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Feasibility study on HYSOL CSP

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Abstract

Concentrating Solar Power (CSP) plants utilize thermal conversion of direct solar irradiation. A trough or tower configuration focuses solar radiation and heats up oil or molten salt that subsequently in high temperature heat exchangers generate steam for power generation. High temperature molten salt can be stored and the stored heat can thus increase the load factor and the usability for a CSP plant, e.g. to cover evening peak demand. In the HYSOL concept (HYbrid SOLar) such configuration is extended further to include a gas turbine fueled by upgraded biogas or natural gas. The optimized integrated HYSOL concept, therefore, becomes a fully dispatchable (offering firm power) and fully renewable energy source (RES) based power supply alternative, offering CO_2-free electricity in regions with sufficient solar resources. The economic feasibility of HYSOL configurations is addressed in this paper. The analysis is performed from a socio- and private- economic perspective. In the socio-economic analysis, the CO_2 free HYSOL alternative is discussed relative to conventional reference firm power generation technologies. In particular, the HYSOL performance relative to new power plants based on natural gas (NG) such as open cycle or combined cycle gas turbines (OCGT or CCGT) are in focus. In the corporate-economic analysis the focus is on the uncertain technical and economic parameters. The core of the analyses is based on the LCOE economic indicator. In the corporate economic analysis, NPV and IRR are furthermore used to assess the feasibility. The feasibility of renewable based HYSOL power plant configurations attuned to specific electricity consumption patterns in selected regions with promising solar energy potentials are discussed.

Keywords: *Feasibility analysis; CSP, Hybridization; Storage; Steam turbine; Firm power; HYSOL; OCGT; CCGT*

1. Introduction

Concentrating Solar Power (CSP) plants utilize thermal conversion of direct solar irradiation. A trough or tower configuration focuses solar radiation and heats up oil or molten salt that subsequently in high temperature heat exchangers generates steam for power generation. High temperature molten salt can be stored and the stored heat can thus increase the load factor and the usability for a CSP plant, e.g. to cover night (peak) demand. In the HYSOL concept (HYbrid SOLar) such configuration is extended further to include a gas turbine fueled by upgraded biogas or natural gas. The optimised integrated HYSOL concept, therefore, becomes a fully dispatchable (offering firm power) and a fully renewable energy (RES) based power supply alternative, offering CO_2-free electricity in regions with sufficient solar resources. The economic feasibility of HYSOL configurations is addressed in this paper. The analysis is performed from a socio- and corporate- economic perspective. In the socio-economic analysis, the CO_2 free HYSOL alternative is discussed relative to conventional reference firm power generation technologies. In particular the HYSOL performance relative to new power plants based on natural gas (NG) such as open cycle or combined cycle gas turbines (OCGT or CCGT) are in focus. In the corporate-economic analysis the focus is on the uncertain technical and economic parameters. The core of the analyses is based on the LCOE economic indicator. In the corporate economic analysis, NPV and IRR are furthermore used to assess the feasibility.

The feasibility of renewable based HYSOL power plant configurations attuned to specific electricity consumption patterns in selected regions with promising solar energy potentials are discussed.

1.1. Example studied

The analytical approach used is illustrated from an example where a HYSOL configuration is optimised to conditions seen e.g. in the Kingdom of Saudi Arabia (KSA). Thus, the HYSOL Power Plant studied has been attuned to solar potentials and power system characteristics resembling conditions in the Kingdom of Saudi Arabia (KSA).

The KSA HYSOL plant configuration particularizes the basic HYSOL outline by the choices:

- A CSP Tower configuration has been assumed. HYSOL configurations can also be applied with CSP trough design.
- No biogas plant and biogas supply have been assumed for this KSA case. HYSOL's 100% renewable configuration would have a biogas plant included and would use biogas upgraded to NG quality.

The KSA HYSOL configuration analysed uses natural gas (NG) and not biogas based methane, and may thus not be termed fully renewable, - though being a firm, fully dispatchable and mainly renewables based power plant.

1.2. The HYSOL alternative and competing technology

This paper compares, from a socio-economic perspective, electricity production costs for a HYSOL plant alternative to production cost for conventional power plant solutions or reference plants. In this KSA case it has been assumed that the main competing reference technologies are an Open Cycle Gas Turbine (OCGT) and a Combined Cycle Gas Turbine (CCGT) using natural gas (NG). Furthermore, the study investigates, from a corporate-economic perspective, the impact of technical and economic parameters in determining the electricity production cost for the same HYSOL plant.

