RECENT INNOVATIONS IN SOLAR ENERGY EDUCATION AND RESEARCH TOWARDS SUSTAINABLE ENERGY DEVELOPMENT

Ramalingam Senthil*
Department of Mechanical Engineering, SRM Institute of Science and Technology
Kattankulathur, Chennai, India, senthilr@srmist.edu.in
https://orcid.org/0000-0001-7570-8351

Article history: Received 1 November 2021, Received in revised form 29 November 2021, Accepted 29 November 2021, Available online 29 November 2021

Highlight

This review focuses on recent developments in solar energy-based research and education and future trends toward sustainable energy development.

Abstract

The essential requirements of our everyday lives are fresh air, pure water, nourishing food, and clean energy in a most sustainable manner. The present review article concisely discusses recent innovations in solar energy education, research, and development toward providing clean and affordable energy and clean water to some extent. This article primarily addresses the Sustainable Development Goal 7 of the United Nations (SDG 7: Affordable and Clean Energy). Over the past few decades, many research activities have been carried out on solar energy conversion and utilization. The deployment of solar energy technologies has been witnessed to combat global warming and the betterment of the planet. Drivers and barriers to implementing solar energy systems from school to master's level through real-time deployments are discussed for further development and innovations. Mainly, expedited solar energy education and research are essential to improve solar energy utilization. The advancements in solar energy education and research towards sustainable energy development and circular economy are highlighted along with further directions required.

Keywords

solar energy; energy education; climate change; research and development; innovations; sustainable development.

Introduction

The environmental impact of fossil fuel burning has been particularly damaging to human, plant, and animal life. It is commendable that the momentum for conserving the rapidly decreasing available fuels and the utilization of renewable energy is on solid footing. Countries are asked to develop ambitious 2030 emission reduction targets to reach net-zero by the middle of the century at the United Nations Climate Change Conference held in London in November 2021 [1]. At this conference, securing global net-zero by mid-century and keeping 1.5 degrees within reach has been primarily targeted. The current pace must be expedited with maximizing renewable energy utilization to reach such a target. SDG 7 deals mainly with affordable and clean energy to combat climate change. Every citizen must be sensitized to the necessity of protecting our environment, sustaining the fast-depleting natural resource, maximizing the energy potential of clean energy sources, and preserving the natural wealth of the planet to be bequeathed to future generations. Implementation of proper energy education and practical research activities can foster advanced energy conversion technologies. The awareness of harnessing clean energy sources for the continued sustainability of the planet is vital and needs to be acted upon promptly. Solar energy is an option that should be given prime importance.

Solar energy from the Sun is unlimited, and this abundant energy can be utilized by us effectively. It is essential to assess the energy needs and apply the required techno-economical skills to ensure that solar energy is tapped and utilized to our energy needs. Solar energy education is essential to achieve energy awareness and energy sustainability [2,3]. Unbridled human activities have resulted in the extinction of several species all over the world. Before it is too late, precautionary measures must be taken to protect the planet and ensure that it is habitable for generations to come. Therefore, sustainability is at the forefront of all developmental activities. In his context, the present review article focuses on solar energy education and research with the recent advancements.

https://doi.org/10.32933/ActaInnovations.42.3 • ISSN 2300-5599 •

Directly and indirectly, 70% of emissions were from households in Netherlands and Spain. Education and structural factors were significant for climate mitigation on the demand side [3]. Job creation is increasing with solar and wind energy deployments. Solar photovoltaic (PV) installations and maintenance are potential areas of job creation across the globe up to 2050 [4]. New renewable energy programs were required to promote Saudi Arabia's renewable energy utilization goals by 2030 [5]. Various education and research activities are necessitated to provide skilled people for wind and solar power deployments and maintenance [6]. Learning-by-doing and research activities were important drivers of impact reduction cost in energy technologies [7]. Energy management in households by insulating houses and implementing measures for solar energy utilization were the driving factors of sustainability [8–10]. Solar PV systems were projected as potential to meet sustainability goals [11–13]. Carbon pricing and low carbon technologies, such as solar technologies, are potential aspects of energy sustainability [14–17].

A survey among school students and teachers exposed energy savings, solar energy, and biomass technologies [18]. Inculcating renewable energy practices in school curricula is required to promote renewable energy sources (RES) and maintain the green campus. Lack of energy policies, financial assistance, and subscription issues was observed as barriers in promoting solar communities [19]. The driving factors were energy sustainability and grid resilience. Building energy management practices are essential to promote clean energy and energy-saving practices [20]. A laboratory-scale solar microgrid system with wireless data monitoring was introduced as a teaching tool in the engineering technology curriculum [21]. It was found that the students learned solar deployment and integration issues through real-time experiments. Off-grid home electrification was promoted, and the importance of all stakeholders was stressed in the deployment and maintenance of photovoltaic systems [22].

Although novel and highly efficient solar cell materials have been demonstrated on a laboratory scale, the availability of such materials, such as gallium, indium, arsenic, bismuth, and selenium, is unsustainable on larger scales [23]. In the terawatt solar PV deployment path, multijunction solar cells were observed as not sustainable till 2030. Material synthesis aspects are to be concentrated to meet 2050 solar PV deployment targets. Material innovations are essential with the roadmap to sustainability and reliability in the long-term energy market. Large-scale batteries and solar-operated battery vehicles were critical requirements for successfully deploying solar PV installations [24,25]. In addition to energy, water and food are the other SDGs that solar energy technologies should partly support. Several researchers have investigated solar desalination technologies to provide potable water [26,27]. Goel et al. [28] indicated that around 85% of the population is expected to live in developing countries by 2030. A smart agriculture concept was essential for food security by interconnecting agriculture, information systems, and energy systems. Bioinspired solar cells are evolving in research to imitate nature to convert solar rays into useful energy. Currently, ongoing research synthesizes organic materials for such bioinspired energy conversion and storage [29].

Various initiatives have been formulated to educate and encourage renewable energy education to provide fundamental knowledge and hands-on experience in a real-time scenario to promote more innovations and patents, especially in solar PV technologies. The institutional innovative teaching methodologies could be closely associated with people to realize the benefits of renewable energy utilization and protection of environmental concerns. Bridging the gap between academic institutions and industries is a critical factor in reaching out to the community in large-scale solar PV installations and steady progress to combat climate change.

Even though several studies on solar energy research are available, a specific focus on innovations in learning and product developments is demanding. This short review provides deep insights into teaching and learning requirements for various solar applications, ranging from solar thermal to electrical systems. Further, the current research and future directions are essential to solar professionals. This review discussed solar utilization in different sections. The introduction section contains the present study’s needs and objectives. The following methods section are mainly dealing with recent developments in solar energy education and research. The discussion section deals with the pros and cons of the study. The impact section narrates how the present study impacts the solar community. Finally, concluding remarks and future scopes are provided in the conclusions section.

Methods

Solar energy utilization is one of the fastest-growing and cost-competitive renewable energy sources worldwide.

The solar energy-based research and education trends are observed using the widely used Scopus database [30] (www.scopus.com). It was assessed on November 12, 2021, based on the search keyword 'solar energy'. The total documents are 1,85,335, including articles, conference articles, review articles, book chapters, conference review articles, and others, as per Figure 1. This section discusses mainly solar and associated other RES that have been promoted in the last decade. Figure 2 shows Scopus-indexed publications based on solar energy research, education, solar energy utilization, and energy conversion. A significant increase in the number of Scopus-indexed publications of articles on all the areas of solar energy and sustainable education has been witnessed in the last decade due to the various global environmental legislations.

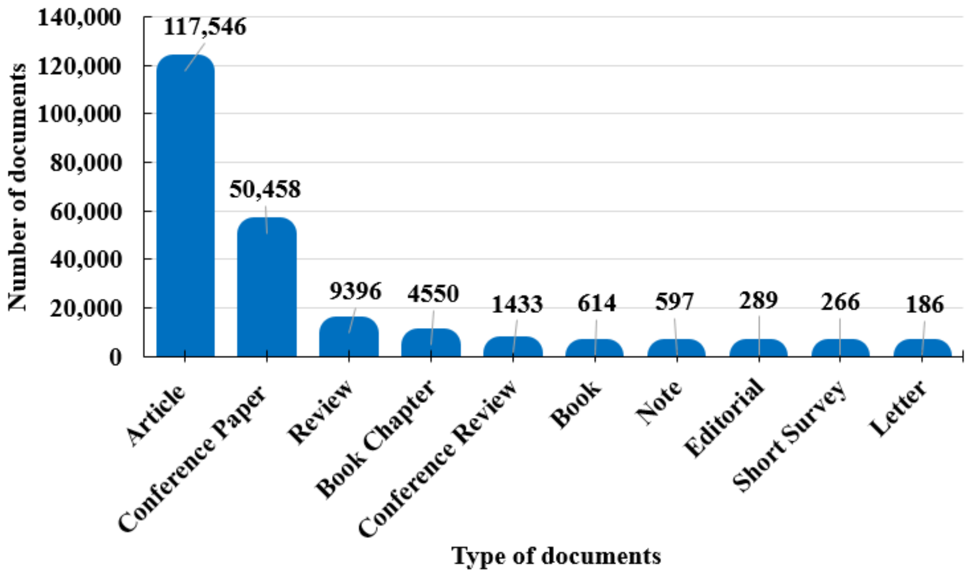

Figure 1. The types of selected documents as per the search keyword "solar energy" on Scopus database 2011 to date (Assessed on 12th November 2021).

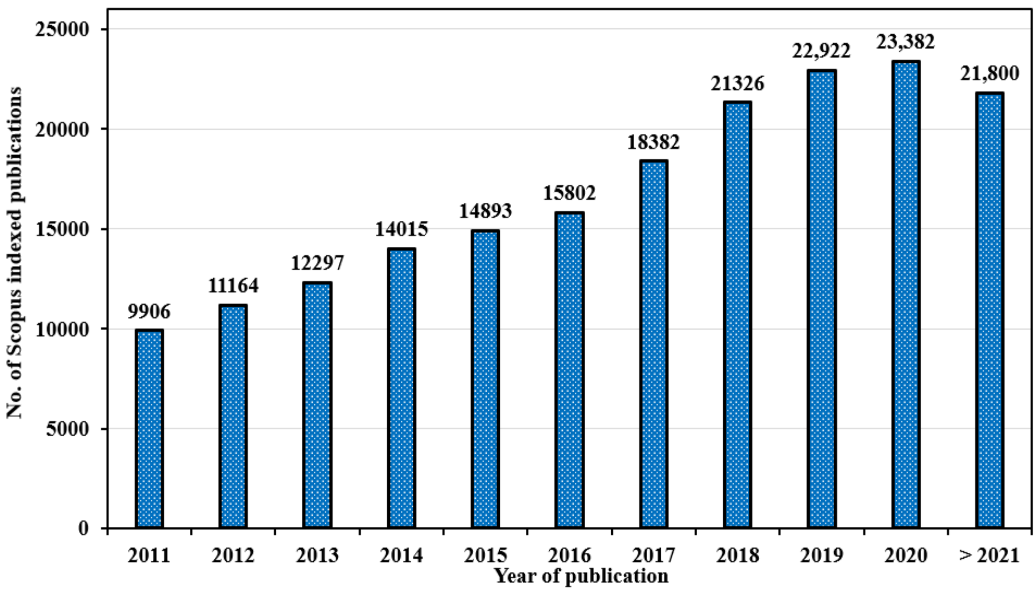

Figure 2. The total number of documents published on solar energy during the recent decade is per the Scopus database.

It has been observed; the article publication statistics have increased gradually; however, from 2017, escalating publications have been observed. This implies that solar energy utilization increased at its best with adequate energy education and related research works in the last three years. Figure 3 illustrates the top ten nations that are excelling in solar-based research publications. China (22%), the United States (18%), and India (11%) were produced almost half of the total documents published in the last decade. In this category, India and Germany were listed in the third and fourth positions, respectively. Almost every country receiving significant solar rays contributes more technologies to society; however, the leading countries are listed here.

