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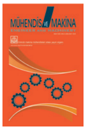

ELECTRICITY GENERATION METHODS FROM SOLAR ENERGY

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Keywords	Abstract
Solar power, fotovoltaic systems, concentrating solar power	*In this study, photovoltaic cells that directly convert solar energy into electrical energy and concentrated solar energy technologies that indirectly generate electrical energy from superheated steam by concentrating solar energy were examined in detail, classified among themselves, and compared technically. Examinations on elec-tricity production methods and technologies from solar energy were carried out in three stages. In the first stage, a comprehensive scheme was created by examining the methods of electricity production from solar energy in general. In the second stage, the structures and types of photovoltaic cells were examined. In the third stage, concentrated solar energy systems were examined. Finally, electricity production systems from solar energy are compared and the results are presented.*

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GÜNEŞ ENERJİSİNDEN ELEKTRİK ÜRETİM YÖNTEMLERİ

Anahtar Kelimeler	Öz
Güneş enerjisi, fotovoltaik sistemler, konsantre güneş sistemleri	*Bu çalışmada, güneş enerjisini doğrudan elektrik enerjisine çeviren fotovoltaik hücreler ve dolaylı yoldan güneş enerjisini yoğunlaştırarak kızgın buhardan elektrik enerjisi üreten konsantre güneş enerjisi teknolojileri detaylı olarak incelenmiş, kendi aralarında sınıflandırılmış ve teknik olarak karşılaştırılmıştır. Güneş enerjisinden elektrik üretim yöntem ve teknolojileri üzerine yapılan incelemeler üç aşamada gerçekleştirilmiştir. Birinci aşamada, güneş enerjisinden elektrik üretim yöntemleri genel olarak incelenerek kapsamlı bir şema oluşturulmuştur. İkinci aşamada fotovoltaik hücrelerin yapıları ve çeşitleri incelenmiştir. Üçüncü aşamada ise konsantre güneş enerji sistemleri incelenmiştir. Son olarak güneş enerjisinden elektrik üretim sistemleri karşılaştırılmış ve sonuçlar sunulmuştur.*

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1. Introduction

Energy serves as the foundational input of civilization and stands as one of the most significant indicators for gauging a civilization's levels of production, consumption, and development. Moreover, it constitutes a fundamental driver for social and economic progress. Particularly with the proliferation of technological devices, there is a noticeable escalation in per capita energy consumption. It is an undeniable reality that alongside this escalating energy demand, fossil fuel-based energy reservoirs are swiftly depleting. The environmental harm resulting from the surge in CO_2 emissions attributed to the utilization of fossil fuel-based energy resources incentivizes global efforts to explore alternative energy sources.

According to the 2022 report by the Organization of Petroleum Exporting Countries (OPEC), solar, wind, and geothermal energy resources are expected to grow at an average annual rate of 7.1% until 2045. The increase in the use of renewable energy resources will be slightly lower than the growth of gas and oil. Renewable energy sources accounted for 2.6% of global energy in 2021, and this rate is expected to increase to just below 11% by 2045 (OPEC, 2022). In 2022, solar power plants accounted for 68.2% of the total renewable energy production worldwide (IEA, 2023).

The sun is composed of hydrogen (H) and helium (He). These atoms are ionized as H+ and He_2+. The Sun continuously acts as a reactor, releasing fusion energy in its core, and these fusion reactions are the source of solar energy. The energy sent by the Sun to the Earth in 1 hour is equivalent to the energy provided by approximately 13 billion tons of hard coal (D. R. Mills, 2001).

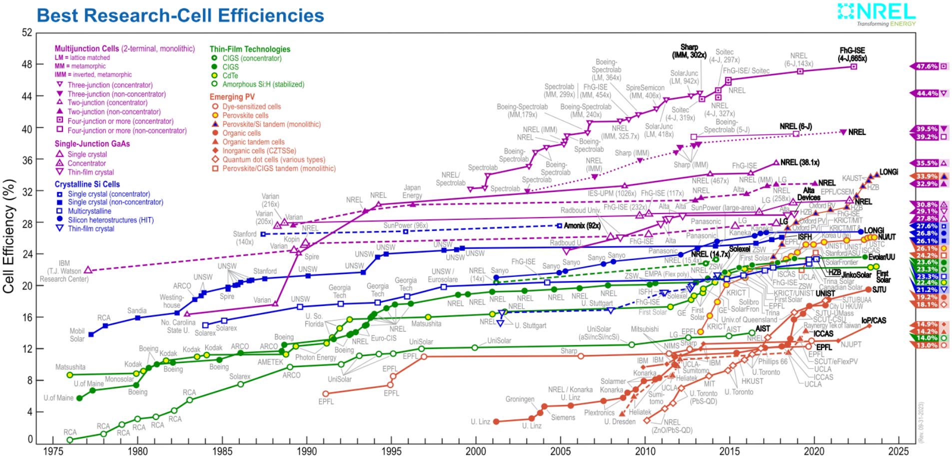


Figure 1. Cell efficiency change graph over the years (NREL, 2023a).

Significant advances have been made in the efficiency of photovoltaic cells used in both space and terrestrial applications to harness the large amounts of energy coming from the sun. These advances in the efficiency values of different photovoltaic cell structures from 1976 to the present are summarized in the graph in Figure 1 by the National Renewable Energy Laboratory (NREL) in the United States (NREL, 2023a). Although the efficiency achieved in the 47-year period was quite high, many of the photovoltaic cell structures could not be commercialized due to cost and were not suitable for mass production.

The history of photovoltaic cells dates back to the 1800s. Alexander Edmond Becquerel discovered the first photovoltaic effect in 1839, during his scientific studies on platinum layers. Becquerel's research gained momentum with the discovery of photoconductivity, which is based on the generation of current by immersing two platinum electrodes in a solution containing a metal halide salt (Prevenslik, 2003). In 1873, Willoughby Smith discovered photoconductivity in Selenium (Se), creating the first simple photovoltaic mechanism (William Grylls Adams, 1875). In 1877, it was proven that solid materials could also produce photovoltaic effects, with GW Adams and R.E. Day observing the photovoltaic effect in Selenium crystals (Jagdeo, Sharon, and White, 2021). In 1883, Charles Fritts developed the first functional 1.1% efficient photovoltaic cell by coating Selenium with a very thin layer of gold (Fraas and O'Neill, 2023). The most comprehensive theoretical study on the photovoltaic effect was carried out by Albert Einstein in 1905. This theoretical work was tested by Robert Millikan in 1916, and in 1932 it was announced that the photovoltaic effect was observed in the Cd-Se structure (Petrova-Koch, Hezel, and Goetzberger, 2008). Russell Ohl patented the modern PV (photovoltaic) cell in 1946 (Patent No. US2443542A, 1948). Silicon PV technology was born in 1954 at Bell Laboratories with the development of the first silicon photovoltaic with %6 efficiency by Daryl Chapin, Calvin Fuller, and Gerald Pearson. (Goetzberger, Luther, and Willeke, 2002). In 1957, Hoffman Electronics developed Silicon PV cells with 8% efficiency, and in 1958 with 9% efficiency (Orton, 2008). The first technical application of electricity generation from silicon photovoltaic cells was carried out on the American Vanguard satellite in 1958. These cells produced 0.1W power per 100 cm^2. The use of photovoltaic cell technology in space studies enabled the rapid development of this technology and its efficiency reached 15% in the early 1960s (Messenger and Abtahi, 2018). In 1970, Zhores Alferov developed GaAs-doped (Gallium Arsenide) heterojunction photovoltaic cells (Alferov et al., 1971; Olgun Konur, 2016). With the onset of the oil crisis in the late 1970s, the search for alternative energy sources began. This increased the interest in PV cells, and R&D and production of PV cells accelerated. PV cells have been produced from different materials such as Amorphous Silicon (a-Si), which was defined as thin film PV cells in 1976, GaAs, Copper Sulphide (CuS) and Cadmium Sulphide (CdS), Cadmium Telluride (CdTe) in the 1980s (Keskinel, 2015). In 1985, 20% efficient Silicon photovoltaic cells were produced at the University of New South Wales. After the 1980s, the efficiency of two-joint GaAs-doped solar cells, which is a new method, reached 22%, and the efficiency of three-joint tandem solar cells reached 24% (Ishibashi et al., 1986). The first organic solar cell was produced at Kodak by Tang et al (Tang, 1986). Three-junction photovoltaic cells were developed with 20% efficiency in 2000, 26% efficiency in 2002, and 28% efficiency in 2005 (Sarver, Al-Qaraghuli, and Kazmerski, 2013). In 2006, 40% efficient three-junction photovoltaic cells were developed at Spectrolab and polysilicon was used in photovoltaics (Ermer et al., 2012; R R King et al., 2007). Fraas et al have developed a 33% efficient Dual Focus HCPV Module in 2006 (Fraas and O'Neill, 2023). In 2007, the University of Delaware announced a new world record in Solar Cell Technology with an efficiency of 42.8% (University of Delaware, 2007). In 2008, NREL broke the world record at the time by developing a 40.8% efficient three-junction photovoltaic cell (NREL, 2008). In 2009, Spectrolab broke NREL's record by developing a 41.6% efficient triple-junction photovoltaic cell (R Richard King et al., 2009). In 2013, cumulative solar PV installations worldwide exceeded 100 GW (Kapluhan, 2015). In 2016, engineers at the University of New South Wales set a new world record for converting unfocused sunlight into electricity, with an efficiency of 34.5% (Eric Mack, 2016). n 2016, it was announced that 22.1 percent of the energy in sunlight was converted into electricity using Cadmium Telluride. This technology covers approximately 5% of the world solar market, today (Richard Martinarchive page, 2016). In 2018, Alta Devices Company in the USA achieved 29.1% solar cell conversion efficiency according to Germany's Fraunhofer ISE CalLab certification. (John Fitzgerald Weaver, 2018). In 2019, NREL in the USA achieved 47.1% solar cell efficiency, a world record, using multi-junction concentrator solar cells (NREL, 2020). Important research and development activities continue in photovoltaic technology, such as how to increase the efficiency of and benefit from solar cells, with different designs (Bi et al., 2022; Chander and Tripathi, 2023; Liu, Jin, Li, Zhao, and Badiei, 2022; Saeed et al., 2022; Salhi, 2022; Shakibi, Afzal, Shokri, and Sobhani, 2022; Sharaf, Huzayyin, and Yousef, 2022; J. Wang et al., 2022; Z. Wang et al., 2023; Zhang et al., 2022).

Another way to convert solar energy into electrical energy is concentrated solar energy systems. In these systems, solar energy is focused on a region and converted first into heat energy and then into electrical energy.

