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Case Study on Decarbonization Strategies for LNG Export Terminals Using Heat and Power from CSP/PV Hybrid Plants

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Abstract. The race towards decarbonization is driving major oil and gas companies to explore means to use renewable heat and power for their plants as part of their commitment to reduce their carbon intensity by 80% to 100% by 2050 [1]. In terms of greenhouse gas (GHG) emissions, natural gas is considered the cleanest fossil fuel option available, and decarbonization of new liquefied natural gas (LNG) projects is on the radar of many LNG projects developers. In addition, LNG cargos will have to be certified in the future by accredited authorities to meet defined GHG emission levels [2].

This research study investigates a concept of providing both heat and power from a photovoltaic (PV) and concentrated solar power (CSP) solar tower hybrid plant to meet the energy demand of LNG export terminals. Two locations have been investigated for potential future LNG projects: Karratha in Australia and Ras Laffan in Qatar. Both locations have direct normal irradiance (DNI) values higher than 2000 kWh/m^2/year, which is the minimum level required for CSP technology [3]. A techno-economic assessment was carried-out taking into consideration the electricity price, the grid carbon intensity and the carbon dioxide (CO_2) tax in the region.

The results indicate that the CSP/PV hybrid plant significantly accelerates the decarbonization of energy supply to the “All electric” LNG Plant. The quantity of CO_2 emitted between 2025 and 2050 is reduced by 81% for Karratha (Australia) and by 88% for Ras Laffan (Qatar) compared to a grid connected LNG plant.

Keywords: Concentrated Solar Power, CSP, Liquified Natural Gas, CO_2 emission reduction

Abbreviations

C3MR	Propane Precooled Mixed Refrigerant
LCCA	Levelized cost of CO_2 abatement
LCOE	Levelized Cost of Electricity
LCOH	Levelized Cost of Heat

Units

kW	kilowatt
MTPA	Million Tons per Annum
MW	Megawatt
MWh	Megawatt hour

Subscript

e	Electric
t	Thermal
ac	Alternating Current

1 Introduction

Liquefying natural gas at cryogenic temperatures of -162 °C allows it to be transported even to locations which are far from gas fields and not accessible via pipelines. However, LNG plants are associated with large energy penalties, mainly compression power, which are costly and result in significant amounts of greenhouse gas emissions [4]. Solar energy when integrated into LNG plants enables producing low carbon intensity power and heat to meet the LNG plant energy demand.

The supply of electricity by hybrid CSP/PV power systems have been proposed by researchers in recent years, as they are expected to combine the characteristics of dispatchable power generation and lower LCOE [5]. It was also shown that by a suitable combination of CSP and PV aiming at a capacity factor higher than 70%, lower costs can be achieved than by increasing storage and solar field size in CSP plants alone [6].

This study evaluates various hybrid CSP solar tower and PV configurations to determine the optimum configuration to supply continuous power and heat to an LNG plant with at least 50% decrease in CO2 emissions between 2025 and 2050 compared to a grid connected LNG plant.

2 Site selection and Energy demand

In this study, it is assumed that both LNG plants in Qatar and Australia will have the same feed characteristics (93% methane) [7] and will produce a total of 4.5 MTPA of LNG to ship. The selected liquefaction technology is C3MR. Each processing unit within the LNG plant has been assessed to determine the electrical power and heat demand requirements (Figure 1).

The LNG Storage and Loading system is designed to operate in two different modes: holding and loading modes. During loading, LNG is transferred from the storage tank to the ship via LNG loading pumps, whilst during holding, no transfer of LNG to ship occurs.

The LNG plant electrical power demand was calculated using the air-dry bulb ambient temperature variation and the ship loading modes frequency for every hour of the year. The ambient temperature hourly profile for each location was extracted from the TMY data files [8]. In **Figure 2**, 3 the resulting 24-hour daily profile is shown averaged for the months June and December. During cold winter months, the gas liquefaction process energy efficiency improves, resulting in lower power consumption.

