SOLAR THERMAL CONVERSION TECHNOLOGIES FOR INDUSTRIAL PROCESS HEATING

Edited by
T.V. Arjunan, Vijayan Selvaraj, and M.M. Matheswaran

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Solar Thermal Conversion Technologies for Industrial Process Heating

Solar Thermal Conversion Technologies for Industrial Process Heating presents a comprehensive look at the use of solar thermal energy in industrial applications, such as textiles, chemical processing, and food. The successful projects implemented in a variety of industries are shown in case studies, alongside performance assessment methodologies. The book includes various solar thermal energy conversion technologies and new techniques and applications of solar collectors in industrial sectors.

Features:

- Covers the key designs and novel technologies employed in the processing industries.
- Discusses challenges in the incorporation of the solar thermal system in industrial applications.
- Explores the techno-economic, environmental impact and life cycle analysis with government policies for promoting the system.
- Includes real-world case studies.
- Presents chapters written by global experts in the field.

The book will be useful for researchers, graduate students, and industry professionals with an aim to promote mutual understanding between sectors dealing with solar thermal energy.

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Preface

Solar energy is the largest and most widely distributed renewable energy resource on the planet and can be utilized for a wide range of applications, such as solar water heating, photovoltaic electricity generation, solar thermal energy generation, and all manner of passive and active solar architectures. Besides environmental consciousness, the dwindling of traditional energy sources also marks solar energy as the appropriate energy source to meet the increasing energy demand worldwide. Solar thermal collectors can be used efficiently to meet the heating needs of industrial processes because many industrial processes in various industries operate at temperatures ranging from 80 °C to 240 °C. Industrial energy analysis shows that solar thermal energy has enormous applications at low (i.e. 20–200 °C), medium, and medium-high (i.e. 80–240 °C) temperature levels. Almost all industrial processes require heat in some parts of their processes.

Despite all its merits, the implementation of solar thermal technology in industries is challenging due to various factors such as awareness, high investment cost, lower conversion efficiency, etc. This book attempts to explore all these challenges and the use of solar thermal energy in various industrial applications along with successful projects implemented in different categories of industries around the world as case studies.

The chapters of this book are compiled into four major parts, and the first part consists of two chapters. Chapter 1 provides an overview of the global energy scenario and highlights the significance of utilizing solar energy in the aspects of environmental impact and energy resource availability. Chapter 2 discusses in detail the fundamental concepts involved in the conversion of solar radiation into useful thermal energy for low and moderate-temperature heating processes in different industries. It also discusses the basic mathematical modeling of non-concentrating and concentrating collectors.

The second part of the book deals with the potential for solar industrial process heating applications in a few sectors along with the case studies. Chapter 3 elaborates on the potential heating processes involved in various industries and the necessary assessments to be implemented for adopting solar thermal technologies in an industrial location and the hurdles to be considered, such as technological, economic, and social barriers, etc. Chapter 4 discusses the processes in a typical pharmaceutical industry and the possible solar thermal integrations, along with highlighting a few case studies in pharmaceutical industries located in various countries. Further, the use of solar energy for small-scale applications in Ayurveda medicinal herb drying is included. Chapter 5 provides the energy consumption profile and the present energy sources used in numerous processes in the automobile manufacturing industry. It discusses the potential processes along with the desired temperatures and the integration methods adopted in conventional heating systems. It also includes the successful implementation of solar thermal systems situated in different parts of the world. Chapter 6 presents an overview of energy usage in the various food industry sectors, and the integration of solar technology in the food processing industries is introduced to overcome issues of the energy crisis and environmental problems and for sustainable economic development. Chapter 7 covers the fundamental techniques and contemporary advancements in thermal-based high-capacity desalination systems, such as multi-stage flash (MSF) evaporation, multi-effect distillation (MED), vapor compression distillation (VCD), low-temperature thermal desalination (LTTD), and others. In addition, the viability of a solar energy integrated desalination system as a long-term solution to the problem of water scarcity and also a case study of existing solar energy-based large-scale desalination has been presented. Chapter 8 deals with the implementation of solar heat for various processes in the oil and gas industries. In addition, the selection of appropriate solar thermal technologies to meet the process heat demand is discussed in detail, along with their economic and environmental effects. Further, the integration of solar thermal technologies with the existing setup of the oil and gas industries has been discussed.

The third part provides insight into the methods that can be adopted to assess the effective implementation of solar thermal systems for industrial heating applications from technical and economic perspectives. Chapter 9 discusses the technique for integrating solar heating systems into industrial settings using pinch analysis. Integration at the supply level and process level is discussed, and pertinent case examples are presented in depth. Chapter 10 deals with the sustainability of solar thermal systems by using life cycle assessment. It discusses various solar thermal technologies, lifetime assessment, and the environmental impact of solar thermal energy on two different-sized plants.

The final part of the book has two chapters, and they are devoted to elaborating the concepts of modern tools and an overview of several solar energy promotion policies adopted by various countries in the world. Chapter 11 discusses the role of contemporary tools, including artificial neural networks, convolution neural networks, fuzzy logic, machine learning, and genetic algorithms, in the prediction of solar radiation, the design, effective integration, and control of solar thermal systems used in industrial heating processes. Chapter 12 explains the global energy model and international solar energy strategies for chosen countries. Worldwide energy usage and regional climate scenarios are provided. International energy policies to promote renewable energy systems are described in depth.

We would like to express our sincere thanks to all the contributing authors, reviewers, book commissioning editor Ms. Kyra Lindholm, and CRC Press for their continuous support and guidance to bring out this book.

T.V. Arjunan
Vijayan Selvaraj
M.M. Matheswaran

Foreword

The scientific odyssey of Guru Ghasidas Vishwavidyalaya indicates that greatness is achievable. Our successes are the outcome of self-disciplined thinking and conduct. We recognize that perseverance with enthusiasm is the only way to achieve outcomes that surpass expectations. One of our core beliefs is unquestionably being enthusiastic about our work.

When it comes to solar energy technologies, the more you discover, the more you realize how little you know about its potential in different sectors. Therefore, there is a need for a book that explores the difficulties associated with switching from fossil fuels to clean technologies, treating these difficulties not as obstacles to change but rather as problems deserving careful consideration, investigation, and contemplation. We need a framework for clarifying the real-world difficulties, advantages, chances, and potential dangers of switching to a renewable energy future.

Professor T.V. Arjunan has been an important part of our odyssey. I have often found Professor Arjunan's way of executing work commendable and feel that one can learn from him that self-control at all levels—mental, emotional, and behavioral—is essential for reaching one's full potential.

The monograph edited by Prof. T.V. Arjunan, Dr. Vijayan Selvaraj, and Dr. M.M. Matheswaran is a compilation of extremely high-quality chapters authored by eminent researchers in the field of solar thermal conversion technologies. The contributors to this book are well-known experts in their respective fields, and the book describes the possible uses of solar energy for addressing the requirements of low-, medium-, and high-temperature industrial process heating applications. The chapters cover a wide range of topics, from simple solar thermal conversion techniques to large-scale industrial applications and various processes for heating purposes in different industries. The book also presents well-researched knowledge about solar thermal conversion technologies, effective integration techniques with industries, modern tools, and government policies particularly useful to researchers, practicing engineers, and policy formulators working in this field.

My hearty congratulations to all the readers of this book. The contents of this book will give you essential knowledge that can be utilized practically and the knowledge acquired can be employed beneficially in solar thermal energy projects. I trust that you will continue to make significant advances in your chosen field if you maintain your commitment to your fundamental convictions and keep building momentum.

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Part I

Solar Thermal Conversion Technologies

Overview

1 Global Energy Scenario with a Special Reference to Solar Systems for Sustainable Environment

N. Kannan

CONTENTS

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1.1 INTRODUCTION

Renewable energy technology is becoming highly important to meet the growing energy demand of the world as it causes minimum impact to the environment and its processes [1]. Renewable energy contributes significantly to the total world's energy demand and usage is reported to be 14% [2]. There are various renewable energy sources such as hydropower, geothermal, wind and biomass commonly used to meet increasing energy demand [3, 4]. It has been anticipated that the contribution of renewable energy sources will increase significantly in 2100 by 30–80% [5]. Moreover, industry, population growth and technological advancements will drastically increase the use of fossil fuel resources to pollute the environment. Because of this consequence, dramatic climate change has been happening all over the world and is causing detrimental impacts to the survival of living organisms [6].

It is interesting to address that most of the countries have now realized the need for renewable energy sources and their contribution to waste minimization, pollution mitigation, environmental sustainability and balancing of an ecosystem [7]. Solar energy and wind energy are two main sources freely available in nature. These resources can be utilized effectively to mitigate environmental problems caused by the overuse of fossil fuel resources. Solar energy is most popular among renewable energy sources because of its nature and availability in the environment. Furthermore, advance technologies such as photovoltaic (PV) systems are used to generate electricity from the harvested solar energy. It has been stated that the proper use of solar energy technologies to harvest available solar energy will be sufficient to meet the world's energy demand [8]. Furthermore, around four million EJ (exajoules) of solar energy are received by the earth's surface annually [9]. It is important to note that around 5×10^4 EJ solar energy can be utilized effectively out of the total solar energy available at the earth's surface [9]. However, the use of solar energy is still limited especially due to technical barriers in spite of its availability and environmental sustainability [9].

Moreover, intensive use of freely available solar energy to meet growing energy demand can lead to a significant reduction in global CO_2 emissions from the burning of fossil fuel resources [9]. It has been reported that around 696544 Mt of CO_2 has been reduced in the state of California, the United States, by implementing 113533 household solar systems [10]. Therefore, an effective solar energy system supported by appropriate policies and subsidies to harvest and utilize solar energy in an efficient manner must be practiced for energy sustainability in future. In addition to solar energy, wind energy is also used significantly to meet the energy demand of the world. Wind energy systems are actively practiced in 82 countries worldwide [10]. The growth of wind energy has happened remarkably over the last 20 years [10]. It has now reached its maturity and has been used productively to contribute to the energy demand of the dynamic world [10]. A significant number of wind turbines have been installed in the world. The total availability of the wind energy in the world is around 26000 TWh/yr. However, the utilization is limited to 9000 TWh/yr due to various constraints and economic implications.

As discussed previously, environmental pollution by excessive use of fossil fuel burning is an emerging concept all over the world to be addressed systematically to implement appropriate solutions. As a consequence of this, the concept of utilizing renewable energy sources is growing rapidly as it provides reasonable solution for problems caused by the excessive use of fossil fuel resources in the energy sector. Solar energy is used by many countries with room for future expansions to meet their annual energy demand. There are many reports and research works published to address the significance of this popular renewable energy source. However, there is very limited information available on the review of solar energy systems and environmental sustainability. This short critical review therefore addresses a comprehensive view of solar energy systems in terms of fundamentals, applications, potentials and future prospects to develop a clean and sustainable environment.

Moreover, this chapter is presented with an intention of filling the knowledge gaps identified by providing critical discussions on the global energy scenario, need of renewable energy sources (RES) and climate change scenarios, solar energy technologies, potentials and barriers of solar energy sources with respect to environmental sustainability. Therefore, this structured chapter will help researchers, policy makers and stakeholders to critically understand and justify real-world scenarios related to solar and wind energy systems in order to better select and expand these systems for viable applications.

1.2 GLOBAL ENERGY SCENARIO

World energy demand is steadily growing because of population growth and industrial revolutions. Figure 1.1 shows the past, present and future energy demand in the world. The energy demand was 1.81×10^5 TWh in 2020 as shown in Figure 1.1. However, it is expected to increase to 2.25×10^5 TWh in 2035. The main cause for

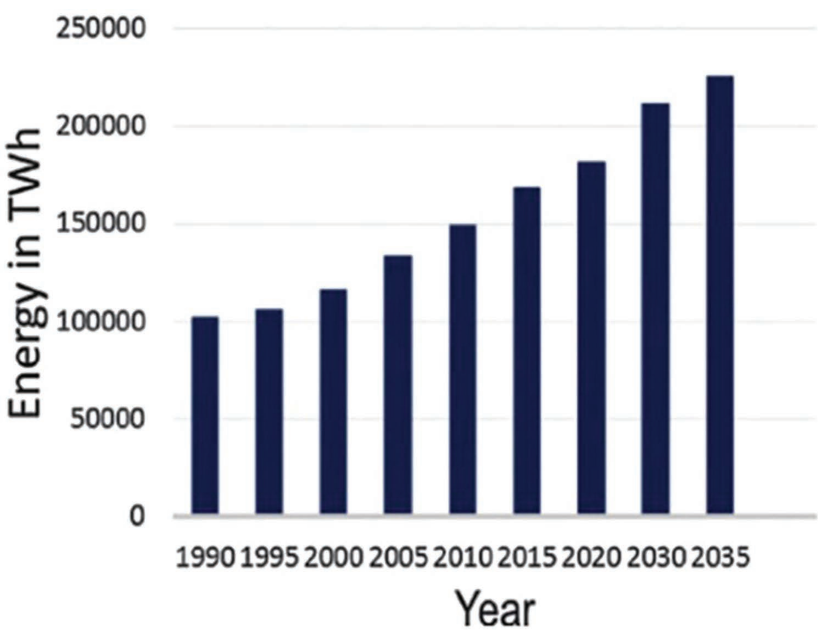

FIGURE 1.1 Past, present and future energy demand in the world [1, 11].

this is population growth. Many energy sources are used to meet such energy demand worldwide. However, around 77.9% of electricity has been produced by fossil fuel and nuclear sources which are expensive and cause environmental pollution particularly through CO_2 generation, and around 0.7% has been met by solar PV [1].

Therefore, there is an enormous gap for the expansion of the PV industry to use freely available solar energy for a better future. The world gets polluted and causes damage to living things mainly due to CO_2 emissions. This generation has caused several environmental issues such as climate change and global warming. Because of environmental pollution and exhaustion of fossil fuel resources, the world has to stimulate the growth of renewable energy sources for better production. Figure 1.2 shows the world fossil fuel energy status.

It is clear from Figure 1.2 that the energy sources will not be obtainable after the year 2300. Hence, many steps are now being taken to increase the use of renewable sources. A significant increase of around 39%, which has been recorded for solar PV in the year 2013, clearly shows its promising trends towards fulfilling the world's energy need. Photovoltaic technology is developing very fast to generate more electricity for satisfying the needs of people [1].

The significant increase has taken place after the year 2007 because of the combination of new technologies such as tracking, focusing and the development of evacuated tube collectors. In addition, the solar thermal industry is also growing significantly. Various collectors are used to capture sunlight to generate heat with minimum loss. Around 326 GW thermal energy has been formed by solar collectors in the year 2013. The largest installations of solar heating systems occurred in China and Europe. Brazil, by 2015, also devised to install roughly 1000 MW of solar heating systems to reduce the use of fossil fuel sources for energy recovery [1].

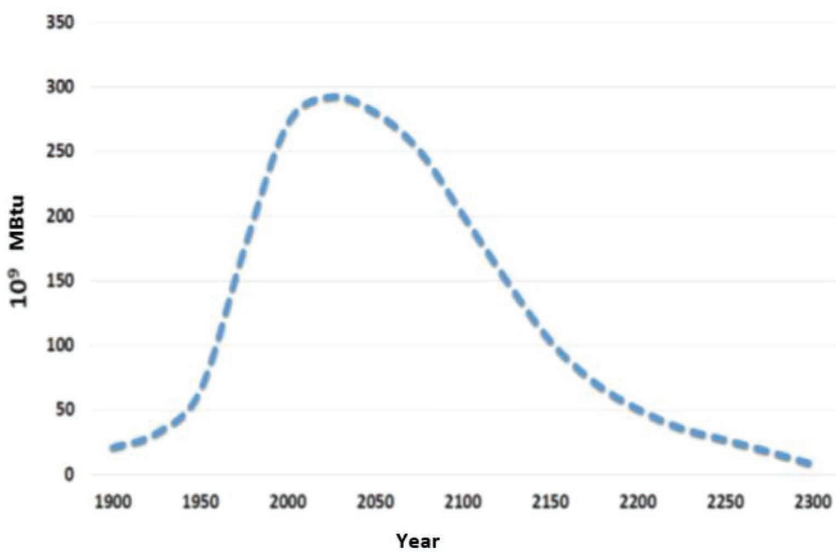

FIGURE 1.2 World fossil fuel energy status [1].

Moreover, the development of renewable energy sources was very significant in the year 2020. Many countries have developed new policies to promote solar industries to generate energy for distinct industrial applications. However, much attention is still being paid to fossil fuel resources for energy recovery as many industrial applications have been set to adapt fossil fuel reserves for energy recovery [12]. The attention to the renewable energy sources and the steps towards the promotion of renewable energy sources are basically due to an increase in the global total energy consumption. The attention to traditional biomass resources are also considered important due to handling ease.

As indicated in Figure 1.3, around 11.2% of the total final energy consumption was contributed by energy sources of so-called modern renewables in the year 2019. However, it was 8.7% in 2009. Moreover, the contributed values of fossil fuel sources to the total final energy consumption in years 2009 and 2019 are 80.3% and 80.2% respectively. It clearly shows the significant contribution of fossil fuel resources to the total final energy consumption in the world. The total final energy consumption of 11.2% in the year 2019 was shared by the electricity generated from renewable sources (6%), heat energy generated from renewable sources (4.2%) and the biofuels for transport activities (1%) [12].

Anyhow, it is highly essential to promote renewable energy sources for various industrial applications as they are freely available and pollute the environment at a minimum level compared to fossil fuel resources. Furthermore, the growth of renewable energy sources to share the total final energy consumption during the last

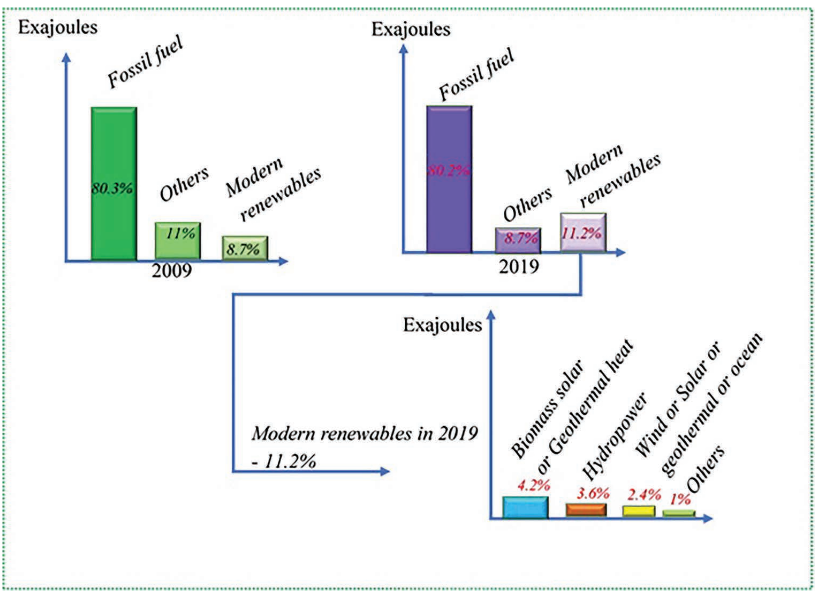

FIGURE 1.3 The estimated renewable energy share of the total final energy consumption between years 2009 and 2019.

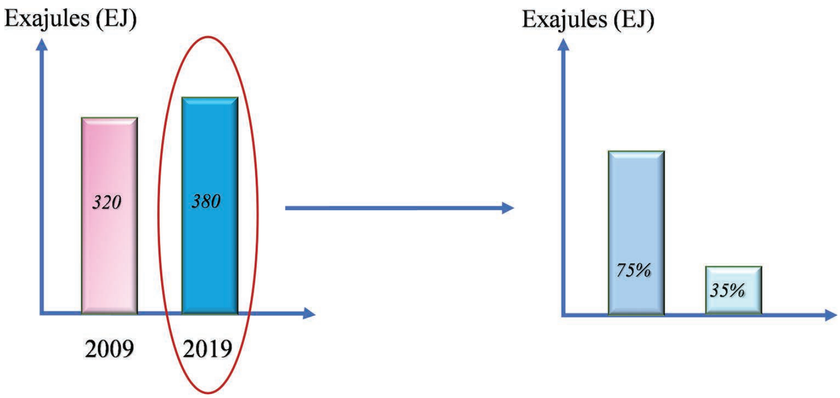

FIGURE 1.4 The estimated growth of modern renewables as a share of total final energy consumption between years 2009 and 2019.

10 years from 2009 to 2019 has been moderate despite some drastic growth patterns in some specific renewable energy sources. During this period, modern renewables grew significantly with the contributed value of 15.1 EJ at an annual growth rate of 4.4% [12].

However, the increase in the total final energy consumption during the period mentioned earlier was 60.9 EJ at the annual growth rate of 1.8%. Hence, it is visible that the renewable energy sources accounted for 25% of the total growth of the energy demand as shown in Figure 1.4. It is obvious from the aforementioned fact that the growth of the modern renewable energy sources are considerably prominent compared to the growth of total final energy consumption during the same period. Moreover, as shown in Figure 1.4 and the facts discussed previously, it is obvious that fossil fuel resources grew at a slow rate of 1.7% annually during such period, and the contribution of other energy sources was 75% of the total growth of the energy demand [12]. This fact clearly shows the increasing share of the modern renewables to the total final energy consumption, mainly because of the need to reduce emissions so as to maintain environmental sustainability for future generations. The contribution of modern renewables can further be improved by developing novel strategies that can increase the efficiency of renewable sources by minimizing unwanted energy losses in the harvesting process.

During the past years, the highest share (17%) of the renewable energy was for electrical applications, mainly lighting and electrical instruments. The lowest share of 3.4% of modern renewables was for transport activities, whereas around 10.2% of the share of the modern renewables was used for industrial process heating, heating and cooling of water and the space [12]. Therefore, it is clear that industrial process heating operations can be improved by modern renewables with proper design configurations and integrations. These operations will ultimately help conserve environmental processes and their balances.

Moreover, the cost associated with the generation of energy from various solar systems is still problematic all around the world. Different solar thermal systems have different costs associated with their manufacture and operations. This obstacle of the solar thermal system makes it complex to deal with. The cost associated with concentrated solar power systems, parabolic troughs and solar towers is specific and isolated. A study conducted in the USA clearly shows the differences in costs associated with different solar systems as mentioned. The cost values are not uniform as far as manufacturing of solar thermal systems is concerned.

Researchers reported that the construction costs associated with concentrated solar power parabolic troughs and concentrated solar power solar towers were 5213–6672 $/kW and 6084 $/kW respectively without thermal storage. However, the addition of thermal storage systems can increase the construction costs significantly [13]. The actual costs associated with solar power parabolic troughs and concentrated solar power solar towers were 8258 $/kW and 9227 $/kW respectively with thermal storage arrangements. Moreover, the construction costs associated with solar photovoltaic systems are lower than solar thermal systems. Solar photovoltaic systems can be constructed with 4739 $ per kW capacity [13]. This is because of less complexity of accessories used in solar photovoltaic systems compared to solar thermal systems. However, there is a need to perform in-depth research activities to reduce the costs associated with solar thermal systems for effective industrial applications in future.

1.3 GREENHOUSE EFFECT AS A MAJOR DRIVING FORCE TO IMPLEMENT RENEWABLE ENERGY SOURCES

Environmental pollution due to the emission of greenhouse gases is a highly significant reason to propose solutions for the development of a sustainable future. Moreover, prolonged environmental pollution by anthropogenic activities including various industrial operations leads to dramatic climate change, which is one of the most important concerns in the 21st century [14]. Drastic change in climate due to such complex industrial processes can lead to many detrimental impacts such as sea level rise, acid rain, flooding, drought, escalation of heat waves, spread of contagious diseases and food scarcity. Developing countries, compared to developed countries, are more prone to the impact of adverse climate change, as the technologies adopted by developing countries to deal with climate change impacts are weak compared to developed countries. However, a significant effect of heat waves was recorded in Europe in 2003 [15]. It clearly shows the sudden impact of unexpected climatic events that influence environmental balance significantly.

Hence, it is obvious that dramatic climate change due to human-made activities, especially industrial operations producing greenhouse gas emissions, is a big threat to both developed and developing countries. The use of fossil fuels to meet the increasing energy demands of the world due to industrial revolution, population growth and technological advancements increased exponentially over the last century. Moreover, industries such as paper production, metal plating, textile and paint production lead to a significant emission of greenhouse gases into the environment. This significant increase in fossil fuel use ultimately released a considerable addition of greenhouse gases (CO_2, NOx, CH_4, CFC and ozone) into the environment. These greenhouse gases are responsible for the greenhouse effect as shown in Figure 1.5.

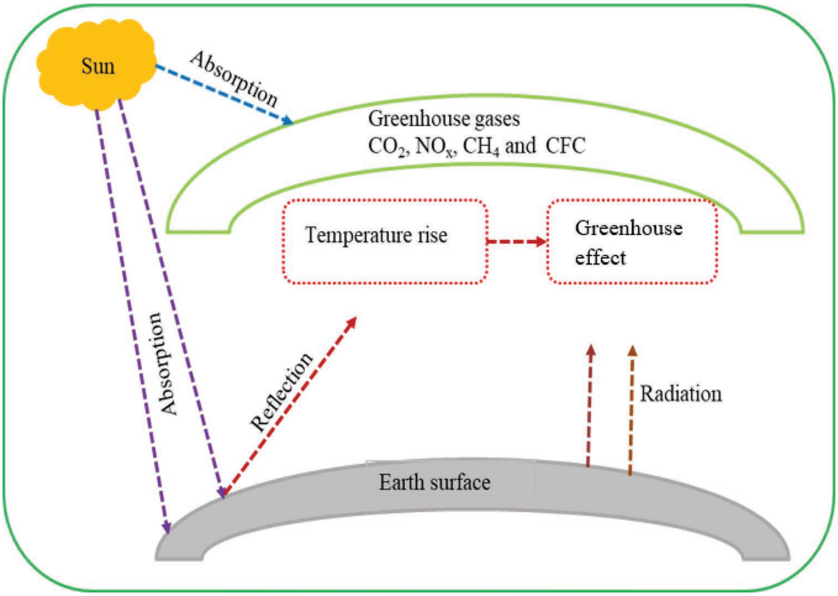

FIGURE 1.5 Schematic of the greenhouse effect.