Focusing the sun's rays was first used to light fire. It is said that in 250 BC, Archimedes burned the wooden ships surrounding Syracuse by concentrating the sun's rays with mirrors (Doraiswamy, 2002). With the discovery of the lens in 1600, studies in this field accelerated. In 1860, Mouchot focused sunlight on a specific surface with parabolic mirrors and invented a small steam engine. These machines were the forerunners of today's modern parabolic dish collectors. In 1907, Maier and Remshardt patented the Parabolic Trough Collector (PTC), which they designed for direct steam production (Kılıç Abdurrahman and Öztürk Aksel, 1983). The solar collector roughly reached its present design in 1908, when William J. Bailey invented a collector with an insulated box and copper coils (Gong and Sumathy, 2016). In 1913, Shuman and Boys designed a steam engine using parabolic mirrors. In this way, they were able to draw water from the Nile river with a water pump (Ackermann, 1915; Mohanad Abdulazeez Abdulraheem Alfellag, 2014). Baum et al. developed the principle of the Linear Fresnel Collector (LFC), followed by Italian Mathematician Giorgio Francia in 1961, who designed Fresnel reflectors that performed both linear and two-axis tracking (Baum, Aparasi, and Garf, 1957). A kinematic Stirling engine called the solar-powered steam Stirling 4-95 was developed in the late 1970s and early 1980s by several companies, including United Stirling AB, Advanco Corporation, McDonnell Douglas Aerospace Corporation (MDA), and NASA (Baharoon, Rahman, Omar, and Fadhl, 2015). Lorin and Hull conducted optical system research to achieve maximum power in heliostat field arrangement in central receiver solar towers (Vant-Hull, 1977). In 1979, Gaul and Rabl examined the optical efficiency of parabolic trough type solar concentrators by recording the efficiency change with solar radiation at all hours of the day. (Gaul and Rabl, 1980). Gee examined linear focusing solar concentrators and solar tracking systems. He compared solar tracking systems and conducted experimental studies (Gee and Institute, 1980). Collares-Pereira et al. have studied parabolic trough systems. They found the formulation required for the highest concentration (Collares-Pereira et al., 1979). McDonnell Douglas Aerospace Corporation (MDA) produced 8 prototype dish engines to commercialize parabolic dish technology in the mid-1980s , but due to the state of the energy market, the company ceased all its energy-related activities. Prototypes of MDA were sold to Southern California Edison (SCE) (T. R. Mancini, 1997). The commercial United Stirling 4-95 was operated by SCE from 1986 to 1988. It converted solar energy into electricity with a net efficiency of approximately 30% and recorded an annual efficiency of approximately 12% in its last year of operation (Stine and Diver, 1994).

Hession and Bonwick worked on the system that monitors concentrators of different sizes (Hession and Bonwick, 1984). Jeter worked on the distribution of concentrated rays on parabolic trough systems and the calculation of optical efficiency (Jeter, 1986). Collares-Pereira et al. have studied the reduction of heat losses in parabolic corrugated concentrators (Collares-Pereira, Gordon, Rabl, and Winston, 1991). In 1993, a linear Fresnel collector was developed at the University of Sydney, a prototype was designed and named Compact Linear Fresnel Collector (CLFC). The system includes two receiver towers to collect reflected solar rays from diffusing mirrors (D. Mills, 2004; D. R. Mills and Morrison, 2000). In the early 1990s, Cummins Engine Company tried to commercialy produce bowl/Stirling systems using a free-piston engine instead of a kinematic engine to reduce maintenance and cost (T. R. Mancini, 1997). In 1991, in a development program called the Dish/Stirling Joint Venture Program (DSJVP), development of a 5–10 kW Stirling system for remote power applications began, but in 1996, Cummins Engine Company ceased all activities in the development phase due to major unresolved technical problems and decided to cancel the project (John R Bean and Diver, 1995; J R Bean and Diver, 1992). A program called the Utility Scale Joint Venture Program (USJVP) was initiated by Science Applications International Corporation (SAIC) and Stirling and Thermal Motors (STM) to develop a 25-kW dish/Stirling engine system in late 1993. They have been successful in demonstrating a 20 kW Stirling engine (Phase 1) in Golden, Colorado (Gallup, Mancini, Christensen, and Beninga, 1994). Kalogirou et al. have worked on modeling steam production systems in parabolic trough-type condensers (Kalogirou, Lloyd, and Ward, 1997). Genç has developed a single-axis solar tracking system (Asım Genç, 1998). Siala and Elayeb tried to design heliostats using the graphical method in solar towers with central receivers. They expressed their designs in graphical data using mathematical formulas (Siala and Elayeb, 2001). Zarza et al. have worked on the development of new types of solar power plants that provide direct steam production in the absorber tube of parabolic trough-type solar concentrators (Zarza et al., 2002). Çolak worked on modeling the parts required for optics and heat used in parabolic trough concentrators (Levent Çolak, 2003). Chen et al. made two different heliostat designs in solar towers with central receivers and evaluated their performances (Chen et al., 2004). Kribus et al. were interested in receiver designs in solar towers with central receivers and conducted research on how power changes with temperature (Kribus, Vishnevetsky, Yogev, and Rubinov, 2004).

Bakos worked on two-axis solar tracking for parabolic trough concentrators (Bakos, 2006). Riffelmann et al. have studied the optical efficiency of parabolic trough concentrator solar power plants (Riffelmann, Neumann, and Ulmer, 2006). Garcia-Valladares and Velazquez have simulated the heat and flow behavior of single- and double-pass parabolic trough-type solar concentrators (Garcia-Valladares and Velázquez, 2009). Wu et al. studied the parabolic dish solar thermal power system and evaluated the average heat-electricity conversion performance of the system. They found the average efficiency of the system to be 20.6% (Wu, Xiao, Cao, and Li, 2010). A three-dimensional numerical study of heat transfer in a longitudinally finned parabolic slotted receiver using different types of nanofluids was carried out by Fernández-Garcia et al (Fernández-Garcia, Zarza, Valenzuela, and Pérez, 2010). Today, research on photovoltaic systems and concentrator solar energy systems continues intensively. Important research and development activities continue in concentrated solar system technology, such as how to increase the efficiency of and benefit from those systems, with different designs (Arias, Cardemil, Zarza, Valenzuela, and Escobar, 2022; Khan, Asfand, and Al-Ghamdi, 2022; Merchán, Santos, Medina, and Hernández, 2022; A. Sharma, Shukla, Singh, and Sharma, 2022; Sheikholeslami, 2022; Xu et al., 2022).

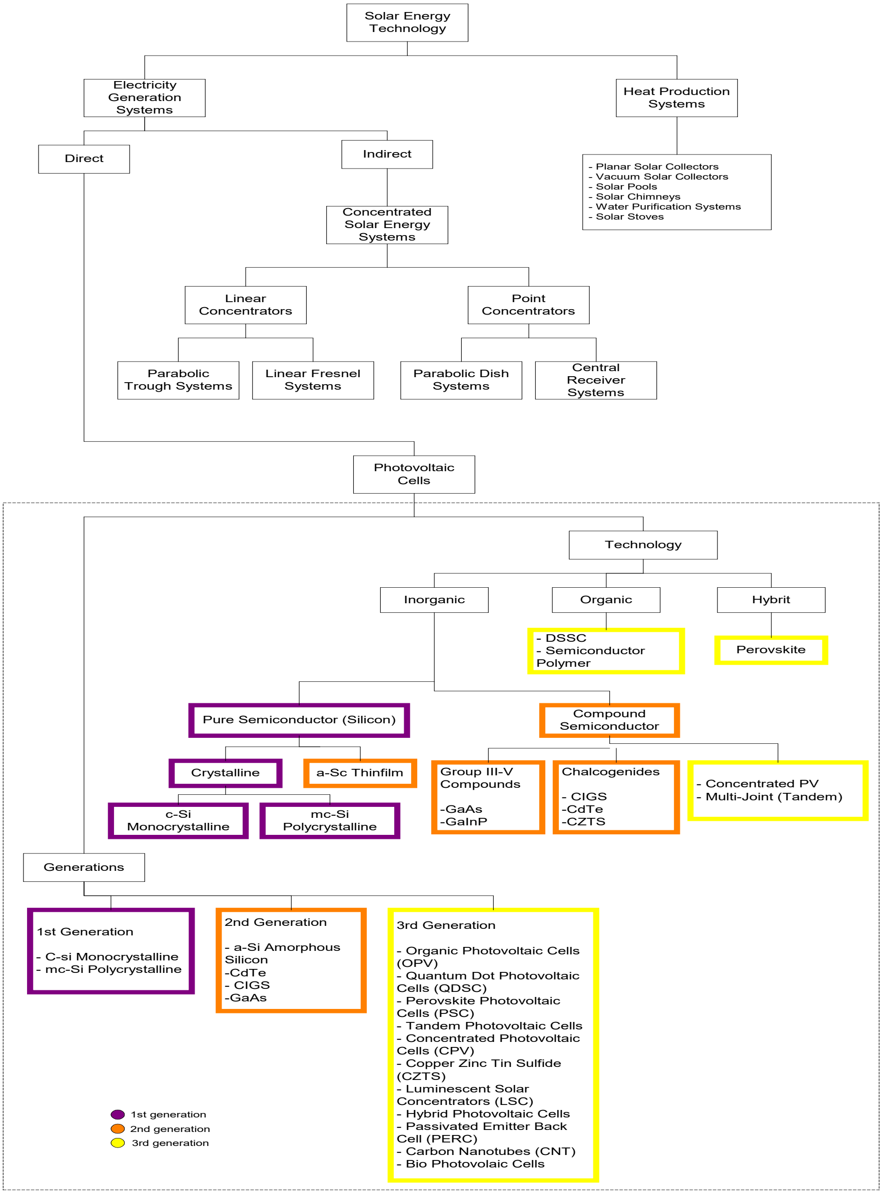


Figure 2. Solar Energy Technologies.

Within renewable energy systems, there are hybrid structures that utilize multiple conversion systems together, such as solar, wind, and bio-energy. Hybrid systems are not within the scope of this study. However, researchers can refer to the following sources for hybrid systems: (Abdolmaleki and Berardi, 2024; Ahmed, Das, Das, Hossain, and Kibria, 2024; Falope, Lao, Hanak, and Huo, 2024; Güven and Mete, 2021; Güven and Samy, 2022; Güven, Yörükeren, and Mengi, 2024; Güven, Yörükeren, and Samy, 2022; Güven and Yücel, 2023; Padmanabhan and Anbazhagan, 2024).

In this study, photovoltaic cells that directly convert solar energy into electrical energy and concentrated solar energy technologies that indirectly produce electrical energy from superheated steam by concentrating solar energy were examined in detail, classified among themselves, and compared technically.

2. Method

In this study, methods for generating electricity from solar energy in the literature have been researched. The research was not limited to academic literature; reports from official organizations working on energy were also included in the study. First, an in-depth literature review was conducted to identify the studies conducted so far on generating electricity from solar energy. Then, the current state of PV and CSP solar energy technologies was investigated. Based on the information obtained, a detailed graphical tree representation of solar energy technologies was created. Finally, PV and CSP technologies were compared in terms of their advantages and disadvantages. Overall workflow of the review methodology is depicted in Figure 3. In this study, adherence to research and publication ethics has been ensured.

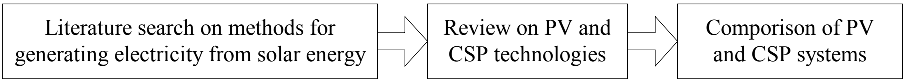


Figure 3. An overall workflow of the review methodology.

