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Integrated Solar Combined Cycles vs Combined Gas Turbine to Bottoming Molten Salt Tower Plants – A Techno-economic Analysis

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Abstract. The present work deals with the techno-economic analysis of a novel combined power cycle consisting of a molten-salt solar tower power plant with storage supported by additional heat provided from the exhaust of a topping gas-turbine unit. A detailed model has been elaborated using in house simulation tools that simultaneously encompass meteorological, demand and required dispatch data. A range of possible designs are evaluated for a suitable location with both good solar resource and vast natural gas resources in order to show the trade-offs between the objectives of achieving low carbon-intensive and economically competitive designs. These were compared against more conventional integrated solar combined cycles of equivalent capacity factors. It is shown that the novel concept is worth further investigating as it is able to outperform the more conventional cycle while simultaneously offering additional flexibility to grid-operators.

INTRODUCTION

Integrated Solar Combined Cycles (ISCC) have been suggested as a sustainable means of power production for countries under high direct irradiance and with vast natural gas resources, such as those in the Middle East region. One main driver for the deployment of ISCCs is to reduce fuel consumption compared to conventional combined cycle gas turbine plants, whilst simultaneously achieving a lower levelized cost of electricity (LCOE) than a size-equivalent concentrated solar power (CSP) plant. In this way, these countries can diversify their power portfolio and reduce their CO_2 footprint. However, most of commercial ISCCs account for annual solar shares of only 6% approx. [1], which can be deemed as insufficient for justifying the added complexity to the plants. Indeed, in most ISCCs parabolic troughs are used to preheat or boil the water through additional oil-to-water heat exchangers [1], which leads to higher investments and complexity in the control of the plant, see Figure 1 (left). In addition, conventional ISCCs do not include thermal energy storage (TES) systems, which means that the energy provided from the solar field (SF) is intermittent, resulting in off-design steam turbine operation. Previous research from the authors [2][3] have shown that a more effective alternative to such a concept would be the combination of a topping open cycle gas turbine (OCGT) coupled to a bottoming molten salt tower plant with TES. In such Topping-Gas to Solar-Tower (TGST), the exhaust from the gas turbine (GT) is integrated in parallel to a solar tower receiver in the plant layout (Fig.1 right), as an additional source for heating molten salts during GT operation. Molten salts from the GT and from the receiver are then mixed and stored in the hot tank (HT), which can be dispatched as desired (e.g. at whichever load and time) to drive a steam turbine (ST) cycle. By doing so the production from GT and ST can be decoupled (e.g. GT only for peaking), the operation of both cycles can be optimized (e.g. controlled to operate at nominal conditions), and the share of solar energy can be increased depending on the sizes of the SF, the GT and the ST, for instance. The present work shows a techno-economic comparative analysis between the ISCC and a TGST configurations when considering specific boundary conditions set by the market and location, as gathered for a suitable site. Results are ultimately used to provide recommendations to policy makers and developers, and to analyze the viability of the proposed cycle.

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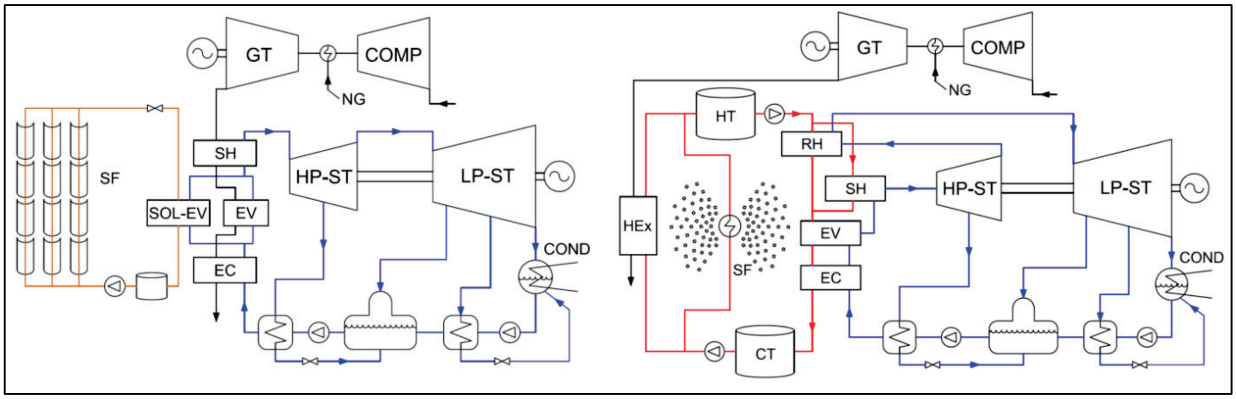