Greenhouse gases form a layer over the earth's surface. Part of the radiation from the sun falls directly on the surface of the earth and is absorbed. A part is reflected back to the atmosphere through the radiating waves as shown in Figure 1.5. Moreover, radiation from the absorbed solar rays at the earth's surface also occurs into the atmosphere. However, the layer of the greenhouse gases acts as a shield to prevent the escape of radiating waves coming from the earth. They further absorb a fraction of the radiation of the sun directly and emit back to the atmosphere. The greenhouse gas layer is transparent to visible light (incoming radiation) of the sun and not transparent to the backward radiation from the earth surface as it is in the infrared (IR) form [16].

It has been noticed that the increase of human activities to meet escalating energy demand contributes significantly to greenhouse gas accumulation. Greenhouse gases, CO_2, CH_4, N_2O, R-11 (trichlorofluoromethane) and R-12 (dichlorofluoromethane) are likely potential greenhouse gases produced by human activities as shown in Figure 1.6 (a). Moreover, these gases pose an ability to retain IR radiation which is highly responsible for the heating effect. It is obvious from Figure 1.6 (a) that the annual growth rate of CO_2, CH_4, N_2O, R-11 and R-12 is 0.4, 1, 0.2, 5 and 5% respectively.

The annual growth rate of R-11 and R-12 is comparatively high compared to other gases as shown in Figure 1.6 (a) due to the increased use of refrigerators. Moreover, the growth rate of CH_4 and CO_2 is basically due to the burning of fossil fuel for meeting the increasing energy demand. Furthermore, the highest share of 71% of the greenhouse effect is held by CO_2 along with its highest contribution of 50% increase with 5% standard deviation due to human activities. As shown in Figure 1.6

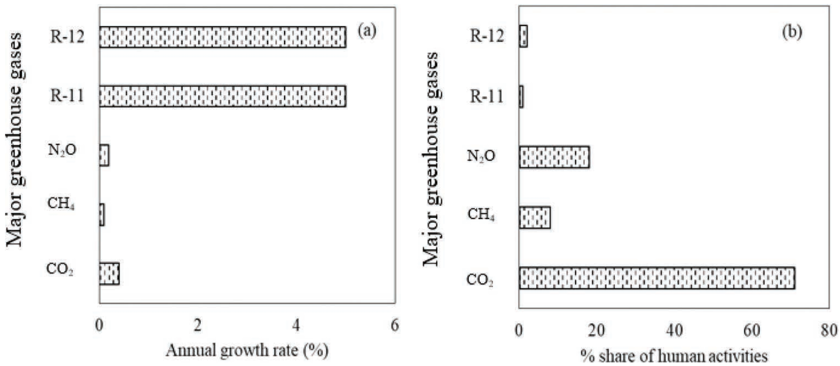

FIGURE 1.6 Annual growth rate of major greenhouse gases (a); percent share of human activities to major greenhouse gases (b).

(b) the most significant greenhouse gas is CO_2 which is produced via human activities. However, the growth rate of R-11 and R-12 is also critically important compared to other gases. Therefore, there is a prompt action needed to mitigate such harmful gases into the atmosphere to keep the environmental system sustainable for future generations.

In addition to the effect of various greenhouse gases on climate change, consideration of the countries that generate such greenhouse gases is also very crucial to propose viable mitigation strategies effectively. As shown in Figure 1.6, CO_2 emissions have grown by an average of 1.7% during the period of 24 years from 1971 to 1995. Moreover, this growth rate has been modeled to be at 2.2% for the year 2020. Furthermore, developing countries will account for half of this growth as shown in Figure 1.7. China and Organization for Economic Development and Cooperation (OECD) countries will contribute significantly to the emission of CO_2 into the atmosphere as shown in Figure 1.7 due to increased industrial activities.

Moreover, it has been reported that around 31% of CO_2 level increase occurred over the last 200 years. In addition, around 20 Gt of carbon has been added to the environment due to the cutting of trees [17]. Moreover, the ozone layer depletion has been severe due to an increase in CH_4 levels. All these greenhouse effects ultimately have caused a rise in global surface temperature by 0.4–0.8 °C during the last century above the reference temperature of 14 °C [17]. This rise in surface temperature in the end caused a sea level rise at an annual rate of 1–2 mm during the last century. However, around 37% of the contribution to the global greenhouse gas emission has been made by industries. The significant fraction of around 80% of the total greenhouse gas emissions is contributed by fossil fuel consumption for recovering energy [17].

According to the discussion made in this section, it is obvious that the emission of CO_2 into the environment is increasing at a faster rate due to human-made activities, technological advancements and the significant use of fossil fuel resources for meeting the energy demand. As evidenced in this section of the discussion, appropriate

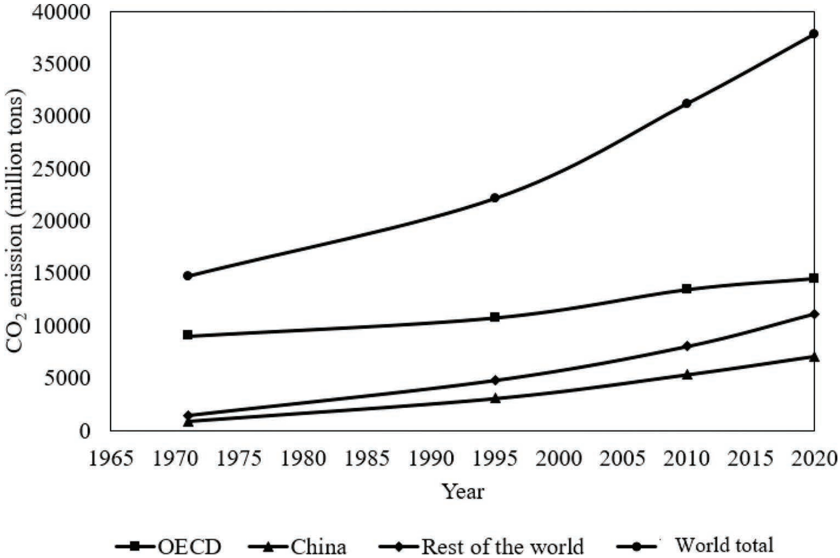

FIGURE 1.7 CO_2 emission rate by OECD countries, China, the rest of the world and the world total.

strategies need to be developed systematically in order to flatten this growing issue of greenhouse gas emissions into the environment. The most reliable option for this problem is the comprehensive, effective and economic use of renewable resources available in the world. The following section is therefore to describe how renewable energy sources have grown significantly to mitigate climate change scenarios with a special emphasis on the solar and wind energy sections as there is limited research presented so far.

1.3.1 Highlights of the Development of the Solar Energy Sector

As discussed in Section 1.3, structured development of the renewable energy sector is extremely important for the betterment of the sustainable future. This part therefore gives an overview on the growth, development and importance of the renewable energy sector with a special emphasis on solar energy sources for environmental sustainability. The growth of the renewable energy sector has been occurring steadily over the last few decades. It has been reported that the contribution of renewable energy sources would reach 47.7% from 13.6% in 2001 as shown in Figure 1.8 [17]. It is a remarkable growth of the renewable energy sector which significantly tends to mitigate adverse climate change scenarios.

Moreover, solar thermal contribution would be 480 million tons equivalent in 2040 from 4.1 million tons equivalent in 2001. Photovoltaic and solar thermal energy will reach their contribution of 784 million tons equivalent and 68 million tons equivalent, respectively, in 2040, as shown in Figure 1.9. As shown in Figure 1.9, solar sectors have a potential to meet the energy demand by 2040. The growth of the solar

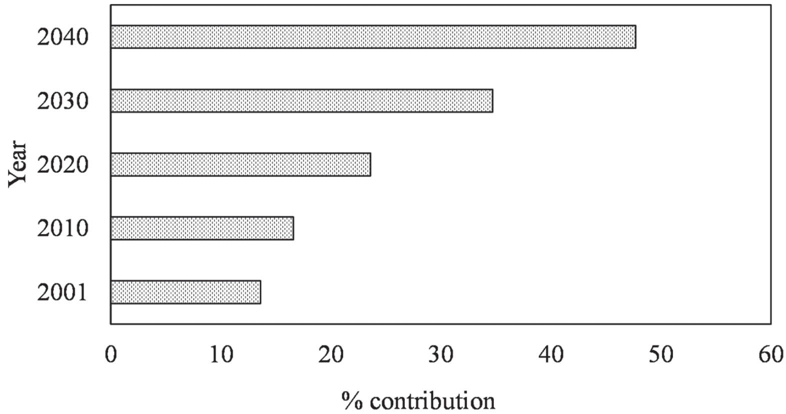

FIGURE 1.8 Percentage contribution of RES.

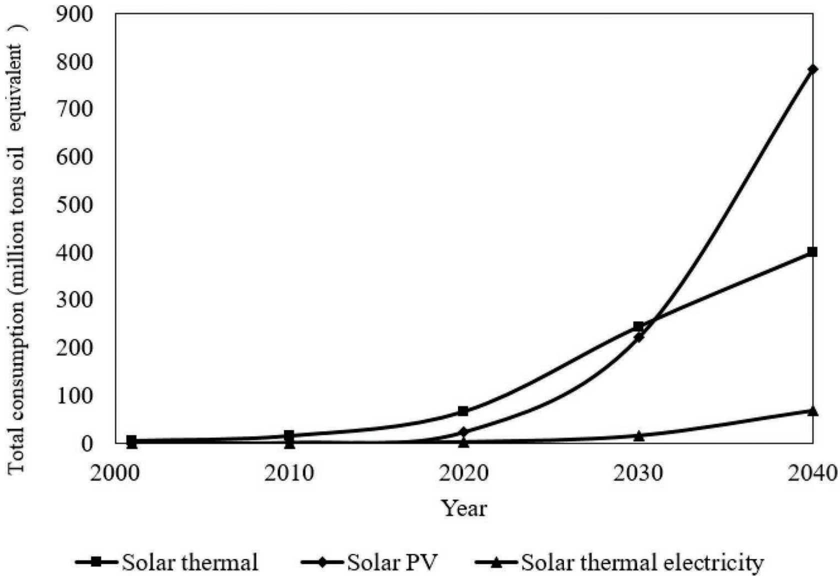

FIGURE 1.9 Total consumption of wind energy, solar thermal power, solar PV and solar electricity.

energy sector is highly significant because of considerable research and investment initiatives made to harvest as much solar energy as possible.

This difference is basically due to various policies and activities of various countries related to energy sectors and their functions. The use of these renewable energy sources will lead to zero or nearly zero emissions of pollutants such as aerosols and greenhouse gases. Moreover, development of the renewable energy sector will make the world sustainable energy wise with minimal impact to the environment compared to the fossil fuel burning energy recovery [18]. The contribution of solar energy sources to environmental sustainability is incredible in terms of distribution and reliability.

1.3.2 Solar Thermal Energy Use for Industrial Process Heating Systems

Solar thermal technology is generally obtained from solar radiation upon its heat conversion. Moreover, solar thermal energy systems can replace the use of fossil fuel systems significantly. For the application of solar energy for industrial heat applications, various solar thermal structures along with concentrators are being used. Nowadays, it is important to consider optimum working parameters of solar collectors, concentrators and heat exchangers for having high industrial outcomes through process heating.

The major barriers of the solar heating industrial systems are associated with solar radiation distribution over a day. However, it is vital to obtain some hybrid systems for better process heating applications. Moreover, around 17%, 44% and 10% of global energy demand are occupied by electricity, low temperature heat applications and high temperature process heat respectively [19]. As solar radiation is freely available in the world, its application to industrial heating process is broad and effective. Industrial processes, solar drying, cleaning, washing, water heating, pasteurization and sterilization, are highly prominent examples of industrial applications of solar thermal heat. A simple water solar thermal system used for industrial process heating is represented by Figure 1.10. All these aforementioned applications require a temperature value less than 250 °C.

Furthermore, for increasing applications of industrial solar heating systems, various solar collectors such as flat-plate solar collectors, evaluated tube solar collectors, unglazed collectors, vacuum tube collectors and fresh collectors are used. The flat-plate collector has plates to transmit the absorbed energy to the working fluid. This collector generally has a high absorption efficiency. The design system at the flat-plate collectors provides thermal stability and handling easiness. However, the evacuated tube collectors are very effective compared to the flat-plate collectors [19]. The heat loss from the absorber plate in this system is prevented by a well-organized glass envelope. Furthermore, the collector system is isolated from the industrial process heating systems.

The use of an unglazed system is basically only for low temperature applications. Additionally, in a vacuum tube collector, water is circulated inside pipes placed in vacuum glass tubes. The heat loss in this system is very low, and it can develop high temperature profiles. It is important to note that temperature values above 400 °C can be obtained for industrial process heat applications using the Fresnel collector. The efficiency at this system can be improved by the incorporation of a tracking system. However, there is a need to develop appropriate protocols for the better development of solar collectors for effective industrial heating applications. The research activities on this concept are still at an embryonic stage, and it requires further in-depth research.

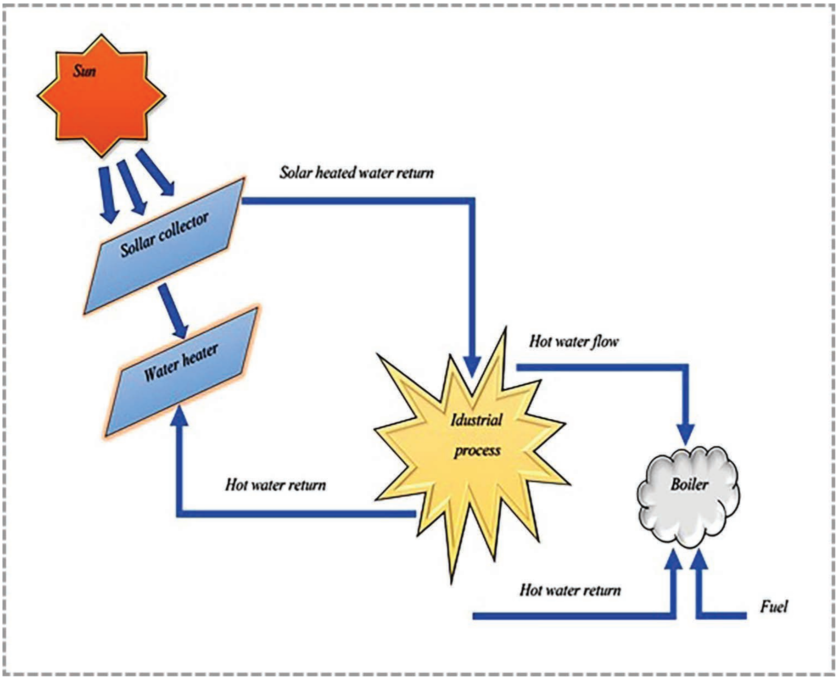

FIGURE 1.10 Simple representation of solar thermal heat for industrial process applications.

More importantly, it is highly vital to make a critical note on the current status of solar thermal technologies all around the world so as to provide readers with effective pieces of information. Europe, Asia and North America have been successfully using solar thermal systems for industrial process heating applications. In addition to this, solar thermal energy for electricity generation is also becoming popular in the world. However, the effectiveness of solar thermal systems are mainly influenced by the distribution of the solar radiation. Most of the Asian countries, some parts of Africa and Australia have a potential to have stabilized solar radiation throughout the year, and therefore, it is possible for them to implement solar thermal systems for the effective process heating applications [19].

Globally, solar thermal energy is used for various industrial operations based on the processing conditions. Automobile industries of South Africa heavily use solar thermal energy for painting purposes. It is also used heavily in various agricultural operations such as drying and water heating by countries like Spain, China and Germany. Drying of agricultural produce is mainly used by solar thermal energy in countries such as the USA, India, China and Germany [19]. The global importance of solar thermal energy is based on the nature and the stability of various industrial processes. Overall, it is used for water heating, drying, preheating, steam heating, pasteurization, sterilization and washing at different temperatures according to the need.

1.3.3 Heat Energy Demand by a Range of Industrial Process Temperatures

Different industrial processes are set with various temperature ranges. The actual temperature required by a preferred industrial process should be addressed properly for accurate heat requirement calculations. Moreover, it is also highly important to note that most industrial processes are set with a medium heat range. However, the scientific findings of heat demand by temperature range of various industrial processes are still very limited [19]. Hence, the need for further systematic scientific research in this regard is highly needed. Table 1.1 shows the temperature range of different industrial processes commonly in use.

TABLE 1.1
The Temperature Range of Different Industrial Processes [19]

Division	Process Type	Industrial Temperature Range (°C)
Chemicals	Biochemical reaction	20–60
	Distillation	100–200
	Compression	105–165
	Cooking	80–100
	Thickening	110–150
Food and Beverages	Blanching	60–100
	Scaling	45–90
	Evaporation	40–130
	Cooking	70–120
	Pasteurization	60–145
	Smoking	20–85
	Cleaning	60–90
	Sterilization	100–140
	Tempering	40–80
	Drying	40–100
	Washing	30–80
Paper	Bleaching	40–150
	De-inking	50–70
	Cooking	110–180
	Drying	95–200
Fabricated Metal	Picking	40–150
	Chroming	20–75
	Degreasing	20–100
	Electroplating	30–95
	Phosphating	35–45
	Purging	40–70
	Drying	60–200

Division	Process Type	Industrial Temperature Range (°C)
Rubber and Plastic	Dying	50–150
	Preheating	50–70
Machinery and Equipment	Surface heating	20–120
Textile	Bleaching	40–100
	Coloring	40–130
	Dying	60–90
	Washing	50–100
	Fixing	160–180
	Pressing	80–100
Wood	Steaming	70–900
	Picking	40–70
	Compression	120–170
	Cooking	60–90
	Drying	40–150
Diary	Pasteurization	60–80
	Sterilization	100–120
	Drying	120–80
	Concentrates	60–80
	Boiler feed water	60–90
Tinned Food	Sterilization	110–120
	Pasteurization	60–80
	Blanching	60–90
Heat	Washing	60–90
	Sterilization	60–90
	Cooking	90–120
	Thermo diffusion beam	80–100
Flour and Byproducts	Drying	60–100
	Preheating water	60–90
	Preheating pump	100–120
Bricks and Blocks	Curing	60–140
Plantation	Preparation	120–140
	Distillation	140–150
	Separation	200–220
	Extension	140–160
	Drying	180–200
	Blanching	120–140
Automobile	Water heating	~90
	Cleaning	~120
Pharmacy	Different processes	7–180

(Coninued)

TABLE 1.1
Coninued

Division	Process Type	Industrial Temperature Range (°C)
	Cleaning	~60
Mine	Electric-mining	~50
	Other processes	~80
Agriculture	Drying	~80
	Water heating	~90
Leather	Retaining	~80
	Other processes	~90
Metal	Heating	~180
	Washing	~160

Moreover, the solar thermal heating systems can be incorporated into the industrial process heating systems in two ways: either at the process level or at the supply level. Integration of solar thermal systems in industrial process is carried out based on the temperature desired. The supply level temperature requirement is greater than the process level temperature. The capacity of solar heating systems is different from different industrial processes. Around 36–51% of the installed solar thermal systems in industries around the world are for water heating or washing process, 14% systems for heating baths, 6% of the systems used for drying applications, and approximately 29% of the water heating systems utilized for other purposes like car washing, etc. The temperature profile of the industrial process is very important as it determines the yield of the industry [19]. Many industrial process are associated with temperature values less than 40 °C or between 40 °C and 60 °C.

Moreover, there are there major types of solar collectors such as flat-plate, evacuated tube and dish, mainly used for various industrial applications. The temperature ranges of the flat-plate collector, evacuated tube collector and dish collector are 40–80 °C, 80–150 °C and >150 °C respectively as shown in Table 1.2.

Process series of an industry can take either one of these collectors or the combination of two or more based on their need, mainly the process temperature. For

TABLE 1.2
Operational Temperatures of Various Solar Collectors Commonly in Use [20]

Operational Temperature (°C)	Solar Collector Type
40–80	Flat plate
80–150	Evacuated tube
>150	Dish

TABLE 1.3
Suitable Solar Collectors for Different Industrial Applications [20]

Industry	Suitable Solar Collector	Temperature (°C)
Textile	Evacuate tube collector	80–150
	Flat plate	40–80
Pulp and Paper Industry	Flat plate	40–80
	Evacuate tube collector	80–150
Leather Industry	Flat plate	40–80
	Evacuate tube collector	80–150
Automobile Industry	Evacuate tube collector	80–150
	Dish	>200

industries such as textile, pulp and paper, dairy and leather, flat-plate and evacuated tube collectors can be used based on the temperature range of the sub-processes. However, for the automobile industries, dish collectors are used in addition to the use of evacuated tube collectors so as to meet temperatures above 200 °C for some drying purposes as shown in Table 1.3. The pieces of information in Tables 1.1, 1.2 and 1.3 can be used effectively for the selection of solar collectors for various industrial applications. Moreover, there is a need to induce structured research activities in order to develop a common protocol for the confirmation of solar collectors for industrial operations based on the mass and energy balance concept of various industrial processes.

1.3.4 Factors That Are to Be Considered for Thermal Collectors in Industrial Process Heating Systems

The degree of a solar thermal collection is important for effective industrial solar heating processes. The space effectiveness, temperature control and the integration process are important for the effective design of solar collectors. A simplified flowchart is displayed in Figure 1.11 to help readers understand the important factors that influence the selection of solar collectors for industrial applications. Most importantly, climatic factors, design factors and operational factors must be considered for the effective use of solar collectors in industrial applications [21]. Solar collectors should be designed in such a way that the absorption of solar energy is maximum for reasonable industrial process heating. The space required for an industry must be considered as it is very limited for many industrial processes. Hence, rooftop solar collector installations are mostly prepared. As temperature profiles of industrial processes are complex, the collection system should be set to meet such requirements precisely. The use of heat carrier fluid is important in industrial solar heating applications. Solar heating systems of industrial processes are mostly associated with conventional heating systems.

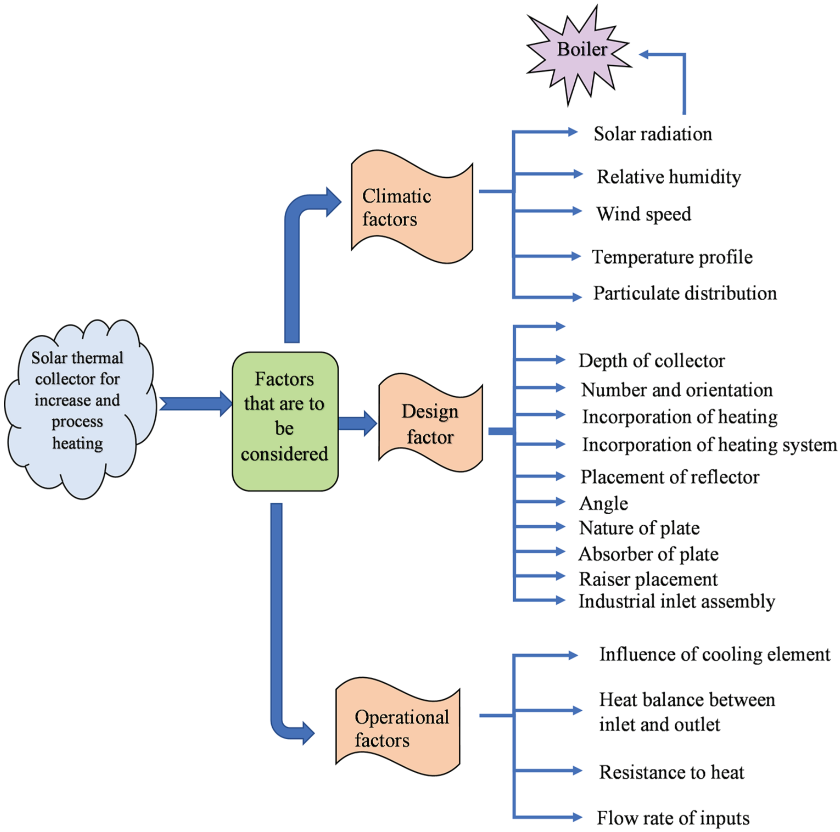

FIGURE 1.11 Simple representation factors that influence solar thermal collectors for industrial process heating applications [21].

1.3.4.1 Appropriate Industries and Processes for Solar Thermal Applications

Moreover, it is not possible to use solar thermal energy for all industrial applications. Hence the identification of suitable industries whose processes can be dealt effectively with an incorporation of solar thermal heat. The industries can be selected with the heat demand value below 300 °C. Based on the literature, machinery, automobile and electrical equipment are not considered suitable for this process since their major fraction of the heat energy is used for space heating. Most importantly, the sectors that deal with chemicals and the products related to chemicals have a significant potential to use solar thermal heat for process applications since there is considerable heat demand at low (<100 °C) and medium (<300 °C) temperatures [20].

This sector is mostly associated with sub-processes that require temperature values below 100 °C most of the time. Furthermore, the food and beverages sector, like chemicals and chemical products sector as discussed earlier, has a potential heat demand of its processes at low and medium temperatures. Hence, it is also highly suitable for the incorporation of solar thermal energy systems. The sub-processes of food industries such as drying, evaporation, blanching, hot water cleaning and pasteurization are set with low heat demand, below 300 °C [20]. Therefore, this sector can be successfully developed with the use of solar thermal heating inputs.

Furthermore, the paper and paper product industries have the potential to utilize solar heat for their operations. Around two-thirds of the processes of the paper and paper product industries is associated with temperature values between 100 °C and 500 °C. This temperature range is basically for drying purposes. However, one-third of the heat demand is still associated with temperature values below 100 °C. Moreover, the efficiency of the dyeing systems and de-inking systems of paper industries must be improved by appropriate strategies to save considerable energy cost. In addition to paper industries, metal products industries have an ability to utilize low temperature heat energy for their operations. It is basically associated with process heat, space heat and hot water production at temperature values below 100 °C. The processes such as degreasing, pickling and electroplating do require slow heat at temperatures below 100 °C. Appropriate insulation techniques can minimize the heat loss significantly, resulting in the saving of energy costs [20]. The processes associated with rubber and plastic product industries have a potential ability to use low temperature heat energy at temperature values below 100 °C. The solar thermal energy in plastic and rubber industries is mainly used for drying of plastic products and space heating activities at low heat energy demand. Besides, a significant number of processes associated with textile and wood industries utilize low temperature heat energy for better outcomes. In textile industries, processes like washing, coloring and drying are set below 150 °C. Around 82% of the total processes in the wood industry is associated with slow drying at temperatures below 100 °C so as to preserve the quality of the wood for better appearance [20].