3. Solar Energy Technology

2.2 billion units of the energy emitted by the Sun reaches the Earth and constitutes our main energy source. The energy falling from the Sun on the total landmass for 270 minutes is equal to the energy consumed by the whole world in one year (International Energy Agency, 2011). This energy has been used for many years.

The main purpose of preferring solar energy is to mitigate the damage fossil-based energy sources cause to the environment and the limited nature of these energy sources. Solar energy can be converted to another type of energy by a suitable method depending on the area of use. The most needed types of energy today are heat and electrical energy. As shown in Figure 2, solar energy can be converted into heat energy and electrical energy using different technologies. This conversion occurs by using PV cells, which directly convert solar energy into electrical energy, or indirectly by using concentrated solar power (CSP) technology, which produces electrical energy from steam by concentrating solar energy.

Two types of classification can be made in electricity generation using PV cells: i) according to their generation and ii) according to the technology used.

In the classification of PV cells according to their generation, the first generation includes crystalline silicon (c-Si) wafer-based cells as monocrystalline (single crystalline silicon: mono c-Si) and polycrystalline (polycrystalline silicon: m-Si, poly c-Si). The raw material of these cells is high purity silicon crystals. The production process requires advanced technology.

The second generation is based on thin film technology. This includes Si-based tandem solar cell technologies such as Amorphous Silicon (a-Si), Cadmium Telluride (CdTe), Copper Indium Gallium Selenide (CIGS)/Copper Indium Selenide (CIS) and single crystal thin film technology such as Gallium Arsenide (GaAs). These cells are mostly manufactured for roof applications.

Third generation PV cells include organic materials as well as multijunction cell technologies, innovative non-silicon-based technologies, namely organic/semi-organic PV cells (OPV), dye-sensitized solar cells (DSSC), quantum dot (QD) solar cells, Perovskite solar cells (It covers many new concept devices such as PSC), Tandem solar cells, CZTS, Luminescent solar cells.

The efficiency and performance of these types vary since different types of semiconductors are used. While the first- and second-generation PV modules are commercially more efficient and available for large-scale production, some of the third generations are still in the R&D (Research & Development) stage.

According to the technology used, classification is made in three parts: inorganic, organic and hybrid. Traditional Silicon-based solar cells (c-Si, mc-Si) and compound polymers (CIGS, CdTe, GaAs, GaInP, CZTS, CPV, Tandem) are in the inorganic class. Although the production cost of inorganic materials is high, they are preferred due to their high efficiency. Conductive polymers, dyes, pigments and liquid crystals can be used to make organic-based solar cells. DSSC and Semiconductor Polymer based organic cells are included in this group. Hybrid cells have been developed to combine the advantages of organic and inorganic-based cells. Perovskite photovoltaic cells are included in this group.

Two types of classification can be made in electricity production using CSP systems. The first type includes Parabolic Trough Concentrators and Planar Fresnel concentrators, which perform linear condensation. The second type includes the Central Receiver and Parabolic Dish concentrators, which follow the sun in two axes, concentrate the sun rays by point focusing and thus reach very high temperatures.

The methods and classifications given so far are examined in detail under subheadings in the following sections.

3.1 Photovoltaic Cells

The word photovoltaic (PV) consists of the Greek words; photos, meaning light, and volt. The term photovoltaic means the production of electricity from light. In this section, photovoltaic cell structure and various photovoltaic technologies will be discussed.

3.1.1 Structure and Working Principle of Photovoltaic Cells

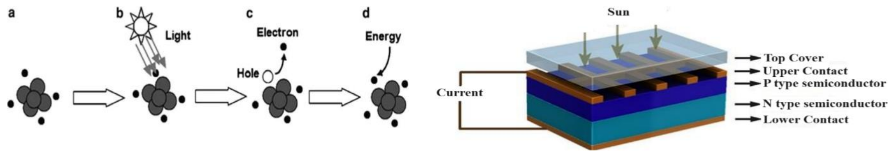
The photovoltaic system uses the concept of the photovoltaic effect, first observed by Alexandre Edmond Becquerel in 1839 (Prevenslik, 2003). The PV effect can be defined as the formation of a voltage difference when light falls on a system between two electrodes connected to each other, whether solid or liquid.

A Photovoltaic cell (solar cell) is a simple semiconductor device that, in principle, converts sunlight into electrical energy. In other words, when solar radiation (photon energy) hits the semiconductor material and is absorbed by this material, an electron is broken off from the atomic bond in that material and the electrons broken off from the atoms they are bonded to begin to circulate freely within the material. Thus, electron current occurs. The electron current creates voltage in the potential field of the cell, resulting in electric current as shown in Figure 4-a. Depending on the current and voltage, power output is obtained between the photovoltaic cell contacts (Ayşe Özge Küpeli, 2005).

There are three basic elements in the structure of the photovoltaic cell to create photocurrent (Fortunato et al., 2016; Tushar K. Ghosh and Mark A. Prelas, 2011):

1. A photosensitive material (absorber material) in which photons can form charge carriers
2. Separation of load carriers (PN Junction),
3. An external circuit (metal grid) to collect photon-generated charge carriers.

The absorber material transfers the energy of the incident photons to the valence electrons. PN junction is the combination of N-type (emitter) and P-type (base) region that creates an electric field. The metal grid ensures current flow and captures electrons. The design of the metal grating can be optimized to minimize drag and ghosting. In addition, the photovoltaic cell structure is basically similar to the structure and operation of the diode.



a) b)

Figure 4. a) Mechanism of generating energy from solar radiation (photon) in semiconductor material (Tushar K. Ghosh and Mark A. Prelas, 2011) b) Photovoltaic Cell Structure (Özgün, ÖZDEMİR, and ÖZMEN, 2022).

The photon affecting the junction region is absorbed by the semiconductor material. The photon provides energy to the electron to move it from the valence band to the conduction band. So, an electron-hole pair is formed. During this formation, the electron-hole pair is separated from each other by the effect of the electric field in this region, and the electrons move towards the N region and the holes move towards the P region. The separated excitons create voltage at the ends of the photovoltaic cell. These processes continue as long as the photons fall on the battery surface. Photons coming from the sun that are not converted into electrical energy increase the temperature of the photovoltaic cell (Clean Energy Institute, 2014; Tushar K. Ghosh and Mark A. Prelas, 2011).

The main material of the photovoltaic cell structure consists of PN semiconductors in the middle layer, as seen in Figure 4-b. The top part of the photovoltaic cell is covered with transparent glass and plastic materials to protect it from external influences. The bottom layer has an anti-reflective coating to absorb sunlight as much as possible and prevent reflection. If there is no anti-reflective coating, nearly one-third of the sunlight falling on the battery surface will be reflected and cannot be used. Under the anti-reflective coating, there is a front negative contact (front contact surface, upper connection contact, negative pole grid), whose material is usually Copper (Cu), which allows the electric current to be collected and transmitted to the network. Under this layer, there is a structure where electric current occurs. This structure consists of two different layers. The first is the N-layer, which is the layer with the addition of Phosphorus atoms to Silicon and forms the negative side of the PV cell. The second P-layer is the layer that forms the positive side of the battery, consisting of Silicon with added Boron atoms. The area where positive and negative charges meet, called the PN junction, is between these two layers. The back contact (layer), where electrons enter and acts as a positive contact, is on the back surface of the PV cell. This layer provides support to the cell and ensures that the circuit in which electrons enter is completed (Özgün et al., 2022; Tushar K. Ghosh and Mark A. Prelas, 2011).

3.1.2 Power Efficiencies and Usage Areas of Photovoltaic Cells

Photovoltaic battery is measured by its efficiency, and the most important parameter that determines the efficiency is the percentage of the generated energy that can be converted into usable electricity. Additionally, efficiency can be defined as the ratio of the photon energy falling on the photovoltaic cell surface to the resulting voltage. A beam of light corresponding to a wavelength above a certain energy level is sufficient to provide the required energy. The majority of the remaining light beam is either absorbed or reflected by the structural material in the cell. However, the efficiency of the solar cell depends on factors such as the area of the PV module, the terrain, the manufacturing and assembly method, etc. Efficiencies ranging from 10% to 40% are observed for various materials used in PV cells (Geisz et al., 2018; Green et al., 2018).

PV technologies are widely used in the direct conversion of radiant energy to electricity. PV technology is suitable for regions with low and high solar radiation.

Solar PV systems can be used for large-scale electricity generation. PV technology is also sustainable, especially for small-scale applications. PV systems can be used both connected to the grid and independently of the grid.

Some of their notable features are that they operate silently, do not cause any pollution, and can operate in harsh (arid/semi-arid) climate conditions with few people for operation and maintenance (Ma, Yang, and Lu, 2014).

Another important feature is that maintenance and operating costs after installation are lower than other energy production systems. Since the panel efficiency is around 20-30% in the first use and the efficiency decreases over the years, the payback period for its costs is quite long. For this reason, in order to benefit from photovoltaic panels effectively, it is extremely important to choose a system suitable for the purpose of use and the area to be installed.

A lot of research has been donated to achieve the most efficient and cost-effective material for PV cells. The following requirements are sought for ideal solar cell material. (Goetzberger et al., 2002):

- The material used to produce solar cells must have a band gap of 1.1 to 1.7 eV.
- The material must have a direct band structure

- The material should be easily available and non-toxic.
- The material must be suitable for large-scale production and can be easily reproduced,
- The material must have a long-term stability factor and good PV conversion efficiency.

Some major disadvantages associated with PV solar cell technologies are:

- In the solar cell production process, nano-sized semiconductor materials, hazardous chemicals, etc. is dealt with. If not used and disposed of appropriately, these materials can affect the environment and health (Kazmerski, 2012; Mitigation, 2011).

For large-scale electricity generation applications, it requires large land due to the low power density of the photovoltaic module (Cucchiella, D'Adamo, Gastaldi, and Koh, 2010).

3.1.3 Classification of Photovoltaic Cells

In this section, the classification of photovoltaic cells according to their generation is presented under subheadings.

First Generation Photovoltaic Cells

Cells that use high purity Silicon crystals as raw materials are called first generation cells. Monocrystalline or polycrystalline silicon can be utilized with large grain sizes. It is the most dominant PV cell type on the market. Since silicon has no reserve shortage, its efficiency has improved considerably since its first production. Silicon is the most widely used material in solar cell production due to its excellent electronic, chemical and mechanical properties, durable crystal structure and non-toxic properties. Silicon's crystal structure, which does not deteriorate easily, ensures its optical and electrical properties are permanent. Solar energy technologies based on this semiconductor are considered the most advanced.

In general, the advantages of first-generation can be given as more efficient at lower temperatures and need less space for a given unit of power. Additionally, due to the development of strip silicon technology, it is anticipated that the production cost of this generation will decrease further.

Second Generation Photovoltaic Cells

Second-generation technology was introduced in the 1970s to avoid the high economic and environmental cost (in terms of materials and energy) of crystalline silicon-based cells. This generation uses less semiconductor material while maintaining the appropriate efficiency of the cell. Thin film cells are considered second generation PV cells. Solar cells produced with this technology are very thin. Thin film solar cell technology uses a 1-10µm thick photoactive layer (Boutchich et al., 2012).

