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Exergy and Economic Evaluation of a Hybrid Power Plant Coupling Coal with Solar Energy

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Abstract: Hybrid power plants that couple conventional with renewable energy are promising alternatives to electricity generation with low greenhouse gas emissions. Such plants aim to improve the operational stability of renewable power plants, while at the same time reducing the fuel consumption of conventional fossil fuel power plants. Here, we propose and evaluate the thermodynamic and economic viability of a hybrid plant under different operating conditions, applying exergy and economic analyses. The hybrid plant combines a coal plant with a solar-tower field. The plant is also compared with a conventional coal-fired plant of similar capacity. The results show that the proposed hybrid plant can emit 4.6% less pollutants due to the addition of solar energy. Fuel consumption can also be decreased by the same amount. The exergy efficiency of the hybrid power plant is found to be 35.8%, 1.6 percentage points higher than the efficiency of the conventional coal plant, and the total capital investment needed to build and operate a plant is 8050.32 $/kW. This cost is higher than the necessary capital investment of 5979.69 $/kW to build and operate a coal-fired power plant, and it is mainly due to the higher purchased equipment cost. Finally, the levelized cost of electricity of the hybrid plant is found to be 0.19 $/kWh (using both solar and coal resources) and 0.12 $/kWh when the plant is fueled only with coal.

Keywords: hybrid power plants; exergy analysis; economic analysis; solar tower; levelized cost of electricity; CO_2 emissions

1. Introduction

Over the past ten years, power generation from coal has been responsible for more than 40% of the global energy production [1]. The International Energy Agency (IEA) estimates a further increase in coal-based electricity production due to the industrialization of developing countries [2]. At the same time, concerns related to climate change [3–5], resource depletion, as well as supply insecurity and fossil fuels' price volatility are growing [6]. These aspects have led to the development of certain protocols and climate agreements between countries, as for example the Kyoto Protocol and the Paris Agreement [7,8]. In Spain, renewable electricity production decreased during the recent economic crisis, while coal use increased. This situation has been changing in the last few years; in 2016, coal-fired power generation constituted 14.5% of the electricity generation in Spain, while the respective figure for renewable energy was 41.1% [9].

Despite the growing importance of renewable energy, it still has drawbacks that need to be addressed. The main disadvantages of renewable technologies are the lack of continuity in the supply, relatively high cost, and system complexity [10,11] when compared to fossil fuel plants. Hybrid power plants appear as a promising alternative that could address current energy challenges, both in the short and medium term. Hybrid plants are based on the combination of two or more resources with the goal of benefitting from the advantages of each of the incorporated technologies. Hybrid plants operate with different energy sources that complement each other to obtain a desired power output [12,13]. Hybrid plants may combine conventional fossil fuel power plants with renewable energy plants or combine two or more renewable energy sources [14]. Some of the possible technologies that could form a hybrid power plant are wind and solar photovoltaic (PV); hydropower and solar PV; concentrating solar thermal and coal/natural gas; wind and coal/natural gas; coal/natural gas and biomass; wind and diesel; or wind, solar PV, and diesel. By using complementary energy sources in the same power plant, the hybrid plants can reduce emissions related to the combustion of conventional fuels, alleviate random behavior [15,16], and achieve greater supply stability [2,17–19].

In the last few years, several research articles on the hybridization of coal-fired power plants with renewable energy sources have been published in the literature. Ong et al. [2] and Duan et al. [20] proposed the hybridization of coal plants with fuel cells. Bandyopadhyay et al. [21] studied the effect of coupling wind energy with coal. Rashid et al. [22] studied the design of a hybrid photovoltaic-wind-diesel energy system at coastal areas in Bangladesh in order to achieve the maximum power output from renewable sources while keeping the cost of electricity to a minimum. Shezan et al. [23] made a techno-economic analysis of a smart grid solar-wind-diesel system to support a small community in Brisbane (Australia), concluding on its economic and environmental feasibility. Concerning the hybridization of coal plants with biomass, Bae et al. [24] analyzed the range of bioliquids that can be burned with coal, and Trop et al. [25] considered the torrefaction of biomass and coal. Nevertheless, the most developed, examined alternative for coal hybridization is concentrated solar power that focuses radiation on small areas (receivers) through mirrors [26]. With regard to concentrated solar power, there are four available options: the parabolic through, the Fresnel reflectors, the dish Stirling, and the solar power tower [27]. Calise et al. [28] designed a dynamic model of a hybrid plant combining concentrated solar and combined cycle technologies, and made a comparison with a conventional combined-cycle power plant using the case study of a plant in Almeria, Spain. Peterseim et al. analyzed the best technology suited for hybridization and concluded that the solar power tower is the optimal option for high temperatures [29]. Zhu et al. conducted an exergy analysis to evaluate the solar contribution in a hybrid coal power plant [30]. Zhu et al. also investigated the performance of a solar tower-aided coal-fired power plant under various operating conditions [31]. Meanwhile, Zhang et al. studied the performance of a solar tower power plant with various boiler schemes [32], and Zhao et al. analyzed ways to improve the solar-to-electricity efficiency in solar-hybrid power plants [33].

In the present article, we study a novel hybrid power plant that couples a coal plant with a concentrated solar plant, including a solar power tower. The novelties of this study are the analyses of the combination of these energy sources using exergetic and economic analyses, the comparison of the proposed hybrid plant to a conventional coal-fired plant, and the consideration of different weather scenarios. The motivation of the present study is to examine each of the technologies' (solar power tower and coal-fired energy system) disadvantages and determine whether the combination of both could lead to enhanced performance. With the proposed plant, we want to reduce CO_2 emissions of coal power generation by relying more on renewable energy sources and increase supply reliability of renewable energy technologies. The aim of this article is to determine the viability of the proposed plant in Almeria (Spain) and evaluate its performance under different conditions, including an exclusively fossil fuel-based operation.

2. Simulations

The hybrid power plant evaluated in this article (Figure 1) coupled a concentrated solar plant with a conventional coal power plant. The simulation of the solar plant is based on the solar power tower plant GEMASOLAR, located in Seville, Spain [34]. The coal power plant follows the structure of the power plant Litoral (Spain) [35]. The proposed hybrid power plant is assumed to be located in Almeria. The simulation and analysis of the hybrid plant are thus based on data from this region.

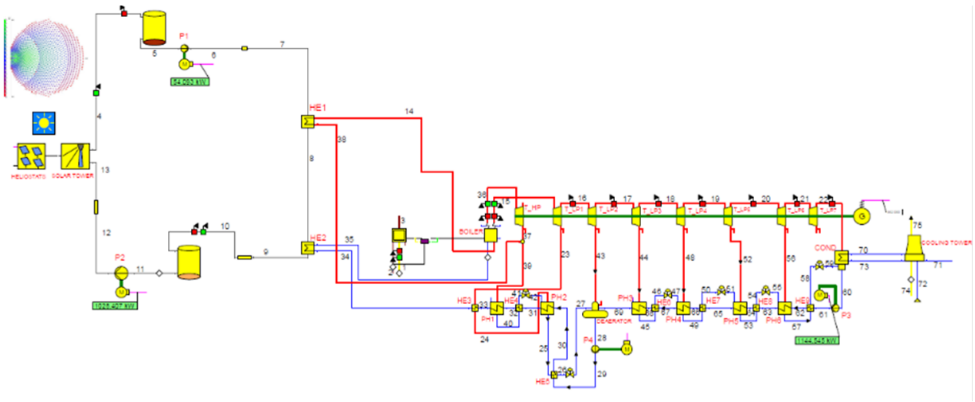

Figure 1. The proposed hybrid power plant that couples a coal plant with a solar power tower.

