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Perspective

Solar energy technology and its roles in sustainable development

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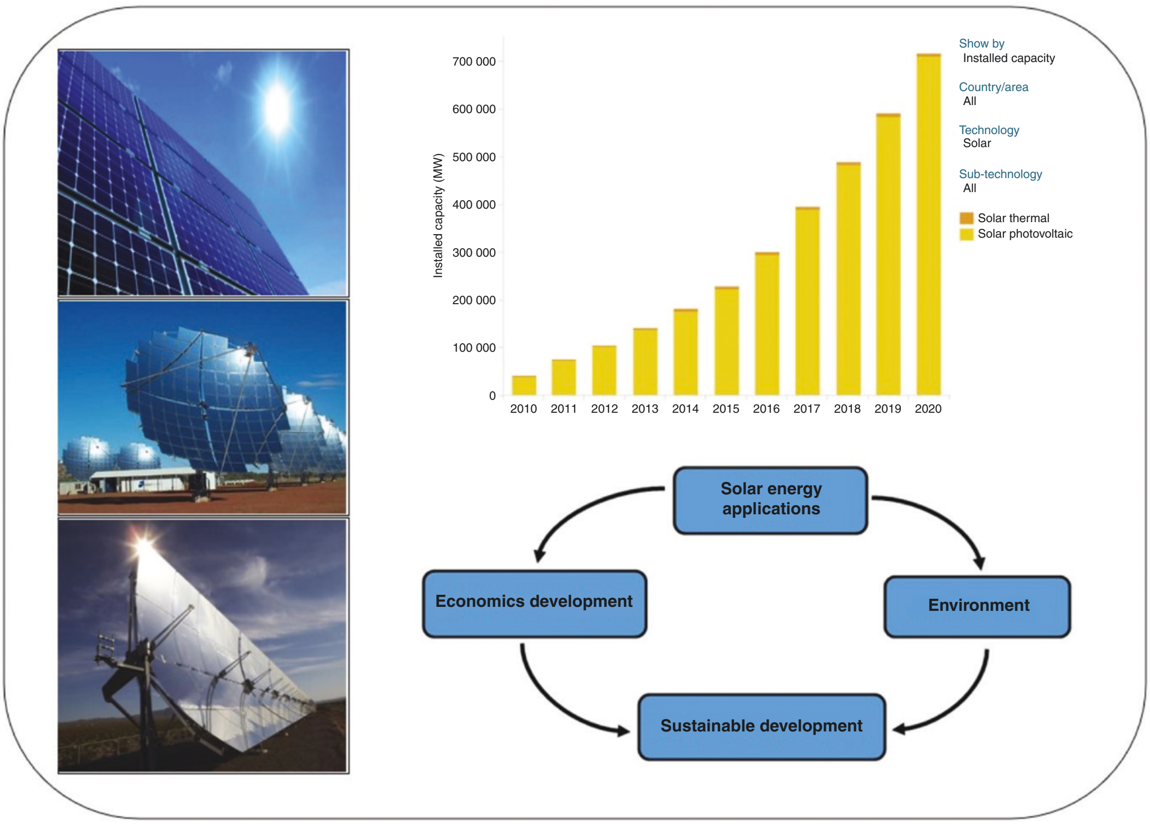
Abstract

Solar energy is environmentally friendly technology, a great energy supply and one of the most significant renewable and green energy sources. It plays a substantial role in achieving sustainable development energy solutions. Therefore, the massive amount of solar energy attainable daily makes it a very attractive resource for generating electricity. Both technologies, applications of concentrated solar power or solar photovoltaics, are always under continuous development to fulfil our energy needs. Hence, a large installed capacity of solar energy applications worldwide, in the same context, supports the energy sector and meets the employment market to gain sufficient development. This paper highlights solar energy applications and their role in sustainable development and considers renewable energy's overall employment potential. Thus, it provides insights and analysis on solar energy sustainability, including environmental and economic development. Furthermore, it has identified the contributions of solar energy applications in sustainable development by providing energy needs, creating jobs opportunities and enhancing environmental protection. Finally, the perspective of solar energy technology is drawn up in the application of the energy sector and affords a vision of future development in this domain.

Graphical Abstract



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Introduction

With reference to the recommendations of the UN, the Climate Change Conference, COP26, was held in Glasgow, UK, in 2021. They reached an agreement through the representatives of the 197 countries, where they concurred to move towards reducing dependency on coal and fossil-fuel sources. Furthermore, the conference stated 'the various opportunities for governments to prioritize health and equity in the international climate movement and sustainable development agenda'. Also, one of the testaments is the necessity to 'create energy systems that protect and improve climate and health' [1, 2].

The Paris Climate Accords is a worldwide agreement on climate change signed in 2015, which addressed the mitigation of climate change, adaptation and finance. Consequently, the representatives of 196 countries concurred to decrease their greenhouse gas emissions [3]. The Paris Agreement is essential for present and future generations to attain a more secure and stable environment. In essence, the Paris Agreement has been about safeguarding people from such an uncertain and progressively dangerous environment and ensuring everyone can have the right to live in a healthy, pollutant-free environment without the negative impacts of climate change [3, 4].

In recent decades, there has been an increase in demand for cleaner energy resources. Based on that, decision-makers of all countries have drawn up plans that depend on renewable sources through a long-term strategy. Thus, such plans reduce the reliance of dependence on traditional energy sources and substitute traditional energy sources with alternative energy technology. As a result, the global community is starting to shift towards utilizing sustainable energy sources and reducing dependence on traditional fossil fuels as a source of energy [5, 6].

