data is used. Through the WD-10 form, data is submitted for DBRA wage surveys. Then, WHD staff analyze and review the survey data to ensure accuracy and completeness. From this data, WHD calculates the basic hourly rate and the prevailing fringe benefits. Wage determinations and the database of planned, ongoing, completed, and published state wage surveys can be accessed through public platforms on the DOL's website (U.S. Department of Labor 2022b). Some researchers and labor stakeholders note that the term "prevailing" may not be uniformly defined across states, resulting in large variations in what is deemed a prevailing wage statewide. This has led to criticism of the larger surveying process and the methods used to collect and evaluate the data. There has also been evidence of incorrect reporting, misfiling, and other fraud or errors in past wage surveying (A. Thieblot 2016).

There are conflicting findings regarding prevailing wage laws and discrimination in construction. Some argue that the DBA has discriminatory effects, particularly because construction unions were exclusionary to nonwhite workers (Bernstein 2017). Others argue that the DBA is "instrumental in bridging the wage gap" for women and minorities, as they are particularly vulnerable to exploitation (Congressional Black Caucus 1995). Some analysis shows an inverse correlation between Black employment and the strength of state-level prevailing wage law (A. J. Thieblot 1999), while others report that Black workers receive higher incomes in prevailing wage states than non-prevailing wage states (Philips 1996). The potential benefits of repealing prevailing wage laws to enable Black employment opportunities have also been analyzed (Thieblot 2003). However, some studies find that state prevailing wage laws have no empirical effect on Black employment in construction, but do have positive benefits for Black take-home pay and for reducing the wage gap (Duncan & Ormiston 2014; Manzo IV et al 2016). Later analyses report conflicting findings and provide detailed critiques of previous studies' statistical methodology, control for regional demographics, and reliance on anecdotal data, among others (Azari-rad & Philips 2003; A. J. Thieblot 2016; Duncan & Ormiston 2014, 2019). On a broader level, Mishel presents an overview of attempts to diversify New York City union and non-union construction trades, with a recap of the historical context that shaped the current state of union construction (Mishel 2017).

3.1.2 Collective Bargaining

The 2022 U.S. Energy and Employment Report (USEER) found that 34,898 solar workers, or about 10% of the solar energy workforce, are represented by a union or project labor agreement (PLA) compared to 6% of the overall workforce (U.S. Department of Energy 2022). This figure is largely driven by California's high unionization rate and comparatively large solar workforce. This difference highlights the importance of understanding the role of collective bargaining and relevant federal policies in solar installation.

The **National Labor Relations Act (NLRA)**, passed by Congress in 1935, establishes a collective bargaining system for most private sector workers. This legislation defines and prohibits five practices of unfair labor: (1) interference with employees' concerted activity, (2) employer domination of a labor organization, (3) discrimination against workers for union activity, (4) retaliation against workers for filing unfair labor practice charges or giving testimony in NLRB proceedings, and (5) refusal to bargain. The NLRA also regulates appropriate bargaining units, a majority rule framework, union certification and recognition, exclusive representation, duty to bargain, written agreements, voluntary mediation, ending agreements, strikes and lockouts, and striker replacements (Compa 2014). The NLRA both prevents employers from restricting employees' right to a labor organization for collective bargaining and prevents labor organizations from restraining or coercing employees. The DOL's Office of Labor-Management Standards has an online listing of public and private sector collective bargaining agreements (NLRB, 2022).

The NLRA allows **union-security agreements** where all employees in a bargaining union are required to become union members and pay union dues upon being hired. Those who object to full union membership are known as objectors and are still protected by the union contract, even though they are not full members. Alternatively, there are 26 states that have **right-to-work laws** related to union membership. In those states, workers have the right to join a labor union, but it is not a requirement to join a union to keep a job, and all workers are still protected by the union's collective bargaining agreement (NLRB n.d.).

Project Labor Agreements (PLAs) are prehire collective bargaining agreements that establish the terms and conditions for employment, generally between the contracting agency and at least one labor organization related to a construction project (FHWA 2022). PLAs establish working conditions, dispute resolution, and community workforce hiring provisions, giving all stakeholders standardized expectations for a project (Herrera et al 2014). Like collective bargaining, a PLA forms an agreement between a union and their contractors, but different types of workers from different unions may be used, and the PLA has project specifications that are different from a union's underlying collective bargaining agreement. PLAs may guarantee a larger number of good jobs for union members on construction projects, which include benefit plans and apprenticeship training programs (Bazaj 2020). PLAs can also have cost benefits, as they have been documented to create efficiencies and coordination that ensure projects are on time and on budget (Herrera et al 2014). However, some argue that PLAs may not benefit all construction projects, depending on the size, duration, and needs of the project. Other criticisms include a potential disadvantage to non-union or open-shop contractors (non-union contractors can bid on any project requiring a PLA as long as they abide by the project's PLA requirements), potential double-paying of benefits, a reduction in the pool of bidders and an associated decrease in competition, representation of women and minorities in PLAs, and conflicts with existing collective bargaining agreements (Bazaj 2020; Herrera et al 2014).

Community Workforce Agreements (CWAs) are similar to PLAs and are sometimes used interchangeably; however, CWAs may include community organizations in the negotiation process (BlueGreen Alliance 2020). These agreements may also include language related to the interests of underserved communities, such as provisions to hire locally, include marginalized or low-income communities, or create pre-apprenticeship pathways (Zabin & MacGillvary 2020).

3.1.3 Health and Safety Regulations

Solar installers are subject to OSHA standards relevant to construction, electrical work, and roof work. Solar energy employers that are connecting their solar systems to the grid or to microgrids are expected to comply with the electric power generation, transmission, and distribution standards found in 29 Code of Federal Regulations (CFR) 1910 (OSHA n.d.). Hazards covered under this section include falls, lockouts or tag outs, crane and hoist hazards, electrical hazards, heat or cold stress, and personal protective equipment. Standards from the National Fire Protection Association (NFPA) are not OSHA regulations; however, NFPA 70 is the National Electrical Code, and NFPA 70E is the Standard for Electrical Safety in the Workplace. Both are National Consensus Standards that are useful for worker protection (OSHA n.d.).

3.1.4 Labor Law Enforcement and Violations

The DOL and the National Labor Relations Board (NLRB) enforce worker protection laws and impose penalties for labor violations of workers' rights ensured in the NLRA, described in Section 3.1.2 above. However, enforcement agencies have limited resources and do not always have the capacity needed to enforce these rights (Fine & Bartley 2019). Funding for enforcement agencies within the DOL and NLRB, such as WHD and OSHA, has remained stagnant as the number of workers has grown. Therefore, these agencies are unable to fully enforce statutes. Underfunding leads to weak enforcement, which reduces labor law violation investigations and penalties (Mangundayao et al 2021). Enforcement agencies also struggle with increasingly complex and "fissured" ownership structures (Fine & Bartley 2019).

Lack of federal enforcement particularly impacts workers in states with less effective or missing labor departments, such as rural areas, concentrated labor markets with dominant employers, and southern states (Ajilore & Willingham 2020). Violations also have highly uneven consequences in marginalized and immigrant workforces. Immigrant workforces are especially susceptible, due to the high potential for exploitation and a reluctance to report violations based on the worker's legal status (Fine & Bartley 2019). These disparities have been exacerbated by the coronavirus pandemic and rising inflation (Mangundayao et al 2021).

Enforcement and violation of union rights are also a concern. One study found that employers were charged with violating federal law in 41.5% of all NLRB-supervised union elections in 2016 and 2017, and that one in five union election campaigns involved a worker illegally fired for union activity. The study also found that in nearly a third of elections, employers were charged with coercion, threats, and retaliation as well as illegally disciplining workers for supporting a union. All of these violations are against the NLRA (McNicholas et al 2019).

3.1.5 Recent Executive Actions

The Biden administration has issued several executive actions relating to workforce development in general, as well as within the clean energy and solar industries specifically. These actions have emphasized the importance of promoting good jobs in the energy transition.

Multiple executive orders on energy jobs were issued by the Biden administration in 2021. In January 2021, President Biden issued **Executive Order 14005**, titled "Ensuring the Future Is Made in All of America by All of America's Workers." The goal of this action was to increase domestic content requirements on federal procurement (U.S. Department of Energy 2022).

In the same month, **Executive Order 14008** was issued, tackling the climate crisis at home and abroad. This action promoted the creation of good-paying union jobs, equity in the clean energy workforce, and a 2050 net-zero goal (U.S. Department of Energy 2022). This action called for a strategy to create a Civilian Climate Corps initiative "to mobilize the next generation of conservation and resilience workers and maximize the creation of accessible training opportunities and good jobs." Through coordination with existing national service programs, it recommended appropriations for fiscal years 2022–2025, nearly 88 years after the New Deal Civilian Conservation Corps (Costantini 2021).

In February 2021, **Executive Order 14063** required project labor agreements (PLAs) on large, federally contracted construction projects (U.S. Department of Energy 2022).

Executive Order 14025, issued in April 2021, promoted worker organizing and empowerment. This action established the Task Force on Worker Organizing and Empowerment to encourage worker organizing and collective bargaining. The task force produced a report with almost 70 recommendations for policy revisions (U.S. Department of Energy 2022).

Following up on previous executive actions, **Executive Order 14052**, titled "Implementation of the Infrastructure Investment and Jobs Act," was issued in November 2021. This action emphasized high labor standards, support of prevailing wages, and the free and fair chance to join a union (U.S. Department of Energy 2022).

In June 2022, the White House invoked an executive action to **authorize the defense production act** to lower energy costs, strengthen the power grid, and create good-paying jobs. This action emphasizes supporting a diverse solar workforce with good-paying jobs and creating pathways to stable careers with a free and fair choice to join a union. Separately, the Economic Development Administration awarded funding to support solar employment training in tribal and coal-impacted communities. They also provided direction to DOE to explore this issue through funding and new collaborations and develop equitable worker-centric training and education programs, work-based learning opportunities, and support services such as career counseling, mentorship, and job readiness programs (The White House 2022a).

More generally, in 2022, the administration issued **Executive Order 13658**, which raised the minimum wage rate to $11.25 per hour for workers performing work on or in connection with applicable contracts. The required minimum cash wage that generally must be paid to tipped employees performing work on or in connection with applicable contracts increased to $7.90 per hour. The goal of this action was to promote economy and efficiency in procuring contracting as well as fair compensation to workers (Executive Order 13658 2022).

More broadly, in January 2021, the White House issued **Executive Order 13985**, titled "Advancing Racial Equity and Support for Underserved Communities Through the Federal Government." This executive order defined equity and directed the creation and expansion of various efforts to measure inequities in federal agency activities and outline programming to support equity in federal government work, including clean energy activities (The White House 2021).

3.1.6 Other Relevant Policies

The White House's **Build Back Better Act** aimed to implement sector-based training programs, build effective partnerships, and guarantee good-quality, in-demand jobs for climate, conservation, and resilience workers. This program also focused on the inclusion of young workers, women, and workers of color in high-quality jobs in clean energy, manufacturing, and infrastructure (The White House 2022b). This act passed the House but did not go to vote in the Senate. It was renegotiated as the **Inflation Reduction Act (IRA)** and was signed into law on August 16, 2022. Through grants, loans, rebates, incentives, and other investments to support the economy, the IRA aims to benefit clean energy workers and accelerate the deployment of clean energy. The IRA offers tax provision bonus credits to projects that pay prevailing wages and use registered apprentices with the goal of creating good-paying, high-quality jobs and economic growth (The White House 2023).

Under the Obama administration, the **2009 American Recovery and Reinvestment Act (ARRA)** gave $500 million to the DOL to prepare workers for clean energy jobs through 25 local energy training partnerships (ETPs) designed to develop workforce development programs (Costantini 2021). DBA labor standards were applied to ARRA-funded projects (Field Operation Handbook (FOH), Chapter 15d00). In a 2013 case study of two ETPs that received funding from the ARRA, researchers found that the programs were not sufficient to provide necessary occupational knowledge, and that there was a mismatch between the training provided and skills necessary for the green jobs they were training for (Costantini 2021).

The **Energy Policy Act of 2005** created the **Investment Tax Credit (ITC)** for residential and commercial solar, and it has been extended and modified since its original passing. Under the prior law, the ITC was scheduled for a gradual reduction and phasedown through 2023. However, with the passage of Inflation Reduction Act in 2022, solar projects beginning construction before 2025 will be eligible for the full 30% ITC without phasedowns (Irmen et al 2022). Since the ITC was first signed into law, most energy credit deadlines have been extended by two years at the expiration of each extension (Congressional Research Service 2021). The ITC was most recently extended by the IRA until the end of 2024 when it turns into a production and investment tax credit through 2032. The IRA also included several bonus credits or "adders" for the ITC, which provide additional tax credits based on meeting certain qualifiers. These qualifiers include building projects in a low-income census, using domestic materials, or building projects in an energy community, which is an area that previously had coal generation facilities or had significant employment related to fossil fuel extraction (U.S. Department of the Treasury 2023; Internal Revenue Service 2023). These adders are designed to increase energy equity by making projects more viable, which will in turn create more solar jobs. Proponents of the ITC argue that the market certainty that comes from the ITC is important to business success and job security for the solar industry. The Solar ITC is credited with helping make the solar sector among the fastest-growing segments of the U.S. energy industry and being an important policy driver for deploying solar energy (Groom 2022).

3.2 State Policies

State labor policies, including state prevailing wage laws, state codes and installation requirements, and state clean energy laws, are unique for each state. The range of policies leads to sizable differences in the rates of state solar deployment, worker well-being, interest in solar installation jobs, and barriers in the state solar industry. This section is purposefully broad to provide context for and examine trends in the range of state policies related to the solar workforce, while leaving out individual policies and state comparisons. Some resources that are helpful in finding state-specific policy data include:

- Union Legislation and Collective Bargaining Law Legislation (The White House, 2022) from the National Conference of State Legislatures (NCSL)
- Dollar Threshold Amount for Contract Coverage Under State Prevailing Wage Laws from the WHD of the U.S. DOL
- State Minimum Wage Laws from the WHD of the U.S. DOL
- Standards and Requirements for Solar Equipment, Installation, and Licensing and Certification: A Guide for States and Municipalities from the U.S. Department of Energy and the Clean Energy States Alliance.