2. Socio economic analysis: Approach and assumption

2.1. Economic indicator

A socio-economic approach is applied. And generally main focus is placed on the economic indicator LCOE (the levelized cost of electricity), and on the sensitivity of the LCOE in particular to variations in the two parameters:

- load factor or the number of full load hours per year, and the
- price of natural gas (given as the levelized NG price covering the period analysed)

The solar potential and the annual power production heavily impact the HYSOL power plant economy. And for fossil based competing reference technologies fuel cost and CO_2 emission cost developments constitute important framework conditions. LCOE dependency on in particular these major parameters will be in focus in this study of (predominantly) renewable energy source (RES) based HYSOL solutions relative to fossil based conventional reference power plant solutions.

2.2. Base Case assumptions

For the present socio-economic analyses, the following general assumptions have been adopted as 'Base Case':

- Price level: Year 2015
- Socio economic rate of calculation (rate of interest): 4 % p.a.
- Project base year: 2020
- Period analysed:
  - Time period: 2021-2045
  - Period in years: 25 years

Chosen Base Case for the KSA HYSOL plant annual production, assigned capacity and load factor are:

- Annual electricity production: 812.7 GWh/year
- Assigned HYSOL capacity (PH): PH = 130 MWel
- Annual full load hours (HFLH) and Load factor (LF): HFLH =812.7 GWh / 130 MW = 6251 hours/year and LF= 6251/8760= 0.714

As mentioned, gas consumed in the KSA HYSOL gas turbine (GT) component is assumed to be natural gas (NG). The KSA Base Case NG price and the sensitivity variations analysed for the NG price are:

- Base case: 13.65 $/MWh (4 $/MMBtu)
- Sensitivity: Base Case +/- 20%, +/-40%

Data on investments, operation and maintenance costs for the KSA HYSOL configuration are found in the Appendix.

2.3. Base Case overview and issues addressed via sensitivity analyses

Electricity production costs (LCOE) are furthermore analysed for its dependence on or sensitivity to variations in the following parameters:

- Natural Gas price:
  - Sensitivity: Base Case -/+40%
- CO_2 emission quota market price
  - Base case: 0 $ / ton CO_2
  - Sensitivity: 40 $ / ton CO_2
- Capacity assignment:
  - Base case: 130 MW
  - Sensitivity: 100 MW<-->180 MW
- Lifetime of initial investment:
  - Base case: 25 years
  - Sensitivity: 20years
- Rate of calculation (interest rate)
  - Base case: 4.0 % p.a.
  - Sensitivity: 10.0 % p.a.
- Initial investment (CAPEX)
  - Sensitivity: Base Case +/- 20%

The combined steam turbine (ST) and gas turbine (GT) capacity in the KSA HYSOL configuration plant has been assigned a total combined capacity of 130 MW. The peak power generated by the plant is limited to 130 MW, and the plant is made to follow a demand curve congruent or analogous to that of country altogether. This implies that the number of full load hours for the combined KSA HYSOL configuration can be calculated as 812.7 GWh/130 MW = 6251 hours/year, and the demand coverage rate is above 99.9%.

2.4. Electricity costs as function of load factor and NG price

In Fig. 1, Fig. 2, Fig. 3 and Fig. 4 results on the LCOE (given along the y-axis) are shown as a function of the annual load. The annual load or electricity production, - here expressed through its equivalent, the number of full load hours per year, is shown along the x-axis. HYSOL plant operation at different load factors is assumed to maintain the relative ST and GT contribution to the electricity production. Thus, even the annual power production may differ from the Base Case assumption the %-split of production contributions from the ST and GT HYSOL plant components is assumed constant. And the share of the annual production based on gas (via the GT directly and indirectly via GT flue gas heat recovered and utilized by the ST) is kept constant.
Furthermore, for this feasibility analysis the HYSOL plant operation efficiency is assumed constant, - even at e.g. lower annual production levels. And gas consumption per MWh electricity generated, accordingly, is assumed constant and independent of the production. This may be a somewhat rough assumption.

2.4.1 Design Point assumptions

Assumptions used as basis for optimizing and configuring the HYSOL plant, will in the following be termed the 'Design Point' data assumptions. Yellow points, 'Design Points', shown in Fig. 1, Fig. 2, Fig. 3 and Fig. 4 represent results for the KSA HYSOL plant based on Base Case assumptions. Black points, correspondingly, represent (OCGT or CCGT) reference technology results based on equivalent assumptions. Other results presented may thus be considered as sensitivity and parameter analyses.

2.5. HYSOL relative to OCGT and CCGT

In what follows the KSA HYSOL plant alternative is compared to competing 'conventional' or reference plant solutions based on equivalent system framework condition. Benchmarked via the LCOE the competing technologies are evaluated using equivalent general assumptions. The so-called Base Case data assumptions form the core for this feasibility comparison. For selected key parameters LCOE consequences of data deviating from Base Case are covered via sensitivity analyses.

