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Review

Progress in Solar Thermal Systems and Their Role in Achieving the Sustainable Development Goals

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Abstract: The use of solar thermal systems (STSs) has recently reached a significant edge. The increasing research on developing an alternative power supply for limiting fossil fuel usage and climate change are the driving forces of STSs. The current work explores the recent progress in STSs' applications, including PV/T or "photovoltaic/thermal" systems, zero-energy buildings, greenhouse solar thermal applications, solar thermal for pumping water, solar thermal refrigerators, solar chimneys, water desalination, and solar collectors, along with the benefits and challenges of these applications. Then, the potential contribution of STSs in achieving the various SDGs or "Sustainable development goals", including barriers and research gaps, are elaborated. In brief, STSs significantly contribute to the seventeen SDGs' achievement directly and indirectly. Recent developments in the engineering applications of STSs are strongly based on the materials of construction, as well as their design, process optimisation, and integration with multidisciplinary sciences and technologies such as modelling, nanoscience/nanotechnology, and artificial intelligence.

Keywords: solar thermal systems; sustainable development goals; renewable energy; climate change

1. Introduction

Recently, energy, environment, and economic development have been exceedingly intertwined. Appropriately utilising available energy requires carefully managing employed technologies and assessing social impacts. The sustainable development of countries' economic growth mainly depends on good planning and the responsible consumption of fossil fuels and renewable energy resources, i.e., solar, hydro, biomass, and wind energy. Solar energy is available everywhere, even in remote locations, making it an adequate substitute for fossil fuels. The sun dissipates a massive quantity of radiation energy to its surroundings by about $174*10^{15}$ W at the layer of the upper atmosphere of Earth. Almost 51% of the total incoming solar energy reaches the land and oceans. Solar energy from the sun can be categorised as light or photons and heat with electromagnetic waves. Fundamentally, the sun is the source of all renewable energy sources, as presented in Figure 1.

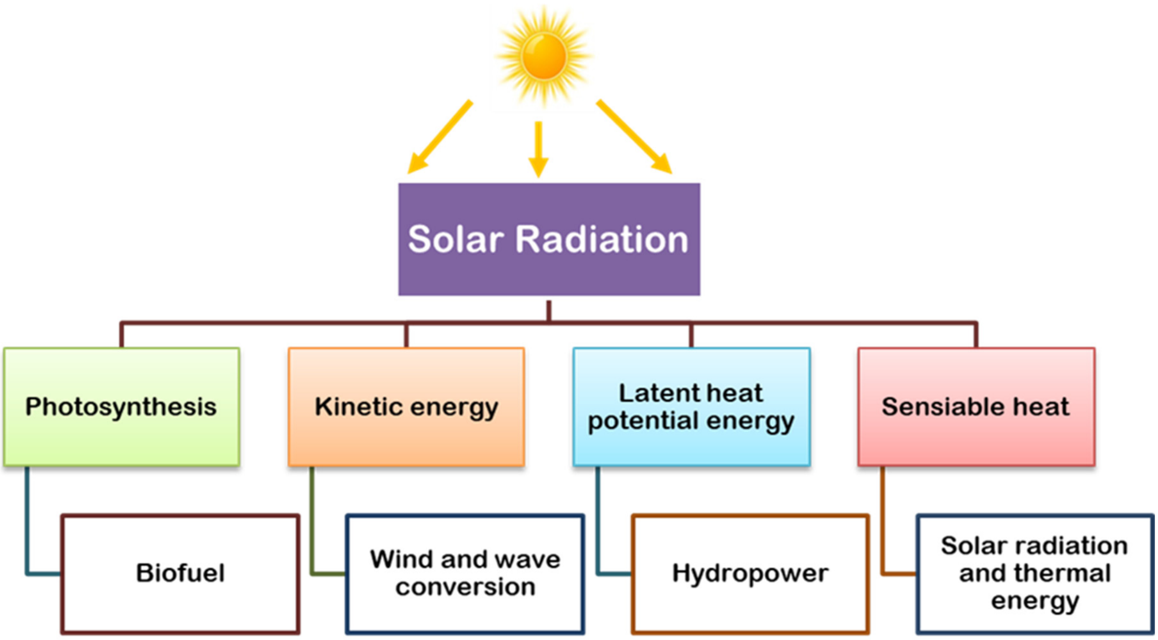

Figure 1. Solar radiation as the main source of renewable energies on Earth.

Demand for cleaner energy sources has grown in recent decades. Most countries have drawn up long-term plans based on renewable sources. Governments worldwide are beginning to use renewable energy resources and reduce their reliance on conventional fossil fuels [1,2]. In 2021, renewable energy technologies garnered 70% of all energy investment, yet worldwide CO_2 emissions rose by 1.5 billion tonnes [3,4]. The European Union (EU2030)'s Framework for Climate and Energy states that emissions must be reduced, with a binding target of at least 40% below 1990 levels before 2030 [5]. Various renewable energy technologies, primarily solar ones, can be used to meet these objectives. Solar devices, in particular photovoltaic (PV) panels [6], solar thermal collectors [5], or photovoltaic/thermal (PVT) collectors [6], are easily integrated into a variety of industries. Future predictions indicate that solar energy will soon surpass fossil fuels. Due to the development of the economy and industry, solar energy generation is anticipated to reach 48% by 2050 [7,8]. Solar energy is used for power generation using PV systems [9,10], heating air with solar air heaters [11,12], dry agricultural products using solar air dryers [12,13], providing drinking water using solar-powered desalination systems [14,15], cooking food using solar cookers [16], etc. Several types of research have been conducted to improve the performance of solar systems. Phase change material (PCM) and nano-enhanced PCMs [17,18], thermoelectric generators [19,20], nano-enhanced coatings [21], and nanofluids [22,23] are different methods for improving the performance of solar systems. The particular approaches employed are primarily determined by the unique features of the solar system and the opportunities that are available for improving performance or utilising additional system availability to produce other forms of energy. For instance, PCMs could be employed in solar thermal systems (STSs) to increase the module's exit temperature [24]. Thermal or PVT collectors utilise nanofluids for a faster rate of heat transfer [25], and thermoelectric generators can be utilised to co-generate electricity and heat/cold from desalination units or solar PV [26].

Modelling and simulation are effective tools for deciding the best operating conditions of various processes, such as tracking the maximum power point of grid-connected solar PV panels [27,28]. Artificial intelligence is an attractive methodology with a lower limitation than physical and mathematical modelling [29]. Artificial intelligence is effectively used to improve the efficiency and performance of several processes [30,31], including hybrid renewable energy sources [32,33]. Artificial intelligence plays an important role in increasing STSs' utilisation, including increasing their overall efficiency, cost minimisation, safety enhancement, scenarios to minimise environmental impacts, developing smart systems, optimising operations, and developing more accurate models of the different systems [8].

Recent advances in solar thermal systems (STSs) undoubtedly have a significant role in achieving the Sustainable Development Goals (SDGs) adopted by the UN in 2015 to be achieved in 2030. In addition to core contributions to SDG 7, which focuses on access to affordable, reliable, sustainable, and modern energy for all, and SDG 13, on urgent action to combat climate change, STSs can also make critical contributions to the other 15 SDGs, including helping to alleviate poverty, fight hunger, increase access to healthcare, education, and clean water, and protecting life on land and in water. It is essential to analyse the role of STSs in achieving the 17 SDGs.

Several works have summarised the progress in solar thermal and solar PV systems. For instance, the challenges facing solar PV systems were discussed by Al-Shahri et al. [34], as well as the application of PVT in desalination [35], the environmental impacts of solar PV systems [36], large-scale solar thermal desalination plants [37], the application of nano-enhanced phase change materials in solar thermal storage systems [38], nanofluids in solar thermal applications [39], etc. However, in accordance with the authors' best knowledge, no work has covered the role of solar thermal in achieving the Sustainable Development Goals. The main aim of this review was to explore how STSs contribute to the achievement of the SDGs adopted by the UN in 2015. Toward this aim, we carried out an elicitation procedure focused on previous studies based on the impact of STSs on economic, environmental, and social aspects. This is followed by gathering the impacts related to a specific goal, and finally, each section was analysed and carefully reviewed. The innovative aspects of this review explore recent advances in the numerous STSs and their performance and efficiency. This work also introduces a multidimensional connection between STSs and SDGs. It analyses the environmental, social, and economic impacts of STSs according to various indicators, whereas most of the previous investigations have focused on renewable energy. It should be mentioned that the acknowledged studies have widely discussed all the STSs: photovoltaic/thermal systems, greenhouse solar thermal applications, zero-energy buildings, solar thermal systems for pumping water, solar thermal refrigerators, solar chimneys, water desalination, and solar collectors. The structure of this review is divided into three main parts. The first part is a general introduction, followed by the second section, "STSs". The second section discusses the different kinds of STSs in more detail, as well as their pros and cons. The third part of the paper deeply investigates the contribution of these STSs in the achievement of the SDGs adopted by the UN. Finally, the main findings of this study are highlighted in the remarkable conclusions.

2. STSs or "Solar Thermal Systems"

Due to growing energy consumption, on the one hand, and the negative environmental effect of different fossil fuels, countries around the world are depending on alternative energy resources as a feasible and suitable choice in different applications, such as industry, agriculture, and domestic usage [40]. Solar energy is one of the cleanest sources of alternative energy. The study of the applications of solar systems in diverse areas of engineering technology is introduced to emphasise the necessity of using solar energy, with a special focus on thermal sources whenever possible, such as zero-energy buildings, greenhouse solar thermal applications, solar thermal energy for pumping water, solar thermal refrigerators, solar chimneys, water desalination, solar collectors, photovoltaic/thermal (PV/T) systems, etc.

2.1. Zero-Energy Buildings

Buildings considerably influence environmental issues, as they consume nearly one-third of the world's energy [41]. The main challenge that must be comprehensively evaluated is energy consumption from an economic perspective, considering its influence on the environment. Zero-energy structure principles were first reported in 1976, and an investigation of ZEB or "zero-energy building" started around 2000 [42,43]. Among countries, communities, and regions, the criteria of ZEBs differ from one place to another [44]. The Sustainable Building Institute Europe listed ten challenges hindering the establishment of zero-energy structures from becoming relevant and realistic. ZEBs were first developed in Denmark, utilising solar energy for household applications in cold seasons. On the other hand, the BIPV or "building-integrated photovoltaic" system is a practical, promising, and innovative application to achieve green buildings, thus the term BIPVT or "building-integrated photovoltaic thermal" [45]. Photovoltaics are designed to be integrated with a building as an alternative to conventional constituents to supply electricity. Rapid advances have been achieved for enhancing the energy output of BIPVT designed for facades, rooftops, and windows. In addition, their thermal performance mechanisms, benefits, applications, barriers, and challenges have been introduced [9,46].

2.2. Greenhouse Solar Thermal Application

The use of greenhouse structures allows for the introduction of more favourable conditions, which are necessary for the rapid growth of crops at any time of the year. Solar energy is utilised to increase the yield of various agricultural products based on the greenhouse system, such as the drying of agricultural products and crop production [47]. Specifically, solar energy is utilised to increase the yield of agricultural products grown in greenhouses. A more comprehensive categorisation of solar thermal applications for greenhouses is presented in Figure 2. After the solar radiation has been absorbed by the plant being grown inside the greenhouse, it is then expelled into the air around it in the form of water vapour. This process occurs after the solar radiation has passed over the greenhouse cover. Radiation can be transferred to the air inside by the floor, or it can be transferred to the ground below by heat conduction [48]. Therefore, the ambient air in the greenhouse is heated, and then various thermal losses are induced via the various pores. There are a few parameters that have a significant impact on the system [49,50]. These include the plant area, plant mass, the area of an aquifer-coupled cavity flow heat exchanger system, and the flow rate of circulating air.

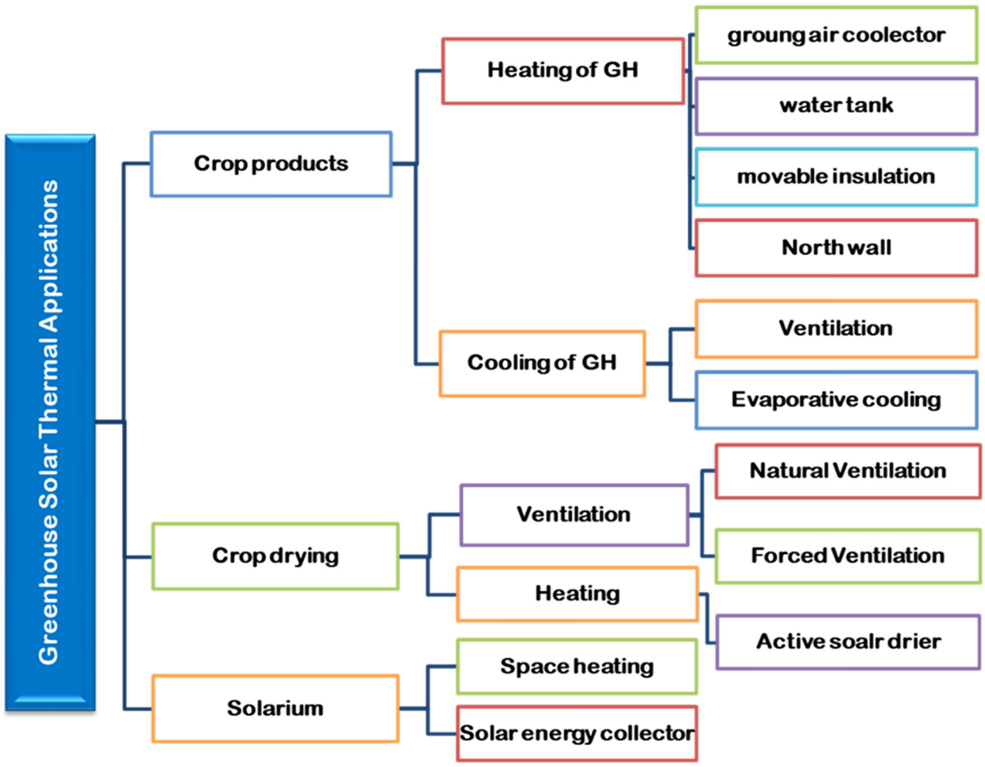

Figure 2. Broader classification of greenhouse solar thermal applications.

2.3. Solar Thermal for Pumping Water

Traditional diesel-powered pumps are commonly implemented for irrigation purposes. However, due to increased oil prices, harmful emissions due to burning, short lifetimes, and high maintenance costs have forced scientists to develop alternative routes. The solar-powered water pump has a number of advantages, for instance, reliability, being more economical, a low maintenance cost, dependence on renewable solar energy, a lack of noise, eco-friendliness, with no effect on environmental pollution, and a long life span compared to diesel-powered water pumps [51]. The generalised representation of a solar-powered water pump is shown in Figure 3. The solar power system is comprised of photovoltaic (PV) panels with or without an appropriate tracking system for improving electrical efficiency. The developed electrical energy is in DC, whereas the pump mostly requires AC, so an inverter is employed to convert the output energy to AC. A water pump or a water submersible pump is installed on the ground level [52,53].

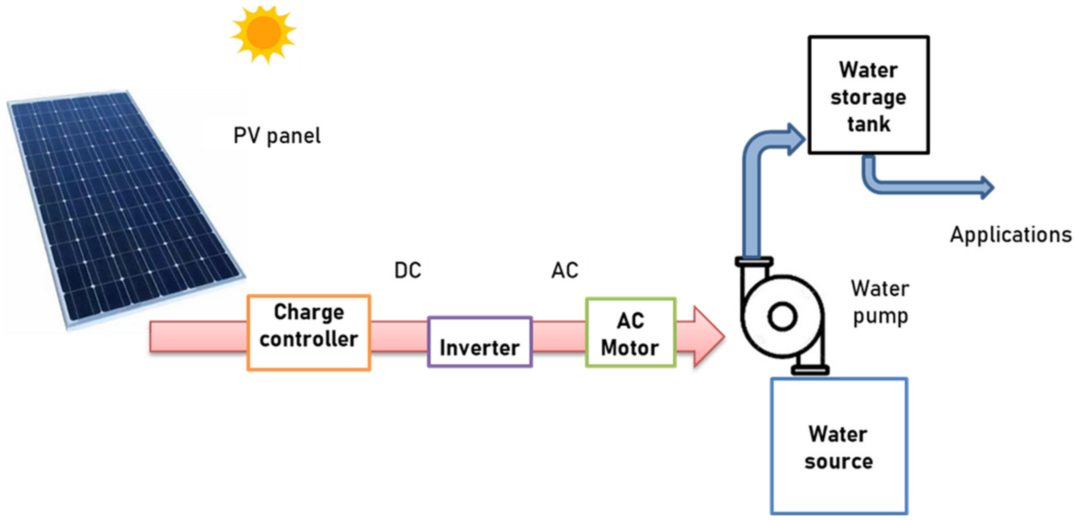

Figure 3. Continuous flow of a solar-powered water pump system.