In 2015, the UN adopted the sustainable development goals (SDGs) and recognized them as international legislation, which demands a global effort to end poverty, safeguard the environment and guarantee that by 2030, humanity lives in prosperity and peace. Consequently, progress needs to be balanced among economic, social and environmental sustainability models [7].

Many national and international regulations have been established to control the gas emissions and pollutants that impact the environment [8]. However, the negative effects of increased carbon in the atmosphere have grown in the last 10 years. Production and use of fossil fuels emit methane (CH_4), carbon dioxide (CO_2) and carbon monoxide (CO), which are the most significant contributors to environmental emissions on our planet. Additionally, coal and oil, including gasoline, coal, oil and methane, are commonly used in energy for transport or for generating electricity. Therefore, burning these fossil fuels is deemed the largest emitter when used for electricity generation, transport, etc. However, these energy resources are considered depleted energy sources being consumed to an unsustainable degree [9–11].

Energy is an essential need for the existence and growth of human communities. Consequently, the need for energy has increased gradually as human civilization has progressed. Additionally, in the past few decades, the rapid rise of the world's population and its reliance on technological developments have increased energy demands. Furthermore, green technology sources play an important role in sustainably providing energy supplies, especially in mitigating climate change [5, 6, 8].

Currently, fossil fuels remain dominant and will continue to be the primary source of large-scale energy for the foreseeable future; however, renewable energy should play a vital role in the future of global energy. The global energy system is undergoing a movement towards more sustainable sources of energy [12, 13].

Power generation by fossil-fuel resources has peaked, whilst solar energy is predicted to be at the vanguard of energy generation in the near future. Moreover, it is predicted that by 2050, the generation of solar energy will have increased to 48% due to economic and industrial growth [13, 14].

In recent years, it has become increasingly obvious that the globe must decrease greenhouse gas emissions by 2050, ideally towards net zero, if we are to fulfil the Paris Agreement's goal to reduce global temperature increases [3, 4]. The net-zero emissions complement the scenario of sustainable development assessment by 2050. According to the agreed scenario of sustainable development, many industrialized economies must achieve net-zero emissions by 2050. However, the net-zero emissions 2050 brought the first detailed International Energy Agency (IEA) modelling of what strategy will be required over the next 10 years to achieve net-zero carbon emissions worldwide by 2050 [15–17].

The global statistics of greenhouse gas emissions have been identified; in 2019, there was a 1% decrease in CO_2 emissions from the power industry; that figure dropped by 7% in 2020 due to the COVID-19 crisis, thus indicating a drop in coal-fired energy generation that is being squeezed by decreasing energy needs, growth of renewables and the shift away from fossil fuels. As a result, in 2020, the energy industry was expected to generate ~13 Gt CO_2, representing ~40% of total world energy sector emissions related to CO_2. The annual electricity generation stepped back to pre-crisis levels by 2021, although due to a changing 'fuel mix', the CO_2 emissions in the power sector will grow just a little before remaining roughly steady until 2030 [15].

Therefore, based on the information mentioned above, the advantages of solar energy technology are a renewable and clean energy source that is plentiful, cheaper costs, less maintenance and environmentally friendly, to name but a few. The significance of this paper is to highlight solar energy applications to ensure sustainable development; thus, it is vital to researchers, engineers and customers alike. The article's primary aim is to raise public awareness and disseminate the culture of solar energy usage in daily life, since moving forward, it is the best. The scope of this paper is as follows. Section 1 represents a summary of the introduction. Section 2 represents a summary of installed capacity and the application of solar energy worldwide. Section 3 presents the role of solar energy in the sustainable development and employment of renewable energy. Section 4 represents the perspective of solar energy. Finally, Section 5 outlines the conclusions and recommendations for future work.

1 Installed capacity and application of solar energy worldwide

1.1 Installed capacity of solar energy

The history of solar energy can be traced back to the seventh century when mirrors with solar power were used. In 1893, the photovoltaic (PV) effect was discovered; after many decades, scientists developed this technology for electricity generation [18]. Based on that, after many years of research and development from scientists worldwide, solar energy technology is classified into two key applications: solar thermal and solar PV.

PV systems convert the Sun's energy into electricity by utilizing solar panels. These PV devices have quickly become the cheapest option for new electricity generation in numerous world locations due to their ubiquitous deployment. For example, during the period from 2010 to 2018, the cost of generating electricity by solar PV plants decreased by 77%. However, solar PV installed capacity progress expanded 100-fold between 2005 and

2018. Consequently, solar PV has emerged as a key component in the low-carbon sustainable energy system required to provide access to affordable and dependable electricity, assisting in fulfilling the Paris climate agreement and in achieving the 2030 SDG targets [19].

The installed capacity of solar energy worldwide has been rapidly increased to meet energy demands. The installed capacity of PV technology from 2010 to 2020 increased from 40 334 to 709 674 MW, whereas the installed capacity of concentrated solar power (CSP) applications, which was 1266 MW in 2010, after 10 years had increased to 6479 MW. Therefore, solar PV technology has more deployed installations than CSP applications. So, the stand-alone solar PV and large-scale grid-connected PV plants are widely used worldwide and used in space applications. Fig. 1 represents the installation of solar energy worldwide.

1.2 Application of solar energy

Energy can be obtained directly from the Sun—so-called solar energy. Globally, there has been growth in solar energy applications, as it can be used to generate electricity, desalinate water and generate heat, etc. The taxonomy of applications of solar energy is as follows: (i) PVs and (ii) CSP. Fig. 2 details the taxonomy of solar energy applications.