Competing reference technologies assumed are the Open Cycle Gas Turbine (OCGT) and the Combined Cycle Gas Turbine (CCGT). For consistency of the comparison it is assumed, that the average annual electricity production is the same for the HYSOL alternative and for the reference plants. Furthermore, plants being compared are assumed to have the same capacity value in the KSA power system, and the plants are assumed to be fully dispatchable (firm power). Thus, all plants are assumed to be able to occupy the same position in the overall power system dispatch.

Data for the KSA HYSOL alternative and for the assumed KSA OCGT and KSA CCGT reference power plants are found in the Appendix [1] [2] [3] [4].

It can be observed from Fig. 1, Fig. 2, Fig. 3 and Fig. 4 that the annual number of full load operation hours for the HYSOL plant, shown along the x-axis, is extremely important for the electricity production cost achieved, - and the plant economy. Low annual power production results in high production costs. For the overall economy of a HYSOL plant, therefore, it is very important to achieve high annual power production, as the total production costs are much dominated by high initial investments. Natural gas prices, however, have minor impact on the HYSOL power production cost due to the relatively low electricity production contribution via the GT part of the KSA HYSOL configuration.

2.5.1 CO_2 *emission costs*

Comparison of HYSOL solutions relative to conventional OCGT and CCGT power plant solutions are carried out for cases with and without inclusion of an assumed CO_2 emission cost. For this sensitivity analysis it has been assumed, as an example, that CO_2 emission costs amounts to 40 \$/ton CO_2 emitted. For natural gas (NG) this CO_2 emission cost is equivalent to 8.17 \$/MWh NG. The CO_2 emission cost assumed thus rises the NG price with an extra 8.17 \$/MWh NG.

3. Corporate economic analysis: Approach and assumption

3.1. Necessity of a different approach

The investigation on economic feasibility of the HYSOL is furthermore performed from the corporate or private perspective. The additional analysis provides an insight of the new energy project oriented toward the investing company. Indeed, while the aim of the socio-economic analysis is mostly society oriented (e.g. asking, is the project of benefit for the society as a whole?), the purpose of the private-economic analysis is more aligned with the optimization of the available investment capital, so that the profitability of the firm is maximized. The evaluation of the energy project thus depends on the perspective from which it is evaluated. Three main differences [1] characterize the two approaches: the prices, the taxes and the rate of interest.

In the private economic analysis, the prices are nominal, i.e. they include inflation in order to represent the change in purchase power during the time horizon. Moreover, discounting on the net cash-flow is also applied. In the socio-economic approach the real prices (i.e. without inflation) are used.

Taxes are part of the private economic analysis, but not of the socio-economic. This comes since, when analysing the investment in the society context, taxes are simply considered as a distributional element that merely transfer money from one area of the society to another.

The rate of interest is assumed according to the perspective selected. For the socio-economic approach, the rate is based on the return that a public investment could generate in the market. On the private-economic analysis, the rate of interest is higher since it includes inflation and industry-specific risks.

The structure of the socio-economic analysis is thus modified in order to consider the differences presented. The corporate or private economic analysis is undertaken to evaluate the project from the perspective of a private company pursuing the goal of determining whether the project is worthwhile to invest on.

3.2. Method and assumptions

The same methodology presented for the socio-economic approach is used in the corporate economic analysis. Supplementary features are added in order to consider economic and technical parameters. Taxes, nominal prices and a new discount rate are added. New assumptions are considered to better represent the detailed functioning of the plant and to include parameters influencing the financial assessment of the HYSOL technology:

- Depreciation of the asset is applied as straight line depreciation throughout the whole lifetime of the project;
- The fuel (natural gas) and CO_2 prices are assumed to increase during the lifetime according to steps (i.e. % increase respect to the previous year) predefined;
- An overhaul period is included in order to consider the renovation rate of the asset;
- For each of the years of the overhaul (and only for these), the O&M prices are assumed to increase 25% (respect to the previous year);
- A degradation rate is included in order to consider the deterioration of the asset. Thus, each year the power production is decreased of 2%, until the end of the overhaul period. After the renovation, the power production gets back to the original value;
- The construction period is included in order to consider the availability of different plants according to their completing date. According to these periods,

[1] Other differences, also to be considered, are not reported since it is out of the scope of this paper to discuss on that. For an exhaustive insight on the topic, [5] provide an extensive description.

gas turbine or CSP plants are producing/consuming only when they are fully completed;

- Offline consumption is included in order to consider the power consumption of devices related to the plant, while being offline;

The new ´Base Case´ now includes:

- Private economic rate of calculation (rate of interest): 10 % p.a.
- Inflation: 2%
- Corporate tax rate: 20%
- Overhaul period: 7 years
- O&M increase after overhaul: 25%
- Reduction rate of power production: 2%
- Depreciation: 25 years

3.3. Economic indicators

The feasibility of the project from the private-economic perspective is assessed through three economic indicators:

- Levelized Cost of Electricity (LCOE),
- Net Present Value (NPV) and
- Internal Rate of Return (IRR).