Sunlight is reflected on the heliostats of the plant toward the receiver of the solar tower, heating up, in this way, the molten salts that flow through the tower. The salts, composed of 40% KNO_3 and 60% $NaNO_3$ [32], are used to heat up steam, and water streams from the Rankine cycle of the plant. In order to ensure continuous operation when solar energy is not adequate to generate the required electricity, a thermal storage system with a capacity of 15 hours is included in the solar plant.

Preheated water (34) is heated up using thermal energy from the molten salts and is then led to the boiler of the plant to be heated up further to the inlet temperature of the steam turbine (560 °C). The superheated steam (36) then expands to 47 bar in the high-pressure turbine, and it is then partly reheated in the boiler (38) to reach the maximum temperature of the main stream. Reheated steam (15) at 560 °C and 41 bar is led to the intermediate-pressure turbine and gradually expands to the operating pressure of the condenser of the plant (0.61 bar) [36]. Once the water exits the condenser, it flows through several water preheaters. The water preheaters are heat exchangers that use successive steam extractions from the steam turbine to progressively increase the water temperature. The water exiting the water preheaters flows through the molten-salt heat exchanger, completing the cycle.

Water preheaters can have open, closed, or mixed structures. In this specific application, we find that preheaters of the closed type are the thermodynamically best choice to implement. The role of the water preheaters is to increase the efficiency of the plant by reducing the difference between the temperature of the water that returns to the boiler and the temperature of the steam exiting the turbine. Based on investment cost and efficiency calculations, the optimized number of extractions is found to be seven. [37]. An iterative process to calculate the conditions of each extraction was followed to achieve operating conditions that led to the required electricity generation (582 MW). The process used to calculate the pressure at each extraction was that indicated by General Electric [37]:

$$p_x = \frac{\dot{m}_{x+1} \cdot f}{10^6} \quad (1)$$

The pressure of extraction x (psia) was calculated using the mass flow rate (lb/h) through the extraction and the f factor shown in Table 1.

Table 1. Factors for the steam turbine.

Nº EXTRACTION (x)	1	2	3	4	5	6	7
f FACTOR	210.3	110.1	59.3	23.87	8.9 2	4.9 9	2.5 9

The proposed hybrid power plant was simulated using the software EbsilonProfessional [38]. The base simulation was further modified to account for several weather conditions, using data during daytime (12:00, 17:00) and night time (03:00) for spring, summer, and winter [39,40]. During daytime, the radiation conditions allow the plant to operate using both coal and solar sources, while during night time the plant operates using coal or stored thermal energy.

The thermodynamic data at the stream level of the plant for the different scenarios are presented in the Appendix A of the manuscript.

3. Methods

In order to study the thermodynamic and economic strengths and weaknesses of the hybrid power plant proposed, exergy and economic analyses were realized.

3.1. Exergy Analysis

Since exergy analysis has been widely studied (e.g., [41]), only a brief description of the methodology is presented here.

Exergy is defined as the maximum useful theoretical work that can be obtained by a stream or a system when the stream or the system is brought to thermodynamic equilibrium with the environment. The environment is a system in equilibrium with constant temperature, pressure (T_0, p_0), and chemical potential, and a total exergy of zero. Exergy can be divided into four main components: physical ($\dot{E}^{PH}$), chemical $\left(\dot{E}^{CH}\right)$, kinetic ($\dot{E}^{KN}$), and potential ($\dot{E}^{PT}$) [42]:

$$\dot{E} = \dot{E}^{PH} + \dot{E}^{KN} + \dot{E}^{PT} + \dot{E}^{CH} \tag{2}$$

Usually, changes in kinetic and potential exergy are very small and can be neglected. Physical exergy is the maximum useful work that can be obtained by passing the unit of mass of a substance from a state with specific temperature and pressure (T and p) to that of the environment (T_0 and p_0) (restricted dead state) by means of physical processes [42]. Chemical exergy is the maximum useful work that can be obtained when passing from the restricted dead state with T_0 and p_0 to the dead state, which is the state of complete equilibrium (mechanical, thermal, and chemical) with the environment, which may not imply a chemical process.

In this work, the reference stream with zero exergy used was the air entering the boiler, with $T_0 = 306$ K and $p_0 = 1.013$ bar. Standard chemical exergy values of the main substances were obtained using the model of Szargut [43]. Air, flue gas, and molten salt streams were treated as ideal mixtures [42]. The chemical exergy of coal was calculated considering the reaction of its combustion [42], following the procedure described by Bejan et al. [44].

To realize an exergy analysis of a power plant, it was required to define an exergy balance for each of the components in the plant and a balance for the overall system. The balance for each component k is defined as follows:

$$\dot{E}_{F,k} - \dot{E}_{P,k} - \dot{E}_{D,k} = 0 \tag{3}$$

where $\dot{E}_{F,k}$ is the exergy of the fuel (required resources to generate the desired product), $\dot{E}_{P,k}$ is the exergy of the product, i.e., the desired output of a process, and $\dot{E}_{D,k}$ is the exergy destruction of the component due to thermodynamic inefficiencies within it [42,45]. The corresponding equation for the overall system is written as:

$$\dot{E}_{F,sys} - \dot{E}_{P,sys} - \dot{E}_{D,sys} - \dot{E}_{L,sys} = 0 \tag{4}$$

where $\dot{E}_{L,sys}$ is the exergy loss of the overall plant. The specific performance evaluation of a component/system was based on the study of its exergetic efficiency, defined as the ratio between its product and the resources used to generate this desired product [42].

$$\varepsilon_{k/sys} = \frac{\dot{E}_{P,k/sys}}{\dot{E}_{F,k/sys}} \tag{5}$$

Therefore, an exergetic analysis is useful to locate the inefficiencies of a thermodynamic system and find their possible cause, facilitating the analysis and optimization of power plants.