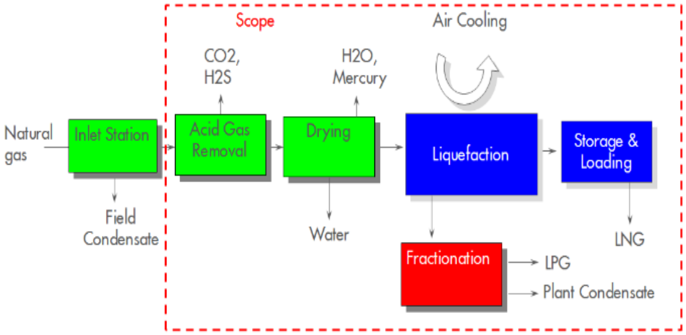

Figure 1. LNG plant block flow diagram

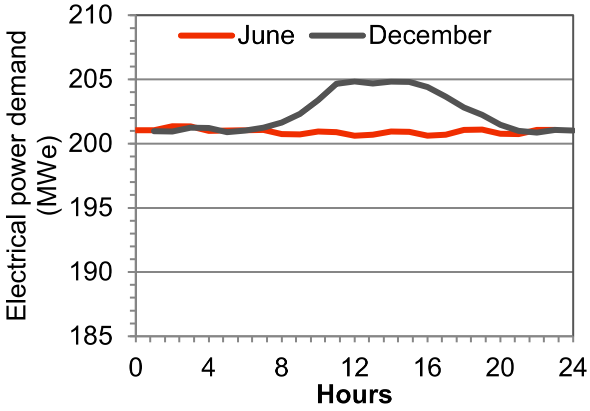

Figure 2. Average day Electrical Power demand for Karratha LNG Plant (Australia)

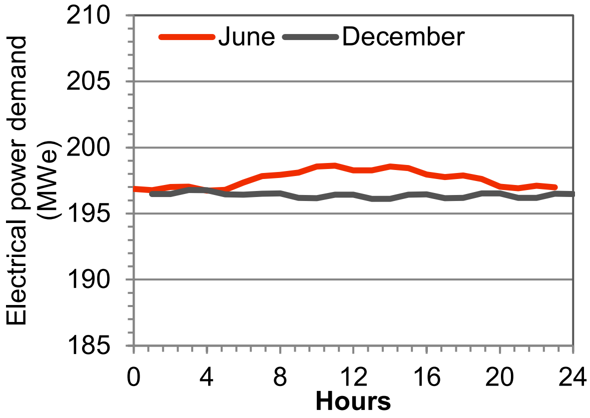

Figure 3. Average day Electrical Power demand for Ras Laffan LNG Plant (Qatar)

Land availability and DNI values were evaluated for both countries to select the location of the solar plant in relation with the LNG plant. Whilst for Australia, the CSP/PV plant would be located next to the LNG plant, for Qatar, the CSP/PV plant would be installed in Qurain El Bawl 130 km away. The latter will produce electricity only, whilst a separate CSP parabolic trough plant co-located with the Ras Laffan LNG plant will supply process heat (The cost assumptions for the economic assessment differ between Qatar and Australia as summarised in Table 2.

Table 1. Annual energy demand of the LNG Plant in Karratha (Australia) and Ras Laffan (Qatar)

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Table 1. Annual energy demand of the LNG Plant in Karratha (Australia) and Ras Laffan (Qatar)

LNG Plant Location	**Electrical Energy demand (MWh/year)**	**Maximum Power demand (MW_e)**	**Heat Demand (MWh_t/year)**	**Maximum Heat demand (MW_t)**
Karratha	1,769,205	215	725,264	90
Ras Laffan	1,724,415	215	725,264	90

Table 2. Difference in cost assumptions for Australia and Qatar [9]

	Grid Carbon Intensity (kg CO_2/MWh)	**Grid Electricity Cost (US$/MWh)**	**Carbon Tax (US$/Ton-$CO_2$)**
	2025/2050		
Australia	618/98	120/60	20/100
Qatar	479/217	35/60	10/75

3 Methodology

The methodology used for the study consists in:

1. Assessing hourly heat and power demand for the two LNG sites
2. Defining the model parameters for the CSP/PV hybrid plant configuration
3. Simulating the CSP/PV configurations using the core tool System Advisor Model (SAM) version 2020.2.29 and a defined set of model parameter
4. Evaluating the equipment cost and CO_2 abatement potential
5. Selecting the optimum solar configuration based on the LCCA to select the option that will bring the greatest amount of CO_2 reduction for the same investment cost [10].

