energies

Review

Innovative Solar Concentration Systems and Its Potential Application in Angola

Erany D. G. Constantino [1], Senhorinha F. C. F. Teixeira [2], José C. F. Teixeira [1] and Flavia V. Barbosa [1,*]

[1] MEtRICs I&D Centre, School of Engineering, University of Minho, 4800-058 Guimarães, Portugal
[2] ALGORITMI I&D Centre, School of Engineering, University of Minho, 4800-058 Guimarães, Portugal
* Correspondence: flaviab@dem.uminho.pt

Abstract: Energy demands have been increasing worldwide, endangering the future supply–demand energy balance. To provide a sustainable solution for future generations and to comply with the international goal to achieve Carbon Neutrality by 2050, renewable energies have been at the top of the international discussions, actively contributing to the energy transition and climatic policies. To achieve the international goal, Angola proposed a long-term strategy that promotes a fair and sustainable development of the national territory by means of improving the electric sector. Among all the renewable resources, solar energy is found to be the most promising solution since it has the second major renewable energy potential in Angola. However, the main problem related to solar energy is the efficiency of the solar systems and the electrical and thermal energy storage. As part of the solution, Concentration Solar Power (CSP) can make a sounder contribution to the transformation of the Angolan energy sector since it enables a significant increase in energy intensity through the concentration of solar energy. Moreover, the large applicability of this technology can contribute to the development of the rural regions which still struggle for energy equity. By considering the potential of CSP, this work presents the status of the Angolan energy sector, and focus is provided on the solar potential of the country. The advantages of the CSP technologies with emphasis on the parabolic dish systems are presented, and the contribution and innovative solutions for the enhancement of thermal efficiency are presented.

Keywords: Angola; concentration solar power; solar energy; parabolic dish; thermal efficiency

Citation: Constantino, E.D.G.; Teixeira, S.F.C.F.; Teixeira, J.C.F.; Barbosa, F.V. Innovative Solar Concentration Systems and Its Potential Application in Angola. *Energies* **2022**, *15*, 7124. https://doi.org/10.3390/en15197124

Academic Editor: Jennifer A. Hayward

Received: 31 August 2022
Accepted: 26 September 2022
Published: 28 September 2022

1. Introduction

Angola is a vast country, with 1,246,700 km^2, whose energy sector suffers severe shortages of power production supply mainly due to weak power infrastructures, which constrained its development [1]. Moreover, it is estimated that in 2019, 58% of the population did not have access to electricity, mostly due to the huge costs involved with the installation of large grid-connected power lines over vast distances to supply a small number of individuals [2]. In order to contribute to the development of the Angolan energy sector, renewable energies have been at the top of governmental discussions. The most abundant resource, hydropower, has been greatly exploited, representing approximately 63% of the total electrical energy produced in the national territory [3]; solar energy has only been slightly explored despite being the second major renewable resource. Therefore, studies have already been conducted by the Angolan government to estimate the potential of the installation of new solar systems for the production of energy, and a total of 17.3 GW of solar photovoltaic projects for energy production have been identified and analyzed [4]. Even though photovoltaic systems have been considered the most appropriate technology to harness Angolan's solar resources, their intermittent character and unpredictable nature endanger the balance between supply and demand [5]. In order to overcome this situation, CSP combined with thermal energy storage was identified as a promising solution for the future of the worldwide energy sector [5–8].

CSP technologies can be divided into four different types: Solar Power Tower, Parabolic Dish System, Linear Fresnel Reflector (LFR), and Parabolic trough [9]. From these technologies, the parabolic dish has been considered one of the most promising solar thermal solutions due to its versatility, high reflectivity, and concentration ratio [10,11]. However, research is needed to increase this system's efficiency. Power generation through the solar thermal route relies on an efficient solar receiver. The receiver, placed at the collector focus, can use the incoming energy to produce electricity through a Stirling engine or thermal energy by heating a fluid that can be used in a thermal cycle such as the ORC. Other thermal applications with high temperatures consist of solar cooling, drying, cooking, and desalination, which are of great interest, mainly for rural populations who do not have access to electricity [11–13]. In order to increase the parabolic dish's efficiency, several studies have been conducted, focusing on the solar receiver design [14–18], heat transfer fluid (HTF) [10,19–23], and heat transfer enhancement techniques [16,24–26]. In addition to enhancing thermal performance, the development of innovative hybrid systems to generate both electricity and heat at reasonable costs and high thermal efficiency can be a key feature in accelerating the dissemination of this technology in Angola and worldwide [12].

From the literature review, it was found that relevant works present the recent developments that have been conducted in the parabolic dish research field [5,11–13,27–29], while few works approached the energy potential of CSP technologies in Africa [30–32]. In order to provide relevant insights regarding the actual situation of the Angolan energy sector and future projections in order to comply with the international goal of Carbon neutrality by 2050, this work presents an overview of the consumption and production of electrical energy, the potential of solar energy in Angola and emphasis is provided to the Parabolic dish technology. This work intended to provide an overview of innovative solutions developed to enhance parabolic dish systems, showing the advantages that this technology can bring to countries that are currently developing and improving their energy sector.

2. Status of the Angolan Energy Sector

This section describes the current state of electricity consumption and production in Angola, and emphasis is provided on the renewable energy technologies implemented in the Angolan territory.

2.1. Energy Consumption

According to data published in 2016 by the Angolan Ministry of Energy and Waters [33], the energy sector in Angola is characterized by a low consumption per capita (about 375 kWh per inhabitant), resulting from a low electrification rate. Data from 2021 show that about 42% of the population has access to electricity, of which 37.8% through connection to the national electricity grid [1]. The provinces in the inland of the country have the lowest levels of access rates, such as Bié, Cunene, and Lunda Norte, which are around 10%, while in Luanda, the access rate is 66%, and in Cabinda, it is 52% [33,34].

Electricity consumption in Angola is mostly urban and residential, as can be observed in Figure 1. In 2015, the domestic segment represented around 45% of all production, while services and industry were around 32% and 9%, respectively [34]. It is estimated that technical losses in the electrical network are close to 14% due to the current state of conservation of the network.

In geographical terms, consumption is still very concentrated in the northern system, which represents around 78% of the country's total electricity consumption [33]. This value is mainly related to the location of the province and city of Luanda, which records the highest number of inhabitants, around 7,976,907 recorded in 2015 [34], presenting the highest concentration of industries and services in the entire country consequently.

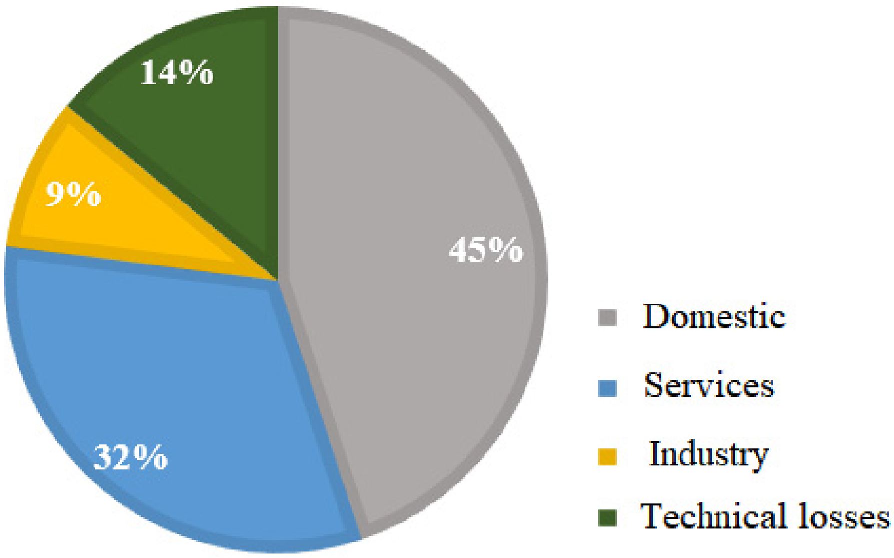

Figure 1. Electrical consumption in Angola, 2015 (data retrieved from [34]).

Due to this strong discrepancy, Angola was included in the top 20 countries with a deficit in access to electricity, published by SDG7 in 2021. SDG7 estimated that in 2019, 17,000,000 people did not have access to electricity, representing 58% of the Angolan population [2]. This deficit in electricity access is related to the lack of infrastructure for the generation, transport, and distribution of electricity, as well as the high level of losses in the electricity grid due to the bad state of the distribution network, mainly associated with the lack of investment in the energy sector [33]. Additionally, Angola currently has one of the lowest electricity tariffs in sub-Saharan Africa, which leads to financial sustainability issues for ENDE (National Energy Distribution Company) that "creates a market distortion that makes renewable solutions not appear to be as competitive as they already are" [4].

In addition to this deficiency in electricity distribution across the country, Angola presented, between 2010 and 2019, an increase in access rate of 46% [2], which is mainly due to increasing efforts in electrification conducted by the Government of Angola; the improvement of the population's living conditions, which translates into greater consumption of electricity and the increasing available production capacity [33].

2.2. Major Sources of Energy for Electrical Production

Electricity in Angola is produced by the company PRODEL (public electricity production company). In 2021, the total installed capacity of electrical production, expressed in Table 1, was 5.9 GW, divided between 62% hydropower and 37% thermal energy, in a market dominated by PRODEL, where there are 66 power stations, of which 63 are public, one corresponds to a partnership public–private, and two are private [3]. As previously mentioned, Angola is a country with a vast area, with the majority of the population located in the cities. Therefore, it is too costly to supply energy to a small number of people located in rural areas [35]. The solution implemented by the government was the implementation of Hybrid Power Systems (HPS) through solar photovoltaic panels, small wind turbines, diesel engines, micro gas turbines, and energy storage systems to supply populations located in remote areas [1]. HPS currently represents 0.6% of the total installed capacity. Data published by the company PRODEL, and presented in Table 1, show the installed and available electric energy production capacity in Angola [36].

Table 1. Current installed vs. available production power plants, 2021 (data retrieved from [36]).

Generation Type	Power (MW)	%
Total installed	5908	100.0
Hydropower installed	3676	62.2
Thermal installed	2197	37.2
Hybrid installed	35	0.6
Total available	4738	100.0
Hydropower available	3349	70.7
Thermal available	1362	28.7
Hybrid available	27	0.6

Even if most of the electricity produced in Angola comes from hydroelectric power plants, amounting to 62%, the thermal plants (37%) include seven plants with gas turbines, of which one with a combined cycle and 35 with diesel engines [3]. The fuels used for energy production are non-renewable and pollutant sources such as diesel, jet B, and natural gas. Data from 2018 show that the total CO_2 emissions recorded in Angola are 17 Mt CO_2, and this scenario is expected to increase to 33 Mt CO_2 by 2040 due to the population and GDP growth [37]. Focusing on the emissions induced by energy generation, data presented in Figure 2 show that, with the introduction of the hydropower plants, the CO_2 emissions decrease since fewer thermal plants that use fossil fuels are used for electricity and heat generation. Therefore, it is expected that the reduction in these emissions will highly decrease in the coming years with increasing the investments in the renewable energy sector.