FIGURE 1. Left: Integrated Solar Combined Cycle (ISCC). Right: Topping Gas to Solar Tower (TGST)

SOLAR HYBRID CYCLE LAYOUTS AND OPERATING MODES

Topping Gas to Solar Tower (TGST) Power Plants

The acronym TGST, standing for Topping-Gas to Solar Tower Plant is used to denote the novel concept involving a topping OCGT and a conventional molten salt solar tower power plant with storage, acting as a bottoming-cycle. In order to be able to perform the techno-economic analysis of the TGST, this section introduces the general layout of the power plant and its different operating modes. The proposed layout for the TGST is displayed in Fig. 1 (right) and it shows that, similarly to conventional CCGT power plants, the OCGT provides additional heat for a bottoming cycle, which in this case is a molten salt solar tower plant with a heliostat SF. In this particular cycle, the exhaust gas leaving the OCGT is used as an extra heat source for the bottoming cycle of the TGST by means of a single air-to-salt heat exchanger, denoted HEx. Fig. 1 (right) shows that the bottoming cycle layout corresponds to a conventional solar tower power plant with storage, which consists of two thermodynamic cycles: the HTF cycle (depicted in red lines) and the steam cycle (in blue lines). In the HTF cycle, the cold molten salts stored in a tank (CT) are first heated, either in the receiver (R) with energy coming from the heliostat field or else in the HEx with energy provided by the topping OCGT. Once heated, the molten salts are stored in the hot tank (HT) which is then discharged at a specified flow rate to enter the steam generation train, comprised of the economizer, the evaporator, the superheater and the reheater, respectively denoted as EC, EV, SH and RH in Fig. 1 (right). Lastly, Fig. 1 (right) shows that the steam powerblock corresponds to a typical reheat Rankine cycle with five extractions for feedwater preheating. In this bottoming steam powerblock, the high pressure and low pressure turbines, and the condenser are denoted as HP-ST, LP-ST, and COND respectively. The proposed layout grants great flexibility and dispatchability concerning the operation of the power plant. The TGST aims to fulfill three different scenarios which might take place in the present environment following the market roles. Firstly, a baseload scheme where the OCGT cycle is running fulltime and the CSP cycle is online as long as there is energy available in the HT. Secondly, a mid-merit scheme which not allow to deliver energy to the grid for a range of time (from 10 am to 4 pm) thereby TGST must not generate. The last scenario, Peak plus baseload, leads to a scheme where the CSP cycle is running as long as there is energy available in the HT and the OCGT starts up during specified peaking hours. Based on the plant layout and the targeted market roles, and in order to better describe the operation of the TGST, Table 1 displays the possible power generation modes of the power plant.

Integrated Solar Combined Cycles (ISCCs)

In this study, the ISCC is designed based on the results and conclusions of Manente et al [1] and Alqahtani et al [4]. Such studies reveal that, for these power plants, the most efficient way to harness and integrate solar energy is by means of parabolic trough collectors, using thermal oil as heat transfer fluid. In this configuration, steam is preheated in the HRSG until saturated conditions. Then, a fraction of that saturated water (high pressure only) is sent to the solar evaporator (oil-to-water heat exchanger), whilst the remaining water is evaporated in the HRSG. Finally, both steam streams are mixed and then superheated in the HRSG for further expansion in both low-pressure and high-pressure steam turbines. Figure 1 (left) shows a schematic flowsheet of the ISCC.