The LCOE is equivalent to the average cost over the lifetime of the project, taking into account the cost of capital.

The NPV is used to compare different projects with different timings and distributions of cash flows over time. Positive values of NPV indicate a favourable undertaking of the project; negative values indicate that the investment should not be carried out.

The IRR represents the annual effective compounded return rate of a project or an investment option (i.e. the annual return a project is expected to yield). For an IRR equal to discount rate, the NPV would become zero. For IRRs greater than the discount rate, the undertaking of the project is favourable. For the opposite case (i.e. IRR lower than the discount rate) the project should be discontinued.

The NPV and the IRR will be useful to indicate the outcome of the feasibility study (i.e. positive or negative). Afterwards, the investigation will focus on the effect of the different parameters on the LCOE. The aim is to evaluate the impact of the uncertain input data on the outcomes and identify the most influencing.

4. Results

4.1. Socio economic: HYSOL compared to OCGT and CCGT

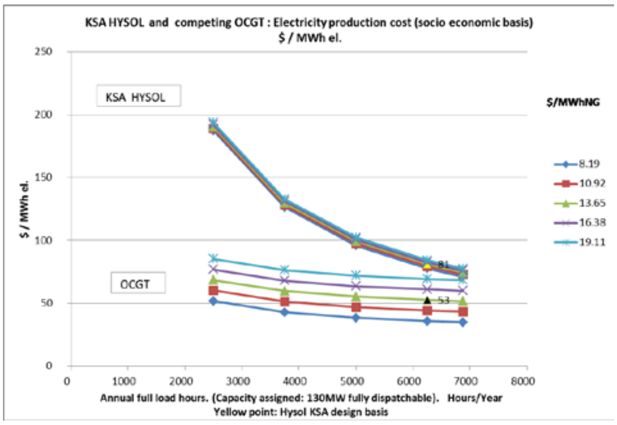

Fig. 1 Electricity production costs for Open Cycle Gas Turbine (OCGT) and KSA HYSOL configuration, as function of load factor and NG price. Assumed: CO_2 costs = 0 \$/ton CO_2, R=4 %p.a., Lifetime=25 years. Unit: \$/MWh el

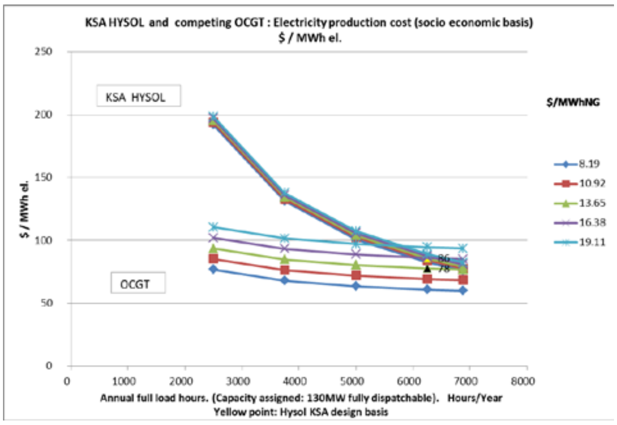

Fig. 2 Electricity production costs for Open Cycle Gas Turbine (OCGT) and KSA HYSOL configuration, as function of load factor and NG price. Assumed: CO_2 costs = 40 \$/tonCO_2, R=4 %p.a., Lifetime=25 years. Unit: \$/MWh el.

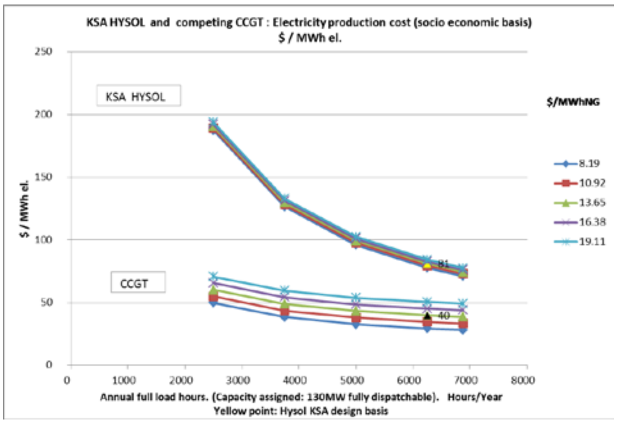

Fig. 3 Electricity production costs for Combined Cycle Gas Turbine (CCGT) and KSA HYSOL configuration, as function of load factor and NG price. Assumed: CO_2 costs = 0 \$/tonCO_2, R= 4%p.a., Lifetime=25 years. Unit: \$/MWh el.