3.2. Economic Analysis

An economic analysis was realized to determine the primary costs associated with the proposed plant and estimate its levelized cost of electricity (LCOE). The analysis implemented was based on the method proposed by Bejan et al. [44] and includes the calculation of the total capital investment (TCI) and the total revenue requirement (TRR). As the costs were calculated for the entire economic life of the plant, it was necessary to establish the reference conditions of the economic, technological, and legal framework assumed in the proposed project:

1. The economic study took place in 2016 with construction starting in 2017 and ending in 2019. Thus, the economic data were calculated in 2016 and were accordingly levelized depending on the year they became effective [44].
2. The capacity factor of the plant was 85% [46].
3. The inflation rate was i = 2.98% [47].
4. The nominal escalation rate (except coal) corresponded to inflation (2.98%).
5. A real escalation rate of 0.5% was assumed for coal [48]. The average growth rate was thus a nominal escalation rate of r_n^f = 3.49%.
6. The useful life of the hybrid power plant was assumed to be 25 years and its economic life 20 years (both calculated from the beginning of operation).
7. It was considered that the residual value of the plant at the end of the 25 years would be zero.
8. Financing was achieved as follows:
    - Debt: 65% of the capital at an interest rate of 10.0%.
    - Common equity: 25% of the capital at an interest rate of 15.0%.
    - Preferred stocks: 10% of the capital at an interest rate of 11.7%.
9. The electricity sale price used was 105.16 $/MWh (price for Spain in 2016) [49].
10. All taxes were considered constant throughout the life of the plant.
    (a) Income tax: t_s = 25.0% [50].
    (b) Property tax (Almería) in 2016: t_{prop} = 0.46% [51].
    (c) Insurance taxes: t_{ins} = 0.5% [44].
11. Operating and maintenance costs were assumed to be 20.0% of purchased equipment cost of the plant (PEC).
12. The price of coal was assumed to be 84.72 $/t [52].
13. It was assumed that 100 employees work in the plant, with an average hourly wage equal to $20.80.

In order to calculate the total capital investment (TCI), the purchased equipment cost (PEC) is required [53–55]. The rest of the costs are obtained based on the PEC, according to the percentages proposed by Bejan et al. [44]. The TRR is the total revenue requirement, i.e., the total amount that the plant needs to earn within a given year through electricity sales to compensate for the expenditures of that same year [44]. Finally, the LCOE represents the levelized cost of power generation and provides the connection between the necessary investment and electricity generation (E) for the 25 years of useful life (UL) of the plant [44]:

$$LCOE = \frac{\sum_{N=1}^{UL} \frac{TRR}{(1+r)^N}}{\sum_{N=1}^{UL} \frac{E}{(1+r)^N}} \quad (6)$$

4. Results and Discussion

The most important results of the analysis are presented in this section. Additional data on the simulation of the plant can be found in the Appendix A of the paper.

The exergy efficiencies obtained are shown in Figure 2 and the components with the highest thermodynamic inefficiencies in Figure 3. The most important inefficiencies in the proposed plant were found in the boiler, since the combustion process constitutes one of the main sources of irreversibilities, i.e., exergy destruction. The relative irreversibilities could be reduced through the preheating of the incoming flows, which in this case were assumed to have the ambient temperature. Another source of inefficiencies within the plant was the cooling system, composed of the condenser and the cooling tower. As a dissipative component, the cooling system does not generate a useful product, but it facilitates the operation of the overall plant. Thus, the destroyed exergy here should be kept to a minimum, without preventing the efficient operation of the rest of the plant components. The solar power tower also resulted in a relatively low efficiency. However, it is expected that working fluids will be further developed in the near future and the current technology will progress, allowing for higher operating temperatures [53]. Heat exchange between fluids of significantly different temperatures also led to high exergy destruction. This is the reason that some heat exchangers resulted in relatively low exergy efficiencies.

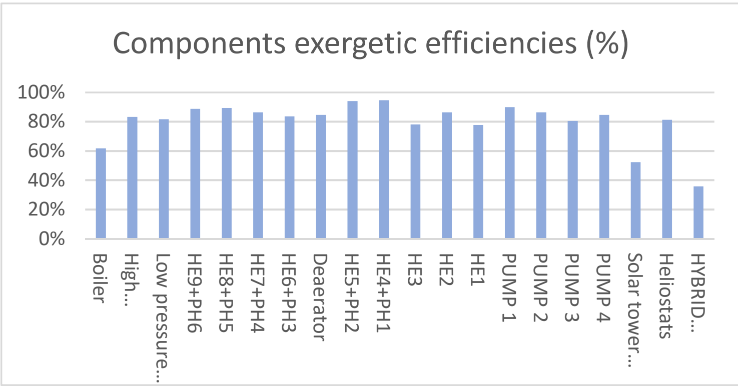

Figure 2. Exergetic efficiencies of the plant components.

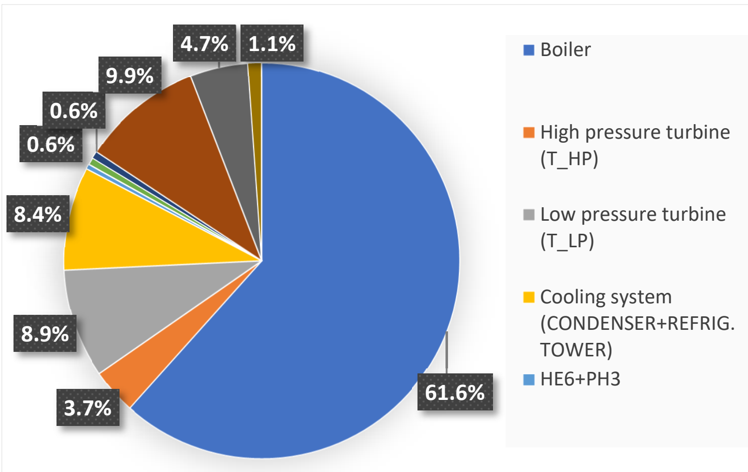

Figure 3. Exergy destruction share of the plant components.

The overall exergy efficiency of the plant was found to be 35.8%, with a total exergy destruction of 917.4 MW. This efficiency was calculated considering only the coal as the fuel and not including the solar heat as a power input. The efficiency was thus higher than that of a conventional coal power plant, as the necessary fuel to achieve the same power output was lower, given that the power was obtained by burning coal and from solar energy. If we also accounted for the solar heat as a fuel, the efficiency of the plant would drop down to 30.7%. This result is comparable to previous studies of solar-coal hybrid power plants that have reported efficiencies in the order of 30% [56]. The calculated efficiency offers an improvement, when compared to solar power tower plants that operate with efficiencies of around 25% [19].

When we compared the operation of the hybrid power plant during the day with its operation during the night (fired only by coal), we obtained the data presented in Table 2. The efficiency of the plant at night was found to be 34.2%. This value is within the range of common efficiencies reported for coal power plants [41]. The reason for this lower efficiency during night hours is the lack of solar energy. To achieve the desired power output in this case, the plant was solely dependent on coal.

The use of coal was reduced by 4.6% when solar energy was used, correspondingly reducing the generated CO_2. The total CO_2 emissions per day of the proposed hybrid plant were calculated to be 18,539.7 tons, while the emissions generated from an analogous coal-fired power plant were 19,430.9 tons. In other words, with the proposed hybrid power plant cam achieve an annual reduction of more than 325,273 tons of CO_2.

Hybrid plants allow for higher capacity factors, when compared to renewable plants. For example, when solar irradiation is not available (night hours, cloudy days), the hybrid power plant is able to continue its operation by using a higher fuel mass flow (coal, in this case) and meet demand requirements in a more flexible manner.

Table 2. Comparison between the operation of the hybrid power plant during night and day.