3.2.1 State Prevailing Wage Policies

Twenty-eight states and the District of Columbia have prevailing wage laws. These states are Alaska, California, Colorado, Connecticut, Delaware, Hawaii, Illinois, Maine, Maryland, Massachusetts, Minnesota, Missouri, Montana, Nebraska, Nevada, New Jersey, New Mexico, New York, Ohio, Oregon, Pennsylvania, Rhode Island, Tennessee, Texas, Virginia, Vermont, Washington, Washington D.C., and Wyoming (Wage and Hour Division 2022).

Twenty-two states do not have prevailing wage laws; these are Alabama, Arizona, Arkansas, Florida, Georgia, Idaho, Indiana, Iowa, Kansas, Kentucky, Louisiana, Michigan, Mississippi, New Hampshire, North Carolina, North Dakota, Oklahoma, South Carolina, South Dakota, Utah, West Virginia, and Wisconsin (Wage and Hour Division 2022).

Support for (or opposition to) prevailing wage laws, particularly at the state level, primarily focuses on topics such as costs, safety, and training. Some studies conclude that prevailing wage laws do not affect construction costs, but promote worker safety, productivity, and training; others conclude that they create higher construction costs with negligible effects on safety and training (Duncan & Ormiston 2019). Although economic justifications are often used to uphold or abolish state prevailing wage laws, some policy termination studies have found that non-economic factors were actually more influential in this decision; these factors included political ideology, union power, and regional diffusion (Hwang 2021). Although studies specific to the PV industry are limited, as previously mentioned in Section 1.5 of this report, one study observed that some states with prevailing wage laws have higher labor costs but lower total solar project costs than some states without prevailing wage laws (Jones 2020b).

3.2.2 Other Categories of State Solar Policies

Individual state solar and energy transition workforce policies are an important metric and driver of solar deployment; however, there are other policies that also impact the solar workforce in both direct and indirect ways. State policies important for solar deployment include regulatory authority over utilities, codes, land use, consumer protection, and taxes, among others (Sarzynski et al 2012). This section reviews three main policy categories (beyond wage policies) that are important for the solar workforce and determining local solar feasibility.

Financial incentives have been used by many states to support the solar energy market and overcome the cost barrier to deployment. For instance, states may offer cash incentives, like rebates and grants, which have demonstrated increased deployment of solar PV technology. Other financial incentives, like tax incentives, have less of an effect on the solar market and deployment, but may also be used by states (Sarzynski et al 2012). Sales tax exemptions or advanced energy workforce tax credits may also be used by clean energy firms participating in workforce training programs, especially programs for those with marginalized populations (Michaud 2020). For example, Ohio provides a tax exemption if 80% of the employees on a solar construction project are Ohio-domiciled (Warnock et al n.d.). Other popular financial incentives include bond programs, feed-in tariffs, corporate tax credits, leasing programs, and loan programs, which offer a variety of options for solar financing (DSIRE 2022). Financial benefits such as the ITC and other direct pay programs may bring regional workforce benefits, including to low- and moderate-income (LMI) residents (Shea & Mendell 2021).

State regulatory solar policies, including technology and deployment policies, and utility commission mandates help drive the solar market and in turn the solar workforce. Supportive state policies may include net metering, renewable portfolio standards (RPSs), interconnection policies, third-party ownership agreements, or other incentives to build solar within a state (Friedman et al 2011). States may also have state-specific building energy codes, EE standards, equipment certifications, contracting licensing, permitting standards, or solar tariffs that may make certain states more conducive to adopting solar and therefore building a solar workforce (DSIRE 2022).

State-based **workforce training** and **education policy**, including certifications or license requirements, vary by state. Whereas some states have solar-specific license requirements, others require only general electrical licenses or have no certification requirements (Friedman 2012). There are opportunities for state-sponsored workforce development or retraining programs to mitigate the instability of displaced workers or those looking to enter the solar workforce (Ardani et al 2021). Education policy may include updating the K-12 school curriculum, designing summer camps or other programs supporting advanced energy courses, or designing learning labs to develop the skills needed for clean energy professions in the emerging workforce (Michaud 2020).

Apprenticeship ratios may be mandated by states, projects, unions, or other groups, because the allowable ratio can vary. An apprenticeship ratio is a standard that determines the number of apprentices per supervising journey-level worker that a contractor must have on a project (LCP Tracker 2021). For instance, in California, the state policy is that the minimum apprenticeship ratio is five journey-level worker hours per one apprentice hour (State of California 2022). The recently passed IRA bill also ties incentives to apprenticeship ratios (Internal Revenue Service 2022; The White House 2023).

3.3 International Standards

In 2015, the International Labor Organization (ILO) created guidelines to provide governments, workers, and employers globally with tools for a just transition, including creating decent jobs on a large scale. Their guidelines highlight that creating green jobs can alleviate poverty and promote social inclusion as well as promoting green economies (IRENA and ILO 2021). Concern around an international just transition gained attention again in 2021, when the U.S. passed the Uyghur Forced Labor Prevention Act to prevent forced labor in the solar supply chain (Dayen 2022).

4 Expanding Solar Workforce Participation

As highlighted in Section 3, the local context for solar deployment and the solar workforce varies across states and has implications for the local solar installation workforce. Certain states have OSHA-approved standards, PLAs, prevailing wage laws, and various licensing and certification requirements to ensure quality solar installs while supporting high-quality jobs. There are also broader trends in the growing solar workforce that are important to consider, as those shape the solar worker experience and solar deployment across the United States.

This section considers strategies and issues around both increasing the size of the solar workforce (for anticipated sector growth) and increasing the participation and success of underserved or underrepresented populations in the workforce. This section builds on the worker well-being piece by reviewing the literature on efforts to expand the solar workforce including—best practices, challenges, and gaps in ongoing efforts. Most of this section is framed by the International Renewable Energy Agency (IRENA) and ILO's categorization of four areas of workforce development that may impede the worker experience in the clean energy economy; these are outlined below.

- **Temporal mismatch**—when job losses precede job gains on a large scale
- **Spatial mismatch**—when new clean energy jobs are not emerging in the same communities or regions where transitioning energy workers reside, and as such, it becomes a challenge for people who have lost jobs and might have the right qualifications and skills, but have financial, family, or property ties to the region where they live
- **Educational mismatch**—when the skill level or the occupation required in the clean energy economy has not been developed or needed under the previous energy system
- **Sectoral mismatch**—when there is a significant change in the key value and supply chains required to deploy clean energy technologies.

4.1 Solar Workforce Development and Local Staffing Dynamics

Programs, pathways, and strategies for recruiting and training relevant to solar installations are widely distributed, varied, and too numerous to catalog exhaustively in this work. Many current pathways may not be solar-specific, which makes them more challenging to track. However, some non-exhaustive summaries of past and current efforts exist that illustrate the distributed and varied nature of these efforts.

DOE supports several programs focused on training the clean energy workforce. Examples of programs from SETO and other resources are summarized on DOE's website (*Solar Design and Installation Training* n.d.). DOE also maintains a map of solar instructor training network sites (Department of Energy n.d.), which includes the Solar Career Map (IREC 2022a). Some examples of programs that offer financial or institutional support to trainees are summarized in (B. L. Smith et al. 2021).

Unions also typically offer pathways to solar certification, such as the NECA/IBEW Electrical Journeyman and Apprenticeship Training, among others. There are also several voluntary personal certification programs offered through organizations such as NABCEP, the National Center for Construction Education and Research (NCCER), and OSHA (Solar Energy Technologies Office 2021).

4.1.1 Skills and Training Needs

The 2021 USEER report found that 88% of electric power generation companies reported that it was either somewhat difficult (69%) or very difficult (20%) to find new employees (U.S. Department of Energy 2022). Building relevant skills is important for the solar PV labor market as well as a just transition, and aligning educational needs with new entrants and transitioning fossil fuel workers is important to building good jobs and providing opportunities in the energy transition (IRENA and ILO 2021).

Skills that may be required from a solar PV installer include an in-depth knowledge of electrical wiring and the National Electrical Code, familiarity with evolving solar and storage technologies, mathematics and engineering skills, quality control analysis, physical dexterity, ability to work safely with power and hand tools at great heights, visual color discrimination, and a driver's license; installers may also be required to pass a drug test (IREC 2022a). To avoid skill shortages and meet skill demand, targeted efforts must be made to address emerging skill requirements. Skill shortages may occur due to the transitory nature of employment or structural disincentives for training, among other reasons (Duncan & Ormiston 2014). Separately, for residential solar installation, there is an added need to consider the nature of the residential installation, which often requires that an installer be trained on several tasks (i.e., that they undergo multi-craft training). This may not align with the five-craft model typically used in larger projects involving the major union trades (UC Berkeley Labor Center 2011a; Ferris 2021; U.S. Solar Energy Technologies Office 2021).

There are several current skill delivery pathways. First, there are opportunities to include new curricula at technical or vocational training institutions and higher education institutions to meet these skill gaps. One barrier to this institutional training may be a lack of adequate practical instruction due to barriers such as a lack of training equipment and materials. Second, there are workplace learning opportunities, such as apprenticeships or short-term placements, where workers can learn from professionals and have opportunities to upskill with evolving sector demands. For example, some unions have local training centers that house common solar racking equipment exclusively for solar installation training purposes (LIUNA 2022). These types of pathways may include multiyear training programs with levels to qualify and train workers. The third current skill delivery pathway is on-the-job training, where those with limited or no training are trained on-site (IRENA and ILO 2021).

Rural and remote areas also require particular attention and support, especially if they have limited capacity for educational and training programs for workforce development (IRENA and ILO 2021). Transitory work may disincentivize training, as contractors focus on retaining more experienced workers instead of hiring and training younger workers (Duncan & Ormiston 2014). However, this creates a feedback loop where in new markets it is difficult to find experienced workers or those with appropriate training. Developers have reported that in rural areas it is often much more difficult to hire union labor (Solar Energy Technologies Office 2021). However, union members are less likely to quit their jobs due to better pay and benefits, more upward mobility, and better working conditions, which may decrease project hiring costs and lost productivity (Bach & Kinder 2021). Employing rural workers with robust labor protections, such as collective bargaining and raising the minimum wage, may also strengthen rural labor markets and working conditions for rural Americans, who often struggle from larger unemployment and poverty rates than metro counties (Ajilore & Willingham 2020).

Tribal areas are also often remote. One study found significant interest in education and employment in solar installation jobs on tribal lands (Clow 2022). The Tribal Employment Rights Ordinance or Office (TERO) requires that employers operating a business on a reservation give preference to qualified Indians. Training and employing people in tribal areas for remote solar installation jobs would have benefits both for spatial alignment of remote solar PV installations and for future jobs, as commercial-scale projects are planned on tribal lands or surrounding areas(Clow 2022).

4.1.2 General PV Installer Licensing, Certification, and Accreditation

Skill shortages can increase construction costs, cause delays, and limit competitive bidding (Duncan & Ormiston 2014). Because there is no **national skill standard** for solar PV installation, local and state governments largely define the requirements for solar PV installers and installation equipment. Licensing is a mandatory requirement, whereas certification is voluntary training typically offered by an accredited third-party organization. In many jurisdictions, the minimum licensing requirement for individual solar installers is having a valid electrician license or operating under the supervision of a licensed electrician. Certification is typically offered upon completion of a third-party administered training program, and accreditations are temporary credentials, usually valid for a few years, that signal competence to perform specific tasks. They standardize expectations and quality guidelines across the industry; well-designed accreditation programs improve the quality of the solar installation workforce and the services provided. Once an individual or organization meets licensing and certification requirements, they receive an accreditation. These independent, third-party organizations play an important role in training the growing solar workforce and maintaining solar industry installation standards.

Figure 1 differentiates between licensing, accreditation, and certification.

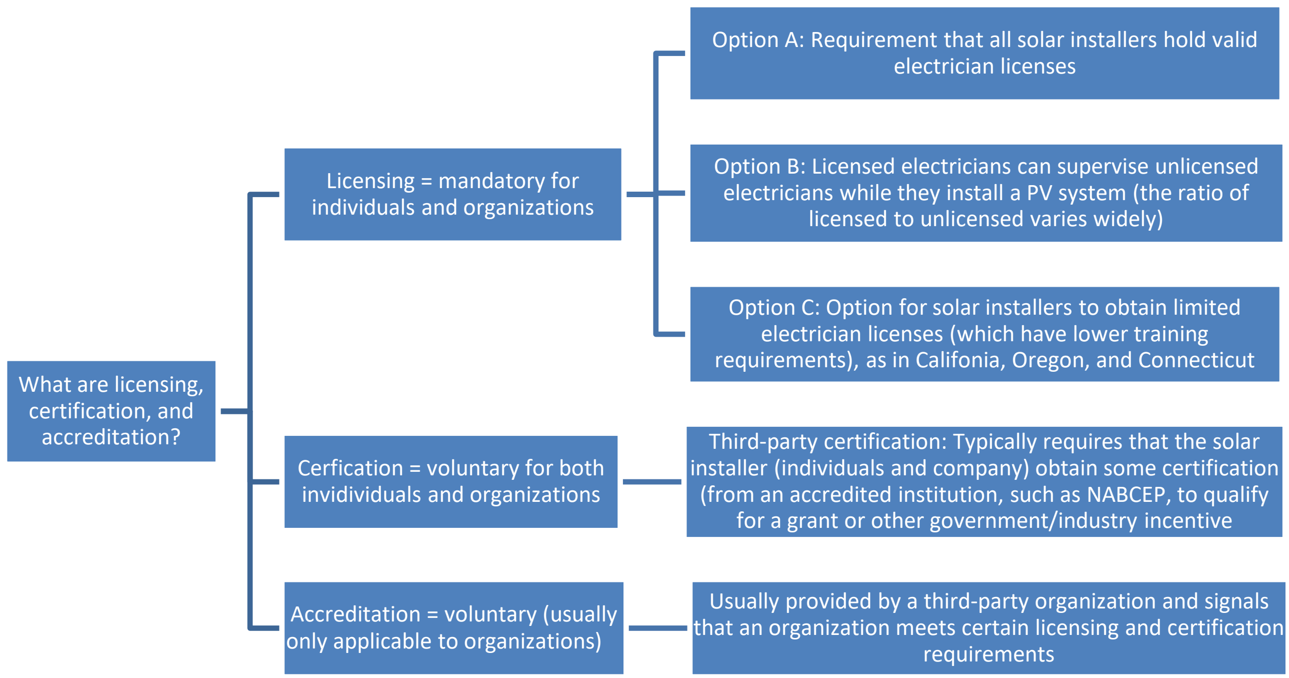

Figure 1. Differences between licensing, certification, and accreditation.

