energies

Article

Cross-Cultural Study on OSH Risk Perception of Solar PV Workers of Saudi Arabia and India: Risk Mitigation through PtD

Abhijit Sen [1], Abdulrahman Khamaj [2], Majed Moosa [2] and Sougata Karmakar [1,*]

[1] Department of Design, Indian Institute of Technology (IIT) Guwahati, Guwahati 781039, Assam, India
[2] Department of Industrial Engineering, College of Engineering, Jazan University, Jazan 45142, Saudi Arabia
* Correspondence: karmakar.sougata@gmail.com; Tel.: +91-0361-2582464

Abstract: A large number of workers are entering the rapidly growing solar photovoltaic industry. The emerging occupational safety and health risks faced by the workers have rarely been measured and aptly addressed. Moreover, there is a lack of cross-cultural studies on solar photovoltaic workers engaged across different countries. This study was planned to measure the occupational safety and health risks, socio-demographic parameters, study the cross-cultural aspects and develop design concepts for risk mitigation. Field studies were conducted in solar installations in Saudi Arabia and India. Socio-demographic data and risk perception scores for eighteen different occupational safety and health risks were obtained from the workers (n = 135). In addition, discomfort glare was also measured. Design concepts were developed following the hierarchy of controls matrix and the bow-tie analysis method using the prevention through design approach. Heat stress, electrocution, solar radiation, and fire/electric flash were found in the high and very high risk categories. This is a first-of-its-kind cross-cultural study in the solar photovoltaic industry which measures the occupational safety and health risks and develops design concepts for mitigation of risks. This study will be beneficial to solar project developers, safety professionals, ergonomists, industrial designers and policy makers.

Keywords: solar photovoltaics; occupational health and safety; design; sustainable development goals; renewable energy

check for updates

Citation: Sen, A.; Khamaj, A.; Moosa, M.; Karmakar, S. Cross-Cultural Study on OSH Risk Perception of Solar PV Workers of Saudi Arabia and India: Risk Mitigation through PtD. *Energies* **2022**, *15*, 9614. https://doi.org/10.3390/en15249614

Academic Editors: Nallapaneni Manoj Kumar and Sofiane Kichou

Received: 11 November 2022
Accepted: 15 December 2022
Published: 18 December 2022

1. Introduction

Climate action and the transition to clean energy sources are global priorities. At the COP26, held in Glasgow in 2021, 197 countries rededicated themselves to a larger adoption of clean energy towards a decarbonized world [1]. Although the technology for harnessing the power of the Sun for generating electricity was developed several decades ago, it is only in the last decade that solar photovoltaic projects have seen an exponential growth. This is indicated by the global growth of solar PV installed capacity from 4 GW in 2010 to 709 GW in 2020 [2]. This growth has stimulated a steady rise in employment of a large number of workers who are engaged in manufacturing, transportation, installation, maintenance, decommissioning and recycling. A study projects that approximately 20 million jobs will be created by 2050 in the solar PV industry [2] in different types of solar PV projects including rooftop, ground-mounted and floating solar.

Utility-scale solar PV projects are new and emerging workplaces. New workplaces and work procedures in the renewable energy industry bring new kinds of occupational safety and health (OSH) risks [3]. Previous studies have reported the diverse OSH risk factors for workers engaged in the solar PV industry [4–6]. These risk factors include ergonomics risks, electrocution, fire, psychosocial factors, inclement weather, harmful materials, heat stress, unstable working platform and skills gaps. Figure 1 shows workers engaged in the installation of a solar photovoltaic project, where one of the workers is seen falling due to an unstable working platform, which is an occupational risk factor.

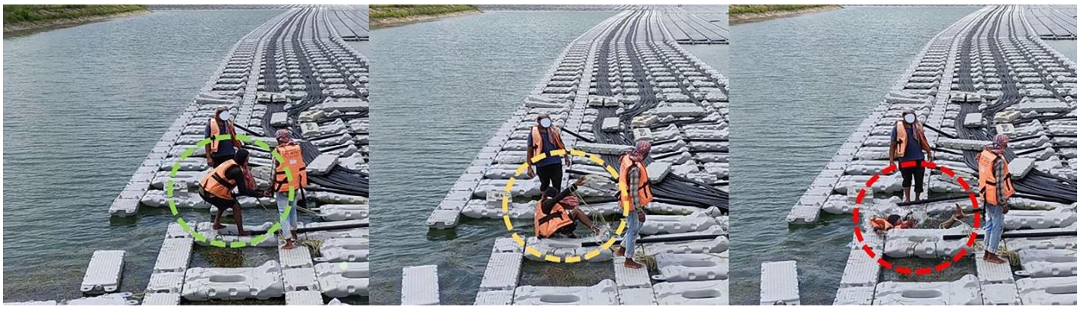

Figure 1. A worker is seen falling (marked in circles) due to an unstable working platform during installation of a solar photovoltaic project in India (image source: authors).

Although several of the OSH risks have been identified, the perception of solar PV workers towards these risk factors and its measurement have rarely been explored. The perceived scores will allow the prioritization of OSH risks and adoption of appropriate mitigation measures. Risk perceptions are subjective opinions about the possible occurrences of negative outcomes. The perceptions consist of both emotional and cognitive dimensions [7]. A study of the perceptions is critical to understanding the presence and degree of workplace risks.

Unaddressed OSH risks can have severe consequences. According to the International Labour Organization [8], approximately 2.3 million people die annually due to work-associated accidents and ailments. In the United Kingdom alone, 1.7 million workers were suffering from work-related ill health in 2020/21 [9]. OSH risks and their manifestations can lead to both direct, indirect and intangible costs. A study of the economic burden of workplace injuries in five countries in the European Union (EU) found the total cost of injuries ranging between 2.9% and 10.2% of the gross domestic product [10]. Therefore, addressing the risk factors is an important precondition for the sustainable growth of the industry. In addition to understanding the risk perceptions, it would be worthwhile to explore the socio-demographic profiles of this emerging workforce. Socio-demographic and work organization factors are known to have relationships with OSH risk factors. Studies have established relationships between individual/personal factors (such as age, gender and health) with propensity of risk [11], between work organization and work-related musculoskeletal disorders [12] as well as between national income and fatal accidents at work [13]. The data on socio-demographic factors have implications for design of work and equipment, selection and deployment of workers, safety and health measures, compensation policies and identification of training needs.

A large number of workers are engaged in installing solar photovoltaic projects across various countries. Understanding the cross-cultural aspects (beliefs, values, customs, etc.), especially in terms of how workers cope with OSH risks and variations associated with their behavioral patterns and risk perceptions, is important for developing country- and population-specific interventions. Psychological, anthropometric, physiological, dialect and national customs/practices should be important considerations in designing solutions, particularly from an ergonomics perspective [14]. For instance, how workers adapt to different climatic environments across countries can result in the requirement of different types of personal protective equipment (material, size, shape, color, etc.) for the same occupational risk. There may also be incompatibilities between the knowhow and cognitive abilities of the user, which vary from culture to culture, and the working requirements [15]. A study has shown cross-cultural differences in several parameters across five countries (divided into low and high income) while studying traffic-related risks, behavior of drivers and attitudes [16]. The mediation of cultural aspects between the user and system has been described under the domain of cultural ergonomics [17].