	ε_k	COAL USE (kg/s)	CO_2 EMISSIONS (kg/s)
DAY	35.83%	59.07	214.58
NIGHT	34.19%	61.91	224.89

The TCI of the plant was found to be 8050.32 \$/kW. This cost agrees with investment values reported for solar power tower plants, fluctuating between 6100 and 8100 \$/kW [57]. The main expense of solar technology, when compared to conventional coal power plants, is the relatively high purchased equipment cost. The same power plant presents a considerably lower TCI (5979.69 \$/kW), when operated as a coal plant. However, it is important to consider the fact that the hybrid power plant would present an important reduction in the cost of fuel, when compared to a conventional coal-fired plant. The TRR needed to maintain the electricity generation at 582 MW is presented in the Appendix A of the paper. The revenue required to cover the expenditures of the plant decreases over the years due to plant depreciation, since taxes and interest rates are reduced as the plant loses its value. However, fuel and operation and maintenance costs increase the required revenue over time due to their increasing trend.

The LCOE of solar power tower plants ranges from 0.15 and 0.21 \$/kWh in 2016 [58]. In this work, the value obtained from the detailed economic analysis of the hybrid plant was 0.19 \$/kWh. The LCOE of the plant during night operation (when it did not use solar energy) was found to be 0.12 \$/kWh. Published values for coal power plants are between 0.07 and 0.14 \$/kWh [58]. The generation is considered to be constant during day and night. The difference of the LCOE of the hybrid and coal plants is due to the relatively higher purchased equipment cost of the first. The thermal storage is another critical factor that increases the investment cost of the solar plant by more than 60% when it offers reliable operation for 15 h instead of 6 h [2]. The complexity of the hybrid system increases the cost of the plant further, as more control instruments and specialized people in charge of the operation and maintenance are needed.

Lastly, the legal, financial, and technological frameworks must be considered when studying the viability of hybrid power plants. Currently, renewable energy is encouraged by governments with subsidies. The European Union launched the European Union Emissions Trading System (EU ETS) that sets a maximum limit to the greenhouse gases that installations are allowed emit. The surplus can be sold in an emission trading system [59]. The aim of this program is to promote new ways of reducing pollution. In the technological framework, higher efficiencies and more developed processes are expected.

5. Conclusions

This article studied the simulation of a hybrid power plant that coupled coal with concentrating solar energy (solar power tower) and presented its evaluation under different conditions. Exergy and economic analyses of the hybrid power plant were conducted to examine the viability of the plant from these two points of view. The most important conclusions drawn from the study are the following:

- Coal consumption and pollutant emissions can be reduced by 4.6% with the introduction of solar energy, implying an annual reduction of CO_2 emissions of 325,273 tons.
- The efficiency of the hybrid power plant can be increased by 1.6%, when compared to the same plant fueled only by coal. This is associated with the lower fuel consumption of the plant due to the use of solar energy.
- Given the higher purchased equipment cost, the net investment required to operate the hybrid power plant would be 8050.32 $/kW, while the coal-fired thermal power plant would cost 5979.69 $/kW.
- The LCOE of the proposed hybrid power plant would be 0.19 $/kWh, and the value for the same plant fueled by coal would be 0.12 $/kWh.
- Operational stability of renewable power plants, the output of which depends on weather conditions, may be improved by coupling them with conventional fossil fuel plants.

The relatively high costs of solar technology may somewhat reduce its applicability, when compared to conventional thermal power plants. Nevertheless, hybrid power plants can decrease the supply instability of renewable plants, the fossil fuel consumption of conventional coal-fired power plants, and, consequently, the pollutants emitted during electricity generation.

An improvement of the plant proposed in this paper could be realized through the examination of ways to minimize the CO_2 emissions of the process using different hybrid power plant configurations. This would most probably imply a higher contribution of renewable energy, taking into account, however, the increase of the associated investment costs. In order to broaden the reach of this study, an examination of the viability of hybrid coal/solar power plants in different regions with different solar resources than southern Spain could also be made. Moreover, a discussion on the most appropriate renewable energy source for the design of a hybrid power plant depending on location and site resources could be a possible drive of future works.

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Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

ε	Exergy efficiency (%)
$\dot{E}$	Exergy rate (MW)
e	Specific exergy (kJ/kg)
E	Electricity production (MW)
f	Extraction factor
H	Enthalpy (kJ/kg)

i	Inflation rate (%)
$\dot{m}$	Mass flow rate (kg/s)
N	number of years
P	Pressure (bar)
r	Escalation rate (%)
S	Entropy (kJ/kgK)
T	Temperature (°C)
t	Tax (%)
UL	Useful life (a)
Subscripts	
0	Environmental conditions
D	Exergy destruction
F	Fuel (exergy)
ins	Insurance (tax)
k	Component
L	Loss (exergy)
n	Nominal (escalation)
P	Product (exergy)
prop	Property tax
s	Income (tax)
sys	Overall system
x	Number of extraction
Superscripts	
CH	Chemical
KN	Kinetic
PH	Physical
PT	Potential
Abbreviations	
AIR	Air flow
ASH	Ash flow
C	Coal flow
DEAERAT	Deaerator
E	Extraction flow
EU ETS	European Union Emissions Trading System
FG	Flue gas flow
HE	Heat exchanger
IEA	International Energy Agency
KNO_3	Potassium nitrate
LCOE	Levelized cost of electricity
MS	Molten salt flow
$NaNO_3$	Sodium nitrate
O&M	Operation and maintenance costs
PEC	Purchased equipment cost
PREH	Preheater
REFRIG TOWER	Refrigeration tower
ROI	Return of interests
S	Steam flow
TCI	Total capital investment
T_HP	High pressure turbine
T_LP	Low pressure turbine
TRR	Total revenue requirement
W	Water flow

Appendix A

Table A1. Stream-level thermodynamic results of the simulation.