TABLE 1. Operating Modes of the TGST

OMs	Description
OM1	There is energy input to the salts from both the exhaust of the OCGT and the SF. The HT is discharged at its nominal flow rate, so that both gas and steam cycles generate electricity.
OM2	There is energy input to the salts only from the exhaust of the OCGT. The HT is being discharged at its nominal flow rate, so that both gas and steam cycles generate electricity.
OM3	The OCGT is offline. There is energy input to the salts only from the SF. The HT is being discharged at its nominal flow rate and only the bottoming steam cycle generates electricity.
OM4	No energy is being supplied, neither by the OCGT exhaust nor the SF, but there is energy stored in the HT, which is being discharged at its nominal flow rate, implying that only the bottoming steam cycle generates electricity.
OM5	No energy is being supplied, neither by the OCGT exhaust nor the SF, and there is no energy stored in the HT. No electricity is generated by the TGST.

One of the advantages of this configuration is that the SF contribution can be incorporated into already existing CCGT plants. However, there are technical limitations as to how much heat from the SF can be efficiently used in the CCGT. Because there is no TES, all the energy harnessed in the SF has to be used at the moment (or else wasted), resulting in highly variable steam mass flows. Therefore, the SF is restricted in size. By analyzing the tradeoffs between capital and operating costs for different CSP capacity shares, Alqahtani et al [4] showed that the optimum ratio of CSP installed capacity to CCGT installed capacity is around 10%. Further addition of heat from the SF would greatly reduce the steam turbine efficiency and increase the LCOE because of the investment cost related to it.

In such configuration, only 30% of the energy input to the HRSG comes from the SF (at solar noon on summer solstice), the remaining 70% comes from that available in the exhaust of the OCGT. Considering the intermittency of the solar resource and, trying to minimize the off-design operation of the steam turbines, the Rankine cycle and all its components are dimensioned as if no heat from the SF was incorporated in the system.

Because of the SF limited contribution, the OCGT must be providing with thermal energy to the steam cycle at all times. Whenever the OCGT is off, the whole ISCC will be too, regardless of the solar resource at the moment. The possible operation modes for the ISCC are listed in Table 2.

TABLE 2. Operating Modes of the ISCC

OMs	Description
OM1	OCGT is online. There is no heat input from the SF. Steam cycle is runs at nominal conditions.
OM2	The OCGT is online. There is enough solar resource to run the SF, therefore, there is heat input from the SF. The steam cycle is running at off-design conditions.
OM3	The OCGT is online. The solar resource is greater than design conditions, therefore, spillage is done and there is heat input from the SF. The steam cycle is running at off-design conditions.
OM4	No energy is supplied, neither by the OCGT exhaust nor the SF. No electricity is generated by the ISCC.

TECHNO-ECONOMIC MODELING APPROACH

The techno-economic analysis of both ISCC and TGST power plants was performed using DYESOPT, a KTH in-house optimization tool [5], and ÅF Aries Energía's in-house model [3], respectively. Optimum plant configurations minimizing the LCOE have been identified for both cycles in terms of operating strategy and component sizing for a given site nearby Dubai in the U.A.E, for which specific location-dependent boundary conditions (e.g. weather and costs) were gathered and tier production schemes (hourly) were assumed as suggested by characteristic demand profile loads and information from recent tenders for power generation in the region. In this study, optimums have been identified by means of an exhaustive sensitivity analysis on key design variables, as shown in the following sub-sections. LCOE calculation approach and cost scaling models used are explained in the following.

Location-related Modeling Boundaries and Production-Scheme Scenarios

In this study, a location near Dubai, UAE, is considered mainly due to its aggressive CSP integration plans and vast natural gas resources. For such a location a whole year's worth of typical hourly meteorological data was gathered for the coordinates 24°74'N, 55°36'E with a time span of one hour as extracted from the Meteonorm dataset [6] (with total annual DNI of 1765 $kWh/m^2/yr$). The main goal of the present paper is to assess and compare the techno-economic performance of the ISCC and TGST cycles under same atmospheric conditions and dispatch-schemes.