4.1.3 Apprenticeships

The U.S. **apprenticeship training** model, which largely occurs through unions, is one of the primary existing workforce development pathways in construction and related occupations. Apprenticeships are one approach for providing hands-on, paid training and a pathway to jobs. It is a demand-driven workforce development model as the number of apprentices trained depends on the work available (i.e., job demand) and the applicable apprentice-to-journeyperson ratio (Inclusive Economics, Illinois Economic Policy Institute, and Sierra Club 2021). Apprenticeships may happen through unilateral employer only programs, joint **labor-management partnerships** or in rare cases, union only programs.

The DOL found that in 2021, employer only programs accounted for 83% of active apprenticeship programs (serving 53% of active apprentices) with 17% of active programs in the form of joint labor-management programs (which served 47% of active apprentices) (U.S. Department of Labor 2021). The major costs of apprenticeship programs for businesses are the start-up costs, tuition and educational materials, the mentor's time, and overhead; however, all companies in one federal study unanimously supported apprenticeships, citing that the programs' value justified the costs (Helper et al 2016). Apprenticeships utilize systematic and paid on-the-job training from an experienced mentor as well as classroom instruction to meet federal and state standards to develop a trained workforce (AFL-CIO 2022). In apprenticeships, the apprentice's wages increase as they become more skilled and accrue more hours of experience. These programs are sometimes referred to as "earn while you learn" training, because apprentices are paid during their training. In the case of electricians, apprentices are trained on a host of required skills, which may include those required for PV installation. Upon completion, apprentices receive an industry-recognized credential and access to further job opportunities in that sector (Helper et al 2016). Apprenticeship programs have also been found to be inclusive of people with disabilities and other underrepresented groups (Winn et al 2022). Apprenticeships are beneficial because companies tend to have the flexibility to adjust the model to their needs, and businesses gain benefits related to production, workforce, and soft skills. This includes a reduction in errors, reduced turnover, improved recruitment, a pipeline of employees, improved employee engagement, greater problem-solving ability, flexibility in task performance, and reduced need for supervision (Helper et al 2016).

However, apprenticeship programs may have several entry requirements, which may create barriers to entry and participation (Inclusive Economics, Illinois Economic Policy Institute, and Sierra Club 2021). Some requirements and associated barriers include:

- High math and reading levels (which could be a barrier for students from underfunded schools that may have had insufficient math and reading instruction)
- High school diplomas or General Educational Development (GED) Tests
- Ability to reach construction worksites early in the morning (which could pose difficulties for those with transportation access issues, such as not having a car or lack of proximity to public transportation) (Inclusive Economics, Illinois Economic Policy Institute, and Sierra Club 2021).

In terms of active apprenticeships across the labor economy, the construction industry in general had the most active apprentices, with 197,421 people in FY21 (U.S. Department of Labor 2021). Per the BLS, Black workers are more likely to be union members than white, Asian, or Hispanic workers. Additionally, men still have a higher union membership rate (10.6%) than women (9.9%), although the gender gap in membership has decreased considerably from 1983, which is the earliest year of comparable data (U.S. Bureau of Labor Statistics 2022). There have been several studies focused on assessing and contextualizing the impact of historical and current union construction hiring practices, especially for Black, Asian, Indigenous, Latinx, and women applicants (Fuchs, Warren, and Bayer 2014; Mishel 2017; Luke et al. 2017). Historically, union construction workers were hired based on informal, family and friendship connections, perpetuating exclusionary hiring practices (Mishel 2017; Inclusive Economics, Illinois Economic Policy Institute, and Sierra Club 2021). Over time, hiring has become more formalized with apprenticeship programs playing a large role in hiring (Mishel 2017). For example, Mishel offers a detailed breakdown of these impacts in New York City's union and non-union construction industry (Mishel 2017).

To help address some of these barriers, there has been an increase in community-based training programs as well as pre-apprenticeship (or apprenticeship readiness programs). These programs focus on programming that can attract, recruit, train, and place applicants in apprenticeship programs that offer a pathway to paid training and full employment (Inclusive Economics, Illinois Economic Policy Institute, and Sierra Club 2021). They may use a very localized program model as well as offer additional programming support such as childcare and transportation support. The goal of pre-apprenticeship programs is not to only place applicants in apprenticeship programs but to also introduce them to jobs in specific industries, such as the solar industry.

Considering solar installation specifically, the DOL currently does not recognize a national solar installer apprenticeship program (that is, there is no federal category for solar as an apprenticeable craft). In 2022, Florida became the only state that has a DOL-recognized solar technician apprenticeship program (Florida Solar Energy Center 2022). As such, apprenticeships are largely developed by unions, contractors, and other third parties.

There are also non-union apprenticeship programs run by third parties. These include apprenticeship programs offered by the Independent Electrical Contractors (IEC) Apprenticeship program and the Western Electrical Contractors Association (WECA), the Installation Basic Training (IBT) Program offered by organizations like GRID Alternatives, and utility-scale apprenticeship programs offered by Engineering, Procurement, and Construction (EPC) firms.

The WECA program offers paid 3–5-year hands-on electrician training programs in Arizona, California, and Utah, focused on commercial, residential, and low voltage electrician programs. Non-wage benefits are offered in some states, and these may include medical and retirement benefits. For California, depending on the year of apprenticeship, type of work, and location, hourly wages can range from $21 - $31, $22 - $45, $22 - $34 per hour for residential, commercial, and low voltage programs respectively (Western Electrical Contractors Association (WECA) n.d.) .

GRID Alternatives is a nonprofit solar installer focused on the residential and commercial market. Due to their focus on the residential and commercial market, their training approach involves multi-craft training. The IBT Program is a paid, six-week hands-on installer training program that offers training on sola array or electrical training. It offers training on job site safety, electrical safety, electrical layout and mounting, and racking installations. It is a certification focused program, with training provided partially tailored towards industry-level certifications such as the NABCEP PV Associate, OSHA10 Construction and CPR/ First Aid certification (GRID Alternatives n.d.).

Some large EPCs offer in-house apprenticeship programs. Several contractors have developed tailored apprenticeship programs (for example, to recruit and train veterans), and some have recently obtained DOL approval to develop in-house solar construction apprenticeship programs (Pickerel 2020; 2023). The IRA bill could lead to an increase in the number of these apprenticeship programs, given the apprenticeship and apprentice-to-journeyworker ratios tied solar incentives (Internal Revenue Service 2022; The White House 2023).

4.2 Broader Barriers to Accessing High-Quality Clean Energy Jobs

In addition to the job creation potential of the clean energy sector, data suggest that certain clean energy jobs provide accessibility, versatility, geographic diversity, higher-than-median wages, more opportunities to join unions, and upward mobility (Truitt et al 2022). However, despite the exciting prospects, COVID-19 revealed how harms and advantages in the energy sector may be unequally experienced (Philip Jordan 2020a, 2020b). These examples of racial and ethnic disparities in the clean energy job landscape require closer examination so that solutions can be developed to ensure that good solar jobs are widely available, accessible, and possible for all segments of the population, particularly historically excluded, oppressed, and socially vulnerable groups.

To this end, it is important to (1) understand the institutional and structural barriers that have created unequal access and working conditions in the fossil fuel industry and the broader labor market, (2) acknowledge and redress unjust labor practices in the burgeoning clean energy economy, especially in solar, (3) support transitioning workers as we transition from a fossil fuel economy to a clean energy economy, and (4) develop strategies that will create and increase access to good jobs across the entire clean energy economy supply chain.

Institutional and structural policies in the fossil fuel sector, the clean energy sector, and the broader U.S. economy create and entrench racial, spatial, and income disparities. Disparities and some associated policy causes include:

- Spatial mismatch between jobs and residential locations (Stacy et al. 2019; Dowell 2020; Ihlanfeldt 1994; Turner and Fortuny 2009; Loh, Coes, and Buthe 2020)
- Housing and employment insecurity among the working poor that increase the likelihood of being laid off (Desmond and Gershenson 2016)
- Lack of access to job opportunities due to residential segregation and limited transit options (Boarnet et al. 2013; Loh, Coes, and Buthe 2020; Christine Chen et al. 2021)
- Strict policies that exclude formerly incarcerated and houseless individuals from accessing quality full-time jobs (Miller 2021; UCLA Institute of the Environment & Sustainability & Dream Corps 2020)
- Lack of access to education and training programs and employment stagnation for socially vulnerable groups (including people experiencing homelessness, people who have been formerly incarcerated, former gang members, disconnected youth, foster youth, transition age youth, veterans, transgender individuals, and people with disabilities) due to residential segregation, unequal and substandard schools, and certain employment policies (Luke et al. 2017; Turner and Fortuny 2009; Loh, Coes, and Buthe 2020; Corporate Partners Program at UCLA and Green for All, Dream Corps 2020; Miller 2021; Voleti and DeShazo 2021)
- Underrepresentation and a lack of career mobility opportunities for Black, Latino, Asian American and Pacific Islander (AAPI), and Indigenous people in the clean energy industry. For example, clean energy job numbers are encouraging in aggregate, but a racial and gender breakdown of these jobs shows underrepresentation of women and Black and Indigenous individuals (with disparities more stark in more senior roles) (Pitts, Steven C. 2008; Luke et al. 2017; Shoemaker and Ribeiro 2018; Sedgwick et al. 2021; U.S. DOE 2021; Voleti and DeShazo 2021).

4.2.1 Efforts To Reduce Job Access Barriers

In response to broad concerns about inequitable labor practices, especially concerns around the misclassification of workers and other challenges, a handful of states have enacted policies, such as prevailing wage laws, to protect workers in the solar workforce and broader clean energy economy (Jones 2020b; Zabin and Appel 2019; Kotler 2018). Other stakeholders, such as unions, have also advocated for worker protections through union organizing and PLAs; however, there have been concerns about the robustness of these pathways in supporting minority workers and business owners (Cliffton et al 2021; Neha Bazaj 2020; Porter & Luong 2021).

Some targeted recruitment efforts for underrepresented populations already exist, such as targeted local hiring programs, partnerships with community colleges, CWAs (as described in Section 3.1.2), and pre-apprenticeship and apprenticeship programs that are being led by cities, states, utilities, employers, unions, and other stakeholders as described in Section 4.1.3 (Manzo IV and Bruno 2020; Voleti and DeShazo 2021; Luke et al. 2017). These efforts recognize that, given systemic barriers to high-quality job opportunities, intentional efforts are needed to recruit and retain new workers from under-resourced backgrounds (UC Berkeley Labor Center 2011b; Zabin and Cha 2020). Some strategies for PV deployment to support minority-owned developers or contractors have been discussed in literature

(Heeter and Reames 2022), but greater resolution into the corresponding workforce populations is warranted.

Additional future research is needed to (1) assess the success of various workforce development strategies and activities in improving employment outcomes for underrepresented groups and (2) identify programs or approaches that have seen measurable success.

4.2.2 Just Transition for Fossil Fuel Workers

As the **transition continues from a fossil fuel to a clean energy economy**, the livelihoods of workers and communities that have been largely or solely dependent on the fossil fuel industry for jobs and economic development could be significantly impacted (Cha et al 2021). There is emerging literature on how the clean energy transition will impact current workers and communities in the fossil fuel economy, who will experience job losses, displacement, and other challenges during this transition (Cha 2017). These workers and communities are actively contributing to labor discussions as this transition is underway and are offering input on pathways to consider that will prioritize worker and local community well-being (Zabin, Carol et al. 2016; Jones, Philips, and Zabin 2016; Cha 2017; Luke et al. 2017; UC Berkeley Labor Center 2018; Cha et al. 2021).

Specific concerns identified in (Zabin and Cha 2020; Cha et al. 2021) include the following.

Skills or educational mismatch in terms of the difference between the skills and training needed in fossil fuel jobs and those needed in clean energy jobs. This mismatch may necessitate retraining. Retraining may involve significant costs that individuals and workers may not be able to afford (IRENA and ILO 2021). One study estimated that the investments needed for retraining workers across U.S. coal-producing states are within states' discretionary budgets or would be about 0.0052%–0.0543% of the U.S. federal budget if completely subsidized by the federal government (Louie & Pearce 2016). The authors noted that retraining programs could be rolled out as programs at more traditional universities, colleges, community colleges, or certification programs, or on digital platforms with online classes or workshops. To reduce or eliminate the cost to workers, retraining could be provided through scholarships, education vouchers, grants, subsidized training, government-sponsored free courses or training, or no/low-interest or subsidized loans (Louie & Pearce 2016).