From the facts discussed, it is possible to identify the most promising industrial sectors that can use solar thermal energy for their various processes effectively. For industries such as motor vehicles, metal and electrical equipment, most of the heat energy is used for space heating, whereas chemicals, food and beverages industries have the strongest potential to use solar thermal heat effectively for their processes because of less process complexity and simplified production steps. However, there is a need to perform systematic research investigations to improve the use of solar thermal energy in these promising, industrial sectors.

It is vital to note that the industries discussed in this section have different industrial processes set with different heat requirements and temperature profiles. As clearly shown in Table 1.1, different industrial processes have an ability to use solar thermal energy effectively based on their processing configurations. Moreover, for the effective utilization of solar thermal energy in such processes, it is necessary to avoid unwanted heat losses in and from industrial process structures. The development of a process-specific solar thermal energy usage protocol is greatly required nowadays for the effective utilization of solar thermal energy in industrial process heating applications.

1.3.5 Challenges and Policy Recommendations for Industrial Solar Heating Systems

Though solar industrial process heating systems are considered to be effective, there are some common practical barriers. The most important problem is the high initial cost associated with industrial solar process heating systems. The barriers to solar industrial process heating can be grouped into economical barriers, policy barriers, technology barriers, technical and human resource barriers and social barriers. The market fluctuation and limited government subsidies to the solar market are potential risks associated with solar industries. These are critically influencing solar industrial processing heating systems [19].

Furthermore, around 25% of the global final energy consumption is associated with industrial processes. Many countries have a strong willingness to promote renewable energy sources, especially solar energy, to meet industrial heat energy requirements in a sustainable manner. As an evidence to support the aforementioned statement, in 2020, significant policy support was developed via financial incentives. For instance, 189 million USD was allocated to support industries that developed strategies to cut greenhouse gas emissions by the incorporation of renewable energy sources. Moreover, in 2020, the European Union developed a renewable hydrogen policy to increase the use of renewable energy sources for industrial processes. As developed and developing countries realize the importance of renewable energy sources for industrial processes to reduce greenhouse gas emissions, incentives and low-interest credits are promoted for the incorporation of solar thermal energy into various industrial processes [12].

Moreover, the policy frameworks that are related to industrial solar heating systems are still confusing. In addition, the subsidy schemes are mostly directed to fossil fuel resources, and the system practiced in industrial solar heating systems is also physically weak. Furthermore, some technological barriers are also present. The technology produced for industrial solar heating systems is not well organized, and there is no advance technology available to manufacture solar cells locally.

The availability of updated solar maps to check the solar heating performance of a system is still problematic all over the world. Therefore, there is need to overcome all the previously mentioned technological barriers for better industrial solar heating processes in future. In addition to technological barriers, social barriers such as poor understanding of solar systems in rural areas, the mentality of people to stick to traditional elements, the opposition of solar projects by some local communities and the poor technical skills of people are also affecting the performance of solar heating systems. Hence, for effective industrial solar heating systems, there is a need to overcome these barriers systematically.

1.3.5.1 Policy Reasons Related to Industrial Solar Heating Systems

Industrial solar heating systems are highly effective as they are sourced with freely available solar radiation. However, as discussed, they have been experiencing so many challenges. Hence, it is important to develop a highly structured policy framework in order to overcome such barriers [19]. The following points can be considered while making a good policy framework for industrial solar heating systems.

- Local people should be educated about the barriers of industrial solar heating systems.
- Government and stakeholders should be linked strongly for the sources of industrial solar heating systems.

- Some micro-finance industries should be developed in rural areas to facilitate industrial solar heating projects.
- Policies should be developed in such a way that they can attract foreign investors to make an investment on solar heating projects in rural areas.
- The importance of renewable energy sources as opposed to conventional energy sources should be explained in the policy framework.
- Marketing systems should be strengthened to promote industrial solar heating systems.
- The technical skills of professionals should be improved via appropriate training systems.
- Government should allocate enough money for industrial solar heating projects.
- Government should open new windows in order to develop international collaboration for future projects (solar heating).

Industrial solar heating systems will definitely be improved as these technical points are incorporated into policy frameworks developed by various countries in the world.

1.4 FUNDAMENTALS OF SOLAR ENERGY TECHNOLOGIES

The understanding of fundamental concepts of solar power systems is very important to make appropriate arrangements to have as much energy as possible for various utilizations. This part therefore tends to bring such concepts in a comprehensive manner to facilitate researchers and relevant personnel to grasp required solid information in order to make actions that are needed to increase the use of solar and wind energy for better environmental sustainability. Solar energy is one renewable energy source used for various environmental applications. It is broadly categorized into two major groups, active technology and passive technology. These technologies are basically defined to harvest the maximum amount of solar energy as possible [22]. The classification of solar energy technologies is presented in Figure 1.12. Passive technology is usually set to utilize solar energy (light and heat) without any further transformation [23].

The typical example of passive solar technology is a home heating system as shown in Figure 1.13, where solar energy is directly used to heat homes for the better survival of people. The heat penetration is possible via rooftops, walls and windows as heat wave radiation. The penetrated heat should be protected from loss so as to have a long heating effect in homes. Hence, an insulation should be provided to the space heated by solar radiation. However, the actual configuration of home heating systems and their optimization are still at the embryonic stage and need further research investigations for better development of home heating systems.

Active solar technology, which is very different from passive technology, is associated with some technical devices (e.g. mirrors or solar cells) to convert the solar energy into either heat or electricity. The most common classification of active solar technology is based on the outcome of the system. It is classified into solar thermal systems and solar photovoltaic systems as shown in Figure 1.12 [24]. Moreover, the

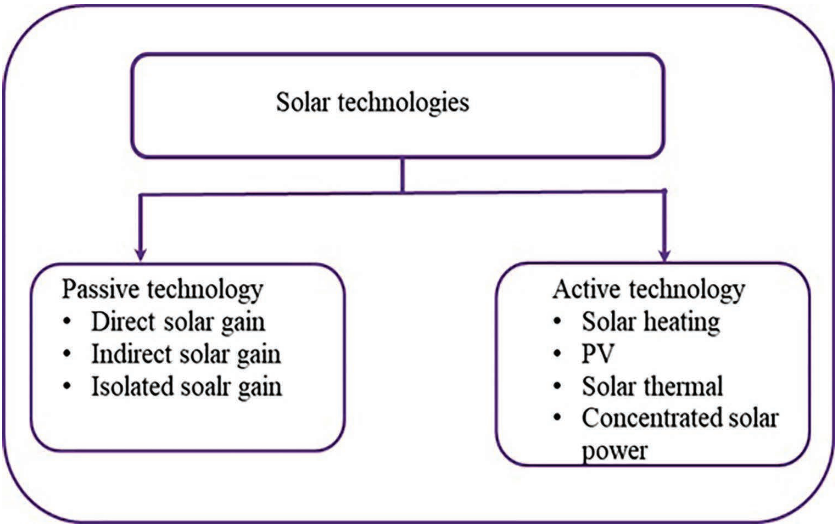

FIGURE 1.12 Classification of solar energy technologies [22].

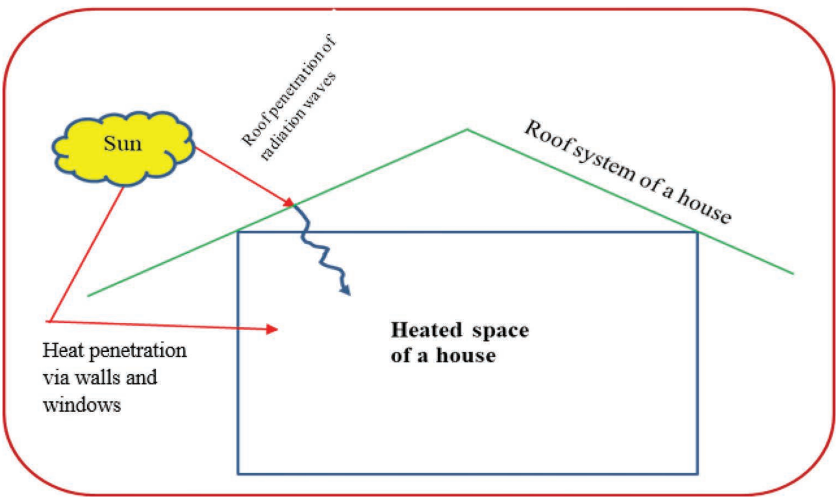

FIGURE 1.13 A simple schematic of a home heating system.

photovoltaic technology (PV) is used to produce electricity from solar energy with the help of semiconductor materials and inverters as shown in Figure 1.14 [25]. Solar PV technology is becoming very popular and a significant amount of well-structured research works have been carried out to increase the efficiency of solar PV technology. However, there is still a need for further research activities to improve the efficiency of solar cells used in PV systems in order to make them commercially viable.

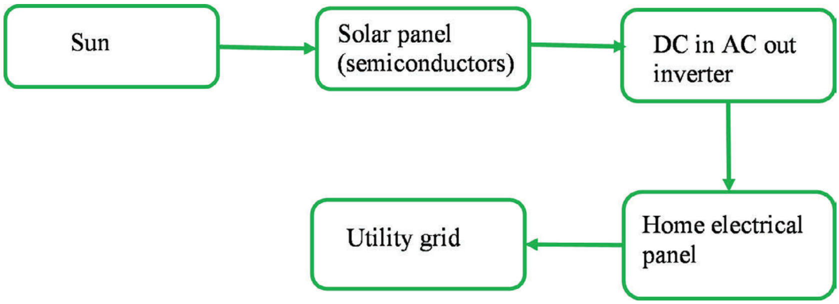

FIGURE 1.14 A simple schematic of a solar PV system.

As a result of intensive research activities, hybrid perovskite solar cells ((CH_3NH_3)PbI_3) have acquired an efficiency of 18% [26]. However, there are many different types of solar cells such as crystalline silicon, commercial thin film cells and perovskite cells available in solar PV systems. The efficiencies of these cells are very different and influenced by manufacturing configurations [27]. Furthermore, solar thermal technology is mainly used for heating purposes such as solar cooking, solar water heating and solar drying as shown in Figure 1.15 (a), (b) and (c). Solar cooking is a simple form of solar energy use [28]. Different manufacturers manufacture different types of solar cookers, out of which the simple box type cooker is highly efficient and user-friendly because of its less technical complexity as shown in Figure 1.15 (b). However, more research works are still needed to improve the efficiency of the solar cookers and increase the usability among users. In addition to this, solar water heaters (Figure 1.15 (a)) play a vital role in mitigating CO_2 emissions into the environment [29].

It has been reported that a solar water heating plate with 100 L capacity was able to mitigate approximately 1237 kg of CO_2 emission per year at 50% efficiency [30]. At the commercial scale, concentrated solar thermal systems (CST) and concentrated solar power systems (CSP) are highly popular [22]. Fresnel mirrors, parabolic troughs, power towers and solar disc collectors are popular types of concentrated solar power systems. These types are distinct in their operations. Parabolic troughs concentrate solar rays to a receiving tube, whereas Fresnel systems use multiple mirrors to concentrate solar rays into a receiver tube. Moreover, thousands of mirrors are used in power towers with a tracking mechanism for concentrating solar radiation to a desired point. That point is situated above the reflector disc to concentrate solar radiation in solar collectors [31]. Furthermore, solar dryers are simple devices to dry different products as shown in Figure 1.15 (c) in an efficient manner. The system must be well insulated and the heat loss from the dryer system should be minimized for better efficiencies. More research activities in the solar dryer systems are still required to improve the efficiency in order to increase their commercial applicability for different agricultural products.

The overall fundamental mechanism of a solar energy conversion system is that it uses solar radiation for heating purposes and electricity generation via concentrated

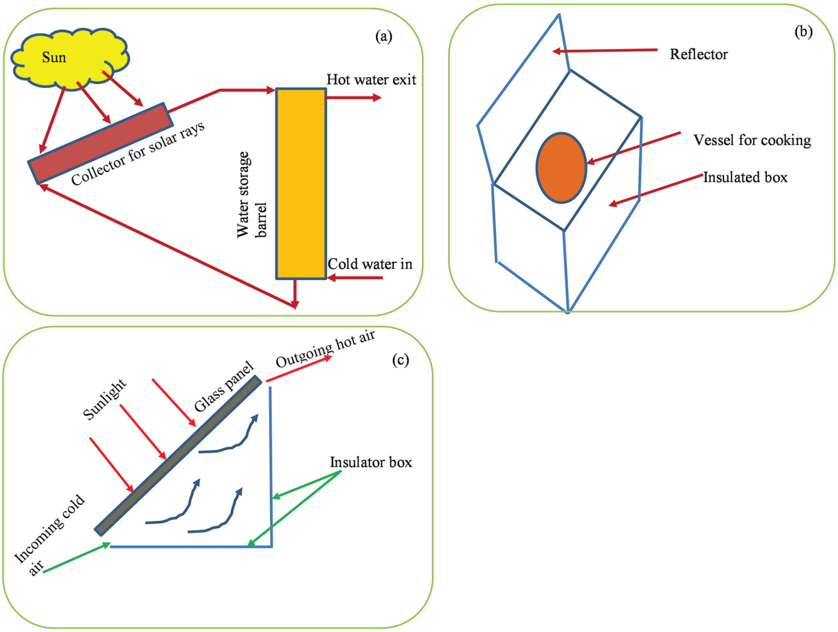

FIGURE 1.15 Solar thermal applications: solar water heating (a); solar cooking (b); solar drying (c).

thermal systems and PV systems, respectively. However, wind energy systems are different from solar energy systems [32, 33, 34, 35, 36], and the research is distinct in this area. Moreover, the research and development related to solar thermal systems are growing at a faster rate to improve the mechanism of harvesting for environmental sustainability. For the continuous supply of effective applications, solar thermal systems are to be associated with appropriate sources of energy so as to make them hybrid in nature. However, more research activities are still required to fabricate economically viable solar energy hybrid systems for energy sustainability and environmental protection.

1.4.1 Global Status of Solar Energy Systems

This part of the comprehensive review provides significant information about the global status of solar energy systems at a glance with necessary comparisons and knowledge gaps identified. The distribution of solar energy is greatly influenced by locational differences among countries. The degree of environmental pollution due to solar systems among countries is different [37]. The solar flux to the earth surface is influenced by seasonal variations, cloud movements, latitude and crop covering [38]. Around 342 Wm^{-2} of solar energy is available at the surface of the earth. However, only around 70% is available for harvesting as the 30% of the total incoming energy is reflected back into the space [39]. Moreover, worldwide annual active solar radiation gain varies from 60–250 Wm^{-2} [40]. This variation is

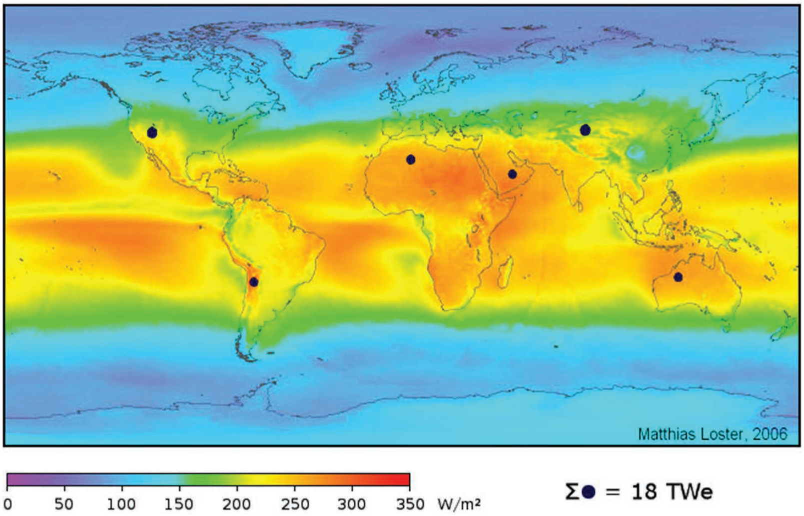

FIGURE 1.16 Distribution of solar radiation on the earth's surface [22].

clearly shown in Figure 1.16 in which the locations marked with black dots could contribute to the total energy demand of the world with at least 90% efficiency [22, 39].

As shown in Figure 1.16, the sunniest locations are found around the continent of Africa. It has been reported that the capacity of CSP and PV systems is 470 and 660 Petawatt hours (PWh) respectively in the sunniest place, Africa [22]. Moreover, Middle East regions; the hottest plains of India, Pakistan and Australia; some parts of the United States, Central and Southern America; and north and south parts of Africa have the limited potential of 125 GWh/km^2 [41]. Furthermore, it has been stated that a significant portion of unused land is available in the Northern and Southern regions of China where electricity generation capacity is 13000 GW per 6300 km^2 [42]. Moreover, reports from the National Renewable Energy Laboratory (NREL) states that the annual solar energy potential in the US is around 400 Zettawatt hours [22].

Furthermore, some countries which have high solar radiation availability have started improving their solar technologies to increase the harvesting potential. For example, the world's largest CSP and PV projects have been activated in Morocco to have improved power generation of 2000 MW by the year 2020 [22]. This move by the Moroccan government is highly productive because of their locational merit to harvest the maximum available sunlight. In addition to this, the highest solar radiation power per meter square of land is available in Australia. Moreover, the Australian continent has been reported to have the highest solar radiation of 4–6 kWhm^{-2} [22]. It is therefore obvious that the nature and distribution of solar radiation are influenced by spatial differences. In order to gain the highest potential of solar energy for future developments, many countries have started upgrading their solar energy harvesting

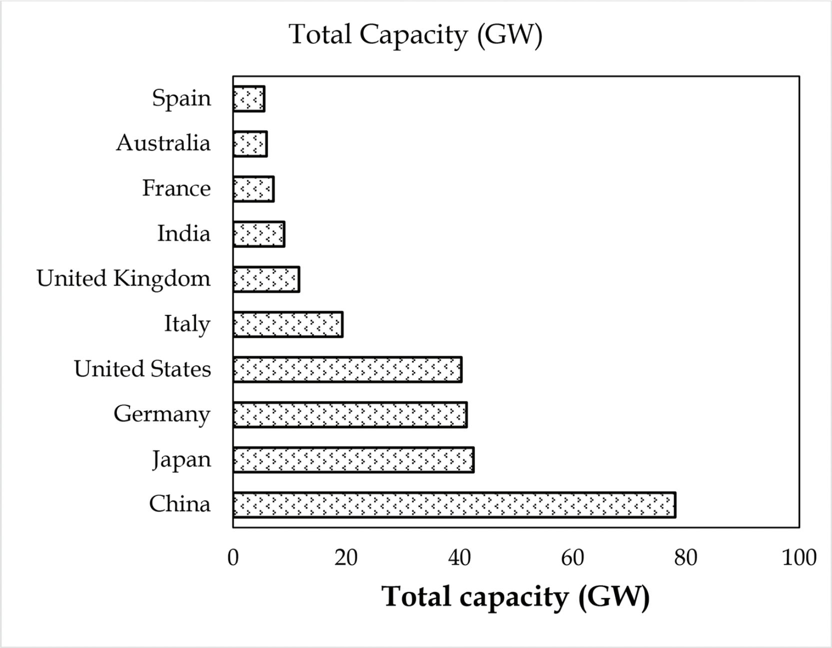

FIGURE 1.17 Solar power capacity of different countries.

systems. For example, the solar power generation capacity of China, Japan and Germany is 78.07, 42.45 and 41.22% respectively [22] as shown in Figure 1.17.

The growth of the solar PV systems is also happening at a faster rate because of advanced research activities. It has grown to produce 2.25 GW in 2015 from 3.7 GW in 2004 [22]. China recorded the most solar power plants installed in the world and its plan was to reach the capacity of 150 GW by the year 2020 [22]. However, it has been a challenging task to meet such expectations. Moreover, countries like America and Australia have also significantly grown in solar PV system development. The USA set the target to reach 45 GW PV capacity in 2017 [43]. Furthermore, the solar PV capacity of 913 MW has been recorded in Australia in 2015.

All these increases contributed significantly to global emission reduction. Apart from these developments, India reached a 8062 MW solar power grid system in 2016 [44] and planned to achieve 100000 MW by 2022 [44]. It is also important to consider wind energy sources so as to develop renewable hybrid power systems that can keep the energy line continuous [45, 46, 47, 48]. Furthermore, a planned structure is being developed by the government of France to construct a 100 km solar roadway system with an intention of providing clean energy for 5000 houses/km [22]. Moreover, most of the countries have recorded drastic growth in solar energy systems. China is leading the world's growth of solar energy system investment. The sudden growth in the solar energy market in the year 2016 has been recorded in the USA due to the anticipation of a federal investment tax credit. It is therefore obvious that the growth of solar systems is very crucial all over the world to achieve environmental sustainability in the near future. However, much more research activities are still required to increase the efficiency of solar systems to harvest more freely available solar energy.

Based on the previous facts discussed, solar energy systems can be researched further to enhance clean energy and environmental sustainability. It is reasonable to produce the following highlights and summary points for the benefit of future readers of this chapter.

- The efficiency and distribution of solar energy systems is influenced by the fluctuation of solar radiation intensity worldwide. Hence, an appropriate selection must be made based on appropriate spatial information before making the decision on which system is suitable for an intended use.
- The African region has huge potential to receive the most solar radiation to be harvested along with the Australian continent. However, most of the usable solar radiation is still wasted because of limited technologies available to increase the harvesting potential significantly.
- Solar PV, CSP and CST systems recorded robust growth to contribute more for future energy demands. This robust growth is basically due to the abundance of solar radiation compared to wind energy systems. However, there is still limited information available on specific efficiency of solar energy systems.
- It is important to have global hybrid solar power systems for better utility and applications.

1.5 MERITS AND DISADVANTAGES OF SOLAR ENERGY SYSTEMS WITH RESPECT TO A CLEAN AND SUSTAINABLE ENVIRONMENT

This section of the review critically summarizes the merits and disadvantages of solar for developing better utilization strategies without damaging the environment.

1.5.1 Merits of Solar Energy Systems

Solar energy systems are becoming popular worldwide due to the abundant nature of solar radiation on the earth's surface. This solar energy potential, if properly harvested, is enough to meet the energy demand of the world. Moreover, there is nothing to worry about the depletion of solar energy unlike fossil fuel resources since it is renewable in nature [49]. Fossil-fuel-driven power plants are significant sources of greenhouse gas emissions responsible for global warming potentials. They further contribute to 255 of anthropogenic emissions worldwide [50]. The use of solar power systems contributed significantly to minimizing greenhouse gas emissions though the manufacturing, maintenance and installation activities reported to produce 0.03–0.09 kg of CO_2 per kWh power generation, which is significantly low compared to coal and natural gas with 0.64–1.63 kg and 0.27–0.91 kg respectively. This clearly shows its significant potential in the reduction of greenhouse gas emissions [22]. Thus, solar energy systems, if properly structured and installed, can contribute significantly to minimizing global warming potential by reducing greenhouse gas emissions from coal-powered power plants in order to develop a sustainable future.

Another important advantage of solar energy systems is the reduction in the particulate matter and other toxic gases which are generally generated when fossil fuel resources are used for power generation. Fossil fuel burning to meet energy demand produces toxic gases like SO_2, volatile organic compounds, suspended particulate matter and soot. These substances are highly toxic and can cause health problems like dysfunctions of the nervous system, heart failure and respiratory complications [51]. A research study insisted that the use of renewable energy sources could minimize infant mortality and expenditure for treating diseases [52]. Moreover, power plants driven by fossil fuel sources require a significant amount of water for cooling. It then leads to the wastage of good quality water and to water scarcity. Inefficient use of water in power plants can drastically reduce the power generation capacity of plants. However, the use of solar energy systems requires no water and produces no toxic substances as power plants driven by fossil fuel resources do. Therefore, the use of solar energy in this sense can minimize this environmental problem significantly.

Furthermore, fossil fuel systems used for power generation are capital intensive, whereas solar energy systems are labor intensive. As solar energy systems are considered to be labor intensive, they can help improve employment opportunities of people worldwide. This is a wise outcome of the solar energy sector and its expansion, as, at present, most of the rural people are suffering from unemployment problems. It has been stated by the Solar Foundation of the USA that the solar industry provided employment opportunities for 208859 people in the USA as part-time or full-time workers for manufacturing, installation, sales and maintenance. Moreover, around 20.2% growth has been recorded in a year [22]. Furthermore, solar energy systems help circulate money within the country. It also lowers the importation of fossil fuel and currency flow into the foreign countries. Therefore, it can help strengthen the economic structure of the country.

Furthermore, as vast research activities progress, the efficiency of solar systems has been significantly improved. As a result of this improvement, the cost of the PV modules has dropped considerably. It is obvious from reports that the cost of a PV module has been reduced from USD 1.3 per watt in 2011 to USD 0.5 per watt in 2014 with around 60% cost reduction [22]. As this scenario happens steadily and progressively in solar markets, the cost of PV modules and related structures will be highly affordable in the near future.

In addition, the economic cycle of the fossil fuel market is highly turbulent with dramatic price instabilities. However, unlike fossil fuel markets, the solar market is comparatively stable for a longer period of time. It further produces no noise, as solar PV systems are set to have no moving parts which are common in generators used to generate power from fossil fuel resources. Additionally, the installation of solar power systems to buildings and rooftops is simple and reliable. Furthermore, large structures in solar systems are rare as solar PV systems are combinations of individual modules. Moreover, a fault to one module can cause no significant impact as others in the system continue to work in order to maintain the supply. These advantages are highly productive as far as the expansion of solar energy systems are concerned.