Since less silicon material is used in the production process, their costs are lower than the first-generation cells and the production process is shorter; However, they still have a small share of the market due to their lower efficiency than c-Si. The thickness of the film layers varies from a few nanometers (nm) to tens of micrometers (µm) . Therefore, they can be placed on flexible materials, connected to modules in the manufacturing process via laser cutting, and stacked vertically to form third-generation tandem (multi-joint) cells (NREL, 2023b).

Thin film modules shows better performance under low irradiance conditions. Aesthetically, they are flexible and lightweight.

Third Generation Photovoltaic Cells

The relatively high cost and complex manufacturing of first- and second-generation silicon cells have encouraged researchers to develop new PV technologies, namely third generation PV cells. Third generation photovoltaic cells are the development of first-generation and second-generation PV cells for higher efficiency and environmental friendliness.

Third generation photovoltaic cells include many innovative technologies, and many are still in the R&D phase. These cells generate electricity using new technology processes based on organic, semi-organic or inorganic materials, hybrid systems, nanometer and molecular scale components. In most cases, they are made with thin-film-based cells in most cases (Blieske et al., 2019).

The notable features of these cells include low material and production costs and simplicity of the production process. Although silicon-based solar cells are more power efficient, third-generation PV cells are better in aspect of sustainability. Lots of effort is being devoted to improving the efficiency of these solar cells. According to the relevant research, the efficiency of third-generation PV cells is comparable to silicon solar cells. (Malinowski, Leon, and Abu-Rub, 2017).

Although they are currently mainly in the laboratory stage, they are quite promising for future applications and will soon take their place in the market.

3.2 Concentrated Solar Energy Systems (CSP)

With today's technology, generating electricity from steam using steam turbines has become widespread. High temperatures are required to produce electricity with steam turbines. Concentrating systems have been developed to reach these levels. Solar capacitor systems focuses the rays from the sun on a narrow area.

Thermal CSP technology does not have a mechanism that is made of crystalline silicon and uses solar energy directly, as in PV cells. CSP is a clean energy source that works according to the principles of traditional thermal power plants. In other words, concentrator systems are used in order to produce electricity from the sun for the longest time and in high volume (Fernández-Garcia et al., 2010; Zarza E, 2010). Concentrator systems are technology based on the concentrated heat system concept, which is to condense direct normal solar radiation for producing steam or hot air, first turning it into heat (superheated steam) and producing electricity using the appropriate thermodynamic cycle and the traditional power cycle. Briefly, CSP technology has two main logics; collecting sunlight and converting it into heat and converting the heat energy into electric energy or another kind of useful energy through secondary mechanisms. Figure 5 shows the simplified operating diagram of the CSP system.

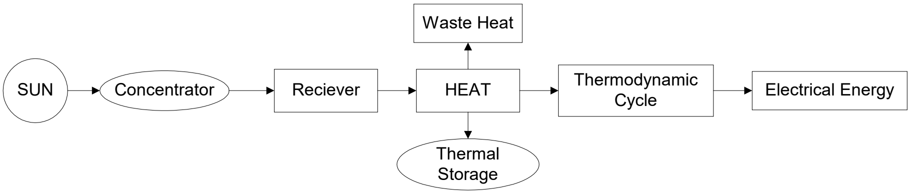


Figure 5. CSP working diagram.

The amount of sunlight falling on the ground varies depending on location on earth, seasons and time of day. While the position of the sun's rays is more perpendicular to the earth on summer days, it is more inclined on winter days. On a clear day, high solar irradiation (DNI) represents 80-90% of the total solar energy, while on a cloudy day, the DNI rate is close to zero. In this context, it is not possible to obtain electricity from solar energy with the same efficiency. While the most electricity can be produced between the hours of 11-15, when the radiation is most intense, it is quite low in the morning and afternoon hours (Şen H, 2009).

The biggest advantage of these systems compared to other solar energy technologies is that the heat can be stored in a short time and thus can produce electricity even during cloudy or evening hours, that is, when there is no sun. This possibility can be realized by integrating energy storage systems to save thermal energy from daylight for use during periods of no sunlight.

The advantages and disadvantages of CSP technology are given below.

Advantages :

- It can be installed in hot, dry, harsh climatic conditions and operate without human intervention.

- It includes readily available components such as mirrors, tubes, and electrical generators.
- It can be hybridized with fuel systems (hybridization, combination) and heat can be stored. Hybridization ensures continuity by increasing electricity production from the power plant to 24 hours a day, 330 days a week. Heat storage, on the other hand, can keep the heat stored during the day in molten salt tanks, producing electricity for another 5-7 hours after sunset and responding to the rising consumption in the evening hours. The biggest advantage of concentrating systems is that they can store heat and quickly convert it into electrical energy when necessary. The ability to provide energy when needed, regardless of time difference, during busy periods makes CSP systems attractive.
- In addition to electricity generation, CSP technologies can also meet industrial heat and desalination (a process that removes mineral components from salt water) needs.

Disadvantages:

- These systems are highly dependent on daylight and affect the efficiency of the system in bad weather conditions.
- CSP needs direct sunlight. For this reason, CSP's installation areas are limited.
- CSP technology has many advantages for large-scale electricity generation, but requires quite large space to install the plant.
- CSP technologies are not suitable for small-scale electricity generation as they require high production costs. Although it is possible to produce small volumes of electricity in CSP systems, as in PV systems, it is not economically advantageous. In Europe, the economic size is determined as 50 MW.

Although all concentrated solar energy systems basically work on the same principle, they differ in terms of collectors, which are the methods of focusing solar energy. One of the most important parameters for collectors that concentrate sunlight is the concentration factor. Concentration factor is the ratio of area of sunlight collected and area of the solar receiver. The condensation ratio is about 300 in two-dimensional concentrators (parabolic trough) and about 40000 in three-dimensional concentrators (parabolic bowl). In such collectors, sunlight can be concentrated linearly or pointwise using reflective or beam-breaking surfaces (Tabak et al., 2009).

Solar concentration technologies can be given under two headings:

- Linear condensers; Parabolic Trough Concentrators and Linear Fresnel Concentrators;

- Point concentrators; Central Receiver Concentrators and Parabolic Dish Concentrators.

3.2.1 Parabolic Trough Concentrators

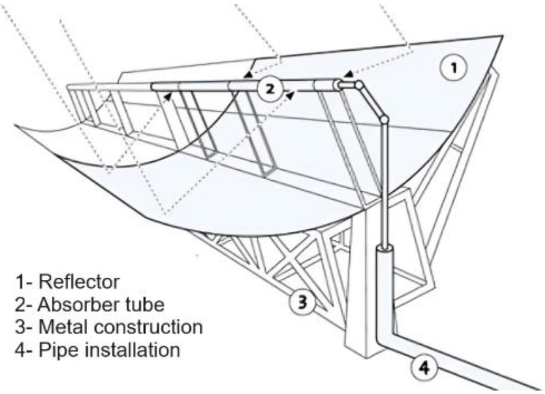
Parabolic trough concentrators are the most proven, most advanced, most economical and commercially creditable CSP technology among the technologies available today. Parabolic trough concentrator systems are equipped with a solar tracking mechanism that monitors the sun throughout the day to receive maximum solar radiation as shown in Figure 6-a.

Power plants with parabolic trough concentrators mainly consist of the following components: Parabolic trough reflector, heat transfer system, Rankine steam turbine/generator cycle, thermal storage system (optional).

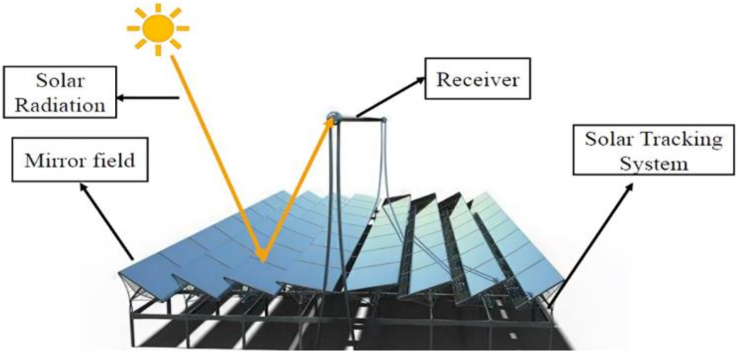
Parabolic trough collectors are placed on the solar field in series and parallel rows and solar energy is collected at the power center and converted into electricity.

The collector consists of a parabolic mirror in which the reflective surfaces inside concentrate the rays on the absorbent receiver tube extending along the focal axis. Parabolic trough reflectors are generally 100m long, 6m aperture, and are positioned on the north-south axis. The mirror placed on the north-south axis focuses the sun along the axis on the receiver tube during daylight hours (Gülay İşler, 2018). The receiver pipe is a stainless-steel pipe coated to maximize the absorbance in the solar spectrum wavelength, with a surface absorbency of approximately 97%, consisting of glass-metal connectors, and containing the working fluid, placed slightly above the middle part of the parabolic mirror. This steel tube is placed inside the glass tube to minimize heat loss.

A vacuum condition is created between the tube and the pipe. Vacuum has a key role in receiver insulation, and lack of vacuum can result in four times more heat loss. Borosilicate glass tube is heat resistant, has an antireflective structure and high transmittance to minimize radiation losses. Solar radiation focuses on the receiver pipe located at the focal point of the parabolic slotted reflector. The concentrated radiation from the sun passes through the glass tube and hits the absorbing coating. It heats the working fluid (molten salt or synthetic oil) in the pipe to a temperature of 150-400°C, making the heated working fluid hot enough to produce steam used to drive a conventional steam turbine that produces power. The oil heated by the condensation process transfers heat energy to the water, causing the water to evaporate. If water is used as the heat transfer fluid, water vapor can be obtained directly. The resulting water vapor rotates the turbine and electricity is produced (Gülay İşler, 2018).



a)



b)

Figure 6. Parabolic and Linear Fresnel power plant schemes a) Parabolic Trough Power Plant Diagram (Eddine Boukelia and Mecibah, 2013) , b) Linear Fresnel concentrator power plant scheme (Patricia Scalco, Jacqueline Biancon Copetti, and Mario Henrique Macagnan, 2021).

PTCs are categorized by their operating temperatures. Generally, PTCs operate in the temperature range between 350 and 550 °C and are used mainly for electricity generation, while those operating in the 100-250 °C range are used for heating purposes (NREL, 2003).

3.2.2 Linear Fresnel Concentrators

This type of collector was first produced in Genoa in 1960 as linear and two-axis tracking, and its development continues (Nelson, Evans, and Bansal, 1975). In 1993, the first linear Fresnel concentrators (LFR) were developed at the University of Sydney and patented in 1995 (Üçgül and Ergün, 2014).