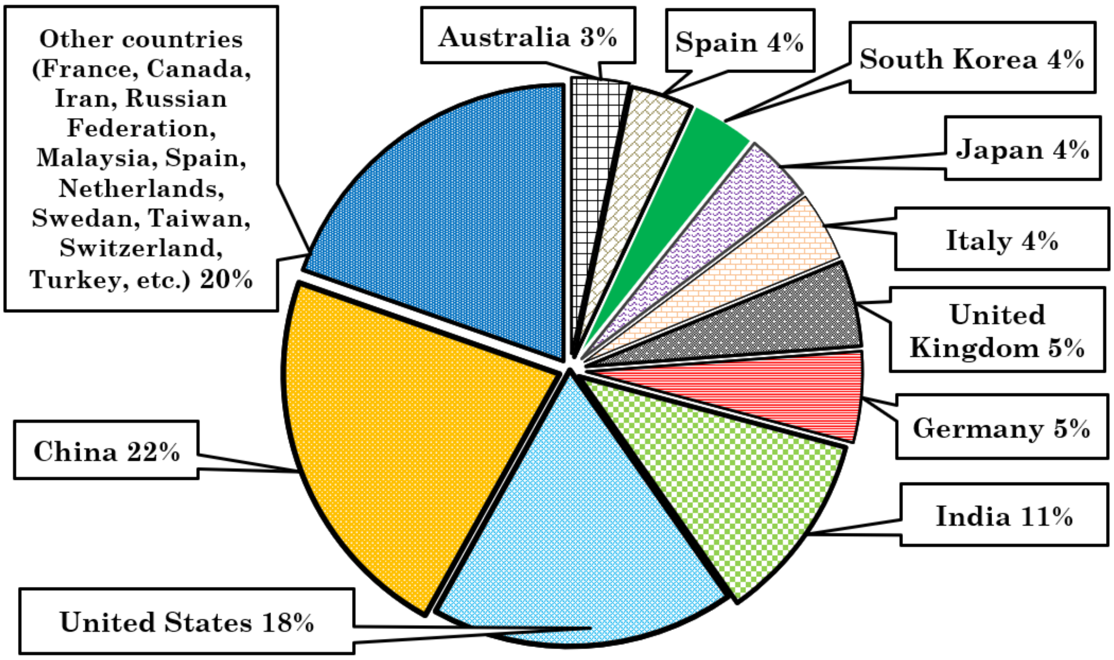

Figure 3. The percentage contribution of leading countries on solar energy research and education. *Source: Scopus indexed publications (2011-2021).*

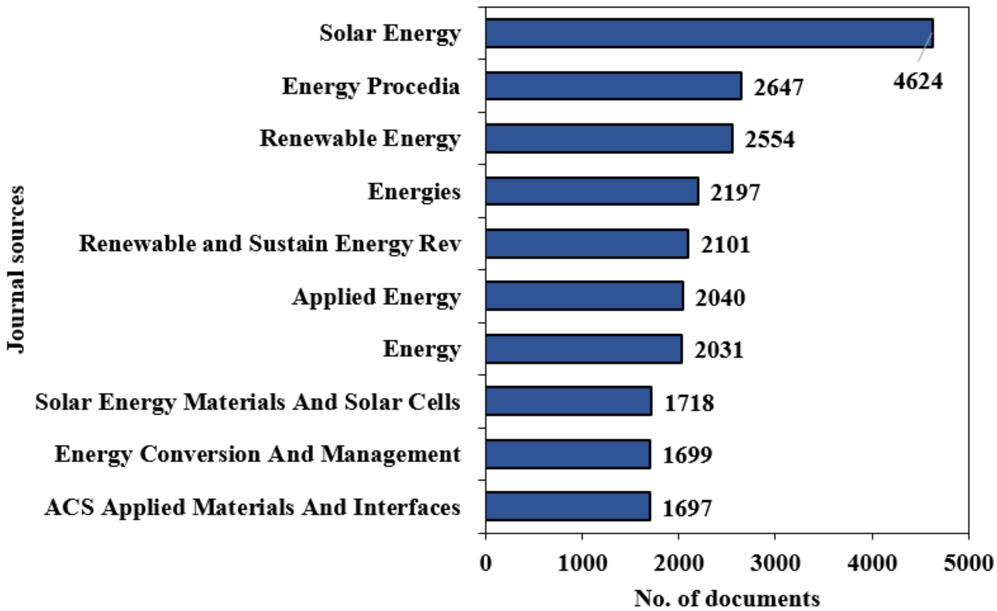

Figure 4. The number of documents published by top ten source titles on solar energy. *Source: Scopus indexed publications (2011-2021).*

The discussion of recently published articles is carried out to give more insight into the prospects of solar energy technologies towards sustainable development. The primary research area in solar energy is solar cell technologies due to their direct conversion of solar rays into electricity. The published articles in the solar cell-based research area are nearly 60% and solar thermal-based research has a share of 40% of the total publications.

In the recent three years, solar cell development has been around 70% of research output in publications. Thus, the statistics of Scopus indexed publications witness the recent development in the solar energy education and utilization aspects. Almost all the top energy journals contribute significantly and promote solar energy research. The various familiar keywords in solar energy are denoted in Figure 5 Solar power generation is the dominant aspect of the use of solar photovoltaics and cells. Although the solar energy market is growing exponentially, several researchers have also sought new solar cell technologies worldwide.

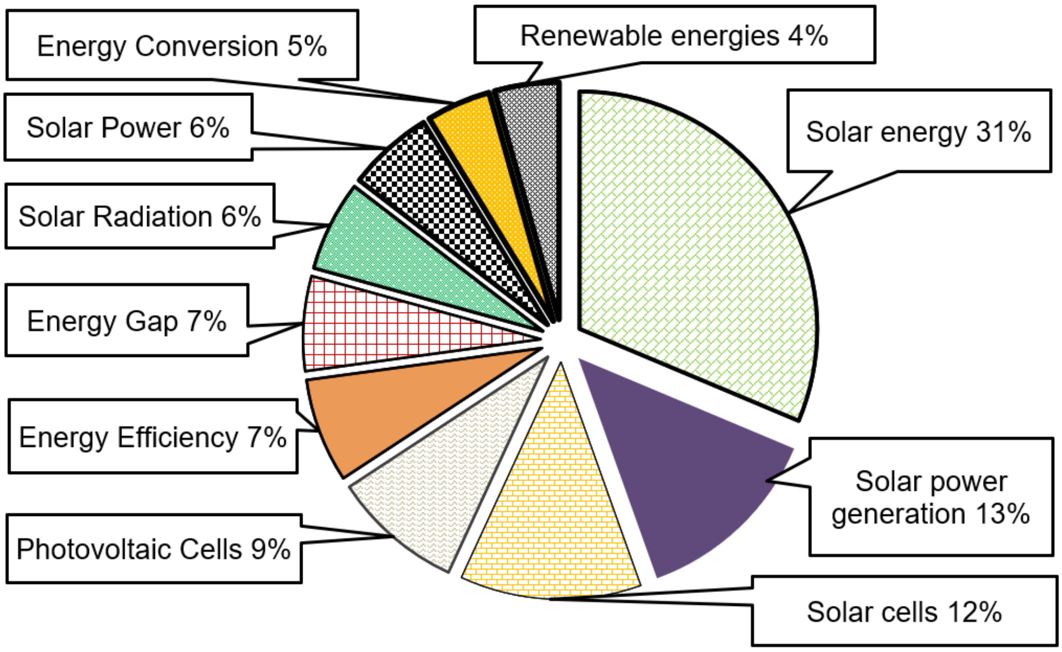

Figure 5. The top ten keywords used by researchers on solar energy. *Source: Scopus indexed publications (2011-2021).*

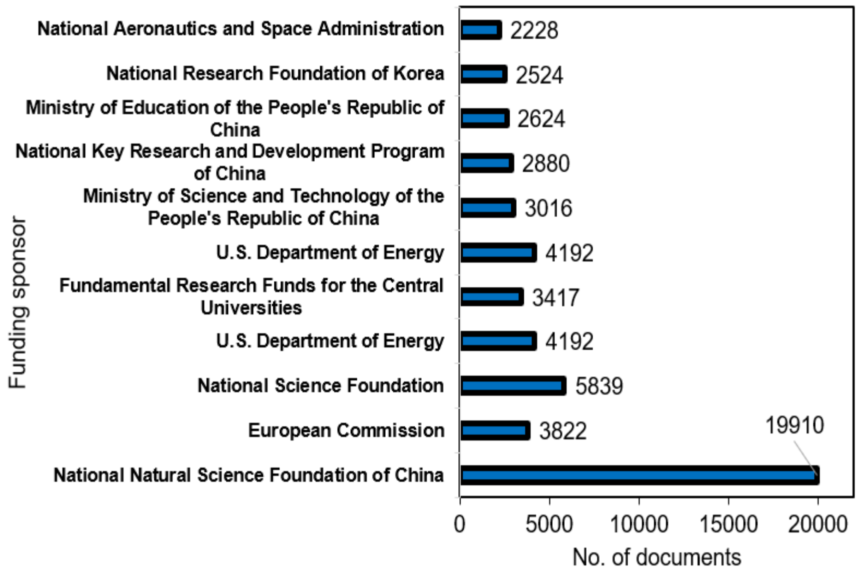

Figure 6. Top ten funding sponsors in solar energy in recent years.

The main findings are that cell efficiency and reliability under the varying solar intensity are investigated for real-time deployments. The leading sponsor in solar energy is shown in Figure 6. The total number of documents published by the sponsors is also shown to understand solar energy researchers better. The funding is an essential aspect to attain carbon-free environments with the help of energy efficiency measures and renewable energy adaptations.

https://doi.org/10.32933/ActaInnovations.42.3 • ISSN 2300-5599 •

Literature on Solar Energy Education.

Renewable energy-related classes, discussions, applied projects, demonstrations, industry interaction, collaborations, laboratory experiments, and programs in higher education institutions (HEI) play an essential role in preparing students for a career in energy-related science, technology, engineering, and mathematics (STEM) fields. Recent innovations in teaching and learning and sustainability are discussed.

- Learning through real-time projects.

A university-level research study was conducted through questionnaire mode on teaching effectiveness and implementation of renewable energy education in Turkey [31]. Only the usual core courses were taught at undergraduate levels. The renewable energy courses were mainly taught only at the master's level. There was an apparent lack of experts in the field of renewable energy and education. The Solar Info Center in Freiburg, Germany, was established to offer many services in renewable energy and energy efficiency [32]. The building features a rational, sustainable, and ecological energy and technology concept. Germany's first energy-certified office building to be 100% emission-free heated with a low energy demand for heating of 26 kWh/m^2. Pasqualetti and Haag discussed the steps considered for meaningful development in solar energy harvesting in the American Southwest [33].

The design, construction and testing of a small solar-powered boat for tourism, with senior class engineering students taking hydrodynamic, energy and economic factors, were discussed by Rivera-Solorio [34]. Students used specialized engineering software tools to explore innovative ideas and new concepts, enhancing their creativity in the context of developing a successful prototype to compete in a solar splash event. The solar energy industry needs professional competence (scientific and technological knowledge) to develop a related engineering education curriculum for green energy [35].

Educational competition influences educational outcomes, and inclusive education is one of the successful measures to meet students' technical and professional ambitions [36]. Most of the students recognized that their knowledge and skills increased with improved experiential learning; they gained valuable conceptual insights and an understanding of technical and multidisciplinary aspects while working on real-time renewable energy projects. Employability indicators were established to capture solar energy enterprises' professional competency requirements and performance standards [37]. The indicators can serve as a basic framework for understanding the critical need for green energy to develop a sound knowledge base. The engineering curriculum covers fundamental concepts and processes to equip students with the necessary skills to design renewable energy systems. Professional knowledge, technical competence, efficient job performance, positive working attitude, career readiness, and perceived employability were essential factors that had a bearing on recruitment and employment by the solar industry.

There continues to be accelerated technological progress in the renewable energy field. Greater dissemination of knowledge of different forms of green energy and public awareness of RES could help popularize the same [38]. The noted factors such as gender, age, education level of family members, and eco-friendly behavior due to occupation influence greater social acceptance of new technologies, change attitudes towards renewable energy initiatives and increase environmental consciousness. The impact of contemporary technology classes, a new online learning platform, video-based e-learning of solar photovoltaic concepts [39] was investigated. The short interactive and informative videos facilitated 'learning by seeing'. They were broadcast through a popular online video channel containing more images, graphics, animations, and less textual content. Feedback obtained from students revealed that the e-learning was informative and educative and supported effective learning of important theoretical concepts. The various dimensions of the e-learning process were explored for gaining knowledge about breakthroughs in energy technologies [40]. Thus, the students explored various aspects of deploying new energy technologies, learning much about the practical aspects such as installation cost, utility-scale renewable energy.

There was a strong correlation between the integration of the study and the associated applications to make solar energy affordable for the masses [41]. Renewable energy applications must be given importance during the minor and major research or design projects and professional curriculum development and dissemination to offer creative technology education to the upcoming generation.

Technical innovation has resulted in intelligent grid systems, prompting to upgrade of the energy engineering curriculum in Jordanian universities to provide more excellent technical knowledge and a better understanding of such systems. Furthermore, equipping engineering students with the required workplace skills in terms of solar and wind power technologies improves employability in the energy sectors [42]. State-of-art laboratories were set up in a bid to offer a comprehensive degree program on smart grids. Identifying the local aspects of the technological learning process for the deployment of new renewable energy technologies was discussed [43]. The local context is essential as technology is deployed regionally using locally available energy resources, local governance, and local talent in selecting, designing, fabricating, installing, and operating energy systems. The study focused on the empirical evidence of learning processes in PV deployment. The implications of government policy must acknowledge the importance of local aspects of technological learning for deploying new energy technologies. The working of solar photovoltaic systems and the maximum power point tracking role in improving power output were taught using soft tools [44].