Cultural beliefs and societal norms may also be associated with acceptability of interventions. For example, use of a certain design of clothing at work (for improving worker safety) may require changes from country to country. The same approach may be required while designing workplace facilities, safety signages and medium and/or mode of training to include social and cultural needs at the workplace. There is little or no study towards understanding these cross-cultural dimensions in the solar photovoltaic industry, especially from an OSH perspective. This paper is an attempt to bridge this research gap and attract attention towards these aspects.

Risk Mitigation Using the PtD Approach

Among many approaches for mitigation of occupational risks, prevention through design (PtD) is being practiced in many industries and sectors. "Designing out risks" is the core philosophy of the PtD approach [18]. The approach is closely linked to the hierarchy of controls approach which considers all dimensions for ensuring safety at work [19]. These include personal protective equipment (PPE), administrative controls, engineering controls, substitution and elimination. Design for preventing unsafe situations can influence all these aspects; however, elimination is the most desired situation. The benefits of applying PtD include reduced costs of operation, reduced risks, higher productivity and avoidance of costly retrofitting [20]. The link between design and safety issues has been established in previous studies. In a study conducted in Australia for 210 workplace-related deaths between the years 2000 and 2002, design aspects were found to be a significant contributor for as many as 77 deaths [21]. For an organization in the US aviation industry, it was found that ergonomics factors (which can be addressed through design interventions) were responsible for 86% of the occupational injuries [22]. Successful PtD interventions have been reported in several industries in the US, resulting in safer workplaces [23]. The approaches included containment of harmful chemicals, replacing manual work with automation and implementing engineering controls. Application of PtD to address health effects in asphalt roofing resulted in several design solutions related to materials, tools and equipment [24]. A study on the identification of hazards in the construction industry reported that two-thirds of the hazards can be noticed at the design phase itself. The study also reports that the success of this approach will depend on the degree of skill of the designers to understand the hazards at the design stage [25]. With the emergence of renewable energy industries, the PtD approach is also being adopted for solar photovoltaic installations. The only study till date in the solar photovoltaic industry adopting a PtD approach is in roof-top solar installations [26]. The study identified several PtD attributes for enhancing safety in small-scale rooftop solar projects in the US. In addition, accidents in the solar installations were also investigated and analyzed to develop a protocol using the PtD philosophy for use by small businesses for greater sustainability. The protocol was also validated through feedback from contractors implementing solar installations. Although the outcome of the study is useful for rooftop solar installations, the findings may not be applicable for other kinds of solar installations such as ground-mounted and floating solar PV (FSPV) installations since the OSH context is different. This establishes the need to develop a PtD framework for solar installations as a whole.

Existing literature was explored to find studies that have examined aspects related to solar PV workers, i.e., socio-demographic factors, cross-cultural aspects and OSH risk measurement. No such study was found in the solar PV industry, indicating the need for immediate attention and need to identify the degree of OSH risks and its prioritization for targeted interventions.

In this backdrop, this study has been planned to address a knowledge gap existing in the solar PV industry. The outcomes will assist stakeholders in designing and developing mitigation measures for the safety and health of solar PV workers.

This study has the following objectives:

1. To obtain the socio-demographic data and OSH risk perception scores of solar PV workers of Saudi Arabia and India,

2. To compare the findings across various parameters between the two countries,
3. To examine relationships and associations between different socio-demographic variables and cross-cultural aspects in relation to OSH risk perception scores, and
4. To develop design concepts using the PtD approach.

2. Materials and Methods

Solar PV projects across two countries, i.e., Saudi Arabia and India, were selected for this study. While Saudi Arabia plans to generate 50% of its energy from renewable sources of energy by 2030 [27], India has targeted installing 500 GW of renewables by the same time, which is 50% of the total installed capacity [28]. Both countries are signatories to the Paris Agreement of 2015. Figure 2 shows the year-wise (2012 to 2021) percentage (%) of solar PV capacity out of the total installed capacity from all electricity generation sources in Saudi Arabia and India and forecast for the year 2030.

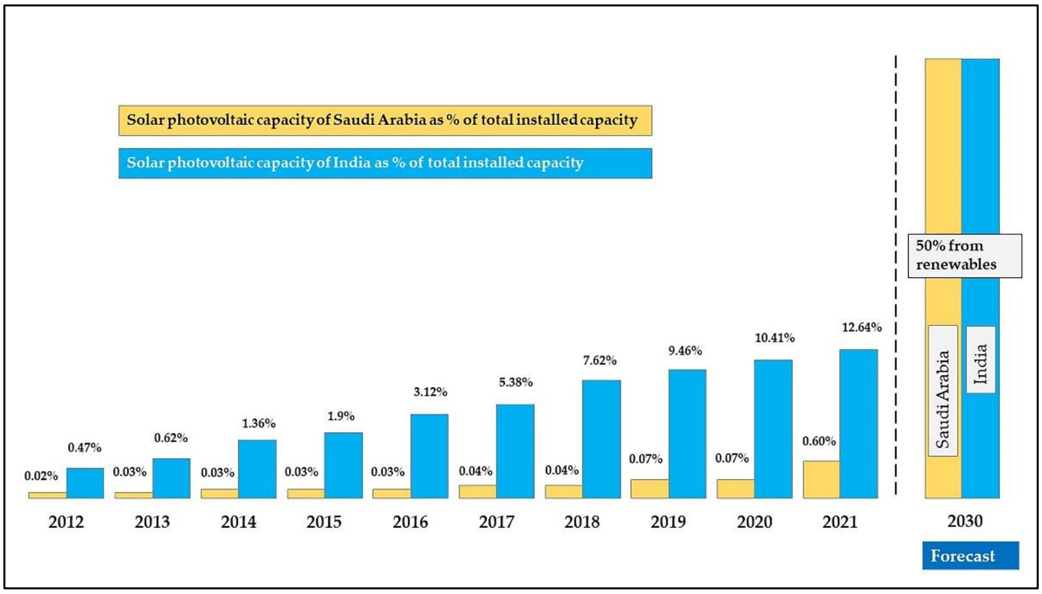

Figure 2. Percentage of solar photovoltaic capacity as a part of total installed capacity from all electricity generation sources in Saudi Arabia and India during the period 2012–2021 and forecast for 2030 (author compilation).

This study was conducted during the period February–April 2021 in India and during December 2021 to February 2022 in Saudi Arabia. In Saudi Arabia, data were collected from one site; and in India, data were collected from two project sites. Prior permission was obtained from project developers for the site visits and for conducting data collection involving human subjects. A purposive sampling technique was adopted in the present study. Workers in both the countries were invited for voluntary participation. All subjects gave their informed consent for inclusion before they participated. This study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Institute Human Ethics Committee, Indian Institute of Technology (IIT) Guwahati prior to collection of data/information. A total of 82 workers in Saudi Arabia and 53 workers in India agreed to be a part of this study.