Geographic or spatial mismatch, in that solar jobs (and other clean energy jobs) may not be in the same location as areas with declining fossil fuel jobs. For instance, California has the most solar jobs in the United States, with over 76,800 in 2018, but produces no coal, whereas Wyoming and West Virginia had a combined total of 431 solar jobs in 2018 but are the two top coal-producing states (Crowe & Li 2020). The EIA estimated that there were 42,159 U.S. coal jobs in 2020, including 4,867 coal jobs in Wyoming and 11,418 coal jobs in West Virginia. However, the number of coal jobs in the United States decreased by 20.2% between 2019 and 2020, including a 9.9% decrease in Wyoming and an 18.4% decrease in West Virginia (EIA 2021). The growth of solar in these two states is shaped by state energy policies, broader electricity market trends, and labor market demand. However, at the community level, there will be questions in transitioning communities about who benefits from solar deployment. Recent modeling analysis estimated the monetary costs of replacing U.S. coal plant jobs with solar and wind jobs within a 50-, 500-, and 1000-mile limit, with these distance constraints serving as a proxy for RE jobs that would limit the need for relocation (i.e., 50-mile constraints) and those that would potentially require relocation (500- and 1000-mile distances) (Vanatta et al 2022).

Parity in job quality, in terms of concerns about the difference in job quality (largely in terms of wage and nonwage compensation) in jobs provided in a clean energy economy versus those in a fossil fuel economy. Communities may be less receptive to the clean energy transition—even with financial incentives—if there is skepticism surrounding how they will benefit from the transition (Crowe & Li 2020). Studies here note the need to have communities as active collaborators in solar deployment efforts, as well as providing clear communication about the tangible economic benefits of solar deployment to workers and their communities.

Furthermore, depending on the geography and maturity of the local solar market, a solar installer may not be able to work locally year-round. Solar installers may thus be required to commute to job sites (or temporarily relocate during a project's timeframe) for large-scale but short-term jobs, which affects workers' ability to have a stable career in a single region with consistent work (Solar Energy Technologies Office 2021). Solar installation jobs may also be seasonal, especially if they are in markets that are subject to extreme cold, extreme heat, or other weather conditions that make solar installation unviable at certain times of the year. Additionally, much of the construction industry is procured through contracting and subcontracting due to the fluctuations in and instability of the industry. Therefore, contractors may have a loose relationship with employees: hiring labor when work is available and laying off labor after a project is completed, at the end of a season, or in an economic downturn. Transitory work may disincentivize training, as contractors focus on retaining more experienced workers instead of hiring and training younger workers (Duncan & Ormiston 2014).

Other concerns raised include the potential long-term impacts of COVID-19 on worker rights and benefits, the effects of job creation and job loss on the local community, and the impact of technological advancement on the job landscape. Understanding the various dimensions of these threads (the institutional and structural barriers that have created unequal access and working conditions, the unjust labor practices in the burgeoning clean energy economy, and nuclear and fossil fuel transition worker and community concerns) provides key context for any efforts to codevelop strategies that will create and increase access to good solar jobs, especially for historically excluded, oppressed, and socially vulnerable groups.

Data Gaps and Future Work

The review of the topics in this work underscored certain data gaps and areas of utility for future analysis, which are summarized below.

- Labor requirements and conditions related to solar manufacturing and the solar supply chain, both globally and within the United States
- Labor impacts and indirect jobs related to increases in domestic solar manufacturing activities
- Potential pathways, industry interest, and requirements for implementing national solar labor standards or national certifications for solar installation
- Improved resolution for NAICS codes with data relevant to the solar industry and solar-specific workers
- Environmentally, economically, and socially responsible mining projects and effective recycling initiatives for strategic materials necessary for solar PV projects, including domestic materials production and innovation
- Safe and healthy working conditions specifically for solar workers, separate from general construction and electrical codes

- Standardized data on worker classification (and misclassification), and its intersection with solar workplace safety
- Statistical analysis of whether minorities and women have fair access to construction opportunities on a trade-by-trade basis
- Best practices for recruitment and training efforts for solar PV installation jobs
- Workforce opportunities for Native American or tribal communities
- Training and workforce opportunities for disenfranchised workers, like those recovering from substance abuse or formerly incarcerated individuals
- Contextualizing the intersection between energy justice, workforce discrimination, and well-being, especially regarding policies like prevailing wage.

Near-Term Analysis Supported by NREL

In order to provide SETO with context on how different solar installation features and labor aspects impact workforce well-being and PV industry growth, we have summarized a set of research priorities that expand on the literature reviewed in this work. Based on the literature and on input from reviewers, the primary aspects of solar installation projects that may impact workers and workforce requirements in substantially different ways are categorized below:

Project features:

- Project sector (utility, commercial and industrial, or residential)
- Development/ownership type (direct ownership, power purchase agreement, etc.)
- System size
- Module size or weight
- Racking type (tracker, ground-mounted fixed tilt, flat roof, sloped roof)
- Pairing with storage.

Regional conditions:

- State energy policy support of solar deployment
- Current solar deployment rates
- Historical cumulative solar deployment (maturity of industry)
- Competitiveness in local industry
- Type of electric utility (investor-owned utility, municipal, cooperative)
- Prevalence of project features in the local area (system size, ownership type, etc.)
- State/local labor policies and standards (prevailing wage laws, license requirements, incentives for labor standards, etc.)
- Availability of local workers and/or organized labor
- Population density
- Cost of living
- Local weather/environmental hazards.

Workforce characteristics and contract terms:

- Share of standard workers (full-time or part-time employees) versus nonstandard workers (subcontractors, independent contractors, leased or temporary workers, etc.)
- Wage and nonwage compensation (health insurance, retirement funds, etc.)
- If significant travel is required, inclusion of per-diem compensation

- Any applicable local labor policies and standards, including prevailing wage requirements, project labor agreements, etc.
- Unionization rates
- Solar training infrastructure, including licensing standards, certifications, and apprenticeships
- Metrics such as team size, productivity, staff turnover
- Workplace safety violations, including injuries and worker compensation claims.

The impacts of these factors on workforce well-being can be assessed through empirical research, regional comparisons, and case studies. A limited number of case study regions can be chosen to capture variation between the factors listed above. The analysis will consider how different socioeconomic contexts are impacting solar workforce well-being and the pace and quality of solar deployment.

Existing NREL models can be used to evaluate the effects of these factors on PV system costs and deployment. These include the NREL PV system cost model (Ramasamy et al 2021), the Regional Energy Deployment System (ReEDS) capacity planning model, and NREL's Distributed Generation Market Demand (dGen) model. The NREL system cost model can capture most differences in project features, some regional cost differences, and some workforce characteristics that impact total labor costs. Cost model scenarios should be consistent with the regions selected for case studies of worker well-being. The ReEDS and dGen models can then illustrate the price sensitivity relationship of how deployment or adoption would change based on system costs.

Given that improved PV system performance can effectively reduce the cost of a project over its life, the potential for these factors to impact system output or maintenance needs should also be evaluated. An empirical approach could consider data sets such as the Section 1603 Treasury grant programor datasets of inspection failures (potentially from the Department of Consumer and Regulatory Affairs, the Institute for Building Technology and Safety, major solar permitting platforms, or third-party inspection and engineering firms). These would need tobe evaluated to determine if there is adequate metadata on the factors listed above, then analyzed to determine whether a statistically significant difference exists in the electricity generation, technical performance, or quality of solar installation projects with differing features. Alternatively, LCOE and O&M cost models could also be used to evaluate potential tradeoffs(H. Walker et al 2020), such as how much additional electricity generation would be required to offset higher labor training expenses, or what reduction in maintenance costs is required to offset an increase in labor training costs.

Conclusions

Considering the current and anticipated need for growth in the U.S. solar workforce, the purpose of this report is to establish what information already exists in the literature and what is most relevant to the intersection of solar PV deployment and the associated workforce. This literature review can then be used to identify data gaps or areas that would most benefit from deeper analysis.

To achieve this, we reviewed available data and metrics on solar workforce and deployment. This included the current size of the solar workforce, including recent changes due to COVID-19; the workforce distribution across the stages of PV system installation and operation as well as the different solar market sectors, such as utility-scale or rooftop; the regional distribution of solar workers, deployment, and costs; the demographic composition of the solar workforce; the distribution of trades across various market segments; data on worker compensation; and the use and availability of organized labor for solar installations. We also presented a review of related studies that assess interactions between some of these metrics, although few exist in the literature.

The second topic that we investigated focused on workforce well-being, namely, contracting mechanisms (including the use of organized labor), compensation (wages and benefits), and occupational health and safety (including standards and certifications, as well as job-specific risks), and broader community impacts. The literature we reviewed revealed a growing but still limited body of work on solar workforce well-being—especially on how various work arrangements (employees versus subcontracts and independent contractors) impact solar workforce well-being (in terms of compensation, workplace safety, and community impacts).

We also summarized the policies most relevant to U.S. solar workers as part of this literature review, at both the national and state level. These included prevailing wage policies and studies that examine their impacts, including the potential for racial discrimination. This also included collective bargaining policies, health and safety regulations, labor law enforcement and violations, executive actions, and other relevant policies, as well as international standards that advance the quality of solar jobs worldwide. These policies can result in a wide range of workforce conditions, particularly those that vary regionally.

Finally, we reviewed known strategies and issues around increasing the size of and access to the solar workforce. This included a brief overview of solar workforce development, including skills needs and training pathways, encompass licensing, certification, accreditation, and the union apprenticeship model. Additionally, literature was reviewed on broader barriers to accessing clean energy jobs, fossil fuel transition workers, and examples of efforts to reduce the identified barriers.

References

Adamson, Maria, and Ian Roper. 2019. "'Good' Jobs and 'Bad' Jobs: Contemplating Job Quality in Different Contexts." *Work, Employment and Society* 33 (4): 551–59. https://doi.org/10.1177/0950017019855510.

AFL-CIO. 2022. "Careers." 2022. https://aflcio.org/about-us/careers.

Ajilore, Olugbenga, and Caius Willingham. 2020. "The Path to Rural Resilience in America." Rural America. Center for American Progress. https://www.americanprogress.org/article/path-rural-resilience-america/.

Al-Tarawneh, Ibraheem S., Steven J. Wurzelbacher, and Stephen J. Bertke. 2020. "Comparative Analyses of Workers' Compensation Claims of Injury among Temporary and Permanent Employed Workers in Ohio." *American Journal of Industrial Medicine* 63 (1): 3–22. https://doi.org/10.1002/ajim.23049.

Amick, Benjamin C., Sheilah Hogg-Johnson, Desiree Latour-Villamil, and Ron Saunders. 2015. "Protecting Construction Worker Health and Safety in Ontario, Canada: Identifying a Union Safety Effect." *Journal of Occupational & Environmental Medicine* 57 (12): 1337–42. https://doi.org/10.1097/JOM.0000000000000562.

Ardani, K, P Denholm, T Mai, R Margolis, E O'Shaughnessy, T Silverman, and J Zuboy. 2021. "Solar Futures Study." *Solar Energy Technologies Office, US Department of Energy, Sept* 8.

Ardani, K., D. Seif, R. Margolis, J. Morris, C. Davidson, S. Truitt, and R. Torbert. 2013. "Non-Hardware ('Soft') Cost-Reduction Roadmap for Residential and Small Commercial Solar Photovoltaics, 2013-2020." United States. https://doi.org/10.2172/1096122.

Ardani, Kristen, Jeffrey Cook, Robert M. Margolis, and Ran Fu. 2018. "Cost-Reduction Roadmap for Residential Solar Photovoltaics (PV), 2017-2030." United States. https://doi.org/10.2172/1419627.

Argetsinger, Beren. 2017. "Standards and Requirements for Solar Equipment, Installation, and Licensing and Certification: A Guide for States and Municipalities." DE-EE0007321. Sustainable Solar Education Project. U.S. Department of Energy SunShot & Clean Energy States Alliance. https://www.cesa.org/wp-content/uploads/Standards-and-Requirements-for-Solar.pdf.

Azari-rad, Hamid, and Peter Philips. 2003. "Race and Prevailing Wage Laws in the Construction Industry: Comment on Thieblot." *Journal of Labor Research* 24 (1): 161–68. https://doi.org/10.1007/s12122-003-1035-9.

Bach, Katie, and Molly Kinder. 2021. "Is Your Business Struggling with the Labor Shortage? Consider a Union." *The Avenue, Brookings* (blog). December 14, 2021. https://www.brookings.edu/blog/the-avenue/2021/12/14/is-your-business-struggling-with-the-labor-shortage-consider-a-union/.

Bae, Jinwon, and Sandy Dall'erba. 2016. "The Economic Impact of a New Solar Power Plant in Arizona: Comparing the Input-output Results Generated by JEDI vs. IMPLAN." *Regional Science Policy & Practice* 8 (1–2): 61–73.

Baker, Shalanda, Subin DeVar, and Shiva Prakash. 2019. "The Energy Justice Workbook." Initiative for Energy Justice. https://iejusa.org/wp-content/uploads/2019/12/The-Energy-Justice-Workbook-2019-web.pdf.

Barbose, Galen, Naim Darghouth, Eric O'Shaughnessy, and Sydney Forrester. 2022. "Tracking the Sun Pricing and Design Trends for Distributed Photovoltaic Systems in the United States 2022 Edition." Lawrence Berkeley National Laboratory. https://emp.lbl.gov/sites/default/files/2_tracking_the_sun_2022_report.pdf.

Barrett, J, and J Yudken. 2020. "The 2020 US Energy & Employment Report." *National Association of State Energy Officials, and Energy Futures Initiative*. https://www.usenergyjobs.org/2020-state-reports.

Bazaj, Neha. 2020. "Daylighting Pathways to Good Jobs in California's Solar Industry." *Department of Urban Studies and Planning, MASSACHUSETTS INSTITUTE OF TECHNOLOGY*, May. https://dspace.mit.edu/bitstream/handle/1721.1/127581/1193321567-MIT.pdf?sequence=1&isAllowed=y.