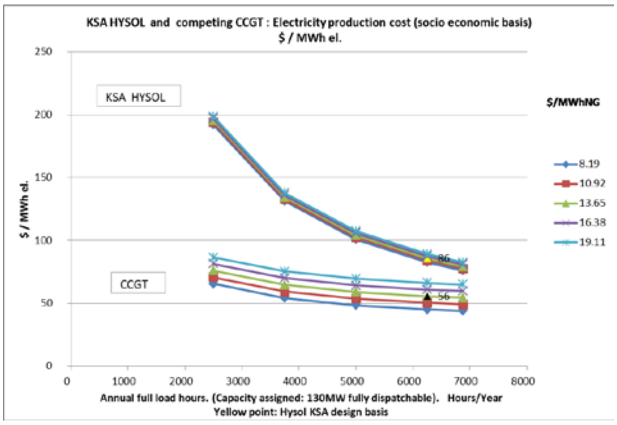

Fig. 4 Electricity production costs for Combined Cycle Gas Turbine (CCGT) and KSA HYSOL configuration, as function of load factor and NG price. Assumed: CO_2 costs = 40 \$/tonCO_2, R=4 %p.a., Lifetime=25 years. Unit: \$/MWh el.

4.2. Socio economic: Power price composition

LCOE results based on Design Point assumptions (shown as yellow and black points in Fig. 1, Fig. 2, Fig. 3, Fig. 4) are presented below with a breakdown or split into its components related to respectively Investment, O&M, and Fuel cost parts.

Table 1 KSA HYSOL alternative: Electricity production cost (LCOE on socio economic basis) for 'design basis' assumptions split on contributions from the Investment, O&M, and Fuel Cost parts to the total cost.

Component	Value [$/MWh el]	% of tot [%]
Investment	60.91	75.1
O & M	12.13	15
Fuel costs	9.05	9.9
TOTAL (at ‘design basis point’data)	81.09	100

Table 2 KSA 130MW OCGT reference: Electricity production cost (LCOE on socio economic basis) for 'design basis' assumptions split on contributions from the Investment, O&M, and Fuel Cost parts to the total cost. OCGT capacity: 130MW

Component	Value [$/MWh el]	% of tot [%]
Investment	8.31	15.8
O & M	2.30	4.4
Fuel costs	42.05	79.8
TOTAL (at ‘design basis point’data)	52.66	100

Table 3 KSA 130MW CCGT reference: Electricity production cost (LCOE on socio economic basis) for 'design basis' assumptions split on contributions from the Investment, O&M, and Fuel Cost parts to the total cost. CCGT capacity: 130MW

Component	Value [$/MWh el]	% of tot [%]
Investment	10.16	25.4
O & M	3.41	8.6
Fuel costs	26.36	66
TOTAL (at ‘design basis point’data)	39.93	100

Table 1 illustrates, as expected, that power production costs from the KSA HYSOL plant are dominated by the investment cost component. On average for the period analysed of about 75% of the total electricity costs relates to the initial investment, whereas the fuel cost component only contributes about 10% to the total costs. Compared to results for OCGT and CCGT plants shown in Table 2 and Table 3, this illustrates that HYSOL plants are less exposed and less vulnerable to gas price (and CO_2 emission cost) uncertainty.

4.3. Private economic: Power price composition

The outcomes of the corporate or private economic analysis are reported in Table 4.

The LCOE resulting from the private economic analysis is found to be 169.4 $/MWh, almost double the result of the socio-economic. The higher LCOE is due to the additional features aimed at better representing the reality along with the added economic parameters.

The resulting values of the NPV and IRR are -634.05 M$ and -3.1% respectively. The values of the economic indicators indicate a negative outcome for the feasibility of the HYSOL.

Table 4 KSA HYSOL alternative: results of the private-economic analysis

LCOE	NPV	IRR
169.4 $/MWh	-634.05 M$	-3.1%

5. Sensitivity analysis

5.1. Socio economic

Sensitivity analyses shown in Fig. 5, Fig. 6, Fig. 7 describe how power productions costs (LCOE) deviate from results based on Base Case and 'design point' assumptions, if one parameter only is changed at a time.

Blue vertical lines in Fig. 5, Fig. 6, Fig. 7 represent the LCOE calculated from Base Case assumptions. Tables 1-3, shown above, thus give details on the Base Case results, that are 'starting points' for the sensitive analysis results shown below, -for the KSA HYSOL, KSA OCGT and KSA CCGT plants respectively.