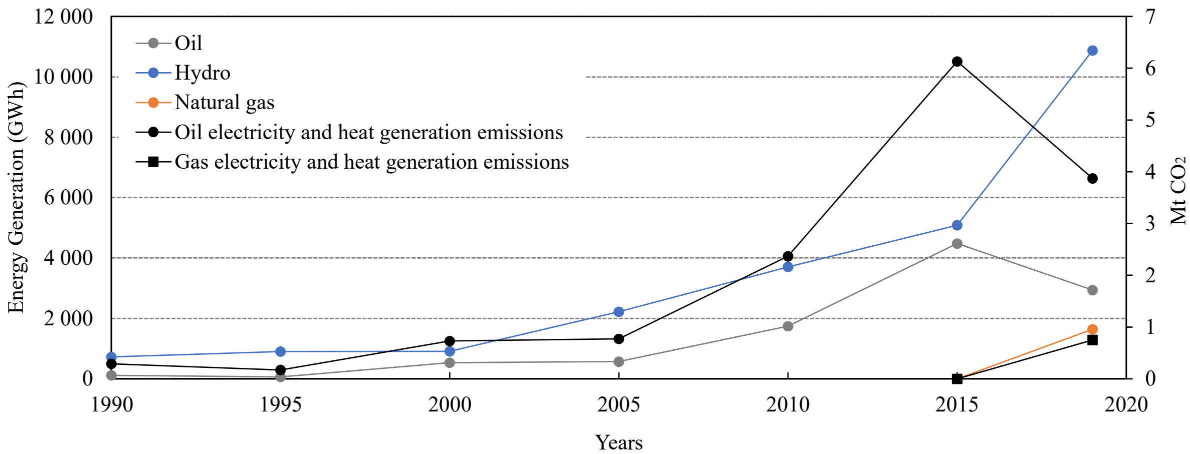

Figure 2. Energy generation by sources and respective CO_2 emissions over the past 30 years (data retrieved from [38]).

2.3. Renewable Energy Sector in Angola

As previously mentioned, Angola currently relies mostly on hydropower and oil for power generation. According to the data presented by [2] and expressed in Figure 3, renewable energy consumption relies only on hydropower, which in 2018 achieved a total of 56.8%. The final consumption of this energy is heat, rising to a total of 202.3 PJ, followed by electricity consumption, 27.1 PJ. However, no renewable energy is yet used in the transportation sector.

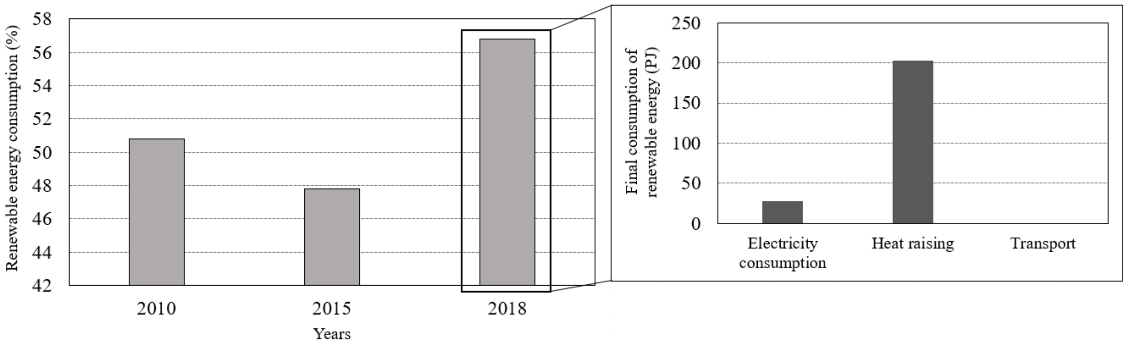

Figure 3. Renewable energy consumption in Angola, 2018 (data retrieved from [2]).

Although hydropower is the only renewable source to produce energy, Angola has a strong potential for other resources. According to [4], in 2018, this potential extended to 42% hydro, 40% solar, 9% wind, and 9% biomass. The government has already identified these resources as the leading technologies for electricity production. Therefore, the policy targets pointed out by the Angolan government by 2025 are the implementation of 100 MW of solar PV, 370 MW of small and medium hydro, 500 MW of biomass, and 100 MW of wind [37]. These initiatives are expected to reduce GHG emissions by 2030 by 35% (unconditional scenario) and 50% (conditional scenario). A list of future projects can be found in [4]. However, even if CSP technologies were proven to provide an effective response to energy supply security in the future due to their high efficiency, low operating costs, scalability to low and high-temperature applications processes, and to be carbon-free [5], currently, there are no systems implemented in Angola. By considering the potential of this country regarding solar resources, it is important to demonstrate the advantages of the implementation of these solar technologies, which can highly contribute to the national strategy in the energy sector.

2.4. Future Projections

Projections presented by the Angolan government show that, by 2025, the electrical demands are expected to reach 39.1 TWh, with a strong share of the domestic segment (37%) and an important contribution from services (28%) and industry (25%) [33]. The electricity demand projection is directly related to an increase in national wealth (GDP) and the increase in electricity consumption [39]. Therefore, forecasting a continuous growth in the national income, strong pressure to increase the available generation for irrigation, cooking, heating, cooling, and lighting is expected.

In order to follow the consumption trends and meet the energy demands, Angolan electricity generation is expected to reach nearly 50 TWh by 2040, with cheap hydropower and gas as the main technologies used, followed by oil, solar PV, and bioenergy [37]. Studies suggested that the total potential for solar energy is about 17.3 GW; followed by biomass, 1.5 GW; and wind and hydro, 0.6 GW each [40]. Moreover, to supply rural populations, the National Strategy for New Renewable Energies in Angola proposed the implementation of 500 solar villages by 2025 over the entire country, with special emphasis on the Central southern region [33].

3. Solar Resources in Angola

This section presents the geography, climate, and topography of the Angolan territory, and emphasis is given to the solar radiation resource of the country. The provided information is the basis for the discussion of the potential application of CSP technologies in Angola. Finally, some market drivers for CSP systems implementation are presented.

3.1. Geography, Climate, and Elevation of the Angolan Territory

Angola is located on the southern Atlantic coast of the African continent; the country is divided by an arid coastal strip, which extends from Namibe to Luanda provinces. A humid interior plateau, a dry savannah in the south and southeast interior, and tropical forest in the north and in Cabinda characterize the Angolan climate [41]. The coastal strip is tempered by the cold Benguela Current, and the inland highlands have a mild climate with a rainy season from November to April, followed by a cooler, dry season from May to October. The altitudes vary between 0 m at the coast and 2300 m, with the most inland areas being between 1000 and 2000 m, as can be observed in Figure 4. Vast plains are considered ideal for the installation of photovoltaic power plants, with the Central Highlands of Huambo being one of the best places.

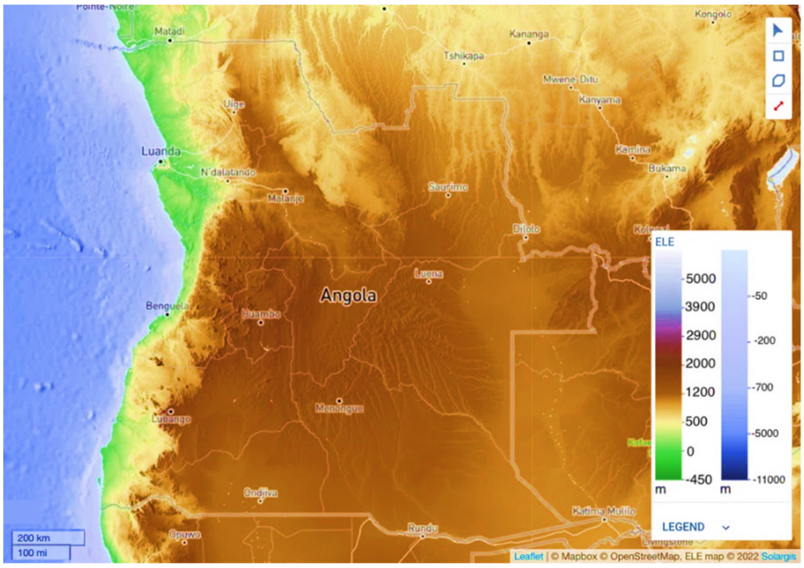

Figure 4. Elevation of the Angolan territory (GHI Solar Map © 2022 Solargis).

Despite being located in a tropical area, it has a climate that is not characterized for that region due to the confluence of three factors [4]: the cold Benguela current along the southern part of the coast, the relief inside, and the influence of the Namibe desert, to the southwest.

On the other hand, while the coastline has high levels of rainfall, which decrease from North to South and from 800 mm to 50 mm, with average annual temperatures above 23 °C, the inland area can be divided into three areas: North, with high rainfall and high temperatures; Central Plateau, with a dry season and average temperatures of around 19 °C; and South, with very accentuated thermal amplitudes due to the proximity to the Kalahari desert and the influence of tropical air masses [42].

3.2. Characterization of the Solar Radiation

Angola has a high solar resource potential, with an average annual global solar irradiation in the horizontal plane between 1350 and 2500 kWh/m^2/year, as can be observed in Figure 5. This is the largest renewable resource in the country and the most evenly distributed throughout the territory. The central and southern regions have the highest potential for solar energy. Provinces such as Cunene, Namibe, Benguela, and Huíla have the highest solar potential, ranging from 1900 to 2500 kWh/m^2/year.

This renewable resource is the most uniformly distributed all over the country. However, regions along the coast or rivers are exposed to frequent fog, and high locations near the mountains can experience significant shadows that can reduce the efficiency of the solar systems. Considering the high solar energy resources in Angola, solar technologies for the production of both thermal and electrical energy are the most appropriate to take advantage of this renewable resource.

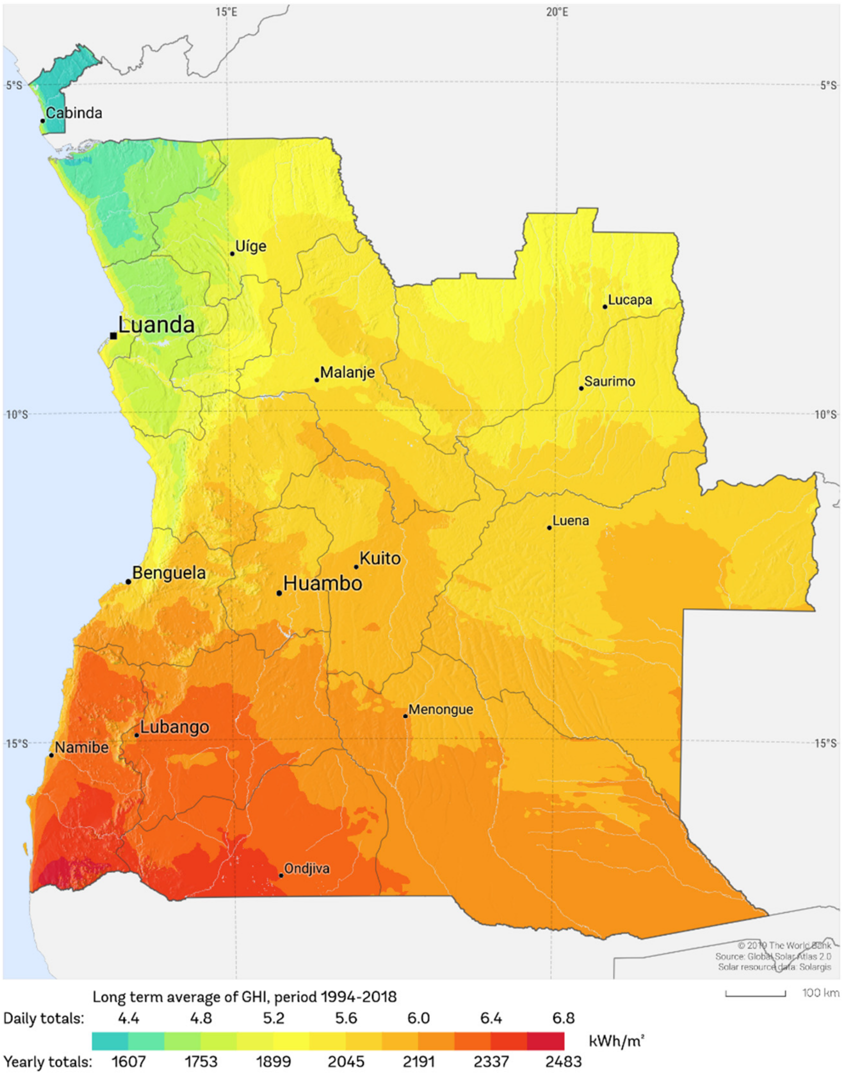

Figure 5. Average global irradiation in the horizontal plane in Angola, 2018 (GHI Solar Map © 2022 Solargis).