Behrer, A. P., R. J. Park, G. Wagner, C. M. Golja, and D. W. Keith. 2021. "Heat Has Larger Impacts on Labor in Poorer Areas." *Environmental Research Communications* 3 (9): 095001. https://doi.org/10.1088/2515-7620/abffa3.

Benavides, F. G., J. Benach, C. Muntaner, G. L. Delclos, N. Catot, and M. Amable. 2006. "Associations between Temporary Employment and Occupational Injury: What Are the Mechanisms?" *Occupational and Environmental Medicine* 63 (6): 416–21. https://doi.org/10.1136/oem.2005.022301.

Bernhardt, Annette. 2017. "What Do We Know About Gig Work in California? An Analysis of Independent Contracting." UC Berkeley Labor Center. https://laborcenter.berkeley.edu/pdf/2017/What-Do-We-Know-About-Gig-Work-in-California.pdf.

Bernstein, David. 2018. "Prevailing Wage Legislation and the Continuing Significance of Race." *Journal of Legislation* 44. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3188989.

Billman, Lynn, and David Keyser. 2013. "Assessment of the Value, Impact, and Validity of the Jobs and Economic Development Impacts (JEDI) Suite of Models." National Renewable Energy Lab.(NREL), Golden, CO (United States).

BLS. 2022. "Solar Photovoltaic Installers, Occupational Employment and Wages, May 2021." U.S. Bureau of Labor Statistics. 2022. https://www.bls.gov/oes/current/oes472231.htm.

BlueGreen Alliance. 2019. "Solidarity for Climate Action." BlueGreen Alliance. http://www.bluegreenalliance.org/wp-content/uploads/2019/07/Solidarity-for-Climate-Action-vFINAL.pdf.

———. 2020. "State-Based Policies to Build a Cleaner, Safer and More Equitable Economy." BlueGreen Alliance. https://www.bluegreenalliance.org/wp-content/uploads/2020/07/StatePolicyToolkit_Report2020_vFINAL.pdf.

Boarnet, Marlon, Genevieve Giuliano, Yuting Hou, and Eun Jin Shin. 2013. "Transportation and Access to Employment in City Heights." *USC Center for Social Innovation*.

Bolinger, Mark, Will Gorman, Joseph Rand, Seongeun Jeong, Ryan Wiser, Joachim Seel, and Cody Warner. 2022. "Hybrid Power Plants: Status of Operating and Proposed Plants, 2022 Edition." None, 1880044, ark:/13030/qt7sx2k5jn. https://doi.org/10.2172/1880044.

Bolinger, Mark, Joachim Seel, Cody Warner, and Dana Robson. 2022. "Utility-Scale Solar, 2022 Edition: Empirical Trends in Deployment, Technology, Cost, Performance, PPA Pricing, and Value in the United States." None, 1888246, ark:/13030/qt7496x1pc. https://doi.org/10.2172/1888246.

Bollinger, Bryan, and Kenneth Gillingham. 2019. "Learning-by-Doing in Solar Photovoltaic Installations." *Available at SSRN 2342406*.

Budd, John W. 2004. "Non-Wage Forms of Compensation." *Journal of Labor Research* 25 (4): 597–622. https://doi.org/10.1007/s12122-004-1013-x.

Cameron, Lachlan, and Bob van der Zwaan. 2015. "Employment Factors for Wind and Solar Energy Technologies: A Literature Review." *Renewable and Sustainable Energy Reviews* 45 (May): 160–72. https://doi.org/10.1016/j.rser.2015.01.001.

Cha, J. Mijin. 2017. "A Just Transition: Why Transitioning Workers Into A New Clean Energy Economy Should Be At The Center of Climate Change Policies." *Fordham Environmental Law Review* 29 (2): 196–220.

Cha, J Mijin, Vivian Price, Dimitris Stevis, and Todd E Vachon. 2021. "Workers and Communities in Transition: Report of the Just Transition Listening Project." Labor Network for Sustainability. https://www.labor4sustainability.org/files/JTLP_report2021.pdf.

Chen, Chien-fei, Yuanyang Liu, Jamie Alexander Greig, Zhenglai Shen, and Yunye Shi. 2022. "The Impacts of COVID-19 on Clean Energy Labor Markets: Evidence from Multifaceted Analysis of Public Health Interventions and COVID-Health Factors." *Energy Policy* 164 (May): 112880. https://doi.org/10.1016/j.enpol.2022.112880.

Chen, Christine, Drew Cutchins, Erica Leonard, and Katie Cheng. 2021. "Improving Public Transit: Learning From Los Angeles and New York City." https://storymaps.arcgis.com/stories/05e8b9664e144d77bbf8c9c708775845.

Cliffton, Rita, Malkie Wall, Sam Ricketts, Kevin Lee, Jessica Eckdish, and Karla Walter. 2021. "The Clean Economy Revolution Will Be Unionized: A Road Map From States on Creating Good, Union Jobs to Build the Clean Energy Economy." Center for American Progress.

Clow, Scott. 2022. "Final Technical Report Ute Mountain Ute Tribe Community-Scale Solar Project." Final-Techical-Report-DE-IE0000095-UMUT. Ute Mountain Ute Tribe. https://doi.org/10.2172/1861005.

Compa, Lance A. 2014. "An Overview of Collective Bargaining in the United States," January. https://ecommons.cornell.edu/handle/1813/75276.

Congressional Black Caucus. 1995. "Congressional Black Caucus to ABC," December 13, 1995. http://www.faircontracting.org/wp-content/uploads/2012/11/Congressional-Black-Caucus-statement-on-Davis-Bacon.pdf.

Congressional Research Service. 2021. "The Energy Credit or Energy Investment Tax Credit (ITC)." https://crsreports.congress.gov/product/pdf/IF/IF10479.

Corporate Partners Program at UCLA and Green for All, Dream Corps. 2020. "Facilitating Reentry of Justice-Involved Individuals into the Green Workforce: Case Studies and Best Practices." https://www.thedreamcorps.org/wp-content/uploads/2020/08/facilitating-reentry-of-justice-involved-individuals-into-the-green-workforce-final-1.pdf.

Costantini, Winn Elliott. 2021. "Integrating Climate, Economic, and Racial Justice through a Boston FutureCorps." *Massachusetts Institute of Technology*, Graduate Theses, , June. https://hdl.handle.net/1721.1/139210.

Crowe, Jessica A., and Ruopu Li. 2020. "Is the Just Transition Socially Accepted? Energy History, Place, and Support for Coal and Solar in Illinois, Texas, and Vermont." *Energy Research & Social Science* 59 (January): 101309. https://doi.org/10.1016/j.erss.2019.101309.

Dayen, David. 2022. "Trade Group Driving Solar Controversy Includes Slave-Labor Companies." The American Prospect. May 12, 2022. https://prospect.org/api/content/3341f434-d17f-11ec-8855-12274efc5439/.

Department of Energy. n.d. "Federal Energy and Manufacturing Workforce Training Programs." Energy.Gov. Accessed October 21, 2022. https://www.energy.gov/eere/education/federal-energy-and-manufacturing-workforce-training-programs.

Desmond, Matthew, and Carl Gershenson. 2016. "Housing and Employment Insecurity among the Working Poor." *Social Problems* 63 (1): 46–67.

Dowell, Earlene K. P. 2020. "Job Sprawl Results in Unemployment for Low-Income Urban Residents." United States Census Bureau. 2020. https://www.census.gov/library/stories/2020/03/spatial-mismatch-when-workers-can-not-get-to-jobs-in-suburbs.html.

DSIRE. 2022. "DSIRE: Summary Tables." 2022. https://programs.dsireusa.org/system/program/tables.

Duncan, Kevin. 2021. "What the Research Tells Us About the Costs and Benefits of Prevailing Wage Laws." Local Government Interim Committee, Montana State Legislature. Colorado State University-Pueblo. https://leg.mt.gov/content/Committees/Interim/2021-2022/Local-Gov/21_Nov/DuncanReport_MontanaPrevailingWageStudy2021.pdf.

Duncan, Kevin, and Russell Ormiston. 2014. "Prevailing Wage Laws: What Do We Know?" Institute for Construction Economic Research. http://iceres.org/wp-content/uploads/2014/10/prevailing-wage-review-duncan-ormiston.pdf.

———. 2019. "What Does the Research Tell Us about Prevailing Wage Laws?" *Labor Studies Journal* 44 (2): 139–60. https://doi.org/10.1177/0160449X18766398.

Duroha, Jesse C., and Gretchen A. Macht. 2021. "Solar Installations & Their Occupational Risks." *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 65 (1): 1243–47. https://doi.org/10.1177/1071181321651275.

E2, Alliance to Save Energy, American Association of Blacks in Energy, Energy Efficiency for All, Black Owners of Solar Services, and BW Research Partnership. 2021. "Help Wanted: Diversity in Clean Energy." E2. https://e2.org/wp-content/uploads/2021/09/E2-ASE-AABE-EEFA-BOSS-Diversity-Report-2021.pdf.

EIA. 2021. "2020 EIA Annual Coal Report." Government. Annual Coal Report. U.S. Energy Information Administration. https://www.eia.gov/coal/annual/.

———. 2022a. "Annual Electric Power Industry Report." EIA-861. U.S. Energy Information Administration. https://www.eia.gov/electricity/data/eia861/.

———. 2022b. "Electric Power Monthly." U.S. Energy Information Administration. https://www.eia.gov/electricity/monthly/.

———. 2022c. "Form EIA-860." U.S. Energy Information Administration. https://www.eia.gov/electricity/data/eia860/.

———. 2022d. "Monthly Electric Power Industry Report." EIA-861M. U.S. Energy Information Administration. https://www.eia.gov/electricity/data/eia861m/.

Feldman, David, Krysta Dummit, Jarett Zuboy, Jenny Heeter, Kaifeng Xu, and Robert Margolis. 2022. "Winter 2021/2022 Solar Industry Update." January 11. https://www.nrel.gov/docs/fy22osti/81900.pdf.

Feldman, David, Vignesh Ramasamy, Ran Fu, Ashwin Ramdas, Jal Desai, and Robert Margolis. 2021. "US Solar Photovoltaic System and Energy Storage Cost Benchmark (Q1 2020)." National Renewable Energy Lab.(NREL), Golden, CO (United States).

Ferris, David. 2021. "The Power Struggle over Tomorrow's Solar Workers." E&E News. May 25, 2021. https://www.eenews.net/articles/the-power-struggle-over-tomorrows-solar-workers/.

FHWA. 2022. "Project Labor Agreement - Construction Program Guide - Contract Administration - Construction - Federal Highway Administration." February 10, 2022. https://www.fhwa.dot.gov/construction/cqit/pla.cfm#:~:text=A%20project%20labor%20agreement%20(PLA,for%20a%20specific%20construction%20project.

Fine, Janice, and Tim Bartley. 2019. "Raising the Floor: New Directions in Public and Private Enforcement of Labor Standards in the United States." *Journal of Industrial Relations* 61 (2): 252–76. https://doi.org/10.1177/0022185618784100.

Florida Solar Energy Center. 2022. "Florida Solar Energy Apprenticeship Program – Providing a Pathway to Becoming a Florida Solar Contractor." February 2022. https://floridasolarapprentice.com/.

Foley, Michael. 2017. "Factors Underlying Observed Injury Rate Differences between Temporary Workers and Permanent Peers." *American Journal of Industrial Medicine* 60 (10): 841–51. https://doi.org/10.1002/ajim.22763.

Fortin, Nicole M., Thomas Lemieux, and Neil Lloyd. 2021. "Labor Market Institutions and the Distribution of Wages: The Role of Spillover Effects." *Journal of Labor Economics* 39 (S2): S369–412. https://doi.org/10.1086/712923.

Friedman, B., P. Jordan, and J. Carrese. 2011. "Solar Installation Labor Market Analysis." NREL/TP-6A20-49339. National Renewable Energy Lab. (NREL), Golden, CO (United States). https://doi.org/10.2172/1031395.

Friedman, Barry. 2012. "PV Installation Labor Market Analysis and PV JEDI Tool Developments (Presentation)." National Renewable Energy Lab.(NREL), Golden, CO (United States).

Fu, Ran, Donald Chung, Travis Lowder, David Feldman, Kristen Ardani, and Robert Margolis. 2016. "US Solar Photovoltaic System Cost Benchmark: Q1 2016." National Renewable Energy Lab.(NREL), Golden, CO (United States).

Fu, Ran, David J. Feldman, and Robert M. Margolis. 2018. "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018." NREL/TP-6A20-72399. National Renewable Energy Lab. (NREL), Golden, CO (United States). https://doi.org/10.2172/1483475.

Fu, Ran, David Feldman, Robert Margolis, Mike Woodhouse, and Kristen Ardani. 2017. "US Solar Photovoltaic System Cost Benchmark: Q1 2017." EERE Publication and Product Library, Washington, DC (United States).

Fuchs, Ester R, Dorian Warren, and Kimberly Bayer. 2014. "Expanding Opportunity For Middle Class Jobs in New York City: Minority Youth Employment in the Building and Construction Trades." Columbia School of International and Public Affairs. https://www.gnylecet.org/wp-content/uploads/2020/04/ColumbiaSIPA03-14.pdf.

Gammon, Tammy, Wei-Jen Lee, and Iragaba Intwari. 2019. "What Occupational Injury Costs and Workers' Compensation Tell Us About Electrical Injuries and the Need to Invest in Electrically Safer Workplaces." *IEEE Transactions on Industry Applications* 55 (4): 4377–83. https://doi.org/10.1109/TIA.2019.2907578.

Gammon, Tammy, and Derek Vigstol. 2020. "A State by State Comparison of Occupational Electrical Fatalities." *IEEE Transactions on Industry Applications* 56 (6): 6062–68. https://doi.org/10.1109/TIA.2020.3023922.