Solar cells are devices that convert sunlight directly into electricity; typical semiconductor materials are utilized to form a PV solar cell device. These materials' characteristics are based on atoms with four electrons in their outer orbit or shell. Semiconductor materials are from the periodic table's group 'IV' or a mixture of groups 'IV' and 'II', the latter known as 'II–VI' semiconductors [21]. Additionally, a periodic table mixture of elements from groups 'III' and 'V' can create 'III–V' materials [22].

PV devices, sometimes called solar cells, are electronic devices that convert sunlight into electrical power. PVs are also one of the rapidly growing renewable-energy technologies of today. It is therefore anticipated to play a significant role in the long-term world electricity-generating mixture moving forward.

Solar PV systems can be incorporated to supply electricity on a commercial level or installed in smaller clusters for mini-grids or individual usage. Utilizing PV modules to power mini-grids is a great way to offer electricity to those who do not live close to power-transmission lines, especially in developing countries with abundant solar energy resources. In the most recent decade, the cost of producing PV modules has dropped drastically, giving them not only accessibility but sometimes making them the least expensive energy form. PV arrays have a 30-year lifetime and come in various shades based on the type of material utilized in their production.

The most typical method for solar PV desalination technology that is used for desalinating sea or salty water is electrodialysis (ED). Therefore, solar PV modules are directly connected to the desalination process. This technique employs the direct-current electricity to remove salt from the sea or salty water.

The technology of PV–thermal (PV–T) comprises conventional solar PV modules coupled with a thermal collector mounted on the rear side of the PV module to pre-heat domestic hot water. Accordingly, this enables a larger portion of the incident solar energy on the collector to be converted into beneficial electrical and thermal energy.

A zero-energy building is a building that is designed for zero net energy emissions and emits no carbon dioxide. Building-integrated PV (BIPV) technology is coupled with solar energy sources and devices in buildings that are utilized to supply energy needs. Thus, building-integrated PVs utilizing thermal energy (BIPV/T) incorporate creative technologies such as solar cooling [23].

A PV water-pumping system is typically used to pump water in rural, isolated and desert areas. The system consists of PV modules to power a water pump to the location of water need. The water-pumping rate depends on many factors such as pumping head, solar intensity, etc.

A PV-powered cathodic protection (CP) system is designed to supply a CP system to control the corrosion of a metal surface.

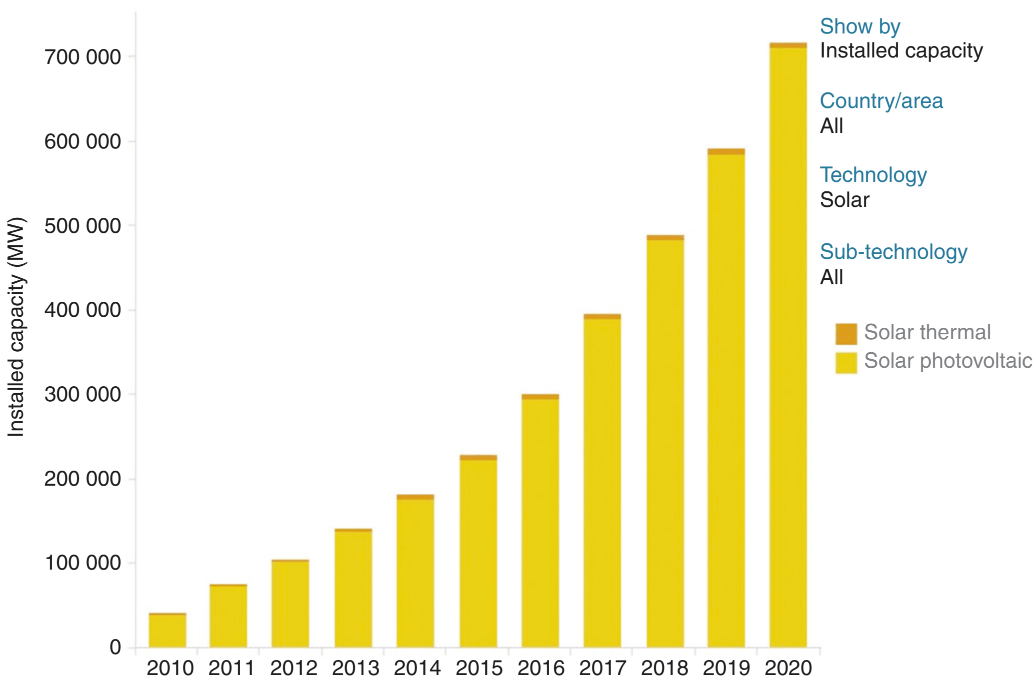

Fig. 1: Installation capacity of solar energy worldwide [20].