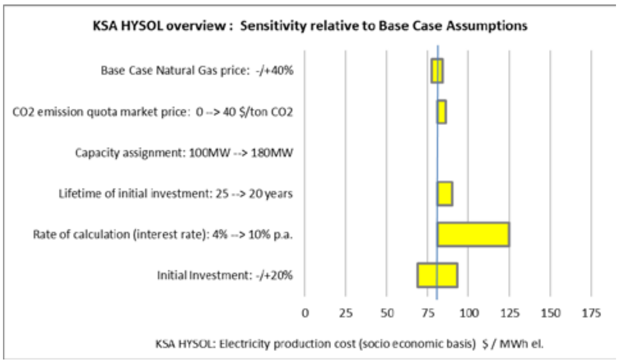

Fig. 5 KSA HYSOL results in overview: Electricity production costs (LCOE) - Sensitivity relative to Base Case Assumptions. Units: $/MWh el

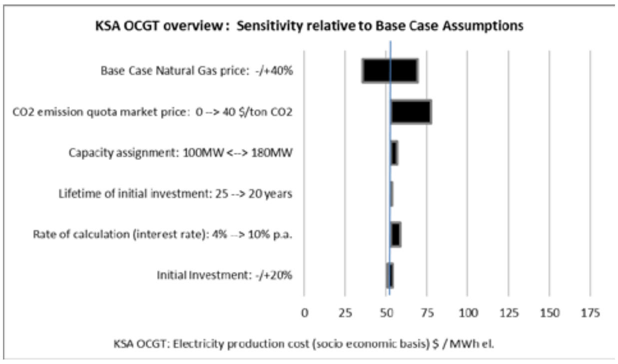

Fig. 6 KSA OCGT results in overview: Electricity production costs (LCOE) - Sensitivity relative to Base Case Assumptions. Units: $/MWh el.

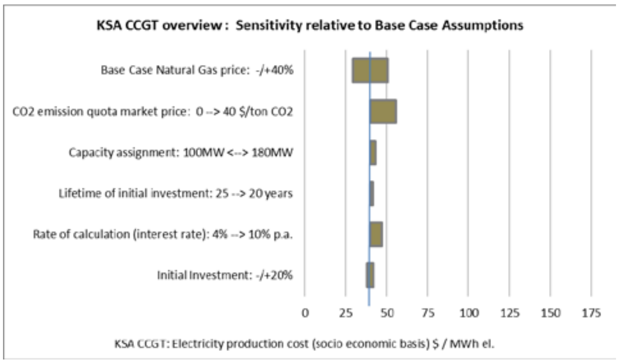

Fig. 7 KSA CCGT results in overview: Electricity production costs (LCOE) - Sensitivity relative to Base Case Assumptions. Units: $/MWh el.

5.2. Private economic

A sensitivity analysis is performed on the uncertain parameters of the private-economic analysis studying their impact on the LCOE. The parameters are arranged in two groups: economic and technical parameters. The first group considers: interest rate, inflation, corporate tax rate and average power price[2].
The second group includes the following parameters: lifetime, natural gas price, CO_2 price, CAPEX, overhaul period, reduction of power production and water price.
The outcomes of the sensitivity analysis are presented in Fig. 8 and Fig. 9.
The origin of the graph (0;0) represents the result obtained with the ´Base Case´ data. This point represents the fulcrum of the sensitivity analysis. The x-axes represent the % change of the parameter selected. That means that at the first thick mark on the right-hand side, the ´Base Case´ value is increased of 10%. For the left side, the same value is decrease of 10 %, and so on for the remaining steps. The y-axes represent the corresponding values of the LCOE in $/MWh.

[2] This represents the annual average power price in KSA [6].