———. 2022. "Occupational Electrical Work Fatalities: A State-By-State Comparison." *IEEE Industry Applications Magazine* 28 (3): 42–55. https://doi.org/10.1109/MIAS.2021.3114656.

Geoffrey Heal and Jisung Park. 2016. "Reflections—Temperature Stress and the Direct Impact of Climate Change: A Review of an Emerging Literature." *Review of Environmental Economics and Policy* 10 (2). https://doi.org/10.1093/reep/rew007.

Gholizadeh, Pouya, Ikechukwu S. Onuchukwu, and Behzad Esmaeili. 2021. "Trends in Catastrophic Occupational Incidents among Electrical Contractors, 2007–2013." *International Journal of Environmental Research and Public Health* 18 (10): 5126. https://doi.org/10.3390/ijerph18105126.

Gillingham, Kenneth, Hao Deng, Ryan Wiser, Naim Darghouth, Gregory Nemet, Galen Barbose, Varun Rai, and Changgui Dong. 2016. "Deconstructing Solar Photovoltaic Pricing." *The Energy Journal* 37 (3). https://doi.org/10.5547/01956574.37.3.kgil.

Goodman, Joseph, Kathryn Nagel, Matthew Wren, and Jesse Morris. 2014. "Applying Lean Process Principles to Improve Labor Efficiency of Solar Photovoltaic Installations." In , 709–18.

Green, Francis, Tarek Mostafa, Agnès Parent-Thirion, Greet Vermeylen, Gijs van Houten, Isabella Biletta, and Maija Lyly-Yrjanainen. 2013. "Is Job Quality Becoming More Unequal?" *ILR Review* 66 (4): 753–84. https://doi.org/10.1177/001979391306600402.

GRID Alternatives. n.d. "Installation Basics Training Program." Accessed February 1, 2023. https://gridalternatives.org/get-training/installation-training-programs/ibt-program.

Groom, Nichola. 2022. "U.S. Solar Industry Jobs Rose 9% in 2021, Mainly in Installation." *Reuters*, July 26, 2022, sec. Sustainable Business. https://www.reuters.com/business/sustainable-business/us-solar-industry-jobs-rose-9-2021-mainly-installation-2022-07-26/.

Grubler, Arnulf, and Gregory F Nemet. 2014. "Sources and Consequences of Knowledge Depreciation." *Energy Technology Innovation: Learning from Historical Successes and Failures*, 133–45.

Gurley, Lauren Kaori. 2022. "Shifting America to Solar Power Is a Grueling, Low-Paid Job." *Vice* (blog). June 27, 2022. https://www.vice.com/en/article/z34eyx/shifting-america-to-solar-power-is-a-grueling-low-paid-job.

Heeter, Jenny, and Tony Reames. 2022. "Incorporating Energy Justice into Utility-Scale Photovoltaic Deployment: A Policy Framework." *Renewable Energy Focus* 42 (September): 1–7. https://doi.org/10.1016/j.ref.2022.04.003.

Helper, Susan, Ryan Noonan, Jessica R Nicholson, and David Langdon. 2016. "The Benefits and Costs of Apprenticeship: A Business Perspective." US Department of Commerce. https://files.eric.ed.gov/fulltext/ED572260.pdf.

Herrera, Lucero, Saba Waheed, Tia Koonse, and Clarine Ovando-Lacroux. 2014. "EXPLORING TARGETED HIRE: An Assessment of Best Practices in the Construction Industry." UCLA Labor Center.

Ho, Chung, Hyun Woo Lee, and John A. Gambatese. 2018. "Improving Safety in Solar Installations through Prevention through Design," March, 717–26. https://doi.org/10.1061/9780784481288.070.

Howard, John. 2017. "Nonstandard Work Arrangements and Worker Health and Safety." *American Journal of Industrial Medicine* 60 (1): 1–10. https://doi.org/10.1002/ajim.22669.

Hwang, Suk Joon. 2021. "An Exploration of the Diffusion of Policy Termination: The Repeal of Prevailing Wage Laws by US State Governments." *Policy Studies* 42 (2): 117–31. https://doi.org/10.1080/01442872.2019.1622662.

Ihlanfeldt, Keith. 1994. "The Spatial Mismatch Between Jobs and Residential Locations Within Urban Areas." *Cityscape* 1 (1): 219–44.

Inclusive Economics, Illinois Economic Policy Institute, and Sierra Club. 2021. "How to Achieve Economic Justice in Illinois' Clean Energy Transition." Sierra Club. https://www.sierraclub.org/sites/default/files/How%20to%20Achieve%20Economic%20Justice%20in%20Illinois%E2%80%99%20Clean%20Energy%20Transition%20%281%29.pdf.

Internal Revenue Service. 2022. "Prevailing Wage and Apprenticeship Initial Guidance Under Section 45(b)(6)(B)(Ii) and Other Substantially Similar Provisions." Internal Revenue Service. https://www.federalregister.gov/documents/2022/11/30/2022-26108/prevailing-wage-and-apprenticeship-initial-guidance-under-section-45b6bii-and-other-substantially.

———. 2023. *Initial Guidance Establishing Program to Allocate Environmental Justice Solar and Wind Capacity Limitation Under Section 48(e)*. https://www.irs.gov/pub/irs-drop/n-23-17.pdf.

IREC. 2022a. "Solar Career Map: Solar PV Installer." Solar Career Map. 2022. https://www.irecsolarcareermap.org/jobs/solar-pv-installer.

———. 2022b. "National Solar Jobs Census 2021." https://irecusa.org/wp-content/uploads/2022/07/National-Solar-Jobs-Census-2021.pdf.

IRENA and ILO. 2021. "Renewable Energy and Jobs - Annual Review 2021." ISBN: 978-92-9260-364-9. Abu Dhabi, Geneva: International Renewable Energy Agency. https://www.irena.org/publications/2021/Oct/Renewable-Energy-and-Jobs-Annual-Review-2021.

Irmen, Nicholas James, Jonathan Katz, and Shawn J. Daray. 2022. "Inflation Reduction Act: Implications for Solar and Wind Tax Credit Equity Markets." *The National Law Review* XII (298). https://www.natlawreview.com/article/inflation-reduction-act-implications-solar-and-wind-tax-credit-equity-markets.

Jacobs, Ken. 2018. "The Union Effectin California: Wages, Benefits, and Use of Public Safety Net Programs." UC Berkeley Labor Center. https://laborcenter.berkeley.edu/pdf/2018/Union-Effect-in-California-1.pdf.

Jacobs, Ronald L., and Joshua D. Hawley. 2009. "The Emergence of 'Workforce Development': Definition, Conceptual Boundaries and Implications." In *International Handbook of Education for the Changing World of Work: Bridging Academic and Vocational Learning*, edited by Rupert Maclean and David Wilson, 2537–52. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-1-4020-5281-1_167.

James, Joey, Evan Hansen, and Alan Collins. 2017. "Capturing the Sun's Rays: An Economic Impact Assessment of Solar Development in Southwest Virginia." https://www.downstreamstrategies.com/documents/reports_publication/solar-workgroup_final-report_9-6-17.pdf.

Jones, Betony. 2020a. "Potential Impacts of Prevailing Wage on Solar Costs in Illinois." Inclusive Economics.

———. 2020b. "Prevailing Wage in Solar Can Deliver Good Jobs While Keeping Growth on Track." *UC Berkeley Labor Center* (blog). November 12, 2020. https://laborcenter.berkeley.edu/prevailing-wage-in-solar-can-deliver-good-jobs-while-keeping-growth-on-track/.

Jones, Betony, Peter Philips, and Carol Zabin. 2016. "The Link Between Good Jobs and a Low Carbon Future." UC Berkeley Labor Center. https://laborcenter.berkeley.edu/pdf/2016/Link-Between-Good-Jobs-and-a-Low-Carbon-Future.pdf.

Jordan, Dirk C., Bill Marion, Chris Deline, Teresa Barnes, and Mark Bolinger. 2020. "PV Field Reliability Status—Analysis of 100 000 Solar Systems." *Progress in Photovoltaics: Research and Applications* 28 (8): 739–54. https://doi.org/10.1002/pip.3262.

Jordan, Philip. 2020a. "Fossil Fuel Employment Initial Impacts from the COVID-19 Economic Crisis, March-October 2020." BW Research Partnership. https://bwresearch.com/covid/docs/BWResearch_FossilFuelsJobsCOVID-19Memo_Oct2020.pdf.

———. 2020b. "US Energy Employment Initial Impacts from the COVID-19 Economic Crisis, October 2020." BW Research Partnership. https://bwresearch.com/covid/docs/BWResearch_EnergyJobsCOVID-19Memo_Oct2020.pdf.

Kalleberg, Arne L. 2011. *Good Jobs, Bad Jobs: The Rise of Polarized and Precarious Employment Systems in the United States, 1970s-2000s*. Russell Sage Foundation.
Kelsay, Michael, and Frank Manzo IV. 2019. "The Impact of Repealing West Virginia's Prevailing Wage Law." Affiliated Construction Trades (West Virginia) and the National Alliance for Fair Contracting (NAFC). https://faircontracting.org/wp-content/uploads/2019/05/THE-IMPACT-OF.pdf.
Keurentjes, Anne J., Sanja Kezic, Thomas Rustemeyer, Carel T. J. Hulshof, and Henk F. van der Molen. 2022. "Stimulating Sunscreen Use Among Outdoor Construction Workers: A Pilot Study." *Frontiers in Public Health* 10. https://www.frontiersin.org/articles/10.3389/fpubh.2022.857553.
Kim, Jaewhan, Chang Kuo-Liang, and Peter Philips. 2012. "The Effect of Prevailing Wage Regulations on Contractor Bid Participation and Behavior: A Comparison of P Alo A Lto, C Alifornia with Four Nearby Prevailing Wage Municipalities." *Industrial Relations: A Journal of Economy and Society* 51 (4): 874–91.
Kirk, Karin. 2022. "2020 a COVID-Year of Major Energy Industry Job Losses » Yale Climate Connections." *Yale Climate Connections* (blog). January 26, 2022. http://yaleclimateconnections.org/2022/01/2020-a-covid-year-of-major-energy-industry-job-losses/.
Kotler, Fred B. 2018. "New York State Prevailing Wage Law: Defining Public Work."
Larson, E, C Greig, J Jenkins, E Mayfield, A Pascale, C Zhang, J Drossman, R Williams, S Pacala, and R Socolow. 2020. "Net-Zero America: Potential Pathways, Infrastructure, and Impacts Interim Report. Princeton University."
LCP Tracker. 2021. "A GUIDE TO FEDERAL APPRENTICESHIP REQUIREMENTS." April 15, 2021. https://lcptracker.com/blog-post/a-guide-to-federal-apprenticeship-requirements/.
LiUNA. 2022. "Training - Laborers Union Local 169." 2022. https://local169.com/training/.
Loh, Tracy Hadden, Christopher Coes, and Becca Buthe. 2020. "Separate and Unequal: Persistent Residential Segregation Is Sustaining Racial and Economic Injustice in the US." *Brookings Institution, December* 16.
Lombardi, David A., Simon Matz, Melanye J. Brennan, Gordon S. Smith, and Theodore K. Courtney. 2009. "Etiology of Work-Related Electrical Injuries: A Narrative Analysis of Workers' Compensation Claims." *Journal of Occupational and Environmental Hygiene* 6 (10): 612–23. https://doi.org/10.1080/15459620903133683.
Loomis, DG, JH Jo, and MR Aldeman. 2016. "Economic Impact Potential of Solar Photovoltaics in Illinois." *Renewable Energy* 87: 253–58.
Louie, Edward P., and Joshua M. Pearce. 2016. "Retraining Investment for U.S. Transition from Coal to Solar Photovoltaic Employment." *Energy Economics* 57 (June): 295–302. https://doi.org/10.1016/j.eneco.2016.05.016.
Luke, Nikki, Carol Zabin, Dalia Velasco, and Robert Collier. 2017. "Diversity in California's Clean Energy Workforce: Access to Jobs for Disadvantaged Workers in Renewable Energy Construction." UC Berkeley Labor Center. https://laborcenter.berkeley.edu/pdf/2017/Diversity-in-Californias-Clean-Energy-Workforce.pdf.
Mahalia, Nooshin. 2008. "Prevailing Wages and Government Contracting Costs : A Review of the Research." Economic Policy Institute. Policy Commons. https://policycommons.net/artifacts/1414800/prevailing-wages-and-government-contracting-costs/.
Mangundayao, Ihna, Celine McNicholas, and Margaret Poydock. 2021. "Worker Protection Agencies Need More Funding to Enforce Labor Laws and Protect Workers." *Working Economics Blog,*