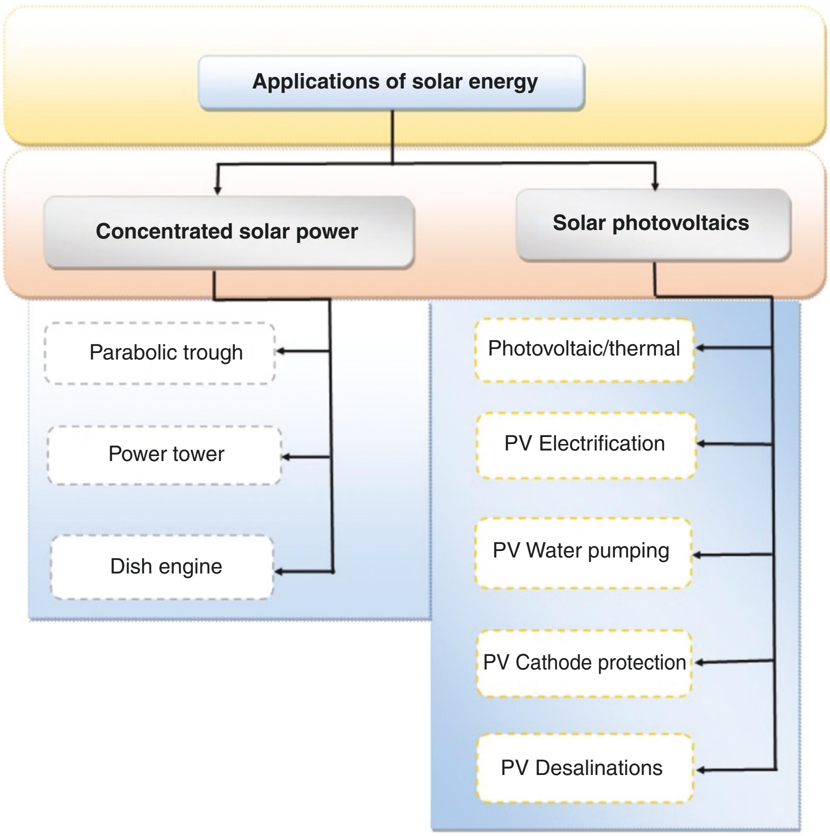

Fig. 2: The taxonomy of solar energy applications.

This technique is based on the impressive current acquired from PV solar energy systems and is utilized for burying pipelines, tanks, concrete structures, etc.

Concentrated PV (CPV) technology uses either the refractive or the reflective concentrators to increase sunlight to PV cells [24, 25]. High-efficiency solar cells are usually used, consisting of many layers of semiconductor materials that stack on top of each other. This technology has an efficiency of >47%. In addition, the devices produce electricity and the heat can be used for other purposes [26, 27].

For CSP systems, the solar rays are concentrated using mirrors in this application. These rays will heat a fluid, resulting in steam used to power a turbine and generate electricity. Large-scale power stations employ CSP to generate electricity. A field of mirrors typically redirect rays to a tall thin tower in a CSP power station. Thus, numerous large flat heliostats (mirrors) are used to track the Sun and concentrate its light onto a receiver in power tower systems, sometimes known as central receivers. The hot fluid could be utilized right away to produce steam or stored for later usage. Another of the great benefits of a CSP power station is that it may be built with molten salts to store heat and generate electricity outside of daylight hours.

Mirrored dishes are used in dish engine systems to focus and concentrate sunlight onto a receiver. The dish assembly tracks the Sun's movement to capture as much solar energy as possible. The engine includes thin tubes that work outside the four-piston cylinders and it opens into the cylinders containing hydrogen or helium gas. The pistons are driven by the expanding gas. Finally, the pistons drive an electric generator by turning a crankshaft.

A further water-treatment technique, using reverse osmosis, depends on the solar-thermal and using solar concentrated power through the parabolic trough technique. The desalination employs CSP technology that utilizes hybrid integration and thermal storage allows continuous operation and is a cost-effective solution. Solar thermal can be used for domestic purposes such as a dryer. In some countries or societies, the so-called food dehydration is traditionally used to preserve some food materials such as meats, fruits and vegetables.

2 The role of solar energy in sustainable development

Sustainable energy development is defined as the development of the energy sector in terms of energy generating, distributing and utilizing that are based on sustainability rules [28]. Energy systems will significantly impact the environment in both developed and developing countries. Consequently, the global sustainable energy system must optimize efficiency and reduce emissions [29].

The sustainable development scenario is built based on the economic perspective. It also examines what activities will be required to meet shared long-term climate benefits, clean air and energy access targets. The short-term details are based on the IEA's sustainable recovery strategy, which aims to promote economies and employment through developing a cleaner and more reliable energy infrastructure [15]. In addition, sustainable development includes utilizing renewable-energy applications, smart-grid technologies, energy security, and energy pricing, and having a sound energy policy [29].

The demand-side response can help meet the flexibility requirements in electricity systems by moving demand over time. As a result, the integration of renewable technologies for helping facilitate the peak demand is reduced, system stability is maintained, and total costs and CO_2 emissions are reduced. The demand-side response is currently used mostly in Europe and North America, where it is primarily aimed at huge commercial and industrial electricity customers [15].

International standards are an essential component of high-quality infrastructure. Establishing legislative convergence, increasing competition and supporting innovation will allow participants to take part in a global world PV market [30]. Numerous additional countries might benefit from more actively engaging in developing global solar PV standards. The leading countries in solar PV manufacturing and deployment have embraced global standards for PV systems and highly contributed to clean-energy development. Additional assistance and capacity-building to enhance quality infrastructure in developing economies might also help support wider implementation and compliance with international solar PV standards. Thus, support can bring legal requirements and frameworks into consistency and give additional impetus for the trade of secure and high-quality solar PV products [19].

Continuous trade-led dissemination of solar PV and other renewable technologies will strengthen the national infrastructure. For instance, off-grid solar energy alternatives, such as standalone systems and mini-grids, could be easily deployed to assist healthcare facilities in improving their degree of services and powering portable testing sites and vaccination coolers. In addition to helping in the immediate medical crisis, trade-led solar PV adoption could aid in the improving economy from the COVID-19 outbreak, not least by providing jobs in the renewable-energy sector, which are estimated to reach >40 million by 2050 [19].