Time- and incentive-based power demand response programs were utilized to meet the high load demand. Its applicability to current smart grids to ensure better power quality and reliable energy supply at competitive rates through a user-friendly two-way digital communication between the consumer and the utility provider using smart metering systems [45]. The implementation of smart grid technology has linked suppliers and consumers, making it possible to reduce energy consumption, minimize power losses, outages and avoid hefty payments for high load demand. The combined power and drinking water production using inclined PV panel integrated solar stills were investigated by Manokar et al. [46]. The parameters studied were fresh drinking water produced, still efficiency, PV panel power production, PV panel efficiency, and exergy efficiency. Sensing the need for renewable energy education, a fully functioning solar photovoltaic laboratory model was used to demonstrate and teach engineering students the components of the system, the working principles, and the maximum power point to improve their understanding of the theoretical course on RES [47]. The experiments were designed to be used along with the theoretical renewable energy course. The results of the hands-on experiments could be viewed in animation form.

- Multidisciplinary approach.

The importance of the multidisciplinary aspects of the Master's program in solar energy was insisted, and the required knowledge includes science, engineering, economics and management disciplines for the successful implementation [2]. The efficient and cost-effective solar systems are the need of the hour to change the perspectives of society. The introduction of laboratory-based courses on sustainable energy as part of the core curriculum was done for students who pursue non-STEM degree choices to create general awareness of the impact of climate change and the importance of clean energy throughout the student community [48]. The courses included hands-on exercises that provided an overview of renewable energy by demonstrating the basic principles. Students must know that the need for affordable, reliable, efficient, clean, and sustainable energy is universal, and it is central to a country's economic growth and development. Knowledge of the main principles of different energy sources, sustainable energy systems and improved energy efficiency measures is necessary to meet the clean energy goals of the future.

With growing interest in alternative energy sources, there is an urgent need to design a well-structured multidisciplinary undergraduate course on alternative energy engineering [49]. A multidisciplinary undergraduate alternative energy engineering (AEE) course is required to bridge the existing gaps in AEE education and social needs and to educate a growing workforce about the need for a future supported by clean energy. The renewable and alternate energy courses were compiled by considering industry needs, potential opportunities, economics and policies of AEE. In addition to covering the principles, practices, and prescribed standards, this educational course addressed the integration of energy sources for effective renewable power generation and utilization. Both the undergraduate and postgraduate levels of study in sustainability engineering were presented by Thürer et al. [50]. Knowledge dissemination will enhance the competencies of students to promote renewable energy vigorously and aggressively.

Brazil's public schools invested large amounts of money in guaranteeing electricity through solar photovoltaic installations, as Brazil enjoys plentiful sunlight [51]. By scaling up solar power systems, a successful roadmap to sustainability was laid by the selected 15 schools. The full electrical demand of all the selected schools was effectively met by power generated from PV plants. There was a significant saving of the amount expended earlier on electricity bills on achieving energy self-sufficiency, which was fruitfully invested in educational programs and extracurricular activities. The residents' response to renewable power subsidies offered by the government was investigated to promote renewable energy while also addressing the problem of high-cost installations [52]. The significant factors influencing the reactions and expectations of people were income, level of education, and employment fields. Table 1 shows various initiatives and measures are practiced in educational programs to promote solar energy deployments.

Table 1. Various educational initiatives and measures.

Reference	Innovative practices	Activities related to learning and promotion of solar technologies
[53]	Solar energy adoption	Integration of institutions to promote solar energy adoptions
[54]	Solar turtle	Providing mobile solar power to no power-grid areas
[55–57]	Consumer's adoption	Improving consumer intentions to adopt solar innovations
[58]	The road to net-zero	Innovations and policy changes to develop a net-zero pathway thought organizations and institutions
[59]	MySuria	Identification of economically weaker people and promoting solar PV, and improving their incomes by providing necessary education
[60]	Organizational life cycle assessment	Providing innovative solutions to solar and wind projects
[61–63]	Energy security in smart cities	Necessitates better management and vital networking of leaders to drive smart city policies and investments
[64]	Inter-sectoral learning	Envisaging the inter-sectoral learning on different renewable energy technologies
[65]	Load-demand pull policy	Promoting solar PV innovations and patents
[66]	Sustainability perspective	Sustainability tool is proposed as an essential aspect to promote solar PV technologies
[67–70]	Biomimetic engineering	Promoting the learning of solar energy technologies by biomimetic engineering cases
[71–74]	Virtual laboratory	Visualization of solar energy systems and their performance in real-time

Literature on Solar energy research

The effect of solar energy research on sustainability is discussed here. The critical policy implications for long-term energy planning in developing countries such as China and India were presented[75]. Between 2009 and 2020, he predicted the rapid development of biomass and wind power and the relatively stable solar power growth.

- Solar cell technologies

A case study on public perceptions of energy efficiency about paying for renewable energy utilized for domestic needs was conducted. A questionnaire method was adopted to interact with residents to obtain their opinion for the study conducted in Greece [76]. The study's findings revealed that the respondents were open to the idea of renewable energy systems; they had reasonably good knowledge of solar and wind energy systems and awareness of the need for environmental protection. The respondents were ready to pay for the switch to green renewable energy systems like solar water heaters and PV power installations. Education, energy subsidy, and government policies are the major factors associated with the willingness of the respondents to utilize solar energy systems.
Smart windows with active dynamic glazing technologies were installed to reduce heat loss, control solar radiation, and improve thermal and visual comfort of buildings [77]. Smart windows were electrochromic, halochromic, and nanocrystal in-glass composites, electrokinetic pixels, and liquid-filled elastomer-deformation windows. The importance of organic solar cells through photon-electron interactions in molecular systems and crystal lattices was discussed [78]. A light-intensity-wavelength diagram was used to discover the photons absorbed dyes. The necessity of framing ethical rules and stringent regulations was discussed to procure conflict minerals, critical minerals, and rare earth elements for alternative energy research in HEI and research laboratories [79]. The importance of using responsibly procured and ethically sourced minerals and metals fully complying with established laws and procurement guidelines was stressed.

Dye-sensitized solar cells (DSSCs) have garnered widespread scientific and technological interest. A scientific teaching module was formulated to support the continued growth of technological innovation in renewable energy and foster learning through inquiry by enabling high school students to fabricate using a simple process using natural dyes to make their own DSSC. The conversion of solar energy to electrical energy is demonstrated to power small household electrical appliances used in everyday life using sunlight to produce the energy needed to drive a small fan motor; more than 80% of high school and middle school students successfully constructed

https://doi.org/10.32933/ActaInnovations.42.3 • ISSN 2300-5599 •

a DSSC in 2.5 hours [80]. The process also gave them a better understanding of the working principles of solar cells, solar energy utilization, and the importance of alternative sources of sustainable green energy. Such practical application modules will help foster good conceptual understanding, spark interest, and encourage lifelong learning to improve the quality and speed up engineering education and research.

Luminescent solar concentrator (LSC) is a newly emerging, promising technology because it allows a large collecting area of virtually transparent glass with a comparatively small area of expensive solar cells. It is being investigated as a low-cost method to expand the use of solar energy. Painting with a technical activity aims to promote greater creativity in LSC construction and engage students in adopting renewable energy [81]. Students first painted luminescent dyes on plastic waveguides. Students were encouraged to show off their artistry on devices that could produce energy. The process was beneficial in improving students' creativity in STEM through the painting and testing of LSC materials at the laboratory, motivating students to harvest the freely and abundantly available solar energy. The popularity of a residential solar water heater offers both economic and environmental advantages were studied [82]. They discussed the economics of the usage of solar water heaters in Turkish households.
The adoption of solar water heaters largely depended on factors like income, education, geographical location, type of space heating system, and the whether the residents were owners or tenants. The percentage of households using polluting solid fuels for heating was determined as 61%. The installation of solar water heaters reduced energy consumption by 13%. The solar water heater installation in the owner and tenant-occupied homes was 6% and 3%, respectively. The popularization of solar technology discussed the importance of small solar home systems and solar lanterns in rural areas of the Global South and the impact on rural livelihoods and living standards [83]. The awareness and understanding of the common public about various renewable energy options needed improvement. The awareness and acceptance, particularly of people from rural areas, was not up to the desired level due to a lack of demonstration of the working of solar systems and knowledge needed to use solar energy products in daily life. The author stressed the importance of more research to bridge the gap between installation and implementation with a simple and clear demonstration of new technologies and imparting practical knowledge of proper maintenance of solar devices to the rural people to educate them about the value of solar energy. It can establish pathways for the economic and social progress of the rural population by providing a clean and efficient way to meet energy needs.

The utilization and constant up-gradation of solar energy-based artifacts was required to keep abreast of the latest trends and developments. Increasing awareness of renewable energy, promoting clean energy education, and building capacity to maximize solar utilization [3]. Proper solar energy education and skill development must be readily available, and solar training, teaching, and learning processes must be improved to promote renewable energy utilization. Education plays an essential role in the implementation of solar energy systems. It is equally as important to identify the people who are to receive and benefit from renewable energy education as it is to have a sound teaching methodology and training framework for capacity building. A discussion on a holistic method for assessing the success of renewable energy studies was made [84]. All stakeholders in the renewable energy study program share equal importance: students, technicians, lecturers, industries, researchers, mechanics, and entrepreneurs. Renewable energy education programs disseminate relevant knowledge and skills about the utilization of green energy for domestic and industrial applications. Hence, well-trained lecturers must handle it in student-friendly learning environments with the added input of expertise from professional experts to keep pace with current industry requirements.

A small prototype was designed and built solely to teach students about automatic solar tracking systems [85]. The prototype was built using open-source hardware and computer vision to test the control algorithms developed in Mathematica and Simulink. For effective learning, students need practical working knowledge. The simulations provided an excellent platform for students to study the theory and then explore the workings of the solar-tracking solar power system. The students learned much about increasing the efficiency and getting more energy from a solar panel and automatic tracking control and applications. The various factors that influenced the adoption of solar technologies in rural areas of Ethiopia for household energy needs were discussed by Guta [86]. The author found that modern energy technologies were practically non-existent in the Horn of Africa, necessitating the scaling up of realistic renewable energy programs that could meet the community’s energy demand. The significant positive socioeconomic determinant factors were the size of the household, age, educational level of the people, occupational skills, household income, female-headed families, poverty reduction policies, and adult education.

The adsorption system was tested under different periods of mass recovery, heat recovery, and cogeneration to determine optimal operating conditions and technical viability [87]. The cogeneration performance of the selected system was studied at different heat transfer fluid (HTF) temperatures. The principles and practices of sustainable development must form an integral part of the higher education curriculum, particularly university studies, along with effective teaching and learning practices to establish a knowledge platform that will promote and popularize clean, affordable, and reliable renewable energy. The energy efficiency measures adopted by a Brazilian university worked towards achieving the targeted, SDGs were investigated [88]. The point of discussion was a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis for the setting of the SDG in the academic sector, particularly in HEI. The authors stressed the importance of educating and directing students who would be change-makers who work for a sustainable society. The focus was mainly on the transition to solar PV power generation. SWOT is a helpful tool to improve the adoption of renewable energy (RE) technologies.

HEIs play a crucial contributing role in the popularization of sustainable development by incorporating sustainability principles, values, and practices into the educational processes of teaching, learning, and research. The effects of the implementation of sustainable practices in the University of Minho were analyzed [89]. A mixed top-down and bottom-up approach was noted to be successful. The other measures were teaching and research, systematic collection, and data monitoring during the implementation of sustainability measures in HEI. Implementing sustainability policies within the institutional framework was used to formulate the guiding principles for executing strategies for a sustainable future. Abu-Rayash and Dincer [90] introduced a novel and comprehensive sustainability assessment model for energy systems. The model adopted an integrated approach that included many multidisciplinary aspects that affect an energy system, such as energy, exergy, economy, environment, society, technology education, and size of the RE systems. The model was applied to two case studies on solar PV and wind energy systems for 150 households in Ontario to meet their annual electricity, hot water, heating, and cooling needs.

An efficient bilayer wood solar steam generator and desalination system were simulated by Zhao et al. [91]. Almost all developing countries face the problem of increasing energy demand. Due to the pressing problem of climate change, attention must importantly be given to carbon dioxide mitigation and reduction of greenhouse gas emissions along with a capacity expansion of power production. The diffusion of RE in the electricity system for power generation was analyzed in Indonesia using a model used to determine the energy and carbon dioxide impacts of expanding a power system using a particular energy source [92]. It provided a clear picture of the optimal pathway of power system development. The total cost of electricity with the applied model was 4-10% lower than the electricity system without considering it. This target decreased CO_2 emissions by 25% compared to the reference scenario. This model estimated the capacity added, technology mix, cumulative electricity production and CO_2 emissions were reliable. Therefore, energy policies could focus on early deployment of renewable energy, upgrading of the variable RES grid capacity, and faster local learning to provide reliable and affordable electrical energy and ensure electricity access for the entire population of Indonesia.