2.1. Development of Questionnaires for Measuring OSH Risk Perception and Collection of Socio-Demographic Data

A questionnaire was developed to measure the OSH risk perception in solar projects. The questionnaire consists of a five-point Likert scale (on a scale ranging from very low risk to very high risk) consisting of eighteen different OSH risks. OSH risks were obtained from existing studies in the solar photovoltaic industry [4–6]. The five choices are presented as a visual scale consisting of emoticons to measure the risk perception towards the various risks. Figure 3 shows one construct of the visual questionnaire. The visual questionnaire was tested for validity across two locations and reliability was ascertained through a pilot study amongst solar PV workers (n = 10). The value of Cronbach's alpha was found to be above the acceptable limit of 0.70 [29].

Figure 3. An extract of the visual questionnaire showing an OSH risk for obtaining risk perception scores.

The responses obtained using the visual questionnaire was converted into quantitative scores for statistical analysis, where (a) very low risk=1, (b) low risk = 2, (c) medium risk = 3, (d) high risk= 4 and (e) very high risk = 5. Since workers are engaged in outdoor work for a significant period, they are exposed to sunlight. Apart from solar radiation, sunlight is also a source of glare that causes discomfort in vision for the workers. de Boer's subjective rating scale [30] was used to elicit responses from the workers to understand the severity of the discomfort glare.

Another questionnaire was developed to obtain information on socio-demographic parameters such as age, gender, weight, height, income, skill level, background, education level, working hours and work experience. In addition to data collection through questionnaires, photographs were taken of workers engaged at the sites. At the end of data collection, statistical analysis was carried out using SPSS v.20 to understand the relationships between the different sets of data.

2.2. Development of Hierarchy of Controls and Design Concepts

After collection of the OSH risk perception scores, a matrix of hierarchy of controls [31,32] was constructed to explore risk mitigation opportunities. The matrix was developed for those risks which have a mean risk perception score of 4 or more, i.e., in the high- and very high-risk categories. Subsequently, some design solutions were developed for the solar PV industry following the PtD approach. Existing literature was evaluated to consider only those designs that were novel and in accordance with research gaps pertaining to the solar PV industry. Designs were created using the Google Sketchup software (version 22).

3. Results

This section summarizes the findings of the present study under various headings. The proposed design concepts developed to mitigate the risks and their potential benefits are also described.

3.1. Overview of the Study Locations and Socio-Demographic Profiles

An overview of solar photovoltaic projects considered for the present study is given in Table 1. The solar radiation and power output at the solar PV site in Saudi Arabia is higher as compared to the solar photovoltaic sites in India.

Table 1. Overview of the locations considered for this study.

Parameters	India		Saudi Arabia
Region	Site 1—Mejia (West Bengal State)	Site 2—Simhadri (Andhra Pradesh State)	Sakaka City, Al Jawf Province
Number of workers engaged	30	23	82
Direct normal irradiation (DNI) *	1187 kWh/m^2 per year	1298 kWh/m^2 per year	2270.03 kWh/m^2 per year
Peak months *	March and April	March and April	March and July
Power output for 1000 kWp *	1.297 GWh per year	1.41 GWh per year	1.89 GWh per year

* Source: Global Solar Atlas. Abbreviations: kWp, kilowatt peak; kWh/m^2, kilowatt hour/meter square; GWh, gigawatt hour.

The socio-demographic parameters of the workers are summarized in Table 2. A total of 135 workers participated in this study. The workers engaged in India were mostly from the local population while those in Saudi Arabia were mostly migrant workers. The working hours were from 10 a.m. to 5 p.m. and no night shift work was involved.

Table 2. Summary of socio-demographic features of the workers.

Demographic Parameter	Saudi Arabia (n = 82)		India (n = 53)	
	Mean	SD	Mean	SD
Age (years)	35.25	8.99	26.69	5.35
Height (cm)	174.46	5.49	169.76	3.94
Weight (kg)	73.04	9.42	63.01	5.67
Monthly income (INR)	8298.78	2825.52	15,362.49	2404.37
Work experience (years)	2.80	1.30	1.37	0.80

Abbreviations: cm, centimeter; kg, kilogram; INR, Indian National Rupees.

3.2. OSH Risk Perception Scores

A summary of the OSH risk perception scores is presented in Table 3. In order to compare the means of two groups (between workers of Saudi Arabia and India) for each OSH risk, independent two-tailed t-tests were carried out. The mean scores for each risk factor (on a scale of five) and comparison are summarized in Table 3. Heat stress was perceived as a strenuous risk factor in both the sample populations and there was no statistical significance at the $p < 0.05$ level, indicating general agreement amongst the workers of the two countries. Other OSH risks in the very high- and high-risk categories include fire/electric flash, electrocution and solar radiation for workers engaged in Saudi Arabia and India. Ergonomics risks, cold stress, hazardous materials, work organization and risk from falling objects were perceived in the medium-risk category for workers in Saudi Arabia. At the Indian sites, workers perceived ergonomics risks, inclement weather, psychosocial factors, work organization and use of power tools in the medium-risk category. There was significant difference in thirteen out the eighteen OSH risks perceived by the solar workers of the two countries (Table 3).

A comparative representation of the mean OSH risk score is shown in Figure 4.

Understanding the association (positive or negative) between the various risk factors and socio-demographic factors would assist in designing interventions for causative risk factors. Pearson's correlation coefficient scores were calculated towards this objective. The scores are presented in Table 4.

Table 3. Summary of the comparison of means between the two groups of workers.

OSH Risk Parameter	Saudi Arabia Mean Score	Saudi Arabia SD	India Mean Score	India SD	t Value	at $p < 0.05$
Heat stress	4.68	0.46	4.73	0.59	−0.57	Not significant
Cold stress	3.66	0.76	1.51	0.58	17.62	Significant
Solar radiation	3.96	0.72	4.20	0.68	−1.94	Not significant
Electrocution	4.46	0.63	4.47	0.91	−0.06	Not significant
Fire/electric flash	4.47	0.61	4.16	1.03	2.15	Significant
Ergonomics risks	3.87	0.82	3.92	0.93	−0.30	Not significant
Hazardous materials	3.78	0.77	1.24	0.61	20.13	Significant
Risk from animals	1	0	1.17	0.75	−2.04	Significant
Unstable platform/slope	1	0	2.64	1.66	−8.94	Significant
Falling objects	3.12	0.71	1.15	0.53	17.30	Significant
Lighting, storms, hail, etc.	2.36	0.88	3.49	1.95	−4.54	Significant
Skills gaps	2.2	0.80	3.5	1.3	−7.40	Significant
Psychosocial factors	2.62	0.81	3.37	0.88	−5.10	Significant
Work organization	3.31	0.96	3.18	0.76	0.81	Not significant
Noise	2.01	0.66	1.19	0.40	8.20	Significant
Use of power tools	1.74	0.71	3.39	0.88	−11.91	Significant
Occupational stress	1.80	0.69	2.94	1.44	−6.12	Significant
Working alone	1.75	0.71	1.33	0.99	2.82	Significant