The framework for energy sustainability development, by the application of solar energy, is one way to achieve that goal. With the large availability of solar energy resources for PV and CSP energy applications, we can move towards energy sustainability. Fig. 3 illustrates plans for solar energy sustainability.

The environmental consideration of such applications, including an aspect of the environmental conditions, operating conditions, etc., have been assessed. It is clean, friendly to the environment and also energy-saving. Moreover, this technology has no removable parts, low maintenance procedures and longevity.

Economic and social development are considered by offering job opportunities to the community and providing cheaper energy options. It can also improve people's income; in turn, living standards will be enhanced. Therefore, energy is paramount, considered to be the most vital element of human life, society's progress and economic development.

As efforts are made to increase the energy transition towards sustainable energy systems, it is anticipated that the next decade will see a continued booming of solar energy and all clean-energy technology. Scholars worldwide consider research and innovation to be substantial drivers to enhance the potency of such solar application technology.

2.1 Employment from renewable energy

The employment market has also boomed with the deployment of renewable-energy technology. Renewable-energy technology applications have created >12 million jobs worldwide. The solar PV application came as the pioneer, which created >3 million jobs. At the same time, while the solar thermal applications (solar heating and cooling) created >819 000 jobs, the CSP attained >31 000 jobs [20].

According to the reports, although top markets such as the USA, the EU and China had the highest investment in renewables jobs, other Asian countries have emerged as players in the solar PV panel manufacturers' industry [31].

Solar energy employment has offered more employment than other renewable sources. For example, in the developing countries, there was a growth in employment chances in solar applications that powered 'micro-enterprises'. Hence, it has been significant in eliminating poverty, which is considered the key goal of sustainable energy development. Therefore, solar energy plays a critical part in fulfilling the sustainability targets for a better plant and environment [31, 32]. Fig. 4 illustrates distributions of world renewable-energy employment.

The world distribution of PV jobs is disseminated across the continents as follows. There was 70% employment in PV applications available in Asia, while 10% is available in North America, 10% available in South America and 10% availability in Europe. Table 1 details the top 10 countries that have relevant jobs in Asia, North America, South America and Europe.

3 The perspective of solar energy

Solar energy investments can meet energy targets and environmental protection by reducing carbon emissions while having no detrimental influence on the country's development [32, 34]. In countries located in the 'Sunbelt', there is huge potential for solar energy, where there is a year-round abundance of solar global horizontal irradiation. Consequently, these countries, including the Middle East, Australia, North Africa, China, the USA and Southern Africa, to name a few, have a lot of potential for solar energy technology. The average yearly solar intensity is >2800 kWh/m^2 and the average daily solar intensity is >7.5 kWh/m^2. Fig. 5 illustrates the optimum areas for global solar irradiation.

The distribution of solar radiation and its intensity are two important factors that influence the efficiency of solar PV technology and these two parameters vary among different countries. Therefore, it is essential to realize that some solar energy is wasted since it is not utilized. On the other hand, solar radiation is abundant in several countries, especially in developing ones, which makes it invaluable [36, 37].

Worldwide, the PV industry has benefited recently from globalization, which has allowed huge improvements in economies of scale, while vertical integration has created strong value chains: as manufacturers source materials from an increasing number of suppliers, prices have dropped while quality has been maintained. Furthermore, the worldwide incorporated PV solar device market is growing fast, creating opportunities enabling solar energy firms to benefit from significant government help with underwriting, subsides, beneficial trading licences and training of a competent workforce, while the increased rivalry has reinforced the motivation to continue investing in research and development, both public and private [19, 33].

The global outbreak of COVID-19 has impacted 'cross-border supply chains' and those investors working in the renewable-energy sector. As a result, more diversity of solar PV supply-chain processes may be required in the future to enhance long-term flexibility versus exogenous shocks [19, 33].

It is vital to establish a well-functioning quality infrastructure to expand the distribution of solar PV technologies beyond borders and make it easier for new enterprises to enter solar PV value chains. In addition, a strong quality infrastructure system is a significant instrument for assisting local firms in meeting the demands of trade markets. Furthermore, high-quality infrastructure can help reduce associated risks with the worldwide PV project value chain, such as underperforming, inefficient and

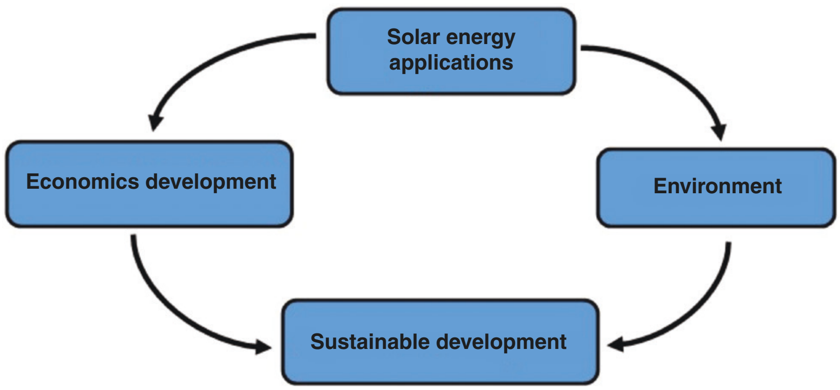

Fig. 3: Framework for solar energy applications in energy sustainability.