3.3. Best Locations for the Implementation of Solar Technologies

CSP systems can be used in different applications, and the production of electricity is only one of the possible advantages of these solar systems. These solar technologies provide an effective solution to the high energy consumption related to cooking, irrigation, and desalination/distillation, among others. In order to estimate the best locations for the implementation of CSP plants for different applications, it is important to understand the development plan proposed by the Angolan government for the coming years.

As previously mentioned, Angola is growing, and its current GDP, estimated at USD 199 billion by 2018, is expected to achieve USD 287 billion by 2030 [37]. This growth stimulates the government to design strategies and establish a set of priority projects that will boost Angola's development. These projects are grouped into eight major clusters [34]: (1) feeding, agro-industry, and forest; (2) housing and construction; (3) oil and natural gas; (4) tourism and leisure; (5) transport and logistic; (6) mineral resources; (7) Industrial Development Hubs (PDI); (8) other industries. As presented in [34], the main growth drivers are the PDI and mining activities, followed by the agro-industry and the construction sector. The estimated locations of these major clusters of energy consumption are illustrated in Figure 6.

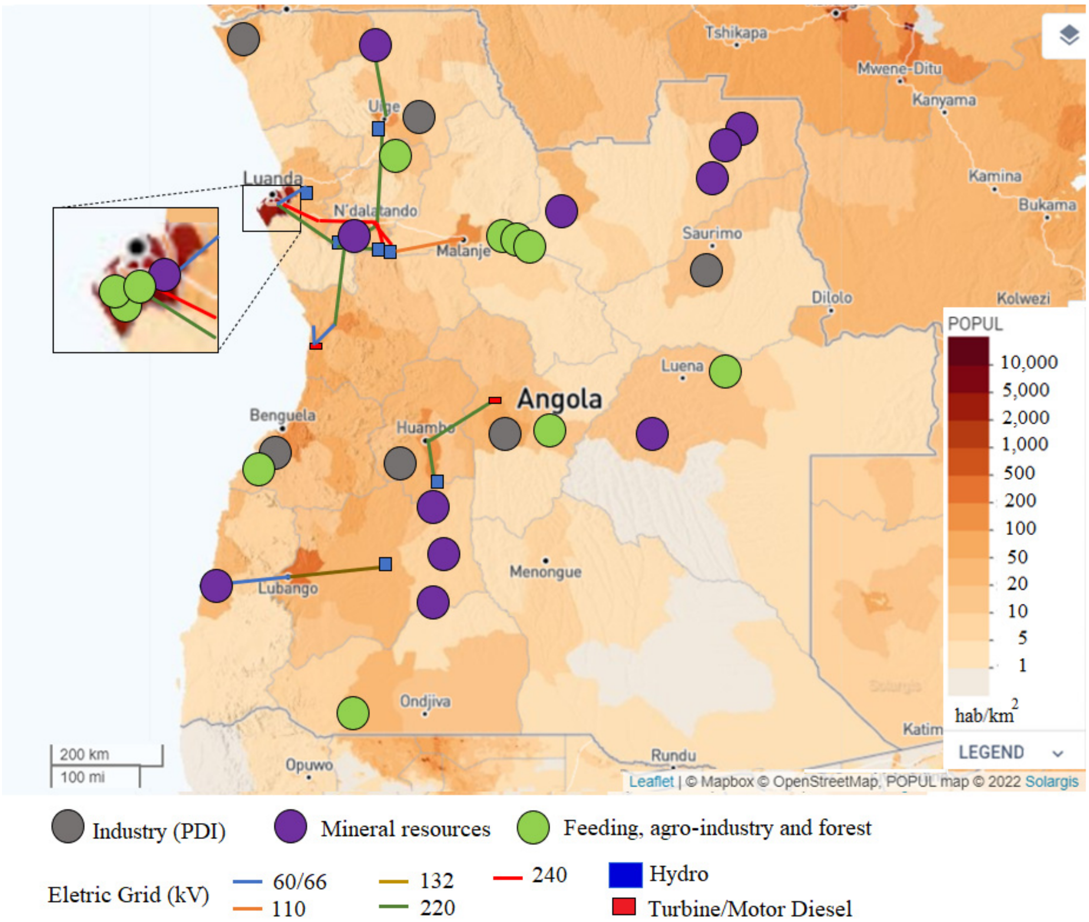

Figure 6. Angolan current demographic map and electric grid with locations of the major cluster of energy consumption expected by 2025 (data retrieved from [34] and GHI Solar Map © 2022 Solargis).

Combining the location of the priority cluster's energy consumption expressed in Figure 6 with the solar resources and demography of Angola, it is possible to define the best location for CSP plants in the function of the final purpose. Starting with industry and exploitation of mineral resources, CSP power plants can contribute to the production of clean energy and must be located in the provinces of Lunda Norte and Lunda Sul, Huila, Namibe, Huambo, Moxico, Bié, and Luanda, supplying 60% of the total population. Considering that several industries use water in their processes and that mineral extraction, as well as oil and gas recovery, needs water for their activities, the implementation of CSP plants for water distillation can also be an important step towards the sustainability of these mining activities, reducing the consumption of water through its recycling. By focusing on the development of feeding and agro-industry, the use of CSP technologies for irrigation and pumping is one of the major concerns for the provinces of Luanda, Cuanza Norte and Cuanza Sul, Malanje, Bié, Benguela, Moxico and Cunene. The implementation of CSP technologies for water desalination is considered one of the most promising solutions to reduce water stress in several African countries. The large Angolan coast, which combines zero elevation and high horizontal solar irradiation varying between 1700 kWh/m^2/year and 2400 kWh/m^2/year, makes the provinces of Namibe, Benguela, Cuanza Sul, Luanda, Bengo, and Zaire favorable regions for desalination plants.

Regarding cooking applications and looking at the data expressed in Figure 6, it can be observed that the electrification of the country is concentrated in the city and province of Luanda and provinces nearby, where the majority of the population lives. Therefore, the inland of the territory seems to be the most critical, showing that CSP systems for cooking must be installed in these regions.

Recently, studies have been conducted by the Angolan government in order to determine the potential for the application of solar energy technologies throughout the territory [34]. Results show that medium and large-scale projects present a levelized cost of electricity (LCOE) lower than USD 0.2/kWh, indicative of an economical alternative to diesel. Regarding the Central and Southern systems, it is estimated that LCOE < USD 0.15/kWh can be reached [33]. The implementation of these technologies will reduce the use of diesel with economic profitability, working in a complementary way to the generators.

Based on these results, the strategy set a target of installing 100 MW of solar projects by 2025. The rural electrification planning study identified the potential to integrate 22 MW of solar photovoltaic projects in the efforts of rural electrification: 10 MW in solar villages, 10 MW in a complementary way to diesel in town halls electrified by isolated systems, and 2 MW in the 100% solar project of Rivungo [4]. Locations are already identified as potential candidates for the installation of power plants, and the regions selected for the installation of the 78 MW connected to the grid in medium and large-scale projects are necessary to complete the target of 100 MW. Mostly, the provinces of Zaire, Bié, Lunda Norte, Lunda Sul, Moxico, Cunene, Huíla, Cuando-Cubango, and Cuanza Sul were selected for their lowest LCOE and are essentially located in the Center and South of the country, as can be identified in detail in [33].

4. Potential Application of CSP Technologies in Angola

Even though photovoltaic systems have been identified by the Angolan government as the most appropriate technology to harness the solar resource in Angola, rural electrification is still one of the major concerns since the need to use batteries makes the implementation of this technology too costly [4]. Therefore, a need arises to find more profitable and versatile solutions to be implemented all over the country.

CSP technologies present great advantages for countries with a high solar radiation resource, such as Angola, since they can be used for several purposes, from the production of energy, water heating, space heating and cooling, cooking, irrigation, and water distillation, and desalination. More information regarding the developments conducted in this field can be found in [11]. However, the majority of the CSP technologies implemented worldwide have been used for electricity generation. Information regarding the CSP plants implemented worldwide is presented in this section, and the benefits of this technology for Angola are explored.

4.1. CSP Technologies Implementation Worldwide

CSP with thermal energy storage has already proved to be a viable solution to achieve the international goals of carbon neutrality by 2050, as it is being implemented in several countries with high solar resources. The majority of CSP plants are implemented in regions with high direct solar irradiation, with a total of around 6 GW of operating CSP plants worldwide by 2022, which are concentrated in Spain (2.30 GW), the USA (1.77 GW), China (0.52 GW), South Africa (0.50 GW), and Morroco (0.49 GW) [43,44]. As expressed in Figure 7, this represents 35.5%, 28.3%, and 7–8%, respectively, of the total net capacity installed worldwide. From these CSP plants, a total of around 14,213 GWh/year of net electricity is currently generated, and the technology that mostly contributes to this production is the parabolic trough, followed by the power tower, as can be confirmed in Figure 8.

According to [43], the major benefits of the CSP technologies that leads to its worldwide implementation are related to its capacity to: (1) enhance the grid reliability; (2) enable grids to incorporate a larger share of renewable resources, reducing curtailment; (3) allow systems to adapt to the variation in the electricity demands profiles; (4) provide lowest energy storage costs; (5) contribute to the integration of regional electricity markets; (6) support the international environmental goals; and (7) promote domestic, industrial and socioeconomic development.

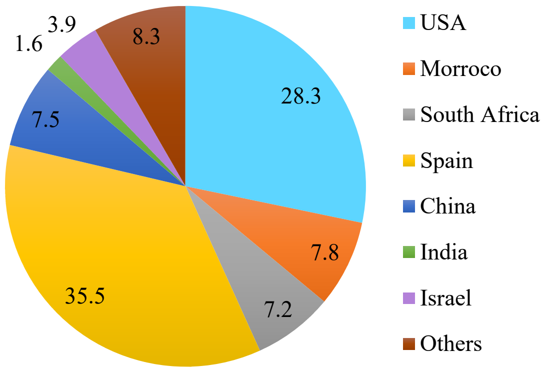

Figure 7. Net capacity (MW) percentage of CSP plants worldwide, 2022 (data retrieved from [44]).

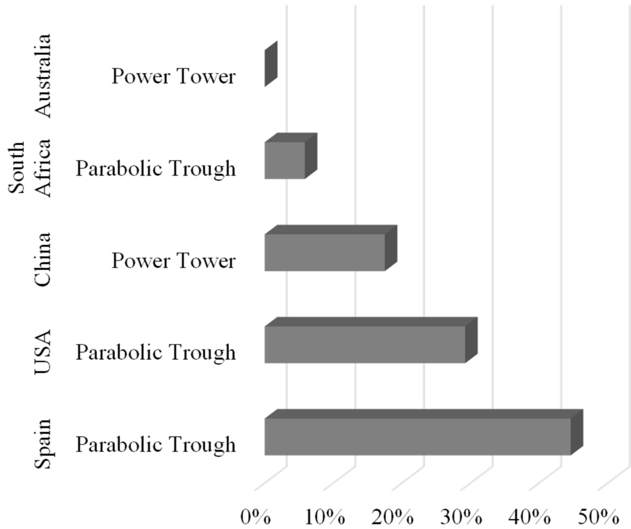

Figure 8. Percentage of net electricity generated worldwide per prominent CSP technology in each leading production country, 2022 (data retrieved from [44]).

4.2. Benefits of CSP Technologies for Angola

Even though no CSP plants exist or are projected to be implemented in Angola, the advantages are strong, namely due to the high solar radiation of the country but also to boost the development of the Angolan society.

4.2.1. Electricity and Heat Generation

As presented in the previous section, the majority of the CSP technologies implemented worldwide are used for electricity generation. Currently, only 44% of the Angolan population has access to electricity [37], making the implementation of CSP systems an important and almost mandatory solution for the development of Angola.

According to the recent energy plan presented by the Angolan government, by 2025, a total of 9.9 GW of installed power is expected to be achieved with a strong focus on hydropower (6.5 GW) and natural gas (1.9 GW) [33]. The remaining installed capacity is expected to be complemented by renewable energies (solar, eolic, and biomass) for a total of 800 MW, while the other 700 MW is based on thermal-based generation. Therefore, CSP can have an important contribution in these last 1500 MW, mainly in the portion related to thermal generation. If all the system that uses diesel for the generation of heat and electricity are replaced by CSP plants, a decrease of around 4 Mt CO_2 is expected to occur, helping Angola to achieve its carbon neutrality goals.