FLOW	T (°C)	p (bar)	$\dot{m}$ (kg/s)	H (kJ/kg)	S (kJ/kgK)	e^{PH} (kJ/kg)
1	33.00	1.01	816.25	33.17	6.89	0.0
2	20.00	1.01	59.07	14.39	0.05	0.2
3	370.00	1.01	875.32	379.57	7.26	114.3
14	390.95	45.00	602.06	3183.66	6.67	1148.3
15	560.00	41.00	602.06	3582.20	7.25	1370.3
16	525.20	32.92	565.75	3510.75	7.26	1295.4
17	424.67	16.59	522.69	3307.42	7.30	1080.6
18	300.80	6.29	490.35	3063.01	7.35	819.4
19	191.81	2.27	474.05	2852.91	7.41	591.4
20	135.36	1.23	467.82	2745.48	7.45	473.6
21	113.79	0.95	462.22	2704.58	7.46	428.6
22	86.42	0.61	462.22	2638.88	7.48	355.8
23	525.20	32.92	36.31	3510.75	7.26	1295.4
24	288.97	32.87	36.31	2955.98	6.44	993.8
25	238.46	32.57	66.46	1030.16	2.69	215.2
26	217.01	32.52	66.46	930.14	2.49	176.4
27	203.14	16.59	66.46	930.14	2.49	174.6
28	203.14	16.59	632.22	866.58	2.36	151.9
29	207.01	182.75	632.22	890.57	2.37	172.8
30	209.37	182.70	632.22	901.08	2.39	176.6
31	233.97	182.40	632.22	1012.03	2.62	218.9
32	234.97	182.35	632.22	1016.61	2.63	220.7
33	255.10	182.05	632.22	1110.46	2.81	259.1
34	261.78	182.00	632.22	1142.32	2.87	272.6
35	268.26	181.00	632.22	1173.72	2.93	286.1
36	560.00	176.00	632.22	3450.78	6.46	1481.9
37	359.51	47.00	632.22	3101.22	6.53	1110.5
38	359.51	47.00	602.06	3101.22	6.53	1110.5
39	359.51	47.00	30.15	3101.22	6.53	1110.5
40	259.71	46.70	30.15	1133.39	2.88	259.0
41	239.97	46.65	30.15	1037.52	2.70	219.2
42	238.97	32.87	30.15	1037.52	2.70	218.2
43	424.67	16.59	43.06	3307.42	7.30	1080.6
44	300.80	6.29	32.34	3063.01	7.35	819.4
45	160.66	6.29	32.34	678.44	1.95	89.6
46	129.22	6.29	32.34	543.28	1.63	53.4
47	124.22	2.27	32.34	543.28	1.63	53.0
48	191.81	2.27	16.30	2852.91	7.41	591.4
49	124.22	2.27	48.64	521.72	1.57	48.1

Table A1. *Cont.*

FLOW	T (°C)	p (bar)	$\dot{m}$ (kg/s)	H (kJ/kg)	S (kJ/kgK)	e^{PH} (kJ/kg)
50	110.41	2.27	48.64	463.15	1.42	35.4
51	105.41	1.23	48.64	463.15	1.42	35.2
52	135.36	1.23	6.23	2745.48	7.45	473.6
53	105.41	1.23	54.87	441.94	1.37	31.2
54	103.18	1.23	54.87	432.52	1.34	29.4
55	98.18	0.95	54.87	432.52	1.34	29.2
56	113.79	0.95	5.60	2704.58	7.46	428.6
57	98.18	0.95	60.48	411.42	1.29	25.5
58	96.62	0.95	60.48	404.84	1.27	24.4
59	86.42	0.61	60.48	404.84	1.27	23.8
60	86.42	0.61	522.69	361.91	1.15	17.5
61	86.62	16.99	522.69	364.02	1.15	19.2
62	86.80	16.94	522.69	364.78	1.15	19.3
63	93.18	16.89	522.69	391.58	1.23	23.5
64	93.41	16.84	522.69	392.57	1.23	23.7
65	100.41	16.79	522.69	422.00	1.31	28.8
66	101.70	16.74	522.69	427.45	1.32	29.8
67	119.22	16.69	522.69	501.49	1.52	44.7
68	121.19	16.64	522.69	509.85	1.54	46.5
69	155.66	16.59	522.69	657.40	1.90	84.3
70	83.42	1.01	3685.61	349.34	1.12	15.7
71	15.00	1.01	36.86	63.08	0.22	2.3
72	33.00	1.01	443.06	138.37	0.48	0.0
73	15.00	1.01	3685.61	63.08	0.22	2.3
74	33.00	1.01	1465.08	33.17	6.89	0.0
75	69.73	1.01	1871.28	78.60	8.00	36.2

Table A2. Depreciation of the hybrid power plant.

N° YEAR	YEAR	DEPRECIATION FACTOR (%)	ANNUAL TAX DEPRECIATION (mill $)	VALUE (mill $)
0	2018	0.00	0.00	4499.79
1	2019	4.76	214.28	4285.51
2	2020	4.76	214.28	4071.24
3	2021	4.76	214.28	3856.96
4	2022	4.76	214.28	3642.69
5	2023	4.76	214.28	3428.41
6	2024	4.76	214.28	3214.13
7	2025	4.76	214.28	2999.86
8	2026	4.76	214.28	2785.58
9	2027	4.76	214.28	2571.31
10	2028	4.76	214.28	2357.03

Table A2. *Cont.*

Nº YEAR	YEAR	DEPRECIATION FACTOR (%)	ANNUAL TAX DEPRECIATION (mill $)	VALUE (mill $)
11	2029	4.76	214.28	2142.76
12	2030	4.76	214.28	1928.48
13	2031	4.76	214.28	1714.21
14	2032	4.76	214.28	1499.93
15	2033	4.76	214.28	1285.65
16	2034	4.76	214.28	1071.38
17	2035	4.76	214.28	857.10
18	2036	4.76	214.28	642.83
19	2037	4.76	214.28	428.55
20	2038	4.76	214.28	214.28
21	2039	4.76	214.28	0.00

Table A3. Total capital recovery (TCR) (in millions of USD).

Nº YEAR	YEAR	BOOK DEPRECIATION	TOTAL DEPREC. INVESTMENT	RECOVERY OF COMMON EQUITY	TCR
1	2019	179.99	10.29	3.36	193.64
2	2020	179.99	10.29	3.36	193.64
3	2021	179.99	10.29	3.36	193.64
4	2022	179.99	10.29	3.36	193.64
5	2023	179.99	10.29	3.36	193.64
6	2024	179.99	10.29	3.36	193.64
7	2025	179.99	10.29	3.36	193.64
8	2026	179.99	10.29	3.36	193.64
9	2027	179.99	10.29	3.36	193.64
10	2028	179.99	10.29	3.36	193.64
11	2029	179.99	10.29	3.36	193.64
12	2030	179.99	10.29	3.36	193.64
13	2031	179.99	10.29	3.36	193.64
14	2032	179.99	10.29	3.36	193.64
15	2033	179.99	10.29	3.36	193.64
16	2034	179.99	10.29	3.36	193.64
17	2035	179.99	10.29	3.36	193.64
18	2036	179.99	10.29	3.36	193.64
19	2037	179.99	10.29	3.36	193.64
20	2038	179.99	10.29	3.36	193.64
21	2039	179.99	10.29	3.36	193.64
22	2040	179.99	−54.00	3.36	129.36
23	2041	179.99	−54.00	3.36	129.36

Table A3. *Cont.*

Nº YEAR	YEAR	BOOK DEPRECIATION	TOTAL DEPREC. INVESTMENT	RECOVERY OF COMMON EQUITY	TCR
24	2042	179.99	−54.00	3.36	129.36
25	2043	179.99	−54.00	3.36	129.36
				TOTAL	4583.85
				Land cost and working capital	101.44
				Total investment	4685.29

Table A4. Return of interests (ROI) on debt (65%) (in millions of USD).