2.4. Solar Thermal Refrigerators

Recently, the development of refrigeration technologies has been pursued to reduce energy consumption and avoid peak electrical demand without sustaining the desired standard of comfort conditions [54]. Solar refrigeration technology has the advantage of avoiding the negative impacts of conventional refrigeration systems, and the requirements of the cold often coincide with solar radiation availability. As such, researchers' primary area of attention has been the advancement of solar refrigeration technologies. In STSs, heat is actually used more frequently than solar energy's electricity. The flat-plate and evacuated tube collector is the most prevalent kind of solar thermal system. Current systems for generating the refrigeration effect using solar thermal energy are essentially based on the sorption mechanism: the gas/solid adsorption process and the gas/liquid absorption process [55,56]. The mechanism of the adsorption process depends on the separation of a substance from one phase and its accumulation onto the surface of a solid surface; the process efficiency depends on the affinity of the adsorbent towards a specific adsorbate as well as the specific surface area of the adsorbent. In contrast to the absorption process, the working substance is transferred from a specific phase to another to form a solution [57]. A schematic diagram of a solar-powered absorption refrigeration system is presented in Figure 4.

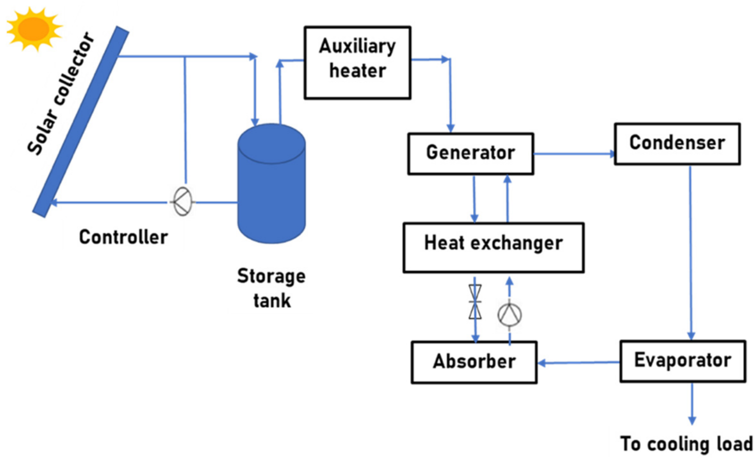

Figure 4. A schematic diagram of a solar-powered absorption refrigeration system.

2.5. Solar Chimney

The use of energy in buildings covers many reasons, such as heating and cooling for a comfortable lifestyle, transportation in tall structures, lighting for many appliances, and other services. This is a crucial issue. As shown in Figure 5, the solar chimney (SC) is primarily an open-loop natural circulation system that can be utilised for electricity generation or natural ventilation (NV) [58]. The SC that produces electricity contains a sizable area of solar collectors that can efficiently absorb solar radiation [59,60]. The buoyant force that affects passive air circulation is produced in part by the height of the solar chimney. The solar chimney is additionally used in air-conditioning systems for passive cooling in natural ventilation systems of various buildings [61,62]. Natural ventilation relates to various SDGs or "Sustainable Development Goals" under the umbrella of the UN Agenda 2030, including climate action, thermal comfort, wellbeing, energy efficiency, and clean energy [63,64]. Conventional air-conditioning systems consume approximately 15% of the world's total electricity [65]. Otherwise, solar and natural ventilation is recommended to provide cooling needs, with a 10% and 15% reduction in power and yearly usage, respectively [66].

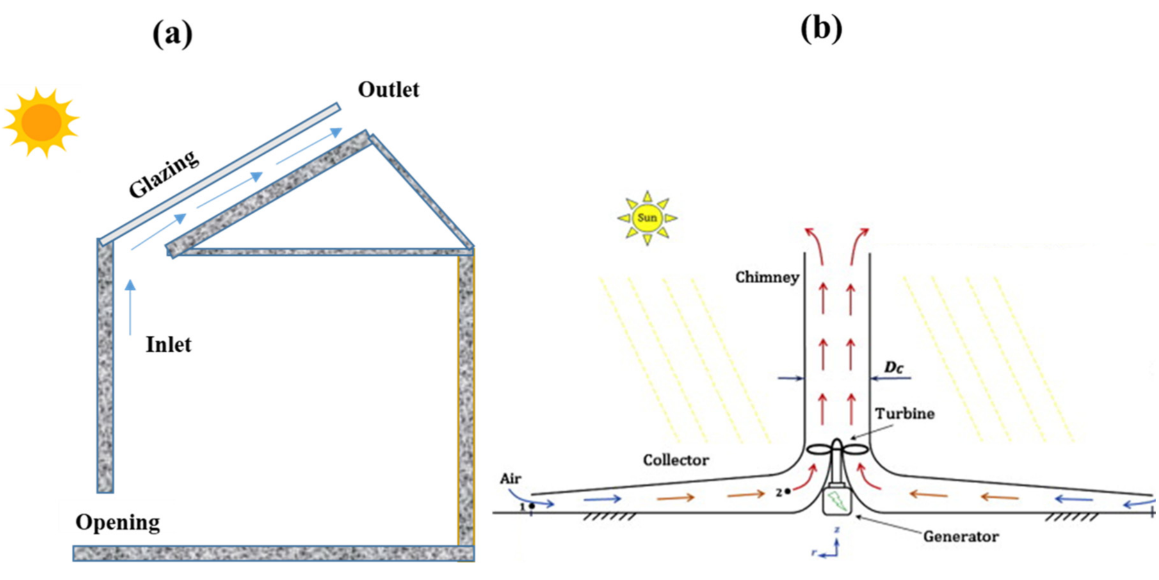

Figure 5. Applications of solar chimney: (**a**) natural ventilation and (**b**) power generation, adapted from [67] with permission No. 5413141175242.

2.6. Water Desalination

Water desalination processes can be categorised as thermal, mainly depending on the phase change and the membrane processes associated with a single phase [67,68]. For water desalination based on thermal systems, the phase change of seawater is conducted via the applied thermal energy that can be supplied using renewable energy sources such as solar energy [69,70]. Solar energy is implemented in water desalination systems either for the thermal process to introduce the thermal energy necessary or for the membrane processes to produce the necessary electrical power [71].

2.7. Solar Collectors

Solar collectors gather solar thermal energy by absorbing it with working fluid for different applications. Solar collectors are mainly categorised into two kinds based on the concentration ratios, i.e., non-concentrating collectors and concentrating collectors [72]. Concentrated solar collectors (CSC) that have been under implantation for several decades are mainly a simple scheme that uses mirrors to redirect sunlight to focus and collect heat, which can, in turn, be used to heat, power, or generate electricity. Concentrating collectors include heliostat field collectors, linear Fresnel reflectors, parabolic dish collectors, parabolic trough collectors, etc. Concentrated solar collector technology can be employed for electrical power generation, water desalination, industrial heating, cooling, detoxification and disinfection, etc.

2.8. PV/T or "Photovoltaic/Thermal" System

PV or "photovoltaic" panels are the most commonly implemented green energy-generating electricity. The implementation of solar energy is a key parameter for supplying on-site renewable energy for PVs [73]. The PV cell converts the incident solar energy into electrical energy. Diverse technologies using different applications of solar cells constitute the practical area of photovoltaics. The critical factors affecting the performance features of photovoltaic panels are well-established and well-studied [74]. The electrical performance of PV modules relies mainly on the temperature of the PV modules. Reducing the temperature enhances the electrical performance of the PV module. Additionally, to improve the efficiency of the PV, the thermal energy generated in the PV should be collected using a cooling system, such as either water or air, and is known as a PV/T or "photovoltaic thermal" system. The heat removal from PV panels ensures higher electrical productivity, in addition to the thermal energy collected from the modules that can be utilised in adsorption cooling systems and domestic hot water production [75,76]. It is worth mentioning here that the recent progress in PV technology has resulted in decreasing the deterioration of the PV [77,78], which has gradually improved the economics of PV or PVT systems.

2.9. Other Applications of Solar Systems

The thermal energy needed to derive water desalination systems can be achieved via solar energy with the aid of solar ponds or solar collectors. Solar collectors, the main components of solar water desalination systems, absorb the incoming solar irradiation and directly convert it into thermal energy. Recently, nanofluids have been thermally, environmentally, and economically evaluated based on sustainable methodologies to assess their benefits in STSs. Various nanofluids can considerably improve the base fluid's thermophysical properties, enhancing the heat transfer efficiency of thermal processes. Simple and hybrid nanofluids are employed in STSs, such as parabolic trough collectors and solar collectors [79], water-heating systems [80], water desalination [15,81], evacuated tubes [82], and photovoltaic/thermal (PVT) systems [83], focusing on the life cycle methodology [84].

3. Contribution of STSs to SDGs

In September 2015, the United Nations General Assembly (UNGA) identified seventeen SDGs. The main aims were to overcome hunger and poverty, protect the planet on land and under water, secure resources, ensure fair access to potable water and hygiene sanitation, provide renewable energy for all generations around the world [85–89], and ensure prosperity and peace by 2030. Numerous countries are aiming to achieve 100% renewable energy utilisation by 2050. They have been strongly motivated by many drivers, including but not limited to: mitigating climate change, increasing economic growth, improving the security of energy, and ensuring access to green electricity. Owning to the recent sharp interest in renewable energy, its effect on the SDGs should be fully investigated. Solar PV and wind form two-thirds of renewables. The following sections deeply investigate the various STSs' contribution to these SDGs.

SDG 1: Overcoming poverty

There are many poor people in the world's developing nations. Young people and women are disproportionately impacted by a lack of opportunities in the job market. Population growth in developing countries puts a strain on resources. All of these factors encourage the expansion of the economy to better provide for people's wants and needs. The price of fossil fuels is higher in wealthier countries than in poorer countries, which often export oil [88]. Flat-plate and PVT modules, which are mature in technology and applications, are the most frequently studied STSs. STSs are commonly applied in space heating, agricultural drying, and domestic water heating. The development of the PVT energy harvesting approach was spurred by the proliferation of energy recovery, which pushed designers to utilise harvested thermal power for various purposes [90]. PVTs can utilise solar energy to generate heat and electricity simultaneously. In general, solar thermal energy offers a large potential for integration with the current industry, which uses low- and medium-temperature ranges of 150–400 °C for drying, cooking, cleaning, oleochemical manufacturing, and fertiliser manufacturing. Due to the environmental and economic benefits, various developing countries have offered incentives to increase the installation of solar systems. Fewer carbon dioxide emissions and more high-tech solar technology jobs are two examples. Further, a skilled labour force capable of the fabrication, installation, and maintenance of solar systems will be required for the development and maintenance of these systems. When compared to coal, petroleum, and nuclear energy, solar systems for electricity production are expected, firstly, to help save on the amount of foreign currency spent on imported fossil fuels; secondly, to yield more vacancies per unit of electricity developed; thirdly, to decrease oil and coal imports; fourthly, to safeguard the environment by reducing contamination; and finally, to support energy independence and increase energy security. All of the aforementioned merits of the applications of STSs would increase people's incomes, decrease their electricity and health bills, and eventually reduce poverty, especially in developing countries.

SDG 2: Zero hunger

Food scarcity has increased with the increasing population growth, climate change, and food waste worldwide. Food that is produced requires storage to ensure its sufficiency for future needs. Some STSs have indirect impacts on reducing hunger, e.g., greenhouse solar and PVT systems have a significant impact on reducing hunger via increasing the quantities and growth rates of different agricultural products and keeping them from spoilage. Solar drying satisfies sustainable development requirements, because it addresses several issues, including global warming, uneven climatic change, rapid population growth, food scarcity, etc. [91]. OSD or "open sun drying" dates back thousands of years and is mostly used to dry agricultural items. However, OSD has numerous drawbacks, including the large workforce and excessive space necessary to accomplish it, animal attacks, increased dust, sluggish response time, quantity loss, and poor quality of produced foods [92]. However, the solar dryer is expected to solve most of the limitations of OSD. Solar dryers offer a green route for preserving food, because these dried products are utilised when fresh food is absent. These solar dryers enhance food quality, since they reduce the drying time required for different vegetables and fruits, such as bananas, chilli, and coffee [93]. Hybrid systems are also utilised to increase overall efficiency. For example, combining a greenhouse dryer and solar air heater reduces the drying time required for sultana grapes and red pepper compared to traditional dryers. Some of these solar dryers have been developed to be used in industrial sectors, such as beef [94] and medicinal plants [95]. Figure 6a shows the drying process inside a greenhouse, and Figure 6b,c show some greenhouse solar dryers' installations [96]

Figure 6. (**a**) Drying arrangement inside a greenhouse and (**b**,**c**) photos of a few installations [96], with permission No. 5413090348588.

Numerous sun dryers that are made explicitly for drying grapes have been described. Several popular sun drier models have been presented, along with some usual variations and drawbacks of conventional grape-drying techniques. Functional and financial analyses have demonstrated that drying grapes with solar energy is possible and less expensive. Solar grape drying has not taken off commercially as anticipated because of the high initial cost and weak dryer power. Farmers' response to the tested solar dryers has also been uninspiring. A variety of solar dryers have been used for drying grapes, with payback times of 1 to 5 years and long service lives of 15 to 30 years [97]. Solar dryers produce high-quality dried products. Determinants of solar drying technologies include product moisture, the hot air mass flow rate, and the temperature of the dryer chamber. The energy and exergy involved, as well as economic and environmental analyses of drying processes have been detailed [98]. Safe moisture content improves a product's quality, durability, and energy storage losses. Solar drying technology's biggest challenge is intermittent energy supply. Phase change materials store energy to fix this issue. Parabolic reflectors speed up solar drying and improve dryer performance. Solar energy has been found to be good for drying processes due to its low cost, uniform distribution, abundance, and ability to be integrated with other energy resources such as geothermal, wind, and biomass energy [98].

Farmers use an irrigation system powered by the sun to boost crop yields in the modern era. Surplus food contributes to greater food security and the minimisation of hunger, contributing to SDG 2. Studies have shown that farmers can increase their annual savings by about 161% when they switch from diesel-powered pumps to solar-powered ones. Studies have also demonstrated all economic indicators (gross margin, farm profit, benefit–cost ratio, and NPV or "net present value") to be positive for solar-powered irrigation systems, whereas all of these were negative for diesel-powered systems [99]. Solar cookers help achieve the UN SDGs. UN insights on eco-friendly energy for cooking and the 2030 goals have been helpful [100]. Clean cooking solutions may be a priority for promoting a healthy lifestyle. Solar cookers are crucial for achieving the UN SDGs. A solar cooker with a tracking-type bottom parabolic reflector and internal reflectors was proposed to achieve the SDGs, and the solar cooker was tested for a four-person family [100].

SDG 3: Good health and wellbeing

A few key facts highlight the importance of solar energy for the SDGs: 90% of the world's population is at risk of exposure to pollution due to air contamination [101]. Poor sanitation has been linked to the spread of deadly diseases such as cholera, diarrhoea, guinea worm, and typhoid. By its very nature, solar energy does not contribute to releasing harmful pollutants into the atmosphere [102]. Harmful chemicals can have a corrosive effect on infrastructure and the environment. Exposure to air pollution increases the risk of developing cardiovascular diseases, cancer, and respiratory illnesses such as asthma [102]. Compared to fossil fuels, solar energy does not produce waste or contaminate water, which is critical. Thus, most countries adopting solar energy have clean air, and their citizens rarely experience pollution-related health problems.

Additionally, solar energy can enhance the efficiency and modernity of healthcare facilities. Lights, life-saving equipment, and refrigerated vaccines are just a few of the many life-saving necessities that can be met by healthcare facilities that rely on solar energy. More and more buildings will need to adopt solar energy systems in order to reach SDG 3. Solar energy systems supply electricity that is both stable and inexpensive. Money saved on electricity costs can be reinvested into healthcare facilities. Cookstoves that use solar applications have been shown to significantly reduce indoor air pollution, and decentralised solar systems can help bring electricity to hospitals (which aids in the possibility of storing vaccines, increasing the number and quality of interventions, etc.). Electric vehicles powered by renewable energy electricity can also help to reduce air pollution and related health problems, such as asthma and other respiratory illnesses. At the same time, more than 4.3 million people die prematurely due to contamination from fossil fuel combustion. Providing continuous electricity and clean water to hospitals and health clinics in small or remote areas positively impacts human health [103].