Moreover, rural electrification, one of the most critical aspects of Angola's strategic plan for development, is composed of three proposals, electrification through grid extension, isolated systems, and individual systems, covering 5%, 1%, and 7% of the Angolan population, respectively. The electrification by means of isolated systems combined with mini-hydro, diesel generators, and solar systems. According to the government plan, a total of 21 solar and diesel systems are expected to be implemented over the territory: 8 in the province of Malanje, 3 at Menongue, 2 at Moxico, 21 at Lunda Norte, and 1 at Cunene, Huíla, Huambo, Cuanza Sul, Caxito and Uíge. However, the use of diesel as fuel will increase the release of GHG. In order to minimize this impact, the CSP system must be implemented. Combining these isolated systems with individual systems, which mainly consist of "solar villages", we can conclude that CSP systems can contribute to the energy demands of 2.4 million inhabitants by 2025.

4.2.2. Clean Cooking

Access to clean technologies for cooking has been another topic of international discussion since, in 2019, 34% of the global population has no access to them. In Angola, statistics from 2019 show that 77% of the urban population has access to clean cooking while the rural population only has access to 8% [2]. Considering that currently, the rural population of Angola corresponds to 32.54% of the total population, a total of 1,015,864 rural inhabitants and 526,507 urban inhabitants do not have access to clean cooking. This huge discrepancy makes clean cooking in Angola one of the major concerns. If CSP systems are implemented throughout the country, the living conditions of more than 1.5 million inhabitants will increase. Studies show that the use of solar cookers, compared with other technologies, can reduce CO_2 emissions by 100 to 400 kg/year [45].

Moreover, since biomass is the main source of energy used for cooking, significant levels of deforestation around major urban areas occur in the country [34]. In order to minimize the negative impact and to provide an effective solution for the rural Angolan population, CSP systems must be implemented.

4.2.3. Water Desalination and Crop Irrigation

In addition to electricity, interest in irrigation and water distillation/desalination has been emerging in Sub-Saharan African countries. This region suffers from an inconsistent supply of safe water mainly due to contaminated groundwater and logs dry seasons [46]. In Angola, only 0.1% of the total available groundwater resources are consumed by the population since the costs of harvesting the reserves are very high due to the high investment costs of generators and pumps [47,48]. These costs are even more unbearable for small-scale independent communities; it is estimated that 72% of the rural population has no access to an improved water supply [48]. Moreover, the agricultural sector is the largest water user, consuming 95% of the total resources, while the domestic sector only uses 5% [48]. In this context, crop irrigation is another important topic since Angola is currently facing the worst recorded drought in 40 years, affecting about 1.58 million people who are experiencing high levels of food insecurity [49]. In order to improve the agricultural sector at low costs, solar energy was identified as a potential resource [50]. Data presented by [51] show that Angola can double its cultivated land if its irrigation potential is reached, as it is possible to decrease the levels of food insecurity and enhance the life quality of the Angolan population.

Water distillation and desalination using membrane technologies combined with solar systems were recently discussed by the research community as a promising solution to help to mitigate the water and food insecurity of several countries. According to [52], the water production cost can achieve USD 0.64/m^3, which is USD 0.36/m^3 lower than the current average costs. Some desalination plants' capacity from brackish water can achieve 46,000 m^3/day, while from seawater, these values can reach 320,000 m^3/day [53]. Considering that it is expected that each individual must access a minimum of 40 L of water per day [54], this system can supply 8,000,000 inhabitants of the provinces located on the Angolan coast, while 1,150,000 inland inhabitants can have access to water if desalinated brackish water is used.

By considering the need of the Angolan population to increase and improve the quality of electricity production, clean cooking, water consumption, and crop irrigation, the implementation of CSP technologies seems to be a promising path to address these issues. Studies presented by [55,56] demonstrated that a decrease in PV potential is expected to occur due to the projections of climate changes in the African continent, giving an opportunity for CSP technologies to grow in the near future. Compared with PV systems, CSP conversion efficiency is not negatively affected by the increase in the ambient temperature, increasing its potential for application in the African territory [56]. Moreover, research conducted by [8] concluded that PV systems have higher environmental impacts than CSP plants. In that sense, several studies were conducted to analyze the viability of the implementation of CSP technologies and enhance their efficiency in order to demonstrate the potential of these solar systems to achieve the goals established in terms of energy, water consumption, and decarbonization.

4.3. Market Drivers for CSP Technologies

According to [9], the new generation of CSP technology (Gen3) must meet important criteria to be successfully commercialized. Therefore, to obtain early stage guidance on desired technology attributes and capabilities, some requirements were highlighted. These requirements allow spreading the implementation of CSP technologies in the international market. Table 2 presents these main criteria.

Table 2. Requirements for Gen3 technology commercialization, 2017 (data retrieved from [9]).

Metric	Requirement
Plant Capacity	50 MW minimum
Ramp Rate	Absolute Ramp Rate: 2 MW/min–28 MW/min Percent of Regulation Range per Minute: 1–40% of plant regulation range/min
Start-Up Time	Hot: 60–120 min; Warm: 120–270 min; Cold: 200–480 min
Equivalent forced outage rate (EFOR *)	8–15%
Equivalent Availability Factor (EAF *)	80% to 81%
Time from Notice to Proceed to EPC to Commercial Operation Date	3 years maximum
Operations and Maintenance	Simplicity
Cost	2 ¢/kWh < LCOE < 7 ¢/kWh; Promote the use of annualized net cost (USD M/yr) in specific regions
Demonstration Projects	Nominally 10 MW scale
Flexibility	Capacity to decouple the collection of energy from the production of electricity

$$* EFOR = \frac{Unplanned\ (forced) outage\ hours + Equivalent\ unplanned\ (forced) derated\ hours}{Unplanned\ (forced) outage\ hours + Equivalent\ unplanned\ (forced) derated\ hours\ during\ reserve\ shutdowns\ only + service\ hours} \times 100$$

$$EAF = \frac{Available\ hours - equivalent\ planned\ derated\ hours - equivalent\ unplanned\ derated\ hour - equivalent\ seasonal\ derated\ hours}{Period\ hours} \times 100.$$

5. High Temperature Solar Systems

As previously mentioned, CSP technologies are considered an efficient and clean energy technology that can contribute to energy and water demands as well as decrease environmental pollution. These systems offer both electrical and thermal production from small-scale to large power plants and have proven their ability to provide dispatchable electricity using low-cost thermal energy storage [12].

In this Section, CSP technologies are presented, and emphasis is provided on parabolic dish systems.

5.1. Solar Concentration Systems

CSP is recognized as a renewable energy technology that can make a sounder contribution to the transformation of Angolan energy since it captures and stores the sun's energy in the form of heat, using materials that are low cost and materially stable for decades [9]. CSP uses solar radiation to produce high-temperature thermal power that can be converted into electricity by means of a conventional thermodynamic cycle. In CSP systems, the solar reflector concentrates the solar radiation on a focus where the solar receiver is placed. The latter is, arguably, the key component of a CSP system since it transfers the energy of the concentrated solar beams to a heat transfer fluid (HTF), which in turn, directly or indirectly drives the thermodynamic cycle [57]. Although CSP technologies present many advantages since they can produce electricity continuously even in the absence of sunlight, these systems have not had much commercial success compared with solar photovoltaics, mainly due to the higher LCOE [6]. Compared with solar PV, the electricity cost is at least three times higher [58]. Thus, one of the main objectives for the third CSP generation (or Gen3) is to make use of solar technologies adapted to 50% nominal conversion efficiency on the thermodynamic cycle [9]. However, the current state-of-the-art has a conversion efficiency below that target due to the limited operation temperature [59]. This leads to a clear market failure in Angola to bring new CSP technologies to the market [60]. In order to provide an innovative solution that contributes to the clean transformation of Angolan energy and advances toward the next generation (Gen3) CSP technology, innovative systems were developed and studied in order to increase the system's efficiency in both collection and storage systems [61]. The solar receiver is the most critical component in CSP efficiency since it absorbs and converts solar energy into thermal energy [9,62].

5.2. Parabolic Dishes

Four solar thermal technologies are promoted by the international market: Solar Power Tower, Parabolic Dish System, Linear Fresnel Reflector (LFR), and Parabolic trough [9]. From these technologies, the parabolic dish (Figure 9) presents a high grow potential due to its large applicability which varies from energy production [12,29,63–67], heating processes [17,68–70], cooking [45,71,72], irrigation [46,73], water desalination, and distillation [74–76]. The parabolic dish, shown in Figure 5, is a parabolic reflector (dish) with a dual-axis solar tracking system, which reflects solar radiation into a focal point at which the thermal receiver is located. In order to collect maximum radiation and transfer it to the receiver, the parabolic structure realizes the total tracking of the sun's path, allowing a very advantageous use of energy for thermal applications [57]. This configuration makes the parabolic dish appropriate for high-temperature applications such as solar thermal power and solar thermal steam generation [7]. The range of temperature in this system can vary between 400 °C and 750 °C, and the concentration ratio can achieve a value higher than 3000 [74]. These characteristics make this system highly efficient compared with other CSP technologies [12].

The solar receiver is the main component of a solar concentrator. Through this element, the heat is exchanged between the absorber surface and the fluid. The receiver must be designed to allow maximum absorption of solar radiation by ensuring minimum heat losses to the ambient. The receiver structure varies according to the fluid applied and depends on the system application. However, the main problem related to the typical solar receivers used in parabolic dish systems is mainly related to high thermal radiation loss on its surface, reducing the efficient power generation at higher temperatures [14]. In order to overcome this issue, two important challenges arise: the improvement of the absorber surface and the enhancement of the heat transfer between the absorber surface and the thermal fluid. In order to approach these challenges, several studies were conducted in order to optimize solar systems [18,75]. To summarize the major developments conducted in this field, a literature review was conducted and presented in Section 5.

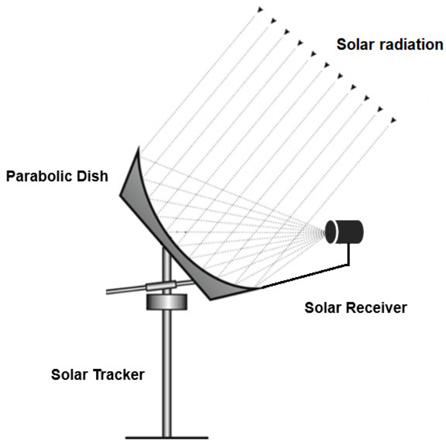

Figure 9. Parabolic dish system.

5.3. Technology Limitations

The parabolic dish has several advantages, such as high power density and efficiency, modularity and versatility, hybrid operation and long lifetime, as well as low construction costs [11]. By considering these relevant features, this system can provide an economical source of energy, both thermal and electrical. Therefore, it has been highly investigated in the past few years and is considered one of the most promising renewable energy systems. However, there are still problems related to solar parabolic dish technologies that affect its efficiency and prevent its dissemination in the international market. These issues can be divided into four main challenges [76]: the heat transfer media, the uneven distribution of the energy flow, the heat losses, and the heat transfer capacity. Table 3 summarizes the issues and presents possible solutions that were investigated to enhance the system's efficiency.

Table 3. Challenges in parabolic dish systems (data retrieved from [5,11–13,76]).