3.1 Economic models

Two economic models were assessed and compared against the base case to quantify the CO_2 abated by the solar plant. In the base case, no solar plant is installed, the LNG plants gets its electricity from the grid and its heat by firing fuel gas produced locally by the LNG plant. It is assumed that the CSP/PV hybrid plant is owned by a separate entity that sells both electricity and heat to the LNG plant under a power purchase agreement (PPA). Model A is when back-up fuel gas firing is used. Whilst model B is when back-up electricity is supplied from the grid, considering the carbon intensity of the electric system in the region. Both scope 1 and 2 CO_2 emissions were used for CO_2 emissions calculations. Scope 1 covers direct CO_2 emissions from fuel gas firing in model A whilst Scope 2 covers indirect CO_2 emissions from the import of electricity in model B.

3.2 Simulation

The PV plant was first modelled in SAM for different nameplate capacities, the CSP solar tower thermal power output was then adapted to the load profile in order to fill up the gap between the PV system electrical output and the LNG plant electrical demand. The turbine dispatch factor which represents a multiple of the power block thermal input was manipulated to scale the CSP power block power output up or down as a fraction of its design. The dispatch factor was defined for each hour of the day with 24 hours representing an average day of each month of the year.

In addition to suppling electric power, the CSP plant also supplies process heat to the LNG plant where part of the molten salts bypasses the boiler to heat a liquid heat transfer fluid to 300 °C before it returns back to the cold tank (Figure 4).

The PV plant nameplate capacity was varied between 215 MW_{ac} and 400 MW_{ac} using a step size of 50 MW_{ac}. The CSP solar multiple was varied between 1.25 and 2.5 with a step size of 0.25, whilst thermal energy storage (TES) hours were varied between 8 hrs and 20 hrs with a step size of 1 hr. Also, the CSP Power block is designed for 215 MWac capacity. In total, 390 CSP/PV hybrid solar configurations were simulated in SAM.

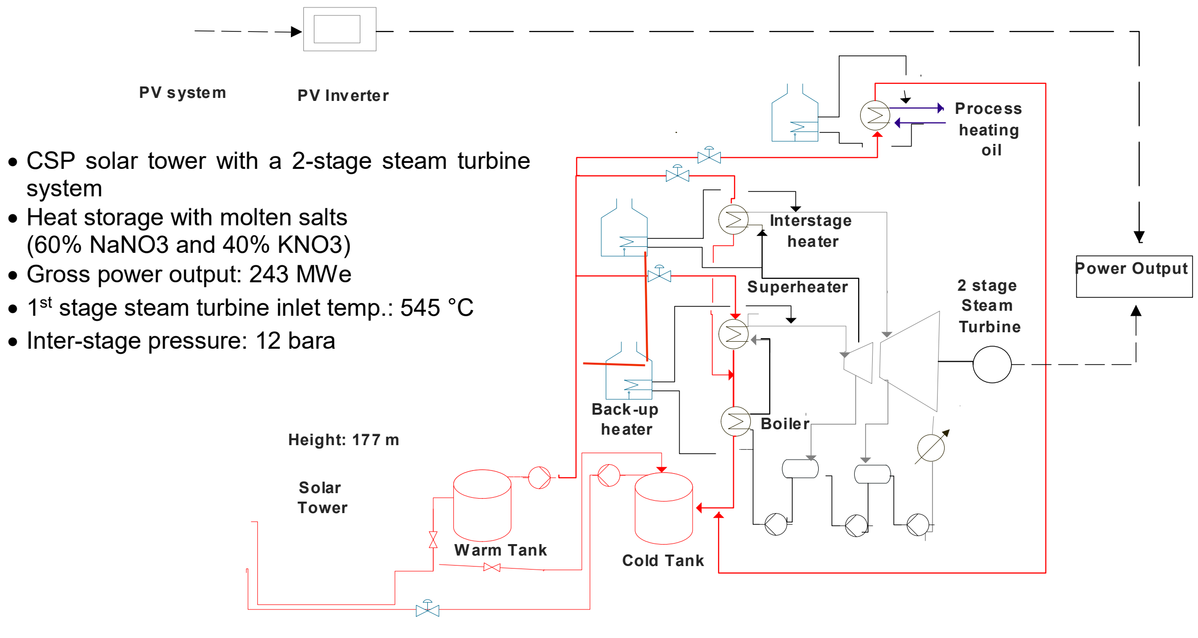

Figure 4. CSP/PV hybrid plant for electricity and heat supply with back-up fuel gas heaters

4 Summary of economic assessment results

The solar configurations were grouped by the solar field solar multiple (SM) represented by 6 groups of 65 configurations each. For each group, the solar configuration with the minimum LCCA was selected. The optimum solar configuration among all groups is the option at which increasing the solar field SM will only result in marginal reduction of LCCA (by less than 1%) (Figure 5,6).