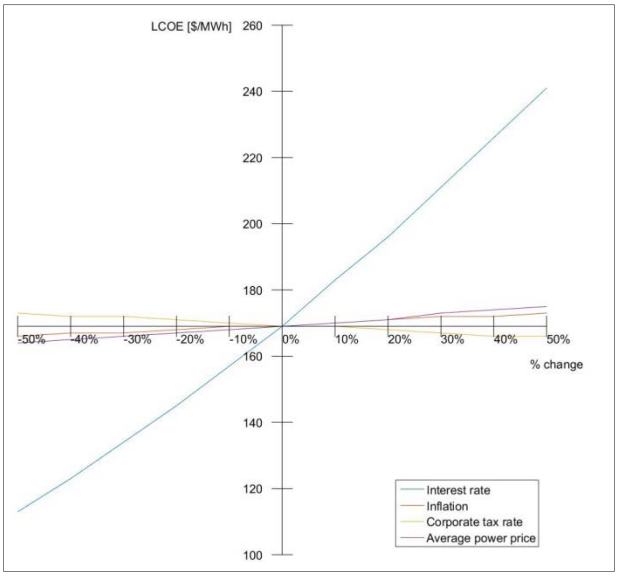

Fig. 8 Sensitivity analysis Private economic: economic parameters

Fig. 8 highlights that the most influencing economic parameter on the LCOE is the interest rate. Indeed, the relation between the % increase of the value and the corresponding LCOE is described by a steeper curve compared to the others. That means that to a small change in the % increase/decrease corresponds a big change in the LCOE values. On the other hand, for the other parameters, the outcomes show that even with a 50% increase/decrease, the final LCOE will not show significant changes compared to the original value. The order of impact thus sees the interest rate as first, followed by average power price, inflation and corporate tax rate. It is worth observing that this last parameter shows an opposite behavior compared to the other: the higher the corporate tax rate, the lower the LCOE. This is due to the fact that the corporate tax rate is used in the calculation of tax shield from depreciation. That imply that the higher is the corporate tax rate, the lower are the taxes to pay. Hence the value of the resulting LCOE decreases.

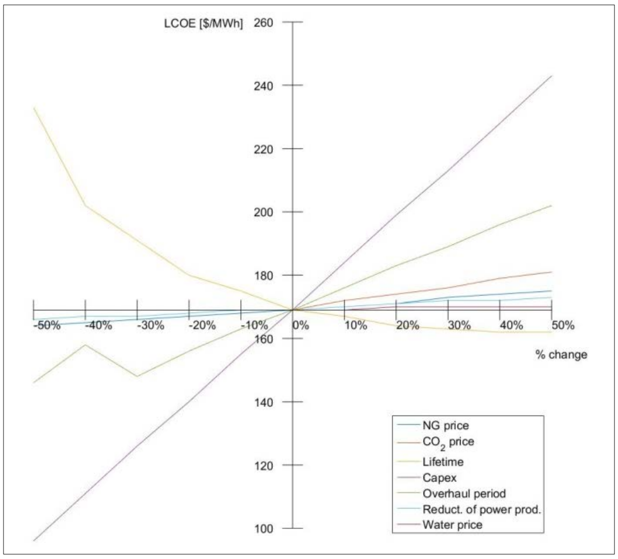

Fig. 9 Sensitivity analysis Private economic: technical parameters

Fig. 9 show results of the sensitivity analysis on the technical parameters. The steeper the relation between the change and the resulting LCOE (identified by the lines/curves), the more significant is the parameter. The outcomes thus show that the

CAPEX is the parameter with greatest significance. The second most influent parameter is the ‘overhaul period’. It then follows the CO_2 price, NG price, reduction of power production and water price. For all these parameters, an increase in the value corresponds to a higher LCOE, and a decrease of the same value to a lower LCOE. Only for the lifetime, the relation develops differently. Indeed, an increase in the lifetime of the project leads to a lower LCOE, while a decrease of the same leads to higher values of the LCOE.

6. Discussion

6.1. Socio economic

The price of natural gas (NG) and its expected development strongly impacts the economic attractiveness of HYSOL solutions relative to NG based competing technologies, such as OCGT and CCGT power plants.
CO_2 emission costs acts heavily in favour of HYSOL solutions. As seen from Fig. 5, Fig. 6 and Fig. 7(as expected) in particular an OCGT plant solution is strongly exposed to potential rising CO_2 emission costs.
The capacity of a HYSOL plant is defined by the size of firm capacity it may substitute being part the power system in question (KSA). This impacts the required capacity investments for competing solutions (OCGT or CCGT) matching the HYSOL plant in the system. The economic implication of different capacity assignments, however, as seen from Fig. 5, Fig. 6 and Fig. 7 , is relatively minor. This due to the relative low initial investment component for OCGT and CCGT plants, which may be seen comparing power price composition results shown in Table 1, Table 2 and Table 3.
The period analysed and the lifetime of the initial investments has minor impact on the electricity production cost for the OCGT and CCGT plant solutions. Being an initial investment intensive RES based technology the HYSOL solution is seen to be impacted, though moderately, from changes in lifetime of the investment.
The interest rate or the rate of calculation is important for initial investment intensive plants, such as the HYSOL solution. In Base Case a rate of calculation of 4% p.a. has been assumed, which may correspond to typical socio-economic conditions. Assuming a higher rate of interest of 10% p.a., that may resemble a private economic situation, it is seen from Fig. 5 that power production costs (LCOE) are increased substantially. Thus, in particular the HYSOL solution is very sensitive to changes in the interest rate.
HYSOL solutions, being investment intensive are as such very sensitive to changes in the overall investment costs, and the rate of interest, whereas the OCGT and CCGT solutions are considerable less exposed to changes in the overall investment.