Challenges	Issues	Ongoing Solutions
Heat transfer media	Low thermal efficiency; Low exergetic efficiency; Temperature limitation; High pumping work consumption.	• Molten salt ($NaNO_2$, $LiNO_3$, KNO_3, $NaNO_3$, $CsNO_3$, KBr, NaCl, LiF); • Use of supercritical carbon dioxide; • Use of nanofluids (Al_2O_3, Cu, SiO_2, TiO_2 based thermal oil, MWCNT/oil).
Uneven distribution of the energy flow	Deformation of the collector structure; Fail of vacuum; Concentration losses; Reduced optical efficiency; Non-uniform temperature distribution inside the receiver; Large temperature gradients; High-temperature hot spots; Thermal stress and deformation of the receiver.	• Optimization of the reflective structure; • Implementation of a dual axis solar tracker; • Improvement of the reflector material and shape, solar radiation concentration, concentration ratio, and rim angle; • Enhancement of the receiver design (geometry, size, wall absorptivity distribution).
Heat losses	Radiative losses; Natural convection losses; Free-forced convection losses.	• Optimization of the receiver orientation and geometry; • Reduction in the emissivity of the absorber surface; • Increase the absorptivity of the receiver surface; • Multi-layer insulation; • Glass cover; • Reduction in the absorption diameter.
Heat transfer capacity	Low system efficiency	• Optimization of the receiver design (material, diameter, etc.); • Optimized absorber surface; • Application of porous media; • Implementation of forced convection process (e.g., jet impingement).

6. Future Developments

As previously mentioned, CSP systems are currently used to harness solar thermal energy with negligible CO_2 emissions. Moreover, the hybridization of parabolic dishes with other renewables such as thermo-coupled generators, biomass, or even conventional fuels could be advantageous, and the development of innovative multi-generation systems to generate electricity and heat with reasonable cost and higher thermal efficiency could accelerate the commercialization of this technology [12]. Therefore, research to enhance these systems has been increasing in the past few years, and relevant developments conducted in this field are presented in this section. Table 4 summarizes the major findings.

6.1. Solar Receivers

As previously mentioned, the solar receiver is the most important component of parabolic dish systems since they are responsible for heating the HTF, which can be applied for different purposes. In that sense, research focus on the development of innovative configurations that increase heat transfer rates and reduce heat losses.

A numerical and experimental study conducted by [15] compared two receivers, one with a cubic cavity and another with a cylindrical cavity. The results showed that the cubic cavity receiver has higher thermal efficiency and heat transfer coefficient than the cylindrical one. While the cubic cavity receiver has an average thermal efficiency of 65.1%, the cylindrical cavity receiver reached a value of 56.4%. Moreover, a work presented by [66] shows that for steam generation, the most suitable receiver's shape is the conical cavity helical tube. According to [77], convective heat losses are lower in a conical cavity receiver. Hemispherical cavity, copper tubes wound in a spiral, with a small opening at the bottom, was also proved to be a configuration that reduces the heat losses compared with other configurations [78]. According to the experimental study conducted by [17], a coiled spiral tube solar receiver constructed of mild steel can reach an average thermal efficiency of about 56.2% and an average exergetic efficiency of 5.5%. They also concluded that this receiver could be used for temperatures up to 100 °C.

The relevance of porous media for heat transfer augmentation has been an area of increasing interest in PSDS. The porous structure offers a much larger surface area for heat and fluid flow interaction, which is in itself the greatest advantage for thermal applications in compact systems [79]. A review conducted by [62] mentioned studies that apply porous medium into the absorber to enhance the heat transfer in solar receivers. An example of this application is porous volumetric solar receivers that have drawn much attention recently due to their high-efficiency performance in solar radiation absorption and heat transfer enhancement [25]. The complex three-dimensional structure of the porous media increases the turbulence inside the fluid channels and larger heat exchange surface, which are favorable to the convective heat transfer [25]. However, issues related to non-uniformity of solar flux distribution, pressure drop, and viscous dissipation, induce non-uniform temperatures and affect the exergetic characteristic of the system, leading to a decrease in efficiency [79–81]. This complicated flow dynamics also brings a challenging task in the numerical investigation of the fluid flow and heat transfer characteristics for the porous media applied in solar receivers [14,25]. According to [26], the most important characteristics of porous media are porosity and pore size. The propagation and absorption phenomena depend on these parameters and on the radiation and temperature of the porous material, as well as the angle of incidence. Given the complexity of porous media, they can, in practice, be heterogeneous and anisotropic, with pores having different geometric shapes, and they seem to be a promising solution to increase the receiver's thermal efficiency.

Table 4. Innovation in parabolic solar dish systems.

References	Focus	Main Goals	Range of Parameters	Findings
[12] Malik et al. (2022)	Review on PSDS	Review of the design parameters of the parabolic solar dish Stirling (PSDS) system and their applications.	$1 < C < 1200$; $100 < T < 1000$ (°C).	The overall maximum theoretical and experimental efficiency of a PSDS system is close to 23%, with the LCOE = USD 0.2565/kWh.
[13] Kumar at al. (2022)	Review on PSDS	A detailed review of the design parameters for achieving higher overall efficiency in PSDS systems.	$23.6 < C < 4920$; $0.86 < D_c < 20$ (m); $15 < \varphi < 90$ (°); $0 < \theta < 90$ (°).	• The overall efficiency of the system depends on the receiver only; • Nanofluids improve thermal performance from 10 to 13% compared with regular heat transfer fluids.
[45] Arameh et al. (2019)	Review on CSP for cooking	A detailed review of experimental and analytical socioeconomic studies of solar cooking technologies.	$250 < T < 280$ (°C); $Rsun \approx 800$ (W/m^2)	• Parabolic concentrating cookers have the highest efficiency; • Employing a heat storage unit can increase cooker efficiency.
[46] Wazed et al. (2018)	Review on CSP for irrigation	Review on solar technologies for pumping water for irrigation	$650 < T < 800$ (°C).	• Stirling engine holds the highest potential for small-scale remote farms usage; • Stirling engines positively depict solar thermal water pumping cap abilities keeping low costs and reducing the carbon footprint
[82] Bahrami et al. (2019)	Design and construction of SDC	Experimental and theoretical investigation of a new solar still mounted at solar dish concentrator (SDC) focal point for saltwater desalination.	$D_c = 2$ (m); $f = 1.4$ (m)	• Parabolic dish optical efficiency increases from 0.5 to 0.8 when the absorber plate reflectivity reduces from 0.7 to 0.4 and the distilled water produced increases up to 120 and 80%, respectively.

Table 4. *Cont.*

References	Focus	Main Goals	Range of Parameters	Findings
[83] Yan et al. (2018)	Design and construction of SDC	A novel discrete SDC is proposed for improving the flux uniformity of the absorber surface inside the cavity receiver.	$6 < f < 8.45$ (m); $R_{rec} = 140$ (mm); $0 < U_w < 5$ (m/s); $0.01 < \dot{m} < 0.125$ (kg/s). $R_{sun} = 900$ (W/m^2)	• Optical efficiency is kept between 88.93% and 92.19%; • Optimization is obtained for 6 divisions of the parabolic generatrix and a focal length $f = 6$ m, which reduces the non-uniformity factor from 0.63 to 0.18.
[84] Srithar et al. (2016)	Design and construction of SDC	Experimental analysis of stand-alone triple basin solar desalination system.	$D_c = 1.25$ (m); $f = 0.50$ (m);	• The triple basin glass solar still with charcoal and TBSS with river sand enhances the distillate by 34.2 and 25.6% higher than conventional TBSS distillates
[85] Bumataria and Pater (2013)	Design of PSDS	Review of solar Stirling engine used for pumping water in rural areas.	$6500 < T < 8000$ (°C); $0.4 < U_w < 30$ (m/s);	• The theoretical design provides an efficiency varying between 52% and 72%; • Heating hot end of the engine up to 4500 °C to 8000 °C, and air-cooled fins are used for cooling the cold end of the engine up to 350 °C to 700 °C.
[86] Omara and Eltawil (2013)	Design and construction of SDC	Design and installation of SDC, simple solar collector, and modified boiler for brackish water desalination.	$f = 0.40$ (m);	• The daily average efficiency of SDC and conventional solar still was 68 and 34%, respectively; • The increase in distillate production for SDC is about 244% and 347% higher than that of CSS without and with preheating, respectively

Table 4. *Cont.*

References	Focus	Main Goals	Range of Parameters	Findings
[66] Houcine et al. (2022)	A conical thermal receiver using a beam splitter filter(PV/PDC-CTR-BSF)	Optical and thermal performance analysis and optimization of a hybrid photovoltaic/parabolic dish concentrator with a conical thermal receiver using a beam splitter filter.	A = 2.5 (m) f = 3 (m) r_{max} = 0.1 r_{min} = 0.05	• PV/PDC-CTR-BSF has a breakthrough in the record of the optical efficiency with a value of 67%; • Combined electrical power output with PV/PDC- CTR-BSF system employing helical-coil steam generator is possible to achieve 10% to 20% increase in power.
[87] Afrin et al. (2021)	Cavity receiver	Numerical and experimental analysis using ANSYS FLUENT and SolTrace. Was.	$120 < T < 170$ (°C) $0 < \theta < 20$ (°)	• The optimized performance occurs at 5° inclination between the absorber axis and the solar flux incident angle; • The tube with Alanod outperforms the other coating types.
[17] Thirunavukkarasu and Cheralathan (2020)	Spiral tube receiver	Experimental analysis of energy and exergy performance of an external type spiral tube receiver	$30 < T < 100$ (°C) $\dot{m}$ = 1.5 (L/min); A_{apert} = 16 (m^2); D_e = 0.4 (m). R_{sun} = 750 (W/m^2)	• The average thermal and exergy efficiencies are 56.21% and 5.4%, respectively; • The compact receiver has the potential to be used in applications with operating temperatures up to 100 °C.
[26] Barreto et al. (2018)	Volumetric receiver	Three-dimensional modeling and analysis of solar radiation absorption in a porous volumetric receiver using the Monte Carlo Ray Tracing (MCRT) method.	C = 500; f = 0.7 (m) d_p = 0.025 (m); r_{rec} = 0.25 (m);	• The propagation and absorption phenomena depend on the porosity and the size of the pores; • A peak of absorbed solar radiation of 156 MWm^{-3} and absorption efficiency of 90.55% was obtained for a phase function asymmetry factor of 0.4

Table 4. *Cont.*

References	Focus	Main Goals	Range of Parameters	Findings
[15] Loni et al. (2018)	Cavity receiver	Experimental and Numerical study of cubical and cylindrical cavity receivers	C = 184; f = 1 (m); D_e = 0.16 (m); D_i= 0.14 (m).	• The average thermal efficiency of the cubical and cylindrical cavity receiver was obtained as 65.14% and 56.44% in the steady-state period, respectively; • The cubical cavity receiver can be recommended for an efficient heat gain in comparison with the cylindrical cavity receiver.
[88] Wang and Laumert (2017)	Cavity receiver coating	Study of the effects of cavity surface materials on the radiative flux distribution of solar cavity receivers with the help of a ray-tracing methodology	f = 4.5 (m)	• Low absorptivity coating on the bottom and high absorptivity coating on the cylindrical surface improves the overall flux distribution in the cavity; • The total optical efficiency lies between 92.2% and 95.3%, increasing with the increase in the material absorptivity on the cavity surfaces.
[89] Reddy et al. (2016)	Cavity receiver	Numerical investigation of convective heat losses from the modified cavity receiver.	$0 < \theta < 90$ (°); $0 < U_w < 10$ (m/s); $0.4 < R < 1$	• The critical wind speed was found to be less than 5 m/s; • The highest convection heat loss occurs for the fully open (R = 1) receiver.
[68] Reddy et al. (2015)	Cavity receiver	Modified cavity receiver 3D model for steam generation.	$30 < T < 500$ (°C); $0 < \theta < 60$ (°); $0 < U_w < 10$ (m/s).	• Forced convection heat loss at a wind speed of 5 m/s is 7 to 8 times higher than natural convection heat loss.