It was shown from the study that the CSP/PV hybrid plant significantly accelerates the decarbonisation of the energy supply to the LNG Plant. In Karratha, CO_2 emissions (direct and indirect) are reduced by 78- 81% (SM 2.25) for electricity and heat supply. Whilst in Qatar CO_2 emissions are reduced by 82-88% (SM 2) for electricity supply and 69% (SM 3) for heat supply when compared to the electric grid for power supply (Figure 7).

For the solar tower co-located with the LNG plant in Karratha, the lowest LCCA value corresponds to a CSP solar multiple SM of 2.25, a TES of 13 hours and a 215 MW_{ac} PV plant size. In Qurain El Bawl where the solar tower is located far from the LNG plant and supplies electricity only, the lowest LCCA is associated with a CSP SM of 2, a TES of 13 hours and a 300 MW_{ac} PV plant size. In Ras Laffan, where the Parabolic trough supplies process heat to the LNG plant, the LCCA value is 45 US$/Ton corresponding to a solar field SM of 3 and a TES of 10 hours.

The LCCA is influenced by the grid carbon intensity and type of back-up system. When comparing both countries, LCCA values are higher in Qatar since Australia still uses coal, more carbon intensive that natural gas in Qatar for electric power generation. In addition, the LCOE is influenced by the country carbon tax, electric grid carbon intensity and price of electricity. The LCOE values for the CSP/PV plant in Australia and Qatar are 109 US$/MWh and 101 US$/MWh respectively when using the electric grid as back up. For an LNG plant connected to the grid with no solar plant installed, the LCOE is higher in Australia at 117 US$/MWh but lower in Qatar at 56 US$/MWh.

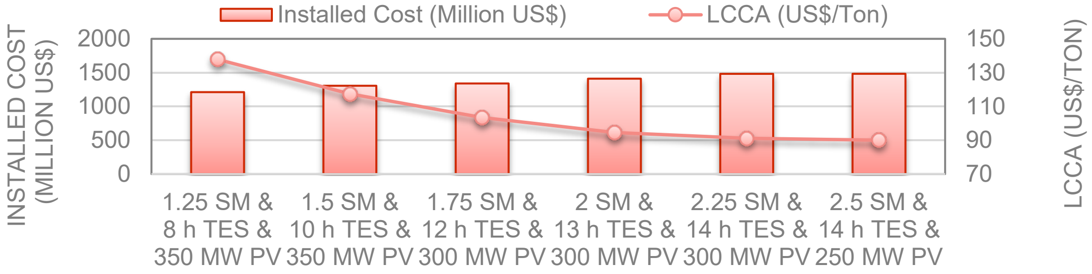

Figure 5. Solar configurations selection in Karratha (Model A)

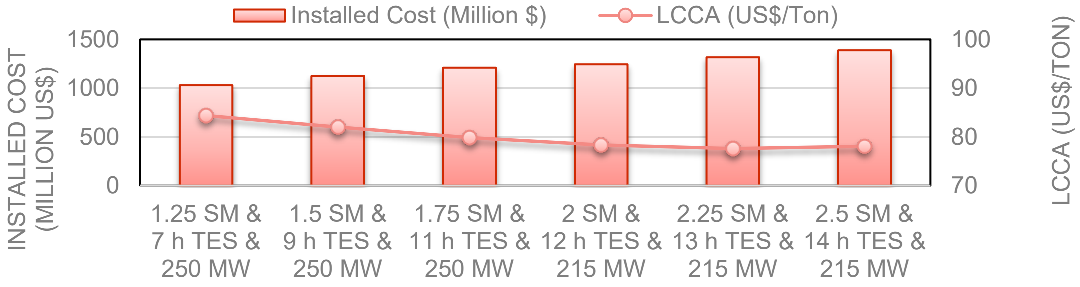

Figure 6. Solar configurations selection in Karratha (Model B)

5 Conclusion

The study demonstrated that a CSP/PV hybrid plant would significantly decarbonise LNG export terminals by providing heat and power from solar. The LCCA was used to evaluate the CO_2 abatement potential of the solar configurations and its value was shown to be satisfactory for Australia as the CO_2 tax is predicted to increase to 100 US$/ton-$CO_2$ in 2050. In addition, the economic assessment indicated that buying electricity from the grid during the period 2025-2050 would be more expensive for Australia then investing in a CSP/PV solar plant.