SDG 4: Quality education and SDG 5: Gender equality

Worldwide, 1.3 billion people lack basic access to electricity. Only 32% of primary schools in low-income countries have access to electricity (SDG 4) [104]. There were currently 11.5 million people working in renewable energy in 2019 [105], with 32 percent being women (SDG 5). In 2020, it became clear how important the internet is for students to access learning resources. Quality education, which is addressed by SDG 4, has been slowed this year, especially in areas without reliable access to electricity and the internet [106]. Solar thermal and solar PV systems can continuously produce significant amounts of electricity in remote areas in the daytime, and part of it can be stored to be used at night. Such continuous electricity may enhance educational learning outcomes (through studying for much more hours and using the computer and other electricity-based educational devices) [103]. The availability of electricity is another issue that can arise in classrooms. Without it, both time and resources for education are severely constrained. Now, however, thanks to solar panels, schools have the electricity they need to keep students in class longer. To further the education of the youth in those areas with electricity access issues, computers and internet access can now be set up.

One of SDG 5's main goals is to ensure that all women and girls have the same opportunities as men. Access to electricity makes it possible for children in developing countries to attend school, especially girls. Women are more likely to take the entrepreneurial plunge when they feel energised. Because of this, women gain economic independence and confidence as they gain access to more job opportunities. Access to solar energy in their communities can help females take an effective role in society [102]. Renewables relieve the negative impacts of fuel collection on children and women and alleviate the adverse health effects of conventional biomass use. Solar energy systems based on street lighting can enhance safety and allow women and girls to attend community, productive, or educational activities after dark. Solar systems provide continuous electricity, which improves the intended learning outcomes by increasing studying hours and facilitating the implementation of computers and other electricity-based educational tools such as the internet [103].

SDG 6: Clean water and sanitation

Because so much energy has been required to heat water for use in homes, hospitals, and other industrial applications, solar water heating is becoming increasingly important [106–108]. Producing hot water accounts for 15% to 20% of household energy use. The solar thermal collector is the main part of the "solar water heating" (SWH) system. SWHs are very common, since they are easy to use, affordable, and require little upkeep. To create an economically viable SWH system, thermal efficiency is essential. To maximise solar energy and accomplish future sustainable energy targets, SWH systems are most frequently used [109].

Solar energy is the most viable renewable resource because of its low cost and low environmental impact [110]. However, solar energy's unreliability limits its usefulness in residential and commercial contexts, especially for heating water. Several studies have shown that modifying design elements such as the absorber plate geometry, solar selective coatings, collector tilt angle, fluid flow rates, phase change materials as a thermal energy storage unit, and the addition of twisted tape can all increase the thermal output of SWH systems [111].

Global decisionmakers are becoming increasingly concerned about the energy–water–food nexus. The availability of clean water will rise thanks to the desalination of water. Traditional electric power systems, such as thermal power plants, use significant amounts of water for cooling, whereas solar and wind generation use very little water [112]. Decades ago, solar power expanded from the household to industrial- and global-scale use. Hot water systems, water distillation from salt and brackish water, drying of agricultural products, water pumping, cooling and heating of indoor spaces, daylighting, and building integrated photovoltaic and solar refrigeration systems are all examples of small-scale solar applications.

Due to population growth and industrialisation, freshwater demand is rising. Solar desalination is a renewable way to make fresh water from salty or brackish water [113]. Solar desalination helps to decarbonise and reduce CO_2 and other greenhouse gases, thus achieving SDGs 6, 7, and 13. To fill a gap in the literature and highlight the improvement in techniques of various active and passive solar stills with and without PCM, numerous absorber configurations and designs have been examined. Recent solar-driven active and passive solar stills (SS) have been examined with thermal energy storage developments, wind, water depth, PCM thickness, and distillate production [114]. It was found that every day, integrated solar stills with evacuated tube collectors (ETC) produce 13.62 to 18.6 L/m^2 of freshwater. To meet the SDGs, the data has identified the best solar-driven desalination systems with PCM for small and large applications [114].

Water pumping and desalination with renewables can widen potable water sources [115]. Compared to fossil fuel, solar energy consumes less water, giving it a bonus advantage [10,36,116]. The quantity of potable water on the planet is limited; subsequently, using solar thermal for water pumping and desalination, as well as water treatment, has a positive impact on providing clean water to those who live in rural and decentralised areas. STSs are considered untraditional resources that could be applied to extract water from the air humidity.

An economic study has been performed to compare a SWHS, a "solar water heating system", to a natural gas boiler in terms of greenhouse gas (GHG) emissions and economics [117]. The SWHS economic assessment performed best. Since the first year, the return rate was 25 times the minimum, and the net present value was positive. Payback took 5 months [117], and the profitability rate said the SHWS returned BRL 29.46 for every BRL 1.00 invested. The SWHS had higher equipment-related GHG emissions than the natural gas system, but its emissions (annual basis) were 50 times less due to the latter's heavy fossil fuel use [117].

An increase in distilled water output is possible when a PV/T solar collector is connected to a solar still. However, various factors, including the price of the investigation and installation maintenance, can affect the decision to employ active solar distillation. Even though the annual production of the active system is 3.5 times more than that of the passive system, the cost of production for the passive system is expected to be 2.8 times lower. The payback periods for an active system range from 3.3 to 23.9 years, whereas they are between 1.1 and 6.2 years for a passive system. The high cost of solar thermal collector systems and PV panels is the issue with this disparity [118]. Solar membrane distillation (MD) systems' thermo-economic performance and hybridisation configurations have been discussed. In terms of freshwater productivity and thermo-economics, the study found that MD systems based on solar evacuated tube collectors are more efficient and reliable than solar flat plate collectors at various membrane configurations [119]. Furthermore, MD systems powered by HPVTCs or "hybrid photovoltaic panels and thermal collectors" had high daily potable water productivity. MD systems using concentrating photovoltaic thermal collectors for freshwater and electricity co-generation produced higher specific potable water distillates, satisfactory daily electricity production, and lower STEC or "specific thermal energy consumption" compared to compound parabolic concentrators. Salt-gradient solar ponds were also insufficient to meet MD system feed heat requirements. They generated extremely poor freshwater distilled fluxes with a high STEC. The heat supply from solar energy versus the latent heat of total saltwater within membrane modules limits the performance of MD. Future research should focus on novel enhanced methodologies and improved system designs to supplement the solar thermal source using photo-thermal membranes or efficient heat recovery strategies. Finally, the price of freshwater per litre varies depending on the MD configuration, solar collectors, daily freshwater capacity, heat recovery system, cost analysis process, etc. Economic analysis of solar MD systems is still challenging. Thus, multi-objective cost optimisation studies are advised to lower the cost of water productivity and encourage the commercialisation of MD desalination [119].

SDG 7: Affordable and clean energy

More than 2.8 and 1.1 billion people lack access to modern energy services and electricity [103]. Solar thermal collectors, solar air heaters, solar chimneys, solar dryers, etc., with and without the integration of a thermoelectric module to convert excess/waste heat into electrical energy, are effectively used to produce clean energy on a commercial scale in various applications [120]. Solar energy, including solar thermal sources, are not only sources of clean energy, but they are also available in remote areas where there are no grid connections; thus, they can secure energy for areas with limited energy sources. As mentioned in section three, solar thermal energy systems are clean energy systems that can be used in securing energy from a small source, such as hot water in district heating [121] to solar thermal power plants with several hundred mega-scale power outputs [122,123]. Due to a lack of conventional energy infrastructure, developing countries are adopting solar power due to its low cost and environmentally friendly production [124]. Solar energy has many benefits beyond cost savings. Reliable, low-cost clean energy has major economic and social impacts. Solar energy can generate electricity, and a solar thermal collector field can supply thermal energy for domestic hot water and building space heating [125]. Several energy sectors commercialise many applications. Heat pumps and photovoltaic fields can provide building space heating/cooling and domestic hot water [125,126]. Several studies have shown that PV systems coupled with heat pumps can achieve a "net zero energy building" target [127]. Solar thermal collectors can match users' thermal energy demand and absorption and adsorption chillers' cooling energy demand in private buildings and building districts [128,129]. Solar thermal collectors can generate electricity in solar power plants [130]. Solar thermal energy can dry agricultural materials, saving energy and enhancing quality [131].

In STSs, thermal conductive plates directly absorb sun energy, elevating the system's temperature. Heat exchangers either transfer the absorbed heat or use it to raise the temperature of the material. Seasonal Thermal Energy Storage (STES) linked with STS is used as a thermal management system for residential and commercial construction in cold regions [132]. Integrating STS with continuous STES is a crucial and dependable alternative for indoor thermal control. STSs are essential because of the Leadership in Energy and Environmental Design (LEED) accreditation for green buildings [133]. The impact of solar energy and its correlation with building energy estimation and the inter-building effect show that urbanised communities require solar thermal energy [134]. Despite extensive study in this field, only a small number of household residences have access to these devices. Many developed and developing nations still cannot invest more money upfront in household STSs

The goal of reducing CO_2 emissions by 75% by 2050 compared to 1985 is expected to be met through the wise and practical use of renewable energy sources and associated technology. The main problem with traditional PV systems is their low efficiency, which is caused by their inability to fully utilise the solar energy spectrum [135]. Whereas photovoltaic systems can effectively use the solar energy spectrum of visible light from a small wavelength up to the ultraviolet region, solar thermal collectors can use the spectrum up to the infrared region. One fascinating area of study has been integrating solar thermal and photovoltaic technologies for optimal solar spectrum use, which has significant potential to address rising energy needs while promoting eco-sustainable development [135]. Researchers prioritise the search for synergistic solutions. PV cell components, mass flow rate, packing ratios, working fluids, and collector geometry are all variables that influence PVT hybrid solar collector performance both independently and synergistically. To reduce temperature and improve electrical conversion efficiency, the back of the PV module can be effectively cooled with water [135]. The heat energy lost by the heat transfer fluid (HTF) during the cooling process could be used for secondary heating as hot water, air, or both. Design changes can significantly improve the electrical and total efficiency of PV/T systems. Figure 7 depicts a thorough understanding and inferred applications of the PV/T hybrid solar energy system.

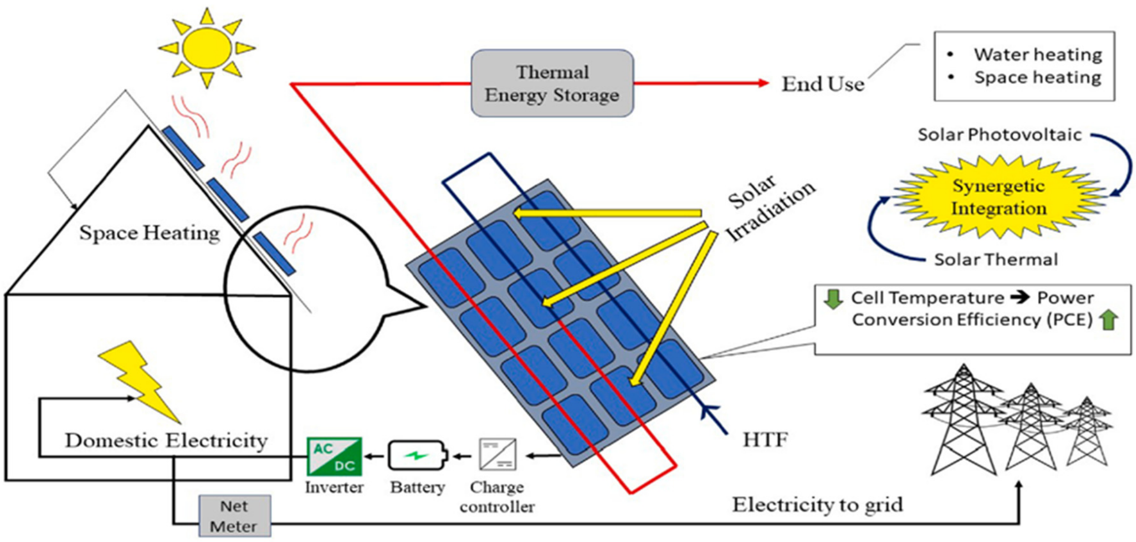

Figure 7. A schematic of PV/T working system and its applications [135], with permission No. 5413090138010.

SDG 8: Decent work and economic growth

Sustainability in development is based on economics. It also looks at ways to meet long-term objectives for clean air, energy access, and climate benefits. Renewable energy, intelligent grids, energy pricing, energy security, and sound energy policy are additional components of sustainable development. Solar electricity costs dropped 77% between 2010 and 2018 [136]. Solar-installed capacity increased 100-fold between 2005 and 2018. Solar power has become essential to the low-carbon sustainable energy system needed to provide reliable and affordable electricity to meet the Paris climate agreement and the

2030 SDGs [137]. As energy needs rise, more solar power equipment is being installed worldwide. Solar PV capacity grew from 40,334 to 709,674 MW between 2010 and 2020, and STSs' capacity grew from 1266 to 6479 MW [136]. More PV installations exist than STSs. Both small-scale and large-scale PV systems are widely implemented on Earth and in space. Figure 8 shows the worldwide installed capacity [138].

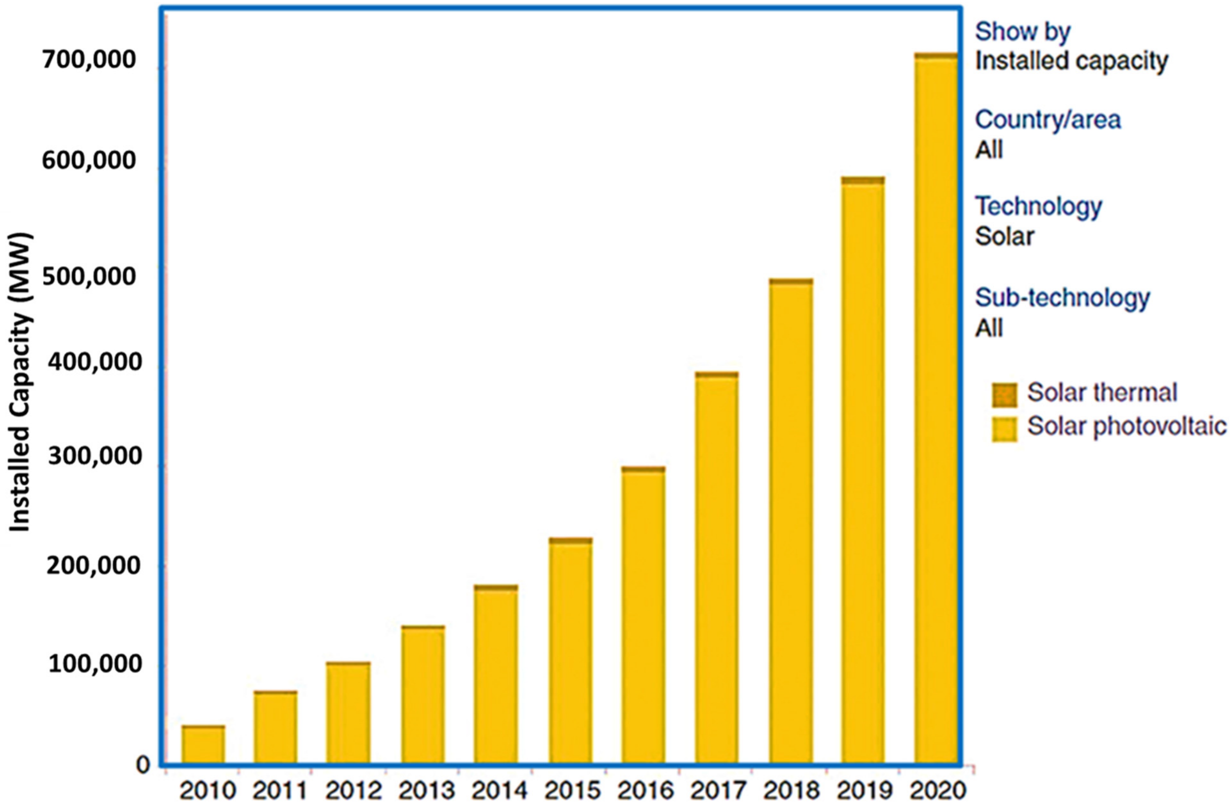

Figure 8. Installation capacity of solar energy worldwide [138], open access.

Quality infrastructure requires international standards. Developing global solar standards could benefit many countries. Solar manufacturing and deployment leaders have adopted global solar system standards and greatly contributed to green energy development. Assistance and capacity-building to improve infrastructure in developing economies may also help with the implementation of and compliance with international solar systems standards. Thus, funding can standardise legal requirements and frameworks, encouraging the solar systems industry to sell reliable products [139]. All solar and other renewable technologies should be continuously traded to improve national infrastructure. It is expected that by 2050, >40 million people will work in the renewable energy sector [139], and trade-led solar systems adoption could help the economy recover from COVID-19.