Table 4. *Cont.*

References	Focus	Main Goals	Range of Parameters	Findings
[90] Ngo et al. (2015)	Cavity receiver	Numerical modeling and optimization of natural convection heat suppression in a solar cavity receiver with plate fin.	$125 < T < 725$ (°C); $0 < \theta < 30$ (°).	• 20% reduction in the natural convection heat losses from the cavity receiver is achieved by using the plate fins at 0 ° receiver inclination.
[91] Reddy et al. (2015)	Cavity receiver	Experimental analysis of the flux distribution at the focal plane by considering the optical imperfection of the reflected ray's cone.	$0 < \theta < 90$ (°); $0 < U_w < 10$ (m/s).	• The average thermal efficiency of the parabolic dish collector with a modified cavity is found to be 74% for the flow rate of 250 L/h.
[78] Wu et al. (2010)	Cavity receiver	Detailed review of different solar receiver designs (cubical and rectangular, cylinder, hemispherical)	$-90 < \theta < 90$ (°); $0.1 < \mathrm{Pr} < 8.7$.	• Convective heat loss is dominated by the radiation heat loss for higher receiver tilt angle (>45°); • A small receiver should have wind guards installed to reduce the wind effect.
[21] Loni et al. (2017)	HTF	Numerical modeling of SDC performance using different nanofluids as the working fluid.	$D_c = 1.8$ (m); $D_e = 0.14$ (m); $D_i = 0.01$ (m); $\varphi = 45$ (°); $U_{w\,=}$ 1.2 (m/s); $R_{sun} = 650$ (W/m^2).	• The thermal efficiency decreased with increasing nanoparticle volume concentration; • Cu/thermal oil nanofluid presents the best exergy efficiency compared to other nanofluids in the cylindrical cavity receiver.
[92] Senthil and Cheralathan (2019)	HTF	Experimental analysis of the thermal performance, the flux distribution, flux uniformity, and intensity of receivers with phase change materials (PCMs)	$A_{apert} = 16$ (m^2) $D_e = 0.406$ (m); $L = 0{,}1$ (m); $U_w = 0, 2.5$ (m/s); $\dot{m} = 72, 80, 90$ (kg/h); $R_{sun} = 600$ (W/m^2).	• Using multiple PCMs in the solar receiver improves the thermal performance; • The optimum HTF flow rate is 80 kg/h, which shows 66.7% energy efficiency and 13.8% exergy efficiency at the average solar radiation of 600 W/m^2.

Table 4. *Cont.*

References	Focus	Main Goals	Range of Parameters	Findings
[93] Li et al. (2022)	HTF	Numerical modeling of the absorption and scattering of the solar radiation by the aerogel	$0 < \theta < 90$ (°) $f = 0.05$ (m); $D_e = 0.2$ (m).	• A cavity receiver with a 0.01 m thick aerogel can reach an efficiency of 85.0%, which is 5.1% higher than that of the cavity receiver without the aerogel.

6.2. Thermal and Optical Losses

Heat losses in CSP systems occur in three possible ways, convection, radiation, and conduction. Studies were carried out with the aim of reducing heat losses, which tend to increase with wind speed and direction, ambient temperature, material from which the CSP system is built, the insulation and inclination of the receiver, working fluid, and other factors. According to [94], heat losses are influenced by the angle of inclination of the receiver, and greater losses by radiation are identified at an inclination of 46° upwards, while at an inclination angle of 0°, the maximum losses by convection are verified. Prakash et al. [95] added that the condition of 0° inclination of the receiver and wind impinging frontally results in greater total and convective heat losses. Crosswinds of 1 to 3 m/s cause less heat loss than the no wind condition and 0° receiver tilt. Convective and total heat losses become independent of wind direction and receiver inclination from 3 m/s wind speed. Moreover, it seems that crosswind causes greater heat losses in forced convection compared to headwind and counterwind. For crosswind speed of 5 m/s, the heat loss by forced convection is 7 to 8 times greater than in natural convection, and forced convection heat losses are greater at higher wind speeds, whereas at lower wind speeds, natural convection heat losses prevail [68].

According to [90], heat losses by natural convection can be reduced by up to 20% at the 0 ° receiver inclination using plate fins, which act as heat transfer suppressors of the receiver. Another way to reduce heat loss in the receiver cavity is by using an aerogel. According to [93], it is possible to increase the system efficiency up to 5.1% by applying aerogel in the receiver cavity with a 0.01 m thickness, and the aerogel receiver has better photothermal performance at high working temperatures. In order to improve the overall distribution of the solar radiation flux in the receiver cavity, Wang and Laumert [88] recommended the use of low absorption coating on the bottom and high absorption coating on the cylindrical surface. They also stated that the higher the absorption of the material on the cavity surfaces, the greater the total optical efficiency.

6.3. Heat Transfer Fluid

The HTF in solar concentrating systems exchanges heat with the receiver. Thermal energy can be stored or used to produce high-temperature steam or gas for electricity generation or to heat water that can be used in different applications. The HTF is crucial in SDC systems, and studies were conducted in order to increase its efficiency. The thermal performance of the HTF highly depends on operating temperature. According to [96], water is the most appropriate working fluid for low-temperature conditions compared with Therminol VP-1 and air. However, the results proved that air is a promising solution in low operating temperatures due to the high heat transfer coefficients obtained between the absorber and the fluids, while Therminol VP-1 presents the optimum exergetic performance for an inlet temperature of about 155 °C. In order to increase the thermal performance of the HTF, nanofluids have been considered a promising solution [10]. These fluids consist of a mixture of base fluids, usually water or thermal oil, with metallic or non-metallic nanoparticles, frequently Al_2O_3, Fe, CuO, Cu, Al, TiO_2, SiO_2, and carbon nanomaterial [19]. The main advantage of the nanofluids compared with the base fluids is the higher thermal conductivity, which increases the heat transfer inside the flow, increasing the heat transfer coefficient between the absorber and the fluid [20,22,97]. A review presented by [13] highlighted that improvements in thermal performance could reach 10 to 13%. According to [23], the heat transfer enhancement using nanofluids increases with higher operating temperatures. The use of Cu with thermal oil or water presents a higher exergetic performance compared with other nanofluids [10,21]. According to [10], Al_2O_3 with water presents the best thermal efficiency.

6.4. Innovative Technologies

As previously mentioned, the great advantage of parabolic dish systems is their large applicability. In that sense, several studies were conducted in order to determine the performance of SDC for irrigation, cooking, and water distillation and desalination, but also its potential combined with other technologies such as PV. A hybrid photovoltaic/parabolic dish concentrator with a conical thermal receiver using a beam splitter filter (PV/PDC-CTR-BSF) was developed and studied in detail by [66]. This innovative proposal allows the generation of steam and electricity in the same system since photovoltaic solar panels are added to the solar concentrator. Solar radiation is split by the beam splitter filter using BSF technology as a function of wavelength. The sun's rays are focused on the receiver, and the reflected ones are concentrated on the photovoltaic panels. Finally, they concluded that it is possible to achieve a power increase in the order of 10 to 20% after proper project adaptation and improvement of the parameters [66].

Among the possible applications of the parabolic solar concentration system, we can highlight the distillation and desalination of water. A new design of a solar still mounted at a PSDS focal point was conceptualized and constructed by [82]. The system produced about 20–23 kg for 7 h operating time (5.7–6.5 kg/m^2 day), which is considered economical compared with other thermal desalination systems. In its turn, [86] proposed a new hybrid system for brackish water desalination and obtained a daily average of distillate water of about 6.7 and 3 L/m^2/day for the solar dish concentrator (SDC) with preheating and conventional solar still (CSS), respectively. The daily average efficiency of SDC and CSS was 68 and 34%, respectively, while water production cost was found to be USD 0.028/L for SDC with preheating and USD 0.048/L for CSS, highlighting the advantages of the SDC system for water desalination. Regarding the potential of SDC for irrigation, the review presented by [46] stated that PSDS systems are considered the most promising solution for small-scale remote farms if the correct infrastructures for solar power concentration are used. According to the author, tests proved that the system could provide a water cost for rural areas of 2.4 ¢/m^3, which meet the World Bank target of 6 ¢/m^3. In terms of cooking applications, a review presented by [45] that compares different solar technologies concluded that SDC has the highest efficiency, 77%, which is a solution that must be explored.

7. Conclusions

In this work, a general approach was made to the energy sector in Angola. It was concluded that there is a large deficit of electricity and drinking water in the country, 58% of the population does not have access to electricity, and more than 1.58 million are experiencing high levels of food insecurity since the country faces the most severe drought in the last 40 years [49]. Electricity in Angola is essentially produced from hydro and thermal sources, which use diesel fossil fuels, Jet B, and natural gas that release large amounts of CO_2 and contribute to global warming [3]. In 2018, Angola emitted 17 Mt CO_2, which is expected to increase by 2040 to 33 Mt CO_2 [37]. The Ministry of Energy and Water of the Republic of Angola estimates that the electricity demand will reach 39.1 TWh by 2025 [33]. In order to provide a sustainable solution that complies with the demands of the Angolan population, studies suggested that Angola's total solar energy potential is around 17.3 GW, which is a promising resource for energy generation [40]. CSP technologies have great advantages for countries with high solar radiation resources, such as Angola, since they can be used for different purposes, from energy production, water and space heating and cooling, cooking, irrigation, distillation, and desalination of water. Therefore, it is possible to conclude that investments in solar concentration systems in Angola will be an asset due to the low manufacturing costs, lower environmental impact, shorter installation time, and wide range of applications. In this work, three main purposes are identified:

1 Production of electricity: Studies carried out by the Ministry of Energy and Water of the Republic of Angola, aiming to determine the potential application of solar energy technologies in the national territory, show that medium and large projects present an LCOE < USD 0.2/kWh, indicating an economical alternative to diesel. Regarding the Central and Southern systems, it is estimated that LCOE < USD 0.15/kWh can be achieved [33]. The implementation of this technology will reduce the use of diesel

with economic profitability. Consequently, CO_2 emissions will be reduced, and it will be possible to supply the electricity demand with the installation of large plants since solar radiation is abundant in the country;

2 Water desalination and distillation: Angola has an extension of the Atlantic coast of 1650 km, which goes from the north to the south of the country. Studies on concentration systems and boilers as solar receivers showed high performance in the desalination of seawater. One of the southernmost provinces, Namibe, is washed by the Atlantic coast and faces a severe drought; the installation of solar desalination plants would help to mitigate the effects of the drought. It was estimated by [86] that the cost of desalinated water using parabolic solar dish systems is around 0.084 USD/kg, and about 20–23 kg can be produced per 7 h of operation (5.7–6.5 kg/m^2 day), improvements in these systems can increase water production for the same period;

3 Pumping water for rural communities: In Angola, rural and urban communities have a deficient supply of drinking water, and only 0.1% of the available groundwater resources are consumed, as the capture, generators, and water pumps have very high costs [47,48]. Another problem that rural communities face is the difficulty in irrigating the fields where they practice subsistence or commercial agriculture. The implementation of parabolic solar dish systems for pumping water would be a viable solution. Studies carried out by [85] showed that the solar concentration system and gamma-type Stirling engine theoretically presented an efficiency of 52% to 72% for up to 3000 RPM.

The conclusions presented in this work are not limited to Angola but can be expanded to a large number of countries in Sub-Saharan Africa, South America, and Asia, where the levels of solar radiation are high, and the access to sustainable technologies for electricity and heat generation, cooking, water consumption, and crop irrigation is limited.

Author Contributions: Conceptualization, F.V.B.; methodology, formal analysis, and investigation, E.D.G.C. and F.V.B.; resources, J.C.F.T. and S.F.C.F.T.; writing—original draft preparation, E.D.G.C. and F.V.B.; writing—review and editing, J.C.F.T. and S.F.C.F.T.; project administration, J.C.F.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by FCT–Fundação para a Ciência e Tecnologia within the R&D Units Project Scope: UIDB/00319/2020 (ALGORITMI Center) and Project Scope UIDB/00319/2020 (METRICS Center).