The wide flexibility of these plants enables them to firmly follow different energy delivery scenarios. Specifically, in the present study three dispatch schemes have been considered as boundary conditions, all of which are potential scenarios for the location suggested. The first dispatch scheme proposed (DS1) consisted of a baseload scheme where the power plants are enabled to work at full load and dispatch inject energy to the grid at all times. The second dispatch-scheme scenario (DS2), consisted of a mid-merit scheme in which plants are restrained from delivering energy between 10:00 and 16:00. DS2 resembles an on-going CSP tender in the location of the study. The third dispatch-scheme scenario considered (DS3) was specifically suggested for the analysis of the TGST cycle only, and was built from the combination of DS1 and DS2, by allowing the plant to operate at full capacity at all times but restraining the topping GT from operating between 10:00 and 16:00. Results show optimum ISCC and TGST configurations yielding minimum LCOE for all three DS, these plants are analyzed and also compared on the basis of specific CO_2 emissions.

Steady-State Design and Dynamic Modeling of the TGST

A number of tools have been combined to perform the design and techno-economical assessment of the TGST plant, Firstly, the design of the heliostat field layout has been carried out by means of NREL's SolarPILOT tool [7], which enables users to design the receiver flux profile and the aiming strategy for each one of the expected heliostats in order to achieve the proposed installed power. The System Advisor Model (SAM) [8] has been used for estimating the hourly SF optical efficiency, which is then used to calculate the thermal input to the receiver. Despite of their robustness, both of these tools show limitations when trying to resemble project-specific boundaries such as required dispatch-scheme scenarios. Therefore, AFA developed an internal TGST tool which stems from the combination of two in-house performance tools for the analysis of CSP plants namely "SolARIES" and STIG. Apart from performing a more detailed modelling of the TES system, the power block and BOP auxiliaries, Aries' TGST in-house tool facilitates the definition of project specific dispatch strategies. The inputs to SAM is the SF distribution of each heliostat from SolaPILOT and the inputs to AFA in-house tool are the outputs of the SF model embedded in SAM. SolARIES is a flexible and powerful tool that is based in a Microsoft Excel with Visual Basic code and supported by other advanced calculation software, such as IPSEPro, which is used to model the performance and interaction of various mechanical sub-systems in the CSP plant. SolARIES performs hourly simulations of the system to estimate the annual power output. Optimum TGST cycles for each of the DS mentioned in the precedent subsection were determined from a sensitivity analysis varying critical design parameters for the cycle. These are shown in Table 3, including the ranges of values considered for each parameter.

TABLE 3 Key Design Parameters and values evaluated for the TGST cycle

Total output [MWe]	GT/ST output ratio	GT nominal [MWe]	ST nominal [MWe]	TES [Hours]	Solar Multiple [*]	Tower Height [m]
120	[0.2; 0.7; 1.4]	[20; 50; 70]	[100; 70; 50]	[8; 12; 16]	[1.5; 2; 2.5]	[150; 200]

Steady-State Design and Dynamic Modeling of the ISCC

The modeling of the ISCC is based on a quasi-steady state model of the whole system, which has been elaborated using DYESOPT, an in-house tool designed for the analysis of energy systems. The modeling approach adopted in this study is shown in Fig. 2, which schematizes the flow of information and calculations in the tool. Firstly, the power plants are designed in MATLAB based on a number of decision variables, giving the nominal steady-state performance. The nominal point data is then used to size the components in the TRNSYS simulation studio [5] which, coupled with meteorological and demand data plus specified operation strategies, allows prediction of the annual performance of the power plants. In this way if the decision variables are varied, it is possible then to identify the best plant configurations satisfying the desired techno-economic objective functions, measured by specific performance indicators provided as output from the tool. This study is intended to compare different configurations of TGST against a specific set up for the ISCC. However, for the latter, a wide range of values were evaluated for different parameters in order to confirm the results from the aforementioned authors. For a fixed OCGT gross capacity of 85MW, different SF sizes were investigated, resulting in different ST nominal outputs and GT/ST ratios. These are shown in Table 4, including the ranges of values considered for each parameter. The solar multiple was defined as the ratio of mirror aperture area to nominal aperture area: the latter being the area needed so that the total plant installed capacity goes from 100% (CCGT without solar integration) to 110%.