Renewable energy has also created jobs: over 12 million worldwide. The first solar PV industry created over three million jobs. Solar thermal (heating and cooling) and STSs industries have created over 819,000 and 31,000 jobs, respectively [140]. Despite the USA, China, and the EU investing the most in renewables vacancies, other Asian countries have entered the solar manufacturing industry [140]. Solar energy has the most renewable jobs. Solar applications that power "micro-enterprises" have increased employment opportunities in developing nations. Thus, renewable energy has helped in alleviating poverty. Moreover, solar power is necessary for plant and environmental sustainability [140]. Figure 9 shows renewable energy employment numbers worldwide [138].

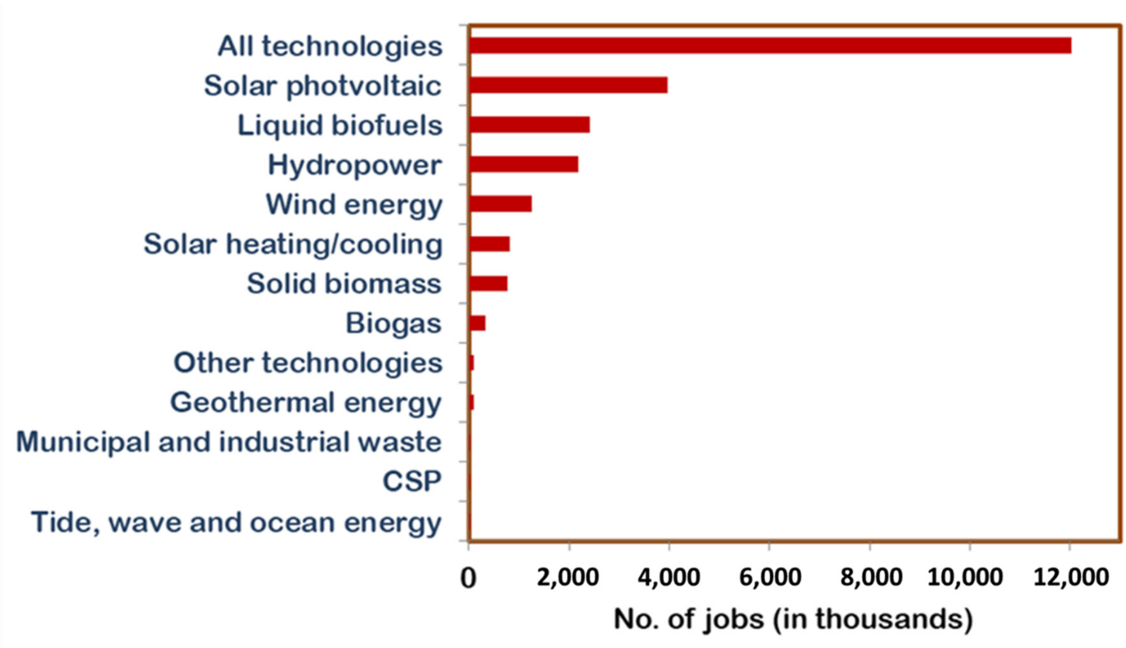

Figure 9. World renewable energy employment numbers [138], open access.

Sustainable economic growth is achieved by fostering economic benefits such as job creation and industry expansion. According to the International Energy Agency, investments in the energy sectors will total up to EUR 90.000 million per year, with the majority of these investments going to developing nations [103]. Solar systems open up new opportunities for value addition and provide new jobs in fabricating and establishing these units and their applications in different sectors [96]. Solar energy production is better for the planet than fossil fuel combustion and improves the quality of our planet's soil, air, and water [141]. Investing in solar energy can help fulfil energy goals, protect the environment, and boost the economy.

SDG 9: Industry, infrastructure and innovation and SDG 10: Reduced inequality

New local enterprises and industries may emerge directly or indirectly as a result of the development of local RES markets. The development of RES-based charging infrastructure for local transportation lowers greenhouse gas emissions and local air pollution [106]. The construction, commercialisation, installation, and maintenance of RES technologies has led to the creation of jobs and small enterprises, which generate cash and aid in removing development impediments. Using domestic energy sources allows local and international money to be used for purposes other than energy [103]. Due to the significant variations in the price of fossil fuels, many applications in agriculture and industry are recommended to be powered by solar thermal energy, especially in hot climates and remote locations. Securing energy sources in isolated areas and poor regions guarantees everyone the same opportunity. For instance, people can utilise solar-powered devices to connect to the rest of the world when solar power is adopted in regions without grid access. The applications of solar thermal energy are challenging due to a lack of broad system component suppliers, as well as the associated required design and installation knowledge and experience, and high initial capital cost. The latter is problematic if the prospective user lacks capital or cannot obtain a reasonable rate of return on a loan.

Designing, installing, and operating solar energy systems for thermal non-domestic applications, such as agriculture and industrial applications, should focus on achieving a balance between effective performance, a high solar fraction, low initial and ongoing costs, robustness and durability, safety, and environmental sustainability to meet the unique energy and temperature needs. It is worth mentioning that the operating temperatures of the various solar industrial processes are significantly varied, as can be seen in Table 1.

Water heating uses 13% of industrial energy. Textiles, buildings, agriculture, food, chemicals, and many other industries use water heaters extensively. Boiler feeding, washing, cleaning, and dyeing use preheated water. Solar water heating is the most common method for heating water with solar energy. Food, paper, pulp, textiles, fertilisers, and chemical industries use low-temperature solar energy systems. The industrial applications of solar systems could reduce CO_2 emissions and provide energy security. Global industrial energy demand is expected to rise 1.3% annually until 2030. Industries consume 25–50% of the world's thermal energy. In recent years, industrial applications of low-temperature solar energy technologies, such as solar water heating, desalination, purification, and air drying, have grown in number [142]. Additionally, in urbanised living environments in industrialised nations, where enormous complexes replace single-family homes, it is impractical to apply STSs to all residences. In these densely populated cities, roof space is often a problem. In addition, the diverse climatic conditions around the world necessitate varying operating temperatures for STSs to maintain their respective indoor temperatures. As a result, techniques for storing thermal energy that are appropriate for a given climate are being developed. Solutions that are optimal for one location may not be effective in another [143]. Insufficient sunlight during the day reduces the efficiency of solar systems. Because of their vulnerability to variable environmental conditions such as cloudy and rainy weather, STSs are not a viable long-term energy option. This drawback motivates the development of concepts and tools to mitigate the impact of solar energy interruptions on systems and plant productivity in domestic and industrial settings [144]. Solar drying emphasises incorporating thermal back-up resources, and integration with thermal energy storage is a realistic way to enhance STSs. Various ways in which to strengthen solar thermal power systems' (SCPP) functionality have been proposed and analysed by some researchers [145,146].

Table 1. Process temperatures in solar-based industrial applications [147].

Sector	Process	Optimum Temp. Range (C)
Chemical	Space heating of plants	30–100
	Preheating of boiler feed water	30–80
	Ancillary processes	120–180
	Distilling	110–300
	Boiling	95–105
Textile	Space heating of plants	30–100
	Preheating of boiler feed water	30–80
	Dyeing	100–160
	Bleaching	60–100
	Washing	40–80
Food and beverage	Space heating of plants	30–100
	Preheating of boiler feed water	30–80
	Heat treatment	40–60
	Sterilisation	140–150
	Boiling	95–105
	Pasteurising	80–110
	Washing	40–80
	Drying	30–90

A community's economic and social wellbeing are taken into account by providing new employment opportunities and reduced energy costs. This has the potential to raise incomes, which will improve people's standards of living. As a result, energy is crucial, as it is the driving force behind every aspect of human existence, including cultural evolution and economic growth. It is expected that in the future decade, a continued boom of solar energy and all clean-energy technology will be seen, as a result of an increasing transition towards sustainable renewable energy-based systems. Research and innovation are seen as major factors in improving the efficacy of such solar application technology.

According to the most recent data, there are several potentials for solar water heating or solar thermal technology across the dairy and agricultural industries. Additionally, case studies from the hotel and auto industries have been detailed. Despite having few uses, solar thermal and water-heating technologies are incredibly more efficient than photovoltaic cells. If such technologies are developed with cutting-edge research, several industry sectors, including dairy, agriculture, hotels, and automobiles, would benefit from using and implementing them [148]. Due to deteriorating climatic conditions and escalating global warming, both developed and developing nations are beginning to recognise the significance of these technologies. The growth of CSP facilities, which have now reached an industrial scale, has been made possible by advancements over the years. The main difficulty at present, aside from design, is the control and operation of integrated facilities, which now include several energy resources rather of just one. New design methodologies and algorithms are needed to address facility design and function. The design of reactors for solar-aided processes is a problem in and of itself. Still, the operation of such facilities over time plays a significant role in industrial applications [7].

SDG 11: Sustainable cities and communities

SDG 11 is especially relevant to resilient, safe, and sustainable cities. The main objectives of this goal include reducing the negative environmental effects of cities by paying special attention to air quality and waste management and providing adequate, safe, affordable housing as well as a sustainable, accessible, safe, and affordable transportation system for city dwellers. Cities utilise 75% of all natural resources, generate 60–80% of greenhouse gases (GHG), and are home to 55% of the world's population as of 2018, with that number anticipated to rise to 68% by 2050 [149]. STSs have attracted much interest in smart homes and green buildings. The STSs' constructions are simpler than electric energy utilities. Most STSs materials are accessible. Nanotechnology enables more productive and efficient STSs. Solar STSs heat up as thermal conductive plates directly absorb solar radiation. Heat exchangers transport or use absorbed heat to heat matter. A seasonal thermal energy storage system (STES) integrated with STSs provides thermal management for homes and businesses in cold countries [132]. Indoor thermal management requires STSs with continuous STES. STSs are important for LEED-certified green buildings [133].

Despite strong research, the implementation of domestic home systems is limited. Many developing and underdeveloped countries cannot invest more into domestic STSs. In developed countries, huge apartments have replaced individual homes, making STSs impossible to apply to all home units. High-density cities also have roof space issues. Apart from this, global climates require different STS operating temperatures for indoor thermal management. This creates climate-specific STES. Thus, optimised systems may not perform well in other locations [150]. Integrating one solar panel powers and heats SPVT systems, improves solar energy conversion, generates high temperatures, and uses steam to generate electricity [151]. All STSs require space management on rooftops, unlike solar PV systems. Seasonal thermal energy management and location-specific energy demand the estimation of STSs' optimisation, performance, and efficiency. Most STS efficiencies are under 30% [151].

Most cities in developing countries experience a variety of economic, social, and environmental issues, including high levels of GHG emissions, irresponsible energy use, water and air pollution, inadequate planning and design, ineffective transportation, traffic congestion, and outdated infrastructure, to name just a few, all of which have a significant impact on climate change [152]. The Energy Technology Perspective 2017 predicts three scenarios for how the climate will change by the end of the century. The Reference Technology Scenario (RTS), also known as the baseline scenario, is based on current promises to deal with energy and the environment. According to this scenario, cumulative energy sector CO_2 emissions will rise by over 1750 GT between now and 2060, and the world's ultimate energy demand will continue to expand by 50%. Future temperature rises are constrained to 2 and 1.75 °C, respectively, by 2100 under the 2 °C Scenario (2DS) and the Beyond 2 °C Scenario (B2DS) [153]. As a result, in recent decades, discussions and debates on a global scale have focused heavily on the issue of changing cities into sustainable and intelligent ones. Global leaders decided in 2015 to complete 17 SDGs by 2030. The seventeen SDGs target, in this order, the supply of affordable and clean energy, decent employment and economic growth, business, innovation, and infrastructure, and sustainable city communities.

Renewable sources of energy have the potential to decarbonise the supply and use of energy in urban areas, particularly in buildings (for heating, cooking, cooling, and appliances), as well as in the transportation sector. A reduction in pollution and in the amount of energy imported are two potential benefits, along with an increase in resilience. Solar technologies can contribute to the electrification of locations located in desert areas in countries that are part of the Sunbelt [103].

A thorough analysis of the relationship between the inter-building effect, building energy, and solar energy utilisation has been published for the first time [154]. The effects of the inter-building effect on building energy consumption, including cooling, heating, and lighting, were explored and quantitatively summarised for cities with various climates. The idea of "smart cities" entails specifically altered energy infrastructure, which is mostly dispersed as electricity. Numerous crucial city entities rely on power systems for essential functionality, including telecom networks, wireless sensor networks, water distribution, waste management, mobility, route guiding, public healthcare, information amenities, and others. The operation of the electrical system must be optimised by being intelligent and environmentally responsible [155]. This can be attained by utilising green information and communication technology (ICT) systems and renewable resources, which contribute to increased energy efficiency. Using efficient and renewable energy will enhance the climate [156]. STSs are crucial to the building of these systems. STSs have been analysed for climate change mitigation, sustainable buildings, recycling, storage, and environmental effects based on numerous electricity combinations [145]. Domestic solar hot water systems are known to have both energy and environmental advantages. Flat plate and evacuated tube systems that were either built into or added to buildings with auxiliary backup systems from various sources are included in the collection of papers that have been evaluated [157]. Green cities can utilise the various STSs in a building (zero-energy buildings, heating, cooling, cooking, and many other daily applications) to reduce the negative emissions from fossil fuels [103].

There are numerous scenarios to replace the existing technologies with eco-friendly technologies like STSs; such a shift could yield greener energy systems than a conventional one. According to a case study on the life cycle assessment of STSs, both the energy and environmental payback times of an STS are less than three years, and the life cycle cost payback period ranges from seven to thirteen years [158]. These systems are characterised by decentralisation, which makes them independent of the public network, yielding an increase in their cost-effectiveness and flexibility; they can create a power supply to small, isolated settlements. This is why numerous STSs are applicable and available in remote areas. Unlike fossil fuels, STSs are unlimited. When these systems are optimised with an energy conservation approach, they can produce sustainable green practices, whereas uranium and other fossil fuels are limited and can be depleted by extraction and consumption [159].

The building and construction sector consumes excessively high energy, and a considerable percentage of this energy is directed to heating purposes; hence, using solar heater systems is an effective approach to lower this consumed energy [160,161]. The construction of STSs is based on factors such as building type, type of heating (water, space, and so on), building capacity, quality of the unit, and the presence of any other renewable energy systems. The main challenges in the wide applications of STSs in new buildings are the requirements needed for the construction of these systems into the buildings, solar industry, product price and quality, maintenance, and public acceptance [145].

Numerous developed communities such as Japan, the USA, the European Union, and South Korea have adopted policies and goals toward the achievement of nearly zero energy building (NZEB). This action will yield considerable decarbonisation in the building sector worldwide. The term "NZEB" refers to green buildings that considerably lower the energy required for heating, air conditioning, lighting, ventilation, household appliances and cooking, etc. via their renewable energy utilisation, passive design, energy conservation, and energy conservation enhancement. NZEBs save up to 60–75% of the total energy standard. The contribution of NZEBs into carbon emissions and energy demand was investigated via three scenarios (steady development (S1), BAU, and high-speed development (S2)). The highest carbon emissions according to S2, S1, and BAU will occur by (1.64 $GtCO_2$) 2025, (1.72 $GtCO_2$) 2030, and (1.94 Gt CO_2) 2040, respectively. Hence, 2030 is considered the mandatory time for the application of NZEBs on a large scale [162].

To create a sustainability index for policymakers and stakeholders, multi-objective optimisation and multi-criteria decision-making machine learning models were developed [163]. In Emmen, the Netherlands retrofitted residential communities with building energy ratings (D) of varying sizes (10–500 houses), and they were compared to a standard decentralised heat pump. According to optimisation results, SDHS could provide 95% of the solar fraction in a 500-house community. With a life cycle cost of 41 V/m2 and a 25-year payback, NZEB status was only economically viable for communities of 100 houses. These findings demonstrated a social (29.7%) and environmental (78.2%) advantage over the decentralised heat pump. The study assessed positive energy communities and recommended SDHS integration to achieve global sustainability goals [163,164]. In a case study in Ouargla city, a hybrid PV/T water solar collector for NZEBs and potable water production was theoretically investigated. The prototype's composition and passive architecture allowed for significant reductions in heating and cooling requirements. Thermal insulation and cool roofing are two examples of passive methods that can improve the situation. If domestic hot water is provided by solar energy, the overall energy required can be significantly reduced. The annual solar production is still increased 2.97 times by preheating brine before injection. The numerical simulation was run for a full year using the TRNSYS 17 program [164].

SDG 12: Responsible consumption and production

A circular economy is critical to achieving SDG12. Circular economy techniques are all about decoupling economic activity from resource usage and its associated environmental and social implications, which is at the heart of this goal [88]. Renewable energy technologies, such as photovoltaic systems and STSs, can make the world's energy supply cleaner and safer if produced and used in an environmentally and socially sustainable way [103].