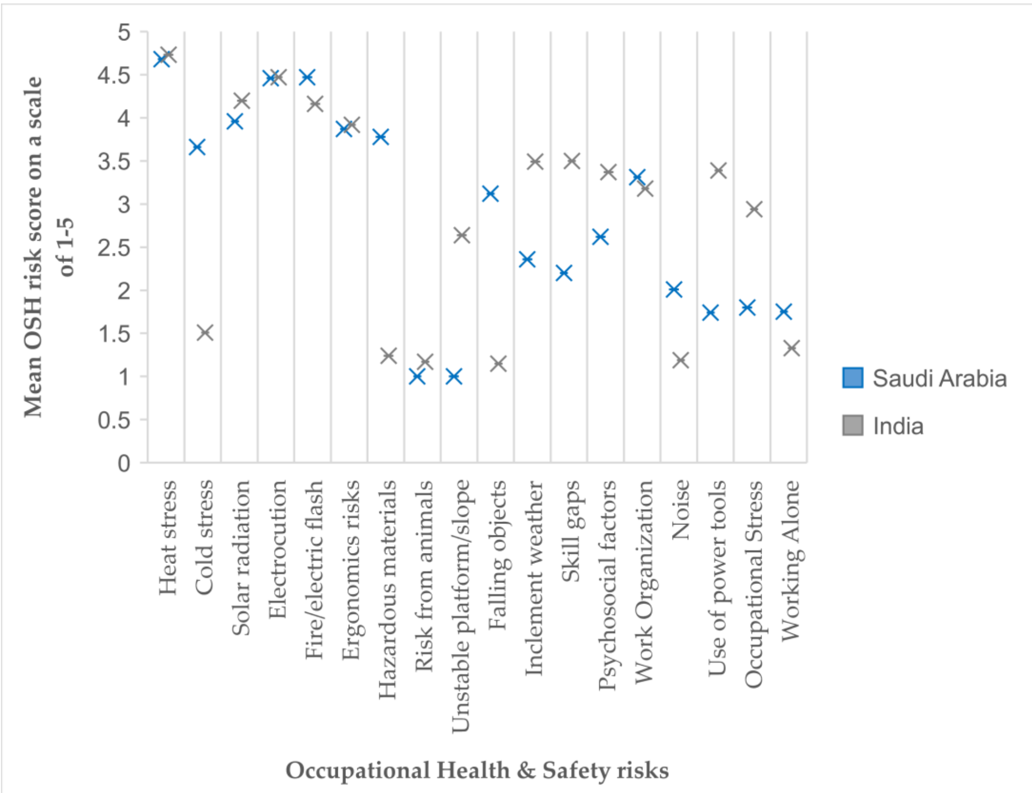

Figure 4. Mean scores for OSH risks for solar PV workers engaged in Saudi Arabia and India. The higher the score, the higher the perceived risk.

Table 4. Correlation between OSH risks and socio-demographic factors for solar PV workers in two countries. Sample size is 53 for Indian workers and 82 for workers in Saudi Arabia, totaling 135 workers. (+ indicates positive correlation, while − indicates negative correlation).

OSH Risk Factor	Age		Height		Weight		Income		Work Experience	
	IND	SA	IND	SA	IND	SA	IND	SA	IND	SA
Heat stress	+	+	+	+	+	+	−	+	−	+
Cold stress	+	−	−	−	+	−	+	−	+	−
Solar radiation	−	−	+	+	+	−	−	−	−	+
Electrocution	−	−	+	−	+	−	−	−	+	+
Fire/electric flash	+	−	+	−	+	−	−	−	+	+
Ergonomics risks	+	+	−	−	+	−	−	+	+	+
Hazardous materials	−	+	+	−	−	−	+	+	−	+
Risk from animals	−	nc	+	nc	−	nc	+	nc	−	nc
Unstable platform/slope	−	nc	+	nc	−	nc	−	nc	−	nc
Falls	−	nc	+	nc	+	nc	−	nc	+	nc
Falling objects	+	+	+	+	+	+	−	+	+	+
Lighting, storms, hail, etc.	+	−	+	+	+	+	−	−	+	−
Skills gaps	+	−	−	+	+	−	−	−	+	+
Psychosocial factors	+	+	−	+	+	+	+	+	+	+
Work organization	+	+	−	−	+	−	+	+	+	+
Noise	+	−	−	−	+	+	−	−	+	−
Use of power tools	+	+	+	+	+	+	−	+	−	+
Occupational stress	+	−	−	+	+	+	+	−	+	−
Working alone	−	+	+	+	−	nc	+	+	−	+

Abbreviations: IND, India; SA, Saudi Arabia; nc, no correlation.

The assessment of discomfort glare is presented in Table 5. Sixty-five percent of the respondents rated glare in the "disturbing" category followed by twenty percent in the "unbearable" category.

Table 5. Responses to the measurement of discomfort glare (n = 135).

Rating Scale	Score	% of Responses
Unbearable	27	20%
Disturbing	88	65%
Just Acceptable	13	10%
Satisfactory	7	5%
Unnoticeable	-	-

3.3. Hierarchy of Controls for OSH Risk Mitigation

A matrix following the hierarchy of controls was constructed to determine the possible opportunities for interventions. The interventions were arranged under the categories of personal protective equipment (PPE), administrative controls, engineering controls, substitution and elimination. The matrix is presented in Figure 5.

OSH risk	PPE	Administrative controls	Engineering controls	Substitution	Elimination
Heat stress	- Reflective and light clothing - Brimmed hat	- Avoid work in the hottest part of the day - Job rotation - Oral rehydration - Heat acclimatization - Buddy system - Reduce work rate - Safety signages	- Climate controlled rest shelter (cool spots) - Canopies	- Mechanization of work	- Cooling vests - Work during early morning & late evening
Electrocution	- Insulated gloves - Insulated mats	- Toolbox training - Permit-to-work system - Lock Out Tag Out	- Accessible multiple emergency switches	- Insulated tools	- Grounding/earthing - Shock/fire proof wires
Solar radiation	- Protective clothing and caps - Anti-glare shields and sunglasses - Sunscreen creams	- Screen workers for symptoms - Monitor health effects of UV radiation	- Anti reflective coating on solar panels to prevent glare	- Design and deployment of prefabricated systems	- Canopy over the installation/working area
Fire/electric flash	- Insulated gloves - Face/eye shield - Fire resistant aprons	- Fire protection system - Allow only trained personnel	- Use of small inverters - Inspection of failure modes - Avoid chimney effect	- Fire resistant materials	- Redesign of wiring system with failsafe features

Figure 5. Hierarchy of controls to mitigate OSH risks under the high- and very high-risk categories (concepts/interventions not exhaustive).