Nº YEAR	YEAR	BALANCE BEGINNING OF YEAR	BOOK DEPRECIATION	ADJUSTMENT	ROI
1	2019	3045.44	121.82	6.69	304.54
2	2020	2916.93	121.82	6.69	291.69
3	2021	2788.43	121.82	6.69	278.84
4	2022	2659.93	121.82	6.69	265.99
5	2023	2531.43	121.82	6.69	253.14
6	2024	2402.92	121.82	6.69	240.29
7	2025	2274.42	121.82	6.69	227.44
8	2026	2145.92	121.82	6.69	214.59
9	2027	2017.41	121.82	6.69	201.74
10	2028	1888.91	121.82	6.69	188.89
11	2029	1760.41	121.82	6.69	176.04
12	2030	1631.91	121.82	6.69	163.19
13	2031	1503.40	121.82	6.69	150.34
14	2032	1374.90	121.82	6.69	137.49
15	2033	1246.40	121.82	6.69	124.64
16	2034	1117.89	121.82	6.69	111.79
17	2035	989.39	121.82	6.69	98.94
18	2036	860.89	121.82	6.69	86.09
19	2037	732.39	121.82	6.69	73.24
20	2038	603.88	121.82	6.69	60.39
21	2039	475.38	121.82	6.69	47.54
22	2040	346.88	121.82	−35.1	34.69
23	2041	260.16	121.82	−35.1	26.02
24	2042	173.44	121.82	−35.1	17.34
25	2043	86.72	121.82	−35.1	8.67

Table A5. Return of interests (ROI) on common equity (25%) (in millions of USD).

Nº YEAR	YEAR	BALANCE BEGINNING OF YEAR	BOOK DEPRECIATION	ADJUSTMENT	ROI
1	2019	1171.32	43.49	5.93	175.7
2	2020	1121.90	43.49	5.93	168.28
3	2021	1072.47	43.49	5.93	160.87
4	2022	1023.05	43.49	5.93	153.46
5	2023	973.63	43.49	5.93	146.04
6	2024	924.2	43.49	5.93	138.63
7	2025	874.78	43.49	5.93	131.22
8	2026	825.35	43.49	5.93	123.8
9	2027	775.93	43.49	5.93	116.39
10	2028	726.5	43.49	5.93	108.98
11	2029	677.08	43.49	5.93	101.56
12	2030	627.66	43.49	5.93	94.15
13	2031	578.23	43.49	5.93	86.73
14	2032	528.81	43.49	5.93	79.32
15	2033	479.38	43.49	5.93	71.91
16	2034	429.96	43.49	5.93	64.49
17	2035	380.53	43.49	5.93	57.08
18	2036	331.11	43.49	5.93	49.67
19	2037	281.69	43.49	5.93	42.25
20	2038	232.26	43.49	5.93	34.84
21	2039	182.84	43.49	5.93	27.43
22	2040	133.41	43.49	−10.14	20.01
23	2041	100.06	43.49	−10.14	15.01
24	2042	66.71	43.49	−10.14	10.01
25	2043	33.35	43.49	−10.14	5

Table A6. Return of interests (ROI) on preferred stock (10%) (in millions of USD).

Nº YEAR	YEAR	BALANCE BEGINNING OF YEAR	BOOK DEPRECIATION	ADJUSTMENT	ROI
1	2019	468.53	18.74	1.03	54.82
2	2020	448.76	18.74	1.03	52.5
3	2021	428.99	18.74	1.03	50.19
4	2022	409.22	18.74	1.03	47.88
5	2023	389.45	18.74	1.03	45.57
6	2024	369.68	18.74	1.03	43.25
7	2025	349.91	18.74	1.03	40.94
8	2026	330.14	18.74	1.03	38.63
9	2027	310.37	18.74	1.03	36.31
10	2028	290.6	18.74	1.03	34
11	2029	270.83	18.74	1.03	31.69

Table A6. *Cont.*

Nº YEAR	YEAR	BALANCE BEGINNING OF YEAR	BOOK DEPRECIATION	ADJUSTMENT	ROI
12	2030	251.06	18.74	1.03	29.37
13	2031	231.29	18.74	1.03	27.06
14	2032	211.52	18.74	1.03	24.75
15	2033	191.75	18.74	1.03	22.44
16	2034	171.98	18.74	1.03	20.12
17	2035	152.21	18.74	1.03	17.81
18	2036	132.44	18.74	1.03	15.5
19	2037	112.67	18.74	1.03	13.18
20	2038	92.9	18.74	1.03	10.87
21	2039	73.14	18.74	1.03	8.56
22	2040	53.37	18.74	−5.4	6.24
23	2041	40.02	18.74	−5.4	4.68
24	2042	26.68	18.74	−5.4	3.12
25	2043	13.34	18.74	−5.4	1.56

Table A7. Calculated taxes and insurance (in millions of USD).

Nº YEAR	YEAR	ANNUAL TAXABLE INCOME	OTHER TAXES AND INSURANCE
1	2019	89.95	40.57
2	2020	85.78	40.57
3	2021	81.61	40.57
4	2022	77.44	40.57
5	2023	73.27	40.57
6	2024	69.11	40.57
7	2025	64.94	40.57
8	2026	60.77	40.57
9	2027	56.6	40.57
10	2028	52.43	40.57
11	2029	48.26	40.57
12	2030	44.09	40.57
13	2031	39.93	40.57
14	2032	35.76	40.57
15	2033	31.59	40.57
16	2034	27.42	40.57
17	2035	23.25	40.57
18	2036	19.08	40.57

Table A7. *Cont.*

Nº YEAR	YEAR	ANNUAL TAXABLE INCOME	OTHER TAXES AND INSURANCE
19	2037	14.91	40.57
20	2038	10.75	40.57
21	2039	6.58	40.57
22	2040	66.69	40.57
23	2041	63.88	40.57
24	2042	61.06	40.57
25	2043	58.25	40.57

Table A8. Fuel cost and operating and maintenance costs (O&M) of the plant (in millions of USD).

Nº YEAR	YEAR	FUEL COST	O&M
1	2019	140.39	154.1
2	2020	145.29	158.68
3	2021	150.36	163.4
4	2022	155.61	168.27
5	2023	161.04	173.27
6	2024	166.66	178.43
7	2025	172.48	183.73
8	2026	178.5	189.2
9	2027	184.73	194.83
10	2028	191.17	200.63
11	2029	197.84	206.59
12	2030	204.75	212.74
13	2031	211.89	219.07
14	2032	219.29	225.59
15	2033	226.94	232.3
16	2034	234.86	239.21
17	2035	243.06	246.33
18	2036	251.54	253.65
19	2037	260.32	261.2
20	2038	269.4	268.97
21	2039	278.81	276.97
22	2040	288.54	285.21
23	2041	298.61	293.7
24	2042	309.03	302.44
25	2043	319.81	311.43

Table A9. Total revenue requirement of the plant (in millions of USD).