PV/T hybrid systems, particularly building integration, represent an exciting new field for engineering applications. Flat plate collectors with water or air as the heat transfer fluid are used in more popular and advanced PV/T systems [165]. PV/T systems based on FPSC are less expensive and more compatible with buildings than concentrating PV/T systems. Heat pipes can help improve the performance of a PV/T system. They can also be used as building envelope materials, making them more cost-effective and environmentally friendly [135]. Because PV/T systems have a higher energy density, they can produce more thermal-equivalent energy than individual PV or thermal systems alone.

It has been suggested that solar-powered dryers for agricultural farms could significantly lower food loss at farms and in consumer food waste [166]. Based on close contact with remote communities, the study found that solar-powered dryers must meet the following tasks and use a trans-disciplinary holistic approach to achieve their goal as follows: (i) the facilitation of academy–producer–industry communication, (ii) farm output surveys, (iii) simulated solar resource availability and reliability, (iv) dryers designed and placed for grid connection and farm proximity, (v) the implementation and adaptation of process flows for each product and the logistics of produce acquisition in a near-zero CO_2 emission scheme, (vi) near-zero-waste packaging and processing innovation, (vii) product nutritional quality and adaptations and consumer feedback-driven product diversification, (ix) energy, water, land use, and (x) academy–farmer feedback.

The technical feasibility of two non-concentrating collectors, the flat plate collector (FPC) and the ETC or "evacuated tube collector", for the application of preheating boiler feed water in Pakistan [167] was investigated. For this city, coal substitution has the highest GHG emissions mitigation potential of 1.823 x105 tonnes of CO_2 and the highest

NPV for oil (1.5 x 103 million PKR). When the entire supply chain is considered, and traditional fossil fuel technologies are compared to solar technologies, the environmental and social impact risk is lower. Solar system technology has the potential to replace a large portion of traditional fossil fuels in Sunbelt countries, resulting in improved sustainability (environmental, socioeconomic, and social) outcomes [103]. Economic growth and progress are constrained by a lack of energy, so clean and renewable energy sources are essential for promoting sustainable development. Rural communities achieve sustainable growth and improvement as a result of affordable energy access [168,169]. Additionally, access to electricity encourages economic activity, such as job prospects and cheaper power costs [170–172].

Solar cell efficiency is one of the key obstacles to the widespread use of solar technology. The theoretical efficiency limits of silicon-based solar cells are being progressively challenged by researchers [173]. These c-Si solar cells were recently recorded to show an efficiency of up to 26.7%, whereas the thermodynamic efficiency limit is around 33% [174]. Recycling polyurethane, steel, and copper in STSs adds to this waste and conserves natural resources for generating electricity [145].

SDG 13: Climate change

An estimated 50% of the anthropogenic greenhouse effect is attributed to CO_2. However, several additional gases, known as greenhouse gases and produced by industrial and residential processes, such as CH_4, chlorofluorocarbons (CFCs), ozone, peroxyacetylnitrate, and N_2O can also contribute to this effect and raise the Earth's temperature. Various factors influence the greenhouse effect, including CO_2 emissions from the combustion of fossil fuels, methane emissions from rising human activity, CFC release, and deforestation. Most scientists agree that measured greenhouse gas emissions and global warming have a cause-and-effect relationship [159]. Greenhouse dryers recorded CO_2 reductions during their lifetime of up to 209.21 tonnes [96]. Following the Paris Agreement, increasing renewable energy sources and improving energy efficiency could put the world on track to keep the rise in temperature within 2 ºC [102,103]. In 2020, the energy sector was estimated to release 13 Gt of CO_2. However, CO_2 accounts for 40% of global energy emissions. Electricity production is at pre-crisis levels. Despite a changing 'fuel mix', CO_2 emissions from the power sector will rise only slightly, and they will remain stable until 2030 [175]. The development of the energy sector in terms of energy generation, distribution, and consumption that is based on sustainability rules is referred to as sustainable energy development. Environmental effects from energy systems will be felt in both industrialised and emerging nations. Therefore, the global sustainable energy system needs to boost effectiveness and cut emissions. Additionally, the quick and extensive use of fossil fuels has resulted in massive carbon dioxide emissions and other hazardous gas emissions [176]. It was found that using solar energy could mitigate global warming, whereby droughts, fires, storms, and cyclones have all been mitigated as a result [177]. Sustainable development and the fight against rising sea levels are both aided by solar energy.

Solar energy systems thrive in industrial and commercial temperatures below 250 degrees Fahrenheit. Industrial and commercial processes that use solar collectors can realise savings of 75–80% of their energy costs with payback periods of less than five years [178]. Developing high-performance collectors and system components can improve the cost-effectiveness of high-temperature systems. Drying agricultural products is one of the most promising applications of active solar heating. Wood is being supplanted by diesel and propane in many countries. Commercial solar crop drying is a reality for a small number of crop types in a few geographic regions. High-temperature heat generated by STSs with concentrating collectors will be used in specialised industrial processes such as decontaminating hazardous waste and treating other materials. A set of straightforward and user-friendly measures has been established to assess the contributions that investments in renewable power generation and advancements in land transportation can make toward lowering CO_2, air pollutant emissions, and the health effects of air pollution [179]. The measures apply these criteria to a group of renewable electricity providers. Considerable variations were discovered in how well the measures did in terms of the SDGs for health, energy, and the climate. A multi-criteria examination of the viability of renewable energy technologies for national-scale assessments and the accompanying uncertainties has been performed in various studies depending on the price, capacity, land usage, water consumption, GHG emissions, etc. of these technologies [180,181]. Table 2 summarises the GHG emissions of the different renewable energy sources. It is clear from the figure that the various renewable energy sources have less GHG emissions than fossil fuels. The reported values are for the CO_2 emission per kWh during the whole life of the renewable energy system, including materials extraction, fabrication, disposal, etc.

Table 2. GHG emissions of the different renewable energy sources [180].

Renewable Technology	GHG Emissions [g CO_{2eq}/kWh]
Energy-from-waste	350 (100–1000)
Dedicated biomass	100 (25–600)
Solar thermal	40 (15–150)
Photovoltaic	60 (20–200)
Geothermal	40 (10–80)
Tidal	25 (10–80)
Wave	25 (12–50)
Hydropower	20 (2–60)
Offshore wind	15 (5–70)
Onshore wind	15 (5–70)

SDG 14: Life below water and SDG 15: Life on land

Solar technologies that substitute or lower the consumption of fossil fuels can minimise pipeline and tanker traffic, lowering the risk of spills in water sources [106]. These systems can reduce the risk of future global warming and ocean acidification by decreasing CO_2 emissions and local and global pollutants [106]. Solar-powered fishing boats were studied as an innovative route to reducing the operational costs of fishing activities [182]. The burning of fossil fuel causes acid rain, which is mainly created by NOx and SO2; these two gases combine with oxygen and water in the atmosphere and yield acids such as nitric and sulfuric acids. The majority (80%) of SO_2 emissions are generated by electric power generation plants, industrial energy, and residential heating, with coal utilisation alone accounting for 70% of these emissions. On the other hand, around 48% of NOx emissions arise from road transportation, and the majority of the remaining percentage is owed to fossil fuel combustion. The deposition of these acids causes the acidification of surface and ground waters, toxicity or damage to different ecosystems, a reduction in crops, and deterioration of the building and structural materials. Even sulfate aerosols change the optical and physical characteristics of clouds [159]. Hence, replacing fossil fuel with STSs in power generation plants, the transportation and industrial sectors, and for heating purposes will significantly reduce SOx and NOx emissions. Chlorofluorocarbons (CFCs) and refrigerants are utilised in refrigerators and air conditioners. NOx emissions from fossil fuel combustion cause a depletion in the stratospheric ozone layer, which leads to eye damage, skin cancer, and many harmful effects on various biological species. Replacement technologies that do not utilise CFCs may mitigate the hazardous effect of ozone depletion [159]. It is possible to avoid harming biodiversity and ecosystems in countries located in the Sunbelt by switching from technologies that rely on fossil fuels to solar technologies. Even in areas that are not connected to the grid, solar energy systems have the potential to replace biomass and cut down on deforestation [183,184]. In contrast to the locations of other renewable energy technologies, which tend to be in regions with a high concentration of biodiversity, solar systems are frequently found in arid regions, which have a lower risk of impacting endangered species [103].

SDG 16: Peace and justice in strong institutions

Clean energy from solar systems can be made available to those who lack it, helping to reduce economic and social disparities within and between nations and fostering more harmonious communities. Many of the world's poorest people live in Sunbelt countries, where solar technologies have the potential to significantly improve access to modern and sustainable energy [102].

SDG 17: Partnerships to achieve these goals

Without national and international integration and cooperation, achieving all of the Sustainable Development Goals listed above is impossible. The most important problems that need to be solved through widespread cooperation involve communications and information technology, sufficient finances, commerce, capacity building, data assessment, monitoring, and compatibility. The 17 sustainable goals for a better planet and community cannot be achieved without solar energy systems. By providing power for schools, hospitals, water treatment plants, and latrines, solar energy helps meet the needs of a community while also lowering its carbon footprint and greenhouse gas emissions [185]. The solar industry creates jobs, helps fight hunger, and increases people's access to necessities such as food and shelter [186]. An increased number of available jobs would make society more just, reducing the prevalence of corruption. Solar power helps level the playing field between men and women, especially in the countryside [187].

As shown in Figure 10, solar technology can support the three pillars (economic, environmental, and social) of sustainable development when used to replace traditional fossil fuel technologies [102]. Rural electricity's social advantages include health, education, and gender advantages in addition to agricultural benefits (through desalination, for example) [188]. Economic maintenance and cheap, environmentally friendly energy production require infrastructure and creativity [189]. The installation of solar energy systems will end slavery, human trafficking, and other forms of involuntary labour in developing countries [190]. Cleaner air benefits all living things, and solar panels help make that possible [191]. Producing energy without negatively impacting the environment can lessen the incidence and severity of health issues and the likelihood of new health threats [192].

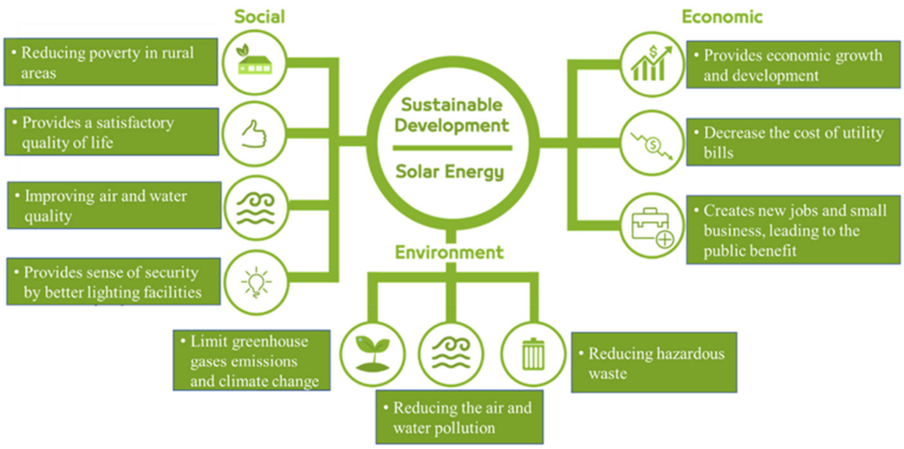

Figure 10. Contribution of solar energy to the three pillars of sustainable development [102], open access.

Figure 10 is a synopsis of solar energy's three main contributions to sustainable development [102]. Solar energy's environmental, social, and economic benefits can aid in our pursuit of the SDGs. Strengthening the global partnership for sustainable development is already beginning via the German Agency for International Cooperation (GIZ), the International Renewable Energy Agency (IRENA), the IEA, i.e., the "International Energy Agency", solar power and chemical energy systems (SolarPaces), etc.

4. Conclusions and Recommendations

This work introduces recent progress in the applications of solar thermal energy in various applications, including PV/T or "photovoltaic/thermal" systems, zero-energy buildings, greenhouse solar thermal applications, solar thermal systems for pumping water, solar thermal refrigerators, solar chimneys, solar-powered water desalination, and solar collectors. The current work has also discussed the role of the STSs in achieving the various SDGs.

The seventeen SDGs, which the UN General Assembly endorsed in September 2015, offer a powerful framework for global efforts to accomplish both human and environmental development. STSs can instantly help achieve these SDGs via facilitating access to essential services, enhancing human health, and assisting in income-generating activities, promoting economic advantages such as industrial expansion, which may support sustainable economic growth. The STSs contribute to the SDGs as follows:

SDG 1: The main socio-economic merits of STSs include the introduction of new renewable vacancies and increases in income. However, more studies are still required to develop cost-effective STSs with higher efficiency.

SDG 2: STSs can achieve food security by supporting sustainable agriculture and increasing yield. More research is needed to enhance solar water pumping, greenhouse solar dryers, water desalination, solar cookers, and solar-powered pumps.

SDG 3: STSs positively impact healthy lives and promote wellbeing, lowering deaths with the replacement of fossil fuel by STSs. On the other hand, STSs support hospitals and small clinics in small or remote areas by providing continuous electricity supply.

SDG 4: STSs promote equitable education by providing continuous electricity, which powers learning facilities.

SDG 5: The achievement of gender equality with STSs occurs via increasing women's participation in the supply chain of STSs as well as providing women with secure sources of income.

SDG 6: STSs ensure water sustainability via solar power desalination systems and water pumps in rural and small communities. Financial contributions should support research and development in desalination plants and water pumping, with a special focus on developing these in rural communities and poor areas.

SDG 7: The recent advances in thermoelectric generators, solar air heaters, solar chimneys, photovoltaic thermal solar collectors, and integrated heating, cooling, and power systems ensure access to clean energy for individuals.

SDG 8: STSs are an essential part of the low-carbon energy systems required to produce affordable and reliable electricity. However, commercialising STSs will play a significant role in achieving this goal.

SDG 9: Building an innovative solar thermal industry depends mainly on minimising the potential negative effects associated with the fabrication process of all STSs.

SGD 10: Investments across and within countries/economic sectors significantly impact the achievement of SDG10.

SDG 11: STSs can significantly contribute to decarbonising the supply and use of energy in urban areas by lowering pollution compared with other nonrenewable systems and enhancing the environmental and socio-economic conditions. The wide implementation of STSs depends on certain factors, such as the type and capacity of the building, the type of heating used, the system's efficiency, and the presence of other renewable energy systems. The main challenges in the applications of STSs in new buildings involve the requirements for constructing these items into the buildings, product price and quality, the solar industry, maintenance requirements, and public acceptance.

SDG 12: More dependence on STSs causes more resource conservation, especially oil and coal.

SDG 13: STSs could mitigate global warming.

SDG 14: There would be less risk of environmental catastrophes related to fossil fuel spills.

SDG 15: Switching from technologies that rely on fossil fuels to solar technologies could mitigate the negative effects on biodiversity and ecosystems. Moreover, STSs have the potential to substitute biomass and thus help in stopping deforestation.

SDG 16: STSs promote societies because they help to reduce economic and social disparities between and within nations and foster more harmonised communities.

SDG 17: Strengthening the global partnership for sustainable development is beginning via the GIZ, the IRENA, the IEA, SolarPaces, etc.