TABLE 4 Key Design Parameters and values evaluated for the ISCC cycle

Total output [MWe]	**GT/ST output ratio**	**GT nominal [MWe]**	**ST nominal [MWe]**	**Solar Multiple [*]**	**Aperture Area [Ha]**
[120-124]	[2.6-2.1]	[82.45]	[31-41]	[0.2-2.2]	[1.4-14]

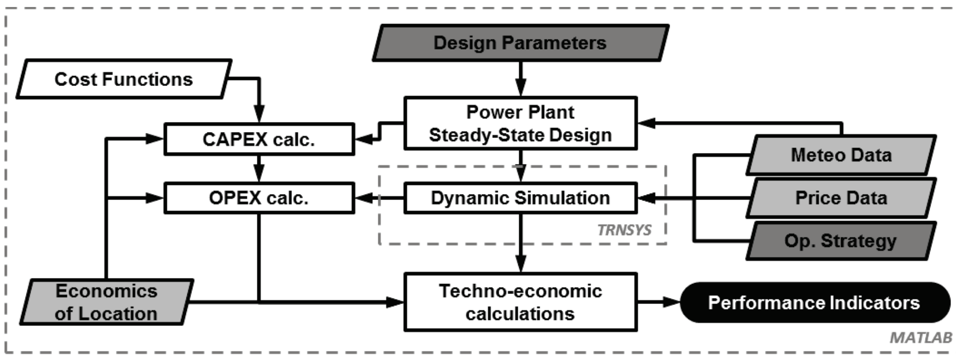

FIGURE 2. Simplified schematics of information flow in DYESOPT

Cost Modeling and Techno-economic Performance Indicators

The performance of the ISCC and the TGST was evaluated both from economic and environmental standpoints. The LCOE was used as the economic performance indicator and was calculated by means of equation (1), as a function of the annual investment costs '*I*', the annual operation and maintenance costs '*O*', the annual fuel costs '*F*' and the net electricity generated 'E_{net}', when considering a specific discount rate '*r*'. In this study the discount rate was fixed to 5%, which corresponds to a weighted average capital cost (WACC) resulting from a debt to equity ratio of 85/25, a cost of equity of 10%, and a cost of debt of 4%. For both the ISCC and the TGST the lifetime of the plants '*N*' was assumed to consist of 25 years of operation and 2 of construction during which investment contribution is even.

$$LCOE = \sum_{i=0}^{N} \frac{I_i + O_i + F_i}{(i+r)^i} \Big/ \sum_{i=0}^{N} \frac{E_{net\,i}}{(i+r)^i} \quad (1)$$

For both cycles, a button-up cost model at key-component level is considered for calculating and scaling the investment costs or capital expenditures (CAPEX). Direct costs consider all equipment related costs from purchasing to installation on site, whereas indirect costs relate to development costs and related expenses undertaken during commissioning. Reliability functions are used in this study for cost scaling-up based on cost values from reference plants and respective material and labor cost multipliers. A typical function for cost scaling is shown in (1), where the cost of equipment *'m'*, can be calculated based on n_1 reference cost values C_{ref}, which are sensitive to n_2 critical design parameters *'X'*, each in different degrees of relevance expressed by n_2 size scaling exponents '*y*'.

$$C_m = \sum_{\gamma=1}^{n_1} \left\{ C_{ref,\gamma} \cdot \prod_{\beta=1}^{n_2} \left[\left(\frac{X_{m,\beta}}{X_{ref,\beta}} \right)^{y_\beta} \right] \right\} \quad (2)$$