The study showed no significant difference in students knowledge of RE based on gender, educational level of students, and parental education level [93]. Students pursuing vocational studies were more aware of RE than university students studying normal engineering subjects. Students believed Palestine has high wind and solar power potential of around 46% and 40%, respectively. Most of the students favored using solar energy for water heating purposes and felt that RE projects in Palestine could succeed. The authors recommended that RE concepts be incorporated into and form an integral part of the university and school curriculum to increase students' awareness and knowledge levels irrespective of their field of study or specialization. They felt that the education of young people was the key to popularizing the implementation of RE in an occupied country such as Palestine.

Many rural electrification schemes have been implemented in Indian villages at a low rate, under the ‘right to clean light for every child in rural India’. However, their impact and success/failure have not been examined. Sharma et al. [94] studied the learning outcomes, educational attainments, and the increase in study time of poor children with the replacement of kerosene lamps by solar lamps in rural households in four states of India using a purpose-based random sampling method. The total study time per day during dusk hours increased from 88 to 118 min as the off-grid solar lamps enabled the students to study for longer periods even in the absence of natural light. Daily study time was found enhanced by 32 min and 27 min for girls and boys, respectively. The influencing parameters of the total study time are several rooms in the house, the education level of parents, and the class in which the child was studying. The introduction of solar study lamps reduced the dependency on kerosene lamps. The students' study time and academic performance increased due to the use of solar lamps

https://doi.org/10.32933/ActaInnovations.42.3 • ISSN 2300-5599 •

in the households of economically weaker sections. The wide adoption of solar technology can transform the lives of poor and marginalized students by supporting their educational pursuits.
Passive solar heating in residential buildings has been investigated to alleviate energy poverty [95]. The clean technology of passive solar heating effectively reduced the waste of large amounts of conventional coal energy consumption and improved the indoor thermal environment in the renovated building. To meet the energy goals and alleviate energy poverty using passive solar measures, technical, economic, social, and policy issues must be given more attention. An assessment and quantification of the different environmental footprints (energy, carbon, and water) of a sustainable university campus, Keele University, United Kingdom, was carried out considering the university as a small community [96]. The campus has more than 250 buildings, 10,000 students and employs 3,000 staff, necessitating sustainable technologies, materials, systems, and approaches. The university implemented a combined environmental and energy policy to take concerted action within the sustainability framework. The findings serve as a reference for policy makers and practitioners making decisions based on studies on environmental sustainability in universities and other communities. There is a need for more favorable Governmental policies and more significant financial incentives. Such incentives are tax benefits and rebates to promote the extensive and rapid adoption of solar photovoltaic technologies and educational programs on the utilization of renewable energy to drive the nation toward sustainable energy [66]. Solar panels and wind turbines are energy technologies that are clean, renewable, and viable energy resource alternatives to the planet-warming effects of fossil fuels. Based on extensive interviews with women working in US and Canadian RE companies who are passionate about the environment, take proactive steps to stop its degradation, are committed to energy conservation measures and effectively address the developmental challenge of sustainability [97].
The efficiency of perovskite solar cells combining a thermally evaporated p-type perovskite layer was 21.38% [98]. It was due to the reduction in carrier recombination losses. Layered hybrid metal halide perovskites-ensembles of 2D perovskites domains were used to fabricate a low-loss LSC [99]. They achieved an optical quantum efficiency of 26%, a fourfold enhancement over the previously reported LSCs. High current density and output power (27 W) were achieved while maintaining high energy conversion due to a close electronic integration between the photo absorber and the electrocatalyst [100]. 2D-perovskite layer deposition using a slot-die process produced power conversion efficiencies (PCEs) of about 12.5% and 8.0%, respectively [101]. A new fluorine-substituted wide-bandgap small molecule non-fullerene acceptor used in tandem with solar cells produced a PCE of 15%, the energy loss was 0.63 eV [102]. The review on organic-inorganic halide perovskite solar cells with PCE rose from 3.8% to over 23.3% [103].
Recently, the broad solar absorption and high conversion efficiency of photothermal materials were reviewed by Gao et al. [104]. The utilization of sunlight as a RE source for clean water production is a fast-growing research area. It is a promising approach to provide solutions for clean water scarcity with minimum environmental impact. Green solar-driven water vaporization technology has regained the attention of researchers as an efficient and sustainable solution to water scarcity. Approximately 1-20% of the energy has been generated from RES to engage buildings, machinery, and equipment [105]. Solar PV was the major share towards sustainable energy. Energy analysis was carried out on sustainability and energy use at Texas State University [106]. They conducted financial analysis of selected sustainable energy projects. The results are reduced energy use and commitments towards sustainability at the smaller institution level and a more extensive level among all the sustainable energy stakeholders. The teachers' adoption of solar PV systems to promote a sustainable culture was investigated [107]. The knowledge and attitudes of the teachers were improved towards sustainable ways in daily life.

- Solar Thermal Energy Technologies

Nonconcentrated solar thermal technologies are beneficial for water heating and air heating applications. Solar concentrated collectors can produce a high temperature on the point focus solar receivers. The energy storage density of the concentrated solar receiver with a parabolic dish collector was investigated [108–110]. The concentrated heat flux was absorbed and stored at the solar receiver using phase change materials. Hence, such solar receivers can provide the thermal buffering effect to compensate for the short time unavailability of solar rays due to passing clouds and act as a mobile heat battery for later uses. This work is helpful to the students to understand integration issues of the solar collector and thermal energy storage in outdoor experiments.

- Implementation of solar energy

The deployment policies of different early-stage energy technologies must be framed based on specific applications rather than generic deployment policies [111]. The authors observed two Germany's solar photovoltaic feed-in tariff policies, namely technology-specific and application-specific policies, to accelerate photovoltaic growth. The implications of implementing solar projects in Africa were assessed towards implementing the 2030 plan [112]. The lack of performance assessment methods of the solar power project is one of the major concerns in implementing RE projects in Africa based on case studies on Ghana, Kenya and South Africa. China's solar photovoltaic power was studied using a model to explore its development during 2018-2050 [113]. Learning and technological progress are the main factors in reducing the cost of solar PV power. The use of a solar home system as a source of electricity in remote areas in Côte d'Ivoire was analyzed by Diallo and Moussa [114].

The solar home system practice improved the per capita energy consumption, increased schooling, and reduced illness. The influencing factors for rooftop solar panel installation were income, education, knowledge about Australia's RE policies, and conviction about the environmental benefits of solar energy [115]. Australia enjoys the distinction of having one of the highest rates of installed residential rooftop solar systems globally, with over 20% of households favoring the same. The use of solar energy by deploying solar PV in rural households in India was analyzed by Yadav et al. [116]. The high satisfaction observed for distributed solar PV among the households who were received subsidized PV connections paid connections from solar microgrids and purchased solar energy systems for power reliability. Table 2 shows selective applications of innovative research and developments in various fields.

Table 2. Recent innovative applications through solar energy research and development.

Solar energy system	**Innovative applications**
Solar thermal	Fluidized bed and bioreactors [117,118], absorption chillers [119], Hydrogen fuel and ammonia production [86,120,121], energy efficient buildings [20,122], Fuel cells [123], iron ore agglomeration [124], wastewater treatment [125], medical sterilization [126,127], cooling of building by triple vacuum-glazed windows [128]
Solar PV	Smart textiles [129], agrivoltaic system [130,131], electric vehicles [132], flexible solar cells [133], road structures and marine applications [134,135], hybridization with biogas system [136], solar home systems [137].

Results and discussion

RES has the potential to offer solutions to long-standing energy problems and environmental concerns. Many countries such as Germany, Sweden, and China have actively focused on solar energy education and training to understand the possibilities of renewable energy and move to green technology for energy security. Besides encouraging research on energy efficiency technologies and best energy practices to help respond to the challenges of mitigating global climate change. Solar energy education and training can be successfully implemented only when other equally essential skills like verbal and written communication, teamwork, business, and project management are also imparted. The requisite technical skills for young engineers are the primary factors to become successful solar energy professionals.

Only a few countries are actively promoting solar energy education to scale up solar energy generation, advance solar photovoltaic technologies, and increase economic PV deployment on a large scale to achieve greater sustainability. Strategies must be adopted to reach out the benefits of solar power energy and promote the utilization of solar power systems for meeting almost all thermal or electrical energy requirements. Exploring new and more effective applications of solar energy systems and grid technologies that are both technically viable and financially sustainable will ensure continuous improvements in providing efficient and affordable alternative energy for homes and commercial buildings, paving the way towards sustainable cities and countries.

The drivers, barriers and enablers of end-of-life solar PV panels and battery energy storage systems [138]. Economic drivers are dependent on the research and development of educational institutions and industries. The barriers are related to the lack of profits/collecting network, and no regulations/ incentives. The high school students were motivated to learn new concepts by fabricating a handmade solar cell [139]. Such solar cells consist of chlorophyll extract from the leaves of Diacol Capiro potatoes and nickel-silver electrodes. The students learned the making of low-cost natural dye to make a solar cell. An individual chlorophyll cell produced a maximum voltage of 1 V. Thus, around 90% of the students learned to use visible light to produce electricity.

The willingness to pay towards renewable electricity in rural households in Ethiopia was analyzed because 55% of the people were with lack electricity [140]. Compared to hydroelectric dams, solar photovoltaic energy is preferable to rural electricity in Ethiopia. The benefits of solar photovoltaic systems for low-income families in Korea were discussed by Lee et al. [141]. The people were satisfied with the utilization of solar energy. However, the mismatch between the PV capacity and the electricity bill reduction should be considered in the long-term analysis with a balance of systems. Estimated gross career opportunities for solar PV, wind onshore and offshore deployment were up to 2050 for the European Union [6]. For the analyzed period (2014-2050), the photovoltaic sector possibly provides more careers in operation and maintenance. Table 3 shows the various activities required to reach sustainability through solar energy education, serving as clean energy for all.

A model was designed to demonstrate high-efficiency maximum power point tracking (MPPT) with intelligent controllers [142]. MPPT helps achieve maximum output from a PV panel, ensures that the solar PV system is used effectively, and improves the solar conversion efficiency; the demonstration was aimed at PV engineers and researchers. The focus of the training program was to give fresh engineers access to better employment opportunities and equip them with the necessary know-how to be eligible to work on start-up projects on power point tracking. Quantum dot solar cells are promising organic methods of solar energy conversion [143].

Students must gather knowledge of RE systems in any country with solar energy potential considering three significant aspects: energy source, environment, and economic aspects. The solar energy industry needs enterprising students who possess multidisciplinary skills to be involved in research activities to explore new generic or specialized solar system designs that are cost-effective for commercialization to meet societal needs and for the continued growth of this field. The power of the current generation to bring about a solar revolution to meet future energy needs lies in the hands of the current generation.

Table 3. Activities for promoting solar energy utilization.

Items	**Description**
Government policies	The Central and State governments must adopt a broad policy framework and its programmes, incentives, fund subsidies, and promotional activities to favor capacity addition and people to adopt solar energy-based utilities.
Mandatory courses at undergraduate levels for science programs	Greater awareness of the urgent need for sustainability, increasing knowledge of solar energy systems and skill development in the student community.
Activity-based curricula and multidisciplinary skills	All educational modules are embedded with project-based practical activities such as power kits and solar products to inculcate multidisciplinary skills [81].
Industry-Institution Collaboration	Industries and institutions should work closely with research centers and academia for mutual interaction to address sustainability issues and strive towards eco-friendly energy generation and use [36].
Outside classroom activities	Providing more hands-on activities and experiments outside the classroom leads to a better conceptual understanding of solar energy principles. It also facilitates involvement in renewable energy-related projects.
Research and development of new technologies	Pioneering research activities and development efforts are underway to make the best possible use of RE, materials, design of energy-efficient systems, improving products and manufacturing processes, and competitive costs.

It is essential that solar energy professionals could possess multidisciplinary knowledge for more significant solar deployment, increasing solar adoption, and improving solar installations. Novel solar energy materials and efficient energy storage conversion technologies can lead to sustainability [144–147]. Access to clean, affordable, and reliable energy as thermo-electric needs constitute a significant portion of the energy requirements. The SDGs were outlined in the 2030 Agenda for Sustainable Development of the United Nations

to guide a sustainable future. Sustainable and affordable energy is one of the 17 goals to ensure access to reliable energy [148]. New energy storage materials and system designs are evolving to store solar energy effectively in electrical and thermal energy storage to meet the energy needs of society [149–154]. The record performance of different solar cell technologies is shown in Figure 7. Solar energy technologies can provide input to several indicators of other SDGs, such as water, a decent work environment, and others.
Solar energy is an ideal sustainability model as it can help reap the benefits of a green economy by providing clean energy. Solar energy education should systematically provide fundamental knowledge of solar technology and photovoltaic applications, a good understanding of concepts and principles, skill development, and vocational training programs to undergraduate students to empower them to face various challenges and opportunities in solar energy. Undoubtedly, solar power generation is one of the fields that provide more job creations in installing and maintaining solar PV plants and the research careers in solar energy materials development.