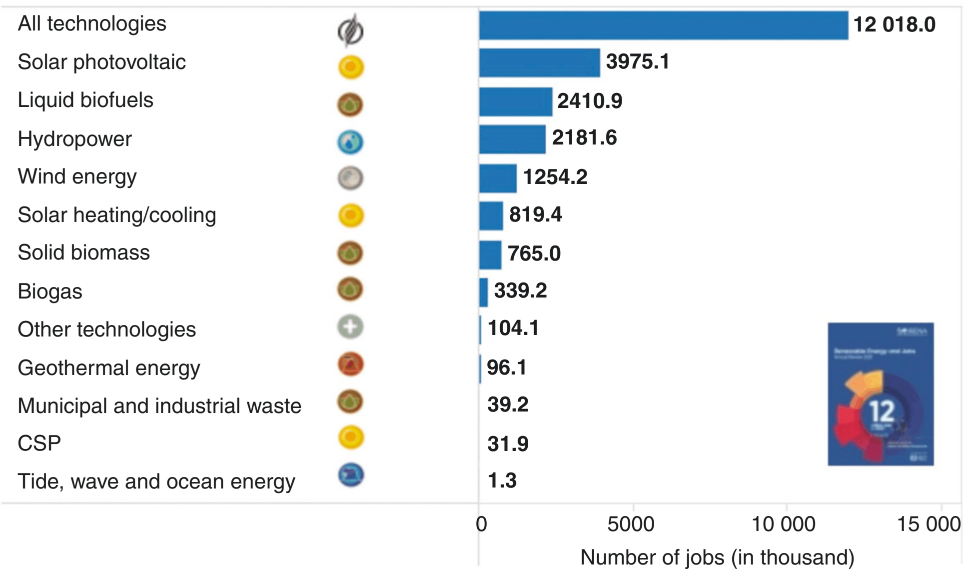

Fig. 4: World renewable-energy employment [20].

Table 1: List of the top 10 countries that created jobs in solar PV applications [19, 33]

Continent	Country	Prevalent jobs (millions of jobs)
Asia	China	2.240
Asia	Japan	0.250
North America	United States	0.240
Asia	India	0.205
Asia	Bangladesh	0.145
Asia	Viet Nam	0.055
Asia	Malaysia	0.050
South America	Brazil	0.040
Europe	Germany	0.030
Asia	Philippines	0.020

failing goods, limiting the development, improvement and export of these technologies. Governments worldwide are, at various levels, creating quality infrastructure, including the usage of metrology i.e. the science of measurement and its application, regulations, testing procedures, accreditation, certification and market monitoring [33, 38].

The perspective is based on a continuous process of technological advancement and learning. Its speed is determined by its deployment, which varies depending on the scenario [39, 40]. The expense trends support policy preferences for low-carbon energy sources, particularly in increased energy-alteration scenarios. Emerging technologies are introduced and implemented as quickly as they ever have been before in energy history [15, 33].

The CSP stations have been in use since the early 1980s and are currently found all over the world. The CSP power stations in the USA currently produce >800 MW of electricity yearly, which is sufficient to power ~500 000 houses. New CSP heat-transfer fluids being developed can function at ~1288°C, which is greater than existing fluids, to improve the efficiency of CSP systems and, as a result, to lower the cost of energy generated using this technology. Thus, as a result, CSP is considered to have a bright future, with the ability to offer large-scale renewable energy that can supplement and soon replace traditional electricity-production technologies [41]. The DESERTEC project has drawn out the possibility of CSP in the Sahara Desert regions. When completed, this investment project will have the world's biggest energy-generation capacity through the CSP plant, which aims to transport energy from North Africa to Europe [42, 43].

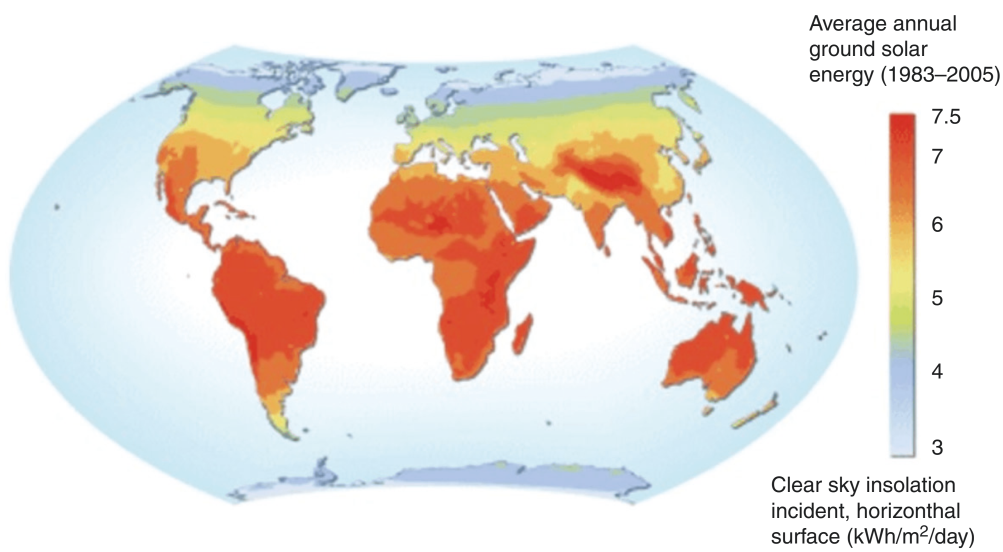

Fig. 5: World global solar irradiation map [35].