Specifically, the direct CAPEX of the TGST was calculated as the addition of a number of key sub-systems available in the plant namely: the GT power block, the air-to-salt heat exchanger, the SF, the receiver, the tower, the ST power block set, the balance of plant, the TES system, and civil/land works. For all of these, reference costs suitable for the location of study were extracted from [9-12] and also from previous experience from the authors from projects in the region. The indirect CAPEX accounted mainly for the developer, engineering, and financial costs (indirect CAPEX was calculated as a percentage of the direct CAPEX). In the TGST, direct costs were scaled through reliability functions such as (2) considering the following critical design parameters: the SF aperture area, the TES capacity, the installed capacity of GT and ST cycles, the tower height, and the receiver rated power. The TGST operation '*O*' and the fuel costs '*F*' (the operational expenditures or OPEX) were calculated as a function of the installed capacities, the energy generated, the fuel consumed and the cost of fuel. In this study a reference NG price of 26.2 USD/$MWh_{\text{-th}}$ was considered, as extracted from the U.S. Energy Information Administration (EIA). Worth highlighting that SF costs (approx. 125 USD/m^2) and more importantly the fuel cost assumptions had a great impact on the results, reason for which a sensitivity is also included in the Results section of this study.

Similarly, the cost structure of the ISCC model was also divided into CAPEX and OPEX. The first, also considered direct and indirect costs. Within direct CAPEX costs following costs were considered at component level: the cost of the power block equipment (GT, heat recovery steam generation, ST, water treatment plant, air-cooled condenser, deaerators, electric generators, electronics, solar evaporator, SF and its heat transfer fluid system), the installation costs and the costs of civil works related to both, SF and power block.. Likewise the TGST case, critical design variables i.e. the installed capacity and the SF size, were used for scaling up the costs by means of cost-scaling functions such as that shown in equation (2). Annual OPEX of the ISCC was divided into maintenance costs (as a function of equipment´s CAPEX), labor costs (for plant operation) and operation costs (such as water and fuel costs). Fuel costs were calculated undertaking same fuel composition and prices as that assumed for the TGST (LHV_{fuel} = 5x10^4 kJ/Kg). Reference cost values for the ISCC were extracted from [9-12]

The environmental performance of the cycles was measured on the basis of the specific CO_2 emissions 'F_{CO2},' calculated by means of (3) as a function of the quantity of natural gas burnt annually Q_f (calculated based on the performance specifications of the GT) and the carbon content of such fuel c_c, for which a value of 230 kg/MW_{th} was used. The other two relevant performance indicators used for the comparative analysis were the capacity factor (CF) and the annual solar share 'F_{solar}'. In this study, the CF is calculated by means of (4) and can be understood as the percentage of time at which the full installed capacity of the plant is used throughout the year. The annual solar share 'F_{solar}' is calculated by means of (5) as the product of the power collected in the receiver 'Q_{rec}' and the average ST power block efficiency '$\overline{\eta}_{STPB}$' divided by the total electricity generated by the plant 'E_{net}', and so it can be understood as an approximate value of the total electricity generated due to solar energy.

$$F_{CO_2} = Q_f c_c \cdot (E_{net})^{-1} \quad (3)$$

$$CF = \left[E_{net} \cdot (120 \times 8760)^{-1} \right] \cdot 100\% \quad (4)$$

$$F_{solar} = \left[\dot{Q}_{rec} \times \overline{\eta}_{STPB} \times (E_{net})^{-1} \right] \cdot 100\% \quad (5)$$