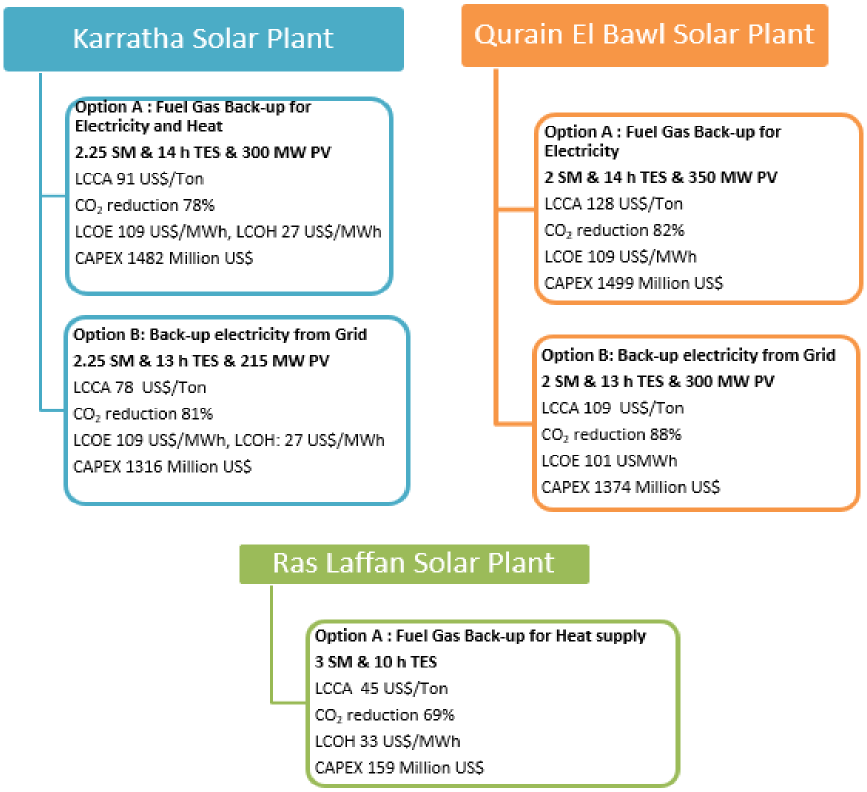

Figure 7. Summary of economic assessment results

The economic conditions in Australia in terms of carbon tax and cost of electricity offer a suitable environment for the development of such solar projects. In Qatar, electricity is largely subsidized by the government, however both the carbon tax and electricity price will need to be raised to the same level as in Australia to diversify and expand the power sector in the region. By providing an incentive for such solar projects, carbon-free electricity will be produced, and natural gas will be better utilised as feedstock for the local petrochemical industry or sold as green LNG product.

Considerations for future work

The CSP/PV hybrid plant capacity can be expanded beyond the LNG plant energy demand requirements to form a green energy hub that will cover the electricity demand in the region to serve the local communities and neighbouring industrial plants.

In this study, back-up electricity and heat consisted of either fuel gas or electricity from the grid, however other fuels such as green hydrogen can also be investigated. Also, this work considered the use of a steam turbine condenser with sea cooling water in an open loop system, however there is an opportunity to substitute the condenser by a desalination unit to recover the waste heat of condensation. The solar plant will thus produce not only electricity and heat, but also desalinated water.

6 Competing interests

The authors declare no competing interests.

7 Data availability statement

Data supporting the results are non confidential. Typical meteorological year data files were extracted from the Photovoltaic Geographical Information System [8]

8 Author contributions

Sabrina Hasni: Development, writing

Werner J. Platzer: Supervision, review of manuscript

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