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References

1. Kannan, N.; Vakeesan, D. Solar energy for future world: A review. *Renew. Sustain. Energy Rev.* **2016**, *62*, 1092–1105. [CrossRef]
2. Watts, R.G. *Engineering Response to Climate Change*; CRC Press: Boca Raton, FL, USA, 2013.
3. Calise, F.; D'Accadia, M.D.; Vicidomini, M. Integrated Solar Thermal Systems. *Energies* **2022**, *15*, 3831. [CrossRef]
4. Khan, I.; Hou, F.; Zakari, A.; Tawiah, V.K. The dynamic links among energy transitions, energy consumption, and sustainable economic growth: A novel framework for IEA countries. *Energy* **2021**, *222*, 119935. [CrossRef]
5. Musiał, W.; Zioło, M.; Luty, L.; Musiał, K. Energy Policy of European Union Member States in the Context of Renewable Energy Sources Development. *Energies* **2021**, *14*, 2864. [CrossRef]
6. Calise, F.; Cappiello, F.L.; Cimmino, L.; D'Accadia, M.D.; Vicidomini, M. Dynamic Simulation and Thermoeconomic Analysis of a Hybrid Renewable System Based on PV and Fuel Cell Coupled with Hydrogen Storage. *Energies* **2021**, *14*, 7657. [CrossRef]
7. Martín, M. Challenges and opportunities of Solar thermal energy towards a sustainable chemical industry. *Comput. Chem. Eng.* **2022**, *165*, 107926. [CrossRef]
8. Hannan, M.; Al-Shetwi, A.Q.; Ker, P.J.; Begum, R.; Mansor, M.; Rahman, S.; Dong, Z.; Tiong, S.; Mahlia, T.I.; Muttaqi, K. Impact of renewable energy utilization and artificial intelligence in achieving sustainable development goals. *Energy Rep.* **2021**, *7*, 5359–5373. [CrossRef]
9. Maghrabie, H.M.; Elsaid, K.; Sayed, E.T.; Abdelkareem, M.A.; Wilberforce, T.; Olabi, A. Building-integrated photovoltaic/thermal (BIPVT) systems: Applications and challenges. *Sustain. Energy Technol. Assess.* **2021**, *45*, 101151. [CrossRef]
10. Alami, A.H.; Rabaia, M.K.H.; Sayed, E.T.; Ramadan, M.; Abdelkareem, M.A.; Alasad, S.; Olabi, A.-G. Management of potential challenges of PV technology proliferation. *Sustain. Energy Technol. Assess.* **2021**, *51*, 101942. [CrossRef]
11. Al-Kayiem, H.H.; Gitan, A.A. Flow uniformity assessment in a multi-chamber cabinet of a hybrid solar dryer. *Sol. Energy* **2021**, *224*, 823–832. [CrossRef]
12. Abdelkader, T.K.; Salem, A.E.; Zhang, Y.; Gaballah, E.S.; Makram, S.O.; Fan, Q. Energy and exergy analysis of carbon nanotubes-based solar dryer. *J. Energy Storage* **2021**, *39*, 102623. [CrossRef]
13. Shoeibi, S. Numerical Analysis of Optimizing a Heat Sink and Nanofluid Concentration Used in a Thermoelectric Solar Still: An Economic and Environmental Study. *Environ. Res. Eng. Manag.* **2021**, *77*, 110–122. [CrossRef]
14. Maleki, A.; Pourfayaz, F.; Ahmadi, M.H. Design of a cost-effective wind/photovoltaic/hydrogen energy system for supplying a desalination unit by a heuristic approach. *Sol. Energy* **2016**, *139*, 666–675. [CrossRef]
15. Iqbal, A.; Mahmoud, M.S.; Sayed, E.T.; Elsaid, K.; Abdelkareem, M.A.; Alawadhi, H.; Olabi, A. Evaluation of the nanofluid-assisted desalination through solar stills in the last decade. *J. Environ. Manag.* **2020**, *277*, 111415. [CrossRef]
16. Palanikumar, G.; Shanmugan, S.; Janarthanan, B.; Sangavi, R.; Geethanjali, P. Energy and Environment control to Box type Solar Cooker and Nanoparticles mixed bar plate coating with Effect of Thermal Image cooking pot. *Mater. Today Proc.* **2019**, *18*, 1243–1255. [CrossRef]
17. Olabi, A.; Wilberforce, T.; Elsaid, K.; Sayed, E.T.; Ramadan, M.; Rahman, S.A.; Abdelkareem, M.A. Recent progress on Carbon-based nanomaterial for phase change materials: Prospects and challenges. *Therm. Sci. Eng. Prog.* **2021**, *23*, 100920. [CrossRef]
18. Maghrabie, H.M.; Elsaid, K.; Sayed, E.T.; Radwan, A.; Abo-Khalil, A.G.; Rezk, H.; Abdelkareem, M.A.; Olabi, A. Phase change materials based on nanoparticles for enhancing the performance of solar photovoltaic panels: A review. *J. Energy Storage* **2022**, *48*, 103937. [CrossRef]

19. Abdelkareem, M.A.; Mahmoud, M.S.; Elsaid, K.; Sayed, E.T.; Wilberforce, T.; Al-Murisi, M.; Maghrabie, H.M.; Olabi, A. Prospects of Thermoelectric Generators with Nanofluid. *Therm. Sci. Eng. Prog.* **2022**, *29*, 101207. [CrossRef]
20. Shoeibi, S.; Rahbar, N.; Esfahlani, A.A.; Kargarsharifabad, H. Energy matrices, economic and environmental analysis of thermoelectric solar desalination using cooling fan. *J. Therm. Anal. Calorim.* **2022**, *147*, 9645–9660. [CrossRef]
21. Zanganeh, P.; Goharrizi, A.S.; Ayatollahi, S.; Feilizadeh, M. Nano-coated condensation surfaces enhanced the productivity of the single-slope solar still by changing the condensation mechanism. *J. Clean. Prod.* **2020**, *265*, 121758. [CrossRef]
22. Elsaid, K.; Abdelkareem, M.A.; Maghrabie, H.M.; Sayed, E.T.; Wilberforce, T.; Baroutaji, A.; Olabi, A. Thermophysical properties of graphene-based nanofluids. *Int. J. Thermofluids* **2021**, *10*, 100073. [CrossRef]
23. Maghrabie, H.M.; Elsaid, K.; Sayed, E.T.; Abdelkareem, M.A.; Wilberforce, T.; Ramadan, M.; Olabi, A. Intensification of heat exchanger performance utilizing nanofluids. *Int. J. Thermofluids* **2021**, *10*, 100071. [CrossRef]
24. Manirathnam, A.; Manikandan, M.D.; Prakash, R.H.; Kumar, B.K.; Amarnath, M.D. Experimental analysis on solar water heater integrated with Nano composite phase change material (SCi and CuO). *Mater. Today Proc.* **2020**, *37*, 232–240. [CrossRef]
25. Rostami, Z.; Rahimi, M.; Azimi, N. Using high-frequency ultrasound waves and nanofluid for increasing the efficiency and cooling performance of a PV module. *Energy Convers. Manag.* **2018**, *160*, 141–149. [CrossRef]
26. Shafii, M.B.; Shahmohamadi, M.; Faegh, M.; Sadrhosseini, H. Examination of a novel solar still equipped with evacuated tube collectors and thermoelectric modules. *Desalination* **2016**, *382*, 21–27. [CrossRef]
27. Abdelwahab, S.A.M.; Elbaset, A.A.; Yousef, F.; Abdellatif, W.S. Performance Enhancement of PV Grid Connected Systems with Different Fault Conditions. *Int. J. Electr. Eng. Inform.* **2021**, *13*, 873–897. [CrossRef]
28. Saleh, B.; Yousef, A.M.; Abo-Elyousr, F.K.; Mohamed, M.; Abdelwahab, S.A.M.; Elnozahy, A. Performance Analysis of Maximum Power Point Tracking for Two Techniques with Direct Control of Photovoltaic Grid -Connected Systems. Energy Sources, Part A: Recover. *Util. Environ. Eff.* **2021**, *44*, 413–434. [CrossRef]
29. Nassef, A.M.; Fathy, A.; Sayed, E.T.; Abdelkareem, M.A.; Rezk, H.; Tanveer, W.H.; Olabi, A. Maximizing SOFC performance through optimal parameters identification by modern optimization algorithms. *Renew. Energy* **2019**, *138*, 458–464. [CrossRef]
30. Oubelaid, A.; Albalawi, F.; Rekioua, T.; Ghoneim, S.S.M.; Taib, N.; Abdelwahab, S.A.M. Intelligent Torque Allocation Based Coordinated Switching Strategy for Comfort Enhancement of Hybrid Electric Vehicles. *IEEE Access* **2022**, *10*, 58097–58115. [CrossRef]
31. Larouci, B.; Ayad, A.N.E.I.; Alharbi, H.; Alharbi, T.E.A.; Boudjella, H.; Tayeb, A.S.; Ghoneim, S.S.M.; Abdelwahab, S.A.M. Investigation on New Metaheuristic Algorithms for Solving Dynamic Combined Economic Environmental Dispatch Problems. *Sustainability* **2022**, *14*, 5554. [CrossRef]
32. Elnozahy, A.; Yousef, A.M.; Abo-Elyousr, F.K.; Mohamed, M.; Abdelwahab, S.A.M. Performance improvement of hybrid renewable energy sources connected to the grid using artificial neural network and sliding mode control. *J. Power Electron.* **2021**, *21*, 1–14. [CrossRef]
33. Abdelwahab, S.A.M.; Yousef, A.M.; Ebeed, M.; Abo-Elyousr1, F.K.; Elnozohy, A.; Mohamed, M. Optimization of PID Controller for Hybrid Renewable Energy System Using Adaptive Sine Cosine Algorithm. *Int. J. Renew. Energy Res.* **2020**, *10*, 669–677. [CrossRef]
34. Al-Shahri, O.A.; Ismail, F.B.; Hannan, M.; Lipu, M.H.; Al-Shetwi, A.Q.; Begum, R.; Al-Muhsen, N.F.; Soujeri, E. Solar photovoltaic energy optimization methods, challenges and issues: A comprehensive review. *J. Clean. Prod.* **2020**, *284*, 125465. [CrossRef]
35. Anand, B.; Shankar, R.; Murugavelh, S.; Rivera, W.; Prasad, K.M.; Nagarajan, R. A review on solar photovoltaic thermal integrated desalination technologies. *Renew. Sustain. Energy Rev.* **2021**, *141*, 110787. [CrossRef]
36. Tawalbeh, M.; Al-Othman, A.; Kafiah, F.; Abdelsalam, E.; Almomani, F.; Alkasrawi, M. Environmental impacts of solar photovoltaic systems: A critical review of recent progress and future outlook. *Sci. Total Environ.* **2020**, *759*, 143528. [CrossRef]
37. Zheng, Y.; Gonzalez, R.A.C.; Hatzell, K.B.; Hatzell, M.C. Large-scale solar-thermal desalination. *Joule* **2021**, *5*, 1971–1986. [CrossRef]
38. Nazari, M.A.; Maleki, A.; Assad, M.E.H.; Rosen, M.A.; Haghighi, A.; Sharabaty, H.; Chen, L. A review of nanomaterial incorporated phase change materials for solar thermal energy storage. *Sol. Energy* **2021**, *228*, 725–743. [CrossRef]
39. Rios, M.S.B.-D.L.; Rivera-Solorio, C.I.; Nigam, K. An overview of sustainability of heat exchangers and solar thermal applications with nanofluids: A review. *Renew. Sustain. Energy Rev.* **2021**, *142*, 110855. [CrossRef]
40. Mekhilef, S.; Faramarzi, S.; Saidur, R.; Salam, Z. The application of solar technologies for sustainable development of agricultural sector. *Renew. Sustain. Energy Rev.* **2012**, *18*, 583–594. [CrossRef]
41. Srinivasan, R.; Braham, W.W.; Campbell, D.E.; Curcija, C.D. Re(De)fining Net Zero Energy: Renewable Emergy Balance in environmental building design. *Build. Environ.* **2012**, *47*, 300–315. [CrossRef]
42. Panagiotidou, M.; Fuller, R.J. Progress in ZEBs—A review of definitions, policies and construction activity. *Energy Policy* **2013**, *62*, 196–206. [CrossRef]
43. Hong, T.; D'Oca, S.; Turner, W.J.; Taylor-Lange, S.C. An ontology to represent energy-related occupant behavior in buildings. Part I: Introduction to the DNAs framework. *Build. Environ.* **2015**, *92*, 764–777. [CrossRef]
44. Wilberforce, T.; Olabi, A.; Sayed, E.T.; Elsaid, K.; Maghrabie, H.M.; Abdelkareem, M.A. A review on zero energy buildings—Pros and cons. *Energy Built Environ.* 2021. [CrossRef]
45. Shukla, A.K.; Sudhakar, K.; Baredar, P. Recent advancement in BIPV product technologies: A review. *Energy Build.* **2017**, *140*, 188–195. [CrossRef]

46. Maghrabie, H.M.; Abdelkareem, M.A.; Al-Alami, A.H.; Ramadan, M.; Mushtaha, E.; Wilberforce, T.; Olabi, A.G. State-of-the-Art Technologies for Building-Integrated Photovoltaic Systems. *Buildings* **2021**, *11*, 383. [CrossRef]
47. Das, T.; Bora, G.C. Greenhouse Solar Thermal Application. In *Handbook of Research on Solar Energy Systems and Technologies*; IGI Global: Hershey, PA, USA, 2013; pp. 462–479.
48. Taki, M.; Rohani, A.; Rahmati-Joneidabad, M. Solar thermal simulation and applications in greenhouse. *Inform. Process. Agric.* **2018**, *5*, 83–113. [CrossRef]
49. Sethi, V.; Sharma, S. Thermal modeling of a greenhouse integrated to an aquifer coupled cavity flow heat exchanger system. *Sol. Energy* **2007**, *81*, 723–741. [CrossRef]
50. Nayak, S.; Tiwari, G. Energy and exergy analysis of photovoltaic/thermal integrated with a solar greenhouse. *Energy Build.* **2008**, *40*, 2015–2021. [CrossRef]
51. Verma, S.; Mishra, S.; Chowdhury, S.; Gaur, A.; Mohapatra, S.; Soni, A.; Verma, P. Solar PV powered water pumping system—A review. *Mater. Today Proc.* **2020**, *46*, 5601–5606. [CrossRef]
52. Kinkaid, C. *Solar PV Water Pumping: How to Build Solar PV Powered Water Pumping Systems for Deep Wells, Ponds, Creeks, Lakes, and Streams*; Createspace Independent Pub: North Charleston, SC, USA, 2014.
53. Khatib, T.; Muhsen, D.H. *Photovoltaic Water Pumping Systems Concept*; Academic Press: Cambridge, MA, USA, 2020; pp. 5–38. [CrossRef]
54. Florides, G.; Tassou, S.; Kalogirou, S.; Wrobel, L. Review of solar and low energy cooling technologies for buildings. *Renew. Sustain. Energy Rev.* **2002**, *6*, 557–572. [CrossRef]
55. Speight, J.G. *Reaction Mechanisms in Environmental Engineering: Analysis and Prediction*; Butterworth-Heinemann: Oxford, UK, 2018.
56. Wang, R.; Wang, L.; Wu, J. *Adsorption Refrigeration Technology: Theory and Application*; John Wiley & Sons: Hoboke, NJ, USA, 2014.
57. Ghenai, C.; Salameh, T. *Sustainable Air Conditioning Systems*; BoD–Books on Demand: Norderstedt, Germany, 2018.
58. Maghrabie, H.M.; Abdelkareem, M.A.; Elsaid, K.; Sayed, E.T.; Radwan, A.; Rezk, H.; Wilberforce, T.; Abo-Khalil, A.G.; Olabi, A. A review of solar chimney for natural ventilation of residential and non-residential buildings. *Sustain. Energy Technol. Assess.* **2022**, *52*, 102082. [CrossRef]
59. Kaushik, S.C.; Lal, S.; Bhargava, P.K. Research and development in solar chimney power plant technologies: A review. *Int. J. Renew. Energy Technol.* **2015**, *6*, 197–223. [CrossRef]
60. Kasaeian, A.B.; Molana, S.; Rahmani, K.; Wen, D. A review on solar chimney systems. *Renew. Sustain. Energy Rev.* **2017**, *67*, 954–987. [CrossRef]
61. Bansal, N.; Mathur, J.; Mathur, S.; Jain, M. Modeling of window-sized solar chimneys for ventilation. *Build. Environ.* **2005**, *40*, 1302–1308. [CrossRef]
62. Harris, D.; Helwig, N. Solar chimney and building ventilation. *Appl. Energy* **2007**, *84*, 135–146. [CrossRef]
63. Olabi, A.; Obaideen, K.; Elsaid, K.; Wilberforce, T.; Sayed, E.T.; Maghrabie, H.M.; Abdelkareem, M.A. Assessment of the pre-combustion carbon capture contribution into sustainable development goals SDGs using novel indicators. *Renew. Sustain. Energy Rev.* **2021**, *153*, 111710. [CrossRef]
64. Obaideen, K.; Abdelkareem, M.A.; Wilberforce, T.; Elsaid, K.; Sayed, E.T.; Maghrabie, H.M.; Olabi, A. Biogas role in achievement of the sustainable development goals: Evaluation, Challenges, and Guidelines. *J. Taiwan Inst. Chem. Eng.* **2022**, *131*, 104207. [CrossRef]
65. Fernandes, M.; Brites, G.; Costa, J.; Gaspar, A.; Costa, V. Review and future trends of solar adsorption refrigeration systems. *Renew. Sustain. Energy Rev.* **2014**, *39*, 102–123. [CrossRef]
66. Emmerich, S.J.; Dols, W.S.; Axley, J.W. *Natural Ventilation Review and Plan for Design and Analysis Tools*; US Department of Commerce, Technology Administration, National Institute of Standards and Technology: Gaithersburg, MD, USA, 2001. [CrossRef]
67. Dehghani, S.; Mohammadi, A.H. Optimum dimension of geometric parameters of solar chimney power plants—A multi-objective optimization approach. *Sol. Energy* **2014**, *105*, 603–612. [CrossRef]
68. Mohamed, A.S.A.; Ahmed, M.S.; Maghrabie, H.M.; Shahdy, A.G. Desalination process using humidification–dehumidification technique: A detailed review. *Int. J. Energy Res.* **2020**, *45*, 3698–3749. [CrossRef]
69. Gude, G.G. *Renewable Energy Powered Desalination Handbook: Application and Thermodynamics*; Butterworth-Heinemann: Oxford, UK, 2018.
70. Cipollina, A.; Micale, G.; Rizzuti, L. *Seawater Desalination: Conventional and Renewable Energy Processes*; Springer: Berlin/Heidelberg, Germany, 2010.
71. Santosh, R.; Arunkumar, T.; Velraj, R.; Kumaresan, G. Technological advancements in solar energy driven humidification-dehumidification desalination systems—A review. *J. Clean. Prod.* **2018**, *207*, 826–845. [CrossRef]
72. DeWinter, F. *Solar Collectors, Energy Storage, and Materials*; MIT Press: Cambridge, MA, USA, 1990.
73. Chou, C.-C.; Chiang, C.-T.; Wu, P.-Y.; Chu, C.-P.; Lin, C.-Y. Spatiotemporal analysis and visualization of power consumption data integrated with building information models for energy savings. *Resour. Conserv. Recycl.* **2017**, *123*, 219–229. [CrossRef]
74. Parida, B.; Iniyan, S.; Goic, R. A review of solar photovoltaic technologies. *Renew. Sustain. Energy Rev.* **2011**, *15*, 1625–1636. [CrossRef]
75. Wang, R.; Zhai, X. Development of solar thermal technologies in China. *Energy* **2010**, *35*, 4407–4416. [CrossRef]
76. Ahmed, M.S.; Mohamed, A.S.A.; Maghrabie, H.M. Performance Evaluation of Combined Photovoltaic Thermal Water Cooling System for Hot Climate Regions. *J. Sol. Energy Eng.* **2019**, *141*, 4042723. [CrossRef]