1.5.2 Barriers to Solar Energy Systems

There are some limitations observed for solar energy systems though it is considered to be an effective source of renewable energy. It can only provide a constant power supply if it is well structured with other components like inverters and high-quality batteries. This section highlights barriers related to solar energy usage. The initial cost associated with the installation of solar systems is high compared to other renewable energy sources. It has been reported that the cost for a watt of solar energy was $3.7 in 2016 in the USA [22]. Moreover, a solar system of 5kW for a household costs around $13000 with 30% cost reduction due to federal tax credit. The long payback period diminishes the good value of the system [22]. Another critical bottleneck of the solar systems is that its efficiency is low. The commonly used solar panels with homes currently have an efficiency value from 10 to 20% [22]. However, highly efficient solar cells like perovskite cells are very expensive.

As discussed, for a continuous supply of electricity, PV panels should be associated with high-quality batteries. The cost associated with such batteries and inverters is high. In addition to the cost, the life of batteries is unstable and short. The quality of batteries and other associated components should be improved in order to reduce the cost of production and increase the durability. The batteries which are currently used in solar systems have some metal ions (Pb and Cu). The disposal of such batteries after use is a challenging task in the solar industry. Moreover, commonly available batteries are big in size with significant weight resulting in larger space requirements for safe storage.

Additionally, maintenance of solar systems and installation of components require technically sound human resources, and these are barriers to solar energy systems. In addition to these, people who live in rural areas tend to have poor technical knowledge about solar systems and their proper maintenance, resulting in damage to solar panels, batteries and circuits. This ultimately incurs additional cost for repair and maintenance. Another significant problem associated with solar PV modules is the formation of cracks, which lead to the intrusion of water into the solar cells. This intrusion can ultimately yield algal growth that can reduce the overall efficiency of the solar system. Moreover, solar panels can actively work only during the day time.

It is not a viable option in areas where abrupt weather conditions are generally reported. In addition to bad weather conditions, severe air pollution due to particulate matters and smog can reduce the efficiency of solar panels [53]. It has been reported that the exposure of solar panels to extreme smokes and aerosols resulted in 10 and 7% current reduction respectively in silicon solar cells [53]. Furthermore, the land area requirement to install larger solar panels at commercial scale is high. For example, solar panels made up of crystalline cells with 1 MW capacity require four acres of land, whereas panels made with thin-film technology need six acres of land for effective operation [54]. However, concentrated attention needs to be given to preserve the environment while implementing different renewable energy projects: solar, wind, etc. [55, 56, 57, 58].

As discussed in this section, major bottlenecks associated with solar systems are high cost of manufacturing, installation, the requirement of a skilled workforce, poor battery life, technical complexity of inverters, significant influence of weather and air pollution, and larger land area requirements for commercial-scale applications. These bottlenecks do prevent the expansion of solar energy systems for environmental sustainability.

1.6 CONCLUDING REMARKS WITH IDENTIFIED KNOWLEDGE GAPS FOR FUTURE RESEARCH

The aim of this chapter is to bring all basic aspects of solar energy sources under one umbrella to inform readers about relevant information for research activities, policy frameworks and educational purposes in order to achieve a clean and sustainable environment. Therefore, the information about the need of renewable energy sources, contribution of solar sources to climate change mitigation, fundamental aspects of solar energy technologies, global status of solar energy technologies and highlights of the merits and disadvantages of solar energy systems were analyzed and critically presented. The following points are major conclusions made, along with knowledge gaps identified for future improvements of solar and wind energy systems.

- Environmental pollution due to increasing fossil fuel burning is a critical problem because of industrial revolution, population growth and technological advancements. The emission of CO_2 into the atmosphere creates a lot of environmental problems including a greenhouse effect. Around 31% of the CO_2 level increase has been recorded over the last 200 years, with significant contribution from the burning of fossil fuels to meet increasing energy demand. There are various sources contributing to the increase in CO_2 levels in the atmosphere. Though there are reports available on CO_2 emissions due to various processes, process mapping of contributors of global CO_2 emissions is still a limited task to be completed. This map is highly required in future to identify potential sources of CO_2 emission and to propose viable mitigation strategies for a clean and sustainable future.
- The growth of renewable sources is happening at a significant rate due to the reasons indicated in the previous point. Renewable energy sources are expected to meet 47.7% of the total energy demand of the world in 2040. As sources are abundant in the world, appropriate strategies need to be developed to harvest the maximum amount of energy as possible from these resources. It is evidenced from the literature that most of these resources are still wasted and there is a need to develop and expedite research innovations to fill this knowledge gap.
- Solar energy is used for electricity generation through PV technology using semiconductors. In addition to this, it is used for concentrated thermal systems and direct uses like cooking and heating of spaces. However, wind energy is mainly used for generating electricity using wind turbines. It is obvious that solar and wind energy systems have distinct utility phases. However, availability of these two resources are highly affected by environmental factors and locational differences. In order to maintain continuity in the supply system from these two resources, an appropriate integration (solar-wind hybrid systems) should be developed to maintain the uniformity in the supply line for better consumer preferences. There are many research activities reporting on the performance reliability of solar energy systems and wind energy systems in isolation. However, further studies are required to make a comprehensive evaluation of solar-wind

hybrid systems for better applications since there is a lack of scientific understating in this sector.

- The costs for manufacturing solar systems are extremely high. Solar cells are made to harvest as much solar energy as possible. However, its efficiency has not gone beyond 30% so far. It is interesting that researchers are now working on hybrid perovskite solar cells and quantum dots to increase the efficiency further. However, the efficiency of solar cells has not been increased significantly. Therefore, there is an opening in the manufacturing of novel solar cells to fill this reach gap. Solar energy systems have their own cons and pros. Materials used in the manufacturing of solar systems are very toxic in nature. There is still a limited facility available to manage these toxic waste materials after use. Moreover, little has been known so far about specific impacts of such toxic materials on environmental processes. For example, heavy metals and radioactive substances used in the manufacturing of PV cells can significantly damage the health of living organisms. It is therefore required to investigate in-depth the general and specific effects of commonly used toxic manufacturing materials on living organisms. Moreover, cost-effective systems are needed for managing such toxic waste materials generated by the solar energy sector in order to maintain environmental sustainability.
- Industrial processes use solar thermal energy effectively. However, proper research activities are needed to develop appropriate protocols for the promotion of solar thermal energy for various other industrial applications.
- Though solar energy systems are reliable sources of renewable energy, it is highly necessary to identify their risks associated with environmental processes. For example, the effect of heat waves on the population dynamics of flora and fauna in areas where highly active concentrated solar power systems are used has not been studied well yet. Hence, highly structured research activities are needed to be conducted to fill this knowledge gap for the better application of solar and wind energy systems without damaging natural environmental processes.

As discussed, solar energy systems are highly reliable sources of renewable energy in the world. This short critical review made a comprehensive overview of such resources in terms of global status, fundamentals, advantages and disadvantages and highlights of knowledge as identified for future researchers in order to achieve a clean and sustainable environment for future generations. This short critical review will definitely be useful for researchers from various disciplines, policy makers and stakeholders to make necessary steps to gain as many benefits as possible from these renewable energy sources of nature's gifts.

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REFERENCES

1. Kannan, N. and D. Vakeesan, *Solar energy for future world:—A review*. Renewable and Sustainable Energy Reviews, 2016. **62**: p. 1092–1105.
2. Demirbas, A., *Effects of moisture and hydrogen content on the heating value of fuels*. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2007. **29**(7): p. 649–655.
3. Dincer, I., *Environmental issues: II-potential solutions*. Energy Sources, 2001. **23**(1): p. 83–92.
4. Bilgen, S., K. Kaygusuz, and A. Sari, *Renewable energy for a clean and sustainable future*. Energy Sources, 2004. **26**(12): p. 1119–1129.
5. Fridleifsson, I.B., *Geothermal energy for the benefit of the people*. Renewable and Sustainable energy Reviews, 2001. **5**(3): p. 299–312.
6. Farhad, S., M. Saffar-Avval, and M. Younessi-Sinaki, *Efficient design of feedwater heaters network in steam power plants using pinch technology and exergy analysis*. International Journal of Energy Research, 2008. **32**(1): p. 1–11.
7. Sims, R.E.H., *Bioenergy to mitigate for climate change and meet the needs of society, the economy and the environment*. Mitigation and Adaptation Strategies for Global Change, 2003. **8**(4): p. 349–370.
8. Blaschke, T., M. Biberacher, S. Gadocha, and I. Schardinger, *'Energy landscapes': Meeting energy demands and human aspirations*. Biomass and Bioenergy, 2013. **55**: p. 3–16.
9. Rutovitz, J., E. Dominish, and J. Downes, *Calculating global energy sector jobs: 2015 methodology*. 2015.
10. Arif, M.S., *Residential solar panels and their impact on the reduction of carbon emissions*. University of California, Berkeley. Retrieved from https://nature.berkeley.edu/classes/es196/projects/2013final/ArifM_2013.pdf, 2013.
11. Reddy, K.G., T.G. Deepak, G.S. Anjusree, S. Thomas, S. Vadukumpully, K.R.V. Subramanian, S.V. Nair, and A.S. Nair, *On global energy scenario, dye-sensitized solar cells and the promise of nanotechnology*. Physical Chemistry Chemical Physics, 2014. **16**(15): p. 6838–6858.
12. Murdock, H.E., D. Gibb, T. Andre, J.L. Sawin, A. Brown, L. Ranalder, U. Collier, C. Dent, B. Epp, and C. Hareesh Kumar, *Renewables 2021—Global status report*. 2021.
13. Boretti, A., *Cost and production of solar thermal and solar photovoltaics power plants in the United States*. Renewable Energy Focus, 2018. **26**: p. 93–99.
14. Tingem, M. and M. Rivington, *Adaptation for crop agriculture to climate change in Cameroon: turning on the heat*. Mitigation and Adaptation Strategies for Global Change, 2009. **14**(2): p. 153–168.
15. Kobayashi, T., K. Ishiguro, T. Nakajima, H.Y. Kim, M. Okada, and K. Kobayashi, *Haines A, Kovats RS, Campbell-Lendrum D, Corvalan C. 2006. Climate*. Health, 2007. **120**: p. 585–596.
16. Dincer, I., *Energy and environmental impacts: present and future perspectives*. Energy Sources, 1998. **20**(4–5): p. 427–453.
17. Panwar, N.L., S.C. Kaushik, and S. Kothari, *Role of renewable energy sources in environmental protection: A review*. Renewable and Sustainable Energy Reviews, 2011. **15**(3): p. 1513–1524.
18. Zakhidov, R.A., *Central Asian countries energy system and role of renewable energy sources*. Applied Solar Energy, 2008. **44**(3): p. 218–223.
19. Farjana, S.H., N. Huda, M.A.P. Mahmud, and R. Saidur, *Solar process heat in industrial systems—A global review*. Renewable and Sustainable Energy Reviews, 2018. **82**: p. 2270–2286.
20. Suresh, N.S. and B.S. Rao, *Solar energy for process heating: a case study of select Indian industries*. Journal of Cleaner Production, 2017. **151**: p. 439–451.

21. Elbreki, A.M., M.A. Alghoul, A.N. Al-Shamani, A.A. Ammar, B. Yegani, A.M. Aboghrara, M.H. Rusaln, and K. Sopian, *The role of climatic-design-operational parameters on combined PV/T collector performance: A critical review*. Renewable and Sustainable Energy Reviews, 2016. **57**: p. 602–647.
22. Kabir, E., P. Kumar, S. Kumar, A.A. Adelodun, and K.-H. Kim, *Solar energy: Potential and future prospects*. Renewable and Sustainable Energy Reviews, 2018. **82**: p. 894–900.
23. Sun, D. and L. Wang, *Research on heat transfer performance of passive solar collector-storage wall system with phase change materials*. Energy and Buildings, 2016. **119**: p. 183–188.
24. Herrando, M. and C.N. Markides, *Hybrid PV and solar-thermal systems for domestic heat and power provision in the UK: Techno-economic considerations*. Applied Energy, 2016. **161**: p. 512–532.
25. Mohanty, P., T. Muneer, E.J. Gago, and Y. Kotak, *Solar radiation fundamentals and PV system components*, in *Solar Photovoltaic System Applications*. 2016: Springer. p. 7–47.
26. Jeon, N.J., J. Lee, J.H. Noh, M.K. Nazeeruddin, M. Grätzel, and S.I. Seok, *Efficient inorganic-organic hybrid perovskite solar cells based on pyrene arylamine derivatives as hole-transporting materials*. Journal of the American Chemical Society, 2013. **135**(51): p. 19087–19090.
27. Alharbi, F.H. and S. Kais, *Theoretical limits of photovoltaics efficiency and possible improvements by intuitive approaches learned from photosynthesis and quantum coherence*. Renewable and Sustainable Energy Reviews, 2015. **43**: p. 1073–1089.
28. Biermann, E., M.Y. Grupp, and R. Palmer, *Solar cooker acceptance in South Africa: results of a comparative field-test*. Solar Energy, 1999. **66**(6): p. 401–407.
29. Kalogirou, S., *Thermal performance, economic and environmental life cycle analysis of thermosiphon solar water heaters*. Solar Energy, 2009. **83**(1): p. 39–48.
30. Kumar, A. and T.C. Kandpal, *CO2 emissions mitigation potential of some renewable energy technologies in India*. Energy Sources, Part A, 2007. **29**(13): p. 1203–1214.
31. Romero, M. and J. González-Aguilar, *Solar thermal CSP technology*. Wiley Interdisciplinary Reviews: Energy and Environment, 2014. **3**(1): p. 42–59.
32. Singh, S., T.S. Bhatti, and D.P. Kothari, *Indian scenario of wind energy: problems and solutions*. Energy Sources, 2004. **26**(9): p. 811–819.
33. Pryor, S.C. and R.J. Barthelmie, *Climate change impacts on wind energy: A review*. Renewable and Sustainable Energy Reviews, 2010. **14**(1): p. 430–437.
34. Nagrath, I.J., *Power system engineering*. 2007: Tata McGraw Hill India.
35. Ozgener, O., K. Ulgen, and A. Hepbasli, *Wind and wave power potential*. Energy Sources, 2004. **26**(9): p. 891–901.
36. Balat, M., *A review of modern wind turbine technology*. Energy Sources, Part A, 2009. **31**(17): p. 1561–1572.
37. Balat, M., *Usage of energy sources and environmental problems*. Energy Exploration & Exploitation, 2005. **23**(2): p. 141–167.
38. Holm-Nielsen, J. and E.A. Ehimen, *Biomass supply chains for bioenergy and biorefining*. 2016: Woodhead Publishing.
39. Hart, M., *Hubris: The troubling science, economics, and politics of climate change*. 2015: Lulu. com.
40. Luqman, M., S.R. Ahmad, S. Khan, U. Ahmad, A. Raza, and F. Akmal, *Estimation of solar energy potential from rooftop of Punjab government servants cooperative housing society Lahore using GIS*. Smart Grid and Renewable Energy, 2015. **6**(05): p. 128.
41. Adaramola, M., *Solar energy: application, economics, and public perception*. 2014: CRC Press.
42. Hang, Q., Z. Jun, Y. Xiao, and C. Junkui, *Prospect of concentrating solar power in China—the sustainable future*. Renewable and Sustainable Energy Reviews, 2008. **12**(9): p. 2505–2514.

43. Hemmeline, C., *Overview of solar energy in Texas-Texas solar market update*. CATEE conference, 2017.
44. Indora, S. and T.C. Kandpal, *Institutional cooking with solar energy: A review*. Renewable and Sustainable Energy Reviews, 2018. **84**: p. 131–154.
45. Kalvig, P. and E. Machacek, *Examining the rare-earth elements (REE) supply-demand balance for future global wind power scenarios*. GEUS Bulletin, 2018. **41**: p. 87–90.
46. Kar, S.K., A. Sharma, and B. Roy, *Solar energy market developments in India*. Renewable and Sustainable Energy Reviews, 2016. **62**: p. 121–133.
47. Marugán, A.P., F.P.G. Márquez, J.M.P. Perez, and D. Ruiz-Hernández, *A survey of artificial neural network in wind energy systems*. Applied Energy, 2018. **228**: p. 1822–1836.
48. Dincer, F., *The analysis on wind energy electricity generation status, potential and policies in the world*. Renewable and Sustainable Energy Reviews, 2011. **15**(9): p. 5135–5142.
49. Görig, M. and C. Breyer, *Energy learning curves of PV systems*. Environmental Progress & Sustainable Energy, 2016. **35**(3): p. 914–923.
50. Jerez, S., I. Tobin, R. Vautard, J.P. Montávez, J.M. López-Romero, F. Thais, B. Bartok, O.B. Christensen, A. Colette, and M. Déqué, *The impact of climate change on photovoltaic power generation in Europe*. Nature Communications, 2015. **6**(1): p. 1–8.
51. Burt, E., P. Orris, and S. Buchanan, *Scientific evidence of health effects from coal use in energy generation*. Chicago and Washington: School of Public Health, University of Illinois and Health Care Without Harm, 2013.
52. Machol, B. and S. Rizk, *Economic value of US fossil fuel electricity health impacts*. Environment International, 2013. **52**: p. 75–80.
53. Radivojević, A.R., T.M. Pavlović, D.D. Milosavljević, A.V. Đorđević, M.A. Pavlović, I.M. Filipović, L.S. Pantić, and M.R. Punišić, *Influence of climate and air pollution on solar energy development in Serbia*. Thermal Science, 2015. **19**(suppl. 2): p. 311–322.
54. Castillo, C.P., F.B. e Silva, and C. Lavalle, *An assessment of the regional potential for solar power generation in EU-28*. Energy policy, 2016. **88**: p. 86–99.
55. Owusu, P.A. and S. Asumadu-Sarkodie, *A review of renewable energy sources, sustainability issues and climate change mitigation*. Cogent Engineering, 2016. **3**(1): p. 1167990.
56. Ahmed, S., A. Mahmood, A. Hasan, G.A.S. Sidhu, and M.F.U. Butt, *A comparative review of China, India and Pakistan renewable energy sectors and sharing opportunities*. Renewable and sustainable Energy reviews, 2016. **57**: p. 216–225.
57. Miller, L.M. and D.W. Keith, *Climatic Impacts of Wind Power,* Joule, *2018*. **2**: p. 2618–2632. 2018.
58. Nazir, M.S., A.J. Mahdi, M. Bilal, H.M. Sohail, N. Ali, and H.M.N. Iqbal, *Environmental impact and pollution-related challenges of renewable wind energy paradigm—a review*. Science of the Total Environment, 2019. **683**: p. 436–444.

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Kannan, N. and D. Vakeesan , Solar energy for future world:—A review. Renewable and Sustainable Energy Reviews, 2016. 62: p. 1092–1105.

Demirbas, A. , *Effects of moisture and hydrogen content on the heating value of fuels*. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2007. 29(7): p. 649–655.

Dincer, I. , Environmental issues: IIpotential solutions. Energy Sources, 2001. 23(1): p. 83–92.

Bilgen, S. , K. Kaygusuz , and A. Sari , Renewable energy for a clean and sustainable future. Energy Sources, 2004. 26(12): p. 1119–1129.

Fridleifsson, I.B. , Geothermal energy for the benefit of the people. Renewable and Sustainable energy Reviews, 2001. 5(3): p. 299–312.

Farhad, S. , M. Saffar-Avval , and M. Younessi-Sinaki , Efficient design of feedwater heat ers network in steam power plants using pinch technology and exergy analysis. International Journal of Energy Research, 2008. 32(1): p. 1–11.

Sims, R.E.H. , Bioenergy to mitigate for climate change and meet the needs of society, the economy and the environment. Mitigation and Adaptation Strategies for Global Change, 2003. 8(4): p. 349–370.

Blaschke, T. , M. Biberacher , S. Gadocha , and I. Schardinger , 'Energy landscapes': Meet ing energy demands and human aspirations. Biomass and Bioenergy, 2013. 55: p. 3–16.

Rutovitz, J. , E. Dominish , and J. Downes , Calculating global energy sector jobs: 2015 methodology. 2015.

Arif, M.S. , Residential solar panels and their impact on the reduction of carbon emis sions. University of California, Berkeley. Retrieved from https://nature.berkeley.edu/classes/es196/projects/2013final/ArifM_2013.pdf, 2013.

Reddy, K.G. , T.G. Deepak , G.S. Anjusree , S. Thomas , S. Vadukumpully , K.R.V. Subramanian , S.V. Nair , and A.S. Nair , On global energy scenario, dyesensitized solar cells and the promise of nanotechnology. Physical Chemistry Chemical Physics, 2014. 16(15): p. 6838–6858.

Murdock, H.E. , D. Gibb , T. Andre , J.L. Sawin , A. Brown , L. Ranalder , U. Collier , C. Dent , B. Epp , and C. Hareesh Kumar , Renewables 2021—Global status report. 2021.

Boretti, A. , Cost and production of solar thermal and solar photovoltaics power plants in the United States. Renewable Energy Focus, 2018. 26: p. 93–99.

Tingem, M. and M. Rivington , Adaptation for crop agriculture to climate change in Cameroon: turning on the heat. Mitigation and Adaptation Strategies for Global Change, 2009. 14(2): p. 153–168.

Kobayashi, T. , K. Ishiguro , T. Nakajima , H.Y. Kim , M. Okada , and K. Kobayashi , Haines A, Kovats RS, CampbellLendrum D, Corvalan C. 2006. Climate. Health, 2007. 120: p. 585–596.

Dincer, I. , Energy and environmental impacts: present and future perspectives. Energy Sources, 1998. 20(4–5): p. 427–453.

Panwar, N.L. , S.C. Kaushik , and S. Kothari , Role of renewable energy sources in environ mental protection: A review. Renewable and Sustainable Energy Reviews, 2011. 15(3): p. 1513–1524.

Zakhidov, R.A. , Central Asian countries energy system and role of renewable energy sources. Applied Solar Energy, 2008. 44(3): p. 218–223.

Farjana, S.H. , N. Huda , M.A.P. Mahmud , and R. Saidur , Solar process heat in indus trial systems—A global review. Renewable and Sustainable Energy Reviews, 2018. 82: p. 2270–2286.

Suresh, N.S. and B.S. Rao , Solar energy for process heating: a case study of select Indian industries. Journal of Cleaner Production, 2017. 151: p. 439–451.

Elbreki, A.M. , M.A. Alghoul , A.N. Al-Shamani , A.A. Ammar , B. Yegani , A.M. Aboghrara , M.H. Rusaln , and K. Sopian , The role of climaticdesignoperational parameters on combined PV/T collector performance: A critical review. Renewable and Sustainable Energy Reviews, 2016. 57: p. 602–647.

Kabir, E. , P. Kumar , S. Kumar , A.A. Adelodun , and K.-H. Kim , Solar energy: Potential and future prospects. Renewable and Sustainable Energy Reviews, 2018. 82: p. 894–900.

Sun, D. and L. Wang , Research on heat transfer performance of passive solar collec torstorage wall system with phase change materials. Energy and Buildings, 2016. 119: p. 183–188.

Herrando, M. and C.N. Markides , Hybrid PV and solarthermal systems for domestic heat and power provision in the UK: Technoeconomic considerations. Applied Energy, 2016. 161: p. 512–532.
Mohanty, P. , T. Muneer , E.J. Gago , and Y. Kotak , *Solar radiation fundamentals and PV system components*, in *Solar Photovoltaic System Applications* . 2016: Springer. p. 7–47.
Jeon, N.J. , J. Lee , J.H. Noh , M.K. Nazeeruddin , M. Grätzel , and S.I. Seok , Efficient inor ganicorganic hybrid perovskite solar cells based on pyrene arylamine derivatives as holetransporting materials. Journal of the American Chemical Society, 2013. 135(51): p. 19087–19090.
Alharbi, F.H. and S. Kais , Theoretical limits of photovoltaics efficiency and possible improvements by intuitive approaches learned from photosynthesis and quantum coher ence. Renewable and Sustainable Energy Reviews, 2015. 43: p. 1073–1089.
Biermann, E. , M.Y. Grupp , and R. Palmer , Solar cooker acceptance in South Africa: results of a comparative fieldtest. Solar Energy, 1999. 66(6): p. 401–407.
Kalogirou, S. , Thermal performance, economic and environmental life cycle analysis of thermosiphon solar water heaters. Solar Energy, 2009. 83(1): p. 39–48.
Kumar, A. and T.C. Kandpal , CO2 emissions mitigation potential of some renewable energy technologies in India. Energy Sources, Part A, 2007. 29(13): p. 1203–1214.
Romero, M. and J. González-Aguilar , Solar thermal CSP technology. Wiley Interdisciplinary Reviews: Energy and Environment, 2014. 3(1): p. 42–59.
Singh, S. , T.S. Bhatti , and D.P. Kothari , Indian scenario of wind energy: problems and solutions. Energy Sources, 2004. 26(9): p. 811–819.
Pryor, S.C. and R.J. Barthelmie , Climate change impacts on wind energy: A review. Renewable and Sustainable Energy Reviews, 2010. 14(1): p. 430–437.
Nagrath, I.J. , Power system engineering. 2007: Tata McGraw Hill India.
Ozgener, O. , K. Ulgen , and A. Hepbasli , Wind and wave power potential. Energy Sources, 2004. 26(9): p. 891–901.
Balat, M. , A review of modern wind turbine technology. Energy Sources, Part A, 2009. 31(17): p. 1561–1572.
Balat, M. , Usage of energy sources and environmental problems. Energy Exploration & Exploitation, 2005. 23(2): p. 141–167.
Holm-Nielsen, J. and E.A. Ehimen , Biomass supply chains for bioenergy and biorefining. 2016: Woodhead Publishing.
Hart, M. , Hubris: The troubling science, economics, and politics of climate change. 2015: Lulu. com.
Luqman, M. , S.R. Ahmad , S. Khan , U. Ahmad , A. Raza , and F. Akmal , Estimation of solar energy potential from rooftop of Punjab government servants cooperative housing society Lahore using GIS. Smart Grid and Renewable Energy, 2015. 6(05): p. 128.
Adaramola, M. , Solar energy: application, economics, and public perception. 2014: CRC Press.
Hang, Q. , Z. Jun , Y. Xiao , and C. Junkui , Prospect of concentrating solar power in China—the sustainable future. Renewable and Sustainable Energy Reviews, 2008. 12(9): p. 2505–2514.
Hemmeline, C. , Overview of solar energy in TexasTexas solar market update. CATEE conference, 2017.
Indora, S. and T.C. Kandpal , Institutional cooking with solar energy: A review. Renewable and Sustainable Energy Reviews, 2018. 84: p. 131–154.
Kalvig, P. and E. Machacek , Examining the rareearth elements (REE) supplydemand balance for future global wind power scenarios. GEUS Bulletin, 2018. 41: p. 87–90.
Kar, S.K. , A. Sharma , and B. Roy , Solar energy market developments in India. Renewable and Sustainable Energy Reviews, 2016. 62: p. 121–133.
Marugán, A.P. , F.P.G. Márquez , J.M.P. Perez , and D. Ruiz-Hernández , A survey of artifi cial neural network in wind energy systems. Applied Energy, 2018. 228: p. 1822–1836.
Dincer, F. , The analysis on wind energy electricity generation status, potential and poli cies in the world. Renewable and Sustainable Energy Reviews, 2011. 15(9): p. 5135– 5142.
Görig, M. and C. Breyer , *Energy learning curves of PV systems*. Environmental Progress & Sustainable Energy, 2016. 35(3): p. 914–923.
Jerez, S. , I. Tobin , R. Vautard , J.P. Montávez , J.M. López-Romero , F. Thais , B. Bartok , O.B. Christensen , A. Colette , and M. Déqué , The impact of climate change on photovol taic

power generation in Europe. Nature Communications, 2015. 6(1): p. 1–8.
Burt, E. , P. Orris , and S. Buchanan , Scientific evidence of health effects from coal use in energy generation. Chicago and Washington: School of Public Health, University of Illinois and Health Care Without Harm, 2013.
Machol, B. and S. Rizk , Economic value of US fossil fuel electricity health impacts. Environment International, 2013. 52: p. 75–80.
Radivojević, A.R. , T.M. Pavlović , D.D. Milosavljević , A.V. Đorđević , M.A. Pavlović , I.M. Filipović , L.S. Pantić , and M.R. Punišić , Influence of climate and air pollution on solar energy development in Serbia. Thermal Science, 2015. 19(suppl. 2): p. 311–322.
Castillo, C.P. , F. B.e Silva , and C. Lavalle , An assessment of the regional potential for solar power generation in EU28. Energy policy, 2016. 88: p. 86–99.
Owusu, P.A. and S. Asumadu-Sarkodie , A review of renewable energy sources, sustain ability issues and climate change mitigation. Cogent Engineering, 2016. 3(1): p. 1167990.
Ahmed, S. , A. Mahmood , A. Hasan , G.A.S. Sidhu , and M.F.U. Butt , A comparative review of China, India and Pakistan renewable energy sectors and sharing opportunities. Renewable and sustainable Energy reviews, 2016. 57: p. 216–225.
Miller, L.M. and D.W. Keith , Climatic Impacts of Wind Power , Joule, 2018. 2: p. 2618– 2632. 2018.
Nazir, M.S. , A.J. Mahdi , M. Bilal , H.M. Sohail , N. Ali , and H.M.N. Iqbal , Environmental impact and pollutionrelated challenges of renewable wind energy paradigm—a review. Science of the Total Environment, 2019. 683: p. 436–444.