6.2. Private economic

Despite most of the results of the private economic analysis are in line with the outcomes of the socio-economic, the sensitivity analysis performed over the most uncertain parameters provided a clear understanding on which are the most influent input data on the LCOE. The electricity production cost is found to be greatly sensible to the variation of the interest rate and the Capex. The analysis indeed revealed that an increase of 10% in these values correspond to an increase of almost 8% in the LCOE values, while for other parameters (e.g. natural gas price or inflation) the same increase corresponds to only 1%. The result is though expected, being the HYSOL´s costs heavily based on the great initial investment.
Concerning the economic parameters, the investigation shows that both inflation and average power price have small influence in the change of the LCOE value. Surely, from the investor perspective even a small change in the LCOE is significant, since the final profitability of the investment in the energy market depends on that. Nevertheless, variations of both average power price and inflation in KSA will not affect significantly the LCOE.
Similar considerations can be gathered from the analysis performed on the technical parameters. The change in the initial investments results to be the most influencing component in the LCOE investigation. The overhaul period (defined as period of time after which the plant is cleaned, inspected, repaired as necessary and tested using factory service manual approved procedures) is identified as the second most sensible parameter. Analysing the results, one would assume that the maintenance of the plants should be performed almost yearly, since a longer time period would compromise the output of the plant and increase the final LCOE. As for the socio economic, the results also confirm that the CO_2 costs acts in favour of the HYSOL configuration. The higher the costs, the higher will be the conventional electricity production cost, thus improving the competitiveness of the HYSOL in the energy market in KSA.

7. Conclusion

The aim of this paper has been to present methodologies to investigate the economic feasibility of HYSOL technology from the socio and private economic perspective. In the socio-economic analysis the investment is compared to conventional reference firm power generation technologies (namely OCGT and CCGT). In the private-economic the focus is on the uncertain technical and economic parameter. The core of the analyses is based on the LCOE economic indicator. In the private economic, NPV and IRR are also used to assess the feasibility.
The outcomes show different values of the LCOE for the two analyses; the difference lies in the different economic assumptions considered for the two investigations. Given the assumptions considered in our example, the values of the NPV and IRR suggest that the investment should be discarded. The sensitivity analysis performed on the Base Case assumptions shows that, for both the socio and private-economic analyses, the LCOE of the HYSOL plant is highly dependent on the investments (capex), the interest rate, the overhaul period and the CO_2 price. The investor should thus further investigate on these parameters, since an incorrect estimation can bring to considerable changes in the final LCOE.
The feasibility study performed on the renewable based HYSOL power plant configuration can be seen as a starting point. If properly supported, the HYSOL project can lead to high profitability and become a reality in the KSA power market characterized by use of fossil fuel based technologies. HYSOL projects based mainly on CSP technology, would reduce dependence on the fossil fuels. The introduction of this new technology in the selected markets can thus bring large environmental benefit, reducing GHG emissions and, at the same time, provide clean and stable power production.

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Appendix

KSA HYSOL: CAPEX & OPEX

CAPEX:	
Power block:	124 M$
Solar field and TES:	470 M$
BoP and miscellaneous:	109 M$
Indirect costs:	70.3 M$
TOTAL:	773.3 M$
OPEX:	
Water consumption:	240.000 m3/year @ 2.3 $/m3
NG consumption:	32.250 Tm/year @ 4 $/MBtu
Spare parts:	0.67% of CAPEX/year
Staff:	44 persons @ 65.000 $/year
Land rental, insurance and other costs:	1.25 M$/year

KSA OCGT: CAPEX & OPEX

CAPEX:	
Power block:	39.1 M$
Solar field and TES:	- M$
BoP and miscellaneous:	51.4 M$
Indirect costs:	9.1 M$
TOTAL:	99.6 M$
OPEX	
Water consumption:	- m3/year
NG consumption:	150.800 Tm/year @ 4 $/MBtu
Spare parts:	0.5% of CAPEX/year
Staff:	17 persons @ 72.000 $/year
Land rental, insurance and other costs:	0.15 M$/year

KSA CCGT: CAPEX & OPEX

CAPEX:	
Power block:	61.7 M$
Solar field and TES:	- M$
BoP and miscellaneous:	59.4 M$
Indirect costs:	12.1 M$
TOTAL:	133.1 M$
OPEX:	
Water consumption:	24.000 m3/year @ 2.3 $/m3
NG consumption:	106.100 Tm/year @ 4 $/MBtu
Spare parts:	0.5% of CAPEX/year
Staff:	27 persons @ 69.000 $/year
Land rental, insurance and other costs:	0.20 M$/year