Economic Policy Institute (blog). July 29, 2021. https://www.epi.org/blog/worker-protection-agencies-need-more-funding-to-enforce-labor-laws-and-protect-workers/.
Manzo IV, Frank, and Robert Bruno. 2020. "The Apprenticeship Alternative: Enrollment, Completion Rates, and Earnings in Registered Apprenticeship Programs in Illinois." Illinois Economic Policy Institute; University of Illinois at Urbana-Champaign. https://illinoisepi.files.wordpress.com/2020/01/ilepi-pmcr-the-apprenticeship-alternative-final.pdf.
Manzo IV, Frank, Alex Lantsberg, and Kevin Duncan. 2016. "The Economic, Fiscal, and Social Impacts of State Prevailing Wage Laws: Choosing Between the High Road and the Low Road in the Construction Industry," February.
Manzo IV, Frank, Lantsberg, Alex, and Duncan, Kevin. n.d. "The Economic, Fiscal, and Social Impacts of State Prevailing Wage Laws: Choosing Between the High Road and the Low Road in the Construction Industry." Accessed September 13, 2021. http://www.faircontracting.org/wp-content/uploads/2016/02/PW-national-impact-study-FINAL2.9.16.pdf.
Marinescu, Ioana, Yue Qiu, and Aaron Sojourner. 2021. "Wage Inequality and Labor Rights Violations," 50.
Mayfield, Erin, Jenkins, Jesse, Larson, Eric, and Greig, Chris. 2020. "Princeton's Net-Zero America Study Annex R: Employment Transition (Methods)." https://netzeroamerica.princeton.edu/img/NZA%20Annex%20R%20-%20Labor%20modeling%20methodology.pdf.
McNicholas, Celine, Margaret Poydock, Julia Wolfe, Ben Zipperer, Gordon Lafer, and Lola Loustaunau. 2019. "Unlawful: U.S. Employers Are Charged with Violating Federal Law in 41.5% of All Union Election Campaigns." Economic Policy Institute. December 11, 2019. https://www.epi.org/publication/unlawful-employer-opposition-to-union-election-campaigns/.
Memarian, Babak, Sara B. Brooks, and Jean Christophe Le. 2022. "Obstacles and Solutions to Implementing Job Hazard Analysis in Construction: A Case Study." *International Journal of Construction Education and Research* 0 (0): 1–12. https://doi.org/10.1080/15578771.2022.2027053.
Memarian, Babak, Sara B. Brooks, Jean Christophe Le, and Jerry E. Rivera. 2022. "High-Risk Electrical Tasks & Contributing Work Factors." *Professional Safety* 67 (08): 14–20.
Michaud, Gilbert. 2020. "Examining Renewable Energy Transitions: A Tool to Enhance Workforce Development." Renewable Energy Policy Initiative. George V. Voinovich School of Leadership and Public Affairs, Ohio University. https://closup.umich.edu/sites/closup/files/uploads/repi/REPI-Michaud.pdf.
Michaud, Gilbert, Christelle Khalaf, Michael Zimmer, and David Jenkins. 2020. "Measuring the Economic Impacts of Utility-Scale Solar in Ohio."
Miller, Reuben Jonathan. 2021. *Halfway Home: Race, Punishment, and the Afterlife of Mass Incarceration*. Little, Brown.
Minimum Wage for Federal Contracts Covered by Executive Order 13658, Notice of Rate Change in Effect as of January 1, 2022. 2022. *86 FR 51683*. https://www.federalregister.gov/documents/2021/09/16/2021-19995/minimum-wage-for-federal-contracts-covered-by-executive-order-13658-notice-of-rate-change-in-effect.
Mishel, Lawrence. 2017. "Diversity in the New York City Union and Nonunion Construction Sectors." Economic Policy Institute. https://files.epi.org/pdf/119517.pdf.

Morris, Jesse, Koben Calhoun, Joseph Goodman, and Daniel Seif. 2014. "Reducing Solar PV Soft Costs: A Focus on Installation Labor." In *2014 IEEE 40th Photovoltaic Specialist Conference (PVSC)*, 3356–61. https://doi.org/10.1109/PVSC.2014.6925654.
National Employment Law Project. 2016. "On-Demand Workers Should Be Covered By Worker's Compensation." National Employment Law Project. https://www.nelp.org/wp-content/uploads/Policy-Brief-On-Demand-Covered-Workers-Compensation.pdf.
National Fire Protection Association. 2021. "NFPA 70E®: Standard for Electrical Safety in the Workplace®." 2021. https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70E.
Neha Bazaj. 2020. "Pathways to Good Jobs in California's Solar Industry." Massachusetts Institute of Technology. https://dspace.mit.edu/handle/1721.1/127581.
Neitzel, Dennis K. 2018. "Identifying the Requirements for Qualified, Unqualified, and Competent Persons Electrical Safety Training." *IEEE Transactions on Industry Applications* 54 (1): 5–9. https://doi.org/10.1109/TIA.2017.2741445.
Nemet, Gregory F., Jiaqi Lu, Varun Rai, and Rohan Rao. 2020. "Knowledge Spillovers between PV Installers Can Reduce the Cost of Installing Solar PV." *Energy Policy* 144 (September): 111600. https://doi.org/10.1016/j.enpol.2020.111600.
NLRB. 2022. "Employer/Union Rights and Obligations | National Labor Relations Board." 2022. https://www.nlrb.gov/about-nlrb/rights-we-protect/your-rights/employer-union-rights-and-obligations.
NREL. 2022. "About JEDI." About JEDI. 2022. https://www.nrel.gov/analysis/jedi/about.html.
Occupational Safety and Health Administration. n.d. "About OSHA | Occupational Safety and Health Administration." Accessed August 22, 2022. https://www.osha.gov/aboutosha.
Office of Labor-Management Standards. 2020. "Collective Bargaining Agreements File: Online Listings of Private and Public Sector Agreements." January 10, 2020. https://www.dol.gov/agencies/olms/cba.
Oregon Solar Energy Industries Association. 2006. "Solar Construction Safety." Oregon Solar Energy Industries Association. https://www.scribd.com/document/46253277/OSEIA-Solar-Safety-12-06.
OSHA. n.d. "Green Job Hazards." Government. OSHA Safety and Health Topics. https://www.osha.gov/green-jobs/solar.
Park, Jisung, Nora M. C. Pankratz, and A. Behrer. 2021. "Temperature, Workplace Safety, and Labor Market Inequality." *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3892588.
Phadke, Amol, Umed Paliwal, Nikit Abhyankar, Taylor McNair, Ben Paulos, David Wooley, and Ric O'Connell. 2020a. "2035 Report: Appendix." University of California Berkeley, Goldman School of Public Policy. https://www.2035report.com/wp-content/uploads/2020/06/2035-Appendix.pdf.
———. 2020b. "The 2035 Report: Plummeting Solar, Wind, and Battery Costs Can Accelerate Our Clean Electricity Future." University of California Berkeley, Goldman School of Public Policy. https://www.2035report.com/wp-content/uploads/2020/06/2035-Report.pdf.
Pickerel, Kelly. 2020. "McCarthy Will Support Apprentice Program to Recruit More Military Veterans for Careers in Solar." Solar Power World. December 2, 2020. https://www.solarpowerworldonline.com/2020/12/mccarthy-will-support-apprentice-program-to-recruit-more-military-veterans-for-careers-in-solar/.
———. 2023. "Burns & McDonnell Get DOL Approval for Solar Construction Apprenticeship Program." Solar Power World. January 24, 2023.

https://www.solarpowerworldonline.com/2023/01/burns-mcdonnell-get-dol-approval-for-solar-construction-apprenticeship-program/.
Pitts, Steven C. 2008. "Job Quality and Black Workers: An Examination of the San Francisco Bay Area, Los Angeles, Chicago and New York." Center for Labor Research and Education, UC Berkeley. https://laborcenter.berkeley.edu/pdf/2007/blackworkers_07.pdf.
Porter, Eduardo, and Tony Luong. 2021. "Can Progress on Diversity Be Union-Made?" *The New York Times*, November 6, 2021, sec. Business. https://www.nytimes.com/2021/11/06/business/economy/unions-race-boston.html.
Ramasamy, Vignesh, David Feldman, Jal Desai, and Robert Margolis. 2021. "US Solar Photovoltaic System and Energy Storage Cost Benchmarks: Q1 2021." National Renewable Energy Lab.(NREL), Golden, CO (United States).
Russo, Simone, Jana Sillmann, Sebastian Sippel, Monika J. Barcikowska, Claudia Ghisetti, Marek Smid, and Brian O'Neill. 2019. "Half a Degree and Rapid Socioeconomic Development Matter for Heatwave Risk." *Nature Communications* 10 (1): 136. https://doi.org/10.1038/s41467-018-08070-4.
Samaniego-Rascón, Danyela, Manuel C. Gameiro da Silva, Almerindo D. Ferreira, and Rafael E. Cabanillas-Lopez. 2019. "Solar Energy Industry Workers under Climate Change: A Risk Assessment of the Level of Heat Stress Experienced by a Worker Based on Measured Data." *Safety Science* 118 (October): 33–47. https://doi.org/10.1016/j.ssci.2019.04.042.
Sarzynski, Andrea, Jeremy Larrieu, and Gireesh Shrimali. 2012. "The Impact of State Financial Incentives on Market Deployment of Solar Technology." *Energy Policy* 46 (July): 550–57. https://doi.org/10.1016/j.enpol.2012.04.032.
Scheiber, Noam. 2021. "Building Solar Farms May Not Build the Middle Class." *New York Times*, July 16, 2021. https://www.nytimes.com/2021/07/16/business/economy/green-energy-jobs-economy.html.
Sedgwick, Shannon, John Ramsey, Arthur Girard, Luke Meyer, Kristen Moore, and Juan Madrigal. 2021. "Middle-Skill Occupations and Related Career Education Programs Through the Lens of Race and Ethnicity." Center for a Competitive Workforce. file:///C:/Users/amoe/Downloads/CCW_RaceEthnicity_FINAL02_web.pdf.
Seel, Joachim, Galen L. Barbose, and Ryan H. Wiser. 2014. "An Analysis of Residential PV System Price Differences between the United States and Germany." *Energy Policy* 69 (June): 216–26. https://doi.org/10.1016/j.enpol.2014.02.022.
Seel, Joachim, Galen Barbose, and Ryan Wiser. 2013. "Why Are Residential PV Prices in Germany so Much Lower than in the United States." *A Scoping Analysis, Presentation, Lawrence Berkeley National Laboratory. Download under Http://Eetd. Lbl. Gov/Node/50173*.
SEIA. 2022. "Solar Power Purchase Agreements." SEIA. 2022. https://www.seia.org/research-resources/solar-power-purchase-agreements.
Sharma, Anjali, and Rangan Banerjee. 2021. "Framework to Analyze the Spatial Distribution of the Labor Impacts of Clean Energy Transitions." *Energy Policy* 150 (March): 112158. https://doi.org/10.1016/j.enpol.2021.112158.
Shea, Ryan, and Russell Mendell. 2021. "Congress Cannot Ignore Residential Solar Tax Credit Inequities." *RMI* (blog). October 14, 2021. https://rmi.org/congress-cannot-ignore-residential-solar-tax-credit-inequities/.
Shoemaker, Mary, and David Ribeiro. 2018. "Through the Local Government Lens: Developing the Energy Efficiency Workforce." American Council for an Energy-Efficient Economy.

Sicotte, Diane M., Kelly A. Joyce, and Arielle Hesse. 2022. "Necessary, Welcome or Dreaded? Insights on Low-Carbon Transitions from Unionized Energy Workers in the United States." *Energy Research & Social Science* 88 (June): 102511. https://doi.org/10.1016/j.erss.2022.102511.

Siqueira, Carlos E. 2016. "Does Informal Employment Exist in the United States and Other Developed Countries?" *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy* 26 (2): 337–39. https://doi.org/10.1177/1048291116650974.

Slick, Jodi Lyn. 2018. "Final Report- Local Energy Matters: Solar Development in Duluth, Minnesota." DOE-Ecolibrium3-6908. Ecolibrium3, Duluth, MN (United States). https://doi.org/10.2172/1436577.

Smith, Brittany L., Michael Woodhouse, David Feldman, and Robert Margolis. 2021. "Towards Decarbonization: Establishing a Sustainable, Equitable, Diverse Workforce in the US Photovoltaic Industry." In , 2632–36. IEEE.

Smith, Caroline K., Barbara A. Silverstein, David K. Bonauto, Darrin Adams, and Z. Joyce Fan. 2010. "Temporary Workers in Washington State." *American Journal of Industrial Medicine* 53 (2): 135–45. https://doi.org/10.1002/ajim.20728.

"Solar Design and Installation Training." n.d. Energy.Gov. Accessed October 21, 2022. https://www.energy.gov/eere/solar/solar-design-and-installation-training.

Solar Energy Technologies Office. 2021. "Summary: Solar Energy Technologies Office Workforce Request for Information and Convenings." DOE/EE-2460, 1859676, 8799. https://doi.org/10.2172/1859676.

Sondermeyer Cooksey, Gail L., Jason A. Wilken, Jennifer McNary, Debra Gilliss, Dennis Shusterman, Barbara L. Materna, and Duc J. Vugia. 2017. "Dust Exposure and Coccidioidomycosis Prevention Among Solar Power Farm Construction Workers in California." *American Journal of Public Health* 107 (8): 1296–1303. https://doi.org/10.2105/AJPH.2017.303820.

Stacy, Christina, Terry-Ann Craigie, Brady Meixell, Graham MacDonald, Sihan Vivian Zheng, and Christopher Davis. 2019. "Too Far from Jobs: Spatial Mismatch and Hourly Workers." Urban Institute. https://www.urban.org/features/too-far-jobs-spatial-mismatch-and-hourly-workers.

State of California. 2022. "Division of Apprenticeship Standards - Minimum Ratios." 2022. https://www.dir.ca.gov/das/RatioExemption.htm.

Steinberg, Daniel, Gian Porro, and Marshall Goldberg. 2012. "Preliminary Analysis of the Jobs and Economic Impacts of Renewable Energy Projects Supported by the.. Section.. 1603 Treasury Grant Program." National Renewable Energy Lab.(NREL), Golden, CO (United States).

The White House. 2021. *Executive Order On Advancing Racial Equity and Support for Underserved Communities Through the Federal Government*. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/20/executive-order-advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government/.

———. 2022a. "FACT SHEET: President Biden Takes Bold Executive Action to Spur Domestic Clean Energy Manufacturing." *Briefing Room* (blog). June 6, 2022. https://www.whitehouse.gov/briefing-room/statements-releases/2022/06/06/fact-sheet-president-biden-takes-bold-executive-action-to-spur-domestic-clean-energy-manufacturing/.

———. 2022b. "FACT SHEET: How the Build Back Better Plan Will Create a Better Future for Young Americans." *Briefing Room* (blog). July 22, 2022. https://www.whitehouse.gov/briefing-room/statements-releases/2021/07/22/fact-sheet-how-the-build-back-better-plan-will-create-a-better-future-for-young-americans/.