Low and Medium Temperature Solar Thermal Collectors

Alawi, O.A. , Kamar, H.M. , Mallah, A.R. , Mohammed, H.A. , Kazi, S.N. , Che Sidik, N.A. , and Najafi, G. , 2021. Nanofluids for flat plate solar collectors: Fundamentals and applications. Journal of Cleaner Production, 291, 125725.
Balijepalli, R. , Chandramohan, V.P. , and Kirankumar, K. , 2017. Performance parameter evaluation, materials selection, solar radiation with energy losses, energy storage and turbine design procedure for a pilot scale solar updraft tower. *Energy Conversion and Management*, 150, 451–462.
Barone, G. , Buonomano, A. , Forzano, C. , and Palombo, A. , 2019. Solar thermal collectors. In Calise, F. , D'Accadia, M.D. , Santarelli, M. , Lanzini, A. , & Ferrero, D. (Eds.) Solar Hydrogen Production (pp. 151–178). Academic Press.
Bellas, D.V. , and Lidorikis, E. , 2017. Design of high-temperature solar-selective coatings for application in solar collectors. Solar Energy Materials and Solar Cells, 170, 102–113.
Bellos, E. , Daniil, I. , and Tzivanidis, C. , 2018. Multiple cylindrical inserts for parabolic trough solar collector. Applied Thermal Engineering, 143, 80–89.
Bellos, E. , and Tzivanidis, C. , 2018. Investigation of a star flow insert in a parabolic trough solar collector. Applied Energy, 224, 86–102.
Bellos, E. , Tzivanidis, C. , and Tsimpoukis, D. , 2018. Enhancing the performance of parabolic trough collectors using nanofluids and turbulators. Renewable and Sustainable Energy Reviews, 91, 358–375.
Bhatia, S.C. , 2014. Solar thermal energy. In Advanced Renewable Energy Systems (pp. 94–143). Woodhead Publishing India Ltd.
Chopra, K. , Tyagi, V.V. , Pandey, A.K. , and Sari, A. , 2018. Global advancement on experimental and thermal analysis of evacuated tube collector with and without heat pipe systems and possible applications. Applied Energy, 228, 351–389.
Das, P. and Chandramohan, V.P. , 2019. Computational study on the effect of collector cover inclination angle, absorber plate diameter and chimney height on flow and performance parameters of solar updraft tower (SUT) plant. Energy, 172, 366–379.
Das, P. , and Chandramohan, V.P. , 2021. Experimental studies of a laboratory scale inclined collector solar updraft tower plant with thermal energy storage system. Journal of Build ing Engineering, 41, 102394.
Dović, D. , and Andrassy, M. , 2012. Numerically assisted analysis of flat and corrugated plate solar collectors thermal performances. Solar Energy, 86 (9), 2416–2431.

Faizal, M. , Saidur, R. , Mekhilef, S. , and Alim, M.A. , 2013. Energy, economic and environmental analysis of metal oxides nanofluid for flat-plate solar collector. Energy Conver *sion and Management*, 76, 162–168.
Fernández-García, A. , Zarza, E. , Valenzuela, L. , and Pérez, M. , 2010. Parabolic-trough solar collectors and their applications. Renewable and Sustainable Energy Reviews, 14 (7), 1695–1721.
Ghazouani, K. , Skouri, S. , Bouadila, S. , and Guizani, A.A. , 2019. Thermal analysis of linear solar concentrator for indirect steam generation. Energy Procedia, 162, 136–145.
Gilago, M.C. , and Chandramohan, V.P. , 2022. Performance evaluation of natural and forced convection indirect type solar dryers during drying ivy gourd: An experimental study. Renewable Energy, 182, 934–945.
Goudarzi, K. , Shojaeizadeh, E. , and Nejati, F. , 2014. An experimental investigation on the simultaneous effect of CuO—H2O nanofluid and receiver helical pipe on the thermal efficiency of a cylindrical solar collector. Applied Thermal Engineering, 73 (1), 1236–1243.
Hafez, A.Z. , Soliman, A. , El-Metwally, K.A. , and Ismail, I.M. , 2016. Solar parabolic dish Stirling engine system design, simulation, and thermal analysis. Energy Conversion and Management, 126, 60–75.
Hayek, M. , Assaf, J. , and Lteif, W. , 2011. Experimental investigation of the performance of evacuated-tube solar collectors under eastern mediterranean climatic conditions. Energy Procedia, 6, 618–626.
Hess, S. , 2016. Solar thermal process heat (SPH) generation. In Renewable Heating and Cool ing (pp. 41–66). Woodhead Publishing.
Iparraguirre, I. , Huidobro, A. , Fernández-García, A. , Valenzuela, L. , Horta, P. , Sallaberry, F. , Osório, T. , and Sanz, A. , 2016. Solar thermal collectors for medium temperature applications: A comprehensive review and updated database. Energy Procedia, 91, 64–71.
Javaniyan Jouybari, H. , Saedodin, S. , Zamzamian, A. , and Nimvari, M.E. , 2017. Experimental investigation of thermal performance and entropy generation of a flat-plate solar collector filled with porous media. Applied Thermal Engineering, 127, 1506–1517.
Jradi, M. , and Riffat, S. , 2014. Medium temperature concentrators for solar thermal applications. International Journal of LowCarbon Technologies, 9 (3), 214–224.
Kalogirou, S. , 2003. The potential of solar industrial process heat applications. Applied Energy, 76 (4), 337–361.
Kalogirou, S. , 2008. Recent patents in solar energy collectors and applications. Recent Patents on Engineering, 1 (1), 23–33.
Kalogirou, S.A. , 2004. Solar thermal collectors and applications. Progress in Energy and Combustion Science, 30 (3), 231–295.
Kalogirou, S.A. , and Lloyd, S. , 1992. Use of solar parabolic trough collectors for hot water production in cyprus. A feasibility study. Renewable Energy, 2 (2), 117–124.
Kalogirou, S.A. , Lloyd, S. , Ward, J. , and Eleftheriou, P. , 1994. Design and performance characteristics of a parabolic-trough solar-collector system. Applied Energy, 47 (4), 341–354.
Kumar, L. , Hasanuzzaman, M. , and Rahim, N.A. , 2019. Global advancement of solar thermal energy technologies for industrial process heat and its future prospects: A review. Energy Conversion and Management, 195, 885–908.
Lamnatou, C. , Papanicolaou, E. , Belessiotis, V. , and Kyriakis, N. , 2012. Experimental investigation and thermodynamic performance analysis of a solar dryer using an evacuated-tube air collector. Applied Energy, 94, 232–243.
Martínez-Rodríguez, G. , Fuentes-Silva, A.L. , and Picón-Núñez, M. , 2018a. Targeting the maximum outlet temperature of solar collectors. Chemical Engineering Transactions, 70, 1567–1572.
Martínez-Rodríguez, G. , Fuentes-Silva, A.L. , and Picón-Núñez, M. , 2018b. Solar thermal networks operating with evacuated-tube collectors. Energy, 146, 26–33.
Mills, D.R. , 2012. Linear Fresnel reflector (LFR) technology. In Concentrating Solar Power Technology (pp. 153–196). Woodhead Publishing.
Nawsud, Z.A. , Altouni, A. , Akhijahani, H.S. , and Kargarsharifabad, H. , 2022. A comprehensive review on the use of nano-fluids and nano-PCM in parabolic trough solar collectors (PTC). Sustainable Energy Technologies and Assessments, 51, 101889.
Nikolić, N. , and Lukić, N. , 2015. Theoretical and experimental investigation of the thermal performance of a double exposure flat-plate solar collector. Solar Energy, 119, 100–113.

Orosz, M. , and Dickes, R. , 2017. Solar thermal powered organic rankine cycles. In Organic Rankine Cycle (ORC) Power Systems (pp. 569–612). Woodhead Publishing.

Ramaiah, R. and Shekar, Kss., 2018. Solar thermal energy utilization for medium temperature industrial process heat applications—a review. *IOP Conference Series: Materials Science and Engineering*, 376 (1), 012035.

Ramos, C. , Ramirez, R. , and Beltran, J. , 2014. Potential assessment in Mexico for solar process heat applications in food and textile industries. Energy Procedia, 49, 1879–1884.

Redpath, D.A.G. , 2012. Thermosyphon heat-pipe evacuated tube solar water heaters for northern maritime climates. Solar Energy, 86 (2), 705–715.

Sabiha, M.A. , Saidur, R. , Mekhilef, S. , and Mahian, O. , 2015. Progress and latest developments of evacuated tube solar collectors. Renewable and Sustainable Energy Reviews, 51, 1038–1054.

Sakhaei, S.A. , and Valipour, M.S. , 2019. Performance enhancement analysis of The flat plate collectors: A comprehensive review. Renewable and Sustainable Energy Reviews, 102, 186–204.

Sharma, A.K. , Sharma, C. , Mullick, S.C. , and Kandpal, T.C. , 2017. Solar industrial process heating: A review. Renewable and Sustainable Energy Reviews, 78, 124–137.

Singh, P.L. , Sarviya, R.M. , and Bhagoria, J.L. , 2010. Thermal performance of linear Fresnel reflecting solar concentrator with trapezoidal cavity absorbers. Applied Energy, 87 (2), 541–550.

Solar Heat for Industrial Processes Technology Brief [online], 2022. Available from: www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_ETSAP_Tech_Brief_E21_Solar_Heat_Industrial_2015.pdf [Accessed 2 Feb 2022].

Solar Heat Worldwide 2021—a rich source of global, national and sector-specific data—Solarthermalworld [online], 2022. Available from: https://solarthermalworld.org/news/solar-heat-worldwide-2021-rich-source-global-national-and-sector-specific-data/ [Accessed 25 Mar 2022].

Solar Process Heat Technologies & Solar Collectors [online], 2022. Available from: www.solar-payback.com/technology/ [Accessed 2 Feb 2022].

Solar thermal | Ipieca [online], 2022. Available from: www.ipieca.org/resources/energy-efficiency-solutions/power-and-heat-generation/solar-thermal/ [Accessed 2 Feb 2022].

Solar thermal capacity globally 2018 | Statista [online], 2022. Available from: www.statista.com/statistics/1064418/solar-thermal-energy-cumulative-capacity-globally/ [Accessed 30 Mar 2022].

Solar Thermal Plants Database | Solar Heat for Industrial Processes (SHIP) Plants Database [online], 2022. Available from: http://ship-plants.info/solar-thermal-plants [Accessed 2 Feb 2022].

Taibi, E. , Gielen, D. , and Bazilian, M. , 2012. The potential for renewable energy in industrial applications. Renewable and Sustainable Energy Reviews, 16 (1), 735–744.

Tian, Y. , and Zhao, C.Y. , 2013. A review of solar collectors and thermal energy storage in solar thermal applications. Applied Energy, 104, 538–553.

Tian, Z. , Perers, B. , Furbo, S. , and Fan, J. , 2018. Thermo-economic optimization of a hybrid solar district heating plant with flat plate collectors and parabolic trough collectors in series. Energy Conversion and Management, 165, 92–101.

Vengadesan, E. , and Senthil, R. , 2020. A review on recent developments in thermal performance enhancement methods of flat plate solar air collector. Renewable and Sustainable Energy Reviews, 134, 110315.

Verma, S.K. , Gupta, N.K. , and Rakshit, D. , 2020. A comprehensive analysis on advances in application of solar collectors considering design, process and working fluid parameters for solar to thermal conversion. Solar Energy, 208, 1114–1150.

Verma, S.K. , Sharma, K. , Gupta, N.K. , Soni, P. , and Upadhyay, N. , 2020. Performance comparison of innovative spiral shaped solar collector design with conventional flat plate solar collector. Energy, 194, 116853.

Zelzouli, K. , Guizani, A. , Sebai, R. , Kerkeni, C. , Zelzouli, K. , Guizani, A. , Sebai, R. , and Kerkeni, C. , 2012. Solar thermal systems performances versus flat plate solar collectors connected in series. Engineering, 4 (12), 881–893.

Zhu, T. , Diao, Y. , Zhao, Y. , and Ma, C. , 2017. Performance evaluation of a novel flat-plate solar air collector with micro-heat pipe arrays (MHPA). Applied Thermal Engineering, 118, 1–16.

Solar Thermal Energy for Industrial Process Heating

Jangde, P. K. , Singh, A. , & Arjunan, T. V. (2022). Efficient solar drying techniques: A review. Environmental Science and Pollution Research, 29(34), 50970–50983.

Schoeneberger, C. A. , McMillan, C. A. , Kurup, P. , Akar, S. , Margolis, R. , & Masanet, E. (2020). Solar for industrial process heat: A review of technologies, analysis approaches, and potential applications in the United States. Energy, 206, 118083.

Kumar, L. , Hasanuzzaman, M. , & Rahim, N. A. (2019). Global advancement of solar thermal energy technologies for industrial process heat and its future prospects: A review. Energy Conversion and Management, 195, 885–908.

Kumar, L. , Hasanuzzaman, M. , Rahim, N. A. , & Islam, M. M. (2021). Modeling, simulation and outdoor experimental performance analysis of a solar-assisted process heating system for industrial process heat. Renewable Energy, 164, 656–673.

Cresko, J. , Shenoy, D. , Liddell, H. P. H. , & Sabouni, R. (2015). Innovating clean energy technologies in advanced manufacturing. In: Quadrennial Technology Review.

Sharma, A. K. , Sharma, C. , Mullick, S. C. , & Kandpal, T. C. (2017). Solar industrial process heating: A review. Renewable and Sustainable Energy Reviews, 78, 124–137.

Allouhi, A. , Agrouaz, Y. , Amine, M. B. , Rehman, S. , Buker, M. S. , Kousksou, T. , . . . & Benbassou, A. (2017). Design optimization of a multi-temperature solar thermal heating system for an industrial process. Applied Energy, 206, 382–392.

Uppal, A. , Kesari, J. P. , & Zunaid, M. (2016). Designing of solar process heating system for Indian automobile industry. International Journal of Renewable Energy Research, 6(4), 1627–1636.

Farjana, S. H. , Huda, N. , Mahmud, M. P. , & Saidur, R. (2018). Solar process heat in industrial systems–A global review. Renewable and Sustainable Energy Reviews, 82, 2270–2286.

Sing, C. K. L. , Lim, J. S. , Walmsley, T. G. , Liew, P. Y. , Goto, M. , & Bin Shaikh Salim, S. A. Z. (2020). Time-dependent integration of solar thermal technology in industrial processes. Sustainability, 12(6), 2322.

Ismail, M. I. , Yunus, N. A. , & Hashim, H. (2021). Integration of solar heating systems for low-temperature heat demand in food processing industry–A review. Renewable and Sustainable Energy Reviews, 147, 111192.

Kalogirou, S. (2003). The potential of solar industrial process heat applications. Applied Energy, 76(4), 337–361.

Sharma, A. K. , Sharma, C. , Mullick, S. C. , & Kandpal, T. C. (2017). Potential of solar industrial process heating in dairy industry in India and consequent carbon mitigation. Journal of Cleaner Production, 140, 714–724.

Hasanuzzaman, M. , Rahim, N. A. , Hosenuzzaman, M. , Saidur, R. , Mahbubul, I. M. , & Rashid, M. M. (2012). Energy savings in the combustion-based process heating in industrial sector. Renewable and Sustainable Energy Reviews, 16(7), 4527–4536.

Gajendiran, M. , & Nallusamy, N. (2014). Application of solar thermal energy storage for industrial process heating. Advanced Materials Research, 984, 725–729.

Karki, S. , Haapala, K. R. , & Fronk, B. M. (2019). Technical and economic feasibility of solar flat-plate collector thermal energy systems for small and medium manufacturers. Applied Energy, 254, 113649.

Sharma, A. K. , Sharma, C. , Mullick, S. C. , & Kandpal, T. C. (2017). GHG mitigation potential of solar industrial process heating in producing cotton based textiles in India. Journal of Cleaner Production, 145, 74–84.

Peters, M. , Schmidt, T. S. , Wiederkehr, D. , & Schneider, M. (2011). Shedding light on solar technologies—A techno-economic assessment and its policy implications. Energy Policy, 39(10), 6422–6439.

Ramos, C. , Ramirez, R. , & Beltran, J. (2014). Potential assessment in Mexico for solar process heat applications in food and textile industries. Energy Procedia, 49, 1879–1884.

Sharma, A. K. , Sharma, C. , Mullick, S. C. , & Kandpal, T. C. (2015). Potential of solar energy utilization for process heating in paper industry in India: A preliminary assessment. Energy Procedia, 79, 284–289.

Sharma, A. K. , Sharma, C. , Mullick, S. C. , & Kandpal, T. C. (2016). Carbon mitigation potential of solar industrial process heating: Paper industry in India. Journal of Cleaner Production, 112, 1683–1691.

Lauterbach, C. , Schmitt, B. , Jordan, U. , & Vajen, K. (2012). The potential of solar heat for industrial processes in Germany. Renewable and Sustainable Energy Reviews, 16(7), 5121–5130.
Ismail, M. I. , Yunus, N. A. , Kaassim, A. Z. M. , & Hashim, H. (2022). Pathways and challenges of solar thermal utilisation in the industry: ASEAN and Malaysia scenarios. Sustainable Energy Technologies and Assessments, 52, 102046.
Fuller, R. J. (2011). Solar industrial process heating in Australia–Past and current status. Renewable Energy, 36(1), 216–221.
Huang, J. , Li, R. , He, P. , & Dai, Y. (2018). Status and prospect of solar heat for industrial processes in China. Renewable and Sustainable Energy Reviews, 90, 475–489.
Farjana, S. H. , Mahmud, M. P. , & Huda, N. (2020). Solar process heat integration in lead mining process. Case Studies in Thermal Engineering, 22, 100768.
Rezæi, M. , Farzaneh-Gord, M. , Arabkoohsar, A. , & Dashtebayaz, M. D. (2011). Reducing energy consumption in natural gas pressure drop stations by employing solar heat. In: World Renewable Energy Congress-Sweden (No. 057, pp. 3797–3804). Linköping University Electronic Press.
Mostafaeipour, A. , Alvandimanesh, M. , Najafi, F. , & Issakhov, A. (2021). Identifying challenges and barriers for development of solar energy by using fuzzy best-worst method: A case study. Energy, 226, 120355.
Shojaee, S. M. N. , Moradian, M. A. , & Mashhoodi, M. (2015). Numerical investigation of wind flow around a cylindrical trough solar collector. Journal of Power and Energy Engineering, 3(01), 1–10.
Sindhu, S. P. , Nehra, V. , & Luthra, S. (2016). Recognition and prioritization of challenges in growth of solar energy using analytical hierarchy process: Indian outlook. Energy, 100, 332–348.
Sharma, A. K. , Sharma, C. , Mullick, S. C. , & Kandpal, T. C. (2017). Effect of incentives on the financial attractiveness of solar industrial process heating in India. Renewable Energy and Environmental Sustainability, 2, 33.
Bellos, E. , & Tzivanidis, C. (2018). Development of an analytical model for the daily performance of solar thermal systems with experimental validation. Sustainable Energy Technologies and Assessments, 28, 22–29.
Srivastava, S. P. , & Srivastava, S. P. (2013). Solar energy and its future role in Indian economy. International Journal of Environmental Science: Development and Monitoring, 4(3), 81–88.
Rimar, M. , Fedak, M. , Vahovsky, J. , Kulikov, A. , Oravec, P. , Kulikova, O. , Smajda, M. , & Kana, M. (2020). Performance evaluation of elimination of stagnation of solar thermal systems. Processes, 8(5), 621.
Hussain, S. , & Harrison, S. J. (2015). Experimental and numerical investigations of passive air cooling of a residential flat-plate solar collector under stagnation conditions. Solar Energy, 122, 1023–1036.
Schnitzer, H. , Christoph, B. , & Gwehenberger, G. (2007). Minimizing greenhouse gas emissions through the application of solar thermal energy in industrial processes. Approaching zero emissions. Journal of Cleaner Production, 15, 1271–1286.

Solar Thermal Energy for Industrial Process Heating Applications

Alzohairy, M. A. (2016). Therapeutics role of azadirachta indica (Neem) and their active constituents in diseases prevention and treatment. *EvidenceBased Complementary and Alternative Medicine*, *2016* . https://doi.org/10.1155/2016/7382506.
ARUN Solar Boiler, Solar Thermal Technology in the Pharmaceutical Sector. (n.d.). Retrieved April 9, 2022, from www.cliquesolar.com/PharmaceuticalSolution.aspx.
Asl Roosta, R. , Moghaddasi, R. , & Hosseini, S. S. (2017). Export target markets of medicinal and aromatic plants. Journal of Applied Research on Medicinal and Aromatic Plants, 7, 84–88. https://doi.org/10.1016/j.jarmap.2017.06.003.
Bhaskara Rao, T. S. S. , & Murugan, S. (2021). Solar drying of medicinal herbs: A review. Solar Energy, 223, 415–436. https://doi.org/10.1016/j.solener.2021.05.065

Brunner, C. (2014). Solar Heat Integration in Industrial Processes. 2. http://task49.iea-shc.org/data/sites/1/publications/IEA_SHC-Task49-Highlights- 2014.pdf.

Dry Granulation Process in Pharmaceutical Industry | Production. (n.d.).

Farnsworth, N. R. , & Soejarto, D. D. (1991). Global importance of medicinal plants. In: O. Akerele , V. Heywood , & H. Synge (eds.), Conservation of Medicinal Plants (pp. 25–51). University Press.

Guillaume, M. , Wagner, G. , Jobard, X. , Eicher, S. , & Citherlet, S. (2020). Solar thermal systems for the swiss pharmaceutical industry sector. *Proceedings of the ISES Solar World Congress 2019 and IEA SHC International Conference on Solar Heating and Cooling for Buildings and Industry 2019*, *2018* , 550–559. https://doi.org/10.18086/swc.2019.12.06.

Haagen, M. , Zahler, C. , Zimmermann, E. , & Al-Najami, M. M. R. (2015). Solar process steam for pharmaceutical industry in Jordan. *Energy Procedia* , 70, 621–625. https://doi.org/10.1016/j.egypro.2015.02.169.

Hayat, M. B. , Ali, D. , Monyake, K. C. , Alagha, L. , & Ahmed, N. (2019). Solar energy—A look into power generation, challenges, and a solar-powered future. International Journal of Energy Research, 43(3), 1049–1067. https://doi.org/10.1002/er.4252.

Identification of industrial sectors promising for commercialisation of solar Energy. (2011).

Jamshidi, N. , & Cohen, M. M. (2017). The clinical efficacy and safety of tulsi in humans: A systematic review of the literature. *EvidenceBased Complementary and Alternative Medicine*, *2017* , 1–13. https://doi.org/10.1155/2017/9217567.

Jia, T. , Huang, J. , Li, R. , He, P. , & Dai, Y. (2018). Status and prospect of solar heat for industrial processes in China. Renewable and Sustainable Energy Reviews, 90(June 2017), 475–489. https://doi.org/10.1016/j.rser.2018.03.077.

Kala, C. P. , Dhyani, P. P. , & Sajwan, B. S. (2006). Developing the medicinal plants sector in northern India: Challenges and opportunities. Journal of Ethnobiology and Ethnomedi *cine*, 2(1), 1–5. https://doi.org/10.1186/1746-4269-2-32.