The costs of manufacturing materials for PV devices have recently decreased, which is predicted to compensate for the requirements and increase the globe's electricity demand [44]. Solar energy is a renewable, clean and environmentally friendly source of energy. Therefore, solar PV application techniques should be widely utilized. Although PV technology has always been under development for a variety of purposes, the fact that PV solar cells convert the radiant energy from the Sun directly into electrical power means it can be applied in space and in terrestrial applications [38, 45].

In one way or another, the whole renewable-energy sector has a benefit over other energy industries. A long-term energy development plan needs an energy source that is inexhaustible, virtually accessible and simple to gather. The Sun rises over the horizon every day around the globe and leaves behind ~108–1018 kWh of energy; consequently, it is more than humanity will ever require to fulfil its desire for electricity [46].

The technology that converts solar radiation into electricity is well known and utilizes PV cells, which are already in use worldwide. In addition, various solar PV technologies are available today, including hybrid solar cells, inorganic solar cells and organic solar cells. So far, solar PV devices made from silicon have led the solar market; however, these PVs have certain drawbacks, such as expenditure of material, time-consuming production, etc. It is important to mention here the operational challenges of solar energy in that it does not work at night, has less output in cloudy weather and does not work in sandstorm conditions. PV battery storage is widely used to reduce the challenges to gain high reliability. Therefore, attempts have been made to find alternative materials to address these constraints. Currently, this domination is challenged by the evolution of the emerging generation of solar PV devices based on perovskite, organic and organic/inorganic hybrid materials.

4 Conclusions

This paper highlights the significance of sustainable energy development. Solar energy would help steady energy prices and give numerous social, environmental and economic benefits. This has been indicated by solar energy's contribution to achieving sustainable development through meeting energy demands, creating jobs and protecting the environment. Hence, a paramount critical component of long-term sustainability should be investigated. Based on the current condition of fossil-fuel resources, which are deemed to be depleting energy sources, finding an innovative technique to deploy clean-energy technology is both essential and expected. Notwithstanding, solar energy has yet to reach maturity in development, especially CSP technology. Also, with growing developments in PV systems, there has been a huge rise in demand for PV technology applications all over the globe. Further work needs to be undertaken to develop energy sustainably and consider other clean energy resources. Moreover, a comprehensive experimental and validation process for such applications is required to develop cleaner energy sources to decarbonize our planet.

Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] World Health Organization. *COP26 Special Report on Climate Change and Health: The Health Argument for Climate Action*. Geneva: World Health Organization, 2021.

[2] Hunter DB, Salzman JE, Zaelke D. *Glasgow Climate Summit: COP26*. UCLA School of Law, Public Law Research Paper No. 22-02. 2021. doi: org/10.2139/ssrn.4005648 30 March 2022, date last accessed).

[3] UNFCCC. *Paris Agreement-Status of Ratification, United Nations Framework Convention on Climate*, 2016. https://unfccc.int/process/the-paris-agreement/status-of-ratification (25 January 2022, date last accessed).

[4] UNFCCC. *The Paris Agreement*. Archived from the original on 19 March 2021. Retrieved 18 September 2021. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement (2 February 2022, date last accessed).

[5] Watts RG. *Engineering Response to Climate Change*. 2nd edn. Boca Raton, FL: CRC Press, 2013.

[6] Sorensen B. *Renewable Energy: Physics, Engineering, Environmental Impacts, Economics and Planning*. 4th edn. London: Academic Press, 2010.