3.4. Bow-Tie Risk Analysis

Electrocution has been found as a significant OSH risk in the present study. A bow–tie analysis was carried out to derive risk mitigation opportunities. Bow-tie analysis belongs to the domain of safety and reliability and has been used in several industries [33]. The bow-tie diagram (Figure 6) looks like a fault tree on the left-hand side and an event tree on the right-hand side. The top event (electrocution) is presented at the center, the threats are mapped at the left side and the consequences are mapped on the right side. A top event can result into many threats, which can lead to many consequences. The analysis is completed with the inclusion of prevention barriers (left side) and mitigation barriers (right side). Design concepts are derived from these barriers. Although bow-tie analysis is predominantly used as a risk analysis method, it can also be used as a tool for developing concepts for hazard control and risk management. Analysis of the top event of "electrocution" is presented in Figure 6.

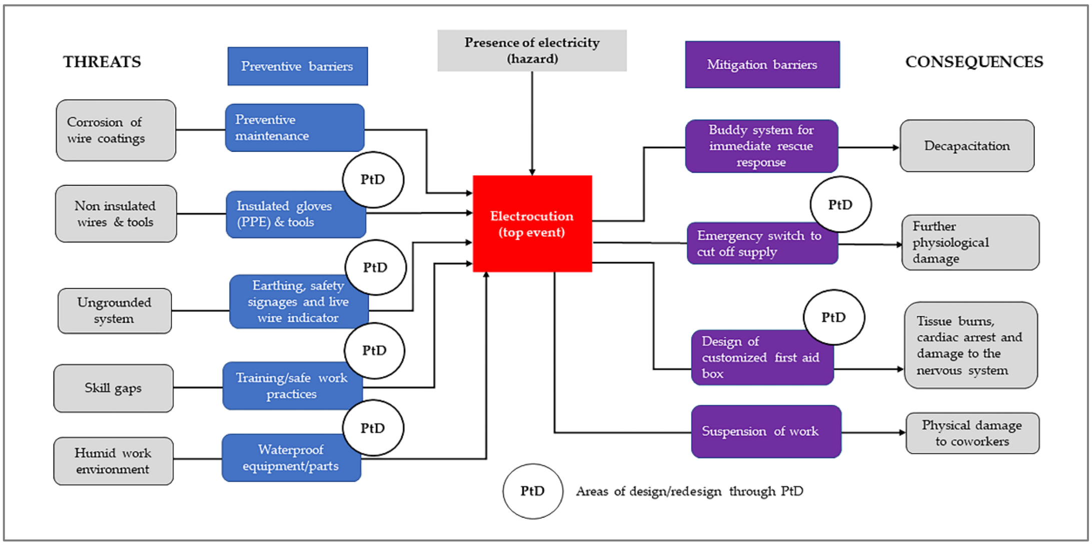

Figure 6. Bow-tie analysis of the top event of "electrocution".

The design opportunities derived from bow-tie analysis of electrocution are the following: Preventive barriers

(a) Insulated gloves and tools,
(b) Live wire indicator,
(c) Earthing,
(d) Safety signage,
(e) Design of training modules, and
(f) Waterproof equipment (for humid environments).

Mitigation barriers

(a) Emergency switch within worker reach, and
(b) Customized first aid box.

3.5. Opportunities for Design Interventions

The different concepts obtained from the matrix in Figure 5 and from the bow-tie analysis in Figure 6 were compared to the available literature in the solar PV industry. A comprehensive review study [6] identified existing design interventions and research gaps/future opportunities to mitigate OSH risks in the solar PV industry, particularly in FSPV projects. A study applied the PtD approach in roof-top solar PV projects [26]. These are the only two available studies to date that proposes design as a tool for mitigating or neutralizing OSH risks. The comparison elicited several unexplored design concepts/interventions under various categories. The design opportunities and their possible applications from an industrial design perspective are summarized in Table 6.

Table 6. Summary of design opportunities (not exhaustive).

Concepts	Design Application and Benefits
Anti-glare eye shield	Protects workers from glare and solar radiation
Rest shelters/canopies	Protects workers from heat stress, solar radiation and inclement weather
Insulated nuts/connectors/wires	Protects workers from electrocution
Safety signages specific to solar photovoltaics	Communicates risks and indicates unsafe locations
Live wire indicators	Visual cue for a charged system which acts as a deterrent from electrocution
First aid box customized	Specific first aid for solar project-related incidents such as electric shocks and heat stroke
Redesign of workplace layout	Mitigate exposure to ergonomics and other OSH risks

Several design concepts have been identified and presented in Table 6. Amongst them, one of the design concept we propose is the anti-glare eye shield to protect the workers from discomfort glare. Glare has also been identified as a significant OSH risk in this study (Table 5). The design concept is shown in Figure 7 which is compared to the existing working situation. The hierarchy of controls matrix and bow-tie analysis (Figures 5 and 6) can be referred for a more holistic intervention approach at various levels [15] and adoption of designs of diverse kinds. Development and application of such interventions will form a part of future work.

Solar PV workers are primarily engaged in long hours of outdoor work under the Sun which exposes them to the OSH risk of discomfort glare. Discomfort glare is caused from three main sources. The first source is the sunlight itself, the second source is the reflection of sunlight from the surface of solar photovoltaic panels and the third source is reflectance from the surface of the water body. The anti-glare eye shield consists of an anti-glare film fixed within a frame integrated with the safety helmet (Figure 7). Although anti-glare safety eyewear is available, they require individual customization in terms of size, shape and ergonomics. Moreover, standard safety eyewear cannot be used by users wearing spectacles which requires an overspec design. Storing safety eyewear is also a limitation in

FSPV projects, where work near water is involved. The proposed adjustable design can be universally used in all kinds of solar photovoltaic projects and in all occupations involving outdoor work.

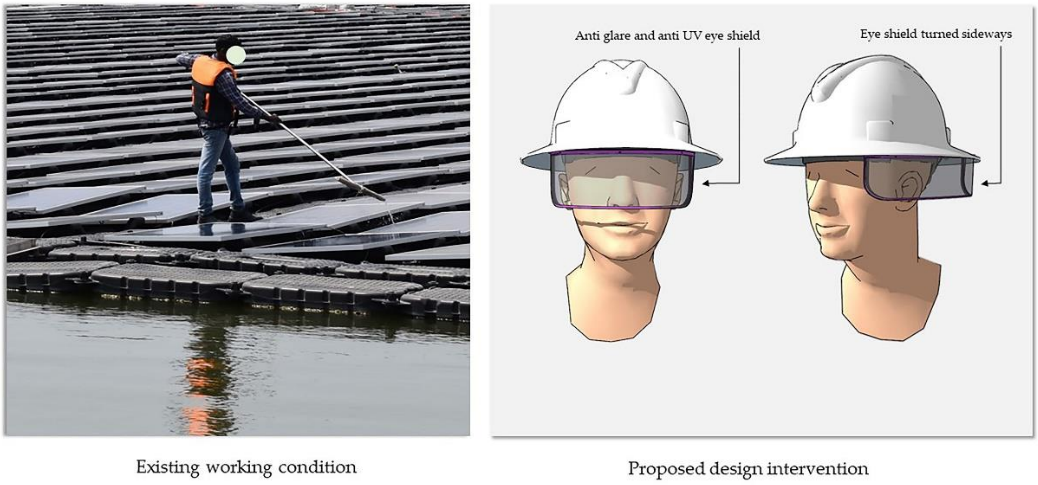

Figure 7. Design of anti-glare eye shield for use in the installation and maintenance of solar photovoltaics projects (image: authors).