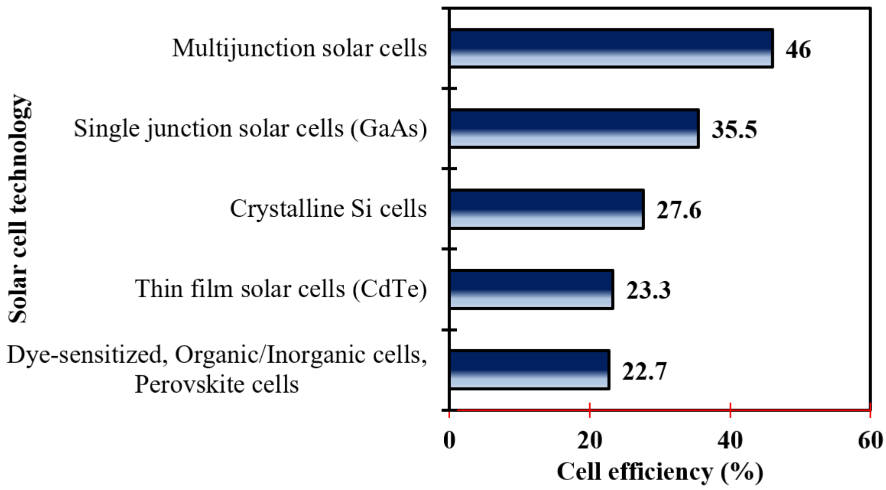

Figure 7. Solar cell technologies and their respective recorded efficiencies.

The notable barriers are lack of awareness, financial policies, reliability, and end-of-life management practices towards a circular economy. The drivers are governmental policies, financial assistance, incentives, reliability and maintenance measures, energy consciousness, climate change mitigation, and environmental benefits. Further developments in solar energy require developing more reliable and sustainable energy materials for energy conversion and storage. Solar energy technologies must be strengthened to provide clean water through effective desalination, clean air through solar-powered carbon capture methods, thermal management of buildings, and wastewater treatment technologies [155–158]. Implementation of such green technologies can create more jobs and sustainable energy infrastructure [159]. The interlinking of other SDGs with SDG 7 has already gained momentum, and it is essential to increase the implementation rate to meet the climate change goals of 2030. The Effective solar thermal conversion technologies are to be strengthened for the thermal energy requirements to provide uninterrupted energy needs from the domestic to the community level and power generation.

Impact
The impact of the present short review article comprehensively discusses the recent trends in solar energy-based education and research as per the recently published documents. Several measures and institutional initiatives were undertaken in solar energy education to provide awareness and hands-on solar energy technologies. The topic-wise published documents are shown to understand the recent solar energy-relevant work carried out by several researchers to motivate the solar community to bring out more such solar energy innovations in education and product innovations. To improve the use of solar energy to the maximum possible extent, imparting proper knowledge promptly at the institution level is essential with solid motivation towards sustainability.
Solar cells are primarily investigated area in solar energy research. Various solar photovoltaic and cell technologies are continuously studied globally to improve cell conversion efficiencies and reliability. Research on novel materials should focus on the reliability and sustainability of large-scale deployments. Furthermore, solar cell research activities should combine with advanced developments in sustainable energy materials

to witness sustainable development. The need-based poly-generation systems using solar energy are vital to simultaneously minimize environmental degradation by satisfying thermal and electrical needs.
The present review sheds light on the recent innovations in solar energy from a country's perspectives on the learning environment and product development. The discussion and future directions are incredibly beneficial to all the stakeholders of the solar community. The immediate impacts of effective solar energy utilization are social interconnections, economic opportunities, environmental security, and financial benefits. In addition, solar energy utilization satisfies one of the 17 sustainable development goals, 13-climate action, by minimizing fossil fuel usage. The discussion of the present review could help the sustainable energy community to explore more reliable products for society with minimal carbon footprints in the long term.

Conclusions
Solar energy is evidently a key to a sustainable future. It can effectively meet a significant part of the energy demand without the undesirable repercussions of environmental degradation, carbon emissions, and global warming and meet SDG 7 and 13. The major conclusions are given below.

- Proper solar energy education and research strategies can spearhead a country's efforts to achieve its sustainability goals and ensure sustainable living for its citizens and the earth.
- The strengthening of green campus initiatives in each institution plays a pivotal role in RE explorations.
- Courses related to RE must focus on various topics and issues related to solar energy, which should be a core course in science and engineering curricula to utilize solar energy for daily energy needs.
- Learning by doing like activity-based learning is effective to learning solar technologies.
- Research work is continually needed in the solar photovoltaic field to promising alternative energy. The flexible and organic solar cells require more research to produce stable solar cells with higher efficiencies.
- Several potential applications of solar energy are to be explored with reliable energy storage technologies.
- Emerging solar cell technologies are demanding research on developing low-cost and sustainable energy materials.
- Thermal management of concentrated solar PV and subsequent poly-generation needs improvement.
- Hybridization of other energy technologies with solar energy systems is helpful to alleviate variable and intermittent solar radiation.
- Integration of computing smart technologies into solar energy systems can reach and benefit society.
- Promoting SDG 7 with other closely associated SDGs can lead to materializing the carbon-free environment.

Solar energy can help meet the energy needs of the future and resolve the energy crisis with its high energy saving potential and minimize adverse impacts on the environment. There must be greater dissemination and awareness of the many advantages of using solar energy, such as improved environmental quality, increased energy stability and security, and local economic development benefits to accelerate the shift to clean energy. Cost-effective solar energy technologies with energy storage systems and products can underpin progress in all areas of development and go a long way in powering a future with easy access to reliable, affordable, completely sustainable clean and green energy for all.

Abbreviations

AEE	Alternative energy engineering
DSSC	Dye-sensitized solar cells
HEI	Higher education institutions
HTF	Heat transfer fluid
LSC	Luminescent solar concentrator
MPPT	Maximum Power Point Tracking
PCE	Power conversion efficiencies
PV	Photovoltaic
RE	Renewable energy
RES	Renewable energy sources
SDG	Sustainable development goals
STEM	Science, technology, engineering, and mathematics
SWOT	Strengths, Weaknesses, Opportunities, and Threats

https://doi.org/10.32933/ActaInnovations.42.3 • ISSN 2300-5599 •

Conflict of interest
The author declares that there is no conflict of interest.

Funding information
There is no fund involved in this work.

Acknowledgments
This research has not been supported by any external funding.

References
[1] 26th UN Climate Change Conference, (2021). https://ukcop26.org/.
[2] R. Ciriminna, F. Meneguzzo, M. Pecoraino, M. Pagliaro, Rethinking solar energy education on the dawn of the solar economy, Renew. Sustain. Energy Rev. 63 (2016) 13–18. https://doi.org/10.1016/j.rser.2016.05.008.
[3] A. Ott, L. Broman, K. Blum, A pedagogical approach to solar energy education, Sol. Energy. 173 (2018) 740–743. https://doi.org/10.1016/j.solener.2018.07.060.
[4] L. Niamir, O. Ivanova, T. Filatova, A. Voinov, H. Bressers, Demand-side solutions for climate mitigation: Bottom-up drivers of household energy behavior change in the Netherlands and Spain, Energy Res. Soc. Sci. 62 (2020) 101356. https://doi.org/10.1016/j.erss.2019.101356.
[5] E.M. Barhoumi, P.C. Okonkwo, M. Zghaibeh, I. Ben Belgacem, T.A. Alkanhal, A.G. Abo-Khalil, I. Tlili, Renewable energy resources and workforce case study Saudi Arabia: review and recommendations, J. Therm. Anal. Calorim. 141 (2020) 221–230. https://doi.org/10.1007/s10973-019-09189-2.
[6] M. Ortega, P. del Río, P. Ruiz, W. Nijs, S. Politis, Analysing the influence of trade, technology learning and policy on the employment prospects of wind and solar energy deployment: The EU case, Renew. Sustain. Energy Rev. 122 (2020) 109657. https://doi.org/10.1016/j.rser.2019.109657.
[7] A. Elia, M. Kamidelivand, F. Rogan, B. Ó Gallachóir, Impacts of innovation on renewable energy technology cost reductions, Renew. Sustain. Energy Rev. 138 (2021) 110488. https://doi.org/10.1016/j.rser.2020.110488.
[8] O. Kaya, A.M. Klepacka, W.J. Florkowski, The role of personal and environmental factors in rural homeowner decision to insulate; an example from Poland, Renew. Sustain. Energy Rev. 150 (2021) 111474. https://doi.org/10.1016/j.rser.2021.111474.
[9] Y.T. Wassie, M.M. Rannestad, M.S. Adaramola, Determinants of household energy choices in rural sub-Saharan Africa: An example from southern Ethiopia, Energy. 221 (2021) 119785. https://doi.org/10.1016/j.energy.2021.119785.
[10] S. Kolosok, Y. Bilan, T. Vasylieva, A. Wojciechowski, M. Morawski, A scoping review of renewable energy, sustainability and the environment, Energies. 14 (2021) 4490. https://doi.org/10.3390/en14154490.
[11] L.F. Hirt, M. Sahakian, E. Trutnevyte, What socio-technical regimes foster solar energy champions? Analysing uneven photovoltaic diffusion at a subnational level in Switzerland, Energy Res. Soc. Sci. 74 (2021) 101976. https://doi.org/10.1016/j.erss.2021.101976.
[12] M. Uriona-Maldonado, T. Caliari, L.H. de Souza Costa, C.R. Vaz, The diffusion of solar photovoltaics in brazil: A technological innovation system approach, in: Smart Innov. Syst. Technol., 2021: pp. 377–385. https://doi.org/10.1007/978-3-030-55374-6_37.
[13] M. Victoria, N. Haegel, I.M. Peters, R. Sinton, A. Jäger-Waldau, C. del Cañizo, C. Breyer, M. Stocks, A. Blakers, I. Kaizuka, K. Komoto, A. Smets, Solar photovoltaics is ready to power a sustainable future, Joule. 5 (2021) 1041–1056. https://doi.org/10.1016/j.joule.2021.03.005.
[14] Q. Zhang, L. Suresh, Q. Liang, Y. Zhang, L. Yang, N. Paul, S.C. Tan, Emerging Technologies for Green Energy Conversion and Storage, Adv. Sustain. Syst. 5 (2021) 2000152. https://doi.org/10.1002/adsu.202000152.
[15] M. Temiz, I. Dincer, Design and analysis of nuclear and solar-based energy, food, fuel, and water production system for an indigenous community, J. Clean. Prod. 314 (2021) 127890. https://doi.org/10.1016/j.jclepro.2021.127890.
[16] K. Zaman, A.R.A. Aziz, S. Sriyanto, Sasmoko, Y. Indrianti, H. Jambari, The role of solar energy demand in the relationship between carbon pricing and environmental degradation: A blessing in disguise, J. Public Aff. (2021). https://doi.org/10.1002/pa.2702.
[17] I. Ari, M. Koc, Philanthropic-crowdfunding-partnership: A proof-of-concept study for sustainable financing in low-carbon energy transitions, Energy. 222 (2021) 119925. https://doi.org/10.1016/j.energy.2021.119925.
[18] D. Drosos, G.L. Kyriakopoulos, S. Ntanos, A. Parissi, School managers perceptions towards energy