[7] IEA, IRENA, WMO, WBG, WHO. *Tracking SDG7: The Energy Progress Report 2021*. Washington, DC: The World Bank, 2021.
[8] Edenhofer O, Pichs-Madruga R, Sokona Y, *et al*. *Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press, 2011.
[9] Roaf S, Roaf S, Crichton D, *et al*. *Adapting buildings and Cities for Climate Change: A 21st Century Survival Guide*. 2nd edn. Oxford: Architectural Press, 2009.
[10] Sims RE. Renewable energy: a response to climate change. *Solar Energy*, 2004, 76:9–17.
[11] Muneer T. *Solar Radiation and Daylight Models*. 2nd edn, London: Routledge, 2004.
[12] Martin J. 'Green growth': from a growing eco-industry to economic sustainability. *Energy Policy*, 2012, 48:13–21.
[13] IRENA. *A Roadmap to 2050: International Renewable Energy Agency: Global energy Transformation*. Abu Dhabi: IRENA, 2018.
[14] Kost C, Mayer JN, Thomsen J, *et al*. *Levelized Cost of Electricity Renewable Energy Technologies*. Freiburg: Fraunhofer Institute for Solar Energy Systems (ISE), 2013, 144.
[15] Cozzi L, Gould T, Bouckart S, *et al*. *World Energy Outlook 2020*. Paris: International Energy Agency, 2020.
[16] Ku AY, de Souza A, McRobie J, *et al*. Zero-emission public transit could be a catalyst for decarbonization of the transportation and power sectors. *Clean Energy*, 2021, 5:492–504.
[17] Bouckaert S, Pales AF, McGlade C, *et al*. *Net Zero by 2050: A Roadmap for the Global Energy Sector*. Paris: International Energy Agency, 2021.
[18] Fraas LM. History of solar cell development. *Low-cost Solar Electric Power*. 2014:1–12. doi: 10.1007/978-3-319-07530-31.
[19] Gahrens S, Alessandra S, Steinfatt K. *Trading Into a Bright Energy Future. The Case for Open, High-Quality Solar Photovoltaic Markets*. Abu Dhabi: IRENA, 2021, 1–44. https://irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jul/IRENA_WTO_Trading_Energy_Future_2021.pdf (21 April 2022, date last accessed).
[20] IRENA. *Solar Energy—International Renewable Energy Agency*. 2021. www.irena.org/solar (2 February 2022, date last accessed).
[21] Honsberg C, Bowden S. *Sun Position Calculator*. 2014. http://pveducation org/pvcdrom/properties-of-sunlight/sun-position-calculator (25 January 2022, date last accessed).
[22] Green MA, Hishikawa Y, Dunlop ED, *et al*. Solar cell efficiency tables (version 52). *Progress in Photovoltaics*, 2018, 26:427–436.
[23] Kylili A, Fokaides PA. Investigation of building integrated photovoltaics potential in achieving the zero energy building target. *Indoor Built Environment*, 2014, 23:92–106.
[24] Maka AO, O'Donovan TS. A review of thermal load and performance characterisation of a high concentrating photovoltaic (HCPV) solar receiver assembly. *Solar Energy*, 2020, 206:35–51.
[25] Mohamed ET, Maka AO, Mehmood M, *et al*. Performance simulation of single and dual-junction GaInP/GaAs tandem solar cells using AMPS-1D. *Sustainable Energy Technologies Assessments*, 2021, 44:101067.
[26] Maka AO, O'Donovan TS. Dynamic performance analysis of solar concentrating photovoltaic receiver by coupling of weather data with the thermal-electrical model. *Thermal Science Engineering Progress*, 2021, 24:100923.
[27] Maka AO, O'Donovan TS. Transient thermal-electrical performance modelling of solar concentrating photovoltaic (CPV) receiver. *Solar Energy*, 2020, 211:897–907.
[28] Radovanovic M, Popov S, Dodic S. *Sustainable Energy Management*. Cambridge, MA: Academic Press, 2012.
[29] Salvarli MS, Salvarli H. For sustainable development: future trends in renewable energy and enabling technologies. In: Al Al Qubeissi M, El-kharouf A, Soyhan HS (eds). Qubeissi M, El-kharouf A, Soyhan HS (eds). *Renewable Energy-Resources, Challenges and Applications*. London: IntechOpen, 2020.
[30] Maka AO, Salem S, Mehmood M. Solar photovoltaic (PV) applications in Libya: challenges, potential, opportunities and future perspectives. *Cleaner Engineering Technology*, 2021, 51:100267.
[31] IRENA. *Renewable Energy and Jobs—Annual Review 2021, (REJ)*. 2021. https://www.irena.org/publications/2021/Oct/Renewable-Energy-and-Jobs-Annual-Review-2021 (2 January 2022, date last accessed).
[32] Obaideen K, AlMallahi MN, Alami AH, *et al*. On the contribution of solar energy to sustainable developments goals: case study on Mohammed bin Rashid Al Maktoum Solar Park. *International Journal of Thermofluids*, 2021, 12:100123.
[33] IRENA. *International Renewable Energy Agency, Renewable Energy and Jobs—Annual Review 2020*. Abu Dhabi: IRENA, 2020.
[34] Strielkowski W, Civín L, Tarkhanova E, *et al*. Renewable energy in the sustainable development of electrical power sector: a review. *Energies*, 2021, 14:8240.
[35] Grid-Arendal. *Natural Resources—Solar Power (Potential)*. 2008. https://www.grida.no/resources/7308 (9 February 2022, date last accessed).
[36] Kannan N, Vakeesan D. Solar energy for future world: a review. *Renewable Sustainable Energy Reviews*, 2016, 62:1092–1105.
[37] Löf GO, Duffie JA, Smith CO. World distribution of solar radiation. *Solar Energy*, 1966, 10:27–37.
[38] Kabir E, Kumar P, Kumar S, *et al*. Solar energy: potential and future prospects. *Renewable Sustainable Energy Reviews*, 2018, 82:894–900.
[39] Johansson TB, Goldemberg J. *Energy for Sustainable Development: A Policy Agenda*. New York: United Nations Development Programme (UNDP), 2002.
[40] Lowe R, Drummond P. Solar, wind and logistic substitution in global energy supply to 2050—barriers and implications. *Renewable Sustainable Energy Reviews*, 2022, 153:111720.
[41] Asmelash E, Prakash G. *Future of Solar Photovoltaic: Deployment, Investment, Technology, Grid Integration and Socio-economic Aspects*. Abu Dhabi: IRENA, 2019.
[42] Griffiths S. Strategic considerations for deployment of solar photovoltaics in the Middle East and North Africa. *Energy Strategy Reviews*, 2013, 2:125–131.
[43] Hafner M, Tagliapietra S, El Andaloussi EH. *Outlook for Electricity and Renewable Energy in Southern and Eastern Mediterranean Countries*. WP4b, Energy and Climate Change Mitigations, MEDPROTechnical Report No. 16/October 2012. www.medpro-foresight.eu (25 January 2022, date last accessed).
[44] Martí A, Luque A. *Next Generation Photovoltaics: High Efficiency Through Full Spectrum Utilization*. 1st edn. Boca Raton, FL: CRC Press, 2003.
[45] Dimroth F, Kurtz S. High-efficiency multijunction solar cells. *MRS Bulletin*, 2007, 32:230–235.
[46] Kashmir J. *Solar Energy for Sustainable Development*. 2018. https://www.dailyexcelsior.com/solar-energy-sustainable-development/ (15 January 2022, date last accessed).