4. Discussion

This study was planned to collect and compare OSH risk perception scores from solar PV workers engaged in solar photovoltaics projects across two countries to obtain a cross-cultural perspective, to find interrelationships between different factors and for developing design interventions for risk mitigation. The socio-demographic parameters of the workers show variation in the two countries considered in this study (Table 2). The difference in age, height, weight and income will have implications for deployment of workers, design of tools/equipment and design of compensation patterns. The approach of "fitting the job to the man" to design such interventions can be used for safe and productive work [15].

A statistical analysis of the risk perception scores (Table 3) between the two countries reveals that there is no significant difference in relation to heat stress, solar radiation, electrocution, ergonomics risks and work organization, indicating agreement regarding severity of the risks. Significant differences regarding the remaining thirteen risk factors were found between two countries. These findings have implications for design of interventions in consideration of country-specific needs. Occupational stress, skills gaps, psychosocial factors and use of power tools have been ranked much higher in the risk perception scale by the workers from India as compared to workers in Saudi Arabia. This indicates that the immediate focus should be accorded to stress management, hand, arm and ear protection during use of power tools, and upskilling of workers engaged in India. In addition, psychosocial factors such as job demands, job control, workload, interpersonal relationships, coping style and low support at home are some of the factors that may be considered while designing jobs and workplaces. For workers engaged in Saudi Arabia, protection against cold stress, hazardous materials, PPE for protection from falling objects, noise control at source or provision of ear buds to prevent hearing loss and implementation of a buddy system to address the problem of working alone can be explored.

An analysis of data presented in Table 4 shows that there is a positive correlation between age, height and weight with heat stress and use of power tools for workers engaged in both countries, while there is negative correlation between age and income with electrocution. Before considering deployment of workers to an outdoor work environment, age, height and weight of the workers should be taken into consideration. A study has shown that whole body heat loss reduces with increase in age [34]. According to a report by International Labour Organization, workers lose approximately fifty percent of their work capacity between 33 and 44 °C, which negatively affects labor productivity [35]. Therefore, PPE and administrative controls must be adopted to reduce unproductive work and prevent harm to workers' health. Psychosocial factors and work organization risk factors are positively correlated with income and work experience. Fair compensation, job design, social support, placement of aged workers in low risk jobs and screening of psychosocial hazards can be some of the approaches in solar PV projects. Amongst workers in India, ergonomics risks have a positive association with age, weight and work experience and negative association with height and income. Accordingly, ergonomics assessments and risk management considering the demographic parameters must be an integral part of the safety management practices during the installation and maintenance of solar projects. Since this is a first-of-its-kind study on socio-demographic factors related to solar PV workers, we have no way of corroborating these findings with previous studies.

There are several cross-cultural aspects emerging from the results. There is significant difference (Table 3) between how workers perceive psychosocial risks, cold stress, inclement weather, hazardous materials, occupational stress, working alone and skills gaps in both the countries. For example, cold stress is an area of concern for workers in Saudi Arabia. At the same time, heat stress is also high on the risk perception scale. This may be due to large variations in the microclimate during working hours. Therefore, design of light and reflective clothing (to combat heat stress) for Indian workers will not be suitable for workers in Saudi Arabia. Alternatively, design interventions that strike an optimum balance between neutralizing both heat and cold stress will be beneficial for workers engaged in Saudi Arabia. Even while addressing heat stress, climatic conditions and the ability of the workers to adapt physiologically may vary. This implies that interventions must also consider coping ability, individual factors and acclimatization history related to working under warm environments. Accordingly, different approaches across countries may be adopted for OSH risk mitigation. An important aspect that requires attention is the difference in risk perception of psychosocial factors between the two countries (Table 3). Loneliness, social standing, behavior of co-workers, stressful life events, traumatic occupational incidents, size of project, number of co-workers, etc., can have critical implications during working hours. These factors in relation to migrant workers in Saudi Arabia as compared to local workers in India may vary significantly and can form a part of future work. There is a positive correlation between occupational stress and work experience for workers in India and also a positive correlation between working alone and work experience for workers in Saudi Arabia (Table 4). This indicates that interventions such as screening of workers, health promotion and addressing the causes of workplace stress is recommended for the solar projects in India. Introduction of a buddy system policy to neutralize the OSH risk of "working alone" can be adopted for solar workers in Saudi Arabia. Under this system, a set of two workers can work together in close proximity to monitor each other. This helps in raising an alarm and preventing several unsafe situations. A buddy system also helps in faster rescue and recovery. The factor of work experience is important here since solar projects are new and workers may not be previously exposed to different kinds of projects or work procedures. The association of work experience with different factors can be addressed through comprehensive training, especially in safety aspects, deployment of experienced workers in relatively risky jobs, failsafe design interventions to prevent surprises during work and promoting two-way communication between workers and supervisors. Work organization is also positively correlated with income and work experience in both the countries. This has implications for job design, where consideration of worker skill level, income and work experience should be important priorities. Some work organization-related macroergonomic dimensions worth considering include pace of work, supervision, work rules, job allocation, job enlargement, use of technology, work–rest cycle, job rotation and refreshment facilities. These findings related to cross-cultural dimensions are in conformity with the aspects of cultural ergonomics pointed out by different studies [14–17].

The design of an anti-glare eye shield (Figure 7) is proposed to mitigate the OSH risk of discomfort glare in all kinds of solar projects. Glare has been identified as an underestimated outdoor risk that is closely related to occupational safety and visual performance [36]. Glare can cause severe discomfort while performing work involving dexterity such as connecting wires, attaching panels to frames, comprehending safety signage, communicating with co-workers and during general movement along the solar installation. The risk can lead to falls (as a result of blinding glare), human errors, a decrease in productivity, especially in close work, problems in readability of signage/labels, and both short-term and long-term damage to eyesight.

This study measures the contextual OSH risks and proposes several interventions from a design perspective. Immediate adoption of design opportunities (Figure 5) to address risks in the very high- and high-risk categories should be priorities for the stakeholders in the solar photovoltaic industry. The deleterious cost of injuries, occupational diseases and accidents can have significant implications for worker health, sustainability of the industry and safety practices. We discuss the direct and indirect effects of the OSH risks in very high- and high-risk categories identified in the present study. Unaddressed heat stress can lead to heat stroke, heat syncope, heat cramps, heat edema and rhabdomyolysis at a physiological level. Indirect effects of workers suffering from heat stress-related injuries include stoppage of work, lower productivity, increased health care costs, absenteeism and avoidance of work in hot outdoor environments. A study has positively linked exposure to heat with incidence of work-related injuries [37]. Long-term exposure to solar radiation can affect the skin and the eyes [38]. Electrocution is an invisible risk. Health effects include muscle spasm, burns, unconsciousness, respiratory and cardiac arrest and even death. Electric arc flash and fire (a resultant outcome of arc flash) have similar or even more harmful health effects. Other effects of electrocution incidents and arc flash events include temporary shutdown of the solar photovoltaic plant affecting electricity generation and damage to various components of the installation. Effects of glare include eye pterygium, ocular melanoma, photoconjunctivitis (inflammation of the conjunctiva), photokeratitis, cataracts, and macular degeneration [38,39]. All these alarming direct and indirect negative effects can be avoided by the adoption of design interventions at the earliest. Most of the proposed interventions are low cost and can be implemented quickly.