efficiency and renewable energy sources, Int. J. Renew. Energy Dev. 10 (2021) 573–584. https://doi.org/10.14710/ijred.2021.36704.
[19] D. Hirsh Bar Gai, E. Shittu, D. Attanasio, C. Weigelt, S. LeBlanc, P. Dehghanian, S. Sklar, Examining community solar programs to understand accessibility and investment: Evidence from the U.S., Energy Policy. 159 (2021) 112600. https://doi.org/10.1016/j.enpol.2021.112600.
[20] X.J. Luo, L.O. Oyedele, Assessment and optimisation of life cycle environment, economy and energy for building retrofitting, Energy Sustain. Dev. 65 (2021) 77–100. https://doi.org/10.1016/j.esd.2021.10.002.
[21] L. Guo, J. Kors, Design of a laboratory scale solar microgrid cyber-physical system for education, Electron. 10 (2021) 1562. https://doi.org/10.3390/electronics10131562.
[22] E. Harrington, A.W. Wambugu, Beyond technical standards: Creating an ecosystem for quality and repair in Kenya's off-grid solar sector, Energy Res. Soc. Sci. 77 (2021) 102101. https://doi.org/10.1016/j.erss.2021.102101.
[23] E. Gervais, S. Shammugam, L. Friedrich, T. Schlegl, Raw material needs for the large-scale deployment of photovoltaics – Effects of innovation-driven roadmaps on material constraints until 2050, Renew. Sustain. Energy Rev. 137 (2021) 110589. https://doi.org/10.1016/j.rser.2020.110589.
[24] I.M. Peters, C. Breyer, S.A. Jaffer, S. Kurtz, T. Reindl, R. Sinton, M. Vetter, The role of batteries in meeting the PV terawatt challenge, Joule. 5 (2021) 1353–1370. https://doi.org/10.1016/j.joule.2021.03.023.
[25] M. Ghasri, A. Ardeshiri, N.J. Ekins-Daukes, T. Rashidi, Willingness to pay for photovoltaic solar cells equipped electric vehicles, Transp. Res. Part C Emerg. Technol. 133 (2021) 103433. https://doi.org/10.1016/j.trc.2021.103433.
[26] V.K. Chauhan, S.K. Shukla, J.V. Tirkey, P.K. Singh Rathore, A comprehensive review of direct solar desalination techniques and its advancements, J. Clean. Prod. 284 (2021) 124719. https://doi.org/10.1016/j.jclepro.2020.124719.
[27] X. Xu, S. Ozden, N. Bizmark, C.B. Arnold, S.S. Datta, R.D. Priestley, A Bioinspired Elastic Hydrogel for Solar-Driven Water Purification, Adv. Mater. 33 (2021) 2007833. https://doi.org/10.1002/adma.202007833.
[28] R.K. Goel, C.S. Yadav, S. Vishnoi, R. Rastogi, Smart agriculture – Urgent need of the day in developing countries, Sustain. Comput. Informatics Syst. 30 (2021) 100512. https://doi.org/10.1016/j.suscom.2021.100512.
[29] R. Senthil, S. Yuvaraj, A comprehensive review on bioinspired solar photovoltaic cells, Int. J. Energy Res. 43 (2019) 1068–1081. https://doi.org/10.1002/er.4255.
[30] 2021, Scopus, (n.d.). https://www.scopus.com/.
[31] A. Karabulut, E. Gedik, A. Keçebaş, M.A. Alkan, An investigation on renewable energy education at the university level in Turkey, Renew. Energy. 36 (2011) 1293–1297. https://doi.org/10.1016/j.renene.2010.10.006.
[32] R.C. Buschmann, C. Prettner, Solar info center freiburg (germany) an energy efficient name card for clean energy development, Int. J. Sustain. Build. Technol. Urban Dev. 2 (2011) 191–194. https://doi.org/10.5390/SUSB.2011.2.3.191.
[33] M.J. Pasqualetti, S. Haag, A solar economy in the American Southwest: Critical next steps, Energy Policy. 39 (2011) 887–893. https://doi.org/10.1016/j.enpol.2010.11.013.
[34] K. Mahmud, S. Morsalin, M.I. Khan, Design and Fabrication of an Automated Solar Boat, Int. J. Adv. Sci. Technol. 64 (2014) 31–42. https://doi.org/10.14257/ijast.2014.64.04.
[35] C.G. Kuo, C.C. Chang, Building professional competencies indices in the solar energy industry for the engineering education curriculum, Int. J. Photoenergy. 2014 (2014) 1–6. https://doi.org/10.1155/2014/963291.
[36] I. Navarro, Á. Gutiérrez, C. Montero, E. Rodríguez-Ubiñas, E. Matallanas, M. Castillo-Cagigal, M. Porteros, J. Solórzano, E. Caamaño-Martín, M.A. Egido, J.M. Páez, S. Vega, Experiences and methodology in a multidisciplinary energy and architecture competition: Solar Decathlon Europe 2012, Energy Build. 83 (2014) 3–9. https://doi.org/10.1016/j.enbuild.2014.03.073.
[37] C.G. Kuo, C.C. Chang, C.C. Huang, Constructing employability indicators for enhancing the effectiveness of engineering education for the solar industry, Int. J. Photoenergy. 2014 (2014) 1–11. https://doi.org/10.1155/2014/491353.
[38] S. Karytsas, H. Theodoropoulou, Socioeconomic and demographic factors that influence publics' awareness on the different forms of renewable energy sources, Renew. Energy. 71 (2014) 480–485. https://doi.org/10.1016/j.renene.2014.05.059.
[39] M. Torres-Ramírez, B. García-Domingo, J. Aguilera, J. De La Casa, Video-sharing educational tool applied to the teaching in renewable energy subjects, Comput. Educ. 73 (2014) 160–177. https://doi.org/10.1016/j.compedu.2013.12.014.

[40] P. Criqui, S. Mima, P. Menanteau, A. Kitous, Mitigation strategies and energy technology learning: An assessment with the POLES model, Technol. Forecast. Soc. Change. 90 (2015) 119–136. https://doi.org/10.1016/j.techfore.2014.05.005.
[41] J. Buelin, A.C. Clark, J. V. Ernst, Engineering's grand challenges: Priorities and integration recommendations for technology education curriculum development, J. Technol. Educ. 28 (2016) 37–52. https://doi.org/10.21061/jte.v28i1.a.3.
[42] A. Faza, M. Batarseh, W. Abu-Elhaija, Upgrading power and energy engineering curricula in Jordanian universities: A case study at PSUT, Int. J. Electr. Eng. Educ. 54 (2017) 57–81. https://doi.org/10.1177/0020720916673648.
[43] L. Neij, E. Heiskanen, L. Strupeit, The deployment of new energy technologies and the need for local learning, Energy Policy. 101 (2017) 274–283. https://doi.org/10.1016/j.enpol.2016.11.029.
[44] A.S.O. Ogunjuyigbe, T.R. Ayodele, E.E. Ekoh, Development of a MATLAB based Educational Software (UISOLAR) For Solar Application, Energy Eng. J. Assoc. Energy Eng. 114 (2017) 33–54. https://doi.org/10.1080/01998595.2017.11882308.
[45] N.A. Jefry, N.A. Zambri, Suitability of demand response program equipped with solar energy in UTHM, Indones. J. Electr. Eng. Comput. Sci. 6 (2017) 294–300. https://doi.org/10.11591/ijeecs.v6.i2.pp294-300.
[46] A.M. Manokar, D.P. Winston, A.E. Kabeel, R. Sathyamurthy, Sustainable fresh water and power production by integrating PV panel in inclined solar still, J. Clean. Prod. 172 (2018) 2711–2719. https://doi.org/10.1016/j.jclepro.2017.11.140.
[47] A. Alqahtani, M. Alsaffar, M. El-Sayed, H. Behbehani, A photovoltaic system experiment in a laboratory environment, Int. J. Electr. Eng. Educ. 55 (2018) 31–43. https://doi.org/10.1177/0020720917750956.
[48] S.A. Nathan, F. Loxsom, A Sustainable Energy Laboratory Course for Non-Science Majors, Phys. Teach. 54 (2016) 420–422. https://doi.org/10.1119/1.4962779.
[49] A.S. Leger, A multidisciplinary undergraduate alternative energy engineering course, IEEE Trans. Educ. 62 (2019) 34–39. https://doi.org/10.1109/TE.2018.2844811.
[50] M. Thürer, I. Tomašević, M. Stevenson, T. Qu, D. Huisingh, A systematic review of the literature on integrating sustainability into engineering curricula, J. Clean. Prod. 181 (2018) 608–617. https://doi.org/10.1016/j.jclepro.2017.12.130.
[51] J. da S. Pereira, D.A. Ribeiro, F.H. Lucena, J. Urbanetz Júnior, Assessment of the potential implementation of solar energy generation in state schools in Curitiba/PR, Brazilian Arch. Biol. Technol. 61 (2018). https://doi.org/10.1590/1678-4324-smart-2018000300.
[52] L. Ding, F. Zhang, J. Shuai, How do chinese residents expect of government subsidies on solar photovoltaic power generation?-a case of Wuhan, China, Energies. 11 (2018) 228. https://doi.org/10.3390/en11010228.
[53] D. Asante, Z. He, E. Mintah Ampaw, S. Gyamerah, M. Ankrah Twumasi, E. Opoku-Mensah, F. Kyere, B. Asante, E. Afia Akyia, Renewable energy technology transition among small-and-medium scale firms in Ghana, Renew. Energy. 178 (2021) 549–559. https://doi.org/10.1016/j.renene.2021.06.111.
[54] B. Urban, J. Maphalala, Solar turtle: searching for the game changer, Emerald Emerg. Mark. Case Stud. 9 (2019) 1–20. https://doi.org/10.1108/EEMCS-02-2019-0032.
[55] K.K. Kapoor, Y.K. Dwivedi, Sustainable consumption from the consumer's perspective: Antecedents of solar innovation adoption, Resour. Conserv. Recycl. 152 (2020) 104501. https://doi.org/10.1016/j.resconrec.2019.104501.
[56] P.C. Sun, H.M. Wang, H.L. Huang, C.W. Ho, Consumer attitude and purchase intention toward rooftop photovoltaic installation: The roles of personal trait, psychological benefit, and government incentives, Energy Environ. 31 (2020) 21–39. https://doi.org/10.1177/0958305X17754278.
[57] J. Abreu, N. Wingartz, N. Hardy, New trends in solar: A comparative study assessing the attitudes towards the adoption of rooftop PV, Energy Policy. 128 (2019) 347–363. https://doi.org/10.1016/j.enpol.2018.12.038.
[58] C. O'Flynn, V. Seymour, J. Crawshaw, T. Parrott, C. Reeby, S.R.P. Silva, The road to net zero: A case study of innovative technologies and policy changes used at a medium-sized university to achieve Czero by 2030, Sustain. 13 (2021) 9954. https://doi.org/10.3390/su13179954.
[59] S.A. Malik, A.R. Ayop, Solar energy technology: Knowledge, awareness, and acceptance of B40 households in one district of Malaysia towards government initiatives, Technol. Soc. 63 (2020) 101416. https://doi.org/10.1016/j.techsoc.2020.101416.
[60] H. Marx, S. Forin, M. Finkbeiner, Organizational life cycle assessment of a service providing SME for renewable energy projects (PV and wind) in the United Kingdom, Sustain. 12 (2020) 4475. https://doi.org/10.3390/su12114475.

[61] W. Strielkowski, T. Veinbender, M. Tvaronavičienė, N. Lace, Economic efficiency and energy security of smart cities, Econ. Res. Istraz. 33 (2020) 788–803. https://doi.org/10.1080/1331677X.2020.1734854.

[62] A. Hazarika, S. Poddar, M.M. Nasralla, H. Rahaman, Area and energy efficient shift and accumulator unit for object detection in IoT applications, Alexandria Eng. J. 61 (2022) 795–809. https://doi.org/10.1016/j.aej.2021.04.099.

[63] J. Liu, B. Gong, Q. Wang, A trusted proof mechanism of data source for smart city, Futur. Gener. Comput. Syst. 128 (2022) 349–364. https://doi.org/10.1016/j.future.2021.10.012.

[64] A. Malhotra, T.S. Schmidt, J. Huenteler, The role of inter-sectoral learning in knowledge development and diffusion: Case studies on three clean energy technologies, Technol. Forecast. Soc. Change. 146 (2019) 464–487. https://doi.org/10.1016/j.techfore.2019.04.018.

[65] X. Gao, V. Rai, Local demand-pull policy and energy innovation: Evidence from the solar photovoltaic market in China, Energy Policy. 128 (2019) 364–376. https://doi.org/10.1016/j.enpol.2018.12.056.

[66] Y.H. Cho, A. Shaygan, T.U. Daim, Energy technology adoption: Case of solar photovoltaic in the Pacific Northwest USA, Sustain. Energy Technol. Assessments. 34 (2019) 187–199. https://doi.org/10.1016/j.seta.2019.05.011.

[67] J.M. Delgado-Sanchez, I. Lillo-Bravo, Learning solar energy inspired by nature: biomimetic engineering cases, Eur. J. Eng. Educ. 46 (2021) 1058–1075. https://doi.org/10.1080/03043797.2021.1988906.

[68] N. Ali, E.L. Gyllye, C. Duanmu, Y. Yang, A. Khan, F. Ali, M. Bilal, H.M.N. Iqbal, Robust bioinspired surfaces and their exploitation for petroleum hydrocarbon remediation, Environ. Sci. Pollut. Res. (2021). https://doi.org/10.1007/s11356-021-16525-3.

[69] Y. Dong, F. Wang, Y. Zhang, X. Shi, A. Zhang, Y. Shuai, Experimental and numerical study on flow characteristic and thermal performance of macro-capsules phase change material with biomimetic oval structure, Energy. 238 (2022) 121830. https://doi.org/10.1016/j.energy.2021.121830.