LFR are systems that focus and concentrate direct solar radiation coming at different angles onto a raised linear receiver with planar strip mirrors arranged on both sides of the receiver and transfer the heat to heat transfer fluid (HTF). The receiver, as in Figure 6-b, is a long tube coated with absorbing material known as a black chrome solar absorber. In this way, the air in the absorber is heated and this heat is transferred to the pipe inside the absorber and the fluid in the pipe. The resulting steam can be used directly if desired, or it can transfer this thermal energy to the traditional electricity generation system and be converted into electrical energy through a turbine (Engin Ergün, 2011). The most visible difference against the parabolic trough concentrators is the use of planar mirrors as reflecting surfaces in these systems.

Some components of the reflector are not used due to obstruction and inter-row shading. The energy cost of LFR increases due to a couple of reasons like heat losses, tube absorptivity and reflectivity of surfaces. LFR has thermal storage capacity as the operating temperature can reach up to 565°C with molten nitrate as HTF (Morin, Karl, Mertins, and Selig, 2015; V. Sharma, Nayak, and Kedare, 2015).

Linear Fresnel systems have several advantages that have attracted the attention of researchers. The notable ones are listed as follows:

- Linear Fresnel concentrators provide very high temperature for a variety of thermal energy applications.
- It is not necessary to use HTF or heat exchanger in DSG type power plants using linear Fresnel condenser.
- Since flat or elastic reflectors are used in its structure, it is much lower cost than parabolic trough reflectors.
- Due to its location close to the ground, less space is needed.
- High operating temperature and thermal efficiency, reduced investment costs and shortened payback period are other advantages of these systems.
- This technology can be used to produce hydrogen.

Being an innovative technology that has made great progress, the disadvantages associated with LFR are mostly technical and commercial as follows:

- Linear Fresnel concentrators are less efficient than other concentrators due to heat losses resulting from the single-axis solar tracking mechanism and linear focusing (Ong, Campbell, Denholm, Margolis, and Heath, 2013).
- Improved materials are needed to prevent ultraviolet degradation.
- To prevent dust from remaining in the gutters, they must be cleaned constantly.
- It requires excessive cost and maintenance due to the necessity of a monito-

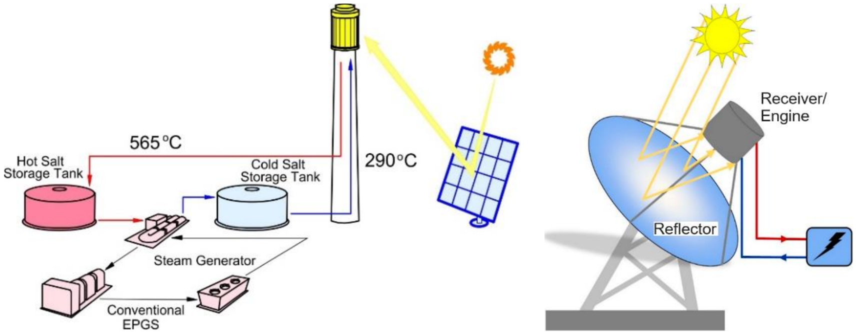
ring system that increases its efficiency.

- To perform well, HTF such as molten salt is required as the operating temperature of the system is relatively high.
- It requires high solar radiation.

3.2.3 Central Receiver System (Solar Tower)

Central receiver tower technology is a type of solar thermal electricity generation system that performs point focusing. Central receiver systems (Solar tower) basically consist of two units: a tower carrying the receiver and mirrors (heliostat) placed around the tower to reflect the sun's rays to the receiver.

The rays coming from the sun are concentrated on the fixed receiver in the tower by mirrors with dual-axis solar tracking mechanism spread over a wide area, as shown in Figure 7-a. Distributed mirrors called heliostats follow the sun throughout the day. Each heliostat moves independently of each other and is constantly controlled by the computer, ensuring that the receiver always receives sunlight. The fixed receiver absorbs the radiation concentrated by the heliostats and obtains concentrated high heat energy. It transfers this heat to the heat transfer fluid (HTF). The molten salt (liquid salt melt) passing through the receiver is sent to the storage tank by increasing the temperature of a working fluid such as hot gas or water up to 565°C, and then the HTF produces steam by transferring the heat to the water (Tushar K. Ghosh and Mark A. Prelas, 2011). The produced steam is sent to the turbine to produce electrical energy. The efficiency of a typical solar tower is 15% to 25%. These facilities are the most suitable for applications between 30-400 MW.



a) b)

Figure 7. Central receiver and parabolic dish systems: a) Power plant scheme with central receiver system (Avila-Marin, Fernandez-Reche, and Tellez, 2013) b) Parabolic dish collector (Soomro et al., 2019).

Heat storage systems have been developed to enable central receiver systems to operate even when there is no sun. Thus, the continuity of the system is ensured. It is not commercially common like parabolic trough systems due to its high costs.

3.2.4 Parabolic Dish Concentrators

Parabolic dish concentrators can be defined as point focusing devices consisting of a concave (dish) concentrator, as in Figure 7-b, a solar tracking system, a heat absorber (receiver) placed at the focal point of the dish, a power conversion unit and a system control unit. It consists of many small flat mirrors placed to provide the shape of the parabolic dish collector or a single reflector in the form of a parabolic dish.

The bowl-shaped surface is concentrated (3000-4000 times) by focusing sunlight (about 92%) onto the receiving surface. The concentrated solar radiation collected by the receiver can be used in two ways: it is converted into thermal energy and used as direct heat energy, or it is transferred to the working fluid in the Stirling engine connected to the receiver and converted into electrical energy (T. Mancini et al., 2003).

Parabolic dish concentrators, consisting of one or more reflective surfaces, follow the sun on a dual axis and have high focusing rates. Independently these dishes can produce 5–50kW of electricity and their capacity can be increased by using them in series (J R Bean and Diver, 1993; Tushar K. Ghosh and Mark A. Prelas, 2011). The temperature range for Parabolic Dish Concentrators ranges from 400°C to 750°C with a condensation ratio of over 3000 and a thermal efficiency of 23%.

Stirling engine, which has good performance at temperatures lower than 950°C, is generally preferred for electricity generation in parabolic bowl concentrators. However, Brayton, Rankine or Rankine/Brayton engine systems can also be used. At higher temperatures, gas turbines used in combined cycles perform better (Barlev, Vidu, and Stroeve, 2011). Since there is no water cycle in parabolic dish systems with point concentration, they are very suitable for arid and desert environments.

Parabolic dish technology is suitable for small-scale power generation. Parabolic dish technology is also part of distributed solar power generation and can plays an important role to reduce the load on central power plants.

Parabolic bowl concentrators are very advantageous in terms of heat concentration rate and total system efficiency. However, they are technologically more complex and costly systems. Since energy storage is not possible, a hybrid structure design is recommended.

4. Comparison of Photovoltaic and Concentrated Systems

PV technology uses sunlight that causes the movement of electrons to produce electric current through the photovoltaic effect. CSP, on the other hand, uses sunlight to heat a liquid substance that will be used to power an electrical generator. CSP produces alternating current (AC). PV produces direct current (DC). Once the direct electric current is generated, it is converted to AC, usually using inverters, thus being distributed to the power grid.

While CSP systems can be applied in projects larger than 25 MW, PV systems also cover residential areas and the energy sector with their simple and small-scale installation.

Since PV systems produce electricity directly from sunlight instead of the sun's heat, they cannot store thermal energy. Therefore, it is clear that in terms of energy storage and efficiency, thermal energy storage technologies are better. This fact makes CSP systems a more attractive option for large-scale energy production.

Although the overall efficiency of PV plants is lower compared to CSP plants, PV systems require smaller installation area. In the same area, PV plants produce more electricity than CSP plants. The economy and efficiency of the PV cell mainly depend on its material.

PV systems can be installed more easily, at lower cost and in a much shorter time than CSP power plants, but they require more space for large-scale applications.

Installation of PV systems has a greater environmental impact compared to CSP plants. In the PV cell production process, various hazardous materials are used for semiconductor surface cleaning; Therefore, there is a risk of inhaling silicone dust for workers involved in manufacturing.

Today, PV panel prices have dropped significantly by 30-40%, and this rate is expected to increase further. Due to abundant module capacity, BNEF expects the price to drop to around $0.19 per Watt for standard modules based on 166 mm wafers. The cost per unit of CSP is higher than that of PV.

Today, CSP plants are typically combined with thermal energy storage because it reduces the cost of electricity and provides production flexibility. The biggest advantage of CSP is that it can store energy using Thermal Energy Storage technologies and quickly convert it into electrical energy when necessary. The ability to provide optionally distributed power with long-term storage during peak times and regardless of day or night makes CSP systems preferred over PV.

While CSP requires DNI, PV systems can produce electricity by emitting sunlight. For this reason, the installation areas of CSP are more limited than PV.

The solar to electricity conversion efficiency for CSP systems varies between 15-40%. Compared with CSP technologies among themselves, the efficiency of the parabolic dish collector is the highest.

According to reports published by NREL, GHG (Greenhouse gas, greenhouse gas) emissions of central receiver tower and parabolic trough-based CSP systems range between 22-23g CO_2 eq/kWh, while for c-Si and thin film PV-based systems it is 50g CO_2 eq/ kWh. It is below kWh (NREL, 2012b, 2012a). Therefore, considering the GHG emissions of both solar power plants, CSP technologies are environmentally more favorable than PV systems.

Technical comparison of PV and CSP technologies is given in Table 9. As can be seen from the table, CSP systems are more efficient than PV systems. But this does not mean that CSP systems are the best option. Among the two technologies, PV is cheaper, leading energy investors to prefer it over CSP. In other words, despite its advantages, CSP is not a preferred technology.

Table 1. Comparison of PV and CSP Systems

Method	Technology	Best Yield	Advantages	Disadvantages
PV 1st Generation	monocrystalline	16-25%	Silicon is considered the most advanced among solar cell production technologies due to its excellent electronic, chemical and mechanical properties, durable crystal structure and non-toxic properties. They are more efficient at low temperatures.	Obtaining pure Si is a complex and costly process. The production process is complex. A lot of Si is wasted in its production. The energy of the incoming photons is greater than the band gap, so excess energy is lost as heat.
	polycrystalline	14–20%		
PV 2nd Generation	Amorphous Silicon	9-14%	This generation uses less semiconductor material while maintaining the appropriate efficiency of the cell. For this reason, its cost is lower than c-Si. They are very thin, flexible and light. It has a high absorption coefficient. Although it is cheaper than the first generation, its efficiency is lower.	The efficiency of thin film solar cells is lower than silicon solar cells. The toxicity of the material used in the construction is high. It causes environmental pollution during the fabrication process.
	CIGS	23.2%		
	CdTe	22.1%		

PV 3rd Generation	Organic	11-18.22%	It has low material and production costs and simplicity of production process. It uses low-cost semiconductor materials with tunable band gap for optimum performance.	Many have not yet proven themselves commercially.
	DSSC	11.9±0.4%		
	QDSC	1.46-16.6%		
	perovskite	29.15%		
	GaAs	28.8%		
	CZTS	%11th, CZTSSe 12.6%		
	Group III-V compounds (Tandem)	20-20.8%		
CSV	Parabolic Trough	24-26% (15-16% annually)	In addition to electricity generation, it can also meet industrial heat and desalination needs. It can be installed in hot, dry, harsh climatic conditions and operate without human intervention. Its components are simple. They can be hybridized with fuel-fired systems and store heat.	It is not suitable for small-scale electricity production as it requires high production costs. It is highly dependent on daylight and affects the efficiency of the system in bad weather conditions. A solar tracker and cooling system are required and these systems are quite expensive.
	Linear Fresnel	13% (9-13% annually)		
	With Central Receiver	14-20% (17-18% annually)		
	Parabolic Dish	30-34%		

5. Conclusion

Energy is a fundamental input of civilization and one of the most valid symbols used to determine the production, consumption, and development levels of civilizations. It is also a key factor driving social and economic development. With the increase in technological devices, per capita energy consumption is rising day by day. To meet the growing energy demand, water resources, along with fossil and nuclear fuels, are predominantly used. However, the construction costs, construction and commissioning times, and operating costs and durations required for the use of these resources make it challenging for production facilities to keep up with demand. Additionally, the negative environmental impacts and CO_2 emissions of these production facilities pose a threat to current and future generations. This situation encourages the world to seek renewable energy sources.