RESULTS AND COMPARATIVE ANALYSIS

Table 5 summarizes the performance results from the configurations which resulted in the lowest LCOE for both TGST and ISCC under the operating schemes investigated. In terms of configuration, it can be seen that best TGST configurations consisted all of a GT to ST power output (nominal) of 0.2, 16 hours of TES and a SM of 2. As per the ISCC, optimum configurations considered a 2.1 GT to ST ratio and a SM of 1*. In terms of performance, it is shown that the best TGST configuration under DS1 (baseload-like scheme) only reaches a CF of 64%. In order to make the comparison fair, a model of the ISCC was also set to operate from 5:00 to 21:00 which yielded a CF of approx. 65%. Comparing both best TGST and ISCC configurations reaching approx. a 65% CF it is possible to see that, at the assumed NG prices, the ISCC will outperform the TGST on the basis of LCOE i.e. 92 USD/MWh vs. 105 USD/MWh. On the contrary, environmentally speaking the best TGST configuration with a 65% CF under DS1 would generate less than half of the emissions than its equivalent best ISCC, in turn highlighting that there is no definite best plant layout. The latter is possible given that the TGST is able to derive close to 70% of its energy from the Sun, while the annual solar share is only approx. 5% for the best ISCC configuration.

TABLE 5 Summary of Performance Results and Configurations (* *SM for ISCC defined in previous section*)

Cycle	Operating Scheme	LCOE [USD/MWh$_e$]	F_{CO2} [Kg/MWhe]	CF [%]	F_{solar} [%]	GT/ST [-]	TES [Hours]	SM [-]
TGST	DS1	104.84	170.03	63.8%	70.1%	0.2	16	2.0
	DS2	112.07	149.12	46.8%	73.8%	0.2	16	2.0
	DS3	105.73	71.13	50.8%	87.5%	0.2	16	2.0
ISCC	Baseload	80.83	400.76	91.6%	3.4%	2.1	0	1.0*
	5:00 – 21:00	91.81	399.67	65.3%	4.6%	2.1	0	1.0*
	6:00 – 18:00	107.66	387.33	46.9%	5.7%	2.1	0	1.0*

Table 5 also displays the results for the other Operating Schemes considered for the TGST, namely DS2 and DS3. Comparing results among operating schemes, it is possible to see that the lowest LCOE is reached at the baseload-like configuration, but the lowest emissions are reached under DS3, the two-tier scheme. If the TGST plant is required to operate under a scheme similar to DS2 (no operation from 10:00 to 16:00), the LCOE would be 10% higher than that found for the best TGST configuration under continuous operation (DS1 results), but in turn the emissions would be lowered and the solar share would increase. An equivalent ISCC, in terms of installed capacity i.e. 120 MW$_e$ and CF (approx. 47%) would reach lower LCOE, yet generating almost three times more specific CO_2 emissions (Table 5).

In order to make a fair comparison against the best ISCC, the best TGST reaching 90% of CF among cases considered was also identified. Table 6 summarizes the results for the best TGST configurations fond for each of the GT/ST investigated when required to operate under a scheme similar to DS1 (continuous baseload-like operation). First, it can be seen that the impact of the GT/ST ratio is not mainly on the LCOE but on the specific CO_2 emissions. Additionally, it is also shown that larger GT/ST ratios can lead to higher CF, exceeding 90% inclusively. Specifically, the best configuration with a GT/ST ratio of 0.7 was found able to reach a CF of approx. 90%, similarly to the best ISCC design. When comparing among these two configurations with a 90% CF, it is possible to confirm that ISCCs would represent a more attractive alternative in terms of LCOE, but the proposed TGST would be able to reduce the CO_2 emissions generated per MWh. However, as seen in Fig 2 (left) these results are dependent on NG prices assumed.