Kumar, K. R. , Chaitanya, N. K. , Sendhil, K. N. (2021). Solar thermal energy technologies and its applications for process heating and power generation—A review. Journal of Cleaner Production, 282, 125296. https://doi.org/10.1016/j.scitotenv.2019.135907.

Making pharma greener with solar energy—Express Pharma. (n.d.). Retrieved May 13, 2022, from www.expresspharma.in/making-pharma-greener-with-solar-energy/.

Manchanda, H. , & Kumar, M. (2017). Performance analysis of single basin solar distillation cum drying unit with parabolic reflector. Desalination, 416(April), 1–9. https://doi.org/10.1016/j.desal.2017.04.020.

Nathan, A. J. , & Scobell, A. (2012). How China sees America. Foreign Affairs, 91(5), 1689–1699. https://doi.org/10.1017/CBO9781107415324.004.

Pingale, S. S. , Firke, N. P. , & Markandeya, A. G. (2012). Therapeutic activities of Ocimum tenuiflorum accounted in last decade: A review. Journal of Pharmacy Research, 55(44), 2215–2220.

Samant, S. S. , Dhar, U. , & Palni, L. M. S. (1998). Medicinal Plants of Indian Himalaya: Diversity Distribution Potential Value (pp. 155–158). Gyanodaya Prakashan. http://agris.fao.org/agris-search/search.do?recordID=US201300042676.

Schippmann, U. , Cunningham, A. B. , Leaman, D. J. , & Walter, S. (2005). Impact of cultivation and collection on the conservation of medicinal plants: Global trends and issues. Acta Horticulturae, 676(October), 31–44. https://doi.org/10.17660/actahortic.2005.676.3.

Sharma, A. , Chen, C. R. , & Vu Lan, N. (2009). Solar-energy drying systems: A review. Renewable and Sustainable Energy Reviews, 13(6–7), 1185–1210. https://doi.org/10.1016/j.rser.2008.08.015.

Shiva, M. P. (1998). Inventory of Forest Resources for Sustainable Management and Biodi versity Conservation: With Lists of Multipurpose Tree Species Yielding Both Timber & NonTimber Forest Products (NTFPs) and Shrub and herb Species of NTFP Importance (pp. 1–405). Indus Publishing Company.

Solar Process Heat (Pharmaceutical)—IGenSolar. (n.d.).

Tasmin, N. , Farjana, S. H. , Hossain, M. R. , Golder, S. , & Mahmud, M. A. P. (2022). Integration of solar process heat in industries: A review. Clean Technologies, 4(1), 97–131. https://doi.org/10.3390/cleantechnol4010008.

Solar Thermal Conversion Technologies for Process Heating Applications in Automobile Industries

Giampieri, A. , Ling-Chin, J. , Ma, Z. , Smallbone, A. , & Roskilly, A. P. (2020). A review of the current automotive manufacturing practice from an energy perspective. Applied Energy, 261, 114074.

Uppal, A. , & Kesari, J. P. (2015). Solar industrial process heat in Indian automobile industry. International Journal of Latest Technology in Engineering, Management & Applied Science-IJLTEMAS, 4(10), 117–123.

Automotive manufacturing solutions for paint shops, www.automotivemanufacturingsolutions.com/processmaterials/solar-process-heat-for-paintshops.

Clique solar solution for automobile, www.cliquesolar.com/AutomobileSolution.aspx

Streitberger, H. J. , & Dossel, K. F. (Eds.). (2008). Automotive paints and coatings. John Wiley & Sons.

Talbert, R. (2007). Paint technology handbook. CRC Press.

Painting makes the difference; 2012

Akafuah, N. K. , Poozesh, S. , Salaimeh, A. , Patrick, G. , Lawler, K. , & Saito, K. (2016). Evolution of the automotive body coating process—A review. Coatings, 6(2), 24.

Veera Kumar, A. , Arjunan, T. V. , Seenivasan, D. , Venkatramanan, R. , & Vijayan, S. (2021). Techno-Economic evaluation of an evacuated tube solar air collector with inserted baffles. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 235(4), 1027–1038.

Kumar, A. V. , Arjunan, T. V. , Seenivasan, D. , Venkatramanan, R. , & Vijayan, S. (2021) Thermal performance of an evacuated tube solar collector with inserted baffles for air heating applications. Solar Energy, 215, 131–143.

SW-Solar . (2020). Solar Payback. Abgerufen am August 2020 von Solar Payback: www.solarpayback.com

www.altenergy.com/Default.htm Alternate Energy Systems, Inc

https://beeindia.gov.in/sites/default/files/2Ch1.pdf Fuels and Combustion

www.thinchemie.com Dip zinc phosphating-Thin Chemie Formulations

Vijayan, S. , Arjunan, T. V. , Kumar, A. , & Matheswaran, M. M. (2020). Experimental and thermal performance investigations on sensible storage based solar air heater. Journal of Energy Storage, 31, 101620.

Matheswaran, M. M. , Arjunan, T. V. , & Somasundaram, D. (2019). Analytical investigation of exergetic performance on jet impingement solar air heater with multiple arc protrusion obstacles. Journal of Thermal Analysis and Calorimetry, 137(1), 253–266.

Kumar, A. V. , Arjunan, T. V. , Seenivasan, D. , Venkatramanan, R. , Vijayan, S. , & Matheswaran, M. M. (2021). Influence of twisted tape inserts on energy and exergy performance of an evacuated Tube-based solar air collector. Solar Energy, 225, 892–904.

Venkatramanan, R. , Arjunan, T. V. , Seenivasan, D. , & Kumar, A. V. (2022). Parametric study of evacuated tube collector solar air heater with inserted baffles on thermal network for low-temperature applications. Journal of Cleaner Production, 367, 132941.

Mayyas, A. , Qattawi, A. , Omar, M. , & Shan, D. (2012). Design for sustainability in automotive industry: A comprehensive review. Renewable and sustainable energy reviews, 16(4), 1845–1862.

Sopro India, www.soproindia.in/wheelsindia-proj01.html

http://ship-plants.info.

Pathak, A. , Deshpande, K. , & Jadkar, S. (2017). Application of Solar Thermal Energy for Medium Temperature Heating in Automobile Industry. IRA-International Journal of Technology & Engineering (ISSN 2455–4480), 7(2 (S)), 19–33.

www.estif.org/fileadmin/estif/content/policies/downloads/D23-solar-industrial-process-heat.pdf

Yuan, G. , Hong, L. , Li, X. , Xu, L. , Tang, W. , Wang, Z. (2015). Experimental investigation of a solar dryer system for drying carpet. Energy Procedia, 70, 626–633. doi:10.1016/j.egypro.2015.02.170

www.solar-process-heat.eu/

https://www.solar-process-heat.eu/fileadmin/redakteure/So-Pro/Installations/ESCAN_Fasa.pdf

https://www.solar-process-heat.eu/fileadmin/redakteure/So-Pro/Installations/Gertec_Schulte.pdf
Concentrated solar heat India, www.cshindia.in/images/pdf/M&M_1.pdf
Solar heat conference 2012, http://cms.shc2012.org/program/displayattachment/48e7fc94032?filename=26617.pdf&mode=abstract.
Concentrated solar heat India, www.cshindia.in/images/pdf/SKF.pdf
Zahler, C. , & Iglauer, O. (2012). Solar process heat for sustainable automobile manufacturing. Energy Procedia, 30, 775–782.
Kumar, K. R. , Chaitanya, N. K. , & Kumar, N. S. (2021). Solar thermal energy technologies and its applications for process heating and power generation—A review. Journal of Cleaner Production, 282, 125296.
Farjana, S. H. , Huda, N. , Mahmud, M. P. , & Saidur, R. (2018). Solar process heat in industrial systems—A global review. Renewable and Sustainable Energy Reviews, 82, 2270–2286.

Solar Energy in Food Processing Industries

Bowser, T.J. , 2019. Food processing facility design. In Handbook of Farm, Dairy and Food Machinery Engineering (pp. 623–649). Elsevier Inc. https://doi.org/10.1016/B978-0-12814803-7.00024-5.
Briceño-León, M. , Pazmiño-Quishpe, D. , Clairand, J.M. , Escrivá-Escrivá, G. , 2021. Energy efficiency measures in bakeries toward competitiveness and sustainability—case studies in Quito, Ecuador. Sustainability (Switzerland) 13. https://doi.org/10.3390/su13095209.
Cotrado, M. , Dalibard, A. , Söll, R. , Pietruschka, D. , 2014. Design, control and first monitoring data of a large scale solar plant at the meat factory Berger, Austria. Energy Procedia 48, 1144–1151. https://doi.org/10.1016/j.egypro.2014.02.129.
Dhanya, V. , Shukla, A.K. , Kumar, R. , 2020. Food processing industry in India: Challenges and potential. RBI Bulletin March 2020.
Drescher, S. , Rao, N. , Kozak, J. , Okos, M. , 1997. Review of energy use in the food industry. Proceedings ACEEE Summer Study on Energy Efficiency in Industry 29–40.
Eswara, A.R. , Ramakrishnarao, M. , 2013. Solar energy in food processing—A critical appraisal. Journal of Food Science and Technology 50, 209–227. https://doi.org/10.1007/s13197-012-0739-3.
Fathey Mohamed Atia, M. , Mostafa, M. M. , El-Nono, M.A. , Abdel-Salam, M.F. , 2011. Solar energy utilization for milk pasteurization. Misr Journal of Agricultural Engineering 28, 729–744.
Fudholi, A. , Sopian, K. , 2019. A review of solar air flat plate collector for drying application. Renewable and Sustainable Energy Reviews 102, 333–345. https://doi.org/10.1016/j.rser.2018.12.032.
Gowreesunker, B.L. , Mundie, S. , Tassou, S.A. , 2017. The impact of the UK's emissions reduction initiative on the national food industry. Energy Procedia 123, 30–35. https://doi.org/10.1016/j.egypro.2017.05.093.
Hall, G.M. , Howe, J. , 2012. Energy from waste and the food processing industry. Process Safety and Environmental Protection 90, 203–212. https://doi.org/10.1016/j.psep.2011.09.005
Herrando, M. , Simón, R. , Guedea, I. , Fueyo, N. , 2021. The challenges of solar hybrid PVT systems in the food processing industry. Applied Thermal Engineering 184. https://doi.org/10.1016/j.applthermaleng.2020.116235.
Ismail, M.I. , Yunus, N.A. , Hashim, H. , 2021. Integration of solar heating systems for low-temperature heat demand in food processing industry—A review. Renewable and Sustainable Energy Reviews 147, 1–15. https://doi.org/10.1016/j.rser.2021.111192.
Iten, M. , Fernandes, U. , Oliveira, M.C. , 2021. Framework to assess eco-efficiency improvement: Case study of a meat production industry. Energy Reports 7, 7134–7148. https://doi.org/10.1016/j.egyr.2021.09.120
Kizilkan, O. , Kabul, A. , Dincer, I. , 2016. Development and performance assessment of a parabolic trough solar collector-based integrated system for an ice-cream factory. Energy 100, 167–176. https://doi.org/10.1016/j.energy.2016.01.098
Kumar, A. , Kishore, V.V.N. , 1999. Construction and operational experience of a 6000 M2 solar pond at kutch, India. Solar Energy 65, 237–249. https://doi.org/10.1016/S0038092X(98)00134-0

Ladha-Sabur, A. , Bakalis, S. , Fryer, P.J. , Lopez-Quiroga, E. , 2019. Mapping energy consumption in food manufacturing. Trends in Food Science and Technology 86, 270–280. https://doi.org/10.1016/j.tifs.2019.02.034.

Mane, S.R. , 2013. Energy management in a dairy industry. International Journal of Mechanical and Production Engineering 1(4), 27–32.

Mekhilef, S. , Saidur, R. , Safari, A. , 2011. A review on solar energy use in industries. Renewable and Sustainable Energy Reviews 15, 1777–1790. https://doi.org/10.1016/j.rser.2010.12.018.

Regmi, A. , Gehlhar, M. , 2005. New directions in global food markets. Agricultural Information Bulletin No 794. February.

Wojdalski, J. , Grochowicz, J. , Drózdz, B. , Bartoszewska, K. , Zdanowska, P. , Kupczyk, A. , Ekielski, A. , Florczak, I. , Hasny, A. , Wójcik, G. , 2015. Energy efficiency of a confectionery plant—Case study. Journal of Food Engineering 146, 182–191. https://doi.org/10.1016/j.jfoodeng.2014.08.019

Wu, H. , Tassou, S.A. , Karayiannis, T.G. , Jouhara, H. , 2013. Analysis and simulation of continuous food frying processes. Applied Thermal Engineering 53, 332–339. https://doi.org/10.1016/j.applthermaleng.2012.04.023.

Large-Scale Solar Desalination System

Abdallahan, W. (1991). Design and performance desalination systems of solar MSF. Desalination, 82, 175–185.

Abraham, R. (2007). Experimental studies on a desalination plant using ocean temperature difference. International Journal of Nuclear Desalination, 2(4), 383–392.

Abraham, R. , & Robert Singh, T. (2006). Thermocline-driven desalination: The technology and its potential. International Journal of Nuclear Desalination, 2(2), 109–116. https://doi.org/10.1504/IJND.2006.012513.

Abutayeh, M. , Humood, M. , Alsheghri, A. A. , Al Hammadi, A. J. , & Farraj, A. R. (2013). Experimental study of a solar thermal desalination unit. ASME International Mechanical Engineering Congress and Exposition, Proceedings (IMECE), 6 B, 1–9. https://doi.org/10.1115/IMECE2013-66174.

Aguilar-Jiménez, J. A. , Velázquez, N. , López-Zavala, R. , Beltrán, R. , Hernández-Callejo, L. , González-Uribe, L. A. , & Alonso-Gómez, V. (2020). Low-temperature multiple-effect desalination/organic Rankine cycle system with a novel integration for fresh water and electrical energy production. Desalination, 477(November 2019), 114269. https://doi.org/10.1016/j.desal.2019.114269.

Almatrafi, E. , Moloney, F. , & Goswami, D. (2017). Multi effects desalination-mechanical vapor compression powered by low temperature supercritical organic rankine cycle. In *Proceedings of the ASME 2017 International Mechanical Engineering Congress and Exposition*. Volume 6: Energy, 1–9. Tampa, Florida, USA. November 3–9, 2017. V006T08A020. ASME.https://doi.org/https://doi.org/10.1115/IMECE2017-72230.

Almatrafi, E. , Moloney, F. , & Goswami, D. (2018). Performance analysis of solar thermal powered supercritical organic rankine cycle assisted low-temperature multi effect desalination coupled with mechanical vapor compression. *Proceedings of the ASME 2018 Power Conference Collocated with the ASME 2018 12th International Conference on Energy Sustainability and the ASME 2018 Nuclear Forum*. Volume 2: Heat Exchanger Technologies; Plant Performance; Thermal Hydraulics and Computational Fluid Dynamics; Water Management for Power Systems; Student Competition. Lake Buena Vista, Florida, USA. June 24–28, 2018. V002T11A002. ASME. https://doi.org/10.1115/POWER2018-7307.

Al-Othman, A. , Tawalbeh, M. , El Haj Assad, M. , Alkayyali, T. , & Eisa, A. (2018). Novel multi-stage flash (MSF) desalination plant driven by parabolic trough collectors and a solar pond: A simulation study in UAE. Desalination, 443(April), 237–244. https://doi.org/10.1016/j.desal.2018.06.005

Alsehli, M. , Choi, J. K. , & Aljuhan, M. (2017). A novel design for a solar powered multistage flash desalination. Solar Energy, 153, 348–359. https://doi.org/10.1016/j.solener.2017.05.082.

Amelinckx, A. (2016). This Farm Uses Only Sun and Seawater to Grow Food. Retrieved from https://modernfarmer.com/2016/10/sundrop-farms/.
Andrés-Mañas, J. A. , Roca, L. , Ruiz-Aguirre, A. , Acién, F. G. , Gil, J. D. , & Zaragoza, G. (2020). Application of solar energy to seawater desalination in a pilot system based on vacuum multi-effect membrane distillation. Applied Energy, 258(August 2019), 114068. https://doi.org/10.1016/j.apenergy.2019.114068.
Baig, H. , Antar, M. A. , & Zubair, S. M. (2011). Performance evaluation of a once-through multi-stage flash distillation system: Impact of brine heater fouling. Energy Conversion and Management, 52(2), 1414–1425. https://doi.org/10.1016/j.enconman.2010.10.004.
Balaji, D. (2016). Experimental study on the effect of feed water nozzles on non-equilibrium temperature difference and flash evaporation in a single-stage evaporator and an investigation of effect of process parameters on the liquid flashing in a LTTD desalination process. Desalination and Water Treatment, 3994(May), 1–17. https://doi.org/10.1080/19443994.2016.1172511.
Baniasad Askari, I. , & Ameri, M. (2021). A techno-economic review of multi effect desalination systems integrated with different solar thermal sources. Applied Thermal Engineering, 185, 116323. https://doi.org/10.1016/j.applthermaleng.2020.116323.
Bendig, M. , Maréchal, F. , & Favrat, D. (2013). Defining “waste heat” for industrial processes. Applied Thermal Engineering, 61, 134–142. https://doi.org/10.1016/j.applthermaleng.2013.03.020.
Chaibi, M. T. (2000). An overview of solar desalination for domestic and agriculture water needs in remote arid areas. Desalination, 127(2), 119–133. https://doi.org/10.1016/S0011-9164(99)00197-6.
Chandrakanth, B. , Venkatesan, G. , Prakash Kumar, L. S. S. , Jalihal, P. , & Iniyan, S. (2018). Thermal design, rating and second law analysis of shell and tube condensers based on Taguchi optimization for waste heat recovery based thermal desalination plants. Heat and Mass Transfer/Waerme- Und Stoffuebertragung, 54(9), 2885–2897. https://doi.org/10.1007/s00231-018-2326-2.
Chandrasekharam, D. , Lashin, A. , Al Arifi, N. , Al-Bassam, A. M. , & Chandrasekhar, V. (2020). Geothermal energy for sustainable water resources management. International Journal of Green Energy, 17(1), 1–12. https://doi.org/10.1080/15435075.2019.1685998.
Cherchi, C. , Badruzzaman, M. , Becker, L. , & Jacangelo, J. G. (2017). Natural gas and grid electricity for seawater desalination: An economic and environmental life-cycle comparison. Desalination, 414, 89–97. https://doi.org/10.1016/j.desal.2017.03.028.
Cherif, H. , Champenois, G. , & Belhadj, J. (2016). Environmental life cycle analysis of a water pumping and desalination process powered by intermittent renewable energy sources. Renewable and Sustainable Energy Reviews, 59, 1504–1513. https://doi.org/10.1016/j.rser.2016.01.094.
Chik, M. A. T. , Othman, N. A. , Sarip, S. , Ikegami, Y. , My, A. , Othman, N. , . . . Izzuan, H. (2015). Design optimization of power generation and desalination application in Malaysia utilizing ocean thermal energy. Jurnal Teknologi, 77(1), 177–185. https://doi.org/10.11113/jt.v77.4144.
Colagrossi, M. (2019). Solar-powered desalination plant in Kenya gives fresh water to 25,000 people a day. Retrieved from https://bigthink.com/the-present/solar-power-desalination/.
Colmenar-Santos, A. , Palomo-Torrejón, E. , Mur-Pérez, F. , & Rosales-Asensio, E. (2020). Thermal desalination potential with parabolic trough collectors and geothermal energy in the Spanish southeast. Applied Energy, 262(August 2019), 114433. https://doi.org/10.1016/j.apenergy.2019.114433.
Darwish, M. , Hassabou, A. H. , & Shomar, B. (2013). Using Seawater Reverse Osmosis (SWRO) desalting system for less environmental impacts in Qatar. Desalination, 309, 113–124. https://doi.org/10.1016/j.desal.2012.09.026.
El-Feky, A. K. (2015). A comprehensive micro-thermal analysis of thermal desalination plants for improving their efficiency. International Journal of Environmental Protection and Policy, 2, 16–25. https://doi.org/10.11648/j.ijepp.s.2014020601.13.
Eltawil, M. A. , Zhengming, Z. , & Yuan, L. (2009). A review of renewable energy technologies integrated with desalination systems. Renewable and Sustainable Energy Reviews, 13(9), 2245–2262. https://doi.org/10.1016/j.rser.2009.06.011.
Enríquez-de-Salamanca, Á. , Díaz-Sierra, R. , Martín-Aranda, R. M. , & Santos, M. J. (2017). Environmental impacts of climate change adaptation. Environmental Impact Assessment

Review, 64, 87–96. https://doi.org/10.1016/j.eiar.2017.03.005.
Ettouney, H. (2002). Performance of the once-through multistage flash desalination process. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 216, 229–240. https://doi.org/10.1243/095765002320183559.
Fath, H. , Abbas, Z. , & Khaled, A. (2011). Techno-economic assessment and environmental impacts of desalination technologies. Desalination, 266, 263–273. https://doi.org/10.1016/j.desal.2010.08.035.
Feria-Díaz, J. J. , López-Méndez, M. C. , Rodríguez-Miranda, J. P. , Sandoval-Herazo, L. C. , & Correa-Mahecha, F. (2021). Commercial thermal technologies for desalination of water from renewable energies: A state of the art review. Processes, 9(2), 1–22. https://doi.org/10.3390/pr9020262.
García-Rodríguez, L. (2003). Renewable energy applications in desalination: State of the art. Solar Energy, 75(5), 381–393. https://doi.org/10.1016/j.solener.2003.08.005.
García-Rodríguez, L. , Palmero-Marrero, A. I. , & Gómez-Camacho, C. (2002). Comparison of solar thermal technologies for applications in seawater desalination. Desalination, 142(2), 135–142. https://doi.org/10.1016/S0011-9164(01)00432-5.
Gnaneswar, V. , Nirmalakhandan, N. , & Deng, S. (2010). Renewable and sustainable approaches for desalination. Renewable and Sustainable Energy Reviews, 14(9), 2641–2654. https://doi.org/10.1016/j.rser.2010.06.008.
Guo, P. , Li, T. , Wang, Y. , & Li, J. (2021). Energy and exergy analysis of a spray-evaporation multi-effect distillation desalination system. Desalination, 500, 114890. https://doi.org/10.1016/j.desal.2020.114890.
Hoepner, T. , & Lattemann, S. (2003). Chemical impacts from seawater desalination plants— A case study of the northern Red Sea. Desalination, 152(1–3), 133–140. https://doi.org/10.1016/S0011-9164(02)01056-1.
Hou, J. , Cheng, H. , Wang, D. , Gao, X. , & Gao, C. (2010). Experimental investigation of low temperature distillation coupled with spray evaporation. Desalination, 258(1–3), 5–11. https://doi.org/10.1016/j.desal.2010.03.030.
Hou, S. , Zhang, Z. , Huang, Z. , & Xie, A. (2008). Performance optimization of solar multi-stage flash desalination process using Pinch technology. Desalination, 220, 524–530. https://doi.org/10.1016/j.desal.2007.01.052.
Ibrahim, A. G. M. , Rashad, A. M. , & Dincer, I. (2017). Exergoeconomic analysis for cost optimization of a solar distillation system. Solar Energy, 151, 22–32. https://doi.org/10.1016/j.solener.2017.05.020.
Jin, Z. , & Wang, H. (2015). Modelling and experiments on ocean thermal energy for desalination. International Journal of Sustainable Energy, 34(2), 103–112. https://doi.org/10.1080/14786451.2013.820187.
Kalogirou, S. A. (2005). Seawater desalination using renewable energy sources. Progress in Energy and Combustion Science, 31(3), 242–281. https://doi.org/10.1016/j.pecs.2005.03.001.
Kucera, J. (2014). Introduction to desalination. In Desalination: Water from Water. Hoboken, NJ: John Wiley & Sons, Ltd., 1–37. https://doi.org/10.1002/9781118904855.ch1.
Latteman, S. (2010). *Development of an Environmental Impact Assessment and Decision Support System for Seawater Desalination Plants*. 1st Edition. London: CRC Press. https://doi.org/10.1201/b10829.
Lior, N. (2017). Sustainability as the quantitative norm for water desalination impacts. Desalination, 401, 99–111. https://doi.org/10.1016/j.desal.2016.08.008
Low, S. C. (1991). Vacuum desalination using waste heat from a steam turbine. Desalination, 81, 321–331.
Luo, T. , Young, R. , & Reig., P. (2015). Aqueduct Projected Water Stress Country Rankings. Technical Note. Washington, D.C.: World Resources Institute. (August), 1–16.
Luqman, M. , Ghiat, I. , Maroof, M. , Lahlou, F. Z. , Bicer, Y. , & Al-Ansari, T. (2020). Application of the concept of a renewable energy based-polygeneration system for sustainable thermal desalination process—A thermodynamics' perspective. International Journal of Energy Research, 44(15), 12344–12362. https://doi.org/10.1002/er.5161.
Manjarrez, R. , & Galván, M. (1979). Solar multistage flash evaporation (SMSF) as a solar energy application on desalination processes. Description of one demonstration project. Desalination, 31(1–3), 545–554. https://doi.org/10.1016/S0011-9164(00)88557-4.

Manju, S. , & Sagar, N. (2017a). Progressing towards the development of sustainable energy: A critical review on the current status, applications, developmental barriers and prospects of solar photovoltaic systems in India. Renewable and Sustainable Energy Reviews, 70(May 2016), 298–313. https://doi.org/10.1016/j.rser.2016.11.226.

Manju, S. , & Sagar, N. (2017b). Renewable energy integrated desalination: A sustainable solution to overcome future fresh-water scarcity in India. *Renewable and Sustainable Energy Reviews*, 73(January), 594–609. https://doi.org/10.1016/j.rser.2017.01.164

Moustafa, S. M. A. , & Jarrar, D. I. (1985). Performance of a self—regulating solar multistage flash desalination system. Solar Energy, 35(4), 333–340.