Nº YEAR	YEAR	TRR
1	2019	1153.71
2	2020	1136.45
3	2021	1119.49
4	2022	1102.86
5	2023	1086.55
6	2024	1070.58
7	2025	1054.95
8	2026	1039.69
9	2027	1024.81
10	2028	1010.30
11	2029	996.2
12	2030	982.5
13	2031	969.23
14	2032	956.4
15	2033	944.02
16	2034	932.1
17	2035	920.67
18	2036	909.74
19	2037	899.32
20	2038	889.43
21	2039	880.08
22	2040	871.31
23	2041	871.81
24	2042	872.92
25	2043	874.66

References

1. World Bank. Producción de electricidad a partir de carbón (% del total). Available online: https://datos.bancomundial.org/indicador/eg.elc.coal.zs (accessed on 20 January 2019).
2. Ong, K.M.; Ghoniem, A.F. Modeling of indirect carbon fuel cell systems with steam and dry gasification. *J. Power Sources* **2016**, *313*, 51–64. [CrossRef]
3. Collins, R.; Kristensen, P.; Thyssen, N. *Water Resources across Europe—Confronting Water Scarcity and Drought*; European Environment Agency: København, Denmark, 2009.
4. Añel, J.A.; Fernández-González, M.; Labandeira, X.; López-Otero, X.; de la Torre, L. Impact of cold waves and heat waves on the energy production sector. *Atmosphere (Basel)* **2017**, *8*, 209. [CrossRef]
5. Ke, X.; Wu, D.; Rice, J.; Kintner-Meyer, M.; Lu, N. Quantifying impacts of heat waves on power grid operation. *Appl. Energy* **2016**, *183*, 504–512. [CrossRef]
6. Muh, E.; Tabet, F. Comparative analysis of hybrid renewable energy systems for off-grid applications in Southern Cameroons. *Renew. Energy* **2019**, *135*, 41–54. [CrossRef]
7. Naciones Unidas. Protocolo de Kyoto-Información Básica. Available online: http://unfccc.int/portal_espanol/informacion_basica/protocolo_de_kyoto/items/6215.php (accessed on 4 June 2017).
8. Comisión Europea. Acuerdo de París | Acción por el Clima, Comisión Europea. 2016. Available online: https://ec.europa.eu/clima/policies/international/negotiations/paris_es (accessed on 4 June 2017).

9. El País. Descenso de la producción de electricidad con carbón en España. Available online: https://elpais.com/elpais/2016/12/29/media/1483044925_978250.html (accessed on 20 January 2019).
10. Alqahtani, B.J.; Patiño-Echeverri, D. Integrated Solar Combined Cycle Power Plants: Paving the way for thermal solar. *Appl. Energy* **2016**, *169*, 927–936. [CrossRef]
11. Wang, Y.; Lou, S.; Wu, Y.; Miao, M.; Wang, S. Operation strategy of a hybrid solar and biomass power plant in the electricity markets. *Electr. Power Syst. Res.* **2019**, *167*, 183–191. [CrossRef]
12. 12. Hong, H.; Peng, S.; Zhao, Y.; Liu, Q.; Jin, H. A typical solar-coal hybrid power plant in China. *Energy Procedia* **2014**, *49*, 1777–1783. [CrossRef]
13. Shezan, S.; Al-mamoon, A.; Ping, H.W. Performance Investigation of an Advanced Hybrid Renewable Energy System in Indonesia. *Environ. Prog. Sustain. Energy* **2017**, *10*, 31. [CrossRef]
14. Padrón, I.; Avila, D.; Marichal, G.N.; Rodríguez, J.A. Assessment of Hybrid Renewable Energy Systems to supplied energy to Autonomous Desalination Systems in two islands of the Canary Archipelago. *Renew. Sustain. Energy Rev.* **2019**, *101*, 221–230. [CrossRef]
15. Das, B.K.; Zaman, F. Performance analysis of a PV/Diesel hybrid system for a remote area in Bangladesh: Effects of dispatch strategies, batteries, and generator selection. *Energy* **2019**, *169*, 263–276. [CrossRef]
16. Ihsan, A.; Jeppesen, M.; Brear, M.J. Impact of demand response on the optimal, techno-economic performance of a hybrid, renewable energy power plant. *Appl. Energy* **2019**, *23*, 972–984. [CrossRef]
17. Lazarov, V.D.; Notton, G.; Zarkov, Z. Hybrid Power Systems with Renewable Energy Sources-Types, Structures, Trends for Research and Development. In Proceedings of the ELMA 2005, Eleventh International Conference on Electrical Machines, Drives and Power Systems, Sofia, Bulgaria, 15–16 September 2005.
18. Hasan, M.; Tanvir, A.A.; Siddiquee, S.M.S.; Zubair, A. Efficient Hybrid Renewable Energy System for Industrial Sector with On-Grid Time Management. In Proceedings of the 2015 3rd International Conference on Green Energy and Technology (ICGET), Dhaka, Bangladesh, 11–12 September 2015. [CrossRef]
19. Krüger, M. Modelling of a Solid Oxide Fuel Cell for Integrated Coal Gasification Hybrid Power Plant Simulation. *Int. J. Thermodyn.* **2015**, *18*, 95–109. [CrossRef]
20. Duan, L.; Xia, K.; Feng, T.; Jia, S.; Bian, J. Study on coal-fired power plant with CO2 capture by integrating molten carbonate fuel cell system. *Energy* **2016**. [CrossRef]
21. Bandyopadhyay, R.; Patiño-Echeverri, D. An alternate wind power integration mechanism: Coal plants with flexible amine-based CCS. *Renew. Energy* **2016**, *85*, 704–713. [CrossRef]
22. Rashid, S.; Rana, S.; Shezan, S.; Karim, S.; Anower, S. Optimized Design of a Hybrid PV-Wind-Diesel Energy System for Sustainable Development at Coastal Areas in Bangladesh. *Environ. Prog. Sustain. Energy* **2016**. [CrossRef]
23. Shezan, S.; Das, N.; Mahmudul, H. Techno-economic analysis of a smart-grid hybrid renewable energy system for Brisbane of Australia Cost of Energy. *Energy Procedia* **2017**, *110*, 340–345. [CrossRef]
24. Bae, J.S.; Lee, D.W.; Lee, Y.J.; Park, S.J.; Park, J.H.; Kim, J.G.; et al. An investigation of the evaporation behavior of bioliquid in the pores and its application to hybrid coal combining biomass with coal. *Appl. Therm. Eng.* **2015**, *90*, 199–206. [CrossRef]
25. Trop, P.; Anicic, B.; Goricanec, D. Production of methanol from a mixture of torrefied biomass and coal. *Energy* **2014**, *77*, 125–132. [CrossRef]
26. Law, E.W.; Prasad, A.A.; Kay, M.; Taylor, R.A. Direct normal irradiance forecasting and its application to concentrated solar thermal output forecasting—A review. *Sol. Energy* **2014**, *108*, 287–307. [CrossRef]
27. Power, C.S. Technology Roadmap Concentrating Solar Power. *Current* **2010**, *5*, 1–52. [CrossRef]
28. Calise, F.; d'Accadia, M.D.; Libertini, L.; Vicidomini, M. Thermoeconomic analysis of an integrated solar combined cycle power plant. *Energy Convers. Manag.* **2018**, *171*, 1038–1051. [CrossRef]
29. Peterseim, J.H.; White, S.; Tadros, A.; Hellwig, U. Concentrated solar power hybrid plants, which technologies are best suited for hybridisation? *Renew. Energy* **2013**, *57*, 520–532. [CrossRef]
30. Zhu, Y.; Zhai, R.; Zhao, M.; Yang, Y.; Yan, Q. Evaluation methods of solar contribution in solar aided coal-fired power generation system. *Energy Convers. Manag.* **2015**, *102*, 209–216. [CrossRef]
31. Zhu, Y.; Zhai, R.; Qi, J.; Yang, Y.; Reyes-Belmonte, M.A.; Romero, M.; Yan, Q. Annual performance of solar tower aided coal-fired power generation system. *Energy* **2016**. [CrossRef]
32. Zhang, M.; Du, X.; Pang, L.; Xu, C.; Yang, L. Performance of double source boiler with coal-fired and solar power tower heat for supercritical power generating unit. *Energy* **2016**, *104*, 64–75. [CrossRef]