Although renewable energy sources are not a new topic, studies in this field have accelerated, especially due to the limited availability of fossil fuel resources and the visible environmental damages they cause. These studies, particularly focusing on solar and wind energy, fundamentally aim to increase efficiency and reduce costs. As a result of these studies, the share of renewable energy sources (excluding hydro) in global energy production was 2.1% as of 2021, and this is projected to increase to approximately 11% by 2045. As of 2022, the share of solar energy in total global energy production is 68.2%.

In this study, the methods used to generate electrical energy from solar energy have been investigated. In the literature, the methods used to obtain electricity from solar energy are divided into direct conversion and indirect conversion. For direct conversion, the photovoltaic effect is utilized. The PV effect can be defined as the voltage difference generated when light falls on a system consisting of two electrodes connected to each other, either in solid or liquid form. PV systems can be analyzed according to their technologies and generations. In indirect conversion, concentrated solar power technology, which generates electrical energy from steam by concentrating solar energy, is used. CSP systems can be categorized into linear concentrators and point concentrators. Due to their need for large installation areas, they are generally preferred in regions far from residential areas and in production stations with capacities over 25 MW.

This study aims to serve as a resource for researchers working on generating electrical energy from solar energy. To this end, the methods used to generate electrical energy from solar energy to date have been examined from a historical perspective. Both conversion systems have been thoroughly investigated, and the studies in the literature have been reviewed. The technological level, application areas, advantages, and disadvantages of the systems are presented comparatively. In future work, it is planned to publish review studies on other renewable energy sources.

References

Abdolmaleki, L., and Berardi, U. (2024). Hybrid solar energy systems with hydrogen and electrical energy storage for a single house and a midrise apartment in North America. *International Journal of Hydrogen Energy, 52,* 1381–1394. Retrieved from https://www.sciencedirect.com/science/article/pii/S0360319923059682

Ackermann, A. S. E. (1915). *The Utilisation of Solar Energy. Journal of the Royal Society of Arts, 63* (3258), 538–565. Retrieved from https://www.jstor.org/stable/41346462

Ahmed, M. M., Das, B. K., Das, P., Hossain, M. S., and Kibria, M. G. (2024). Energy management and sizing of a stand-alone hybrid renewable energy system for community electricity, fresh water, and cooking gas demands of a remote island. *Energy Conversion and Management, 299,* 117865. Retrieved from https://www.sciencedirect.com/science/article/pii/S0196890423012116

Alferov, Z. I., Andreev, V. M., Garbuzov, D. Z., Zhilyaev, Y. V, Morozov, E. P., Portnoi, E. L., and Trofim, V. G. (1971). Investigation of the influence of the AlAs-GaAs heterostructure parameters on the laser threshold current and the realization of continuous emission at room temperature. *Sov. Phys. Semicond, 4*(9), 1573–1575. Retrieved from http://62.44.99.18/photonics/Lasers/Beginning-of-the-Laser-Era-in-the-USSR.pdf#page=132

Arias, I., Cardemil, J., Zarza, E., Valenzuela, L., and Escobar, R. (2022). Latest developments, assessments and research trends for next generation of concentrated solar power plants using liquid heat transfer fluids. *Renewable and Sustainable Energy Reviews, 168,* 112844. https://doi.org/10.1016/j.rser.2022.112844

Asım Genç. (1998). P*erformance Tests of Parabolic Through Type Solar Concentrator Tracking Sun on One Axis* (MSc). Gazi University, Ankara.

Avila-Marin, A. L., Fernandez-Reche, J., and Tellez, F. M. (2013). Evaluation of the potential of central receiver solar power plants: configuration, optimization and trends. *Applied Energy, 112,* 274–288. https://doi.org/10.1016/j.apenergy.2013.05.049

Ayşe Özge Küpeli. (2005). *Solar cells and their efficiencies* (MSc). Eskişehir Osmangazi University, Eskişehir.

Baharoon, D. A., Rahman, H. A., Omar, W. Z. W., and Fadhl, S. O. (2015). Historical development of concentrating solar power technologies to generate clean electricity efficiently – A review. *Renewable and Sustainable Energy Reviews, 41,* 996–1027. https://doi.org/10.1016/j.rser.2014.09.008

Bakos, G. C. (2006). Design and construction of a two-axis Sun tracking system for parabolic trough collector (PTC) efficiency improvement. *Renewable Energy, 31*(15), 2411–2421. https://doi.org/10.1016/j.renene.2005.11.008

Barlev, D., Vidu, R., and Stroeve, P. (2011, October 1). Innovation in concentrated solar power. *Solar Energy Materials and Solar Cells,* Vol. 95, pp. 2703–2725. Elsevier B.V. https://doi.org/10.1016/j.solmat.2011.05.020

Baum, V. A., Aparasi, R. R., and Garf, B. A. (1957). High-power solar installations. *Solar Energy, 1*(1), 6–12. https://doi.org/10.1016/0038-092X(57)90049-X

Bean, John R, and Diver, R. B. (1995). *Technical status of the dish/stirling joint venture program.* Retrieved from https://www.osti.gov/biblio/79749

Bean, J R, and Diver, R. B. (1992). *The CPG 5-kWe dish-Stirling development program.* Retrieved from https://www.sae.org/publications/technical-papers/content/929181/

Bean, J R, and Diver, R. B. (1993). *Performance of the CPG 7. 5-kW [sub e] Dish-Stirling system.* Retrieved from https://www.osti.gov/biblio/6158070

Bi, P., Ren, J., Zhang, S., Wang, J., Chen, Z., Gao, M., … others. (2022). Low-cost and high-performance poly (thienylene vinylene) derivative donor for efficient versatile organic photovoltaic cells. *Nano Energy, 100,* 107463. https://doi.org/10.1016/j.nanoen.2022.107463

Blieske, U., Müller-Ost, J., Meisenzahl, K., Grommes, E.-M., Gecke, R., Schneble, N., … Volk, M. (2019). Current and future trends in photovoltaic technology. *2019 International Energy and Sustainability Conference (IESC)*, 1–5. https://doi.org/10.1109/IESC47067.2019.8976871

Boutchich, M., Alvarez, J., Diouf, D., i Cabarrocas, P. R., Liao, M., Masataka, I., … Kleider, J.-P. (2012). Amorphous silicon diamond based heterojunctions with high rectification ratio. *Journal of Non-Crystalline Solids, 358*(17), 2110–2113. https://doi.org/10.1016/j.jnoncrysol.2011.12.067

Chander, S., and Tripathi, S. K. (2023). Advancement in CdMnTe-based photovoltaic cells: Grain growth, deep states and device efficiency assessment with chlorine treatment. *Solar Energy, 250,* 91–96. https://doi.org/10.1016/j.solener.2022.12.033

Chen, Y. T., Kribus, A., Lim, B. H., Lim, C. S., Chong, K. K., Karni, J., … Bligh, T. P. (2004). Comparison of two sun tracking methods in the application of a heliostat field. *J. Sol. Energy Eng., 126*(1), 638–644. https://doi.org/10.1115/1.1634583

Clean Energy Institute. (2014). Copper indium selenide(CIS) solar cell. Retrieved July 8, 2021, from https://www.cei.washington.edu/wp-content/uploads/2014/04/PVcelldisplaycards.pdf

Collares-Pereira, M., Gordon, J. M., Rabl, A., and Winston, R. (1991). High concentration two-stage optics for parabolic trough solar collectors with tubular absorber and large rim angle. *Solar Energy, 47*(6), 457–466. https://doi.org/10.1016/0038-092X(91)90114-C

Collares-Pereira, M., Ogallagher, J., Rabl, A., Winston, R., Cole, R., Gorski, A., … Schertz, W. (1979). Applications of CPC's in solar energy-An overview. Sun II, 1, 542–546. Retrieved from https://ui.adsabs.harvard.edu/abs/1979sun2.conf..542C/abstract

Cucchiella, F., D'Adamo, I., Gastaldi, M., and Koh, S. C. L. (2010). A photovoltaic system in a residential building: Environmental and economic optimization analysis. *2010 8th International Conference on Supply Chain Management and Information, 1–9.* Retrieved from https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5681782

Doraiswamy, D. (2002). The origins of rheology: a short historical excursion. *Rheology Bulletin, 71*(1), 1–9. Retrieved from http://www0.rheology.org/sor/publications/rheology_b/Jan02/Origin_of_Rheology.pdf

D. R. Mills. (2001). Solar Thermal Electricity. In J. Gordon (Ed.), *Solar Energy: The State of the Art : ISES Position Papers.* James & James.

Eddine Boukelia, T., and Mecibah, M.-S. (2013). Parabolic trough solar thermal power plant: Potential, and projects development in Algeria. *Renewable and Sustainable Energy Reviews, 21,* 288–297. https://doi.org/10.1016/j.rser.2012.11.074

Engin Ergün. (2011). Usage of linear Fresnel solar power systems at textile companies to supply energy (MsC). *Süleyman Demirel University,* Isparta.

Eric Mack. (2016, May 17). New world record set for converting sunlight to electricity. Retrieved December 5, 2023, from Newatlas website: https://newatlas.com/solar-cell-electricity-efficiency-world-record-unsw/43384/

Ermer, J. H., Jones, R. K., Hebert, P., Pien, P., King, R. R., Bhusari, D., … others. (2012). Status of C3MJ+ and C4MJ production concentrator solar cells at spectrolab. *IEEE Journal of Photovoltaics, 2*(2), 209–213. https://doi.org/10.1109/JPHOTOV.2011.2180893

Falope, T., Lao, L., Hanak, D., and Huo, D. (2024). Hybrid energy system integration and management for solar energy: A review. *Energy Conversion and Management: X,* 100527. Retrieved from https://www.sciencedirect.com/science/article/pii/S2590174524000059

Fernández-Garcia, 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. https://doi.org/10.1016/j.rser.2010.03.012

Fortunato, E., Gaspar, D., Duarte, P., Pereira, L., Águas, H., Vicente, A., … Martins, R. (2016). Optoelectronic devices from bacterial nanocellulose. *In Bacterial Nanocellulose* (pp. 179–197). Elsevier. https://doi.org/10.1016/B978-0-444-63458-0.00011-1

Fraas, L. M., and O'Neill, M. J. (2023). History of solar cell development. *In Low-cost solar electric power* (pp. 1–12). Springer.