———. 2023. "Building A Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action." The White House.

https://www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf.

Thieblot, A. J. 1999. “Prevailing Wage Laws and Black Employment in the Construction Industry.” *Journal of Labor Research* 20 (1): 155–59. https://doi.org/10.1007/s12122-999-1031-9.

———. 2003. “Race and Prevailing Wage Laws in the Construction Industry: Reply to Azari-Rad and Philips.” *Journal of Labor Research* 24 (1): 169–77. https://doi.org/10.1007/s12122-003-1036-8.

Thieblot, A.J. 2016. “The Failure of Arguments Supporting Prevailing Wage Laws and a New Evaluation of the Benefits of Repeal by A. J. THIEBLOT, Ph.D.*.” *Public Service Research Foundation* (blog). November 13, 2016. https://psrf.org/government-union-review-1/2016/11/13/the-failure-of-arguments-supporting-prevailing-wage-laws-and-a-new-evaluation-of-the-benefits-of-repeal-by-a-j-thieblot-phd.

Thieblot, Armand. 2016. “Fraud Prevailing Wage Surveys By: Armand Thieblot, Ph.D.” *Public Service Research Foundation* 18 (November).

Thomason, Sarah. 2018. “The Union Effectin California 2: Gains for Women, Workers of Color, and Immigrants.” UC Berkeley Labor Center. https://laborcenter.berkeley.edu/pdf/2018/Union-Effect-in-California-2.pdf.

Truitt, Sarah, James Elsworth, Juliana Williams, David Keyser, Allison Moe, Julia Sullivan, and Kevin Wu. 2022. “State-Level Employment Projections for Four Clean Energy Technologies in 2025 and 2030.” NREL/TP-5500-81486, 1862660, MainId:82259. https://doi.org/10.2172/1862660.

Turner, Margery Austin, and Karina Fortuny. 2009. “Residential Segregation and Low-Income Working Families.” American Psychological Association. https://doi.org/10.1037/e724112011-001.

UC Berkeley Labor Center. 2011a. “California Workforce Education and Training Needs Assessment For Energy Efficiency, Distributed Generation, and Demand Response: Part 1.” https://laborcenter.berkeley.edu/pdf/2011/WET_Part1.pdf.

———. 2011b. “Part Two: California’s Workforce Education and Training Infrastructure.” https://laborcenter.berkeley.edu/pdf/2011/WET_Part2.pdf.

———. 2018. “Diablo Canyon: A Just Transition for Workers and the Environment.” *UC Berkeley Labor Center* (blog). 2018. https://laborcenter.berkeley.edu/diablo-canyon-just-transition-workers-environment/.

UCLA Institute of the Environment & Sustainability and Dream Corps. 2020. “Facilitating Reentry of Justice-Involved Individuals into the Green Workforce: Case Studies and Best Practices.” https://www.thedreamcorps.org/wp-content/uploads/2020/08/facilitating-reentry-of-justice-involved-individuals-into-the-green-workforce-final-1.pdf.

U.S. Bureau of Labor Statistics. 2021. “Employer-Reported Workplace Injuries and Illnesses (Annual).” https://www.bls.gov/web/osh.supp.toc.htm.

———. 2022. “Union Members - 2021.” U.S. Bureau of Labor Statistics. https://www.bls.gov/news.release/pdf/union2.pdf.

U.S. Department of Energy. 2012. “SunShot Vision Study, Chapter 3: Analysis of PV and CSP Growth in the SunShot Scenario.” https://www.energy.gov/sites/default/files/2014/01/f7/47927_chapter3_0.pdf.

———. 2022a. “Justice40 Initiative Environmental Justice Fact Sheet.” Office of Economic Impact and Diversity. https://www.energy.gov/sites/default/files/2022-07/Environmental%20Justice%20Explainer%207_25_22.pdf.

———. 2022b. “U.S. Energy & Employment Jobs Report (USEER).” DOE/OP-0016. https://www.energy.gov/policy/us-energy-employment-jobs-report-useer.

U.S. Department of Labor. 2015. “Prevailing Wage Resource Book.” https://www.dol.gov/agencies/whd/government-contracts/prevailing-wage-resource-book.
———. 2021. “Registered Apprenticeship National Results Fiscal Year 2021.” September 30, 2021. https://www.dol.gov/agencies/eta/apprenticeship/about/statistics/2021.
———. 2022a. “Good Jobs Principles.” U.S. Department of Labor, U.S. Department of Commerce. https://www.dol.gov/sites/dolgov/files/goodjobs/Good-Jobs-Summit-Principles-Factsheet.pdf.
———. 2022b. “Government Contracts: Wage Surveys.” 2022. https://www.dol.gov/agencies/whd/government-contracts/construction/surveys/status.
———. 2022c. “Fact Sheet #66: The Davis-Bacon and Related Acts (DBRA).” US Wage and Hour Division. https://www.dol.gov/sites/dolgov/files/WHD/legacy/files/whdfs66.pdf.
U.S. Department of Labor (DOL). n.d. “Prevailing Wage Information and Resources |.” Accessed August 20, 2022. https://www.dol.gov/agencies/eta/foreign-labor/wages.
U.S. Department of the Treasury. 2023. “Treasury, Energy Release Guidance on Inflation Reduction Act Programs to Incentivize Investments in Underserved Communities, Hard-Hit Coal Communities.” U.S. Department of the Treasury. January 23, 2023. https://home.treasury.gov/news/press-releases/jy1269.
U.S. DOE. 2021. “US Energy & Employment Jobs Report (USEER).” U.S. DOE. https://www.energy.gov/us-energy-employment-jobs-report-useer.
U.S. DOL. 2022. “Form 5500.” U.S. Department of Labor. 2022. https://www.dol.gov/agencies/ebsa/key-topics/reporting-and-filing/form-5500.
U.S. Solar Energy Technologies Office. 2021. “Summary: Solar Energy Technologies Office Workforce Request for Information and Convenings.” https://www.energy.gov/sites/default/files/2022-03/summary-solar_energy_technologies_office_workforce_rfi_and_convenings.pdf.
———. 2022. “Advancing an Equitable Solar Workforce Webinar.” Virtual, August 16. https://www.energy.gov/sites/default/files/2022-08/Advancing%20and%20Equitable%20Solar%20Workforce%20Webinar%20-%20Slides.pdf.
Vanatta, Max, Michael T. Craig, Bhavesh Rathod, Julian Florez, Isaac Bromley-Dulfano, and Dylan Smith. 2022. “The Costs of Replacing Coal Plant Jobs with Local Instead of Distant Wind and Solar Jobs across the United States.” *IScience* 25 (8): 104817. https://doi.org/10.1016/j.isci.2022.104817.
Voleti, Aditya, and J.R. DeShazo. 2021. “A Community Hire Pipeline Into the LADWP Work Force.” UCLA Luskin Center for Innovation. https://innovation.luskin.ucla.edu/wp-content/uploads/2021/05/A-Community-Hire-Pipeline-Into-the-LADWP-Workforce.pdf.
Wage and Hour Division. 2022. “Dollar Threshold Amount for Contract Coverage.” U.S. Department of Labor. State Labor Laws. January 1, 2022. https://www.dol.gov/agencies/whd/state/prevailing-wages.
Walker, H. A. 2018. “Best Practices for Operation and Maintenance of Photovoltaic and Energy Storage Systems; 3rd Edition.” United States. https://doi.org/10.2172/1489002.
Walker, H, Eric Lockhart, Jal Desai, Kristen Ardani, Geoff Klise, Olga Lavrova, Tom Tansy, Jessie Deot, Bob Fox, and Anil Pochiraju. 2020. “Model of Operation-and-Maintenance Costs for Photovoltaic Systems.” National Renewable Energy Lab.(NREL), Golden, CO (United States).
Warnock, Matt, Dylan Borchers, Kara Herrnstein, and Christopher Furey. n.d. “Qualified Energy Project Tax Abatements for Ohio Solar Projects.” Bricker & Eckler Attorneys At Law. https://www.bricker.com/Documents/Resources/QEP%20_project_white_paper.pdf.

Wei, Max, Shana Patadia, and Daniel M. Kammen. 2010. "Putting Renewables and Energy Efficiency to Work: How Many Jobs Can the Clean Energy Industry Generate in the US?" *Energy Policy* 38 (2): 919–31. https://doi.org/10.1016/j.enpol.2009.10.044.

Western Electrical Contractors Association (WECA). n.d. "Three California Apprenticeship Programs." Accessed February 1, 2023. https://www.goweca.com/Apprenticeship/ThreeCaliforniaApprenticeshipPrograms.aspx.

White Sarah, Dresser Laura, and Joel Rogers. 2010. "Greener Skills: How Credentials Create Value in the Clean Energy Economy." Center on Wisconsin Strategy (COWS). https://cows.org/wp-content/uploads/sites/1368/2020/05/2010-Greener-Skills-How-Credentials-Create-Value-in-the-Clean-Energy-Economy.pdf.

Williams, Juliana, Sarah Truitt, Tony Smith, Jahi Simbai, David Keyser, Elise DeGeorge, Maxwell Brown, et al. 2021. "Energy Jobs - NREL Renewable Energy Workforce Overview." Golden, CO, April 15. Internal.

Winn, Alexander, Devin Boyle, and Josh Christianson. 2022. "Diversifying the Solar Workforce Through Inclusive Apprenticeships." In *Proceedings of the American Solar Energy Society National Conference*, edited by Ashok Kumar Ghosh and Carly Rixham, 286–90. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-08786-8_30.

Wittlich, Marc. 2022. "Criteria for Occupational Health Prevention for Solar UVR Exposed Outdoor Workers-Prevalence, Affected Parties, and Occupational Disease." *Frontiers in Public Health* 9. https://www.frontiersin.org/articles/10.3389/fpubh.2021.772290.

Wood Mackenzie Power & Renewables and SEIA. 2021. "Solar Market Insight Report 2020 Year in Review." SEIA, Wood Mackenzie Power & Renewables. https://www.seia.org/research-resources/solar-market-insight-report-2020-year-review.

Wood Mackenzie, and SEIA. 2022. "US Solar Market Insight Q3 2022." Solar Energy Industries Association.

Zabin, Carol, Abigail Martin, Rachel Morello-Frosch, Manuel Pastor, and Jim Sadd. 2016. "Advancing Equity in California Climate Policy: A New Social Contract for Low-Carbon Transition." Center for Labor Research and Education, University of California Berkeley. https://laborcenter.berkeley.edu/advancing-equity/.

Zabin, Carol, and Sam Appel. 2019. "Truck Driver Misclassification: Climate, Labor, and Environmental Justice Impacts." UC Berkeley Labor Center. https://laborcenter.berkeley.edu/truck-driver-misclassification/.

Zabin, Carol, and Mijin Cha. 2020. "Putting California on the High Road: A Jobs and Climate Action Plan for 2030, Chapter 4: Just Transition: Tools for Protecting Workers and Their Communities at Risk of Displacement Due to Climate Policy," June, 29.

Zabin, Carol, and Jenifer MacGillvary. 2020. "Putting California on the High Road: A Jobs and Climate Action Plan for 2030, Chapter 2: Demand-Side Workforce Policy Levers." https://laborcenter.berkeley.edu/wp-content/uploads/2020/08/Chapter-2-Demand-Side-Workforce-Policy-Levers-Putting-California-on-the-High-Road.pdf.

Appendix

A.1 Definitions

Solar Jobs: A solar worker is defined as anyone who spends 50% or more of their time working on solar related activities (U.S. Department of Energy 2022b). This study specifically focuses on solar PV installation.

Solar Photovoltaic (PV) Installers: Solar photovoltaic (PV) installers assemble, set up, and maintain rooftop or other systems that convert sunlight into energy (BLS 2022).

Good Jobs: A term that is widely used in the jobs and labor field, especially in the context of a just energy future. There are many ways good jobs are defined, with many definitions highlighting the characteristics of a good job. This document uses the following definition: jobs that provide adequate wages and benefits, consistently safe working conditions, transparent growth opportunities, and a sense of belonging to all workers.

Labor Factors or Labor Aspects: For this study, we use this to mean any variable that could influence the characteristics, experiences, or cost of solar PV labor; examples include project type, location, prevailing wage policies, trade, contract type, etc.

Energy Justice: The goal of energy justice is to achieve equity in both the social and economic participation in the energy system, while also remediating social, economic, and health burdens on those historically harmed by the energy system (Baker, DeVar, and Prakash 2019). Similarly, the Department of Energy defines environmental justice as the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation and enforcement of environmental laws, regulations, and policies (U.S. Department of Energy 2022a).

Equity: Equity refers to achieved results where advantage and disadvantage are not distributed based on social identities. Strategies that produce equity must be targeted to address the unequal needs, conditions, and positions of people and communities that are created by institutional and structural barriers (Baker, DeVar, and Prakash 2019)

Workforce Development: Workforce development is the coordination of public and private sector policies and programs that provide individuals with the opportunity for a sustainable livelihood and help organizations achieve exemplary goals, consistent with the societal context (R. L. Jacobs & Hawley 2009). Workforce development activities are typically structured around (1) preparing individuals to enter or reenter the workforce (such as through certification programs or traditional education institutions), (2) providing learning opportunities to improve workplace performance (such as internships or on-the-job training), (3) responding to changes that affect workforce effectiveness (such as providing flexible work options during a pandemic), and (4) supporting individuals undergoing life transitions related to workforce participation (such as provision of adult education services) (R. L. Jacobs & Hawley 2009).

Developers: Developers in this paper describe people or organizations that are responsible for all aspects of solar energy project development, as defined by the Interstate Renewable Energy Council (IREC). Developers are also, in this context, those responsible for hiring and employing solar PV installers and labor for the project.