33. Zhao, Y.; Hong, H.; Jin, H. Mid and low-temperature solar-coal hybridization mechanism and validation. *Energy* **2014**, *74*, 78–87. [CrossRef]
34. Torresol Energy. Planta termosolar Gemasolar, Torresol Energy. Available online: http://www.torresolenergy.com/TORRESOL/planta-gemasolar/es (accessed on 30 December 2016).
35. Endesa. Información general de la Central Térmica Litoral | ENDESA EDUCA. Available online: http://www.endesaeduca.com/Endesa_educa/recursosinteractivos/instalaciones-lectricas/informacion-litoral (accessed on 29 December 2016).
36. Garcí a Garrido, S. Condensador. Ciclo Agua-Vapor, Renove Tecnología S.L., Madrid. Available online: http://www.cicloaguavapor.com/condensador (accessed on 6 May 2017).
37. Drbal, L.; Boston, P.; Westra, K.; Erickson, B. *Power Plant Engineering*; Kluwer Academic Publishers: Dordrecht, The Netherlands, 1996. [CrossRef]
38. STEAG Energy Services GmbH. EBSILON®Professional for the design of power plants, STEAG Energy Services GmbH, Essen. Available online: https://www.steag-systemtechnologies.com/en/products/ebsilon-professional/ (accessed on 30 December 2016).
39. ADRASE. Acceso a datos de radiación solar de España, CIEMAT. Available online: http://www.adrase.com/ (accessed on 24 March 2017).
40. Datos Clima. Base de datos meteorológica. Available online: http://datosclima.es/Aemet2013/Temperatura2013.php (accessed on 17 January 2017).
41. Kaushik, S.C.; Reddy, V.S.; Tyagi, S.K. Energy and exergy analyses of thermal power plants: A review. *Renew. Sustain. Energy Rev.* **2011**, *15*, 1857–1872. [CrossRef]
42. Tsatsaronis, G.; Cziesla, F. *Thermoeconomics*, 3rd ed.; Academic Press: Cambridge, MA, USA, 2002; pp. 659–680.
43. Szargut, J. Appendix 1. Standard Chemical Exergy. *Thermodyn. Destr. Resour.* **2011**, 1–8.
44. Bejan, A.; Tsatsaronis, G.; Moran, M. *Thermal Design and Optimization*; John Wiley & Sons, Inc.: New York, NY, USA, 1996.
45. Kotas, T.J.; Tadeusz, J. *The Exergy Method of Thermal Plant Analysis*; Butterworths: London, UK, 1985.
46. Green, A.; Diep, C.; Dunn, R.; Dent, J. High Capacity Factor CSP-PV Hybrid Systems. *Energy Procedia* **2015**, *69*, 2049–2059. [CrossRef]
47. Global rates. Inflación España - IPC, Triami Media BV, Utrecht. Available online: http://es.globalrates.com/estadisticas-economicas/inflacion/indice-de-precios-alconsumo/ipc/espana.aspx (accessed on 14 April 2017).
48. Ojea. L. La producción y los precios mundiales del carbón en caída libre, El Periódico de la Energía. 2016. Available online: http://elperiodicodelaenergia.com/la-produccion-y-losprecios-mundiales-del-carbon-en-caida-libre/ (accessed on 14 April 2017).
49. Endesa. Precio de la electricidad a tiempo real, Endesa, S.A. Available online: https://www.endesaclientes.com/precio-luz-pvpc.html (accessed on 13 April 2017).
50. Agencia Tributaria. Tipos de gravámen aplicable a períodos impositivos iniciados en el año 2015 y 2016. Agencia Tributaria. Available online: http://www.agenciatributaria.es/AEAT.internet/Inicio/_Segmentos_/Empresas_y_.profesionales/Empresas/Impuesto_sobre_Sociedades/Periodos_impositivos_a_partir_de_1_1_2015/Tipos_de_gravamen/Tipos_de_gravamen_aplicable_a_periodos_impositivos_iniciados_en_el_ano (accessed on 9 May 2017).
51. Concejalía de Economía. El Ayuntamiento rebaja un punto más el tipo de gravamen aplicable al IBI, que será del 0,46., Excelentísimo Ayuntamiento de Almería. Available online: http://www.almeriahacienda.es/index.php?option=com_content&view=article&id=131:2014-09-24-07-51-44&catid=36:noticias-del-area (accessed on 29 April 2017).
52. Vega, A. El carbón internacional duplica su precio en 2016 y ya es más caro que el autóctono., Servicios Generales de Comunicación y Gestión, S.L., León. 2017. Available online: http://www.ileon.com/actualidad/empresas/070332/el-carbon-internacional-duplicasu-precio-en-2016-y-ya-es-mas-caro-que-el-autoctono (accessed on 10 April 2017).
53. IRENA. Renewable Energy Technologies Cost Analysis Series: Concentrating Solar Power. *Compr. Renew. Energy* **2012**, *3*, 595–636. [CrossRef]
54. Hinkley, J.; Curtin, B.; Hayward, J.; Wonhas, A.; Boyd, R.; Grima, C.; Tadros, A.; Hall, R.; Naicker, K.; Mikhail, A. Concentrating solar power—Drivers and opportunities for cost-competitive electricity. *Victoria* **2011**, 1–32.

55. Loh, H.P.; Lyons, J.; White, C.W. *Process Equipment Cost Estimation Final Report*; National Energy Technology Lab (NETL): Morgantown, WV, USA, 2002.
56. Peng, S.; Wang, Z.; Hong, H.; Xu, D.; Jin, H. Exergy evaluation of a typical 330MW solar-hybrid coal-fired power plant in China. *Energy Convers. Manag.* **2014**, *85*, 848–855. [CrossRef]
57. IEA-ETSAP and IRENA. *Concentrating Solar Power Technology Brief*; IEA-ETSAP; IRENA: Abu Dhabi, UAE, 2013; Volume 1, pp. 331–339. [CrossRef]
58. OpenEI. Transparent Cost Database - LCOE, National Renewable Energy Laboratory, U.S.A. Available online: http://en.openei.org/apps/TCDB/ (accessed on 16 May 2017).
59. Comisión Europea. Régimen de comercio de derechos de emisión de la UE (RCDE UE) | Acción por el Clima. Comisión Europea. Available online: https://ec.europa.eu/clima/policies/ets_es (accessed on 4 June 2017).