This study is in pursuance of the Sustainable Development Goals (SDGs) of the UN [40], many of which are intertwined with each other. The SDGs include Goal 3 (good health and well-being), Goal 7 (affordable and clean energy), Goal 8 (decent work and economic growth) and Goal 13 (climate action). Safe, comfortable and productive working conditions are important requirements for the sustainability of the solar PV industry. Accordingly, implementation of design interventions from an OSH perspective is expected to aid in achieving these goals.

Jobs associated with the solar PV industry fall in the category of green jobs. Green jobs not only mean the generation of electricity from renewable energy sources but also signify that such jobs must be safe for the workers engaged in the sector. In pursuance of these objectives, OSH issues need to be considered for design of these jobs to protect the workers wherever human and machine interactions are taking place. The different strategies within the scope of human factors and ergonomics (HFE) can be adopted to achieve sustainable systems [41] in the solar photovoltaic industry. This study is an effort in that direction.

Strength and Limitations

To the best of the authors' knowledge, this is a first-of-its-kind cross-cultural study in the solar photovoltaic industry that surveys the socio-demographic status of the workers. Although previous studies have identified multiple risk factors in the solar industry, measurement of OSH risk perception scores is addressed for the first time. The use of the PtD approach and development of the proposed designs adds to the strength of the present study and to the existing body of knowledge on the safety aspects of solar photovoltaic projects. A limitation of this study is that the proposed designs have not been tested in field trials in actual work environments, which will form part of future studies.

5. Conclusions

Rapid growth in the solar PV industry is expected to increase the size of the solar PV workforce considerably [2]. Solar PV workers, who are mostly engaged in fixed-term employment, are an emerging workforce who are exposed to several types of OSH risks in terms of both severity and vulnerability [42]. The current research is first-of-its-kind study that found varied risk perception responses to the same OSH risks across two different countries, indicating a cross-cultural dimension and also variation in socio-demographic parameters. Such findings are important inputs for achieving designs that are detailed, population specific, context specific, holistic, and robust from an OSH standpoint. Research findings will also enable comfortable and productive use of design interventions by the solar photovoltaic workers in a sustained manner. Therefore, this study bridges a critical knowledge gap and attracts attention towards critical work-related dimensions not explored in the past.

Early adoption of mitigation measures is crucial in preventing both short-term and long-term health effects. "Designing out" of risks is therefore an effective strategy for neutralizing unsafe work, near-miss incidents, injuries, occupational diseases, accidents and even fatalities. By proposing several design concepts, this study is an attempt to attract attention towards the need to adopt design interventions for a safe and sustainable solar photovoltaic industry. The findings would be of interest to health and safety professionals, industrial designers, ergonomists, solar project developers, policy makers and other stakeholders.

Author Contributions: Conceptualization, A.S. and S.K.; methodology, A.S., A.K. and S.K.; data collection, A.S., M.M. and A.K; validation, A.K. and S.K.; formal analysis, A.S. and S.K.; data curation, A.K. and M.M.; writing—original draft preparation, A.S.; writing—review and editing, S.K. and A.K.; supervision, S.K. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded by Abdulrahman Khamaj and Majed Moosa.

Data Availability Statement: Data are available from the corresponding author and can be provided on request.

Acknowledgments: The authors are grateful for the library resources provided by Central Library, IIT Guwahati, Assam, India. The authors also wish to thank the supervisors and project developers of the solar installations for providing necessary permissions and access to the locations considered for this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. The United Nations. COP26: A Snapshot of the Agreement. Available online: https://unric.org/en/cop26-a-snapshot-of-the-agreement/ (accessed on 29 July 2022).
2. IRENA. Future of Solar Photovoltaic: Deployment, Investment, Technology, Grid Integration and Socio-Economic Aspects. 2019. Available online: https://www.irena.org/publications/2019/Nov/Future-of-Solar-Photovoltaic (accessed on 28 July 2022).
3. Sen, A.; Karmakar, S. Exploring the OSH Scenario in Floating Solar PV Projects in India and Opportunities for Ergonomics Design Interventions. *Smart Innov. Syst. Technol.* **2021**, *221*, 245–255. [CrossRef]
4. Bakhiyi, B.; Labrèche, F.; Zayed, J. The Photovoltaic Industry on the Path to a Sustainable Future—Environmental and Occupational Health. Issues. *Environ. Int.* **2014**, *73*, 224–234. [CrossRef] [PubMed]
5. Kamenopoulos, S.N.; Tsoutsos, T. Assessment of the Safe Operation and Maintenance of Photovoltaic Systems. *Energy* **2015**, *93*, 1633–1638. [CrossRef]
6. Sen, A.; Mohankar, A.S.; Khamaj, A.; Karmakar, S. Emerging OSH Issues in Installation and Maintenance of Floating Solar Photovoltaic Projects and Their Link with Sustainable Development Goals. *Risk Manag. Healthc. Policy* **2021**, *14*, 1939–1957. [CrossRef]
7. Paek, H.; Hove, T. Risk Perceptions and Risk Characteristics Risk and Risk Perception: Definitions and Dimensions. *Oxf. Res. Encycl. Commun.* **2017**, 1–15.