Gallup, D., Mancini, T., Christensen, J., and Beninga, K. (1994). The utility-scale joint-venture program. *Intersociety Energy Conversion Engineering Confe-*

rence, 3941. https://doi.org/10.2514/6.1994-3941

Garcia-Valladares, O., and Velázquez, N. (2009). Numerical simulation of parabolic trough solar collector: Improvement using counter flow concentric circular heat exchangers. *International Journal of Heat and Mass Transfer, 52*(3–4), 597–609. https://doi.org/10.1016/j.ijheatmasstransfer.2008.08.004

Gaul, H., and Rabl, A. (1980). *Incidence-angle modifier and average optical efficiency of parabolic trough collectors.* https://doi.org/10.1115/1.3266115

Gee, R., and Institute, S. E. R. (1980). Line-focus Sun Trackers. *Solar Energy Research Institute.* Retrieved from https://books.google.com.tr/books?id=HytwwEACAAJ

Geisz, J. F., Steiner, M. A., Jain, N., Schulte, K. L., France, R. M., McMahon, W. E., … Friedman, D. J. (2018). *Building a Six-Junction Inverted Metamorphic Concentrator Solar Cell. IEEE Journal of Photovoltaics, 8*(2), 626–632. https://doi.org/10.1109/JPHOTOV.2017.2778567

Goetzberger, A., Luther, J., and Willeke, G. (2002). Solar cells: past, present, future. *Solar Energy Materials and Solar Cells, 74*(1–4), 1–11. https://doi.org/10.1016/S0927-0248(02)00042-9

Gong, J., and Sumathy, K. (2016). Active solar water heating systems. *In Advances in Solar Heating and Cooling* (pp. 203–224). Elsevier. https://doi.org/10.1016/B978-0-08-100301-5.00009-6

Green, M. A., Hishikawa, Y., Dunlop, E. D., Levi, D. H., Hohl-Ebinger, J., and Ho-Baillie, A. W. Y. (2018). Solar cell efficiency tables (version 52). *Progress in Photovoltaics: Research and Applications, 26*(7), 427–436. https://doi.org/10.1002/pip.3040

Gülay İşler. (2018). *Energy production analysis and applications of parabolic through collector and solar power tower* (MSc). Bilecik Şeyh Edebali University, Bilecik.

Güven, A. F., and Mete, M. K. (2021). Balkesir'in Erdek ilçesi için şebeke bağlantl hibrit enerji sistemi fizibilite çalışması ve ekonomik analizi. *Mühendis ve Makina, 63*(706), 138–158. Retrieved from https://dergipark.org.tr/tr/download/article-file/1935109

Güven, A. F., and Samy, M. M. (2022). Performance analysis of autonomous green energy system based on multi and hybrid metaheuristic optimization approaches. *Energy Conversion and Management, 269,* 116058. Retrieved from https://www.sciencedirect.com/science/article/pii/S0196890422008469

Güven, A. F., Yörükeren, N., and Mengi, O. Ö. (2024). Multi-objective optimization and sustainable design: a performance comparison of metaheuristic algorithms used for on-grid and off-grid hybrid energy systems. *Neural Computing and Applications, 36*(13), 7559–7594. Retrieved from https://link.springer.com/article/10.1007/s00521-024-09585-2

Güven, A. F., Yörükeren, N., and Samy, M. M. (2022). Design optimization of a stand-alone green energy system of university campus based on Jaya-Harmony Search and Ant Colony Optimization algorithms approaches. *Energy, 253,* 124089. Retrieved from https://www.sciencedirect.com/science/article/pii/S0360544222009926

Güven, A. F., and Yücel, E. (2023). Application of HOMER in assessing and controlling renewable energy-based hybrid EV charging stations across major Turkish cities. *International Journal of Energy Studies, 8*(4), 747–780. Retrieved from https://dergipark.org.tr/en/download/article-file/3250495

Hession, P. J., and Bonwick, W. J. (1984). Experience with a sun tracker system. *Solar Energy, 32*(1), 3–11. https://doi.org/10.1016/0038-092X(84)90042-2

IEA. (2023). *Renewables 2023 Analysis and forecast to 2028.* Retrieved from https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf

International Energy Agency. (2011). *Solar Energy Perspectives.* Retrieved from https://iea.blob.core.windows.net/assets/2b3c53f4-1c8f-478c-a4fa-a98597cde27b/SolarEnergyPerspectives.pdf

Ishibashi, A., Itabashi, M., Mori, Y., Kaneko, K., Kawado, S., and Watanabe, N. (1986). Raman scattering from (AlAs) m (GaAs) n ultrathin-layer superlattices. *Physical Review B, 33*(4), 2887. https://doi.org/10.1103/PhysRevB.33.2887

Jagdeo, K., Sharon, M., and White, S. (2021). Carbon Nanofiber and Photovoltaic Solar Cell. *Carbon Nanofibers: Fundamentals and Applications, 313.* https://doi.org/10.1002/9781119769149.ch12

Jeter, S. M. (1986). Calculation of the concentrated flux density distribution in parabolic trough collectors by a semifinite formulation. *Solar Energy, 37*(5), 335–345. https://doi.org/10.1016/0038-092X(86)90130-1

John Fitzgerald Weaver. (2018, December 17). Efficiency record isn’t the biggest change for Alta Devices’ GaAS solar technology. *PV Magazine.* https://doi.org/10.1109/ACCESS.2020.3039457

Kalogirou, S., Lloyd, S., and Ward, J. (1997). Modelling, optimisation and performance evaluation of a parabolic trough solar collector steam generation system. *Solar Energy, 60*(1), 49–59. https://doi.org/10.1016/S0038-092X(96)00131-4

Kapluhan, E. (2015). A Research In The Fıeld Of Energy Geography: Usage Of Solar Energy In The World And Turkey. *Coğrafya Dergisi, (29)*, 70–98. Retrieved from https://dergipark.org.tr/tr/download/article-file/231256

Kazmerski, L. (2012). Best research cell efficiencies chart*. In National Renewable Energy Laboratory (NREL).* Retrieved from https://www.nrel.gov/pv/cell-efficiency.html

Keskinel, S. (2015). Applied analysis of photovoltaic power systems in buildings within the scope of energy efficiency (MSc). İstanbul Technical University, İstanbul.

Khan, M. I., Asfand, F., and Al-Ghamdi, S. G. (2022). Progress in research and technological advancements of thermal energy storage systems for concentrated solar power. *Journal of Energy Storage, 55,* 105860. https://doi.org/10.1016/j.est.2022.105860

Kılıç Abdurrahman, and Öztürk Aksel. (1983). Güneş Enerjisi. Kipaş Dağıtımcılık.

King, R Richard, Boca, A., Hong, W., Liu, X. Q., Bhusari, D., Larrabee, D., … others. (2009). Band-gap-engineered architectures for high-efficiency multijunction concentrator solar cells. *24th European Photovoltaic Solar Energy Conference and Exhibition, Hamburg, Germany, 21,* 55. Retrieved from https://www.researchgate.net/profile/Chris-Fetzer/publication/267409590_Band-Gap-Engineered_Architectures_for_High-Efficiency_Multijunction_Concentrator_Solar_Cells/links/54590d030cf26d5090acff56/Band-Gap-Engineered-Architectures-for-High-Efficiency-Multijunction-Concentrator-Solar-Cells.pdf

King, R R, Law, a_DC, Edmondson, K. M., Fetzer, C. M., Kinsey, G. S., Yoon, H., … Karam, N. H. (2007). 40% efficient metamorphic GaInP/ GaInAs/ Ge multijunction solar cells. *Applied Physics Letters, 90*(18). https://doi.org/10.1063/1.2734507

Kribus, A., Vishnevetsky, I., Yogev, A., and Rubinov, T. (2004). Closed loop control of heliostats. *Energy, 29*(5–6), 905–913. https://doi.org/10.1016/S0360-5442(03)00195-6

Levent Çolak. (2003). *Mathematical modelling design and technical optimization of sun tracking parabolic trough solar collectors* (MSc). Gazi University, Ankara.

Liu, Z., Jin, Z., Li, G., Zhao, X., and Badiei, A. (2022). Study on the performance of a novel photovoltaic/thermal system combining photocatalytic and organic photovoltaic cells. *Energy Conversion and Management, 251,* 114967. https://doi.org/10.1016/j.enconman.2021.114967

Malinowski, M., Leon, J. I., and Abu-Rub, H. (2017). Solar photovoltaic and thermal energy systems: Current technology and future trends. *Proceedings of the IEEE, 105(11)*, 2132–2146. https://doi.org/10.1109/JPROC.2017.2690343

Mancini, T., Heller, P., Butler, B., Osborn, B., Schiel, W., Goldberg, V., ... Moreno, J. (2003). Dish-stirling systems: An overview of development and status. *Journal of Solar Energy Engineering, Transactions of the ASME, 125*(2), 135–151. https://doi.org/10.1115/1.1562634

Mancini, T. R. (1997). *Solar-electric dish Stirling system development.* Retrieved from https://www.osti.gov/servlets/purl/622476

Ma, T., Yang, H., and Lu, L. (2014). Solar photovoltaic system modeling and performance prediction. *Renewable and Sustainable Energy Reviews, 36,* 304–315. https://doi.org/10.1016/j.rser.2014.04.057

Merchán, R. P., Santos, M. J., Medina, A., and Hernández, A. C. (2022). High temperature central tower plants for concentrated solar power: 2021 overview. *Renewable and Sustainable Energy Reviews, 155,* 111828. https://doi.org/10.1016/j.rser.2021.111828

Messenger, R. A., and Abtahi, A. (2018). *Photovoltaic systems engineering.* CRC press.

Mills, D. (2004). Advances in solar thermal electricity technology. *Solar Energy, 76*(1–3), 19–31. https://doi.org/10.1016/S0038-092X(03)00102-6

Mills, D. R., and Morrison, G. L. (2000). Compact linear Fresnel reflector solar thermal powerplants. *Solar Energy, 68*(3), 263–283. https://doi.org/10.1016/S0038-092X(99)00068-7

Mitigation, C. C. (2011). IPCC special report on renewable energy sources and climate change mitigation. *In Renewable Energy* (Vol. 20). Retrieved from https://www.uncclearn.org/wp-content/uploads/library/ipcc15.pdf

Mohanad Abdulazeez Abdulraheem Alfellag. (2014). *Modeling And Experimental Investigation Of Parabolic Trough Solar Collector* (MSc). Embry-Riddle Aeronautical University.