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Nomenclature

Acronym	
CSP	Concentration Solar Power
CSS	Conventional solar still
EPC	Engineering, Procurement, and Construction
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HTF	Heat Transfer Fluid
HPS	Hybrid Power Systems
LCOE	Levelized Cost of Electricity
ORC	Organic Rankine Cycle
PSDS	Parabolic Solar Dish System
PV	Photovoltaic
SDC	Solar dish concentrator

Symbol	Quantity	SI Unit
A_{apert}	Aperture area	(m^2)
C	Concentration ratio	(m)
D_e	External diameter	(m)
D_i	Internal diameter	(m)
D_W	Wind direction	-
d_p	Pores diameter	(m)
f	Focal distance	(m)
L	Length	(m)
$\dot{m}$	Mass flow rate	(m^3/s)
R	Receiver aperture diameter ratio	-
R_{sun}	Solar radiation	(kWh/m^2)
r	Radius	(m)
T	Temperature	°C
T_{fin}	Inlet flow temperature	°C
T_{fout}	Outlet flow temperature	°C
U_w	Wind velocity	(m/s)
U_f	Flow velocity	(m/s)
W	Width	
Greek Symbol		
ε	Emissivity	-
θ	Inclination	(°)
φ	Rim angle	(°)

References

1. Lei, Y.; Lu, X.; Wang, Y.; Guo, H.; Wang, Y.; Zhong, Z. Climate and Environmental Benefit Study of PV Resource Development: Case Study of Angola. *Adv. Transdiscipl. Eng.* **2021**, *17*, 109–118.
2. IIEA; IRENA; UNSD; World Bank; WHO. *Tracking SDG 7: The Energy Progress Report 2021*; World Bank: Washington, DC, USA, 2021.
3. Andrade, A. Análise do Sector Elétrico Angolano e Estratégias para o Futuro. 2021. Available online: https://www.researchgate.net/publication/350820003_Analise_do_Sector_electrico_Angolano_e_estrategias_para_o_futuro (accessed on 12 August 2022).
4. Ministério Da Energia E Águas (MINEA). *Atlas e Estratégia Nacional Para as Novas Energias Renováveis*, 1st ed.; Gesto Energia: Luanda, Angola, 2018.
5. Achkari, O.; el Fadar, A. Latest developments on TES and CSP technologies–Energy and environmental issues, applications and research trends. *Appl. Therm. Eng.* **2020**, *167*, 114806. [CrossRef]
6. Dutta, P. High temperature solar receiver and thermal storage systems. *Appl. Therm. Eng.* **2017**, *124*, 624–632. [CrossRef]
7. Ahmadi, M.H.; Ghazvini, M.; Sadeghzadeh, M.; Alhuyi Nazari, M.; Kumar, R.; Naeimi, A.; Ming, T. Solar power technology for electricity generation: A critical review. *Energy Sci. Eng.* **2018**, *5*, 340–361. [CrossRef]
8. Desideri, U.; Zepparelli, F.; Morettini, V.; Garroni, E. Comparative analysis of concentrating solar power and photovoltaic technologies: Technical and environmental evaluations. *Appl. Energy* **2013**, *102*, 765–784. [CrossRef]
9. Mehos, M.; Turchi, C.; Vidal, J.; Wagner, M.; Ma, Z.; Ho, C.; Kolb, W.; Andraka, C.; Kruizenga, A. *Concentrating Solar Power Gen3 Demonstration Roadmap*; Office of Scientific and Technical Information (OSTI): Golden, CO, USA, 2017; pp. 1–140.
10. Loni, R.; Pavlovic, S.; Bellos, E.; Tzivanidis, C.; Asli-Ardeh, E.A. Thermal and exergy performance of a nanofluid-based solar dish collector with spiral cavity receiver. *Appl. Therm. Eng.* **2018**, *135*, 206–217. [CrossRef]
11. Hafez, A.Z.; Soliman, A.; El-Metwally, K.A.; Ismail, I.M. Design analysis factors and specifications of solar dish technologies for different systems and applications. *Renew. Sustain. Energy Rev.* **2017**, *67*, 1019–1036. [CrossRef]
12. Malik, M.Z.; Shaikh, P.H.; Zhang, S.; Lashari, A.A.; Leghari, Z.H.; Baloch, M.H.; Memon, Z.A.; Caiming, C. A review on design parameters and specifications of parabolic solar dish Stirling systems and their applications. *Energy Rep.* **2022**, *8*, 4128–4154. [CrossRef]
13. Kumar, K.H.; Daabo, A.M.; Karmakar, M.K.; Hirani, H. Solar parabolic dish collector for concentrated solar thermal systems: A review and recommendations Environ. *Sci. Pollut. Res.* **2022**, *29*, 32335–32367. [CrossRef]
14. Du, S.; Li, M.-J.; He, Y.-L.; Shen, S. Conceptual design of porous volumetric solar receiver using molten salt as heat transfer fluid. *Appl. Energy* **2021**, *301*, 117400. [CrossRef]
15. Loni, R.; Kasaeian, A.; Asli-Ardeh, E.A.; Ghobadian, B.; Gorjian, S. Experimental and numerical study on dish concentrator with cubical and cylindrical cavity receivers using thermal oil. *Energy* **2018**, *154*, 168–181. [CrossRef]
16. Barreto, G.; Canhoto, P.; Collares-Pereira, M. Effect of thickness on the thermo-hydraulic performance of porous volumetric solar receivers with different internal geometries. *J. Physics Conf. Ser.* **2021**, *2116*, 012116. [CrossRef]
17. Thirunavukkarasu, V.; Cheralathan, M. An experimental study on energy and exergy performance of a spiral tube receiver for solar parabolic dish concentrator. *Energy* **2019**, *192*, 116635. [CrossRef]

18. Pavlović, S.R.; Bellos, E.A.; Stefanović, V.P.; Tzivanidis, C.; Stamenković, Z.M. Design, simulation and optimization of a solar dish collector with spiral-coil thermal absorber. *Therm. Sci.* **2016**, *20*, 1387–1397. [CrossRef]
19. Bellos, E.; Tzivanidis, C.; Tsimpoukis, D. Thermal, hydraulic and exergetic evaluation of a parabolic trough collector operating with thermal oil and molten salt based nanofluids. *Energy Convers. Manag.* **2017**, *156*, 388–402. [CrossRef]
20. Mahian, O.; Kianifar, A.; Heris, S.Z.; Wongwises, S. First and second laws analysis of a minichannel-based solar collector using boehmite alumina nanofluids: Effects of nanoparticle shape and tube materials. *Int. J. Heat Mass Transf.* **2014**, *78*, 1166–1176. [CrossRef]
21. Loni, R.; Asli-Ardeh, E.A.; Ghobadian, B.; Kasaeian, A.; Gorjian, S. Thermodynamic analysis of a solar dish receiver using different nanofluids. *Energy* **2017**, *133*, 749–760. [CrossRef]
22. Bellos, E.; Tzivanidis, C. Parametric investigation of nanofluids utilization in parabolic trough collectors. *Therm. Sci. Eng. Prog.* **2017**, *2*, 71–79. [CrossRef]
23. Bellos, E.; Tzivanidis, C.; Antonopoulos, K.; Gkinis, G. Thermal enhancement of solar parabolic trough collectors by using nanofluids and converging-diverging absorber tube. Renew. *Energy* **2016**, *94*, 213–222.
24. Hanshrajkumar, G.; Goyal, B.; Awasthi, S. Heat Transfer Enhancement using Porous Materials as Receiver in Solar Parabolic Trough Collector. *SSRN Electron. J.* **2021**, 1–5. [CrossRef]
25. Du, S.; He, Y.-L.; Yang, W.-W.; Liu, Z.-B. Optimization method for the porous volumetric solar receiver coupling genetic algorithm and heat transfer analysis. *Int. J. Heat Mass Transf.* **2018**, *122*, 383–390. [CrossRef]
26. Barreto, G.; Canhoto, P.; Collares-Pereira, M. Three-dimensional modelling and analysis of solar radiation absorption in porous volumetric receivers. *Appl. Energy* **2018**, *215*, 602–614. [CrossRef]
27. Baharoon, D.A.; Rahman, H.A.; Omar, W.Z.W.; Fadhl, S.O. Historical development of concentrating solar power technologies to generate clean electricity efficiently–A review. Renew. *Sustain. Energy Rev.* **2015**, *41*, 996–1027. [CrossRef]
28. Ferreira, A.C.; Nunes, M.L.; Teixeira, J.C.; Martins, L.A.; Teixeira, S.F.; Nebra, S.A. Design of a solar dish Stirling cogeneration system: Application of a multi-objective optimization approach. *Appl. Therm. Eng.* **2017**, *123*, 646–657. [CrossRef]
29. Ferreira, A.C.; Nunes, M.L.; Teixeira, J.C.; Martins, L.A.; Teixeira, S.F. Thermodynamic and economic optimization of a solar-powered Stirling engine for micro-cogeneration purposes. *Energy* **2016**, *111*, 1–17. [CrossRef]
30. Viebahn, P.; Lechon, Y.; Trieb, F. The potential role of concentrated solar power (CSP) in Africa and Europe-A dynamic assessment of technology development, cost development and life cycle inventories until 2050. *Energy Policy* **2011**, *39*, 4420–4430. [CrossRef]
31. Craig, O.; Duvenhage, D.F.; Brent, A.; Dinter, F. An analysis of local manufacturing capacity, economic and trade impact of concentrating solar power (CSP) in South Africa. *AIP Conf. Proc.* **2019**, *2126*, 130002.
32. Jadhav, A.S.; Chembe, D.K.; Strauss, J.M.; Van Niekerk, J.L. Status of Solar Technology Implementation in the Southern African Developing Community (SADC) Region. *Renew. Sustain. Energy Rev.* **2017**, *73*, 622–631. [CrossRef]
33. Borges, J.B. *Angola Energia 2025*, 1st ed.; Gesto-Energia: Luanda, Angola, 2016.
34. Sustainable Energy for All, Rapid Assessment Gap Analysis Angola. République de Angola, Ministério da Energia e Águas. 2015. Available online: https://www.se4all-africa.org/fileadmin/uploads/se4all/Documents/Country_RAGAs/Angola_RAGA_EN_Released.pdf (accessed on 28 July 2022).
35. Gabler, H. Autonomous power supply with photovoltaics: Photovoltaics for rural electrification-reality and vision. Renew. *Energy* **1998**, *15*, 512–518. [CrossRef]
36. Prodel. Capacidade Instalada para Produção de Energia Elétrica em Angola. *MINEA 2021.* Available online: https://minea.gv.ao/index.php/prodel (accessed on 28 July 2022).
37. International Energy Agency. *Africa Energy Outlook 2019: Overview Angola*; International Energy Agency: Paris, France, 2019.
38. IEA, Angola: Key Energy Statistics. 2019. International Energy Agency. 2019. Available online: https://www.iea.org/countries/angola (accessed on 16 August 2022).
39. European Commission. *Sustainability Impact Assessment (SIA) in Support of Trade Negotiations with Angola for EU-SADC EPA Accession*; European Commission: Brussels, Belgium, 2021.
40. Japan International Cooperation Agency (JICA). *The Project for Power Development Master Plan in the Republic of Angola Final Report*; Japan International Cooperation Agency (JICA): Tokyo, Japan, 2018; p. 216.
41. Huntley, B.J.; Russo, V.; Lages, F.; Ferrand, N. *Biodiversity of Angola: Science & Conservation: A modern Synthesis*; Springer: Berlin/Heidelberg, Germany, 2019.
42. Mendelsohn, J.; Weber, B. *Huambo—An Atlas and Profile of Huambo, Its Environment and People*; DW Angola: Huambo, Angola, 2013.
43. World Bank. *Concentrating Solar Power: Clean Power on Demand 24/7*; World Bank: Washington, DC, USA, 2021.
44. Goyal, N.; Aggarwal, A.; Kumar, A. Concentrated solar power plants: A critical review of regional dynamics and operational parameters. *Energy Res. Soc. Sci.* **2021**, *83*, 102331. [CrossRef]
45. Aramesh, M.; Ghalebani, M.; Kasaeian, A.; Zamani, H.; Lorenzini, G.; Mahian, O.; Wongwises, S. A review of recent advances in solar cooking technology. *Renew. Energy* **2019**, *140*, 419–435. [CrossRef]
46. Wazed, S.M.; Hughes, B.R.; O'Connor, D.; Calautit, J.K. A review of sustainable solar irrigation systems for Sub-Saharan Africa. Renew. *Sustain. Energy Rev.* **2018**, *81*, 1206–1225. [CrossRef]
47. Paveli, P.; Giordano, M.; Keraita, B.; Ramesh, V.; Rao, T. *Groundwater Availability abd Use in Sub-Saharan Africa: A Review of 15 Countries*; International Water Management Institute: Battaramulla, Sri Lanka, 2012.