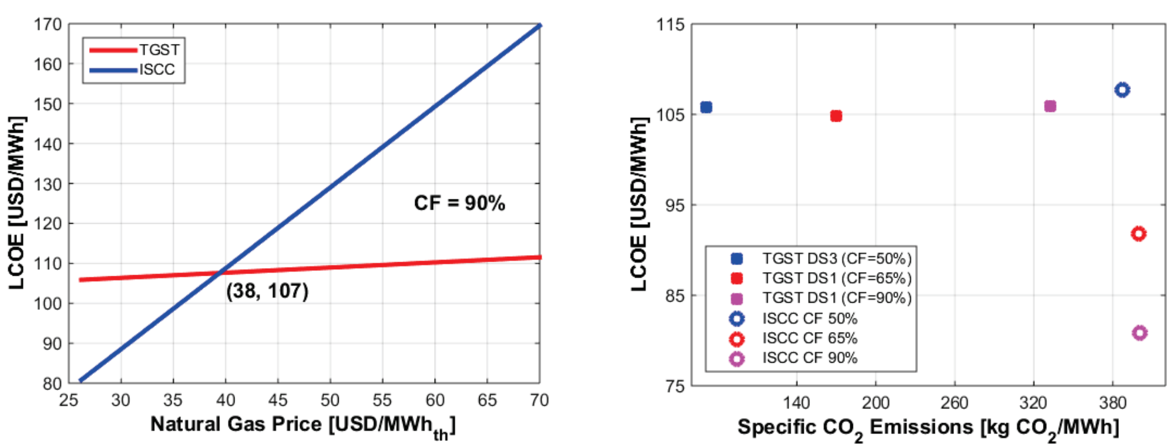

FIGURE 3. Sensitivity to NG costs (left) – Summary of performance of best TGST and ISCC configurations investigated

Indeed Figure 3 (left) shows that at a NG price of approx. 38 USD/MWh both cycles at 90% CF would reach parity in terms of LCOE, and also that the proposed TGST is considerably less susceptible to NG price fluctuations. Figure 3 (right) summarizes also the LCOE and specific CO_2 emissions results found for best TGST and ISCC configurations, highlighting that the cost of the best TGST configurations is less influenced by the required operating scheme (or CF), and also that the lower the CF required the more attractive the TGST configuration would be.

TABLE 6 Summary of Best TGST configurations for all GT/ST ratios investigated under DS1 (baseload-like scheme)

GT/ST [-]	TES [Hours]	SM [-]	Tower H [m]	LCOE [USD/MWh$_e$]	F_{CO2} [Kg/MWhe]	CF [%]	F_{solar} [%]
0.2	16	2.0	200	104.84	170.03	63.8%	70.1%
0.7	16	2.0	200	105.88	332.76	89.7%	41.6%
1.4	16	2.0	200	106.78	389.28	97.6%	31.6%

CONCLUSIONS

The techno-economic evaluation of the novel TGST power plant, whose layout is composed of a topping OCGT and a bottoming molten salt solar tower CSP plant, has been performed in this study and compared against the performance of the conventional ISCC. The study was carried out considering a suitable location nearby Dubai and a number of operating schemes under which the plants were required to operate. The results show that the TGST is indeed a promising concept able to reach competitive LCOE levels while considerably reducing the specific CO_2 emissions. When comparing against an equivalent ISCC, in terms of CF and installed capacity, the best TGST configurations showed that such a cycle would be less susceptible to NG price fluctuations and that the lower the CF required then the more attractive it would be by keeping similar LCOE but being able to bring down the specific CO_2 emissions to a third or less (e.g. the 50% CF case). Specifically, for reference cost values assumed, the LCOE of all best TGST configurations oscillated around the 105 USD/MWh, regardless the CF, while the best ISCCs varied between 80 to 108 USD/MWh when moving from 50% to 90% CF, respectively. Similarly, while the ISCC shows almost no variation in specific CO_2 emissions as a function of the CF (at approx. 395 $kgCO_2$/MWh), the TGST is able to reduce emissions from 333 to 71 $kgCO_2$/MWh, value reached under the proposed two-tier output scheme which is only possible given the flexibility of the new cycle and the possibility to decouple the topping GT cycle from the bottoming one. Conclusively, and despite the low irradiation levels perceived in the location chosen, this study shows that the TGST is an innovative flexible cycle worth investigating further as it can outperform, both economically and environmentally, the other more conventional ISCC and yet with vast opportunities for improvements.

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