8. ILO. The Enormous Burden of Poor Working Conditions. Available online: https://www.ilo.org/moscow/areas-of-work/occupational-safety-and-health/wcms_249278/lang--en/index.htm (accessed on 20 June 2022).
9. Health and Safety Executive. Work-Related Ill Health and Occupational Disease in Great Britain. 2021. Available online: https://www.hse.gov.uk/statistics/causdis/ (accessed on 20 June 2022).
10. Tompa, E.; Mofidi, A.; van den Heuvel, S.; van Bree, T.; Michaelsen, F.; Jung, Y.; Porsch, L.; van Emmerik, M. Economic Burden of Work Injuries and Diseases: A Framework and Application in Five European Union Countries. *BMC Public Health* **2021**, *21*, 49. [CrossRef]
11. Abdalla, S.; Apramian, S.S.; Cantley, F.L.; Cullen, R.M. Injury Prevention and Environmental Health. In *Occupation and Risk for Injuries*, 3rd ed.; Mock, N.C., Nugent, R., Kobusingye, O., Smith, R.K., Eds.; International Bank for Reconstruction and Development/The World Bank: Washington, WA, USA, 2017; pp. 97–132. [CrossRef]
12. Liu, L.; Chen, S.G.; Tang, S.C.; Wang, S.; He, L.H.; Guo, Z.H.; Li, J.Y.; Yu, S.F.; Wang, Z.X. How Work Organization Affects the Prevalence of WMSDs: A Case-Control Study. *Biomed. Environ. Sci.* **2015**, *28*, 627–633. [CrossRef]
13. Kahraman, E.; Akay, O.; Kiliç, A.M. Investigation into the Relationship between Fatal Work Accidents, National Income, and Employment Rate in Developed and Developing Countries. *J. Occup. Health* **2019**, *61*, 213–218. [CrossRef]
14. Chapanis, A. National and Cultural Variables in Ergonomics. *Ergonomics* **1974**, *17*, 153–175. [CrossRef]
15. Bridger, R.S. *Introduction to Human Factors and Ergonomics*, 4th ed.; CRC Press: Boca Raton, FL, USA, 2018; pp. 155–198.
16. Nordfjærn, T.; Jrgensen, S.; Rundmo, T. A Cross-Cultural Comparison of Road Traffic Risk Perceptions, Attitudes towards Traffic Safety and Driver Behaviour. *J. Risk Res.* **2011**, *14*, 657–684. [CrossRef]
17. Kaplan, M. The Culture at Work: Cultural Ergonomics. *Ergonomics* **1995**, *38*, 606–615. [CrossRef]
18. Howard, J. Prevention through Design—Introduction. *J. Saf. Res.* **2008**, *39*, 113. [CrossRef] [PubMed]
19. Schulte, P.A.; Rinehart, R.; Okun, A.; Geraci, C.L.; Heidel, D.S. National Prevention through Design (PtD) Initiative. *J. Saf. Res.* **2008**, *39*, 115–121. [CrossRef] [PubMed]
20. Manuele, F.A. Prevention through Design (PtD): History and Future. *J. Saf. Res.* **2008**, *39*, 127–130. [CrossRef]
21. Driscoll, T.R.; Harrison, J.E.; Bradley, C.; Newson, R.S. The Role of Design Issues in Work-Related Fatal Injury in Australia. *J. Saf. Res.* **2008**, *39*, 209–214. [CrossRef]
22. Eherts, D.M. Lessons Learned from Aviation Safety. *J. Saf. Res.* **2008**, *39*, 141–142. [CrossRef]
23. Ertas, A. Understanding of Transdiscipline and Transdisciplinary Process. *Transdiscipl. J. Eng. Sci.* **2010**, *1*, 48–64. [CrossRef]
24. Young-Corbett, D.E. Prevention through Design: Health Hazards in Asphalt Roofing. *J. Constr. Eng. Manag.* **2014**, *140*, 06014007. [CrossRef]
25. Hallowell, M.R.; Hansen, D. Measuring and Improving Designer Hazard Recognition Skill: Critical Competency to Enable Prevention through Design. *Saf. Sci.* **2016**, *82*, 254–263. [CrossRef]
26. Ho, C.; Lee, H.W.; Gambatese, J.A. Application of Prevention through Design (PtD) to Improve the Safety of Solar Installations on Small Buildings. *Saf. Sci.* **2020**, *125*, 104633. [CrossRef]
27. Lo, J. Saudi Arabia Aims for 50% Renewable Energy by 2030, Backs Huge Tree Planting Initiative. Available online: https://www.climatechangenews.com/2021/03/31/saudi-arabia-aims-50-renewable-energy-2030-backs-huge-tree-planting-initiative/ (accessed on 21 July 2022).
28. Press Trust of India. India Needs $223 Billion to Meet 2030 Renewable Capacity Goals. Available online: https://www.thehindu.com/sci-tech/energy-and-environment/india-needs-223-billion-to-meet-2030-renewable-capacity-goals-report/article65552966.ece (accessed on 29 July 2022).
29. Tavakol, M.; Dennick, R. Making Sense of Cronbach's Alpha. *Int. J. Med. Educ.* **2011**, *2*, 53–55. [CrossRef] [PubMed]
30. Jenkins, D.P.; Baker, L.M.; Harvey, C. A Practical Approach to Glare Assessment for Train Cabs. *Appl. Ergon.* **2015**, *47*, 170–180. [CrossRef] [PubMed]
31. NIOSH. The State of the National Initiative on Prevention through Design. Available online: https://www.cdc.gov/niosh/docs/2014-123/ (accessed on 29 July 2022).
32. Yuan, J.; Li, X.; Xiahou, X.; Tymvios, N.; Zhou, Z.; Li, Q. Accident Prevention through Design (PtD): Integration of Building Information Modeling and PtD Knowledge Base. *Autom. Constr.* **2019**, *102*, 86–104. [CrossRef]
33. Meland, P.H.; Bernsmed, K.; Frøystad, C.; Li, J.; Sindre, G. An Experimental Evaluation of Bow-Tie Analysis for Security. *Inf. Comput. Secur.* **2019**, *27*, 536–561. [CrossRef]
34. McGinn, R.; Poirier, M.P.; Louie, J.C.; Sigal, R.J.; Boulay, P.; Flouris, A.D.; Kenny, G.P. Increasing Age Is a Major Risk Factor for Susceptibility to Heat Stress during Physical Activity. *Appl. Physiol. Nutr. Metab.* **2017**, *42*, 1232–1235. [CrossRef]
35. ILO. Working on a Warmer Planet: The Impact of Heat Stress on Labour Productivity and Decent Work. Available online: https://www.ilo.org/global/publications/books/WCMS_711919/lang--en/index.htm (accessed on 28 August 2022).
36. Sawicki, D.; Wolska, A. Glare at Outdoor Workplaces—An Underestimated Factor of Occupational Risk. *Energies* **2022**, *15*, 472. [CrossRef]
37. Varghese, B.M.; Hansen, A.; Bi, P.; Pisaniello, D. Are Workers at Risk of Occupational Injuries Due to Heat Exposure? A Comprehensive Literature Review. *Saf. Sci.* **2018**, *110*, 380–392. [CrossRef]
38. Modenese, A.; Korpinen, L.; Gobba, F. Solar Radiation Exposure and Outdoor Work: An Underestimated Occupational Risk. *Int. J. Environ. Res. Public Health* **2018**, *15*, 2063. [CrossRef]

39. Wright, C.Y.; Norval, M. Health Risks Associated With Excessive Exposure to Solar Ultraviolet Radiation Among Outdoor Workers in South Africa: An Overview. *Front. Public Health* **2021**, *9*, 14–23. [CrossRef]
40. The United Nations. Do You Know All 17 SDGs? Available online: https://sdgs.un.org/goals (accessed on 31 July 2022).
41. Thatcher, A.; Yeow, P.H.P. Human Factors for a Sustainable Future. *Appl. Ergon.* **2016**, *57*, 1–7. [CrossRef]
42. Sen, A.; Karmakar, S. OSH Risk Perception of Safety Managers and Scope for Ergonomics Design Interventions in Floating Solar Photovoltaic Projects. *Lect. Notes Netw. Syst.* **2022**, *391*, 871–880. [CrossRef]