[70] X.T. Yan, Y.K. Jin, X.M. Chen, C. Zhang, C.L. Hao, Z.K. Wang, Nature-inspired surface topography: design and function, Sci. China Physics, Mech. Astron. 63 (2020) 224601. https://doi.org/10.1007/s11433-019-9643-0.

[71] L. Guo, M. Vengalil, N.M.M. Abdul, K. Wang, Design and implementation of virtual laboratory for a microgrid with renewable energy sources, Comput. Appl. Eng. Educ. (2021). https://doi.org/10.1002/cae.22459.

[72] J.M. Han, E.S. Choi, A. Malkawi, CoolVox: Advanced 3D convolutional neural network models for predicting solar radiation on building facades, Build. Simul. (2021). https://doi.org/10.1007/s12273-021-0837-0.

[73] K. Rajesh, C. Sivapragasam, S. Rajendran, Teaching Solar and Wind Energy Conversion Course for Engineering Students: A Novel Approach, in: 2021 Int. Conf. Adv. Comput. Innov. Technol. Eng. ICACITE 2021, IEEE, 2021: pp. 826–831. https://doi.org/10.1109/ICACITE51222.2021.9404589.

[74] I. Abada, M. Othmani, L. Tatry, An innovative approach for the optimal sizing of mini-grids in rural areas integrating the demand, the supply, and the grid, Renew. Sustain. Energy Rev. 146 (2021) 111117. https://doi.org/10.1016/j.rser.2021.111117.

[75] R.G. Cong, An optimization model for renewable energy generation and its application in China: A perspective of maximum utilization, Renew. Sustain. Energy Rev. 17 (2013) 94–103. https://doi.org/10.1016/j.rser.2012.09.005.

[76] S. Ntanos, G. Kyriakopoulos, M. Chalikias, G. Arabatzis, M. Skordoulis, Public perceptions and willingness to pay for renewable energy: A case study from Greece, Sustain. 10 (2018) 687. https://doi.org/10.3390/su10030687.

[77] M. Casini, Active dynamic windows for buildings: A review, Renew. Energy. 119 (2018) 923–934. https://doi.org/10.1016/j.renene.2017.12.049.

[78] Z. Csernovszky, A. Horváth, Organic solar cells and physics education, Eur. J. Phys. 39 (2018) 045804. https://doi.org/10.1088/1361-6404/aab5d1.

[79] L. Hancock, N. Ralph, M. Armand, D. Macfarlane, M. Forsyth, In the lab: New ethical and supply chain protocols for battery and solar alternative energy laboratory research policy and practice, J. Clean. Prod. 187 (2018) 485–495. https://doi.org/10.1016/j.jclepro.2018.03.097.

[80] S.I. Chien, C. Su, C.C. Chou, W.R. Li, Visual Observation and Practical Application of Dye Sensitized Solar Cells in High School Energy Education, J. Chem. Educ. 95 (2018) 1167–1172. https://doi.org/10.1021/acs.jchemed.7b00484.

[81] A. Renny, C. Yang, R. Anthony, R.R. Lunt, Luminescent Solar Concentrator Paintings: Connecting Art and Energy, J. Chem. Educ. 95 (2018) 1161–1166. https://doi.org/10.1021/acs.jchemed.7b00742.

[82] E. Aydin, P. Eichholtz, E. Yönder, The economics of residential solar water heaters in emerging economies:

The case of Turkey, Energy Econ. 75 (2018) 285–299. https://doi.org/10.1016/j.eneco.2018.08.001.
[83] X. Lemaire, Solar home systems and solar lanterns in rural areas of the Global South: What impact?, Wiley Interdiscip. Rev. Energy Environ. 7 (2018). https://doi.org/10.1002/wene.301.
[84] H. Holtorf, E. Brudler, H. Torío, Development of a holistic method for assessing success of renewable energy study programs, Sol. Energy. 173 (2018) 209–214. https://doi.org/10.1016/j.solener.2018.07.063.
[85] J.A. Carballo, J. Bonilla, L. Roca, M. Berenguel, New low-cost solar tracking system based on open source hardware for educational purposes, Sol. Energy. 174 (2018) 826–836. https://doi.org/10.1016/j.solener.2018.09.064.
[86] D.D. Guta, Determinants of household adoption of solar energy technology in rural Ethiopia, J. Clean. Prod. 204 (2018) 193–204. https://doi.org/10.1016/j.jclepro.2018.09.016.
[87] Y. Yu, Q.W. Pan, L.W. Wang, A small-scale silica gel-water adsorption system for domestic air conditioning and water heating by the recovery of solar energy, Front. Energy. 14 (2020) 328–336. https://doi.org/10.1007/s11708-019-0623-1.
[88] B.G. Rebelatto, A. Lange Salvia, G. Reginatto, R.C. Daneli, L.L. Brandli, Energy efficiency actions at a Brazilian university and their contribution to sustainable development Goal 7, Int. J. Sustain. High. Educ. 20 (2019) 842–855. https://doi.org/10.1108/IJSHE-01-2019-0023.
[89] P.J. Ramísio, L.M.C. Pinto, N. Gouveia, H. Costa, D. Arezes, Sustainability Strategy in Higher Education Institutions: Lessons learned from a nine-year case study, J. Clean. Prod. 222 (2019) 300–309. https://doi.org/10.1016/j.jclepro.2019.02.257.
[90] A. Abu-Rayash, I. Dincer, Sustainability assessment of energy systems: A novel integrated model, J. Clean. Prod. 212 (2019) 1098–1116. https://doi.org/10.1016/j.jclepro.2018.12.090.
[91] Z. Zhao, B. Yang, Z. Xing, Modeling analysis on solar steam generator employed in multi-effect distillation (MED) system, Front. Energy. 13 (2019) 193–203. https://doi.org/10.1007/s11708-019-0608-0.
[92] K. Handayani, Y. Krozer, T. Filatova, From fossil fuels to renewables: An analysis of long-term scenarios considering technological learning, Energy Policy. 127 (2019) 134–146. https://doi.org/10.1016/j.enpol.2018.11.045.
[93] A. Assali, T. Khatib, A. Najjar, Renewable energy awareness among future generation of Palestine, Renew. Energy. 136 (2019) 254–263. https://doi.org/10.1016/j.renene.2019.01.007.
[94] R. Sharma, D. Choudhary, P. Kumar, J. Venkateswaran, C.S. Solanki, Do solar study lamps help children study at night? Evidence from rural India, Energy Sustain. Dev. 50 (2019) 109–116. https://doi.org/10.1016/j.esd.2019.03.005.
[95] Z. Liu, D. Wu, B.J. He, Q. Wang, H. Yu, W. Ma, G. Jin, Evaluating potentials of passive solar heating renovation for the energy poverty alleviation of plateau areas in developing countries: A case study in rural Qinghai-Tibet Plateau, China, Sol. Energy. 187 (2019) 95–107. https://doi.org/10.1016/j.solener.2019.05.049.
[96] Y. Gu, H. Wang, J. Xu, Y. Wang, X. Wang, Z.P. Robinson, F. Li, J. Wu, J. Tan, X. Zhi, Quantification of interlinked environmental footprints on a sustainable university campus: A nexus analysis perspective, Appl. Energy. 246 (2019) 65–76. https://doi.org/10.1016/j.apenergy.2019.04.015.
[97] J. Emmons Allison, K. McCrory, I. Oxnevad, Closing the renewable energy gender gap in the United States and Canada: The role of women's professional networking, Energy Res. Soc. Sci. 55 (2019) 35–45. https://doi.org/10.1016/j.erss.2019.03.011.
[98] P. Cui, D. Wei, J. Ji, H. Huang, E. Jia, S. Dou, T. Wang, W. Wang, M. Li, Planar p–n homojunction perovskite solar cells with efficiency exceeding 21.3%, Nat. Energy. 4 (2019) 150–159. https://doi.org/10.1038/s41560-018-0324-8.
[99] K.K. Zander, G. Simpson, S. Mathew, R. Nepal, S.T. Garnett, Preferences for and potential impacts of financial incentives to install residential rooftop solar photovoltaic systems in Australia, J. Clean. Prod. 230 (2019) 328–338. https://doi.org/10.1016/j.jclepro.2019.05.133.
[100] S. Tembhurne, F. Nandjou, S. Haussener, A thermally synergistic photo-electrochemical hydrogen generator operating under concentrated solar irradiation, Nat. Energy. 4 (2019) 399–407. https://doi.org/10.1038/s41560-019-0373-7.
[101] C. Zuo, A.D. Scully, D. Vak, W. Tan, X. Jiao, C.R. McNeill, D. Angmo, L. Ding, M. Gao, Self-Assembled 2D Perovskite Layers for Efficient Printable Solar Cells, Adv. Energy Mater. 9 (2019) 1803258. https://doi.org/10.1002/aenm.201803258.
[102] G. Liu, J. Jia, K. Zhang, X. Jia, Q. Yin, W. Zhong, L. Li, F. Huang, Y. Cao, 15% Efficiency Tandem Organic Solar Cell Based on a Novel Highly Efficient Wide-Bandgap Nonfullerene Acceptor with Low Energy Loss, Adv. Energy Mater. 9 (2019) 1803657. https://doi.org/10.1002/aenm.201803657.

[103] F. Huang, M. Li, P. Siffalovic, G. Cao, J. Tian, From scalable solution fabrication of perovskite films towards commercialization of solar cells, Energy Environ. Sci. 12 (2019) 518–549. https://doi.org/10.1039/c8ee03025a.
[104] M. Gao, L. Zhu, C.K. Peh, G.W. Ho, Solar absorber material and system designs for photothermal water vaporization towards clean water and energy production, Energy Environ. Sci. 12 (2019) 841–864. https://doi.org/10.1039/c8ee01146j.
[105] W. Leal Filho, A.L. Salvia, A. do Paço, R. Anholon, O.L. Gonçalves Quelhas, I.S. Rampasso, A. Ng, A.L. Balogun, B. Kondev, L.L. Brandli, A comparative study of approaches towards energy efficiency and renewable energy use at higher education institutions, J. Clean. Prod. 237 (2019) 117728. https://doi.org/10.1016/j.jclepro.2019.117728.
[106] M. Mohammadalizadehkorde, R. Weaver, Quantifying potential savings from sustainable energy projects at a large public university: An energy efficiency assessment for texas state university, Sustain. Energy Technol. Assessments. 37 (2020) 100570. https://doi.org/10.1016/j.seta.2019.100570.
[107] M.F. Ferreira, M.A.V. Freitas, N.F. da Silva, A.F. da Silva, L.R.L. da Paz, Insertion of photovoltaic solar systems in technological education institutions in Brazil: Teacher perceptions concerning contributions towards sustainable development, Sustain. 12 (2020) 1292. https://doi.org/10.3390/su12041292.
[108] S.B. Subramaniam, R. Senthil, Heat transfer enhancement of concentrated solar absorber using hollow cylindrical fins filled with phase change material, Int. J. Hydrogen Energy. 46 (2021) 22344–22355. https://doi.org/10.1016/j.ijhydene.2021.04.061.
[109] R. Senthil, A.P. Nishanth, Optical and thermal performance analysis of solar parabolic concentrator, Int. J. Mech. Prod. Eng. Res. Dev. 7 (2017) 367–374. https://doi.org/10.24247/ijmperdoct201737.
[110] R. Senthil, M. Cheralathan, Enhancement of heat absorption rate of direct absorption solar collector using graphite nanofluid, Int. J. ChemTech Res. 9 (2016) 303–308.
[111] L. Haelg, M. Waelchli, T.S. Schmidt, Supporting energy technology deployment while avoiding unintended technological lock-in: A policy design perspective, Environ. Res. Lett. 13 (2018) 104011. https://doi.org/10.1088/1748-9326/aae161.
[112] A.A. Adenle, Assessment of solar energy technologies in Africa-opportunities and challenges in meeting the 2030 agenda and sustainable development goals, in: Energy Policy, 2020: p. 111180. https://doi.org/10.1016/j.enpol.2019.111180.
[113] M. Xu, P. Xie, B.C. Xie, Study of China's optimal solar photovoltaic power development path to 2050, Resour. Policy. 65 (2020) 101541. https://doi.org/10.1016/j.resourpol.2019.101541.
[114] A. Diallo, R.K. Moussa, The effects of solar home system on welfare in off-grid areas: Evidence from Côte d'Ivoire, Energy. 194 (2020) 116835. https://doi.org/10.1016/j.energy.2019.116835.
[115] K.K. Zander, G. Simpson, S. Mathew, R. Nepal, S.T. Garnett, Preferences for and potential impacts of financial incentives to install residential rooftop solar photovoltaic systems in Australia, J. Clean. Prod. 230 (2019) 328–338. https://doi.org/10.1016/j.jclepro.2019.05.133.
[116] P. Yadav, P.J. Davies, S.A. Sarkodie, The prospects of decentralised solar energy home systems in rural communities: User experience, determinants, and impact of free solar power on the energy poverty cycle, Energy Strateg. Rev. 26 (2019) 100424. https://doi.org/10.1016/j.esr.2019.100424.
[117] C. Tregambi, M. Troiano, F. Montagnaro, R. Solimene, P. Salatino, Fluidized Beds for Concentrated Solar Thermal Technologies—A Review, Front. Energy Res. 9 (2021). https://doi.org/10.3389/fenrg.2021.618421.
[118] H.M. Mahmudul, M.G. Rasul, D. Akbar, R. Narayanan, M. Mofijur, A comprehensive review of the recent development and challenges of a solar-assisted biodigester system, Sci. Total Environ. 753 (2021) 141920. https://doi.org/10.1016/j.scitotenv.2020.141920.
[119] H. Vazini Modabber, M.H. Khoshgoftar Manesh, 4E dynamic analysis of a water-power cogeneration plant integrated with solar parabolic trough collector and absorption chiller, Therm. Sci. Eng. Prog. 21 (2021) 100785. https://doi.org/10.1016/j.tsep.2020.100785.
[120] H. Xiang, P. Ch, M.A. Nawaz, S. Chupradit, A. Fatima, M. Sadiq, Integration and economic viability of fueling the future with green hydrogen: An integration of its determinants from renewable economics, Int. J. Hydrogen Energy. 46 (2021) 38145–38162. https://doi.org/10.1016/j.ijhydene.2021.09.067.
[121] X. Zhang, W. Zhang, W. Yang, W. Liu, F. Min, S.S. Mao, J. Xie, Catalyst-coated proton exchange membrane for hydrogen production with high pressure water electrolysis, Appl. Phys. Lett. 119 (2021) 1ENG. https://doi.org/10.1063/5.0060150.
[122] D. Rodríguez-Gracia, J.A. Piedra-Fernández, L. Iribarne, J. Criado, R. Ayala, J. Alonso-Montesinos, C.U.M. de las Mercedes, Microservices and machine learning algorithms for adaptive green buildings, Sustain. 11 (2019) 4320. https://doi.org/10.3390/su11164320.