Mutair, S. , & Ikegami, Y. (2014). Design optimization of shore-based low temperature thermal desalination system utilizing the ocean thermal energy. *Journal of Solar Energy Engineering, Transactions of the ASME*, 136(4), 1–8. https://doi.org/10.1115/1.4027575

Muthunayagam, A. E. , Ramamurthi, K. , & Paden, J. R. (2005). Low temperature flash vaporization for desalination. Desalination, 180, 25–32. https://doi.org/10.1016/j.desal.2004.12.028

Natarajan, S. K. , Suraparaju, S. K. , Elavarasan, R. M. , Pugazhendhi, R. , & Hossain, E. (2022). An experimental study on eco-friendly and cost-effective natural materials for productivity enhancement of single slope solar still. *Environmental Science and Pollution Research*, 29(2), 1917–1936. https://doi.org/10.1007/s11356-021-15764-8.

Ng, K. C. , & Shahzad, M. W. (2018). Sustainable desalination using ocean thermocline energy. Renewable and Sustainable Energy Reviews, 82(June 2017), 240–246. https://doi.org/10.1016/j.rser.2017.08.087.

Qi, C. , Lv, H. , Feng, H. , Lv, Q. , & Xing, Y. (2017). Performance and economic analysis of the distilled seawater desalination process using low-temperature waste hot water. Applied Thermal Engineering, 122, 712–722. https://doi.org/10.1016/j.applthermaleng.2017.05.064

Rabiee, H. , Khalilpour, K. R. , Betts, J. M. , & Tapper, N. (2018). Energy-water nexus: Renewable-integrated hybridized desalination systems. In *Polygeneration with Polystorage: For Chemical and Energy Hubs*. Cambridge, MA: Academic Press, 409–458. https://doi.org/10.1016/B978-0-12-813306-4.00013-6.

Raj, M. M. A. , Murugavel, K. K. , Rajaseenivasan, T. , & Srithar, K. (2015). A review on flash evaporation desalination. Desalination and Water Treatment, 57, 1–10. https://doi.org/10.1080/19443994.2015.1070283.

Saari, R. (1978). Desalination by very low-temperature nuclear heat. Nuclear Technology, 38(2), 209–214. https://doi.org/10.13182/NT78-A32014.

Safi, M. J. (1998). Performance of a flash desalination unit intended to be coupled to a solar pond. Renewable Energy, 14(1–4), 339–343. https://doi.org/10.1016/S09601481(98)00087-1.

Sahu, S. K. , Arjun Singh, K. , & Natarajan, S. K. (2020). Design and development of a low-cost solar parabolic dish concentrator system with manual dual-axis tracking. International Journal of Energy Research, 45(October), 1–11. https://doi.org/10.1002/er.6164.

Sahu, S. K. , Arjun Singh, K. , & Natarajan, S. K. (2021). Impact of double trumpet-shaped secondary reflector on flat receiver of a solar parabolic dish collector system. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 41, 1–19. https://doi.org/10.1080/15567036.2021.1918803.

Saidur, R. , Elcevvadi, E. T. , Mekhilef, S. , Safari, A. , & Mohammed, H. A. (2011). An overview of different distillation methods for small scale applications. *Renewable and Sustainable Energy Reviews*, 15(9), 4756–4764. https://doi.org/10.1016/j.rser.2011.07.077.

Sampathkumar, A. , & Natarajan, S. K. (2021a). Experimental investigation of single slope solar still with Eucheuma (agar-agar) fiber for augmentation of freshwater yield: Thermo-economic analysis. Environmental Progress and Sustainable Energy, 41(August), 2–9. https://doi.org/10.1002/ep.13750.

Sampathkumar, A. , & Natarajan, S. K. (2021b). Experimental investigation on productivity enhancement in single slope solar still using Borassus Flabellifer micro-sized particles. Materials Letters, 299, 130097. https://doi.org/10.1016/j.matlet.2021.130097

Sampathkumar, K. , Arjunan, T. V. , Pitchandi, P. , & Senthilkumar, P. (2010). Active solar distillation-A detailed review. Renewable and Sustainable Energy Reviews, 14(6), 1503–1526. https://doi.org/10.1016/j.rser.2010.01.023.

Senthil Kumar, R. , Mani, A. , & Kumaraswamy, S. (2007). Experimental studies on desalination system for ocean thermal energy utilisation. Desalination, 207(1–3), 1–8. https://doi.org/10.1016/j.desal.2006.08.001.

Shahabi, M. P. , McHugh, A. , Anda, M. , & Ho, G. (2015). Comparative economic and environmental assessments of centralised and decentralised seawater desalination options. Desalination, 376, 25–34. https://doi.org/10.1016/j.desal.2015.08.012

Shahzad, M. W. , Burhan, M. , Ghaffour, N. , & Ng, K. C. (2018). A multi evaporator desalination system operated with thermocline energy for future sustainability. Desalination, 435(January 2017), 268–277. https://doi.org/10.1016/j.desal.2017.04.013.

Sharon, H. , & Reddy, K. S. (2015). A review of solar energy driven desalination technologies. Renewable and Sustainable Energy Reviews, 41, 1080–1118. https://doi.org/10.1016/j.rser.2014.09.002.

Shatat, M. , & Riffat, S. B. (2014). Water desalination technologies utilizing conventional and renewable energy sources. International Journal of LowCarbon Technologies, 9(1), 1–19. https://doi.org/10.1093/ijlct/cts025.

Signh, D. , & Sharma, S. K. (1989). Performance ratio, area economy and economic return for an integrated solar energy/multi-stage flash desalination plant. Desalination, 73(C), 191–195. https://doi.org/10.1016/0011-9164(89)87013-4.

Sistla, P. V. S. , Venkatesan, G. , Jalihal, P. , & Kathiroli, S. (2009). Low temperature thermal desalination plants. In Proceedings of the ISOPE Ocean Mining Symposium. Chennai, India, CA: International Society of Offshore and Polar Engineers (ISOPE), 59–63.

Subramani, A. , Badruzzaman, M. , Oppenheimer, J. , & Jacangelo, J. G. (2011). Energy minimization strategies and renewable energy utilization for desalination: A review. Water Research, 45(5), 1907–1920. https://doi.org/10.1016/j.watres.2010.12.032.

Suraparaju, S. K. , Dhanusuraman, R. , & Natarajan, S. K. (2021). Performance evaluation of single slope solar still with novel pond fibres. Process Safety and Environmental Protec tion, 154, 142–154. https://doi.org/10.1016/j.psep.2021.08.011.

Suraparaju, S. K. , & Natarajan, S. K. (2020). Performance analysis of single slope solar desalination setup with natural fiber. Desalination and Water Treatment, 193(February), 64–71. https://doi.org/10.5004/dwt.2020.25679.

Suraparaju, S. K. , & Natarajan, S. K. (2021a). Augmentation of freshwater productivity in single slope solar still using Luffa acutangula fibres. Water Science and Technology, 84(10–11), 2943–2957. https://doi.org/10.2166/wst.2021.298.

Suraparaju, S. K. , & Natarajan, S. K. (2021b). Augmentation of freshwater productivity in single slope solar still using Luffa acutangula fibres. Water Science and Technology, 84(10–11), 2943–2957. https://doi.org/10.2166/wst.2021.298.

Suraparaju, S. K. , & Natarajan, S. K. (2021c). Experimental investigation of single-basin solar still using solid staggered fins inserted in paraffin wax PCM bed for enhancing productivity. Environmental Science and Pollution Research, 28, 20330–20343. https://doi.org/10.1007/s11356-020-11980-w.

Suraparaju, S. K. , & Natarajan, S. K. (2021d). Productivity enhancement of single-slope solar still with novel bottom finned absorber basin inserted in phase change material (PCM): Techno-economic and enviro-economic analysis. Environmental Science and Pollution Research, 28, 45985–46006. https://doi.org/10.1007/s11356-021-13495-4

Suri, R. K. , Al-Marafie, A. M. R. , Al-Homoud, A. A. , & Maheshwari, G. P. (1989). Cost-effectiveness of solar water production. Desalination, 71(2), 165–175. https://doi.org/10.1016/0011-9164(89)80007-4.

Swaminathan, J. , Nayar, K. G. , & Lienhard v, J. H. (2016). Mechanical vapor compression—Membrane distillation hybrids for reduced specific energy consumption. Desalination and Water Treatment, 57(55), 26507–26517. https://doi.org/10.1080/19443994.2016.1168579.

Szacsvay, T. , Hofer-Noser, P. , & Posnansky, M. (1999). Technical and economic aspects of small-scale solar-pond- powered seawater desalination systems. Desalination, 122, 185–193.

Tay, J. H. , Low, S. C. , & Jeyaseelan, S. (1996). Vacuum desalination for water purification using waste heat. Desalination, 106(1–3), 131–135. https://doi.org/10.1016/S0011-9164(96)00104-X.

Thimmaraju, M. , Sreepada, D. , Babu, G. S. , Dasari, B. K. , Velpula, S. K. , & Vallepu, N. (2018). Desalination of water. In Desalination and Water Treatment. London, UK: IntechOpen. https://doi.org/10.5772/intechopen.78659.

Tiwari, G. N. , Singh, H. N. , & Tripathi, R. (2003). Present status of solar distillation. Solar Energy, 75, 367–373. https://doi.org/10.1016/j.solener.2003.07.005.

Tong, T. , & Elimelech, M. (2016). The global rise of zero liquid discharge for wastewater management: Drivers, technologies, and future directions. Environmental Science and

Technology, 50(13), 6846–6855. https://doi.org/10.1021/acs.est.6b01000.
Toth, A. J. (2020). Modelling and optimisation of multi-stage flash distillation and reverse osmosis for desalination of saline process wastewater sources. Membranes, 10(10), 1–18. https://doi.org/10.3390/membranes10100265.
Tsilingiris, P. T. (1995). The analysis and performance of large-scale stand-alone solar desalination plants. Desalination, 103, 249–255.
Ullah, I. , & Rasul, M. G. (2019). Recent developments in solar thermal desalination technologies: A review. Energies, 12(1). https://doi.org/10.3390/en12010119
Vassilis, B. , Soteris, K. , & Emmy, D. (2016). Thermal Solar Desalination Methods and Systems. London, UK: Academic Press, 1–19. https://doi.org/10.1016/c2015-0-05735-5.
Venkatesan, G. , Iniyan, S. , & Jalihal, P. (2014). A theoretical and experimental study of a small-scale barometric sealed flash evaporative desalination system using low grade thermal energy. Applied Thermal Engineering, 73(1), 629–640. https://doi.org/10.1016/j.applthermaleng.2014.07.059.
Venkatesan, G. , Iniyan, S. , & Jalihal, P. (2015). A desalination method utilising low-grade waste heat energy. Desalination and Water Treatment, 3994(September). https://doi.org/10.1080/19443994.2014.960459.
Vorrath, S. (2016). World-first solar tower powered tomato farm opens in Port Augusta. Retrieved from https://reneweconomy.com.au/world-first-solar-tower-powered-tomato-farm-opens-port-augusta-41643/.
Wakil, M. , Choon, K. , Thu, K. , & Baran, B. (2014). Multi effect desalination and adsorption desalination (MEDAD): A hybrid desalination method. *Applied Thermal Engineering*, 72, 289–297. https://doi.org/10.1016/j.applthermaleng.2014.03.064.
Wang, X. , Christ, A. , Regenauer-Lieb, K. , Hooman, K. , & Chua, H. T. (2011). Low grade heat driven multi-effect distillation technology. International Journal of Heat and Mass Transfer, 54(25–26), 5497–5503. https://doi.org/10.1016/j.ijheatmasstransfer.2011.07.041.
Zheng, H. (2017). Solar desalination system combined with conventional technologies. In Solar Energy Desalination Technology. Beijing, China: Elsevier, 537–622. https://doi.org/10.1016/b978-0-12-805411-6.00007-5.

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“Annual Energy Outlook 2021.” www.eia.gov/outlooks/aeo/ (accessed Feb. 08, 2022).
M. Absi Halabi , A. Al-Qattan , and A. Al-Otaibi , “Application of solar energy in the oil industry—Current status and future prospects,” *Renew. Sustain. Energy Rev.*, vol. 43, pp. 296–314, 2015, doi: 10.1016/j.rser.2014.11.030.
“ MNRE || Physical Progress ,” “Physical progress,” Ministry of New and Renewable Energy, 2021.
S. Ericson , J. Engel Cox , and D. Arent , “Approaches for Integrating Renewable Energy Technologies in Oil and Gas Operations,” Technical Report (NREL/TP-6A50-72842), United States, pp. 1–26, 2019, doi: 10.2172/1491378, 2019.
“ Concentrated Solar Power (CSP)—Analysis ,” IEA. www.iea.org/reports/concentratedsolar-power-csp (accessed Dec. 26, 2021).
H. Sahebi , S. Nickel , and J. Ashayeri , “Strategic and tactical mathematical programming models within the crude oil supply chain context-A review,” *Comput. Chem. Eng.*, vol. 68, pp. 56–77, 2014, doi: 10.1016/j.compchemeng.2014.05.008.
“ What is the Kyoto Protocol? ” UNFCCC. https://unfccc.int/kyoto_protocol (accessed Feb. 09, 2022).
C. Temizel *et al.*, “Technical and economical aspects of use of solar energy in oil & gas industry in the Middle East,” Soc. Pet. Eng.—SPE Int. Heavy Oil Conf. Exhib. 2018 HOCE 2018, 2018, doi: 10.2118/193768-MS.
B. Bierman *et al.*, “Performance of an enclosed trough EOR system in South Oman,” Energy Procedia, vol. 49, pp. 1269–1278, 2014, doi: 10.1016/j.egypro.2014.03.136.
B. Bierman , J. O'Donnell , R. Burke , M. McCormick , and W. Lindsay , “Construction of an Enclosed Trough EOR System in South Oman,” Energy Procedia, vol. 49, pp. 1756– 1765, Jan.

2014, doi: 10.1016/j.egypro.2014.03.186.
A. Askarova *et al.*, “Thermal enhanced oil recovery in deep heavy oil carbonates: Experimental and numerical study on a hot water injection performance,” *J. Pet. Sci. Eng.*, vol. 194, p. 107456, Nov. 2020, doi: 10.1016/j.petrol.2020.107456.
S. Gupta , R. Guédez , and B. Laumert , “Market potential of solar thermal enhanced oil recovery-a techno-economic model for Issaran oil field in Egypt,” *AIP Conf. Proc.*, vol. 1850, 2017, doi: 10.1063/1.4984573.
C. Likkasit , A. Maroufmashat , A. Elkamel , and H. Ku , “Integration of renewable energy into oil & gas industries: Solar-aided hydrogen production,” Proc. 2016 Int. Conf. Ind. Eng. Oper. Manage., Detroit, Michigan, USA, pp. 897–904, 2016.
Z. He , “Application of solar heating system for raw petroleum during its piping transport,” Energy Procedia, vol. 48, pp. 1173–1180, 2014, doi: 10.1016/j.egypro.2014.02.132.
“ Solar-heating system studied for heavy-oil pipelines ,” Oil & Gas Journal, Mar. 29, 1999. www.ogj.com/home/article/17230768/solarheating-system-studied-for-heavyoil-pipelines (accessed Feb. 08, 2022).
A. Sharma , “A comprehensive study of solar power in India and World,” *Renew. Sustain. Energy Rev.*, vol. 15, no. 4, pp. 1767–1776, May 2011, doi: 10.1016/j.rser.2010.12.017.
M. Abdibattayeva , K. Bissenov , G. Askarova , N. Togyzbayeva , and G. Assanova , “Transport of heavy oil by applying of solar energy,” *Environ. Clim. Technol.*, vol. 25, no. 1, pp. 879–893, Jan. 2021, doi: 10.2478/rtuect-2021-0066.
A. E. Rahman , N. As , and H. Mhm , “Application of solar energy heating system in some oil industry units and its economy,” *J. Fundam. Renew. Energy Appl.*, vol. 07, no. 04, 2017, doi: 10.4172/2090-4541.1000233.
R. K. Pal , and K. R. Kumar , “Two-fluid modeling of direct steam generation in the receiver of parabolic trough solar collector with non-uniform heat flux,” Energy, vol. 226, p. 120308, 2021, doi: https://doi.org/10.1016/j.energy.2021.120308.
A. K. Sharma , C. Sharma , S. C. Mullick , and T. C. Kandpal , “Solar industrial process heating: A review,” *Renew. Sustain. Energy Rev.*, vol. 78, no. May, pp. 124–137, 2017, doi: 10.1016/j.rser.2017.04.079.
R. K. Pal , and K. R. Kumar , “Thermo-hydrodynamic modeling of flow boiling through the horizontal tube using Eulerian two-fluid modeling approach,” *Int. J. Heat Mass Transf.*, vol. 168, p. 120794, 2021, doi: 10.1016/j.ijheatmasstransfer.2020.120794.
P. D. Tagle-Salazar , K. D. P. Nigam , and C. I. Rivera-Solorio , “Parabolic trough solar collectors: A general overview of technology, industrial applications, energy market, modeling, and standards,” *Green Process. Synth.*, vol. 9, no. 1, pp. 595–649, 2020, doi: 10.1515/gps-2020-0059.
S. J. W. Klein , and E. S. Rubin , “Life cycle assessment of greenhouse gas emissions, water and land use for concentrated solar power plants with different energy backup systems,” Energy Policy, vol. 63, pp. 935–950, 2013, doi: 10.1016/j.enpol.2013.08.057.
K. Ravi Kumar , N. V. V. K. Chaitanya , and N. Sendhil Kumar , “Solar thermal energy technologies and its applications for process heating and power generation—A review,” *J. Clean. Prod.*, vol. 282, p. 125296, Dec. 2020, doi: 10.1016/j.jclepro.2020.125296.
R. K. Pal , and K. R. Kumar , “Effect of transient concentrated solar flux profile on the absorber surface for Direct Steam Generation in the parabolic trough solar collector,” Renew. Energy, vol. 186, pp. 226–249, 2021, doi: 10.1016/j.renene.2021.12.105.
K. S. Reddy , and K. R. Kumar , “Solar collector field design and viability analysis of stand-alone parabolic trough power plants for Indian conditions,” *Energy Sustain. Dev.*, vol. 16, no. 4, pp. 456–470, 2012, doi: 10.1016/j.esd.2012.09.003.
D. A. Baharoon , H. A. Rahman , W. Z. W. Omar , and S. O. Fadhl , “Historical development of concentrating solar power technologies to generate clean electricity efficiently—A review,” *Renew. Sustain. Energy Rev.*, vol. 41, pp. 996–1027, 2015, doi: 10.1016/j.rser.2014.09.008.
G. Mokhtar , B. Boussad , and S. Noureddine , “A linear Fresnel reflector as a solar system for heating water: Theoretical and experimental study,” *Case Stud. Therm. Eng.*, vol. 8, no. August 2010, pp. 176–186, 2016, doi: 10.1016/j.csite.2016.06.006.
S. M. Besarati and D. Yogi Goswami , “A computationally efficient method for the design of the heliostat field for solar power tower plant,” Renew. Energy, vol. 69, pp. 226–232, 2014, doi: 10.1016/j.renene.2014.03.043.

V. P. Stefanovic , S. R. Pavlovic , E. Bellos , and C. Tzivanidis , “A detailed parametric analysis of a solar dish collector,” *Sustain. Energy Technol. Assess.*, vol. 25, no. December 2017, pp. 99–110, 2018, doi: 10.1016/j.seta.2017.12.005.

R. K. Pal , and K. R. Kumar , “Investigations of Thermo-Hydrodynamics, Structural Stability, and Thermal Energy Storage for Direct Steam Generation in Parabolic Trough Solar Collector: A Comprehensive Review,” *J. Clean. Prod.*, vol. 311, no. March, p. 127550, 2021, doi: 10.1016/j.jclepro.2021.127550.

A. V. Abramova , V. O. Abramov , S. P. Kuleshov , and E. O. Timashev , “Analysis of the modern methods for enhanced oil recovery,” *Energy Sci. Technol.*, vol. 3, no. January, pp. 118–148, 2015, doi: 10.13140/2.1.2709.4726.

S. S. Mardhika , “Determine environment impacts in upstream processes of oil and gas industries,” *E3S Web Conf.*, vol. 73, pp. 8–11, 2018, doi: 10.1051/e3sconf/20187305008.

“ Enhanced oil recovery ,” Fossil Energy and Carbon Management, 2021. https://www.energy.gov/fecm/science-innovation/oil-gas-research/enhanced-oil-recovery (accessed Feb. 09, 2022).

W. C. Lyons , “Mechanisms & recovery of hydrocarbons by natural means (Chapter 3),” Working Guide to Reservoir Engineering, Gulf Professional Publishing, pp. 233–239, 2010, doi: 10.1016/b978-1-85617-824-2.00003-4, ISBN: 978-1-85617-824-2.

K. A. Lawal , and O. Olamigoke , “On the optimum operating temperature for steam floods,” *SN Appl. Sci.*, vol. 3, no. 1, p. 9, 2021, doi: 10.1007/s42452-020-04082-2.

S. Kokal , and A. Al-Kaabi , “Enhanced Oil Recovery: Challenges and Opportunities,” World Petroleum Council, pp. 64–69, 2010. http://www.world-petroleum.org/docs/docs/publications/2010yearbook/P64-69_Kokal-Al_Kaabi.pdf.

E. M. A. Mokheimer , M. Hamdy , Z. Abubakar , M. R. Shakeel , M. A. Habib , and M. Mahmoud , “A comprehensive review of thermal enhanced oil recovery: Techniques evaluation,” J. Energy Resour. Technol. Trans. ASME, vol. 141, no. 3, 2019, doi: 10.1115/1.4041096.

D. A. Z. Wever , F. Picchioni , and A. A. Broekhuis , “Polymers for enhanced oil recovery: A paradigm for structure-property relationship in aqueous solution,” *Prog. Polym. Sci. Oxf.*, vol. 36, no. 11, pp. 1558–1628, 2011, doi: 10.1016/j.progpolymsci.2011.05.006.

A. Al Adasani and B. Bai , “Analysis of EOR projects and updated screening criteria,” *J. Pet. Sci. Eng.*, vol. 79, no. 1–2, pp. 10–24, 2011, doi: 10.1016/j.petrol.2011.07.005.

M. Baviere , Basic Concepts in Enhanced Oil Recovery Processes. United Kingdom, 1991.

J. D. Shosa , and L. L. Schramm , “Surfactants: Fundamentals and applications in the petroleum industry,” Palaios, vol. 16, no. 6, p. 614, 2001, doi: 10.2307/3515635.

D. Kraemer , A. Bajpayee , A. Muto , V. Berube , and M. Chiesa , “Solar assisted method for recovery of bitumen from oil sand,” Appl. Energy, vol. 86, no. 9, pp. 1437–1441, 2009, doi: 10.1016/j.apenergy.2008.12.003.

J. Sandler , G. Fowler , K. Cheng , and A. R. Kovscek , “Solar-generated steam for oil recovery: Reservoir simulation, economic analysis, and life cycle assessment,” Energy Convers. Manag., vol. 77, pp. 721–732, 2014, doi: 10.1016/j.enconman.2013.10.026.

A. Amarnath , “Enhanced Oil Recovery Scoping Study,” An Electric Power Research Institute (EPRI) Report, 1999. https://www.adv-res.com/pdf/electrotech_opps_tr113836.pdf (accessed Apr. 10, 2022).

M. M. Yegane , F. Bashtani , A. Tahmasebi , S. Ayatollahi , and Y. M. Al-Wahaibi , “Comparing different scenarios for thermal enhanced oil recovery in fractured reservoirs using hybrid (solar-gas) steam generators, a simulation study,” All Days, Vienna, Austria, May 2016, p. SPE-180101-MS, doi: 10.2118/180101-MS.

A. P. G. Van Heel , J. N. M. Van Wunnik , S. Bentouati , and R. Terres , “The impact of daily and seasonal cycles in solar-generated steam on oil recovery,” SPE EOR Conf. Oil Gas West Asia, Muscat, Oman, April 11–13, 2010, pp. 347–360, 2010, doi: 10.2118/129225ms, ISBN: 978-1-55563-285-4.

E. M. A. Mokheimer and M. A.-A. M. Habib , “Hybrid solar thermal enhanced oil recovery system with oxy-fuel combustor,” US9845667B2, Dec. 19, 2017 [Online]. Available: https://patents.google.com/patent/US9845667B2/en?oq=US9845667B2. (accessed Mar. 18, 2022).

“ U.S. Manufacturing Energy Use and Greenhouse Gas Emissions Analysis ,” Energy Efficiency & Renewable Energy, 2012. https://www.energy.gov/eere/amo/downloads/us-manufacturingenergy-use-and-greenhouse-gas-emissions-analysis (accessed Feb. 10, 2022).

“ Steam System Opportunity Assessment for the Pulp and Paper, Chemical Manufacturing, and Petroleum Refining Industries ,” Technical Report, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, 2002. https://www.nrel.gov/docs/fy03osti/32806.pdf (accessed Mar. 15, 2022).

“ Energy Efficiency Improvement and Cost Saving Opportunities for Petroleum Refineries ,” Technical Report (Document Number: 430-R-15-002), Energy Star, 2016.

“ Inventory of U.S. Greenhouse Gas Emissions and Sinks ,” Technical Report (Document Number: 430-R-22-003), U.S. Environmental Protection Agency, 2015.

C. Likkasit , A. Maroufmashat , A. Elkamel , H. M. Ku , and M. Fowler , “Solar-aided hydrogen production methods for the integration of renewable energies into oil and gas industries,” Energy Convers. Manag., vol. 168, no. January, pp. 395–406, 2018, doi: 10.1016/j.enconman.2018.04.057.

“ GlassPoint Unveils First Commercial Solar Enhanced Oil Recovery Project ,” 2011. https://www.businesswire.com/news/home/20110224006666/en/GlassPoint-Unveils-First-Commercial-Solar-Enhanced-Oil-Recovery-Project (accessed Apr. 10, 2022).

“ Brightsource Energy Delivers World's Largest Solar-to-Steam Facility for Enhanced Oil Recovery to Chevron ,” 2011. http://www.brightsourceenergy.com/brightsourceenergydelivers-worlds-largest-solar-to-steam-facility-for-enhanced-oil-recovery-tochevron#.YcS6mmhByUk (accessed Jan. 15, 2022).

“ Miraah Solar Thermal Project ,” 2021. https://www.power-technology.com/projects/miraah-solar-thermal-project/ (accessed Apr. 15, 2022).