77. Khan, F.; Alshahrani, T.; Fareed, I.; Kim, J.H. A comprehensive degradation assessment of silicon photovoltaic modules installed on a concrete base under hot and low-humidity environments: Building applications. *Sustain. Energy Technol. Assess.* **2022**, *52*, 102314. [CrossRef]
78. Khan, F.; Kim, J.H. Performance Degradation Analysis of c-Si PV Modules Mounted on a Concrete Slab under Hot-Humid Conditions Using Electroluminescence Scanning Technique for Potential Utilization in Future Solar Roadways. *Materials* **2019**, *12*, 4047. [CrossRef]
79. Sandeep, H.; Arunachala, U. Solar parabolic trough collectors: A review on heat transfer augmentation techniques. *Renew. Sustain. Energy Rev.* **2017**, *69*, 1218–1231. [CrossRef]
80. Kabeel, A.E.; El-Said, E.M.S.; Abdulaziz, M. Thermal solar water heater with H_2O-Al_2O_3 nano-fluid in forced convection: Experimental investigation. *Int. J. Ambient Energy* **2017**, *38*, 85–93. [CrossRef]
81. Sahota, L.; Shyam; Tiwari, G. Energy matrices, enviroeconomic and exergoeconomic analysis of passive double slope solar still with water based nanofluids. *Desalination* **2017**, *409*, 66–79. [CrossRef]
82. Kim, H.; Kim, J.; Cho, H. Experimental study on performance improvement of U-tube solar collector depending on nanoparticle size and concentration of Al_2O_3 nanofluid. *Energy* **2017**, *118*, 1304–1312. [CrossRef]
83. Khanjari, Y.; Kasaeian, A.; Pourfayaz, F. Evaluating the environmental parameters affecting the performance of photovoltaic thermal system using nanofluid. *Appl. Therm. Eng.* **2017**, *115*, 178–187. [CrossRef]
84. Shah, T.R.; Babar, H.; Ali, H.M. Chapter 8—Energy harvesting: Role of hybrid nanofluids. In *Emerging Nanotechnologies for Renewable Energy*; Ahmed, W., Booth, M., Nourafkan, E., Eds.; Elsevier: Amsterdam, The Netherlands, 2021; pp. 173–211.
85. Salameh, T.; Kumar, P.P.; Olabi, A.; Obaideen, K.; Sayed, E.T.; Maghrabie, H.M.; Abdelkareem, M.A. Best battery storage technologies of solar photovoltaic systems for desalination plant using the results of multi optimization algorithms and sustainable development goals. *J. Energy Storage* **2022**, *55*, 105312. [CrossRef]
86. Olabi, A.; Shehata, N.; Sayed, E.T.; Rodriguez, C.; Anyanwu, R.C.; Russell, C.; Abdelkareem, M.A. Role of microalgae in achieving sustainable development goals and circular economy. *Sci. Total Environ.* **2022**, *854*, 158689. [CrossRef]
87. Obaideen, K.; Shehata, N.; Sayed, E.T.; Abdelkareem, M.A.; Mahmoud, M.S.; Olabi, A. The role of wastewater treatment in achieving sustainable development goals (SDGs) and sustainability guideline. *Energy Nexus* **2022**, *7*, 100112. [CrossRef]
88. Shehata, N.; Obaideen, K.; Sayed, E.T.; Abdelkareem, M.A.; Mahmoud, M.S.; El-Salamony, A.-H.R.; Mahmoud, H.M.; Olabi, A. Role of refuse-derived fuel in circular economy and sustainable development goals. *Process Saf. Environ. Prot.* **2022**, *163*, 558–573. [CrossRef]
89. Shehata, N.; Mohamed, O.; Sayed, E.T.; Abdelkareem, M.A.; Olabi, A. Geopolymer concrete as green building materials: Recent applications, sustainable development and circular economy potentials. *Sci. Total Environ.* **2022**, *836*, 155577. [CrossRef]
90. Joshi, S.S.; Dhoble, A.S.; Jiwanapurkar, P.R. Investigations of Different Liquid Based Spectrum Beam Splitters for Combined Solar Photovoltaic Thermal Systems. *J. Sol. Energy Eng.* **2016**, *138*, 021003. [CrossRef]
91. Singh, P.; Gaur, M. Sustainability assessment of hybrid active greenhouse solar dryer integrated with evacuated solar collector. *Curr. Res. Food Sci.* **2021**, *4*, 684–691. [CrossRef]
92. Kumar, M.; Sansaniwal, S.K.; Khatak, P. Progress in solar dryers for drying various commodities. *Renew. Sustain. Energy Rev.* **2016**, *55*, 346–360. [CrossRef]
93. Janjai, S.; Intawee, P.; Kaewkiew, J.; Sritus, C.; Khamvongsa, V. A large-scale solar greenhouse dryer using polycarbonate cover: Modeling and testing in a tropical environment of Lao People's Democratic Republic. *Renew. Energy* **2011**, *36*, 1053–1062. [CrossRef]
94. Mewa, E.A.; Okoth, M.W.; Kunyanga, C.N.; Rugiri, M.N. Experimental evaluation of beef drying kinetics in a solar tunnel dryer. *Renew. Energy* **2019**, *139*, 235–241. [CrossRef]
95. Bhardwaj, A.; Kumar, R.; Chauhan, R. Experimental investigation of the performance of a novel solar dryer for drying medicinal plants in Western Himalayan region. *Sol. Energy* **2018**, *177*, 395–407. [CrossRef]
96. Singh, S.; Gill, R.; Hans, V.; Mittal, T. Experimental performance and economic viability of evacuated tube solar collector assisted greenhouse dryer for sustainable development. *Energy* **2021**, *241*, 122794. [CrossRef]
97. Srivastava, A.; Anand, A.; Shukla, A.; Kumar, A.; Buddhi, D.; Sharma, A. A comprehensive overview on solar grapes drying: Modeling, energy, environmental and economic analysis. *Sustain. Energy Technol. Assess.* **2021**, *47*, 101513. [CrossRef]
98. Ahmadi, A.; Das, B.; Ehyaei, M.; Esmaeilion, F.; Assad, M.E.H.; Jamali, D.; Koohshekan, O.; Kumar, R.; Rosen, M.; Negi, S.; et al. Energy, exergy, and techno-economic performance analyses of solar dryers for agro products: A comprehensive review. *Sol. Energy* **2021**, *228*, 349–373. [CrossRef]
99. Bhandari, S.N.; Schlüter, S.; Kuckshinrichs, W.; Schlör, H.; Adamou, R.; Bhandari, R. Economic Feasibility of Agrivoltaic Systems in Food-Energy Nexus Context: Modelling and a Case Study in Niger. *Agronomy* **2021**, *11*, 1906. [CrossRef]
100. Tawfik, M.; Sagade, A.A.; Palma-Behnke, R.; El-Shal, H.M.; Allah, W.A. Solar cooker with tracking-type bottom reflector: An experimental thermal performance evaluation of a new design. *Sol. Energy* **2021**, *220*, 295–315. [CrossRef]
101. Kurmi, O.P.; Lam, K.B.H.; Ayres, J.G. Indoor air pollution and the lung in low- and medium-income countries. *Eur. Respir. J.* **2012**, *40*, 239–254. [CrossRef]
102. Obaideen, K.; AlMallahi, M.N.; Al-Alami, A.H.; Ramadan, M.; Abdelkareem, M.A.; Shehata, N.; Olabi, A. On the contribution of solar energy to sustainable developments goals: Case study on Mohammed bin Rashid Al Maktoum Solar Park. *Int. J. Thermofluids* **2021**, *12*, 100123. [CrossRef]

103. Caldés, N.; Rodriguez-Serrano, I. Potential contribution of concentrated solar power in meeting the sustainable development goals. *AIP Conf. Proc.* **2018**, *2033*, 120001. [CrossRef]
104. UNICEF. *Every Child Learns: UNICEF Education Strategy 2019–2030*; UNICEF: New York, NY, USA, 2019; pp. 23–36.
105. Khodadadi, E. Investigating the Impact of Renewable Energy Development on World Economy. 2021. Available online: https://www.researchgate.net/publication/358667225_Investigating_the_Impact_of_Renewable_Energy_Development_on_World_Economy (accessed on 1 November 2022).
106. Rodríguez-Serrano, I.; Caldés, N.; de la Rúa, C.; Lechón, Y. Assessing the three sustainability pillars through the Framework for Integrated Sustainability Assessment (FISA): Case study of a Solar Thermal Electricity project in Mexico. *J. Clean. Prod.* **2017**, *149*, 1127–1143. [CrossRef]
107. Vengadesan, E.; Senthil, R. A review on recent development of thermal performance enhancement methods of flat plate solar water heater. *Sol. Energy* **2020**, *206*, 935–961. [CrossRef]
108. Li, W.-T.; Tushar, W.; Yuen, C.; Ng, B.K.K.; Tai, S.; Chew, K.T. Energy efficiency improvement of solar water heating systems—An IoT based commissioning methodology. *Energy Build.* **2020**, *224*, 110231. [CrossRef]
109. Rastogi, V.; Saxena, A.; Singh, A.K.; Karakilcik, M. Thermal Performance Evaluation of a modified solar water heater integrated with parabolic trough concentrator. In *Solar Water Heating*; Nova Science Publishers, Inc.: Hauppauge, NY, USA, 2021.
110. Rabaia, M.K.H.; Abdelkareem, M.A.; Sayed, E.T.; Elsaid, K.; Chae, K.-J.; Wilberforce, T.; Olabi, A. Environmental impacts of solar energy systems: A review. *Sci. Total Environ.* **2020**, *754*, 141989. [CrossRef]
111. Pathak, S.K.; Tyagi, V.; Chopra, K.; Sharma, R.K. Recent development in thermal performance of solar water heating (SWH) systems. *Mater. Today Proc.* **2022**, *63*, 778–785. [CrossRef]
112. Jones, L.E.; Olsson, G. Solar Photovoltaic and Wind Energy Providing Water. *Glob. Chall.* **2017**, *1*, 1600022. [CrossRef]
113. Sayed, E.T.; Olabi, A.; Elsaid, K.; Al Radi, M.; Alqadi, R.; Abdelkareem, M.A. Recent progress in renewable energy based-desalination in the Middle East and North Africa MENA region. *J. Adv. Res.* 2022. [CrossRef]
114. R, R.K.; Pandey, A.; Samykano, M.; Aljafari, B.; Ma, Z.; Bhattacharyya, S.; Goel, V.; Ali, I.; Kothari, R.; Tyagi, V. Phase change materials integrated solar desalination system: An innovative approach for sustainable and clean water production and storage. *Renew. Sustain. Energy Rev.* **2022**, *165*, 112611. [CrossRef]
115. Meldrum, J.R.; Nettles-Anderson, S.; Heath, G.P.; Macknick, J. Life cycle water use for electricity generation: A review and harmonization of literature estimates. *Environ. Res. Lett.* **2013**, *8*, 015031. [CrossRef]
116. Salamah, T.; Ramahi, A.; Alamara, K.; Juaidi, A.; Abdallah, R.; Abdelkareem, M.A.; Amer, E.-C.; Olabi, A.G. Effect of dust and methods of cleaning on the performance of solar PV module for different climate regions: Comprehensive review. *Sci. Total Environ.* **2022**, *827*, 154050. [CrossRef] [PubMed]
117. Barbosa, R.R.; Schultz, H.S.; Garcia, L.d.C.; Martins, D.D.; Carvalho, M. Economic and greenhouse gas assessments for two hot water industrial systems: Solar vs. natural gas. *Clean. Eng. Technol.* **2022**, *6*, 100365. [CrossRef]
118. Kumar, S.; Tiwari, G. Life cycle cost analysis of single slope hybrid (PV/T) active solar still. *Appl. Energy* **2009**, *86*, 1995–2004. [CrossRef]
119. El-Agouz, S.; Zayed, M.E.; Ghazala, A.M.A.; Elbar, A.R.A.; Shahin, M.; Zakaria, M.; Ismaeil, K.K. Solar thermal feed preheating techniques integrated with membrane distillation for seawater desalination applications: Recent advances, retrofitting performance improvement strategies, and future perspectives. *Process. Saf. Environ. Prot.* **2022**, *164*, 595–612. [CrossRef]
120. Kumar, L.; Hasanuzzaman, M.; Rahim, N. Global advancement of solar thermal energy technologies for industrial process heat and its future prospects: A review. *Energy Convers. Manag.* **2019**, *195*, 885–908. [CrossRef]
121. Jodeiri, A.; Goldsworthy, M.; Buffa, S.; Cozzini, M. Role of sustainable heat sources in transition towards fourth generation district heating—A review. *Renew. Sustain. Energy Rev.* **2022**, *158*, 112156. [CrossRef]
122. Assad, M.E.H.; Ahmadi, M.H.; Sadeghzadeh, M.; Yassin, A.; Issakhov, A. Renewable hybrid energy systems using geothermal energy: Hybrid solar thermal–geothermal power plant. *Int. J. Low-Carbon Technol.* **2020**, *16*, 518–530. [CrossRef]
123. Ding, W.; Bauer, T. Progress in Research and Development of Molten Chloride Salt Technology for Next Generation Concentrated Solar Power Plants. *Engineering* **2021**, *7*, 334–347. [CrossRef]
124. Heffron, R.; Halbrügge, S.; Körner, M.-F.; Obeng-Darko, N.A.; Sumarno, T.; Wagner, J.; Weibelzahl, M. Justice in solar energy development. *Solar Energy* **2021**, *218*, 68–75. [CrossRef]
125. Martin-Escudero, K.; Salazar-Herran, E.; Campos-Celador, A.; Belloso, G.D.; Gomez-Arriaran, I. Solar energy system for heating and domestic hot water supply by means of a heat pump coupled to a photovoltaic ventilated façade. *Sol. Energy* **2019**, *183*, 453–462. [CrossRef]
126. Fan, Y.; Xia, X. Energy-efficiency building retrofit planning for green building compliance. *Build. Environ.* **2018**, *136*, 312–321. [CrossRef]
127. Feng, W.; Zhang, Q.; Ji, H.; Wang, R.; Zhou, N.; Ye, Q.; Hao, B.; Li, Y.; Luo, D.; Lau, S.S.Y. A review of net zero energy buildings in hot and humid climates: Experience learned from 34 case study buildings. *Renew. Sustain. Energy Rev.* **2019**, *114*, 109303. [CrossRef]
128. Ahmadi, A.; Ehyaei, M.; Doustgani, A.; Assad, M.E.H.; Hmida, A.; Jamali, D.; Kumar, R.; Li, Z.; Razmjoo, A. Recent residential applications of low-temperature solar collector. *J. Clean. Prod.* **2020**, *279*, 123549. [CrossRef]
129. Karim, S.H.T.; Tofiq, T.A.; Shariati, M.; Rad, H.N.; Ghasemi, A. 4E analyses and multi-objective optimization of a solar-based combined cooling, heating, and power system for residential applications. *Energy Rep.* **2021**, *7*, 1780–1797. [CrossRef]