Morin, G., Karl, M., Mertins, M., and Selig, M. (2015). Molten salt as a heat transfer fluid in a linear Fresnel collector–commercial application backed by demonstration. *Energy Procedia, 69,* 689–698. https://doi.org/10.1016/j.egypro.2015.03.079

Nelson, D. T., Evans, D. L., and Bansal, R. K. (1975). Linear Fresnel lens concentrators. *Solar Energy, 17*(5), 285–289. https://doi.org/10.1016/0038-092X(75)90045-6

NREL. (2003). *Assessment of Parabolic Trough and Power Tower Solar Technology*

Cost and Performance Forecasts. Retrieved from https://www.nrel.gov/docs/fy04osti/34440.pdf

NREL. (2008). *NREL Solar Cell Sets World Efficiency Record at 40.8 Percent.* Retrieved from https://phys.org/news/2008-08-nrel-solar-cell-world-efficiency.html

NREL. (2012a). *Life Cycle Greenhouse Gas Emissions from Concentrating Solar Power.* Retrieved from https://www.nrel.gov/docs/fy13osti/56416.pdf

NREL. (2012b). *Life Cycle Greenhouse Gas Emissions from Solar Photovoltaics.* Retrieved from https://www.nrel.gov/docs/fy13osti/56487.pdf

NREL. (2020, April 13). News Release: NREL Six-Junction Solar Cell Sets Two World Records for Efficiency. Retrieved November 25, 2023, from National Renewable Energy Laboratory website: https://www.nrel.gov/news/press/2020/nrel-six-junction-solar-cell-sets-two-world-records-for-efficiency.html

NREL. (2023a). *Best Research-Cell Efficiency Chart*. Retrieved from https://www.nrel.gov/pv/assets/pdfs/best-research-cell-efficiencies.pdf

NREL. (2023b). *Champion Photovoltaic Module Efficiency Chart.* Retrieved from https://www.nrel.gov/pv/module-efficiency.html

Olgun Konur. (2016). *Energy efficiency improvement techniques on solar powered boats* (MSc). Dokuz Eylül University, İzmir.

Ong, S., Campbell, C., Denholm, P., Margolis, R., and Heath, G. (2013). *Land-use requirements for solar power plants in the United States.* Retrieved from https://www.nrel.gov/docs/fy13osti/56290.pdf

OPEC. (2022). *2022 OPEC's World Oil Outlook 2045.* Retrieved from https://www.opec.org/opec_web/static_files_project/media/downloads/WOO_2022.pdf

Orton, J. W. (2008). *The story of semiconductors.* OUP Oxford.

Özgün, U. Z., ÖZDEMİR, T., and ÖZMEN, Ö. T. (2022). Associating Photovoltaic Energy Production with Meteorological Conditions: The Example of İzmir Bakırçay University. *The Journal of Graduate School of Natural and Applied Sciences of Mehmet Akif Ersoy University, 13*(1), 49–62. https://doi.org/10.29048/makufebed.1053282

Padmanabhan, J. B., and Anbazhagan, G. (2024). A comprehensive review of hybrid renewable energy charging system to optimally drive permanent magnet synchronous motors in electric vehicle. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 46*(1), 3499–3521. Retrieved from https://www.tandfonline.com/doi/full/10.1080/15567036.2024.2319347

Patricia Scalco, Jacqueline Biancon Copetti, and Mario Henrique Macagnan. (2021). Linear Fresnel Solar Collector Concentrator – A Review. *26th ABCM Int. Cong. of Mechanical Engineering.* Florianopolis. Retrieved from https://www.researchgate.net/profile/Patricia-Scalco-2/publication/357067050_Linear_Fresnel_Solar_Collector_Concentrator_-_A_Review/links/61d2ed42da5d105e5517a269/Linear-Fresnel-Solar-Collector-Concentrator-A-Review.pdf

Petrova-Koch, V., Hezel, R., and Goetzberger, A. (2008). *High-efficient low-cost photovoltaics. Springer.* https://doi.org/10.1007/978-3-030-22864-4

Prevenslik, T. V. (2003). *Cavitation induced Becquerel effect. Ultrasonics, 41*(4), 323–327. https://doi.org/10.1016/S0041-624X(03)00083-0

Richard Martinarchive page. (2016, March 3). First Solar's Cells Break Efficiency Record. Retrieved December 5, 2023, from technologyreview website: https://www.technologyreview.com/2016/03/03/161753/first-solars-cells-break-efficiency-record/

Riffelmann, K.-J., Neumann, A., and Ulmer, S. (2006). Performance enhancement of parabolic trough collectors by solar flux measurement in the focal region. *Solar Energy, 80*(10), 1303–1313. https://doi.org/10.1016/j.solener.2005.09.001

Russell S Ohl. (1948). *Patent No. US2443542A. USA.* Retrieved from https://patentimages.storage.googleapis.com/21/a3/d9/a1e314a0faba89/US2443542.pdf

Saeed, M. A., Shahzad, A., Rasool, K., Mateen, F., Oh, J.-M., and Shim, J. W. (2022). 2D MXene: a potential candidate for photovoltaic cells? A critical review. *Advanced Science, 9*(10), 2104743. https://doi.org/10.1002/advs.202104743

Salhi, B. (2022). *The photovoltaic cell based on CIGS: principles and technologies. Materials, 15*(5), 1908. https://doi.org/10.3390/ma15051908

Sarver, T., Al-Qaraghuli, A., and Kazmerski, L. L. (2013). A comprehensive review of the impact of dust on the use of solar energy: History, investigations, results, literature, and mitigation approaches. *Renewable and Sustainable Energy Reviews, 22,* 698–733. https://doi.org/10.1016/j.rser.2012.12.065

Şen H. (2009). Temiz Dünya Rehberi: Güneş Enerjisi. *Doğa Yayınları.*

Shakibi, H., Afzal, S., Shokri, A., and Sobhani, B. (2022). Utilization of a phase change material with metal foam for the performance improvement of the photovoltaic cells. *Journal of Energy Storage, 51,* 104466. https://doi.org/10.1016/j.est.2022.104466

Sharaf, M., Huzayyin, A. S., and Yousef, M. S. (2022). Performance enhancement of photovoltaic cells using phase change material (PCM) in winter. *Alexandria Engineering Journal, 61*(6), 4229–4239. https://doi.org/10.1016/j.aej.2021.09.044

Sharma, A., Shukla, A. K., Singh, O., and Sharma, M. (2022). Recent advances in gas/steam power cycles for concentrating solar power. *International Journal of Ambient Energy, 43*(1), 4716–4727. https://doi.org/10.1080/01430750.2021.1919552

Sharma, V., Nayak, J. K., and Kedare, S. B. (2015). Effects of shading and blocking in linear Fresnel reflector field. *Solar Energy, 113,* 114–138. https://doi.org/10.1016/J.SOLENER.2014.12.026

Sheikholeslami, M. (2022). Numerical investigation of solar system equipped with innovative turbulator and hybrid nanofluid. *Solar Energy Materials and Solar Cells, 243,* 111786. https://doi.org/10.1016/j.solmat.2022.111786

Siala, F. M. F., and Elayeb, M. E. (2001). Mathematical formulation of a graphical method for a no-blocking heliostat field layout. *Renewable Energy, 23*(1), 77–92. https://doi.org/10.1016/S0960-1481(00)00159-2

Soomro, M. I., Mengal, A., Memon, Y. A., Khan, M. W. A., Shafiq, Q. N., and Mirjat, N. H. (2019). Performance and economic analysis of concentrated solar power generation for Pakistan. *Processes, 7*(9), 575. https://doi.org/10.3390/pr7090575

Stine, W. B., and Diver, R. B. (1994). *A compendium of solar dish/Stirling technology.* Sandia National Lab.(SNL-NM), Albuquerque, NM (United States). Retrieved from Sandia National Lab.(SNL-NM), Albuquerque, NM (United States) website: https://www.osti.gov/biblio/10130410

Tabak, C., Dinçer, H., Karayaz, K., Arslan, E., Yıldız, M. H., and Karayaz, S. (2009). Yoğunlaştırıcı Güneş Enerjisi Sistemleri ile Elektrik Enerjisi Üretimi. *III. Enerji Verimliliği ve Kalitesi Sempozyumu.* Retrieved from https://www.emo.org.tr/ekler/d787c069b9f2868_ek.pdf

Tang, C. W. (1986). Two-layer organic photovoltaic cell. *Applied Physics Letters, 48*(2), 183–185. https://doi.org/10.1063/1.96937

Tushar K. Ghosh, and Mark A. Prelas. (2011). E*nergy Resources and Systems: Renewable Resources* (Vol. 2). Springer. https://doi.org/10.1007/978-94-007-1402-1

Üçgül, I., and Ergün, E. (2014). Linear Fresnel Solar Power Systems. *Yekarum, 1*(3).

Retrieved from https://dergipark.org.tr/tr/download/article-file/204143

University of Delaware. (2007, July 30). *University Of Delaware-led Team Sets Solar Cell Record. Retrieved December 5,* 2023, from ScienceDaily website: https://www.sciencedaily.com/releases/2007/07/070726210931.htm

Vant-Hull, L. L. (1977). An educated ray trace approach to solar tower optics. *Optical Engineering, 16*(5), 497–504. https://doi.org/10.1117/12.7972123

Wang, J., Cui, Y., Xu, Y., Xian, K., Bi, P., Chen, Z., ... others. (2022). A new polymer donor enables binary all-polymer organic photovoltaic cells with 18% efficiency and excellent mechanical robustness. *Advanced Materials, 34*(35), 2205009. https://doi.org/10.1002/adma.202205009

Wang, Z., Tang, A., Wang, H., Guo, Q., Guo, Q., Sun, X., ... Zhou, E. (2023). Organic photovoltaic cells offer ultrahigh VOC of~ 1.2 V under AM 1.5 G light and a high efficiency of 21.2% under indoor light. *Chemical Engineering Journal, 451,* 139080. https://doi.org/10.1016/j.cej.2022.139080

William Grylls Adams. (1875). *The action of light on selenium.* Retrieved from https://www.amazon.co.uk/action-light-selenium-William-Grylls/dp/B0008ATF26

Wu, S.-Y., Xiao, L., Cao, Y., and Li, Y.-R. (2010). Convection heat loss from cavity receiver in parabolic dish solar thermal power system: A review. *Solar Energy, 84*(8), 1342–1355. https://doi.org/10.1016/j.solener.2010.04.008

Xu, Y., Lu, B., Luo, C., Wu, F., Li, X., and Zhang, L. (2022). Na2CO3 promoted CaO-based heat carrier for thermochemical energy storage in concentrated solar power plants. *Chemical Engineering Journal, 435,* 134852. https://doi.org/10.1016/j.cej.2022.134852

Zarza E. (2010). The Technologies for Concentrating Solar Radiation: Current State-of-the-Art and Potential for Improvement. *TUBITAKMAM Energy Inst. Gebze Kocaeli Turkey.*

Zarza, E., Valenzuela, L., Leo, J., Weyers, H.-D., Eickhoff, M., Eck, M., and Hennecke, K. (2002). The DISS project: direct steam generation in parabolic trough systems. Operation and maintenance experience and update on project status. *J. Sol. Energy Eng., 124*(2), 126–133. https://doi.org/10.1115/1.1467645

Zhang, T., An, C., Cui, Y., Zhang, J., Bi, P., Yang, C., ... Hou, J. (2022). A universal nonhalogenated polymer donor for high-performance organic photovoltaic cells. *Advanced Materials, 34*(2), 2105803. https://doi.org/10.1002/adma.202105803