“ Belridge Solar Thermal Power Plant, California ,” 2018. https://www.power-technology.com/projects/belridge-solar-thermal-power-plant-california/ (accessed Apr. 18, 2022).

“ GlassPoint and Occidental of Oman Sign Agreement to Cooperate on Project to Facilitate Oil Production in Oman ,” 2018. https://www.businesswire.com/news/home/20181113005392/en/GlassPoint-and-Occidental-of-Oman-Sign-Agreement-to-Cooperate-on-Project-to-Facilitate-Oil-Production-in-Oman (accessed Apr. 10, 2022).

“ Shell Considering Solar Power to Run Its Largest Oil Refinery ,” 2019. http://ieefa.org/shell-considering-solar-power-to-run-its-largest-oil-refinery/ (accessed Feb. 10, 2022).

D. Llamas , “GlassPoint Solar unveiled the world's first commercial solar enhanced oil recovery,” HELIOSCSP. https://helioscsp.com/glasspoint-solar-unveiled-the-worlds-first-commercial-solar-enhanced-oil-recovery/ (accessed Apr. 10, 2022).

“ Solar Thermal Enhanced Oil Recovery ,” Mar. 14, 2022. https://en.wikipedia.org/w/index.php?title=Solar_thermal_enhanced_oil_recovery&oldid=1077048062 (accessed May 10, 2022).

“ McKittrick ,” GlassPoint. www.glasspoint.com/projects/mckittrick (accessed Apr. 10, 2022).

“ Miraah Solar Project ,” Petroleum Development Oman. www.pdo.co.om/en/technicalexpertise/solar-project-miraah/Pages/default.aspx (accessed May 10, 2022).

M. Demirtas , M. Yesilbudak , S. Sagiroglu , and I. Colak , “Prediction of solar radiation using meteorological data,” 2012 Int. Conf. Renew. Energy Res. Appl. (ICRERA 2012), Nagasaki, Japan, Nov. 11–14, 2012, pp. 2–5, 2012, doi: 10.1109/ICRERA.2012.6477329.

Y. Dong , and H. Jiang , “Global Solar Radiation Forecasting Using Square Root Regularization-Based Ensemble,” *Math. Probl. Eng.*, vol. 2019, 2019, doi: 10.1155/2019/9620945.

S. P. Srivastava , and S. P. Srivastava , “Solar energy and its future role in Indian economy,” Int. J. Environ. Sci. Dev. Monit, vol. 4, pp. 81–88, 2013.

Effective Integration and Technical Feasibility Analysis of Solar Thermal Networks for Industrial Process Heating Applications

Nemet, A. , Kravanja, Z. , & Klemeš, J. J. (2012). Integration of solar thermal energy into processes with heat demand. Clean Technologies and Environmental Policy, 14(3), 453–463.

Fuentes-Silva, A. L. , Lizárraga-Morazán, J. R. , Picón-Núñez, M. , & Martínez-Rodríguez, G. (2019). Incorporating the concept of flexible operation in the design of solar collector fields for

industrial applications. Energies, 12(570), 1–20.
Eiholzer, T. , Olsen, D. , Hoffmann, S. , Sturm, B. , & Wellig, B. (2017). Integration of a solar thermal system in a medium-sized brewery using pinch analysis: methodology and case study. Applied Thermal Engineering, 113, 1558–1568.
Allouhi, A. , Agrouaz, Y. , Amine, M. B. , Rehman, S. , Buker, M. S. , Kousksou, T. , . . . & Benbassou, A. (2017). Design optimization of a multi-temperature solar thermal heating system for an industrial process. Applied Energy, 206, 382–392.
Abdelhady, F. , Bamufleh, H. , El-Halwagi, M. M. , & Ponce-Ortega, J. M. (2015). Optimal design and integration of solar thermal collection, storage, and dispatch with process cogeneration systems. Chemical Engineering Science, 136, 158–167.
Baniassadi, A. , Momen, M. , & Amidpour, M. (2015). A new method for optimization of Solar Heat Integration and solar fraction targeting in low temperature process industries. Energy, 90, 1674–1681.
Martínez-Rodríguez, G. , Baltazar, J. C. , Fuentes-Silva, A. L. , & García-Gutiérrez, R. (2022). Economic and environmental assessment using two renewable sources of energy to produce heat and power for industrial applications. Energies, 15(7), 2338.
Walmsley, T. G. , Walmsley, M. R. , Tarighaleslami, A. H. , Atkins, M. J. , & Neale, J. R. (2015). Integration options for solar thermal with low temperature industrial heat recovery loops. Energy, 90, 113–121.
Martínez-Rodríguez, G. , Fuentes-Silva, A. L. , Velázquez-Torres, D. , & Picón-Núñez, M. (2022). Comprehensive solar thermal integration for industrial processes. Energy, 239, 122332.
Muster, B. , Hassine, I. B. , Helmke, A. , Heß, S. , Krummenacher, P. , Schmitt, B. , & Schnitzer, H. (2015). Solar Process heat for Production and Advanced Applications. Integration Guideline; IEA SHC Task, 49.
de Santos López, G. (2021). Techno-economic analysis and market potential study of solar heat in industrial processes: A Fresnel direct steam generation case study [Internet] [Dissertation] (TRITA-ITM-EX). Available from: http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-293918
Brunner, C. , Muster-Slawitsch, B. , Meitz, S. , & Frank, E. (2020). Solar heat integrations in industrial processes. IEA Solar Heating and Cooling Technology Collaboration Programme.
Atkins, M. J. , Walmsley, M. R. , & Morrison, A. S. (2010). Integration of solar thermal for improved energy efficiency in low-temperature-pinch industrial processes. Energy, 35(5), 1867–1873.
Ali, E. N. , Liaquat, R. , Ali, M. , Waqas, A. , & Shahzad, N. (2022). Techno-economic and GHG mitigation analyses based on regional and seasonal variations of non-concentrating solar thermal collectors in textile sector of Pakistan. Renewable Energy Focus, 42, 165–177.
Kumar, P. , Sinha, K. K. , Đurin, B. , Gupta, M. K. , Saxena, N. , Banerjee, M. K. , . . . & Kanga, S . (2022). Economics of implementing solar thermal heating systems in the textile industry. Energies, 15(12), 4277.
Tasmin, N. , Farjana, S. H. , Hossain, M. R. , Golder, S. , & Mahmud, M. P. (2022). Integration of solar process heat in industries: a review. Clean Technologies, 4(1), 97–131.
Mohammadi, K. , Khanmohammadi, S. , Immonen, J. , & Powell, K. (2021). Technoeconomic analysis and environmental benefits of solar industrial process heating based on parabolic trough collectors. Sustainable Energy Technologies and Assessments, 47, 101412.

Solar Thermal Energy Systems Life Cycle Assessment

Allen, J.A. , Rogers, D.F. , Principles of Energy Conversion, McGraw-Hill, 2014.
Alliger, G. , Renewable Energy Resources, Interscience, 2011.
Ardente, F. , Beccali, G. , Cellura, M. , Eco-sustainable energy and environmental strategies in design for recycling: the software ENDLESS. Ecological Modelling, 2003.
Ardente, F. , Beccali, G. , Cellura, M. , Lo, Brano V., Life cycle analysis of solar thermal collector (first part: life cycle inventory). First report of the International Energy Agency (IEA)Task 27 Performance of Solar Facade, Subtask C Project C1 Environmental Per formance; March 2003.
Ardente, F. , Beccali, G. , Cellura, M. , Lo, Brano, V., The environmental product declaration EPD with a particular application to a solar thermal collector. *Proceedings of conference ECOSUD* 2003, Siena, 4–6, 2003.

Ardente, F. , Beccali, G. , Cellura, M. , Lo Brano, V. , Life cycle assessment of a solar thermal collector. Renewable Energy, 30, 1031–1054, 2005. 10.1016/j.renene.2004.

Ardente, F. , Beccali, M. , Cellura, M. , FALCADE: plowboy interview with Mother Earth News, Harold R. Hay 1976.

Aurelie, K. , Germain, A. , Leda, G. , Francois, M. , Life Cycle Assessment and Environomic Optimization of Concentrating Solar Thermal Power Plants. *In:* Proceedings of the 26th international conference on efficiency, cost, optimization, simulation and environmental impact of energy systems, Guilin, China, EPFL—CONF—186393, 2013.

Baum, B. , Parker, C.H. , Energy Security Issues, Reinhold, 2013.

Bauer, E. , Energy Conservation Equipment, Van Nostrand Reinhold, 2012.

Berenson, C. , Solar Energy, Wiley-Interscience, 2018.

Bhatia, S.C. , Advance Renewable Energy Systems, 2014.

Bravo Y. , Carvalho M. , Serra, L.M. Monné C. , Alonso, S. Moreno, F. Muñoz M. , Environmen tal evaluation of dishStirling technology for power generation, Solar Energy, Volume 86, Issue 9, 2012.

Brydson, J.A. , Waste Heat Recovery, Elsevier, 2020.

Blengini, G. , Life cycle of buildings, demolition and recycling potential: a case study in Turin, Italy. Department of Architectural Engineering, Faculty of Urban Architecture No. 2501162, 2009.

Clauser, H.R. , Photovoltaic Solar Devices, Reinhold, 2009.

Clery D. Environmental technology. Greenhouse-power plant hybrid set to make Jordan's desert bloom. Science. 2011.

Collins, P. , The Beautiful Possibility by Paul Collins Cabinet 6, 2002 Spring.

Crawford, R.H. , Treloar, G.J. , Net energy analysis of solar and conventional domestic hot water systems in Melbourne, Australia. Solar Energy, 2004.

Desideri, U. Zepparelli, F. Morettini, V. Garroni E. , Comparative analysis of concentrating solar power and photovoltaic technologies: Technical and environmental evaluations, Applied Energy, Volume 102, 2013, Pages 765–784.

Diakoulaki, D. , Zervos, A. , Sarafidis, J. , Mirasgedis, S. , Cost benefit analysis for solar water heating systems. Energy Conversion Management, 2001.

Duffie, J.A. , Beckman, W.A. , L'energia solare idle applicazioni termiche (Italian language), Liguori ed., 1978.

Efthymiou, E. , Cöcen, Ö. N. , & Ermolli, S. R. (2010). Sustainable Aluminium Systems. Sustainability, 2(9), 3100–3109. https://doi.org/10.3390/SU2093100

Ehtiwesh, I.A.S. , et al. Renewable and Sustainable Energy Reviews, 56, 2016.

Erik Pihl , Duncan Kushnir , Björn Sandén, Filip Johnsson , Material constraints for concentrating solar thermal power, Energy, Volume 44, Issue 1, 2012, Pages 944–954.

F. Dinter , D. Mayorga Gonzalez , Operability, Reliability and Economic Benefits of CSP with Thermal Energy Storage: First Year of Operation of ANDASOL 3, Energy Procedia, Volume 49, 2014, Pages 2472–2481.

Frischknecht, R. , Editors, N. , Althaus, H. , Bauer, C. , Doka, G. , Dones, R. , et al. Implementation *of life cycle impact assessment methods, ecoinvent report no.* 3. Swiss Centre for Life Cycle Inventories, 2007.

Gong Cheng , Xinzhi Wang , Zhangzhou Wang , Yurong He , Heat transfer and storage char acteristics of composite phase change materials with high oriented thermal conductivity based on polymer/graphite nanosheets networks. International Journal of Heat and Mass Transfer, 183, Part B, 2022.

Gardon, J.L. , Energy, the Biomass Option, Interscience, 2020.

Häberle, A. , Zahler, C. , Lerchenmüller, H. , Mertins, M. , Wittwer, C. , Trieb, F. , Dersch, J. , The Solarmundo line focussing Fresnel collector. Optical and thermal performance and cost calculations, 2002.

Hampel, B.H. , Biological Energy Conversion, Reinhold, 2006.

Heckert, W.W. , Combustion Engineering, Wiley-Interscience, 2005.

ISO14040. Environmental management—Life cycle assessment—Principles and framework; 1998.

Mirasgedis, S. , Diakoulaki, D. , Assimacopoulos, D. , Solar energy and the abatement of atmospheric emissions. Renewable Energy, 1996.

Morley, David ., AICP, Editor, Planning for Solar Energy, 2014.
Murty, P.S.R. , Chapter 24 — Renewable energy sources, Editor(s): P.S.R. Murty , Electrical Power Systems, Butterworth-Heinemann, 2017.
Nandi, B.R. , Bandyopadhyay, S. , Banerjee, R. , Analysis of high temperature thermal energy storage for solar power plant. IEE ICSET, Nepal, 2012.
Neslen, Arthur (2015–10–26). Morocco Poised to become a Solar Superpower with Launch of Desert MegaProject. The Guardian. ISSN 0261–3077. Retrieved 2020.
Nils Breidenbach , Claudia Martin , Henning Jockenhöfer, Thomas Bauer , Thermal energy storage in molten salts: overview of novel concepts and the DLR test facility TESIS. Energy Procedia, 99, 2016.
Norton, Brian . Harnessing Solar Heat. Springer. ISBN 978-94-007-7275-5, 2013.
Ortiz, O. , Castells, F. , Sonnemann, G. , Sustainability in the construction industry: a review of recent developments based on LCA. Construction and Building Materials, 2009.
PRé. The Ecoindicator 99—a damage oriented method for life cycle impact assessment, Methodology report. PréConsultants B.V., Amersfoort, The Netherlands; 2001.
Kalogirou, S.A. , Solar thermal collector and applications. Progress in Energy and Combustion Science, 2004.
Kinga Pielichowska , Krzysztof Pielichowski , Phase change materials for thermal energy stor age. Progress in Materials Science, 65, 2014.
SimaPro8 World's Leading LCA Software Package, PRé Consultants. PRé Consultants, (www.pre-sustainability.com/simapro) 2019.
Souliotis, M. , Tripanagnostopoulos, Y. , Experimental study of CPC type ICS solar systems. Solar Energy, 2004.
Solar Millennium AG *. The parabolic trough power plants* Andasol 1 to Germany, 2008.
Szargut, J. , Morris, D. , Steward, F. , Exergy Analysis of Thermal, Chemical and Metallurgical Processes, Hemisphere Publishing Corporation, 1997.
Tripanagnostopoulos, Y.G.T. , Souliotis, M.K. , Battisi, R. , Corrado, A. , Application aspects of hybrid PV/T solar systems. In: ISES Solar World Congress 2003, Go Teborg, Sweden; June 14 19, 2003.
Tsilingiridis, G. , Martinopoulos, G. , Kyriakis, N. , Life cycle environmental impact of a thermosyphonic domestic solar hot water system in comparison with electrical and gas water heating. Renewable Energy, 2004.
Veenstra, A. , Oversloot, H.P. , Spoorenberg, H.H.R. , The environmental performance of solar energy systems and related energy saving installations. In: Dissemination workshop of the International Energy Agency (IA) Task 27 Performance of Solar Facade, Copenhagen, April 2002.
Wagner, H. , Ermittlung des primaerenergieau/wanfes und Abschaetzung der emissionen zur Herstellung und zum Betrieb von augewaehlten alsorberanlangen zur Schimmtadwasserwaermung und von Solarkollector-anlagen zur Brauchwassenerwaermung (German language). VDI Berichte, Reihe 6, no. 325: 1995.
Viebahn, P. , Kronshage, S. , Trieb, F. , Lechon, Y. , Final report on technical data, costs, and life cycle inventories of solar thermal power plants. NEEDS, Project no: 502687, 2008.

Role of Modern Tools in Solar Thermal System Design

Oliver M , Jackson T . Energy and economic evaluation of building-integrated photovoltaics. Energy 2001;26:431–439.
Kumar R , Umanand L . Estimation of global radiation using clearness index model for sizing photovoltaic system. Renew Energy 2005;30:2221–2233.
Chen L , Yan G , Wang T , Ren H , Calbo J , Zhao J , et al. Estimation of surface shortwave radiation components under all sky conditions: modeling and sensitivity analysis. Remote Sens Environ 2012;123:457–469.
Mellit A , Kalogirou SA . Artificial intelligence techniques for photovoltaic applications: a review. Prog Energy Combust Sci 2008;34:574–632.

Hay JE , Hanson KJ . Evaluating the solar resource: a review of problems resulting from temporal, spatial and angular variations. Sol Energy 1985;34:151–161.
Perez R , Seals R , Zelenka A . Comparing satellite remote sensing and ground network measurements for the production of site/time specific irradiance data. Sol Energy 1997;60:89–96.
Hassan GE , Youssef ME , Mohamed ZE , Ali MA , Hanafy AA . New temperature-based models for predicting global solar radiation. Appl Energy 2016;179:437–450.
Janjai S , Laksanaboonsong J , Nunez M , Thongsathitya A . Development of a method for generating operational solar radiation maps from satellite data for a tropical environment. Sol Energy 2005;78:739.
Zarzalejo LF , Ramirez L , Polo J . Artificial intelligence techniques applied to hourly global irradiance estimation from satellite-derived cloud index. Energy 2005;30:1685– 1697.
Lu N , Qin J , Yang K , Sun J . A simple and efficient algorithm to estimate daily global solar radiation from geostationary satellite data. Energy 2011;36:3179–3188.
Ömer Ali Karaman, Tuba Tanyıldızı Ağır , İsmail Arsel . Estimation of solar radiation using modern methods. Alex Eng J 2021;60(2):2447–2455, ISSN 1110–0168
Meenal R , Selvakumar AI . Review on artificial neural network based solar radiation prediction, In 2017 2nd International Conference on Communication and Electronics Systems (ICCES), Coimbatore, 2017.
Senkal O , Sahin M , Pestemalcı V . The Estimation of solar radiation for different time periods. Energy Sources 2010;32:1176–1184.
He, Zhaoyu , Guo, Weimin , Zhang, Peng . Performance prediction, optimal design and operational control of thermal energy storage using artificial intelligence methods. Renew Sustain Energy Rev 2022;156:111977, ISSN 1364–0321.
Jiang, Hou , Lu, Ning , Qin, Jun , Tang, Wenjun , Yao, Ling . A deep learning algorithm to estimate hourly global solar radiation from geostationary satellite data. Renew Sustain Energy Rev 2019;114:109327, ISSN 1364–0321.
Anicic, Obrad , Jović, Srđan , Skrijelj, Hivzo , Nedić, Bogdan . Prediction of laser cutting heat affected zone by extreme learning machine. Opt Lasers Eng 2017;88:1–4.
González-Roubaud, Edouard , Pérez-Osorio, David , Prieto, Cristina . Review of commercial thermal energy storage in concentrated solar power plants: steam vs. molten salts. Renew Sustain Energy Rev 2017;80:133–148.
Kalogirou S. The potential of solar industrial process heat applications. Appl Energy 2003;76:337–361.
Osorio, Julian D. , Wang, Zhicheng , Karniadakis, George , Cai, Shengze , Chryssostomidis, Chrys , Panwar, Mayank , Hovsapian, Rob . Forecasting solar-thermal systems performance under transient operation using a data-driven machine learning approach based on the deep operator network architecture. Energy Convers Manag 2022;252:1–14.
Ajbar W , Parrales A , Cruz-Jacobo U , Conde-Gutiérrez RA , Bassam A , Jaramillo OA , Hernández JA . The multivariable inverse artificial neural network combined with GA and PSO to improve the performance of solar parabolic trough collector. Appl Therm Eng 2021;189:116651, ISSN 1359–4311.
Liu Zhijian , Li Hao , Liu Kejun , Yu Hancheng , Cheng Kewei . Design of high-performance water-in-glass evacuated tube solar water heaters by a high-throughput screening based on machine learning: A combined modeling and experimental study, Solar Energy 142 (2017) 61–67.
Correa-Jullian C. , Miguel Cardemil J , Droguett E L , Behzad M. Assessment of Deep Learning techniques for Prognosis of solar thermal systems, Renewable Energy 145 (2020) 2178–2191.
Correa-Jullian C , López Droguett E , Miguel Cardemil J . Operation scheduling in a solar thermal system: A reinforcement learning based framework, Applied Energy 268 (2020),114943.
Ma T , Guo Z , Lin M , Wang Q . Recent trends on nanofluid heat transfer machine learning research applied to renewable energy, Renewable and Sustainable Energy Reviews.
Bonilla1 J , Carballo J A , Berenguel M , Fernández-Reche J , Valenzuela L. Machine Learning Perspectives in Concentrating Solar Thermal Technology, July 2019, Conference: EUROSIM 2019.10th Congress of the Federation of European Simulation Societies.
Gonzalez Gonzalez A , Alvarez Cabal JV , Vigil Berrocal MA , Peón Menéndez R , Riesgo Fernández A . Simulation of a CSP solar steam generator, using machine learning. Energies

2021;14:3613.
Untrau A , Sochard S , Marias F , Reneaume J-M , Le Roux Galo AC , Serra S . Analysis and future perspectives for the application of dynamic real-time optimization to solar thermal plants: A review. Solar Energy, 2022:275–291.

Global Energy Model and International Solar Energy Policies

IEA (2021). World Energy Model, IEA, Paris www.iea.org/reports/world-energy-model
IEA (2021). World Energy Model, IEA, Paris www.iea.org/reports/world-energy-model
IEA (2021). World Energy Model, IEA, Paris www.iea.org/reports/world-energy-model
IEA , Industry direct CO2 emissions in the Sustainable Development Scenario, 2000– 2030, IEA, Paris www.iea.org/data-and-statistics/charts/industry-direct-co2-emissions-in-the-sustainable-development-scenario-2000–2030
IEA (2020). Tracking Industry 2020, IEA, Paris www.iea.org/reports/tracking-industry-2020
IEA , Final energy consumption and fuel shares in the Sustainable Development Scenario, 2010–2030, IEA, Paris www.iea.org/data-and-statistics/charts/final-energy-consumption-and-fuel-shares-in-the-sustainable-development-scenario-2010–2030
IEA , Renewable heat in industry in the Sustainable Development Scenario, 2010–2030, IEA, Paris www.iea.org/data-and-statistics/charts/renewable-heat-in-industry-in-the-sustainable-development-scenario-2010–2030
IRENA (2018). Global Energy Transformation: A Roadmap to 2050, International Renewable Energy Agency, Abu Dhabi.
Balasubramanian, A. (2013). World Climate Zones. Centre for Advanced Studies in Earth Science, University of Mysore, Mysore.
Hakemzadeh, M.H. (2020). Investigation of photovoltaic system in Malaysian climate as a function of angle and orientation. Universiti Kebangsaan Malaysia. www.ukm.my/ptsl/portal/ethesis
Climate change knowledge portal (https://climateknowledgeportal.worldbank.org/)
Nicholas, Tasie ., Israel-Cookey, Chigozie & Banyie, Ledum .(2018). The effect of relative humidity on the solar radiation intensity in Port Harcourt, Nigeria. International Journal of Research, 5: 128–136.
Agbo, S.N. , & Okoroigwe, E.C. (2007). Analysis of thermal losses in the flat-plate collector of a thermosyphon solar water heater. Research Journal of Physics, 1(1): 35–41.
Zhenkui, W. et al. (2021). Heating performance of solar heat pump heating system with aluminum tube collector, IEEEAccess, 9: 26491–26501. doi: 10.1109/ACCESS.2021.3056121.
Sukarno, Kartini , Teong, Khan Vun , Dayou, Jedol , Chee, Fueipien , Jackson, Chang . (2017). The monsoon effect on rainfall and solar radiation in Kota Kinabalu. Transactions on Science and Technology, 4(4): 460–465.
Solangi, K.H. , Islam, M.R. , Saidura, R. , Rahim, N.A. , Fayaz, H. , (2011). A review on global solar energy policy. Renewable and Sustainable Energy Reviews, 15(4): 2149–2163.
www.un.org/en/climatechange/net-zer0-coalition
www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review- 2021-full-report.pdf
Statistical review of world energy 2021, 70th edition.
www.eea.europa.eu/data-and-maps/figures/correlation-of-per-capita-energy.
www.energy.gov/eere/solar/solar-energy-united-states.
www.forbes.com/advisor/home-improvement/average-cost-of-solar-panels/.
www.dataforma.com/blog/challenges-facing-the-solar-industry-right-now/.
www.epa.gov/statelocalenergy/state-renewable-energy-resources, United States Environmental Protection Agency.
The Power of Renewables: Opportunities and Challenges for China and the United States, (2010), The National Academies Press, Washington, D.C.
https://chineseclimatepolicy.energypolicy.columbia.edu/en/solar-power#:~:text=panels%20are%20cleaned.-,Policies,power%20since%20at%20least% 202011.

www.mordorintelligence.com/industry-reports/germany-solar-energy-market.
https://taiyangnews.info/markets/japan-eyes-over-108-gw-solar-power-capacity-by-2030/
https://en.wikipedia.org/wiki/Solar_power_in_Japan.
https://solarify.in/blog/policies-regulations-solar-energy-india/#:~:text=The%20Indian%20government%20revised%20the,policies%20to%20promote%20solar%20energy.
www.thehindu.com/sci-tech/energy-and-environment/indias-solar-capacity-milestones-and-challenges/article65227709.ece.
www.iea.org/policies?country%5B0%5D=India&technology%5B0%5D=Solar%20PV&technology%5B1%5D=Solar.
https://isolaralliance.org/about/background.
www.aedb.org/images/Draft_ARE_Policy_2019_-_Version_2_July_21_2019.pdf
https://blogs.worldbank.org/endpovertyinsouthasia/expanding-solar-and-wind-pakistan-requires-decisive-action.
www.brecorder.com/news/40184919.
Qudrat-Ullah, Hassan . (2022). A review and analysis of renewable energy policies and CO2 emissions of Pakistan. Energy, 238: 121849.
www.energyfactsaustralia.org.au/explainers/energy-policy/.
www.sciencedirect.com/science/article/abs/pii/S0960148113003170.
https://australiangrants.org/renewable-energy-initiatives-australia/?gclid=EAIaIQobChMIqvDP1en0-AIV0ZVLBR3h4g5-EAAYAiAAEgKb1fD_BwE.
www.sta.org.au/explainers/energy-policy/.
www.cleanenergycouncil.org.au/advocacy-initiatives/renewable-energy-target.
Australian renewable energy policy: Barriers and challenges, Liam Byrnes a,b,*, Colin Brown a, John Foster b, Liam D. Wagner b, Renewable Energy, 60, December 2013, Pages 711–721.