130. Kumar, K.R.; Chaitanya, N.K.; Kumar, N.S. Solar thermal energy technologies and its applications for process heating and power generation—A review. *J. Clean. Prod.* **2020**, *282*, 125296. [CrossRef]
131. Andharia, J.K.; Markam, B.; Dzhonova, D.; Maiti, S. A comparative performance analysis of sensible and latent heat based storage in a small-scale solar thermal dryer. *J. Energy Storage* **2022**, *45*, 103764. [CrossRef]
132. Yang, T.; Liu, W.; Kramer, G.J.; Sun, Q. Seasonal thermal energy storage: A techno-economic literature review. *Renew. Sustain. Energy Rev.* **2021**, *139*, 110732. [CrossRef]
133. Lamnatou, C.; Motte, F.; Notton, G.; Chemisana, D.; Cristofari, C. Building-integrated solar thermal system with/without phase change material: Life cycle assessment based on ReCiPe, USEtox and Ecological footprint. *J. Clean. Prod.* **2018**, *193*, 672–683. [CrossRef]
134. Gürtürk, M.; Benli, H.; Ertürk, N.K. Determination of the effects of temperature changes on solar glass used in photovoltaic modules. *Renew. Energy* **2019**, *145*, 711–724. [CrossRef]
135. Verma, S.K.; Kumar, R.; Barthwal, M.; Rakshit, D. A review on futuristic aspects of hybrid photo-voltaic thermal systems (PV/T) in solar energy utilization: Engineering and Technological approaches. *Sustain. Energy Technol. Assess.* **2022**, *53*, 102463. [CrossRef]
136. Maka, A.O.M.; Alabid, J.M. Solar energy technology and its roles in sustainable development. *Clean Energy* **2022**, *6*, 476–483. [CrossRef]
137. Gahrens, S.; Alessandra, S.; Steinfatt, K. Trading Into a Bright Energy Future, World Trade Organization (WTO). 2021. Available online: https://www.alexandria.unisg.ch/265310/1/energyfuture2021_e.pdf (accessed on 1 October 2022).
138. IRENA, Solar Energy—International Renewable Energy Agency. 2021. Available online: www.irena.org/solar (accessed on 2 February 2022).
139. Gahrens, S.; Steinfatt, K. Trading Into a Bright Energy Future. The Case for Open, High-Quality Solar Photovoltaic Markets. Abu Dhabi: IRENA. 2021, pp. 1–44. Available online: https://irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jul/IRENA_WTO_Trading_Energy_Future_2021.pdf (accessed on 21 April 2022).
140. IRENA. Renewable Energy and Jobs—Annual Review 2021, (REJ). 2021. Available online: https://www.irena.org/publications/2021/Oct/Renewable-Energy-and-Jobs-Annual-Review-2021 (accessed on 2 January 2022).
141. Maka, A.O.; Salem, S.; Mehmood, M. Solar photovoltaic (PV) applications in Libya: Challenges, potential, opportunities and future perspectives. *Clean. Eng. Technol.* **2021**, *5*, 100267. [CrossRef]
142. Goel, M.; Verma, V.S.; Tripathi, N.G. High-Temperature Solar Power Systems. In *Solar Energy*; Springer: Singapore, 2022; pp. 97–106.
143. Sørensen, B. (Ed.) Chapter 11—Environmental Issues Associated with Solar Electric and Thermal Systems with Storage. In *Solar Energy Storage*; Academic Press: Boston, MA, USA, 2015; pp. 247–271.
144. Al-Kayiem, H.H. Energy sustainability through integrated solar thermal systems. *WIT Trans. Ecol. Environ.* **2013**, *179*, 887–897. [CrossRef]
145. Lamnatou, C.; Chemisana, D. Solar thermal systems for sustainable buildings and climate change mitigation: Recycling, storage and avoided environmental impacts based on different electricity mixes. *Sol. Energy* **2021**, *231*, 209–227. [CrossRef]
146. Lamnatou, C.; Chemisana, D.; Mateus, R.; Almeida, M.; Silva, S. Review and perspectives on Life Cycle Analysis of solar technologies with emphasis on building-integrated solar thermal systems. *Renew. Energy* **2015**, *75*, 833–846. [CrossRef]
147. Norton, B. Industrial and Agricultural Applications of Solar Heat. In *Comprehensive Renewable Energy*; Elsevier: Amsterdam, The Netherlands, 2012; pp. 567–594. [CrossRef]
148. Sakhare, K.P.; Kiran; Balsoriya, H.; Kesari, J. Opportunities for solar thermal systems across dairy, agricultural, hotel & automobile industries. *Mater. Today Proc.* **2022**, *56*, 3656–3668. [CrossRef]
149. United Nations. *World Urbanization Prospects: The 2018 Revision*; United Nations Department of Economic and Social Affairs, Population Division: New York, NY, USA, 2019.
150. Ruiz, H.S.; Sunarso, A.; Ibrahim-Bathis, K.; Murti, S.A.; Budiarto, I. GIS-AHP Multi Criteria Decision Analysis for the optimal location of solar energy plants at Indonesia. *Energy Rep.* **2020**, *6*, 3249–3263. [CrossRef]
151. Kumar, A.R.; Ramakrishnan, M. A scoping review on recent advancements in domestic applications of solar thermal systems. *J. Therm. Eng.* **2022**, *8*, 426–444. [CrossRef]
152. Bibri, S.E.; Krogstie, J. Smart sustainable cities of the future: An extensive interdisciplinary literature review. *Sustain. Cities Soc.* **2017**, *31*, 183–212. [CrossRef]
153. Sabory, N.; Senjyu, T.; Danish, M.; Ahmadi, M.; Zaheb, H.; Halim, M. A Framework for Integration of Smart and Sustainable Energy Systems in Urban Planning Processes of Low-Income Developing Countries: Afghanistan Case. *Sustainability* **2021**, *13*, 8428. [CrossRef]
154. Wang, P.; Liu, Z.; Zhang, L. Sustainability of compact cities: A review of Inter-Building Effect on building energy and solar energy use. *Sustain. Cities Soc.* **2021**, *72*, 103035. [CrossRef]
155. Aamir, M.; Uqaili, M.A.; Amir, S.; Chowdhry, B.S.; Rafique, F.; Poncela, J.; González, J.P. Framework for Analysis of Power System Operation in Smart Cities. *Wirel. Pers. Commun.* **2014**, *76*, 399–408. [CrossRef]
156. Ismagiloiva, E.; Hughes, L.; Rana, N.; Dwivedi, Y. Role of Smart Cities in Creating Sustainable Cities and Communities: A Systematic Literature Review. In *International Working Conference on Transfer and Diffusion of IT*; Springer: Cham, Switzerland, 2019; pp. 311–324. [CrossRef]
157. Milousi, M.; Souliotis, M. Life cycle assessment review in solar thermal systems. In *Environmental Assessment of Renewable Energy Conversion Technologies*; Elsevier: Amsterdam, The Netherlands, 2022; pp. 37–53.

158. Fernandes, V.; Mateus, R.; Bragança, L.; Silva, S.M.; Almeida, M.G.d. Life cycle assessment of solar thermal systems. In Proceedings of the IAHS 2014, Sustainable Housing Construction, Funchal, Portugal, 16–19 December 2014.
159. Dincer, I. Renewable energy and sustainable development: A crucial review. *Renew. Sustain. Energy Rev.* **2000**, *4*, 157–175. [CrossRef]
160. Ahmed, S.F.; Khalid, M.; Vaka, M.; Walvekar, R.; Numan, A.; Rasheed, A.K.; Mubarak, N.M. Recent progress in solar water heaters and solar collectors: A comprehensive review. *Therm. Sci. Eng. Prog.* **2021**, *25*, 100981. [CrossRef]
161. Deng, Y.; Dewil, R.; Baeyens, J.; Ansart, R.; Zhang, H. The "Screening Index" to Select Building-Scale Heating Systems. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *586*, 012004. [CrossRef]
162. Zhang, S.-C.; Yang, X.-Y.; Xu, W.; Fu, Y.-J. Contribution of nearly-zero energy buildings standards enforcement to achieve carbon neutral in urban area by 2060. *Adv. Clim. Chang. Res.* **2021**, *12*, 734–743. [CrossRef]
163. Abokersh, M.H.; Gangwar, S.; Spiekman, M.; Vallès, M.; Jiménez, L.; Boer, D. Sustainability insights on emerging solar district heating technologies to boost the nearly zero energy building concept. *Renew. Energy* **2021**, *180*, 893–913. [CrossRef]
164. Sotehi, O.; Chaker, A.; Maalouf, C. Hybrid PV/T water solar collector for net zero energy building and fresh water production: A theoretical approach. *Desalination* **2016**, *385*, 1–11. [CrossRef]
165. Das, S.K.; Stephen, U. A review of heat transfer in nanofluids. *Adv. Heat Trans.* **2009**, *41*, 81–197.
166. Messina, S.; González, F.; Saldaña, C.; Peña-Sandoval, G.R.; Tadeo, H.; Juárez-Rosete, C.R.; Nair, P. Solar powered dryers in agricultural produce processing for sustainable rural development worldwide: A case study from Nayarit-Mexico. *Clean. Circ. Bioecon.* **2022**, *3*, 100027. [CrossRef]
167. Ali, E.N.; Liaquat, R.; Ali, M.; Waqas, A.; Shahzad, N. Techno-economic and GHG mitigation analyses based on regional and seasonal variations of non-concentrating solar thermal collectors in textile sector of Pakistan. *Renew. Energy Focus* **2022**, *42*, 165–177. [CrossRef]
168. Nathwani, J.; Kammen, D.M. Affordable Energy for Humanity: A Global Movement to Support Universal Clean Energy Access. *Proc. IEEE* **2019**, *107*, 1780–1789. [CrossRef]
169. Wijayatunga, P.D.; Attalage, R. Socio-economic impact of solar home systems in rural Sri Lanka: A case-study. *Energy Sustain. Dev.* **2005**, *9*, 5–9. [CrossRef]
170. Mishra, P.; Behera, B. Socio-economic and environmental implications of solar electrification: Experience of rural Odisha. *Renew. Sustain. Energy Rev.* **2016**, *56*, 953–964. [CrossRef]
171. Wijesinghe, J.K.; Najim, M.Y.M.; Fernando, G.L.; Liyanage, M.H. Economic Viability of Solar PV for Domestic Applications in a Middle-Income Country: A case Study of Sri Lanka. In Proceedings of the 2020 International Conference and Utility Exhibition on Energy, Environment and Climate Change (ICUE), Pattaya City, Thailand, 20–22 October 2020; Volume 9306934, pp. 1–10. [CrossRef]
172. Alnaser, W.E.; Alnaser, N.W. The Impact of the Rise of Using Solar Energy in GCC Countries. In *Renewable Energy and Sustainable Buildings: Selected Papers from the World Renewable Energy Congress WREC 2018*; Sayigh, A., Ed.; Springer International Publishing: Cham, Switzerland, 2020; pp. 167–183.
173. Dréon, J.; Jeangros, Q.; Cattin, J.; Haschke, J.; Antognini, L.; Ballif, C.; Boccard, M. 23.5%-efficient silicon heterojunction silicon solar cell using molybdenum oxide as hole-selective contact. *Nano Energy* **2020**, *70*, 104495. [CrossRef]
174. Andreani, L.C.; Bozzola, A.; Kowalczewski, P.; Liscidini, M.; Redorici, L. Silicon solar cells: Toward the efficiency limits. *Adv. Phys. X* **2018**, *4*, 1548305. [CrossRef]
175. IEA. *World Energy Outlook 2020*; IEA: Paris, France, 2020. Available online: https://www.iea.org/reports/world-energy-outlook-2020 (accessed on 30 April 2021).
176. Cocco, D.S.; Costa, A.M. Effect of a global warming model on the energetic performance of a typical solar photovoltaic system. *Case Stud. Therm. Eng.* **2019**, *14*, 100450. [CrossRef]
177. Creutzig, F.; Agoston, P.; Goldschmidt, J.C.; Luderer, G.; Nemet, G.; Pietzcker, R.C. The underestimated potential of solar energy to mitigate climate change. *Nat. Energy* **2017**, *2*, 17140. [CrossRef]
178. Faninger, G. The Potential of Solar Thermal Technologies in a Sustainable Energy Future. IEA Solar Heating & Cooling Programme. Available online: http://www.iea-shc.org/data/sites/1/publications/Potential_of_Solar_Thermal_Technologies_2010.pdf (accessed on 1 October 2022).
179. Buonocore, J.J.; Choma, E.; Villavicencio, A.H.; Spengler, J.D.; Koehler, D.A.; Evans, J.S.; Lelieveld, J.; Klop, P.; Sanchez-Pina, R. Metrics for the sustainable development goals: Renewable energy and transportation. *Palgrave Commun.* **2019**, *5*, 136. [CrossRef]
180. Troldborg, M.; Heslop, S.; Hough, R.L. Assessing the sustainability of renewable energy technologies using multi-criteria analysis: Suitability of approach for national-scale assessments and associated uncertainties. *Renew. Sustain. Energy Rev.* **2014**, *39*, 1173–1184. [CrossRef]
181. Kumar, A.; Sah, B.; Singh, A.R.; Deng, Y.; He, X.; Kumar, P.; Bansal, R.C. A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. *Renew. Sustain. Energy Rev.* **2017**, *69*, 596–609. [CrossRef]
182. Dewi, R.N. TERAPAN (Solar Technology on Fishing Boats) as an Innovation to Reduce the Operational Costs of Fishing Activities. *Indones. Sch. Sci. Summit Taiwan Proc.* **2022**, *4*, 122–128. [CrossRef]
183. Lenzen, M.; Moran, D.; Kanemoto, K.; Foran, B.; Lobefaro, L.; Geschke, A. International trade drives biodiversity threats in developing nations. *Nature* **2012**, *486*, 109–112. [CrossRef]
184. Myers, N.; Mittermeier, R.A.; Mittermeier, C.G.; da Fonseca, G.A.B.; Kent, J. Biodiversity hotspots for conservation priorities. *Nature* **2000**, *403*, 853–858. [CrossRef]

185. Moreno-Leiva, S.; Díaz-Ferrán, G.; Haas, J.; Telsnig, T.; Díaz-Alvarado, F.A.; Palma-Behnke, R.; Kracht, W.; Román, R.; Chudinzow, D.; Eltrop, L. Towards solar power supply for copper production in Chile: Assessment of global warming potential using a life-cycle approach. *J. Clean. Prod.* **2017**, *164*, 242–249. [CrossRef]
186. Cameron, L.; van der Zwaan, B. Employment factors for wind and solar energy technologies: A literature review. *Renew. Sustain. Energy Rev.* **2015**, *45*, 160–172. [CrossRef]
187. Antonucci, T.C.; Bial, M.; Cox, C.; Finkelstein, R.; Marchado, L. The Role of Psychology in Addressing Worldwide Challenges of Poverty and Gender Inequality. *Z. Psychol.* **2019**, *227*, 95–104. [CrossRef]
188. Rodríguez-Serrano, I.; Caldés, N.; de la Rúa, C.; Lechón, Y.; Garrido, A. Using the Framework for Integrated Sustainability Assessment (FISA) to expand the Multiregional Input–Output analysis to account for the three pillars of sustainability. *Environ. Dev. Sustain.* **2017**, *19*, 1981–1997. [CrossRef]
189. Bere-Semeredi, I.; Mocan, A. A review of the Europe indicators on climate change—Industry, innovation and infrastructure. *MATEC Web Conf.* **2019**, *290*, 06001. [CrossRef]
190. Rai, S.M.; Brown, B.D.; Ruwanpura, K.N. SDG 8: Decent work and economic growth—A gendered analysis. *World Dev.* **2018**, *113*, 368–380. [CrossRef]
191. Gasparatos, A.; Doll, C.N.; Esteban, M.; Ahmed, A.; Olang, T.A. Renewable energy and biodiversity: Implications for transitioning to a Green Economy. *Renew. Sustain. Energy Rev.* **2017**, *70*, 161–184. [CrossRef]
192. Sippel, S.; Meinshausen, N.; Fischer, E.M.; Székely, E.; Knutti, R. Climate change now detectable from any single day of weather at global scale. *Nat. Clim. Chang.* **2020**, *10*, 35–41. [CrossRef]