48. Pietersen, K.; Beekman, H. *Groundwater Management in the Southern African Development Community*; Groundwater Management Institute: Bloemfontein, South Africa, 2016.
49. IFRC. Operation Update Report Angola: Drought. United Nations Office for the Coordination of Humanitarian Affairs. 2022. Available online: https://reliefweb.int/report/angola/angola-drought-operation-update-report-n-1-dref-n-mdrao007 (accessed on 31 August 2022).
50. Wong, K.V.; Pecora, C. Recommendations for Energy-Water-Food Nexus Problems. *J. Energy Resour. Technol. Trans. ASME* **2015**, *137*, 032002. [CrossRef]
51. FAO, Aquastat. Food and Agriculture Organization of the United Nations. 2014. Available online: http://www.fao.org/nr/water/aquastat/main/index.stm (accessed on 30 August 2022).
52. Khayet, M. Solar desalination by membrane distillation: Dispersion in energy consumption analysis and water production costs (a review). *Desalination* **2013**, *308*, 89–101. [CrossRef]
53. Shatat, M.; Worall, M.; Riffat, S. Opportunities for solar water desalination worldwide: Review. *Sustain. Cities Soc.* **2013**, *9*, 67–80. [CrossRef]
54. Cain, A.; Baptista, A.C. Community Management and the Demand for 'Water for All' in Angola's Musseques. *Water* **2020**, *12*, 1592. [CrossRef]
55. Dutta, R.; Chanda, K.; Maity, R. Future of solar energy potential in a changing climate across the world: A CMIP6 multi-model ensemble analysis. Renew. *Energy* **2022**, *188*, 819–829. [CrossRef]
56. Soares, P.M.M.; Brito, M.C.; Careto, J.A.M. Persistence of the high solar potential in Africa in a changing climate. *Environ. Res. Lett.* **2019**, *14*, 124036. [CrossRef]
57. Barbosa, F.V.; Afonso, J.L.; Rodrigues, F.B.; Teixeira, J.C.F. Development of a solar concentrator with tracking system. *Mech. Sci.* **2016**, *7*, 233–245. [CrossRef]
58. Westerweel, J. Fundamentals of digital particle image velocimetry. *Meas. Sci. Technol.* **1997**, *8*, 1379–1392. [CrossRef]
59. Dunham, M.T.; Iverson, B.D. High-efficiency thermodynamic power cycles for concentrated solar power systems. Renew. Sustain. *Energy Rev.* **2014**, *30*, 758–770.
60. European Comission. *Initiative for Global Leadership in Concentrated Solar Power Implementation Plan*; European Comission: Brussels, Belgium, 2017.
61. Kumar, A.; Saini, R.; Saini, J. Heat and fluid flow characteristics of roughened solar air heater ducts–A review. *Renew. Energy* **2012**, *47*, 77–94. [CrossRef]
62. He, Y.-L.; Wang, K.; Qiu, Y.; Du, B.-C.; Liang, Q.; Du, S. Review of the solar flux distribution in concentrated solar power: Non-uniform features, challenges, and solutions. *Appl. Therm. Eng.* **2018**, *149*, 448–474. [CrossRef]
63. Hafez, A.Z.; Soliman, A.; El-Metwally, K.A.; Ismail, I.M. Solar parabolic dish Stirling engine system design, simulation, and thermal analysis. *Energy Convers. Manag.* **2016**, *126*, 60–75. [CrossRef]
64. Barreto, G.; Canhoto, P. Modelling of a Stirling engine with parabolic dish for thermal to electric conversion of solar energy. *Energy Convers. Manag.* **2017**, *132*, 119–135. [CrossRef]
65. Marzouk, O.A. Energy Generation Intensity (EGI) for Parabolic Dish/Engine Concentrated Solar Power in Muscat, Sultanate of Oman. *IOP Conf. Ser. Earth Environ. Sci.* **2022**, *1008*, 012013. [CrossRef]
66. Houcine, A.; Maatallah, T.; Saeed, F. Steam and electrical power generation by a hybrid photovoltaic/parabolic dish concentrator using beam splitter technology. *Int. J. Energy Res.* **2022**, *46*, 12341–12361. [CrossRef]
67. Fan, H.; Singh, R.; Akbarzadeh, A. Electric Power Generation from Thermoelectric Cells Using a Solar Dish Concentrator. *J. Electron. Mater.* **2011**, *40*, 1311–1320. [CrossRef]
68. Reddy, K.; Vikram, T.S.; Veershetty, G. Combined heat loss analysis of solar parabolic dish–modified cavity receiver for superheated steam generation. *Sol. Energy* **2015**, *121*, 78–93. [CrossRef]
69. Karimi, R.; Gheinani, T.T.; Avargani, V.M. A detailed mathematical model for thermal performance analysis of a cylindrical cavity receiver in a solar parabolic dish collector system. *Renew. Energy* **2018**, *125*, 768–782. [CrossRef]
70. Calise, F.; D'Accadia, M.D.; Palombo, A.; Vanoli, L. Dynamic simulation of a novel high-temperature solar trigeneration system based on concentrating photovoltaic/thermal collectors. *Energy* **2013**, *61*, 72–86. [CrossRef]
71. Bhave, A.G.; Kale, C.K. Development of a thermal storage type solar cooker for high temperature cooking using solar salt. *Sol. Energy Mater. Sol. Cells* **2020**, *208*, 110394. [CrossRef]
72. Senthil, R. Enhancement of productivity of parabolic dish solar cooker using integrated phase change material. *Mater. Today Proc.* **2020**, *34*, 386–388. [CrossRef]
73. Habib-agahi, H.; Jones, S.C. *Irrigation Market for Solar-Thermal*; U.S. Department of Energy Office of Scientific and Technical Information: Pasadena, CA, USA, 1981.
74. Wu, S.F.; Narayanan, T.V.; Gorman, D.N. Conceptual Design of an Advanced Water/Steam Receiver for a Solar Thermal Central Power System. *J. Sol. Energy Eng.* **1983**, *105*, 34–41. [CrossRef]
75. Bellos, E.; Tzivanidis, C.; Daniil, I.; Antonopoulos, K.A. The impact of internal longitudinal fins in parabolic trough collectors operating with gases. *Energy Convers. Manag.* **2017**, *135*, 35–54. [CrossRef]
76. Ruidong, W.; Jun, M. Status and Future Development Prospects of CSP. *IOP Conf. Series Earth Environ. Sci.* **2021**, *687*, 012088. [CrossRef]

77. Jilte, R.; Kedare, S.; Nayak, J. Investigation on Convective Heat Losses from Solar Cavities under Wind Conditions. *Energy Procedia* **2014**, *57*, 437–446. [CrossRef]
78. Wu, S.-Y.; Xiao, L.; Cao, Y.; Li, Y.-R. Convection heat loss from cavity receiver in parabolic dish solar thermal power system: A review. *Sol. Energy* **2010**, *84*, 1342–1355. [CrossRef]
79. Pati, S.; Borah, A.; Boruah, M.P.; Randive, P.R. Critical review on local thermal equilibrium and local thermal non-equilibrium approaches for the analysis of forced convective flow through porous media. *Int. Commun. Heat Mass Transf.* **2022**, *132*, 105889. [CrossRef]
80. Barbosa, F.V.; Teixiera, S.F.; Teixeira, J.C. 2D PIV analysis of the flow dynamics of multiple jets impinging on a complex moving plate. *Int. J. Heat Mass Transf.* **2022**, *188*, 122600. [CrossRef]
81. Du, B.-C.; He, Y.-L.; Zheng, Z.-J.; Cheng, Z.-D. Analysis of thermal stress and fatigue fracture for the solar tower molten salt receiver. *Appl. Therm. Eng.* **2016**, *99*, 741–750. [CrossRef]
82. Bahrami, M.; Avargani, V.M.; Bonyadi, M. Comprehensive experimental and theoretical study of a novel still coupled to a solar dish concentrator. *Appl. Therm. Eng.* **2019**, *151*, 77–89. [CrossRef]
83. Yan, J.; Peng, Y.-D.; Cheng, Z.-R. Optimization of a discrete dish concentrator for uniform flux distribution on the cavity receiver of solar concentrator system. *Renew. Energy* **2018**, *129*, 431–445. [CrossRef]
84. Srithar, K.; Rajaseenivasan, T.; Karthik, N.; Periyannan, M.; Gowtham, M. Stand alone triple basin solar desalination system with cover cooling and parabolic dish concentrator. *Renew. Energy* **2016**, *90*, 157–165. [CrossRef]
85. Bumataria, R.K.; Patel, N.K. Review of Stirling Engines for Pumping Water using Solar Energy as a source of Power. *Int. J. Eng. Res. Appl.* **2013**, *3*, 864–868.
86. Omara, Z.; Eltawil, M.A. Hybrid of solar dish concentrator, new boiler and simple solar collector for brackish water desalination. *Desalination* **2013**, *326*, 62–68. [CrossRef]
87. Afrin, S.; Hossain, N.; Ma, Z.; Kotteda, V.M.K.; Badhan, A.; Kumar, V. On-Sun Testing of a High-Temperature Solar Receiver's Flux Distribution. *J. Sol. Energy Eng.* **2021**, *144*, 021001. [CrossRef]
88. Wang, W.; Laumert, B. Effect of cavity surface material on the concentrated solar flux distribution for an impinging receiver. *Sol. Energy Mater. Sol. Cells* **2017**, *161*, 177–182. [CrossRef]
89. Reddy, K.; Veershetty, G.; Vikram, T.S. Effect of wind speed and direction on convective heat losses from solar parabolic dish modified cavity receiver. *Sol. Energy* **2016**, *131*, 183–198. [CrossRef]
90. Ngo, L.; Bello-Ochende, T.; Meyer, J. Numerical modelling and optimisation of natural convection heat loss suppression in a solar cavity receiver with plate fins. *Renew. Energy* **2014**, *74*, 95–105. [CrossRef]
91. Reddy, K.; Natarajan, S.; Veershetty, G. Experimental performance investigation of modified cavity receiver with fuzzy focal solar dish concentrator. *Renew. Energy* **2015**, *74*, 148–157. [CrossRef]
92. Senthil, R.; Cheralathan, M. Enhancement of the thermal energy storage capacity of a parabolic dish concentrated solar receiver using phase change materials. *J. Energy Storage* **2019**, *25*, 100841. [CrossRef]
93. Li, X.; Li, R.; Chang, H.; Zeng, L.; Xi, Z.; Li, Y. Numerical simulation of a cavity receiver enhanced with transparent aerogel for parabolic dish solar power generation. *Energy* **2022**, *246*, 123358. [CrossRef]
94. Reddy, K.; Kumar, N.S. Combined laminar natural convection and surface radiation heat transfer in a modified cavity receiver of solar parabolic dish. *Int. J. Therm. Sci.* **2008**, *47*, 1647–1657. [CrossRef]
95. Prakash, M.; Kedare, S.; Nayak, J. Investigations on heat losses from a solar cavity receiver. *Sol. Energy* **2009**, *83*, 157–170. [CrossRef]
96. Pavlovic, S.; Daabo, A.M.; Bellos, E.; Stefanovic, V.; Mahmoud, S.; Al-Dadah, R.K. Experimental and numerical investigation on the optical and thermal performance of solar parabolic dish and corrugated spiral cavity receiver. *J. Clean. Prod.* **2017**, *150*, 75–92. [CrossRef]
97. Mahian, O.; Kianifar, A.; Heris, S.Z.; Wen, D.; Sahin, A.Z.; Wongwises, S. Nanofluids effects on the evaporation rate in a solar still equipped with a heat exchanger. *Nano Energy* **2017**, *36*, 134–155. [CrossRef]