[123] R. Srikanth, M. Venkatesan, Design and modelling of hybrid fuel cell and solar-based electric vehicle, Int. J. Veh. Auton. Syst. 15 (2020) 225–240. https://doi.org/10.1504/IJVAS.2020.116445.

[124] S. Purohit, G. Brooks, M.A. Rhamdhani, M.I. Pownceby, Evaluation of concentrated solar thermal energy for iron ore agglomeration, J. Clean. Prod. 317 (2021) 128313. https://doi.org/10.1016/j.jclepro.2021.128313.

[125] I.A. Gondal, Microbial electrolysis cells and power-to-gas technology – A novel onsite industrial wastewater treatment and CCU arrangement, Water Environ. J. 35 (2021) 1376–1383. https://doi.org/10.1111/wej.12721.

[126] J.F. Ituna-Yudonago, Y.R. Galindo-Luna, O. García-Valladares, R.B. y. Brown, R. Shankar, J. Ibarra-Bahena, Review of solar-thermal collectors powered autoclave for the sterilization of medical equipment, Alexandria Eng. J. 60 (2021) 5401–5417. https://doi.org/10.1016/j.aej.2021.04.007.

[127] L. Zhao, B. Bhatia, L. Zhang, E. Strobach, A. Leroy, M.K. Yadav, S. Yang, T.A. Cooper, L.A. Weinstein, A. Modi, S.B. Kedare, G. Chen, E.N. Wang, A Passive High-Temperature High-Pressure Solar Steam Generator for Medical Sterilization, Joule. 4 (2020) 2733–2745. https://doi.org/10.1016/j.joule.2020.10.007.

[128] Y. Fang, S. Memon, J. Peng, M. Tyrer, T. Ming, Solar thermal performance of two innovative configurations of air-vacuum layered triple glazed windows, Renew. Energy. 150 (2020) 167–175. https://doi.org/10.1016/j.renene.2019.12.115.

[129] G. Chen, Y. Li, M. Bick, J. Chen, Smart Textiles for Electricity Generation, Chem. Rev. 120 (2020) 3668–3720. https://doi.org/10.1021/acs.chemrev.9b00821.

[130] R.A. Gonocruz, R. Nakamura, K. Yoshino, M. Homma, T. Doi, Y. Yoshida, A. Tani, Analysis of the rice yield under an agrivoltaic system: A case study in Japan, Environ. - MDPI. 8 (2021) 65. https://doi.org/10.3390/environments8070065.

[131] M.H. Riaz, H. Imran, R. Younas, N.Z. Butt, The optimization of vertical bifacial photovoltaic farms for efficient agrivoltaic systems, Sol. Energy. 230 (2021) 1004–1012. https://doi.org/10.1016/j.solener.2021.10.051.

[132] M.A. Hannan, A.Q. Al-Shetwi, R.A. Begum, P. Jern Ker, S.A. Rahman, M. Mansor, M.S. Mia, K.M. Muttaqi, Z.Y. Dong, Impact assessment of battery energy storage systems towards achieving sustainable development goals, J. Energy Storage. 42 (2021) 103040. https://doi.org/10.1016/j.est.2021.103040.

[133] A.S. Budiman, S. Anbazhagan, G. Illya, W.J.R. Song, R. Sahay, S.K. Tippabhotla, A.A.O. Tay, Enabling curvable silicon photovoltaics technology using polycarbonate-sandwiched laminate design, Sol. Energy. 220 (2021) 462–472. https://doi.org/10.1016/j.solener.2021.03.021.

[134] Y. Dai, Y. Yin, Y. Lu, Strategies to facilitate photovoltaic applications in road structures for energy harvesting, Energies. 14 (2021) 7097. https://doi.org/10.3390/en14217097.

[135] L. Chen, J. Wang, C. Xu, The Application of Solar Photovoltaic Power Generation System in Ships, J. Coast. Res. 94 (2019) 525–529. https://doi.org/10.2112/SI94-104.1.

[136] S. Buragohain, K. Mohanty, P. Mahanta, Hybridization of solar photovoltaic and biogas system: Experimental, economic and environmental analysis, Sustain. Energy Technol. Assessments. 45 (2021) 101050. https://doi.org/10.1016/j.seta.2021.101050.

[137] N. Jones, P. Warren, Innovation and distribution of Solar Home Systems in Bangladesh, Clim. Dev. 13 (2021) 386–398. https://doi.org/10.1080/17565529.2020.1785829.

[138] H.K. Salim, R.A. Stewart, O. Sahin, M. Dudley, End-of-life management of solar photovoltaic and battery energy storage systems: A stakeholder survey in Australia, Resour. Conserv. Recycl. 150 (2019) 104444. https://doi.org/10.1016/j.resconrec.2019.104444.

[139] C.V. Restrepo, E. Benavides, J.C. Zambrano, V. Moncayo, E. Castro, Hand made solar cells from chlorophyll for teaching in high school energy education, Int. J. Ambient Energy. (2020) 1–7. https://doi.org/10.1080/01430750.2020.1712243.

[140] B.R. Entele, Analysis of households' willingness to pay for a renewable source of electricity service connection: evidence from a double-bounded dichotomous choice survey in rural Ethiopia, Heliyon. 6 (2020) e03332. https://doi.org/10.1016/j.heliyon.2020.e03332.

[141] J. Lee, M.M.C. Shepley, Benefits of solar photovoltaic systems for low-income families in social housing of Korea: Renewable energy applications as solutions to energy poverty, J. Build. Eng. 28 (2020) 101016. https://doi.org/10.1016/j.jobe.2019.101016.

[142] C. Sharma, A. Jain, Entrepreneurship through start-ups in hill areas using photovoltaic systems, Bull. Electr. Eng. Informatics. 6 (2017) 105–121. https://doi.org/10.11591/eei.v6i2.613.

[143] R. Senthil, M. Gupta, S. Makda, The synthesis and production challenges of quantum dot based solar cells, Int. J. Mech. Eng. Technol. 9 (2018) 236–244.

[144] U.K. Priya, R. Senthil, A review of the impact of the green landscape interventions on the urban microclimate of tropical areas, Build. Environ. 205 (2021) 108190. https://doi.org/10.1016/j.buildenv.2021.108190.
[145] G. Raghav, P.K. Sharma, S. Kumar, R. Maithani, Method of research for solar cookers performance characteristics-Analysis and comparison, Acta Innov. 2021 (2021) 54–66. https://doi.org/10.32933/ActaInnovations.39.6.
[146] G. Raghav, P.K. Sharma, S. Kumar, R. Maithani, A. Iung, Q. Mercier, Analysis of solar cooker with thermal storage for remote hilly areas: Determination of heating and cooling characteristic time, Acta Innov. 40 (2021) 5–18. https://doi.org/10.32933/ActaInnovations.40.1.
[147] M. Nagpal, R. Maithani, S. Kumar, Energetic & exergetic analysis of a parabolic trough: Concentrated solar power plant, Acta Innov. 40 (2021) 19–30. https://doi.org/10.32933/ActaInnovations.40.2.
[148] Q. Zhang, C. Prouty, J.B. Zimmerman, J.R. Mihelcic, More than Target 6.3: A Systems Approach to Rethinking Sustainable Development Goals in a Resource-Scarce World, Engineering. 2 (2016) 481–489. https://doi.org/10.1016/J.ENG.2016.04.010.
[149] J. Nan, X. Guo, J. Xiao, X. Li, W. Chen, W. Wu, H. Liu, Y. Wang, M. Wu, G. Wang, Nanoengineering of 2D MXene-Based Materials for Energy Storage Applications, Small. 17 (2021) 1902085. https://doi.org/10.1002/smll.201902085.
[150] A.G. Olabi, M.A. Abdelkareem, T. Wilberforce, E.T. Sayed, Application of graphene in energy storage device – A review, Renew. Sustain. Energy Rev. 135 (2021) 110026. https://doi.org/10.1016/j.rser.2020.110026.
[151] R. Senthil, Effect of charging of phase change material in vertical and horizontal rectangular enclosures in a concentrated solar receiver, Case Stud. Therm. Eng. 21 (2020) 100653. https://doi.org/10.1016/j.csite.2020.100653.
[152] R. Senthil, S. Prabhu, M. Cheralathan, Effect of heat transfer fluid input parameters on thermal output of parabolic dish solar receiver using design of experiment techniques, Int. J. Mech. Eng. Technol. 8 (2017) 1148–1156.
[153] S. Zhang, D. Feng, L. Shi, L. Wang, Y. Jin, L. Tian, Z. Li, G. Wang, L. Zhao, Y. Yan, A review of phase change heat transfer in shape-stabilized phase change materials (ss-PCMs) based on porous supports for thermal energy storage, Renew. Sustain. Energy Rev. 135 (2021) 110127. https://doi.org/10.1016/j.rser.2020.110127.
[154] W. Tushar, C. Yuen, T.K. Saha, T. Morstyn, A.C. Chapman, M.J.E. Alam, S. Hanif, H.V. Poor, Peer-to-peer energy systems for connected communities: A review of recent advances and emerging challenges, Appl. Energy. 282 (2021) 116131. https://doi.org/10.1016/j.apenergy.2020.116131.
[155] A.G. Olabi, K. Obaideen, K. Elsaid, T. Wilberforce, E.T. Sayed, H.M. Maghrabie, M.A. Abdelkareem, Assessment of the pre-combustion carbon capture contribution into sustainable development goals SDGs using novel indicators, Renew. Sustain. Energy Rev. 153 (2022) 111710. https://doi.org/10.1016/j.rser.2021.111710.
[156] D. Binh Nguyen, D. Nong, P. Simshauser, T. Nguyen-Huy, General equilibrium impact evaluation of food top-up induced by households' renewable power self-supply in 141 regions, Appl. Energy. 306 (2022) 118126. https://doi.org/10.1016/j.apenergy.2021.118126.
[157] M. Ram, J.C. Osorio-Aravena, A. Aghahosseini, D. Bogdanov, C. Breyer, Job creation during a climate compliant global energy transition across the power, heat, transport, and desalination sectors by 2050, Energy. 238 (2022) 121690. https://doi.org/10.1016/j.energy.2021.121690.
[158] R. Senthil, P. Sundaram, Effect of phase change materials for thermal management of buildings, Int. J. Civ. Eng. Technol. 8 (2017) 761–767.
[159] U. Shahzad, D. Ferraz, H.H. Nguyen, L. Cui, Investigating the spill overs and connectedness between financial globalization, high-tech industries and environmental footprints: Fresh evidence in context of China, Technol. Forecast. Soc. Change. 174 (2022) 121205. https://doi.org/10.1016/j.techfore.2021.121205.